Civil Aviation Authority

UK Government Review of commercial spaceplane certification and operations

Technical report

July 2014

UK SPACE AGENCY

Department for Business Innovation & Skills

Department for Transport

CAP 1189

Enquiries regarding the content of this publication should be addressed to:
Civil Aviation Authority, Aviation House, Gatwick Airport South, West Sussex, RH6 0YR.

The latest version of this document is available in electronic format at www.caa.co.uk/publications, where you may also register for e-mail notification of amendments.

Contents

CHAPTER 1
Introduction

In August 2012, the Government tasked the Civil Aviation Authority (CAA) under section 16 of the Civil Aviation Act 1982 to undertake a detailed review to understand better the operational requirements of the commercial spaceplane industry. This document is the full technical report of that Review. This chapter sets out the requirements of the Review, the context for it and the approach taken by the CAA.

Requirements of the Review

1.1 In expectation of the advent of commercial space operations, in August 2012 the Department for Transport (DfT) requested, under section 16(1) of the Civil Aviation Act 1982,[1] that the Civil Aviation Authority (CAA) undertake a detailed review to understand better the operational requirements of the commercial spaceplane and spaceport industry.

1.2 The findings of this Review should inform the aerospace and space industry and other key stakeholders about how the UK could accommodate and support future spaceplane operations, and pave the way for an appropriate regulatory framework that would allow this to happen.

1.3 The Review was specifically tasked with providing:

- a description and analysis of actual or anticipated key spaceplane operations and their requirements;
- an assessment of the potential for the growth of the spaceplane industry beyond sub-orbital space tourism and satellite launches;
- an analysis of the applicability of the procedures and requirements utilised by the US Federal Aviation Administration Office of Commercial Space Transportation (FAA AST) to the UK;
- recommendations for the appropriate regulatory framework for commercial spaceplane operations in the UK. This will include:
  - spaceplane airworthiness;
  - airspace requirements;
  - Air Traffic Management;

---

[1] Section 16(1) of the Civil Aviation Act 1982 states: '...it shall be the duty of the CAA to provide such assistance and advice as the Secretary of State may require it to provide for him or any other person in connection with any of the Secretary of State's functions relating to civil aviation.' www.legislation.gov.uk/ukpga/1982/16/section/16 (accessed 7 March 2014)

  - flight operations;
  - flight crew licensing; and
  - flight crew and participant medical requirements;
- an analysis and recommendations regarding the appropriate regulatory requirements for spaceport operations;
- recommendations as to the most suitable locations for a spaceport in the UK;
- consideration of the likely environmental impacts peculiar to spaceplane and spaceport operations; and
- an assessment of the value to the UK of commercial spaceplanes and related technologies.

Output of the Review

1.4 The formal output of the Review consists of two documents: this technical report, and a summary report including high-level recommendations. The two are being published simultaneously.

1.5 As would be expected, the technical report includes far more detail on specific aspects of spaceplane operations. While the overall structure of the two documents is similar, the technical report also includes a separate chapter on environmental considerations.

1.6 The technical report includes the recommendations set out in the summary report that are believed to be essential to enabling spaceplane operations to take place from the UK by 2018 or earlier, but also further recommendations which, if adopted, will help shape spaceplane operations and secure the maximum possible benefit to the UK.

1.7 A glossary is included at the end of this technical report.

Context of the Review

1.8 Just over 50 years after the first manned spaceflight, the prospect of commercial space travel is now becoming a reality. According to its plans at the time of writing, Virgin Galactic will take its first paying participants on a sub-orbital spaceflight experience – or, as it is widely known, a ‘space tourism’ flight – anticipated in late 2014, launching from Spaceport America in New Mexico, USA.

1.9 Within just a couple of years, others are set to follow. XCOR Aerospace intends to start commercial operations from the US in 2016, and several other operators and businesses anticipate being technically able to offer spaceflight experience within the next decade.

1.10 The fundamental enabler of commercial spaceflight experience is the development of the 'spaceplane' – a vehicle that acts as an aircraft while in the atmosphere and as a spacecraft while in space.

1.11 Unlike the majority of earlier spacecraft, spaceplanes are designed to be reused rather than just employed for a single mission. This transforms the economics of spaceflight: it means that development and manufacturing costs can be amortised across multiple flights, and so the total cost per flight – though still significant – will be far lower.

1.12 This not only makes it feasible to offer spaceflight experience on a commercial basis, but also has the potential to reduce the cost of satellite launches and the delivery of cargo and scientific payloads into space. It is anticipated that costs will continue to fall as commercial spaceflight becomes more frequent, potentially opening up spaceflight to the mass market.

1.13 As part of their overall business strategy, a number of spaceplane companies have expressed an interest in operating from the UK. Some have indicated a desire to do so by 2018, or potentially even earlier.

1.14 The UK Government has long been aware of the development of spaceplane technology. In *The Plan for Growth* (2011),[2] the UK Government identified the space industry as one of eight key sectors covered by the Growth Review, and stated that it 'wants the UK to be the European centre for space tourism'. This ambition is built in part on the strength of the UK's space industry, which already contributes £9.1 billion a year to the UK economy and has enjoyed an average annual growth rate of almost 7.5 per cent[3] over the last decade.

1.15 However, *The Plan for Growth* recognised that 'Space tourism and next generation 'hybrid' space planes could not currently operate out of the UK because there is no currently agreed regulatory environment for such vehicles'.[4] It therefore announced the intention that 'The Government will work with the European Aviation Safety Agency (EASA) to ensure that there is an operating and certification environment defined so that these vehicles can operate out of the UK, and so that manufacturers can invest in vehicle design with confidence that they will meet future regulations'.[5]

---

[2] HM Government (2011) *The Plan for Growth*, www.gov.uk/government/uploads/system/uploads/attachment_data/file/31584/2011budget_growth.pdf (accessed 23 February 2014)

[3] See www.bis.gov.uk/ukspaceagency

[4] HM Government (2011) *The Plan for Growth*, p 120 para 2.306, www.gov.uk/government/uploads/system/uploads/attachment_data/file/31584/2011budget_growth.pdf (accessed 23 February 2014)

[5] ibid

1.16 It is within this context that the CAA was tasked to undertake a detailed review of what would be required – from an operational and regulatory perspective – to enable spaceplanes to operate from the UK, particularly within the timescales that operators have proposed.

1.17 The CAA is the UK's specialist aviation regulator; UK and EU legal opinion has determined that horizontally-launched spaceplanes are aircraft – as explained further in Chapter 5 of this report – and, if launching from the UK, would travel through UK airspace. Hence, spaceplane operations in the UK would fall within the CAA's regulatory remit. The CAA therefore has a clear interest in the development of appropriate regulation to accommodate spaceplane operations, as well as relevant knowledge to explore the topic of how best to regulate this new form of transport.

1.18 The Review has focused on developing recommendations for the appropriate regulatory framework to allow commercial spaceplane operations in the UK. It has identified a wide range of potential obstacles that could inhibit operations, ranging from legal barriers to commercial restrictions, issues around disruption to other airspace users and the risks to the uninvolved general public; in each case, the CAA has made recommendations that propose ways to overcome these obstacles and so make it possible for spaceplanes to operate from the UK.

1.19 While it has considered the plans of individual operators, within the context of understanding their potential operating requirements, the Review in no way seeks to validate the readiness of those operators or their spaceplane designs.

1.20 It is important to underline that the commercial space industry and particularly the spaceplanes sector is evolving rapidly. This Review has gathered information over an 18-month period, up to May 2014, and reflects the state of the spaceplane sector at this point. Technological advancement, and the impact of initial commercial spaceplane operations – anticipated, at the time of writing, to commence by the end of 2014 – will undoubtedly change the landscape. Any reference to 'current' technologies or approaches within this report is believed to be correct as of May 2014.

1.21 The core recommendations are designed to remain applicable to the development of a suitable regulatory framework to allow spaceplane operations in the UK by 2018, potential technological development notwithstanding. As the Review also makes clear, however, the regulatory framework will need to evolve rapidly in the medium term as operations mature and volumes of spaceplane flights grow.

Review process

1.22 The Review took place over 18 months. While it was led by the CAA, it also involved experts in the Department for Transport, the Department for Business, Innovation and Skills, and the UK Space Agency. The Ministry of Defence has participated in the capacity of observers.

1.23 The Review included extensive desk research, examining aspects of existing legislation and regulation, as well as detailed studies of previous spaceflight missions, and publicly available information about spaceplane designs. Where relevant, these are cited and referenced within this report.

1.24 Members of the Review team have engaged closely with regulatory peers around the world, in particular at the US's FAA AST, the US National Aeronautics and Space Administration (NASA), EASA and the European Space Agency (ESA), to review the regulatory frameworks in place in different countries and for different types of flight, and to consider their applicability to the UK.
A number of other countries have active space launch programmes, but there is limited publicly available information to suggest that they are involved in the development of spaceplanes.

1.25 In June 2013, the UK Government led a delegation, which included a small team from the CAA, on a technical visit to the US at the invitation of the US Government. The visit included meetings with FAA AST, NASA, the US State Department, Congressional staff, spaceplane operators and commercial space industry bodies, a well as field visits to Spaceport America and the Mojave Air and Space Port. It also provided the opportunity for detailed discussions with FAA AST officials to understand its regulatory approach.

1.26 In addition, the Review team has engaged directly with several of the organisations developing spaceplanes, both on an individual level – with organisations providing detailed responses to specific questions about aspects of their spaceplane design, manufacture and proposed operations and confirming the accuracy of the report in relation to those operations – and through a series of industry days. The team is grateful to the industry for its involvement, which has resulted in face-to-face discussions with key stakeholders and experts in a range of fields, such as space law, insurance and space medicine, and with others from within the commercial spaceplane sector to discuss overarching issues and common concerns.

1.27 The input received has helped to shape the content of this report and, in particular, the recommendations made. What the report does not and cannot fully reflect, however, is the sheer enthusiasm of the industry, regulators, officials and others for the goal of enabling spaceplane operations from the UK. This has been evident from the outset and will be a vital asset in realising that goal.

CHAPTER 2

Spaceplanes today and tomorrow

This chapter explains in more detail what a spaceplane is and how spaceplanes differ from other aircraft and spacecraft. It looks at some of the key players in the emerging spaceplane market, providing an overview of their proposed operations in both the short and the longer term, and in doing so provides an indication of how the commercial space market as a whole may develop. It also considers some of the main differences in spaceplane design and what this may mean from a regulatory perspective.

What is a spaceplane?

2.1 As set out in Chapter 1, a spaceplane[6] is a winged vehicle that acts as an aircraft while in the atmosphere and as a spacecraft while in space. Spaceplanes are designed to be reusable and to operate at either a sub-orbital or an orbital level: a sub-orbital flight is one that reaches space but does not complete a full ‘orbit’ of the Earth. The first commercial spaceplane operations will be sub-orbital.

2.2 Like all earlier spacecraft, spaceplanes use a rocket engine as their primary source of power. Rocket engines generally rely on fuels and oxidiser that are carried within the vehicle; this is different from the gas turbine or piston engines used in most conventional aircraft, which are air-breathing. Rocket engines are required not only for the additional power and thrust they offer, but also because spaceplanes operate at much higher altitudes, where there is insufficient air for conventional aircraft engines to operate.

2.3 For sub-orbital operations, the rocket motor burn is short – anticipated to be less than three minutes in some of the designs – but this will allow the spaceplane to reach a speed of at least Mach 3 and will generate sufficient thrust for it to reach an altitude of over 100 kilometres (generally accepted as where space begins).[7] As well as offering spaceflight experience and scientific research, operations to this altitude may also facilitate the insertion of satellites into orbit.

2.4 The majority of spaceplane designs to date are for sub-orbital operations. However, some may be able to launch an extra rocket stage to achieve an orbital capability for small payloads. There are also some that are designed for orbital operations, such as SKYLON (discussed in more detail below): orbital operations will expend far greater energy than sub-orbital operations, to enable spaceplanes to reach much higher speeds and altitudes.

---

[6] In the absence of internationally agreed terminology, this report uses ‘spaceplane’ in preference to ‘space plane’. It also refers to ‘spaceport’ and ‘spaceflight’ as opposed to ‘space port’ and ‘space flight’.

[7] For further discussion of this, see Chapter 5.

2.5 Spaceplanes are designed to return to land at a conventional aerodrome. For most designs to date, this will involve an unpowered glide.

Main uses of spaceplanes

2.6 Unlike the majority of earlier spacecraft, spaceplanes are designed to be reused, rather than for a single mission only. They are generally designed for short flights: initial spaceflight experience trips are likely to last for no more than a couple of hours in total, with perhaps six minutes in a microgravity environment. These two factors mean that the cost to the operator and the complexity of each spaceplane flight will be significantly lower than almost any space missions to date. Those costs can of course then be recouped through commercial activity.

2.7 The first commercial spaceplane operations are expected to focus on offering spaceflight experience to paying participants. Published prices start at US$95,000 for a spaceflight experience with XCOR Aerospace which, like Virgin Galactic, has already signed up several hundred prospective participants.

2.8 As well as operations for spaceflight experience and scientific research, there is also, as mentioned above, an aspiration to use spaceplanes for satellite launches. At the time of writing, there are more than 1,000 satellites in orbit round the Earth, and a significant number are launched each year. In 2012, 81 satellites were launched, a slight decrease from 90 in 2011.

2.9 Currently, satellites are launched into orbit using expendable vertical launch vehicles (known simply as 'rockets'). Because spaceplanes are reusable, they will be able to meet some of this market demand at a comparatively low cost. The average price of a rocket launch varies between US$10 million and US$150 million; Virgin Galactic has indicated that its orbital launch costs (using its LauncherOne vehicle) would be less than US$10 million, at the bottom end of the current estimated price bracket.

2.10 However, there are limitations on the size of satellites that spaceplanes will be able to carry, and until orbital operations commence, sub-orbital spaceplanes will only be able to insert small satellites into Low Earth Orbit (LEO) or – according to one operator's design – small satellites into geo-stationary orbit.

2.11 A further potential market for spaceplanes is scientific research. Just as spaceplanes will be able to carry people into space, so scientific payloads can be carried and operated in a microgravity environment.

2.12 There has been considerable media coverage of the possibility of using spaceplanes to enable intercontinental travel at very high speeds. There have been suggestions that by travelling on a sub-orbital trajectory, journey times from the UK to Australia could be cut from the current duration of around 20 hours to as little as two hours.

2.13 However, even if such spaceplanes are successfully developed, they are not likely to be cost-effective for mass-market travel in the near future. An alternative approach using hypersonic aircraft flying on a more conventional flight profile is also an option, but again development will be very expensive and is thought to be some decades away.

A short history of spaceplanes

2.14 Although spaceplanes are themselves new vehicles, the concept of a reusable aircraft that could operate in space has been considered since before manned spaceflight began in 1961. The most famous spaceplane of all – the National Aeronautics and Space Administration (NASA) space shuttle – largely owes its existence to the earlier testing aircraft, including NASA X-planes, the first of which flew in the 1940s.

2.15 Some historians point to an even earlier design as the first 'spaceplane' concept: the hypersonic rocket aircraft Silbervogel, designs for which were first published in Germany in 1933.[8] The Silbervogel was to be launched from a sled propelled by rocket engines along rails, an approach that has not been taken further. However, aspects of the design were developed leading to advances in both military rocket technology and aircraft engines. The Silbervogel itself drew on earlier developments in Germany, where in 1928 the first rocket-powered aircraft flight took place. This involved the use of rockets to assist the flight of a glider, the Lippisch Ente.[9]

2.16 The most successful rocket-powered aircraft in operational terms was the Messerschmitt (Me) 163. This high-speed fighter used in World War 2 was designed to reach high speed and altitude in a very short time and was intended to counter the UK and US bomber offensive. Although over 300 were built, it had only limited impact.

2.17 In 1944, a co-operative research programme began in the US, involving the US Air Force and Navy and the National Advisory Committee for Aeronautics (NACA), the predecessor to NASA. This was the programme that led to the development of the X-Planes, including the Bell XS-1, which conducted the first ever supersonic flight in 1947.[10]

2.18 This programme laid the foundations for the hugely influential X-15 programme. The X-15 made 199 flights during the 1960s,[11] mostly from NASA's Flight Research Center in California (now known as the Armstrong Flight Research Center). In July 1962, it reached an altitude of 59.6 miles (95.9 kilometres).[12] It

---

[8] M Van Pelt (2012) *Rocketing Into the Future: The history and technology of rocket planes*, New York, Springer

[9] See www.princeton.edu/~achaney/tmve/wiki100k/docs/JATO.html (accessed 23 May 2014)

[10] See www.nasa.gov/centers/dryden/history/HistoricAircraft/X-1/ (accessed 7 June 2014)

[11] ibid.

[12] F Dreer (2009) *Space Conquest: The complete history of manned spaceflight*, Yeovil, J H Haynes & Co Ltd

was carried to an altitude of about 8.5 miles by a Boeing B-52 aircraft, and then released.

2.19 The main purpose of the programme was research, and it helped develop understanding of some of the critical challenges of spaceflight, from the need for craft to withstand extreme temperatures to the requirement for a comparatively lightweight vehicle. As a result of this, between 1963 and 1975 NASA developed a series of experimental aircraft with lifting bodies,[13] eliminating the need for wings. These assisted greatly in the development of the NASA Space Shuttle, in particular its use of an unpowered glide landing. All of the X-planes were treated, from the regulatory perspective, as experimental aircraft under NASA's oversight.

2.20 Around the same time, Boeing was developing the X-20 Dyna Soar, also designed to be a reusable spaceplane,[14] though the concept involved launch from an (expendable) carrier rocket. This was mainly for military use, and the programme was formally ended in 1963.

2.21 During the 1960s, various concepts were proposed for space transport, however. In 1967, a space technology conference in California featured presentations on 15 different proposals for reusable launch vehicles, including eight as part of the European Aerospace Transporter programme.[15] Some of the key concepts from these designs are being applied by Bristol Spaceplanes (whose founder was at the California conference) in its orbital spaceplane design called Spacecab.

2.22 Other 1960s designs include the Experimental Passenger Orbital Aircraft (EPOS) in the former Soviet Union, and the Multi-Unit Space Transport and Recovery Device or MUSTARD. This latter was outlined in an article in *Flight International* on 24 March 1966 by Mr T W Smith, Chief of Aerospace Department at the British Aircraft Corporation (BAC). He proposed an economic approach to space transport, involving three units – two of which would serve as boosters to launch the third into orbit. At an altitude of between 45 and 60 kilometres – or around 30 nautical miles – the booster units would separate and return to land like aircraft. The spacecraft would place its payload into orbit at around 1,000 nautical miles, approximately 10 minutes after launch, again returning to land like an aircraft.

2.23 EPOS was part of a programme known as Spiral,[16] which incorporated military aspects such as reconnaissance as well as transport. The aim of the programme was to launch an orbital spaceplane from a high-speed carrier aircraft. However, development was delayed and test flights of a manned vehicle to explore low-speed handling and landing only took place in 1976.

---

[13] ibid

[14] See www.boeing.com/boeing/history/boeing/dynasoar.page (accessed 30 April 2014)

[15] D Ashford (2013) *Space Exploration: All that matters*, London, Hachette

[16] As described by Molniya Research and Industrial Corporation, www.buran.ru/htm/molniya3.htm (accessed 30 April 2014)

2.24 In 1975, the French Centre National d'Études Spatiales (CNES) proposed a spaceplane design called Hermes.[17] It was to be launched from an Ariane-5 rocket with the purposes of transporting crews and equipment to space stations, servicing unpiloted platforms and repairing satellites in orbit. The project was taken up later by the European Space Agency but was eventually cancelled in 1992 – though Ariane-5 itself has been developed. However, a modified version of the Hermes design is now being used by Swiss Space Systems, as the basis for its Sub-Orbital Aircraft Reusable (SOAR) spaceplane.

2.25 The 1970s saw considerable development of the NASA Spaceshuttle project, which ran up until 2011. Flight testing began in 1981 – in April of that year, an estimated 320,000 people watched Columbia, the first space shuttle, land at the NASA Flight Research Center – and the first operational mission took place a year later. In all, 135 Space Shuttle missions were flown,[18] providing a considerable share of the body of knowledge around human spaceflight, contributing to scientific research and playing a pivotal role in the construction of the International Space Station.

2.26 During the 1980s, the former Soviet Union developed its reusable spaceplane, the Buran,[19] using a similar launch mechanism to the Space Shuttle. However, Buran was unmanned. Its only flight was in November 1988, when it made two full orbits of the Earth, followed by a fully automated re-entry and landing. The programme was cancelled in 1993.

2.27 The success of the Space Shuttle led to a renewed surge in interest in commercial spaceplanes, with a number of concepts emerging during the 1980s. Among the most notable of these was Sänger II, designed by Messerschmitt-Bölkow-Blohm.[20] The concept involved a carrier aircraft taking off from a runway to reach hypersonic speeds – allowing intercontinental very high speed travel – and a smaller orbital spaceplane, which would have been launched at altitude. The spaceplane too would have been able to carry passengers. The German government funded initial research into the Sänger II concept, but concluded in 1994 that development was too costly and the potential benefits unclear.

2.28 In the early 1980s, another attempt to develop a spaceplane was launched in the UK. British Aerospace (now BAE Systems) proposed a satellite-launching concept that would use an unmanned vehicle, known as HOTOL (Horizontal Take-Off and Landing).[21] The plan was based around a reusable aircraft, which would operate from an existing runway and carry viable payloads into LEO. The project was cancelled in 1988; however, the spaceplane and engine concept was kept

---

[17] See www.aerospaceguide.net/hermes.html (accessed 30 April 2014)

[18] See www.nasa.gov/mission_pages/shuttle/main/index.html (accessed 6 April 2014)

[19] As described by Molniya Research and Industrial Corporation, www.buran.ru/htm/molniya3.htm (accessed 30 April 2014)

[20] See www.astronautix.com/lvs/saegerii.htm (accessed 26 May 2014)

[21] See www.flightglobal.com/pdfarchive/view/1986/1986%20-%200486.html (accessed 30 April 2014)

alive in a new company called Reaction Engines, set up to develop an advanced spaceplane and rocket technology and preserve the wealth of know-how and expertise generated under HOTOL.[22]

2.29 In 1996, the X PRIZE was launched, to be awarded to the first non-government team that could successfully carry three people into space, and fly twice within two weeks. In other words, it demanded a reusable craft. It was renamed the Ansari X Prize in May 2004,[23] following a donation from entrepreneurs Anousheh Ansari and Amir Ansari, and the US$10 million prize was won in October 2004 by Scaled Composites with SpaceShipOne.[24] SpaceShipOne was immediately retired from active service, but its successor, SpaceShipTwo, is the spaceplane that will be used by Virgin Galactic.

2.30 As can clearly be seen by looking at this brief history, today's spaceplane designs and concepts draw considerably on those of their predecessors. Some aspects of the earliest concepts have become established technologies, and as developments in other fields – such as composite materials – have accelerated, so the principles of those initial concepts have been applied with increasing success, bringing us to the point today where commercial spaceplane operations appear technically and economically feasible.

Spaceplane designs

2.31 There are a variety of different spaceplane designs – discussed in more detail below. However, at this stage all can be placed in one of two fundamental categories:

- those that are **launched at altitude from a carrier aircraft**. Some of these use slightly modified conventional aircraft; others involve purpose-built aircraft. However, the fundamental principle is the same: at a certain altitude, the spaceplane is detached from the carrier aircraft. The carrier aircraft returns to land (conventionally) and the spaceplane begins its further journey to space. Where spaceplanes are being used for spaceflight experience, participants will spend their entire journey within the spaceplane: they will not travel in the carrier aircraft.
- those that **take off from a runway**. This category can be further divided into spaceplanes that take off like conventional aircraft (ie using jet engines) and then engage rocket engines at a certain altitude, and those that are rocket-powered from take-off.

2.32 Another difference within spaceplane designs is that some designs do not use onboard flight crew; instead, they would be remotely piloted. This is in keeping

---

[22] See www.reactionengines.co.uk/about_history.html (accessed 8 April 2014)

[23] See http://space.xprize.org/ansari-x-prize (accessed 30 April 2014)

[24] See Scaled Composites website www.scaled.com/projects/tierone/ (accessed 8 April 2014)

with many vertical launch space vehicles; indeed, a steadily growing proportion of aviation traffic is now unmanned, or remotely piloted.

2.33 These differences in design and proposed operation are highly significant from a regulatory perspective, as they create different types and levels of risk – not only to the paying spaceflight experience participants but also to those working with them and to the uninvolved general public. For example, for designs involving carrier aircraft, a key concern will be around the detachment process, to ensure that the two parts separate without impacting each other and that the ignition of the spaceplane rocket engines does not affect the carrier aircraft. For designs that are rocket-powered from take-off, there will be a need for greater oversight and understanding of the take-off process.

2.34 Clearly, this adds to the complexity of regulating the emerging industry – particularly as, unlike with ordinary aviation, there is simply not the same body of knowledge around spaceplanes and their safe operation. While some operators have conducted test flights, others are still very much at the development phase, as the following brief overview of designs and intended operations shows.

2.35 This is not an exhaustive list of companies that are, or claim to be, developing spaceplanes. However, these are the operators that the Review team believes are leading the way and/or that have indicated some intention to operate from the UK. They are listed in alphabetical order.

Airbus Defence and Space

2.36 Airbus Defence and Space (formerly EADS Astrium) is developing a spaceplane about the size of a business jet for spaceflight experience. It will be powered by two turbofan engines for normal flight and a rocket engine for the sub-orbital trajectory, and will take off and land conventionally from a runway using its jet engines. The entire flight will last approximately an hour. No in-service date has yet been set. Assuming relevant funding is available for further development effort, commercial operations would start by the beginning of the next decade.

Figure 2.1: Airbus Defence and Space spaceplane (image courtesy of Airbus Defence and Space)

Bristol Spaceplanes

2.37 Bristol Spaceplanes, based in the UK, was founded in 1991. It has developed plans for Spacecab, which is aimed at being the first orbital spaceplane. Spacecab is an update of the European Aerospace Transporter project of the 1960s. Spacecab is designed to carry six astronauts to a space station, or to launch a 750 kilogram satellite.

2.38 As a lead-in to Spacecab, the company has plans for the Ascender sub-orbital spaceplane. Ascender would carry one paying participant and one crew member. It would take off from a runway and climb to 26,000 feet (8 kilometres) at subsonic speed before starting the rocket engine. It would then accelerate to a speed of around Mach 3 on a near-vertical climb, and follow an unpowered trajectory to a height of 330,000 feet (100 kilometres).

2.39 Bristol Spaceplanes has received some UK government funding, as well as contracts from the European Space Agency, to support feasibility studies into its spaceplane designs. It has also run successful tests of its engines in the Mojave Desert.

Figure 2.2: Spacecab (image courtesy of Bristol Spaceplanes)

Orbital Sciences Corporation

2.40 US-based Orbital Sciences Corporation was behind the world's first privately developed space launch vehicle. It made its maiden voyage in 1990 and has since conducted 42 missions, including launches from the Canary Islands, to insert satellites into LEO. It uses a carrier aircraft and a winged multi-stage solid fuel rocket known as Pegasus. As far as the Review team is aware, the company has not yet expressed an interest in operating from the UK.

Figure 2.3: Launching Pegasus (image courtesy of Orbital Sciences Corporation)

Reaction Engines

2.41 UK-based company Reaction Engines is developing a fully reusable, single-stage to orbit, unmanned spaceplane called SKYLON. It will use a pioneering engine design known as SABRE (Synergetic Air-Breathing Rocket Engine) that will enable it to reach five times the speed of sound (Mach 5) in air-breathing mode and then accelerate to Mach 25 (18,000 miles per hour) for orbital insertion. It will take off from a runway and transition from air-breathing to rocket propulsion at an altitude of 80,000 feet (26 kilometres).

2.42 Proposed initial uses for SKYLON are to launch satellites and carry cargo to the International Space Station (ISS). However, it may also be able to carry spaceflight experience participants, or transport astronauts to the ISS, in a specially designed pod within the existing cargo bay. It is anticipated that after testing, which should commence in 2020, SKYLON would become operational in 2022.

Figure 2.4: SKYLON (image courtesy of Reaction Engines)

Stratolaunch Systems

2.43 Stratolaunch Systems is a relatively new company based in the US. According to information on the company website,[25] it is developing a very large spaceplane that is designed to launch satellites weighing over 6,000 kilograms into LEO. It will also be able to launch smaller payloads into geo-stationary orbit.

2.44 It plans to use a twin-fuselage aircraft, powered by six engines (the same as are used in the Boeing 747). The Air Launch Vehicle booster rocket will be developed by Orbital Sciences Corporation. The aircraft is expected to start flight testing in 2016 and the first launch is expected in 2018.

Figure 2.5: The Stratolaunch Systems spaceplane (image courtesy of Stratolaunch Systems)

---

[25] See http://stratolaunch.com/presskit/Stratolaunch_PressKitFull_May2013.pdf (accessed 10 June 2014)

Swiss Space Systems (S3)

2.45 Swiss Space Systems (S3) plans to offer a means of launching small satellites – weighing up to 250 kilograms – into orbit, using a spaceplane. The first satellite launches are planned for 2018.

2.46 It will launch its spaceplane from a carrier aircraft at high altitude. It plans to use a slightly modified Airbus A300; its spaceplane, the unmanned SOAR vehicle, will then be released and will use rocket-powered engines to reach sub-orbital levels. Both the carrier aircraft and SOAR use standard fuels and are reusable – key to achieving the company's aim of making the launch system highly efficient, secure and affordable. S3 is also considering spaceflight experience and intercontinental very high speed travel as future uses for SOAR in the course of the next decade.

Figure 2.6: SOAR on board an Airbus A300 (image courtesy of Swiss Space Systems)

Virgin Galactic

2.47 As recently as February 2014, the founder of Virgin Galactic, Richard Branson, reaffirmed his confidence that his company anticipates being able to start commercial operations in the US by the end of 2014, after completion of the flight test programme and approval by the FAA AST.[26] These will involve a spaceflight experience for up to six spaceflight participants as well as two crew. The company has been accepting deposits for several years, and more than 700 'future astronauts' have signed up. At the time of writing, the price for the flight experience including training is US$250,000 each.[27]

2.48 Virgin Galactic uses a specially designed carrier aircraft known as WhiteKnightTwo to carry a rocket-powered spaceplane (SpaceShipTwo) to approximately 50,000 feet (15 kilometres). The spaceplane is then released to begin its rocket-powered ascent to over 327,000 feet (100 kilometres) above the Earth's surface. The carrier aircraft returns to land conventionally; after re-entering the atmosphere using a tail feathering system to control speed and angle of descent, the spaceplane glides back to land on the same runway from which it departed. To date, it has performed several successful supersonic test flights.

2.49 As well as offering spaceflight experience, it is intended that SpaceShipTwo will carry scientific payloads which will benefit from approximately five minutes in a microgravity environment. Virgin Galactic also plans to use WhiteKnightTwo to deploy small satellites into orbit with a reusable launch vehicle, LauncherOne, currently in development. The company is currently carrying out test flights from its base at Mojave Air and Space Port in California and plans to undertake its first commercial flights from Spaceport America in New Mexico. It has expressed an interest, subject to US regulatory approvals, in conducting operations outside the United States, and the UK is a potential location.

Figure 2.7: WhiteKnightTwo (image courtesy of Virgin Galactic)

---

[26] See, for instance, 'Richard Branson insists he will be aboard first Virgin Galactic space flight', *Guardian*, 21 February 2014, www.theguardian.com/science/2014/feb/21/richard-branson-first-virgin-galactic-space-flight (accessed 3 March 2014)

[27] See www.virgingalactic.com/booking/ (accessed 3 March 2014)

XCOR Aerospace

2.50 Another Mojave-based company, XCOR Aerospace, is also taking bookings for spaceflight experience on its Lynx spaceplanes. These are two-seat vehicles: one seat is for the pilot; the other can be used by a paying participant. It proposes to offer half-hour sub-orbital flights to 330,000 feet (100 kilometres), and plans to commence commercial operations in the US in 2016.

2.51 Lynx is much smaller than the Virgin Galactic spaceplane and has been designed to take off horizontally from a runway before ascending to space. To do so, it will use rocket engines as its propulsion system from take-off – a significant difference from some other spaceplane designs.

2.52 From space, the Lynx spaceplane will return as a glider to land horizontally on the same runway as departure. The company has also published early-stage designs for future spaceplanes, including Lynx III, which will be able to launch multiple nanosatellites into LEO.

Figure 2.8: XCOR Lynx (image courtesy of XCOR Aerospace)

2.53 Table 2.1 below provides a comparative summary of these operators' intentions and readiness, based on publicly available information at 30 April 2014.

Operator	Spaceplane models	Orbital/sub-orbital	Launch mechanism	Flight crew	Proposed uses	No. of participants	Test flights	Provisional in-service date
Airbus Defence and Space	SpacePlane	Sub-orbital	From runway – powered by jet engines	1	Spaceflight experience	4	Drop tests took place in May 2014	None set
Bristol Spaceplanes	Ascender	Sub-orbital	From runway – powered by jet engines	1	Spaceflight experience/ scientific research	1	None	None set
	Spacecab	Orbital	Carrier aircraft (purpose-built)	2	Spaceflight experience/ scientific research	6	None	None set
Orbital Sciences Corporation	Pegasus	Sub-orbital	Carrier aircraft (modified Lockheed L-1011 Tristar)	0 (crew only on carrier aircraft)	Satellite launch (into LEO)	N/A	40+ commercial missions complete	Already in service
Reaction Engines	SKYLON	Orbital	From runway – powered by SABRE engines	Remotely piloted	Satellite launch; cargo transport Possible spaceflight experience	30 (in specially designed pod)	Expected to start in 2020	2022
Stratolaunch Systems	No name yet announced	Sub-orbital	Carrier aircraft (purpose-built)	0 (crew only on carrier aircraft)	Satellite launch	N/A	Expected to start in 2016	2018
Swiss Space Systems (S3)	SOAR	Sub-orbital	Carrier aircraft (modified Airbus A300)	0 (crew only on carrier aircraft)	Satellite launch/ scientific research	0 (though future plans include offering spaceflight experience)	Expected to start in 2015	2018

Operator	Spaceplane models	Orbital/sub-orbital	Launch mechanism	Flight crew	Proposed uses	No. of participants	Test flights	Provisional in-service date
Virgin Galactic	SpaceShipTwo	Sub-orbital	Carrier aircraft – purpose-built. (WhiteKnightTwo)	2	Spaceflight experience/ scientific research	4	Several complete	2014
	LauncherOne	Sub-orbital	Carrier aircraft – purpose-built. (WhiteKnightTwo)	2	Satellite launch/ scientific research	0	Several complete	2014
XCOR Aerospace	Lynx	Sub-orbital	From conventional runway – rocket-powered from take-off	1	Spaceflight experience/ scientific research	1	Expected to start in 2014	2016

Table 2.1: A comparative summary of the main spaceplane operators' intentions and readiness

Meeting the mandate

2.54 One of the tasks in the Review mandate was to provide 'a description and analysis of actual or anticipated key spaceplane operations and their requirements.' As the above analysis shows, there are no actual spaceplane operations and – based on operators' own views – at the time of publication only one spaceplane design is close to commercial readiness.

2.55 However, this is expected to change considerably over the next 5 to 10 years, during which time several operators anticipate beginning commercial operations. For the UK to be considered as a launch site for such operations, it will need to have a regulatory regime in place that permits spaceplane operations and to have a launch capability of some form – ie a spaceport.

2.56 Establishing a regulatory regime, selecting and, if necessary, developing a site for spaceplane launch will take some time; therefore, in order for the UK to be ready to meet operators' goals, it is essential that work begins as soon as possible to define the regulatory regime and identify a suitable launch site.

2.57 This intention must also be communicated clearly to operators so that they can plan on the basis of the UK being available by the time they are seeking to commence operations. Based on the analysis of anticipated spaceplane operations, this means the UK should aim to be ready to host spaceplane operations by 2018 or earlier.

2.58 The types of operation that will be feasible are spaceflight experience, scientific research and satellite launch. Each has slightly different requirements, but requirements are also influenced by the proposed spaceplane designs. For example, based on its published design, SKYLON would require a runway that is at least 5,000 metres long (runway length is considered in more detail in Chapter 9). There are also different requirements related to issues such as choice of fuel – different fuel types have different storage and handling requirements – and differing flight profiles. Therefore it is not wholly possible at this stage to state what the requirements of spaceplane operations are.

Vertical launch vehicles

2.59 Though spaceplanes may prove to be commercially viable for spaceflight experience, scientific research and some satellite launches within the next decade – a topic considered further in Chapter 3 – it is clear that in the immediate term, they will not be able to fulfil all the functions of vertical launch vehicles.

2.60 Vertical launch vehicles are not the primary focus of this Review; however, they are currently the main method of launching satellites. Therefore, even though satellite technology is rapidly advancing and nanosatellites (satellites weighing between 1 kilogram and 10 kilograms) now have the ability to perform tasks that previously required microsatellites (weighing between 10 kilograms and 100 kilograms), there will remain a need for vertical launch vehicles – not least for UK-based satellite operators.

2.61 Approximately 35 per cent of global satellite launches are funded from, and take place in, the US. However, a large proportion of launch orders are derived from European demand. In 2012, 11 of the 25 recorded orders were from Europe.[28]

2.62 A UK launch capacity would have a good chance of gaining some of these orders, on account of geographical proximity and lower costs. It must be emphasised, however, that due to its northerly latitude, the UK is only suitable for launching satellites into polar orbit (as opposed to equatorial orbit).

2.63 As part of the wider Review, the potential for a vertical launch site in the UK has therefore been considered.

2.64 One of the main reasons for considering this is that previous analyses of the economic feasibility of a UK spaceport have strongly suggested that the greatest commercial benefits would accrue from a site which offers both vertical and horizontal (ie spaceplane) launch.

2.65 This underlines the fact that while spaceplanes are expected to play a fundamental part in the future development of commercial space operations, they are certainly not the only available means of commercial space access.

---

[28] The Tauri Group (2013) *State of the Satellite Industry Report*, Washington DC, Satellite Industry Association, www.sia.org/wp-content/uploads/2013/06/2013_SSIR_Final.pdf (accessed 3 March 2014)

CHAPTER 3

Spaceplanes and commercial spaceflight: the opportunity for the UK

While most of this Review focuses on examining the regulatory requirements for commercial spaceplane operations, the mandate also requested an assessment of the potential for growth of the spaceplane industry beyond sub-orbital space tourism and satellite launches and an assessment of the value to the UK of commercial spaceplanes and related technologies. This chapter fulfils those requirements. It looks at the UK space industry to date, and considers how commercial spaceplane operations would strengthen it. It then examines the wider benefits to the UK of commercial spaceplane operations, and explains why a UK launch capability – ie a spaceport – would maximise those benefits. It then explores the case for government investment in a spaceport.

The UK space industry

3.1 The UK has a strong and fast-growing industrial and academic space sector. Its strengths lie in areas such as:

- advanced manufacturing, with companies that produce a range of satellites from small 'Cube Sats' weighing less than 10 kilograms to large telecommunications satellites that weigh upwards of 8 tonnes and can link distant communities across the globe; and
- a range of international services around satellite broadband, disaster relief and weather forecasting – all of which are based on space data and space infrastructure.

3.2 In 2012-13, the UK space industry had a turnover of £11.3 billion – up from £9.1 billion in 2010-11. Since 2000, revenues in the sector have grown by over 8 per cent per year on average in real terms. The sector directly employs 34,300 people, mostly in high technology jobs.[29]

---

[29] Data compiled by London Economics for UK Space Agency, 2014. Scheduled for publication in Autumn 2014.

3.3 In November 2013, UKspace – the trade association of the UK space industry – published the *Space Growth Action Plan 2014–2030* ('Space GAP'). This set out a series of growth targets for the sector, most notably the ambition that the UK should secure 10 per cent of the global space economy by 2030, a substantial increase on its 6.5 per cent market share in 2010. This would provisionally result in increased revenue for the UK space industry from £9 billion per year in 2012 to £40 billion in 2030, with an interim goal of achieving £19 billion turnover by 2020.[30]

3.4 The Space GAP identified 15 priority space markets that would create the largest value for the UK, and stated that 'each market will be worth at least £1 billion annually to UK-based suppliers within 20 years'.[31] Low-cost access to space was one of these priority markets – both in itself (ie for spaceflight experience and satellite launch) and as a key enabler of wider industry growth. The report advised:

> 'Access to space is a barrier to growth for UK companies as well as a commercial opportunity. The ability of UK companies to secure timely launch slots is decreasing and launch costs are increasing, particularly for satellites to Low Earth Orbit (around 80 per cent of all satellites). This is largely because the availability of low-cost launch vehicles in Eastern Europe is diminishing and may harm growth prospects for low-cost satellite manufacturers.'[32]

3.5 To address this, the report recommended that the UK Space Agency should 'champion policy and investment to establish a Space Port in the UK by 2018 and identify further reforms to regulation needed to allow commercial space flight in the UK'.[33]

3.6 At the time of publication, the UK has no indigenous space launch capability and is dependent on launch services in other nations. Higher 'delivery' costs, as foreseen in the Space GAP report, could potentially devalue the cost-effectiveness of UK satellite manufacturing, as the proportion of manufacturing to launch costs decreases.

---

[30] UKspace (2013) *Space Innovation and Growth Strategy 2014–2030: Space Growth Action Plan*, www.gov.uk/government/uploads/system/uploads/attachment_data/file/298362/igs-action-plan.pdf (accessed 23 June 2014)

[31] ibid, p 9

[32] ibid, p 14

[33] ibid

Spaceplanes: a game-changing technology

3.7 As spaceplanes are a game-changing technology, they have the potential to re-define the economics of the entire space sector. Traditional rocket launch systems using expendable launch vehicles typically account for between a quarter and half of the total cost of in-orbit satellite systems. Operators of reusable spaceplanes have indicated that they hope to be able to reduce these launch costs by as much as 80 per cent when their systems are fully mature.

3.8 These savings are achieved not only because spaceplanes are reusable, unlike most rocket systems, but also because their application of new technology, and the fact that they can gain aerodynamic lift at lower altitudes, reduces the amount of fuel required, compared with conventional rockets.

3.9 Clearly, from the perspective of the UK space sector, this could be an enormous benefit – especially if there was an opportunity to launch from the UK. This would place the UK at the forefront of the spaceplane industry: at the time of writing, there is no launch site within Europe for spaceplanes (although there is a vertical launch site at Kiruna in Sweden, inside the Arctic Circle, and plans are in place for the development of a spaceport at Kalamata in Greece).[34]

3.10 Based on the industry's estimated figure of commercial spaceflight being worth £1 billion per year to UK-based suppliers within 20 years, the total opportunity is significant, potentially worth between £10 billion and £20 billion to the UK economy over 20 years, as Figure 3.1 shows. But this is also an opportunity that will take time and long-term planning to realise. The strategic nature of the opportunity also requires a full partnership between industry and government.

---

[34] 'Europe's Spaceport' is The Guiana Space Centre or, more commonly, Centre Spatial Guyanais (CSG), jointly run by the Centre National d'Etudes Spatiales (CNES) and the European Space Agency (ESA). It is located in Kourou in French Guiana, South America.

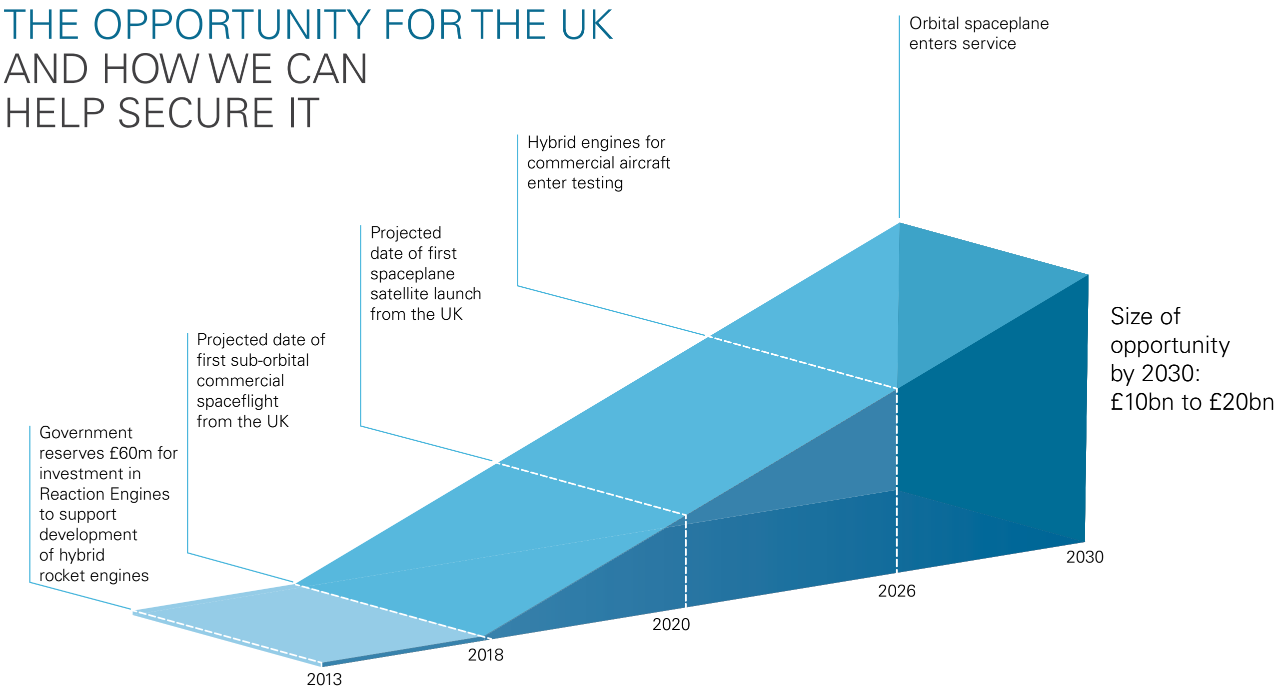


Figure 3.1: The projected growth of the UK commercial spaceplane sector

3.11 The Government has been active in its analysis of the low-cost space access market. In the *Plan for Growth*,[35] it identified the fact that the absence of a safety regulation framework for spaceplanes was a significant barrier to commercial spaceflight in the UK. It committed then to working with international regulatory authorities to define regulations for vehicles that offer low-cost access to space – a commitment this Review helps fulfil.

3.12 Since then, government has reviewed further the potential benefits of commercial spaceflight in the UK, and what would be needed to secure them. In its response to the Space GAP report,[36] the Government announced the creation of a cross-departmental National Space Flight Coordination Group (NSCG), chaired by the UK Space Agency, to take forward spaceplane regulation, investments in spaceplanes and the selection of a UK spaceport. This group reports to Ministers. Its cross-cutting nature reflects the close connections between these activities and also the scale of the challenge inherent in identifying, approving and building a UK spaceport and in supporting all the necessary innovation and technology that that would require.

---

[35] HM Government (2011) *The Plan for Growth*, www.gov.uk/government/uploads/system/uploads/attachment_data/file/31584/2011budget_growth.pdf (accessed 23 February 2014)

[36] UK Space Agency (2014) *Government Response to the UK Space Innovation and Growth Strategy 2014–2030: Space Growth Action Plan*, www.gov.uk/government/uploads/system/uploads/attachment_data/file/307656/Government_response_-_space_growth_action_plan.pdf (accessed 12 May 2014)

The importance of a UK launch capability

3.13 The response to the Space GAP report also underlines the Government's agreement that a UK space launch capability would provide a valuable addition to the UK space ecosystem, in the longer term potentially leading to more reliable, affordable launch services and new local and regional growth opportunities for the space industry.

3.14 The opportunities lie not only in gaining first-mover advantage for low-cost launches within Europe, but also in fields such as advanced manufacturing and space-related services. Despite having no space launch site, the UK does have advanced industrial capabilities in several key aspects of space launch, including rocket motors, high-pressure storage and pumps, low-weight structures and autonomous control systems. The development of commercial spaceplane operations would offer the chance to exploit these capabilities.

3.15 As part of this approach, in 2013 the UK Government reserved £60 million for investment in Reaction Engines, to develop a prototype of its hybrid air-breathing and rocket engine (known as SABRE) for a new breed of single-stage to orbit spaceplanes. The business case for this development, undertaken by London Economics, highlights the potential for this project alone to create £10 billion for the UK economy and 750 new jobs.[37]

3.16 The UK has also determined that a step-by-step approach to building a commercial space launch capability, starting now on a modest scale and building to a fully fledged capability, is a sensible direction of travel. The Government is assessing the benefits and costs of each stage of this approach. Included in this assessment will be the complex interaction between regulation, establishing a spaceport, and securing operations in the UK. Although this assessment is not fully developed, it will take account of this comprehensive picture of investment and benefits from a spread of interlinked activities. It is clear that some public investment will be necessary and, indeed, potentially desirable to lock in the optimum economic benefits for the UK.

3.17 UK satellite manufacturers may, of course, be able to enjoy the benefits of lower cost launches if spaceplanes are adopted by other nations. But this ignores the commercial and export benefits of a UK-based launch capability. Recent international events have also highlighted the vulnerability of UK's space industry to overseas launches.

---

[37] London Economics analysis discussed in ESA (2011) *Skylon Assessment Report*, www.bis.gov.uk/assets/ukspaceagency/docs/skylon-assessment-report-pub.pdf (accessed 13 May 2014)

Commercial launch markets

3.18 Initial assessment of the space launch market suggests that the UK can take advantage of five areas of market interest. These are listed below in approximate chronological order of commencement:

- **spaceflight experience** – the global market for sub-orbital flights carrying paying participants to the edge of space. As set out below, this is a wholly new market, projected to be worth £500 million per year within 10 years of operations starting, and the UK would be one of a small number of countries able to offer it;
- **scientific research** – sub-orbital flights would offer between four and seven minutes of continuous weightlessness for experiments in areas such as materials development and medicine;
- **small satellite launch** – sub-orbital spaceplanes are expected to offer the ability to launch satellites of up to 500 kilograms into Low Earth Orbit (LEO). This is of significant potential use to the UK satellite industry;
- **large satellite launch** – single-stage to orbit vehicles may be able to lift items of up to 15 tonnes into LEO, for further propulsion into geo-stationary orbit, and also deliver supplies and equipment to the International Space Station or other long-term missions; and
- **intercontinental very high speed travel** – as discussed in Chapter 2, there is a future possibility that spaceplanes and/or the technology developed for spaceplanes will be able to offer travel between continents on a sub-orbital or orbital trajectory, and thus radically reduce journey times.

3.19 This list is in no way prescriptive, but serves to indicate the key areas in which the UK may be able to build its operating capabilities, skills, technology and manufacturing base over time to be a major player in this market. These key opportunities are discussed in more detail below.

Spaceflight experience

3.20 Spaceflight experience is expected to be the first market for commercial spaceplane operations: indeed, the market is already open to customers, hundreds of whom have signed up with either Virgin Galactic or XCOR Aerospace.

3.21 Market research undertaken by Surrey Satellite Technology Limited indicates that UK demand for such flights could start at around 120 paying participants per year, increasing to 150 per year by year three.[38] A rough calculation based on the proportion of capacity of the two businesses that are most likely to be able to offer spaceflight experience in the next few years and their corresponding prices would indicate annual revenue from spaceflight experience of approximately US$19 million in year one and US$24 million by year three. In the medium term, it is expected that the number of spaceflights will increase in line with demand, up to perhaps 400+ participants in year ten, offering annual revenues of US$65 million. Independent forecasts confirm the size of the opportunity with The Tauri Group suggesting that the worldwide spaceflight-experience market could climb from around £100 million per annum at the start of operations to £500 million per annum by the tenth year of operation.[39]

3.22 Clearly, the revenue would predominantly go to these main operators, which are both US-based. However, there are significant maintenance and support costs related to spaceflight operations, which could provide a valuable opportunity for the UK. Importantly these are revenues which would be returned immediately, unlike many of the other potential economic returns that would accrue over a longer timescale.

3.23 These projected revenue figures are dependent on a number of factors, such as the ability to reduce prices, the presence of appropriate weather conditions, supply sufficiently meeting demand and the possibility that the market for spaceflight experience could be a short-term bubble, with demand declining relatively quickly. However, if take-up is as predicted, then in only a few years' time annual revenues from spaceflight experience alone could outstrip the capital costs of developing an operational spaceport at an existing aerodrome.

---

[38] Surrey Satellite Technology Limited (2013) Sub-Orbital Reusable Vehicles Market Analysis

[39] The Tauri Group (2012) *Suborbital Reusable Vehicles: A 10-year forecast of market demand,* http://space.taurigroup.com/reports/FAA_SRV_2012.pdf (accessed 13 May 2014)

Scientific research and development

3.24 Increasing access to space offers opportunities for advanced manufacturing and scientific research with potentially very large returns for the UK economy. Space environments provide exposure to microgravity, extreme radiation, vacuum and other stressors. These extremes allow for new insights into fundamental scientific processes and the development of new industrial capabilities and products of benefit to UK industry – even in as short a period as 4–7 minutes of exposure to the space environment. As will be discussed in Chapter 12, space research has already delivered important insights in a number of medical fields, including:

- the development of precision robotics for use in surgery;
- the creation of diagnostic ultrasound technology; and
- a new treatment for lower back pain, based on rehabilitation for astronauts.

3.25 Importantly, these are realised not simply through the ability to carry materials into space, but also through the entire process of preparation for, and analysis of, space travel. It is a very high-tech, research-intensive sector, which creates significant spillover benefits into other scientific disciplines. Industry commentators note that the spaceflight experience and scientific research and development (R&D) markets are highly complementary, because the costs of developing vehicles can be shared across the markets – the cost and risk of developing a product for just one market segment alone would be prohibitive.

3.26 Although it is always difficult to establish the monetary value of R&D to the UK economy, it is generally accepted as being extensive: it is estimated that spillover benefits from R&D generate a social return on investment[40] of a further 20–50 per cent.[41] For basic medical research, it is estimated that there is a perpetual return of £0.50 for every pound invested in biomedical research after the introduction of a therapy. It has also been shown that a £1 increase in public spending on basic biomedical research increases private spending by £2.20 to £5.50.[42]

---

[40] Social Return on Investment (SROI) is 'an approach to understanding and managing the value of the social, economic and environmental outcomes created by an activity' (see www.thesroinetwork.org/what-is-sroi, accessed 22 May 2014). It is used increasingly by UK government organisations as an additional measure of value.

[41] BIS (2012) *Annual Innovation Report*, p 1, www.gov.uk/government/uploads/system/uploads/attachment_data/file/34805/12-p188-annual-innovation-report-2012.pdf (accessed 23 June 2014)

[42] RAND Europe (2010) *Enhancing the Benefits from Biomedical and Health Research Spillovers Between Public, Private and Charitable Sectors in the UK*, www.rand.org/pubs/occasional_papers/OP319.html (accessed 12 May 2014)

Small satellite deployment

3.27 There are currently more than 1,000 satellites in orbit around the Earth, and a significant number are launched each year. In 2012, 81 satellites were launched, a slight decrease from 90 in 2011; however, the total launch revenues increased by 35 per cent year on year, reflecting the fact that 2012 saw a greater proportion of larger, more expensive satellites.

3.28 There is therefore a healthy and growing market for space access that is currently being met with expendable, vertically launched rockets. Because spaceplanes are reusable, they will be able to meet some of this market demand at a comparatively low cost. The average price of a rocket launch varies between US$10 million and US$150 million; Virgin Galactic has indicated that its launch costs would be less than US$10 million, the bottom end of the estimated price bracket. However, with its initial spaceplane designs it would not be able to carry larger payloads or satellites into Medium and High Earth Orbit. Given that the small satellite market is the fastest-growing sector, this is not necessarily an obstacle.

3.29 Approximately 35 per cent of global satellite launches are funded from, and take place in, the US; it is essentially self-sufficient, so even if the UK market matured, it would be unlikely to capture much of the US demand. However, a large proportion of launch orders are derived from European demand. In 2012, 11 of the 25 recorded orders were from Europe.[43] The only operational launch capability within Europe at the time of writing is in Sweden, and to date it has only been used for sounding rockets and scientific balloons. The Guiana Space Centre or, more commonly, Centre Spatial Guyanais (CSG) offers a large-scale European-owned and managed facility, but it is located in French Guiana in South America. A UK launch capacity would thus appear to stand a good chance of gaining some of the European satellite orders, particularly for small satellites into LEO. However, it is important to be clear that, on account of its northerly latitude, the UK – like Sweden – is only suitable for launching satellites into polar orbit (as opposed to equatorial orbit).

3.30 The exact demand is hard to predict, and in the short term it may amount to only one or two launches per year; however, this would be expected to increase as spaceplane technology evolves.

3.31 Ultimately, having the facility for low-cost launches may help transform the demand. UK-designed and manufactured satellites are already being used for a wide range of services, from monitoring the climate and the environment, to satellite navigation and to supporting communications. If launch costs were lower, new uses may emerge.

---

[43] The Tauri Group (2013) *State of the Satellite Industry Report*, Washington, DC, Satellite Industry Association, www.sia.org/wp-content/uploads/2013/06/2013_SSIR_Final.pdf (accessed 3 March 2014)

Large satellite deployment

3.32 In the medium to long term, other platforms led from the UK – notably Reaction Engines' SABRE hybrid engine and the SKYLON single-stage to orbit spaceplane – will come to maturity, with the capability to transport larger satellites (expected to be up to 15 tonnes).[44] This will open up cheaper access to space for most satellite deployments. It is estimated that the SKYLON project would be capable of delivering a payload of this size into LEO at about one-fiftieth of the cost of traditional expendable launch vehicles.[45] If this proves to be the case, it will clearly change the economics of satellite launch. However, there are also plans for reusable vertical launch vehicles, such as SpaceX's Falcon 9. These, too, could substantially reduce the costs of satellite launch, with projected savings of as much as 70 per cent.[46]

3.33 It is important to note here that the opportunity for the UK from having a low-cost launch capability is not solely about operations: the UK is well positioned to become a global leader in the manufacture of critical single-stage to orbit spaceplane components and sub-systems. This will involve some of the highest technology manufacturing taking place on the planet and would rely on a site in the UK for testing and development even if the spaceplanes themselves did not operate from the UK.

Intercontinental very high speed travel

3.34 The largest potential benefit to the UK, and also the benefit that is given least weight in this analysis, is that of intercontinental very high speed travel. The concept is highly attractive: by entering sub-orbital flight paths, vehicles would be subject to lower atmospheric drag and would allow the Earth to rotate under them. This would permit substantially faster journey times for intercontinental flights: for example, it is claimed that a flight from New York to Tokyo could be cut from 13 hours to less than two hours.

3.35 Time savings on this scale would, of course, offer substantial benefits to passengers, as well as to the economy: for example, the cost benefit of reducing travel times from the UK to Australia from 22 hours to just two hours has been estimated at over £160 million per year.[47]

---

[44] London Economics (2013) 'Towards a UK launch infrastructure, Economic analysis work package' p38. Unpublished study, part of the Space Collaborative Innovation Team Initiative (Space CITI) programme within the UK Space Agency's National Space Technology Programme (NSTP)

[45] See www.bis.gov.uk/ukspaceagency/news-and-events/2013/Jul/government-to-invest-60-million-in-worlds-first-air-breathing-rocket-engine (accessed 22 May 2014)

[46] See www.forbes.com/sites/alexknapp/2014/04/25/spacex-falcon-9-reusable-stage-landed-safely-in-the-atlantic (accessed 22 May 2014)

[47] This figure is based on the number of extra hours that passengers would be able to work. It is calculated based on the reduced flight time for 454,000 visits to Australia in 2010 (Office for National Statistics travel data), and the assumption that each person earns the average wage of £12.50 per hour.

3.36 However, there remain considerable doubts about the suitability of sub-orbital or orbital spaceplanes for mass-market travel – and not simply due to the fact that no spaceplane for this purpose has even begun testing. Because it would involve high G flight (see glossary), the nature of the journey would be quite unlike that of commercial aviation, and the physical experience may render it unsuitable for some.

3.37 An alternative would be to apply derivatives of the hybrid engines needed to power orbital spaceplanes to power future commercial aerospace vehicles. Even here, the acceptance of such technology in the commercial airline market will require a significant amount of time. The first step would be to prove the technology to a point where major aircraft manufacturers would consider using it as the basis for new concept designs; they could then share these with airlines, and seek commercial investment.

3.38 No account has been taken of the defence markets for spaceplane technology: this lies outside the scope of this analysis.

Wider benefits for the UK of commercial spaceplane operations

3.39 Aside from these specific commercial uses of spaceplanes, there are a number of further benefits that would accrue from the UK having a commercial spaceplane launch capability. These include:

- **local benefits** – particularly new jobs, firstly in construction during the development phase, and then in retail and services. In the longer term, supply-chain advantage in and around a spaceport might result in 'logistics-driven' growth in the advanced manufacturing and high-tech sectors, with the spaceport acting as a hub;
- **specialist skills and increased high-tech manufacturing** – both maintenance and new-technology development of spaceplanes could create significant numbers of new jobs at various skills levels. This would also aid an indigenous ability to manufacture new systems and potentially even spaceplanes in the future;
- **direct technology spillovers** – the clustering of high-technology firms could spur ongoing growth, knowledge transfer and productive collaboration in the immediate area around a spaceport, but also more widely across the UK;

- **tourism** – it is anticipated that there would be, at least initially, high levels of interest from spectators watching spaceplane operations. This could give a boost to tourism in the immediate area around a spaceport. Furthermore, given the high net worth of likely spaceflight experience participants, this could potentially lead to an increase in business transacted in London and other major UK cities if visiting the UK to take part in a spaceflight experience gives these individuals the chance to progress new business opportunities in the UK;
- **professional services** – a growing space sector would create opportunities for various professional services, such as space finance, legal services and insurance. The UK would develop expertise in each of these areas, and this could then be 'exported' as other countries develop their own space operations;
- **inward investment** – a decision by the UK to create a spaceport has the potential to attract new inward investment either in the spaceport itself or in surrounding technology clusters; and
- **education and outreach** – commercial spaceflight operations from the UK would undoubtedly serve to inspire future generations of young people to embark on space-related careers in disciplines such as science, technology, engineering and mathematics. These are recognised as being valuable to the long-term strength of the economy.

3.40 As is apparent, many of these benefits rely in no small part on the UK having its own launch site – ie a spaceport. Even though a spaceport would have little productive value in isolation – especially in the short term, when the volume of flights is likely to be small – it would be a catalyst for the accelerated growth of the UK space industry. Many of the benefits of this infrastructural asset would derive from the complementary relationship between manufacturing capability and launch capability. Some benefits may be partly realised without the existence of a UK launch capability (for example, through the export of newly developed technology to other space-faring nations); however, they would be significantly diminished.

The case for investing in a spaceport

3.41 Developing a spaceport would require significant capital investment. Exact costs cannot be confirmed at this stage, as they would depend on the location chosen and its existing facilities: some aspects may be usable as they stand, others may need improvement. This is discussed in much more detail in Chapter 9, which sets out the fundamental operational requirements of a spaceport and identifies vital safety criteria for site selection. But selection will also be, in part, an economic issue – finding the site which, while meeting the safety criteria, offers the best balance between development costs and potential benefits to the UK.

3.42 As well as construction on site, there may also be a need for infrastructure improvements. Experience in the US indicates that those paying for a spaceflight experience will expect a high-quality product at the spaceport as well as on the flight itself. In addition, there would be a requirement for broader industrial and academic activities associated with the development of this type of infrastructure.

3.43 Evaluation of costs will need to include:

- capital costs of spaceport infrastructure, for example runway extensions, terminal facilities and specialist ground handling infrastructure;
- transport and maintenance costs, including the provision/development of links between the spaceport and key centres of population;
- spaceport operating and maintenance costs; and
- training and skills development.

3.44 Further investigation would be required to identify how best to fund the construction. In general, programmes of this scale involve a mix of private, central government, regional government and inward investment. But given the timings involved – ie the need to have an operational spaceport by 2018 or earlier, to meet the target dates set by those operators that are keenest to launch from the UK – it is clear that decisions need to be made quickly.

3.45 While spaceplane operators would receive the direct benefit of access to a spaceport, and hence could be expected to contribute towards development, initial assessment indicates sizeable potential returns to the UK economy, as well as large spillovers in the medium to long term. These would not only benefit the operators, but would also radiate out through the UK economy. This means there is a case for exploring how government funding could be combined with private investment. Financial support could come from local government and/or devolved administrations in the region where a spaceport could be located. However, if the Government wants the UK to become the European centre for the space industry, some central funding for a spaceport may be needed.

Vertical launch

3.46 A further potentially complicating factor in the selection of a site for a spaceport and any decision to invest is the potential need for a vertical launch site for expendable rockets. As has been made clear, spaceplanes – horizontally launched – have the potential to transform the economics of space and, in particular, of satellite launches. However, there are limitations (at least in the short term) to the size of satellites that can be carried. This means that there could be a case for a site offering low-cost vertical launch for small satellites in the UK as well.

3.47 In terms of the commercial benefits, it would seem logical to suggest that a vertical launch site should be collocated with a spaceplane launch site. This would help make the site a true industry hub; it may also reduce infrastructure construction costs.

3.48 However, in operational terms, this would be problematic. Several studies have indicated that the only suitable location in the UK for a vertical launch site would be the north coast of Scotland. As explained further in Chapter 9 this is not an ideal location for a horizontal launch site on account of weather conditions. Furthermore, the commercial gains of a collocated site may not be so clear-cut: a site in such a location would necessitate significant investment in infrastructure, and may not be attractive to businesses (or indeed prospective spaceflight participants) because of its distance from major commercial centres.

3.49 In short, the UK could invest in both vertical launch and horizontal launch sites for low-cost access to space systems, but it must be careful to avoid diluting the overall business case for investing in spaceports. Locating the two facilities at the same site risks decreasing the projected benefits of allowing commercial spaceplane operations.

3.50 As an alternative, separate sites could be established. This would obviously increase the total costs. Moreover, given that the long-term goal is to replace vertical launch with the more efficient spaceplane method, investing in a separate vertical launch site would require a compelling case from a vertical launch operator that it could, even as a conventional rocket launch system, significantly reduce costs and offer satellite operators a good choice of launch slots.

Addressing market failures

3.51 The decision to invest in one or more launch sites, and indeed any subsequent decisions about how much to invest, would require a detailed examination of the costs and benefits of different investment options, to ensure both value for money and accountability. In the end, market failures and value for money will underpin the rationale for government intervention to aid the construction of a spaceport in the UK and will also ensure that service operators are attracted to use it.

3.52 There are a number of inherent market failures for projects of this size, particularly as this is a completely new market with unknown technological validity. These include:

- failure to maximise the UK's return from missing and future markets – ie the impact that not having a UK launch capability would have on the wider UK space industry and on its ability to achieve its growth objectives;

- capital market failures – the cost of constructing and operating a spaceport would be prohibitively expensive for most space industry firms to undertake in isolation at this stage, given that the US already has functioning spaceports under an existing regulatory regime. In short, if left to industry, there is a good chance that spaceport construction in the UK would not happen;
- failure to secure first-mover advantage in Europe – there is no doubt that the first commercial spaceplane launch site in Europe will have a significant advantage in attracting high-tech businesses. Should a spaceport be developed elsewhere in Europe before one is available in the UK, the potential benefits to the UK economy would diminish;
- failure to secure commercial investment – if the Government were to commit to part-funding development, it would need to ensure that it offered sufficient investment to reduce risk to the point where commercial companies could also invest;
- failure to gain clustering benefits – if left solely to industry to develop, opportunities may be missed to encourage wider investment in UK capabilities, in the space sector and beyond;
- failure to develop spaceplanes – there is a risk that, after investment in the development of a spaceport, the necessary launch vehicles (ie spaceplanes) may themselves not be ready or available. This may therefore necessitate further investment in R&D to achieve the wider objective of a successful spaceport at the heart of a thriving UK space sector. Clearly, this would involve working with industry to understand development timescales and readiness – not only for UK-manufactured spaceplanes, but also for those manufactured overseas. For US spaceplanes, this links to a wider risk, discussed below and in some depth in Chapter 4, surrounding export controls; and
- the commercial and technical risks arising from the failure of a spaceflight – given that, for the foreseeable future, sub-orbital spaceplanes cannot be expected to operate to the levels of safety required by commercial aviation, catastrophic failure of a commercial spaceflight could significantly impact this nascent industry.

Developing a business case

3.53 Clearly, these are all issues that the Government may wish to consider, and balance the risks and potential gains against the costs. The opportunity is a considerable one, but government has further work to undertake to produce the credible, well-researched business cases to show value for money, affordability and deliverability. The most important elements of the UK's ambitions in this area are the indigenous launch of small satellites and the manufacturing of systems and potentially entire vehicles for orbital spaceplanes. Nonetheless, it is clear that enabling sub-orbital spaceplanes to offer spaceflight experience and scientific research will provide early revenues from commercial spaceplane services and act as a catalyst for further development.

3.54 The Government should therefore:

- continue to support the development of a regulatory environment for spaceplanes and low-cost access to space;
- determine suitable locations for a UK spaceport, and assess how any necessary investments can be secured;
- consider whether it needs to invest in space launch vehicles and start-up services to secure these in the UK; and
- define and adopt a long-term plan for securing commercial space flight.

Recommendation

The National Space Flight Coordination Group should work across government and with delivery partners to build the economic business cases for investment in a UK spaceport and spaceplane services that secures economic benefits for the UK at best value for money.

Securing the benefits of technology transfer

3.55 Both Virgin Galactic and XCOR Aerospace have expressed an interest in launching spaceplane operations outside the US – including in the UK.

3.56 As this chapter has indicated, such operations would be an important catalyst for the development of the UK space industry. They could potentially offer supply opportunities and knowledge transfer to support the development of UK spaceplane technologies. They would also serve to attract other related businesses, including other spaceplane operators, to the UK. Therefore, there is a strong desire within the UK to enable US-based and other international companies to operate from the UK.

3.57 However, the US export control regime presents significant challenges to operations outside the US.

3.58 This chapter has shown that the potential gains to the UK of enabling commercial spaceplane operations are considerable. It has also indicated the likely need for government investment in a spaceport, so that the UK has a suitable launch site ready by 2018, in line with the target launch dates of operators. This is seen as a potential catalyst for the further development of the UK space industry.

3.59 However, there is an important issue to be addressed here. For the UK to secure the maximum possible value from allowing commercial spaceplane operations, UK businesses would need to be able to supply and support a UK spaceport and those who operate from it – offering maintenance services, components and more. To accelerate the development of UK technologies, a process of knowledge transfer between the earliest operators and UK companies would be invaluable.

3.60 As described in more detail in Chapter 4, US export controls could be a significant obstacle to realising such opportunities. Because spaceplanes fall under US International Traffic in Arms Regulations, there are strict controls on the type of information that can be shared with non-US companies, and on non-US citizens working on any aspect of a spaceplane operation.

3.61 While such restrictions would not prevent the UK from growing its commercial space industry, they would almost certainly slow progress – without the additional knowledge transfer – and potentially diminish the scale of the commercial opportunity. The Government is aware of these issues and is working on a way forward to address them, to secure the maximum possible benefit for the UK. This is considered further in the next chapter.

Recommendations

3.62 This chapter has made the following recommendation.

- The NSCG should work across Government and with delivery partners to build the economic business cases for investment in a UK spaceport and spaceplane services that secures economic benefits for the UK at best value for money.

CHAPTER 4

Export controls

This chapter examines US export controls and their potential impact on proposed UK spaceplane operations. It summarises what the controls are and considers not only how these may limit the economic benefits that could be gained by the UK but also how they could more fundamentally limit the scope of operations. It proposes a way forward, requiring high-level political commitment and engagement with spaceplane operators.

The importance of US spaceplane operators to the UK

4.1 As discussed in Chapter 2, the organisations that are expected to commence commercial spaceplane operations first – Virgin Galactic and XCOR Aerospace – are based in the US. They have developed their technology predominantly in the US and, accordingly, much of the expertise around spaceplane design and operation resides in the US.

4.2 Both Virgin Galactic and XCOR Aerospace have expressed an interest in launching spaceplane operations outside the US – including in the UK.

4.3 As Chapter 3 has indicated, such operations would be an important catalyst for the development of the UK space industry. Subject to US government approval, they could potentially offer supply opportunities and knowledge transfer to support the development of UK spaceplane technologies, and they would also serve to attract other related businesses, including other spaceplane operators, to the UK. Therefore, there is a strong desire within the UK to enable the likes of Virgin Galactic and XCOR Aerospace, as well as other US-based companies, to operate from the UK.

4.4 However, as stated in the previous chapter, the current US export control regime limits such operations outside the US.

Export controls

4.5 International export controls exist to restrict the distribution of arms and proliferation of strategic missile systems.[48] There are four major global agreements, two of which are relevant to spaceplanes: the Missile Technology Control Regime (MTCR) and the Wassenaar Arrangement (WA). The UK and the US are signatories to both agreements.

---

[48] For an overview of UK export controls, see www.gov.uk/beginners-guide-to-export-controls (accessed 1 May 2014)

4.6 Spacecraft and space launch vehicles (SLVs), which potentially includes sub-orbital spaceplanes, are subject to export control under these regimes. The WA covers unmanned spacecraft (including satellites) and the MTCR covers SLVs.

Missile Technology Control Regime

4.7 The MTCR was established in 1987 by the US, Canada, France, Germany, Italy, Japan and the UK.[49] A total of 34 states are now participants in the MTCR; the UK and the US are two of the most active participants.

4.8 The MTCR aims to limit the proliferation of strategic missile systems capable of delivering weapons of mass destruction. It was originally established to curb the proliferation of ballistic missiles as they were seen as the preferred delivery vehicle for countries seeking an effective nuclear weapons capability. However, since January 1993, the MTCR has expanded to include delivery systems for chemical and biological weapons. It therefore covers exports from the world's most advanced suppliers of ballistic missiles and missile-related materials and equipment.

4.9 The MTCR establishes a common export control policy based on a list of controlled items (the 'Technical Annex' or simply the 'Annex') and a set of policy guidelines (the 'Guidelines') for transfers, which member countries implement in accordance with their national export controls.

4.10 The Guidelines set out policy, procedures and review factors, and require standards for government assurances to prevent proliferation and transfers to destinations of concern. MTCR members voluntarily pledge to apply the Guidelines and to restrict the export of items contained in the Annex.

4.11 The Annex contains two categories and 20 missile-related goods and technologies sub-categories:

- Category I covers complete missile systems[50] capable of delivering at least a 500 kilogram payload over a range of at least 300 kilometres and the major sensitive sub-systems and production equipment and technology for such missiles. Crucially here, this includes rocket motors.
- Category II covers materials, components, production and test equipment, as well as missile systems with at least a 300 kilometre range regardless of payload capability, and major sub-systems. These are controlled goods, technology and software, but are less sensitive.

---

[49] See www.mtcr.info/english (accessed 1 May 2014)

[50] For the purposes of the MTCR a missile includes ballistic missiles, space launch vehicles (SLVs), sounding rockets, cruise missiles, and certain Unmanned Aerial Vehicles (UAVs).

Wassenaar Arrangement

4.12 The WA was established to contribute to regional and international security and stability, by ensuring greater responsibility in transfers of conventional arms and related dual-use goods and technologies, thus restricting the accumulations of conventional arms that could destabilise specific regions.[51]

4.13 The WA is based on two lists:

- the Munitions List, covering military equipment and weapons; and
- the Dual-Use List, which lists equipment, technology and software related to military equipment and weapons.

How these agreements are applied

4.14 There are similarities in the way the MTCR and the WA are applied in the UK and the US, but also important differences.

4.15 Both the US and the UK list controlled items from each regime in their respective export controls. Indeed, both the US and the UK export control lists largely originate with the WA. In the UK, these form the UK Military List and the EU Dual-Use List.

4.16 However, under current UK interpretation of the WA and MTCR control lists, the UK does not control manned spacecraft. This is because MTCR specifically excludes the control of manned aircraft, and so is unlikely to control manned spaceplanes; meanwhile the WA specifically controls only manned spacecraft designed or modified for military use. In the US, however, manned sub-orbital and orbital spacecraft are on the US Munitions List (USML) and therefore subject to the US International Traffic in Arms Regulations (ITAR). This is because they have a Category I rocket motor and so are defined as MTCR Category I systems.

4.17 This was confirmed during a meeting at the US Department of State,[52] the US government department responsible for controlling the export and temporary import of defence-related products, services and technology on the USML.

The implications of MTCR Category I classification

4.18 As stated above, MTCR was set up in response to the increasing risk of the proliferation of weapons of mass destruction (WMD), in particular strategic delivery systems for WMD. Items classified as Category I are those that would be capable of the delivery of WMD. Based on this, the MTCR Guidelines state that there should be 'a strong presumption to deny' the transfer of all Category I items.[53]

---

[51] See www.wassenaar.org (accessed 1 May 2014)

[52] The meeting was part of the UK Government's technical visit to the US in June 2013.

[53] MTCR Guidelines, point 2, www.mtcr.info/english/guidetext.html (accessed 1 May 2014)

4.19 To allow the transfer of such systems:

- government-to-government undertakings must be in place; and
- all necessary steps must be taken to ensure that the transfer is used only for the stated end use.

4.20 The transfer of design and production technology for Category I systems is controlled to an even greater extent than the equipment, with the result that the transfer of such technology is strictly prohibited.

4.21 It was the view of the US Department of State that, irrespective of the commercial aspirations of companies developing sub-orbital and orbital vehicles, the potential for use to deliver WMD is the critical issue in respect of all items on the USML for MTCR Category I items. The US Department of State therefore begins from a position of a strong presumption to deny any export licence applications for spaceplane technology.

Recommendation

The Government should seek early expert legal and policy advice on the best way to achieve a common understanding with MTCR partners on how to allow the transfer of manned spacecraft, including sub-orbital spaceplanes, which may fall within Category I of MTCR as interpreted by MTCR participating states.

US export controls

4.22 US law and the US court system fundamentally consider exporting to be a privilege, rather than a right. All exports technically require some form of licence or other form of legal authorisation. Specific export controls apply to any item or service that is listed on the USML or that has performance characteristics as described in the dual-use Commerce Control List (CCL) – the US equivalent of the UK's Dual-Use List.[54]

4.23 The US Government maintains and closely enforces laws and regulations that prohibit business activities involving certain technologies, entities, persons or countries. The law and policy of US controls are driven by a combination of national security concerns, foreign policy objectives, efforts to curb international terrorism and the proliferation of WMD, and even domestic politics. The level of control varies according to several factors, including the nature and sophistication of the product or technology in question, the ultimate destination of the export, the identity of the end user and the proposed end use.

---

[54] See www.bis.doc.gov/index.php/regulations/commerce-control-list-ccl (accessed 1 May 2014)

4.24 The system is complex and involves a multiplicity of statutes, regulations and policy objectives. Most US export controls fall under one of two legal frameworks:

- **Export Administration Regulations (EAR)**[55]
  Administered by the Department of Commerce's Bureau of Industry and Security, the EAR control exports and re-exports of a broad range of non-military (dual-use) goods, software and technology for both national security and foreign policy reasons. The controlled items are listed on the CCL.
- **Directorate of Defence Trade Controls (DDTC)**[56]
  Administered by the US Department of State, the DDTC regulates exports of goods, software, technical data and services that are specifically designed for military use, or closely related to military use, as listed in the USML. ITAR is one of the DDTC, and the release of ITAR-controlled technical data almost always requires prior authorisation under DDTC.

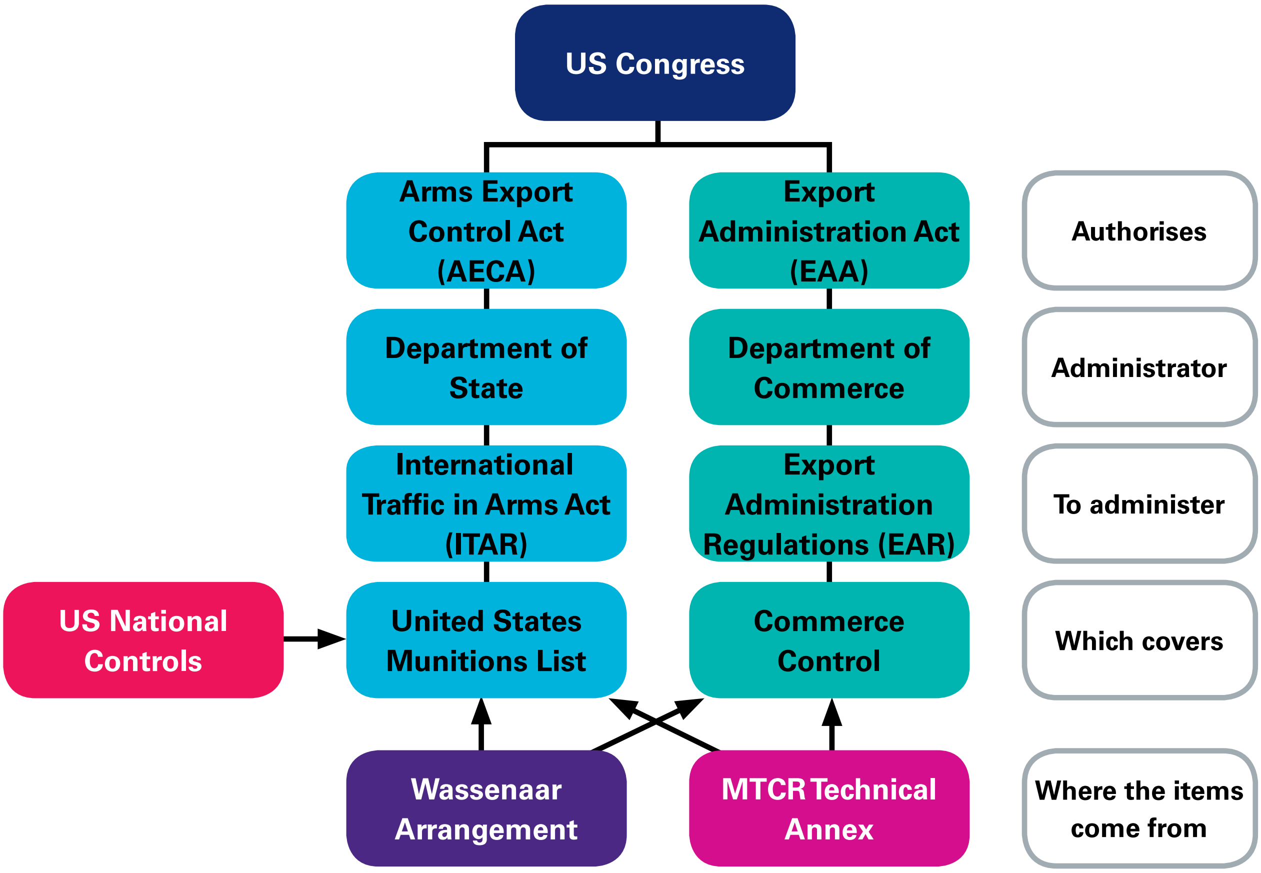


Figure 4.1: Authorisation hierarchy for US export controls

---

55 See www.bis.doc.gov/index.php/regulations/export-administration-regulations-ear (accessed 1 May 2014)

56 See http://pmddtc.state.gov/ (accessed 1 May 2014)

How US export controls apply to the commercial space industry

4.25 Virtually all space-related technologies (including SLVs, spacecraft, rocket motors and propellants) fall under ITAR and not EAR. In 1999, Congressional legislation transferred the jurisdiction for controlling all satellite technology from the Department of Commerce Bureau of Industry and Security to the Department of State, to be regulated under DDTC, because of the potential for space-related technologies to have a military use. This is not necessarily to do with the potential for proliferation of strategic missile capability – the issue MTCR was set up to address; rather, it has to do with the potential threat from other nations to US space assets.

4.26 ITAR is a far stricter regime than EAR. Under EAR, there is a 'presumption of approval'. The Bureau of Industry and Security specifically identifies only those items and countries of destination for which an export licence would be required, and allows exceptions under certain circumstances. Conversely, ITAR is based on 'presumption of denial', with exporters required to prove that their item or service does not pose a significant risk to national security.

4.27 A key point in the ITAR process, particularly regarding the transfer of technical data, is that ITAR applies not only to the end product but also to all information required for its design, development, production, manufacture, assembly, operation, repair, testing, maintenance or modification. This includes information in the form of blueprints, drawings, photographs, plans, instructions or documentation. Like the items themselves, each piece of information is treated under ITAR as a 'defence article'. However, this does not extend to information concerning general scientific, mathematical or engineering principles commonly taught in schools, colleges and universities, or to information in the public domain. This is in accordance with the WA definition of 'technology'.

4.28 For the purposes of export, ITAR is applicable to any of the following:

- sending or taking a defence article out of the US in any manner, except by mere travel outside the US by an individual whose personal knowledge includes technical data;
- transferring registration, control or ownership to a foreign person of any aircraft, vessel or satellite covered by the USML, whether in the US or abroad;
- disclosing (including oral or visual disclosure) or transferring in the US any defence article to an embassy, any agency or subdivision of a foreign government;
- disclosing (including oral or visual disclosure) or transferring technical data to a foreign person, whether in the US or abroad; and

- performing a defence service on behalf of, or for the benefit of, a foreign person whether in the US or abroad.

4.29 'Foreign person' means 'any person who is not a lawful permanent resident of the US. It also means any foreign corporation, business association, partnership, trust, society, or any other entity or group that is not incorporated or organized to do business in the US, as well as international organizations, foreign governments and any agency or subdivision of foreign governments (eg diplomatic missions).'[57]

4.30 All of the above have parallels within UK strategic export controls. However, in the UK they would not necessarily be applied to commercial spaceplanes.

EAR controls

4.31 If a product is considered commercial, of 'dual-use', and is on the CCL, then EAR apply. The CCL divides items into the same ten broad categories that the UK implements in the EU Dual-Use List; with each category further subdivided into five product groups. As stated above, the Bureau of Industry and Security is responsible for implementing and enforcing the EAR.

Categories	Product groups
▪ Nuclear materials, facilities and equipment ▪ Materials, chemicals, microorganisms and toxins ▪ Material processing ▪ Electronics ▪ Computers ▪ Telecommunications and information security ▪ Sensors and lasers ▪ Navigation and avionics ▪ Marine ▪ Propulsion systems, space vehicles and related equipment	▪ Systems equipment and components ▪ Test, inspection and production equipment ▪ Material ▪ Software ▪ Technology

Table 4.1: Categories and product groups used in the CCL

---

[57] See Subchapter M – *International Traffic In Arms Regulations* 120.16, www.pmddtc.state.gov/regulations_laws/documents/official_itar/2013/ITAR_Part_120.pdf (accessed 7 June 2014)

Extraterritorial application of US law

4.32 Unlike UK export controls, US export control laws and regulations also apply extraterritorially to exports from outside the US (referred to as 're-exports') of:

- US-origin products;
- foreign-made products that incorporate US-origin products; and
- foreign-made products that are the direct products of US-origin technology.

4.33 This means that foreign-manufactured equipment containing any ITAR components is also subject to ITAR controls, according to US export controls. Therefore, if a UK company were to supply a component to a US spaceplane operator, that component would theoretically become subject to ITAR controls, and the company would face restrictions on sales of the same component to other markets.

4.34 These controls are based on the US connection to the items or technology being re-exported and are not dependent on any personal connection of the exporter to the US.

4.35 It should be noted that the UK and other EU countries view extraterritorial application of these laws as illegal under national and international law. Nevertheless, the US commonly imposes civil and criminal penalties on foreign countries for violating US export and re-export controls. Even if the US has no jurisdiction over the individual or company, it has the power to issue a Denial Order, which would in effect stop US companies from doing business with any overseas supplier that is in breach of US export controls.[58]

The implications for spaceplane operations in the UK

4.36 ITAR restrictions are of enormous significance to the goal of allowing spaceplane operations to take place in the UK by 2018 or earlier.

4.37 As the situation currently stands, US spaceplane manufacturers would not be allowed to export their goods to the UK. Of more immediate significance, ITAR places restrictions on potential discussions and information-sharing between spaceplane operators and non-US citizens. If strictly enforced, it would severely restrict any commercial opportunities for UK companies to supply spaceplane operators. It would also limit the potential for knowledge transfer.

4.38 Furthermore, the Civil Aviation Authority (CAA) or other UK regulators and government agencies would not be able to access comprehensive technical data about spaceplane launch mechanisms – important for any safety analysis and regulatory regime – nor would they be able to gain access to any unpublished data about test flights or even potentially initial commercial operations in the US.

---

[58] This was confirmed by Benjamin H Flowe Jnr, Attorney at Law specialising in export controls.

4.39 Finding a way forward on this issue will clearly be vital if the UK is to allow commercial sub-orbital or orbital operations in the short term. In line with MTCR, a government-to-government agreement between the UK and the US would be needed to allow UK regulators access to relevant information. There are valuable precedents for this: agreements already exist for the transfer of information between the UK and the US around certain programmes that come under export controls.

Initial operations

4.40 Even if a government-to-government agreement can be reached, it is likely that initial commercial spaceplane operations will be on a similar basis to a 'wet lease' type arrangement. This would mean that though the operation could take place in the UK, the US operator would be wholly responsible for the entire operation, including the aircraft, its flight crew and its maintenance staff – all of whom would be US citizens.

4.41 The operation would be conducted under a licence from the Federal Aviation Administration Office of Commercial Space Transportation (FAA AST) and would be subject to ITAR: the operator would have to take sufficient steps to satisfy the Department of State as to the protection of sensitive equipment and technology.

The implications for the US spaceplane industry

4.42 It is not only the UK that is concerned about the impact of ITAR restrictions: the US commercial spaceplane industry would also be affected. As noted earlier in this Review, some operators have expressed a clear interest in commencing operations from the UK by 2018 or earlier – something that would not be readily permitted under current export controls.

4.43 The US commercial spaceplane industry has therefore voiced its concerns about the US Government's decision to add commercial sub-orbital spaceplanes to the USML – noting a parallel with the US commercial satellite industry, which experienced a significant drop in global market share after satellites were placed on the USML in the late 1990s. Though this drop cannot be directly and wholly attributed to ITAR, the US Aerospace Industries Association has estimated that US satellite manufacturers have lost US$21 billion in satellite revenue since 1999.[59]

4.44 These concerns were reiterated by the Commercial Space Transportation Advisory Committee (an advisory body to the FAA AST) and Commercial Spaceflight Federation representatives during the UK Government technical

---

[59] See www.aia-aerospace.org/news/aia_welcomes_congressional_action_on_satellite_export_control_reform/ (accessed 1 May 2014)

visit to the US in June 2013 – and indeed work is under way in the US to review export controls.

4.45 In August 2009, the President of the US announced a broad-based interagency review of the US export control system,[60] with the aim of identifying those technologies that no longer required the protections offered by ITAR. However, this review did not include Category XV (spacecraft systems and related articles).

4.46 In late 2012, the US Congress passed a bill that, in effect, took commercial satellites and their related components off the USML.[61] (It did not in itself move those items off the list onto the less restrictive CCL, but simply restored the authority to the President to determine which technologies should be on which control list.)

4.47 In May 2013, the US Government published a new USML Category XV,[62] and listed those items that would move to the CCL. One of the biggest concerns about this revised list concerned the status of sub-orbital spacecraft. According to the new rules, 'man-rated sub-orbital, orbital, lunar and interplanetary spacecraft' all remain on the USML and are therefore subject to ITAR. This would currently include vehicles like Virgin Galactic's SpaceShipTwo and XCOR Aerospace's Lynx sub-orbital spacecraft. This creates a challenge for those companies to sell or operate those vehicles outside the US.

4.48 It was the view of officials from the US Department of State that, with a legitimate commercial market outside the US, policy may evolve, but a change is unlikely based upon a speculative market. Furthermore, there has been no move to date from Congress on any relaxation of export controls for the commercial space sector, even between 'friendly' nations: any future change in policy would require an interagency approach across government and including industry.

Proposing a way forward

4.49 The situation described in this chapter will not prevent the UK from growing its commercial space industry, nor from allowing spaceplanes to operate in the UK. However, it is clear that, if left unaddressed, it will certainly delay development – without US spaceplane operators, it is extremely unlikely that there would be any operations from the UK by 2018 – and will potentially diminish the commercial opportunities and economic benefits sought from the sector, including the development of a UK spaceport. At present, the UK is seen by several spaceplane operators as the most suitable location outside the US for operations, not least due to the strong government enthusiasm for, and

---

[60] See http://export.gov/ecr/eg_main_047329.asp (accessed 1 May 2014)

[61] This became the National Defense Authorization Act for Fiscal Year 2013. Full text at www.govtrack.us/congress/bills/112/hr4310/text (accessed 1 May 2014)

[62] See www.federalregister.gov/articles/2013/05/24/2013-11985/amendment-to-the-international-traffic-in-arms-regulations-revision-of-us-munitions-list-category-xv (accessed 1 May 2014)

commitment to, a space industry, as evidenced in publications such as *The Plan for Growth*.[63] This commitment will now be needed to find a way forward that satisfies US concerns about national and international security, many of which the UK fundamentally shares.

4.50 Therefore, rather than seeking consensus about how the international non-proliferation regimes that underpin our common export controls should be applied to spaceplanes – which would be a complex and lengthy task – a more suitable approach might be to work directly with the US to agree a practical way forward that benefits both UK and US commercial interests.

4.51 As indicated earlier, there are precedents for this, reflecting the strong relationship between the UK and the US. As well as the specific agreements for the transfer of information subject to MTCR for more than one defence programme, a UK exemption to certain aspects of ITAR has also been agreed.

4.52 Under ITAR, the information and material concerning defence and military technology (items on the USML) may only be shared with US persons, unless authorisation is received from the US Department of State or a special exemption obtained. In 2011, the US Department of State issued a rule change to ITAR (section 126.18)[64] which provides an exemption for UK end users and consignee companies, removing the need to obtain prior approval from the US Department of State for transfers of unclassified defence articles (including unclassified technical data) to dual and third country national employees of foreign business entities or international organisations that are approved end users or consignees for such defence articles. This is subject to certain screening and record-keeping requirements being satisfied. A similar exemption could perhaps be sought for USML Category XV articles that are not specifically designed for military use.

4.53 Clearly, the exact nature of any exemption would require considerable discussion between the UK and the US, and the UK would have to demonstrate the existence of adequate security measures to protect mutual interests. Given the sensitivity of the issue, it is likely that discussions will involve multiple parties in both the UK and the US, and may need to take place at the highest level.

4.54 A fundamental principle of such discussions would be that it is not the intention to remove any item, technology or piece of information from control; the goal would be simply to permit exports of spaceplane and related technology from the US to the UK, on a case-by-case basis, where there is minimal risk to US national security interests. In the longer term, this could ultimately lead to a

---

[63] HM Government (2011) *The Plan for Growth*, www.gov.uk/government/uploads/system/uploads/attachment_data/file/31584/2011budget_growth.pdf (accessed 23 February 2014)

[64] Full text of ITAR Part 126 at www.pmddtc.state.gov/regulations_laws/documents/official_itar/2013/ITAR_Part_126.pdf (accessed 6 May 2014)

process of knowledge transfer and sharing between US and UK businesses, to the benefit of both.

4.55 In the short term, however, the essential outcome would be agreement for US spaceplane operators to operate from the UK (potentially under a wet lease type arrangement); confirmation of what restrictions would apply; and agreement on what information the CAA or other regulatory body would have access to in order to put in place a suitable regulatory regime. Such an outcome would enable operators to start planning their activities, and the regulatory process to continue.

Recommendation
The UK Government should enter into early discussions with the US Government and the US sub-orbital industry to obtain appropriate export licences to commence operations in the UK.

Recommendations

4.56 This chapter includes the following recommendations.

- The Government should seek early expert legal and policy advice on the best way to achieve a common understanding with MTCR partners on how to allow the transfer of manned spacecraft, including sub-orbital spaceplanes, which may fall within Category I of MTCR, as interpreted by MTCR participating states.
- The UK Government should enter into early discussions with the US Government and the US sub-orbital industry to obtain appropriate export licences to commence operations in the UK. (*Recommendation 1 in summary report*)

CHAPTER 5

Legal context and considerations for commercial spaceplane operations

This chapter examines the legal issues around commercial spaceplane operations. It considers the frameworks that would be expected to apply – space law, aviation law and public transport law – and highlights the specific legal challenges that commercial spaceplane operations will present, particularly in the short term. It recommends a practical route forward to enable spaceplane operations to take place on a legal footing in the short term, and proposes some core principles that should apply to all future commercial space operations.

The need for a legal framework

5.1 Spaceplanes are a new class of vehicle, and are not mentioned directly within existing legislation. As they are vehicles that act as an aircraft while in the atmosphere and as a spacecraft while in space, both space law and aviation law are applicable to spaceplane operations.

5.2 However, as explained within this chapter, neither is wholly appropriate to the nature of spaceplane operations – which, particularly in the short term, will mostly be sub-orbital – nor their current maturity. Ultimately, a comprehensive international legal and regulatory framework will be needed to oversee spaceplane operations and to help deliver an acceptable level of safety, not only for spaceflight participants, but also for other airspace users and the uninvolved general public.

5.3 Such a framework is some way off. The EU formally has competence in relation to the establishment and functioning of the European space market, but it has not yet exercised this. There is as yet no worldwide consensus on what a regulatory framework for sub-orbital spaceplane operations should include, and no specific timetable for developing legislation. Certainly, it seems at best unlikely that international legislation will be in place in time to meet the target of allowing spaceplane operations to commence in the UK by 2018.

5.4 Therefore, an alternative solution must be found that provides a suitable legislative basis on which to regulate spaceplane operations. This must provide an acceptable level of safety for the uninvolved general public – essentially, offering negligible increased risk compared with existing aviation – and for other airspace users, without placing too great a regulatory burden on operators, so as not to impede unnecessarily the development of the commercial spaceplane industry.

5.5 This will necessarily be a national regulatory regime that is aligned with existing legal and regulatory requirements – considered in more detail in the next sections – but that does not place unnecessary obstacles in the way of the development of a full regulatory framework. Work towards this should also commence immediately. This will initially be a process of engagement with other regulators around the world to agree a common approach, which will not only help the emerging spaceplane industry gain clarity about the requirements that must be met, but also provide a shared set of standards for the protection of the uninvolved general public.

Recommendation

A twin-track approach to spaceplane regulation should be pursued:

- In the short term, a national regulatory regime must be developed to enable operations to commence in the next few years.
- In the medium to long term, UK regulators should engage with stakeholders, and in particular with the European Aviation Safety Agency and the US Federal Aviation Administration Office of Commercial Space Transportation (FAA AST), to develop a proper regulatory framework.

Space law

5.6 International space law is based on four United Nations treaties, to which most states are party. These are:

- Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (the 'Outer Space Treaty');
- Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space (the 'Rescue Agreement');
- Convention on International Liability for Damage Caused by Space Objects (the 'Liability Convention'); and
- Convention on Registration of Objects Launched into Outer Space (the 'Registration Convention').

There is also a fifth treaty, the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies (the 'Moon Agreement'). However, the majority of states, including the UK, have not ratified this agreement.[65]

5.7 These international agreements make the UK Government responsible for ensuring that space activities carried out by UK individuals or organisations are

---

[65] Full details of all five are available at www.unoosa.org/oosa/en/SpaceLaw/treaties.html (accessed 3 March 2014)

consistent with the international obligations of the UK and do not jeopardise public health or the safety of persons or property.

5.8 They also mean that the UK Government must maintain a register of space objects launched by UK organisations or individuals and accept liability for third party damage. A space object is defined under these treaties as including 'component parts of a space object as well as its launch vehicle and parts thereof'.

The Outer Space Act 1986

5.9 The Outer Space Act 1986 was introduced to manage the UK's obligations under the UN space treaties and principles.[66] It applies to certain activities carried out by organisations or individuals from the UK or certain British overseas territories. These are:

- launching or procuring the launch of a space object;
- operating a space object; and
- any activity in outer space.

5.10 Other than as mentioned in paragraph 5.9, the Outer Space Act 1986 does not apply to activities carried on by non-UK nationals or companies. These are typically covered by the laws of the country of which they are citizens or in which the companies are registered. For example, in the US the Commercial Space Launch Act[67] applies.[68]

5.11 All space activities carried out by individuals or organisations established in the UK or certain British overseas territories are required to be licensed under the Outer Space Act. The Act confers licensing and other powers on the Secretary of State for Business, Innovation and Skills; these are administered by the UK Space Agency.

5.12 Once a licence has been granted, licensees are obliged to:

- permit reasonable access to documents and inspection and testing of equipment and facilities by the UK Space Agency or its advisers, as appropriate;
- inform the UK Space Agency of any change in the licensed activity (eg change of orbit, change of owner) and seek approval prior to the change being made;
- prevent contamination of outer space and adverse changes in the environment of the Earth;

---

[66] Full text at www.legislation.gov.uk/ukpga/1986/38/contents (accessed 12 June 2014)

[67] Full text at www.gpo.gov/fdsys/pkg/STATUTE-98/pdf/STATUTE-98-Pg3055.pdf (accessed 22 May 2014)

[68] It is important to note that this is not the only legislation that applies to space launches in the US; however, as it incorporates the UN treaties into US law, it is the most relevant direct comparison.

- avoid interference in the space activities of others;
- avoid any breach of the UK's international obligations;
- preserve the national security of the UK;
- insure themselves against third party liabilities arising from the licensed activity (the UK Government should be named as an additional insured, and insurance should be for the launch and in-orbit phases of the mission); and
- dispose of the licensed space object appropriately at the end of the licensed activity and inform the UK Space Agency of the disposal and termination of the activity.

5.13 It is not yet entirely clear how the Outer Space Act 1986, or indeed the UN treaties, apply to sub-orbital operations: none of them provides for the safety regulation of such operations. There are also further issues: for example, though space is commonly considered to commence 100 kilometres above the Earth's surface, there is as yet no internationally established boundary for where outer space begins. Hence it is hard to define what activities would fall under 'any activity in outer space'. Given the political difficulties in defining where space starts – with some states viewing any definition as potentially limiting their sovereignty – it is not expected that a boundary will be agreed in the foreseeable future. Development of regulations should therefore proceed on the basis that there will not be a defined boundary.

5.14 More specifically, tasks such as the licensing of space objects were originally designed to help regulate objects in orbit, minimising the risk of collision between objects and clarifying ownership of such objects. This relies fundamentally on other states fulfilling the same obligations in respect of any space objects owned by companies in their countries. Clearly, for purely sub-orbital operations such as spaceflight experience, these issues would not necessarily be so relevant: the spaceplane will not enter orbit and not remain in space for any length of time. The exception to this would be satellites launched into orbit from a sub-orbital spaceplane. Furthermore, the licensing regime was designed prior to the development of reusable commercial spaceplanes, and hence does not fully address the concept of a reusable spacecraft completing multiple flights, potentially on the same day.

5.15 Given the aim of ensuring that regulation is not overly burdensome to spaceplane operators, it may therefore be appropriate to review the licensing regime and to establish how it should be applied to operators that are using the same spaceplane to complete several similar sub-orbital flights from the same location, on the same day – as well as to other usage models that have been proposed.

Recommendation

The application of the UN treaties and the Outer Space Act 1986 to sub-orbital operations and the role to be played by the Act in providing for the safety regulation of space operations in the UK should be clarified with the Department for Business, Innovation and Skills (BIS) and the UK Space Agency, and any necessary changes to legislation identified as soon as possible.

Vertical launch

5.16 The Civil Aviation Authority (CAA) has no powers to regulate rockets as such. Article 168 of the Air Navigation Order (ANO) requires a person launching a small rocket to comply with specified requirements, and in certain circumstances to obtain the permission of the CAA.[69] But this article is aimed at ensuring that a small rocket does not interfere with aircraft or put them at risk. The CAA is not concerned with the rocket itself or its operation.

5.17 Whether this limitation is of practical significance, or whether it suggests a role for a licence under the Outer Space Act, will need to be considered.

Aviation law

5.18 The International Civil Aviation Organization (ICAO) defines an aircraft as ‘any machine that can derive support in the atmosphere from the reactions of the air other than the reactions of the air against the earth’s surface’.[70] Unlike vertically launched vehicles, spaceplanes clearly meet this definition, and so the existing body of aviation safety regulation would apply to them.

5.19 To operate within the EU, spaceplanes would therefore be required to meet regulations set by the European Aviation Safety Agency (EASA) which cover certification, continuing airworthiness and operations – unless the law is changed or an exemption granted.

5.20 Different regulations and standards apply to different categories of aviation, depending on its use: standards for commercial air transport are higher than those for light aircraft. Spaceplanes used for spaceflight experience would be providing air transport, and so would be expected to comply with the standards for air transport.

5.21 However, as is explained in more detail in Chapters 6 and 7, spaceplanes cannot yet, and may never be able to, achieve the same safety standards as commercial aviation.

---

[69] See full text of the Air Navigation Order and its Regulations at www.caa.co.uk/docs/33/10107-CAA-CAP%20393%20Updated%203.pdf (accessed 23 June 2014)

[70] ICAO – *Annex 1 to the Convention on Civil Aviation, Annex 6 Part I*. Montreal, ICAO, Available to order from www.icao.int

5.22 For example, over the past century commercial aviation has evolved to the extent that, for public transport operations – ie those conducted by commercial airlines – incidents where there is a substantial risk of loss of life take place less than once in every 10 million hours of flight. This is normally expressed as achieving a catastrophic failure rate better than 1×10^{-7}. For aircraft to be allowed to offer public transport, they must be able to meet very high safety and performance standards that enable this overall level of safety.

5.23 Were the same standards to be applied to spaceplanes, it would essentially mean that operations could not take place. For example, rocket engine reliability standards have yet to be demonstrated to anywhere near the acceptable failure rates for engines in light aviation, let alone commercial aviation. Given the potentially catastrophic impact of rocket engine failure, this level of reliability would simply not be acceptable within mainstream commercial aviation.

The ring-fence approach

5.24 One approach would be to ring-fence commercial spaceplane operations as entirely separate from EASA regulation, and disapply existing aviation safety requirements for any operation that takes place inside the ring-fence. (The CAA has the power to regulate aircraft that are not covered by EASA regulations.) Within the ring-fence, there could be little or no regulation of operations, design and manufacture per se; regulation would instead focus on protection of the uninvolved general public. This is essentially the approach taken to enable commercial spaceplane operations in the US.

5.25 There are, however, a number of difficulties with this approach.

- Without any established standards, it may be difficult to insure such operations.
- Cross-border operations would be problematic, because the receiving state has no basis on which to assess the safety of the operation; it would need to be prepared to accept the same unregulated approach as the originating state.
- It offers no protection to participants.

5.26 Hence, a ring-fence with no requirements is unlikely to be acceptable to any of the parties: regulators, operators or participants. Instead, ring-fencing will need to focus on disapplying the standards that spaceplanes cannot meet, such as aircraft certification, while setting some minimum requirements that they must meet, to facilitate insurability and to protect the uninvolved general public.

5.27 With UK domestic aviation, there is an existing legal means of disapplying the necessary standards once a ring-fence is in place. This would involve the CAA using its powers granted under the Civil Aviation Act 1982[71] to issue exemptions and attach special conditions to specific articles of the ANO.[72]

5.28 The question therefore is how a ring-fence can be set up.

Options for disapplying EASA regulation

5.29 There are various theoretical options for creating a ring-fence that would allow spaceplane operations to be exempt from EASA regulation. These include:

- asserting that spaceplanes are not aircraft. This would be a very difficult case to make, as spaceplanes fundamentally meet the ICAO definition of an aircraft for the part of their operations that takes place within the Earth's atmosphere;
- asserting that sub-orbital operations are not air transport. While this could be suitable for certain types of spaceplane operations, it would not be true of spaceflight experience operations. It would also potentially create problems in the future, should spaceplanes for intercontinental very high speed travel be developed; and
- asserting that while the EU has legal competence, it has not, so far as spaceplanes are concerned, exercised that competence, and so Member States are entitled to regulate nationally. This approach would not only be politically sensitive, but it would also create potential problems for the future, should the EU (ie EASA) develop regulation around spaceplanes. The UK would then be obliged to change to any future EU regulations, which may disrupt spaceplane operators should there be significant differences between the UK and EU positions.

Applying Annex II to enable national regulation

5.30 There is, however, a fourth option. Under Annex II of the EASA Basic Regulation, some categories of aircraft are excluded from the ambit of the EASA Regulations and remain subject to national regulation. These include: '(b) aircraft specifically designed or modified for research, experimental or scientific purposes, and likely to be produced in very limited numbers'.[73]

5.31 It is likely that the first generation of spaceplanes will be produced in very limited numbers. By designating them as aircraft designed for 'research, experimental or scientific purposes', it would be possible to regulate sub-orbital spaceplanes on a national basis – hence allowing them to operate as Annex II aircraft, subject to national requirements.

---

[71] Full text of the Civil Aviation Act 1982, at www.legislation.gov.uk/ukpga/1982/16 (accessed 2 May 2014)

[72] Full text at www.caa.co.uk/docs/33/10107-CAA-CAP%20393%20Updated%203.pdf (accessed 8 June 2014)

[73] See http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32002R1592 (accessed 7 June 2014)

5.32 There are certain difficulties with this approach. First, spaceplane operators could be uncomfortable with the idea of marketing spaceflights in a vehicle defined as experimental. However, initial discussions with operators indicate that they understand the situation and are willing to adopt the approach.

5.33 Second, experimental aircraft are not typically allowed to conduct public transport operations – such as the carriage of paying participants for spaceflight experience. Clearly this would be inappropriate for the type of operations envisaged.

5.34 A potential means of addressing this has been identified. As stated above, the CAA can issue exemptions against articles of the ANO and can also attach special conditions. To allow paying participants, a special condition could be applied, requiring all participants to give their informed consent to being carried in a vehicle that is classified as experimental. This latter point is considered further in the next section.

5.35 While further consideration will need to be given to whether Annex II can be applied in this way once paying participants are involved, it could offer a means of enabling the carriage of paying participants in the short term, subject to further legal analysis.

5.36 Third, it is crucial that any national-level regulations put in place do not create potential barriers for the future development of spaceplanes, or potential conflict with future EU regulations. A commercial operator may be reluctant to invest in meeting national requirements when significant redesign (and other) changes may be necessary to meet future European requirements.

5.37 On a practical basis, this can best be addressed by working closely with EASA and the European Commission to assist them in the development of any European regulatory framework for spaceplane operations. Indeed, should the UK proceed with this proposed regulatory option, and thus allow spaceplanes to operate from the UK, the regulatory and operational experience gained here would be of significant value to EASA in defining an EU-wide framework.

5.38 The CAA has already engaged extensively with EASA during this Review. This would need to continue. However, EASA has indicated its broad support for the approach proposed as a short-term solution,[74] particularly given the fact that, due to limited resources and relative lack of priority, EASA rulemaking is unlikely to commence before 2016.

5.39 While these three issues must be addressed, it would appear that applying Annex II to spaceplanes offers the most practical way of enabling spaceplane operations from the UK in the short term.

Recommendation
To enable spaceplane operations to start from the UK in the short term, we recommend that sub-orbital spaceplanes are classified as 'experimental aircraft' and treated as Annex II aircraft under the EASA Basic Regulation. This will allow regulation of sub-orbital spaceplanes to be managed at a national level.

5.40 Once treated under Annex II, spaceplanes will not be required to comply with EASA regulations. On a national level, it would then be possible to identify the provisions of the ANO that would be inappropriate for spaceplanes, and agree on how best to address these. The most expedient route, given the goal of enabling spaceplane operations to commence in the UK by 2018 or earlier, would be for the CAA to apply suitable exemptions and attach special conditions to the ANO to manage and mitigate risk to the uninvolved general public and to allow the carriage of paying participants.

Recommendation
To allow the carriage of paying participants and cargo on sub-orbital spaceplanes while they are classified as experimental aircraft, the CAA should use its powers granted under the Civil Aviation Act 1982 to issue exemptions and attach special conditions to the articles of the ANO.

5.41 However, it is possible that there may be a need to review and adapt primary legislation, rather than just secondary legislation. Should it be determined that this is the case, work must begin immediately to confirm what changes are needed, and to draw up a timetable for the legislative changes to come into force. This is essential to allow spaceplane operators to understand what the

---

[74] In communications between the CAA and the EASA lead on spaceplanes, the EASA lead has stated:
'... while we agree with you (and the [Federal Aviation Administration (FAA)]) on the general principles and objectives, the implementation may take different forms and timing, especially at the beginning of the activity where there is little experience and there shall be more flexibility, but then this could be covered:

a) for governmental flights and pure research purposes (when the aircraft or flight is used for governmental/scientific purposes) by our Basic Regulation Article 2(a) and Annex II respectively: excluded from EASA's scope, fully under [Member States'] own responsibility;
b) for the prototyping/development/showing compliance part by the Experimental Permit Regime in the US (delivered by both FAA [Aviation Safety] and FAA AST), and Flight Conditions (reviewed by EASA) and Permits to fly and/or Exemptions (delivered by [Member States] at a national level) in the EU;
c) for limited commercial operations by Restricted Type Certificates (RTCs issued by EASA) and Restricted Certificates of Airworthiness (RCofA) delivered by the MS;
d) for longer term full-fledged/intensive commercial operations by TCs/CofAs as in commercial civil aviation today'

legal environment would be and recognise any requirements that this would place on them.

5.42 The process of identifying what ANO exemptions and special conditions should apply to spaceplanes is clearly crucial. Chapter 6 contains an initial assessment of which ANO provisions should be retained and which disapplied, as well as suggested requirements which may be imposed as conditions of an ANO exemption.

5.43 However, a full, formal assessment should be undertaken as soon as possible, covering not only the articles of the ANO, but also any other issues that may affect the safety of the uninvolved general public.

5.44 The CAA is ideally placed to lead this assessment, but it would need to engage with other agencies, such as the Health and Safety Executive and the UK Space Agency. To avoid any potential overlap or unnecessary duplication of effort from regulators and operators alike, Memoranda of Understanding should be agreed between all interested agencies. This would ensure clarity of regulatory responsibility for all aspects of spaceplane operations from the outset.

Recommendation

The CAA should be formally tasked with assessing, in partnership with other relevant agencies, which ANO provisions should be disapplied by exemption to spaceplanes, and which should be retained. This work should be commenced in the next phase of the project.

Informed consent

5.45 As stated above, experimental aircraft are not normally allowed to carry paying participants. This is because it has traditionally been assumed that payment of money for a flight triggers reasonable expectations on the part of the participant of high standards – including of safety. The law has responded to this analysis by requiring an Air Operator Certificate whenever a person is carried by an aircraft as a paying participant.

5.46 In the field of conventional aviation, a different regulatory response can now be offered in certain situations. The law can permit lower (typically private) standards to apply, even though an individual is paying, provided that individual understands what those standards are, and consents.

5.47 This approach is known as ‘informed consent’, and it works on the basis that so long as the actual standards and the associated risks are made clear to the prospective participants, they may decide to accept the position and proceed to take part. Their reasonable expectations will be met, because they will expect no more in terms of safety standards than is being delivered.

5.48 The same approach could be appropriate for commercial spaceplane operations. It is clear that these will not meet the standards of safety or comfort that are expected of commercial aviation; however, for those who wish to participate, these factors may not be a priority.

Recommendation
The Government should adopt the principle of informed consent to permit the carriage of participants and cargo on sub-orbital spaceplanes.

Articulating the risks

5.49 The informed consent approach is accepted by spaceplane operators; in fact, it is similar to that used in the US. The key challenge, however, will be to find a means to articulate the safety standards and risks in a way that will enable non-experts to understand them well enough to be able to give their informed consent.

5.50 In general, the requirements are likely to be that operators inform participants and flight crew of the inherent risks, including to their health, of space travel in general, and of travelling on that spaceplane for that mission in particular. Operators would also be required to tell participants before flight of the spaceplane's known safety record.

5.51 In consumer legislation, such as the Consumer Protection from Unfair Trading Regulations 2008 (see extract at Appendix 5A), there are useful pointers for informed consent. These include:

- the obligation not to:
    - omit or hide material information; or
    - provide material information in a manner which is unclear, unintelligible, ambiguous or untimely;
- the concept of material information as being information which the average consumer needs, according to the context, to take an informed transactional decision;
- the recommendation that where the medium used to communicate the information imposes limitations of space or time, other means should be considered to make the information available to consumers.

5.52 In the US, the requirements for informed consent for spaceflight are set out in the Code of Federal Regulations Part 460. These specifically include a duty on the operator to 'inform each space flight participant in writing about the risks of the launch and reentry, including the safety record of the launch or reentry vehicle type',[75] and to 'inform each space flight participant that the United States Government has not certified the launch vehicle and any reentry vehicle as safe for carrying crew or space flight participants'.[76]

5.53 Following that, 'each space flight participant must then provide consent in writing to participate in a launch or reentry'.[77] It is understood that, in addition, some operators propose to video the discussion with each individual participant, to show exactly what has been explained and what the participant has consented to.

5.54 A similar set of requirements is likely to be suitable in the UK. However, the exact details should be developed in partnership with operators, other agencies and those involved in the CAA's wider development of the informed consent concept.

Recommendation
The CAA should work with operators and other agencies to define how the concept of informed consent may apply to spaceplane operations.

5.55 Importantly, informed consent does not absolve the operator of liability claims brought by spaceplane flight crew or participants or their families in the event of death or serious injury following a spaceplane accident or serious incident. Nor would it affect the operator's basic duty of care and responsibility not to act negligently with regard to all relevant requirements – such as health and safety legislation, or spaceplane operating requirements or airworthiness standards. (The exact nature of these latter standards and requirements has yet to be fully determined, but the principle is clear.)

Liability of the operator and Government

5.56 Liability and insurance for space objects is addressed in the Outer Space Act (see above), and at the time of writing it is subject to reform, with the Government stating its intention to 'cap the unlimited liability to €60 million, for the majority of missions'.[78] This is clarified as 'missions employing established launchers, satellite platforms and operational profiles',[79] so there may be some doubt as to whether initial spaceplane operations would benefit from such a cap. However, the same document also states that 'For each license application, a risk assessment will be performed to consider the potential risks posed by the mission and a commensurate level of liability/insurance cover will be

---

[75] Code of Federal Regulations, Title 14, part 460.45, at www.ecfr.gov/cgi-bin/text-idx?rgn=div5&node=14:4.0.2.9.24#14:4.0.2.9.24.2.30.3 (accessed 28 April 2014)

[76] ibid

[77] ibid

[78] UK Space Agency (2013) *Reform of the Outer Space Act 1986: Summary of responses and government response to consultation*, p11, www.gov.uk/government/uploads/system/uploads/attachment_data/file/295769/gov-response-osa-consultation.pdf (accessed 23 June 2014)

[79] ibid

determined.'[80] This therefore seems likely to be applicable to initial spaceplane operations by UK companies.

5.57 Operations by US companies would, under the terms of the UN treaties, be subject to liability under US law. The relevant legislation is the Commercial Space Launch Act, which requires companies to buy insurance cover for third party liability claims based on a maximum probable loss calculated by the FAA AST.

5.58 However, as spaceplanes are also aircraft – as set out above – standard aviation insurance requirements could also apply. Liability of aircraft is considered under section 76 of the Civil Aviation Act 1982,[81] included as Appendix 5B.

5.59 Section 76 applies to all civilian flights in the UK, and provides that the owner or operator of an aircraft cannot be sued for trespass or nuisance simply because the aircraft has flown over any property at a reasonable height and in accordance with the ANO. However, where damage is caused by anything falling from an aircraft, the owner is liable. The person suffering damage does not have to prove negligence.

5.60 Where the aircraft concerned has been hired out for a period exceeding 14 days, the hirer is liable instead of the owner.

Spaceports

5.61 There are no specific safety requirements for spaceports in UK legislation. If a spaceport is also an aerodrome, it may be subject to certification under the EASA Aerodromes Regulation (which is being implemented in the UK over a four-year period commencing in June 2014) or licensing under the ANO.

5.62 Where a certificated or licensed aerodrome is to be used as a spaceport, it may be possible to impose further requirements for such use, by including conditions in an exemption from any of the aerodrome requirements.

5.63 Where no exemption is to be issued, other means of imposing requirements will need to be adopted. This may be through the exemption granted to the spaceplane operator, though that will be indirect. This could impose an obligation on the spaceplane operator to operate only from a site which complies with the specified requirements.

Recommendations

5.64 This chapter has made the following recommendations.

- A twin-track approach to spaceplane regulation should be pursued.

---

[80] ibid

[81] For full text, see www.legislation.gov.uk/ukpga/1982/16 (accessed 28 April 2014)

  - In the short term, a national regulatory regime must be developed to enable operations to commence in the next few years.
  - In the medium to long term, UK regulators should engage with stakeholders, and in particular with the European Aviation Safety Agency and the US Federal Aviation Administration Office of Commercial Space Transportation (FAA AST), to develop a proper regulatory framework.
- The application of the UN treaties and the Outer Space Act 1986 to sub-orbital operations and the role to be played by the Act in providing for the safety regulation of space operations in the UK should be clarified with the Department for Business, Innovation and Skills and the UK Space Agency, and any necessary changes to legislation identified as soon as possible.
- To enable spaceplane operations to start from the UK in the short term, we recommend that sub-orbital spaceplanes are classified as 'experimental aircraft' and treated as Annex II aircraft under the EASA Basic Regulation. This will allow regulation of sub-orbital spaceplanes to be managed at a national level. (*Recommendation 2 in summary report*)
- To allow the carriage of paying participants and cargo on sub-orbital spaceplanes while they are classified as experimental aircraft, the CAA should use its powers granted under the Civil Aviation Act 1982 to issue exemptions and attach special conditions to the articles of the ANO. (*Recommendation 3 in summary report*)
- The CAA should be formally tasked with assessing, in partnership with other relevant agencies, which Air Navigation Order provisions should be disapplied by exemption to spaceplanes, and which should be retained. This work should be commenced in the next phase of the project.
- The Government should adopt the principle of informed consent to permit the carriage of participants and cargo on sub-orbital spaceplanes. (*Recommendation 7 in summary report*)
- The CAA should work with operators and other agencies to define how the concept of informed consent may apply to spaceplane operations.

APPENDIX 5A

Consumer protection from unfair trading

The following is an extract from the Consumer Protection from Unfair Trading Regulations 2008.[82]

A trader is guilty of an offence if he engages in a commercial practice which is a misleading omission under regulation 6.

6.—

1. A commercial practice is a misleading omission if, in its factual context, taking account of the matters in paragraph 2 —
    a) the commercial practice omits material information,
    b) the commercial practice hides material information,
    c) the commercial practice provides material information in a manner which is unclear, unintelligible, ambiguous or untimely, or
    d) the commercial practice fails to identify its commercial intent, unless this is already apparent from the context,

    and as a result it causes or is likely to cause the average consumer to take a transactional decision he would not have taken otherwise.
2. The matters referred to in paragraph 1 are —
    a) all the features and circumstances of the commercial practice; and
    b) where the medium used to communicate the commercial practice imposes limitations of space or time, any measures taken by the trader to make the information available to consumers by other means.
3. In paragraph 1 'material information' means —
    a) the information which the average consumer needs, according to the context, to take an informed transactional decision; and
    b) any information requirement which applies in relation to a commercial communication as a result of a Community obligation.

---

[82] For full text, see www.legislation.gov.uk/uksi/2008/1277/contents/made (accessed 28 April 2014)

APPENDIX 5B

Liability of aircraft under the Civil Aviation Act 1982

The following is an extract from section 76 of the Civil Aviation Act 1982.[83]

76 Liability of aircraft in respect of trespass, nuisance and surface damage

1. No action shall lie in respect of trespass or in respect of nuisance, by reason only of the flight of an aircraft over any property at a height above the ground which, having regard to wind, weather and all the circumstances of the case is reasonable, or the ordinary incidents of such flight, so long as the provisions of any Air Navigation Order and of any orders under section 62 above have been duly complied with and there has been no breach of section 81 below.

2. Subject to subsection 3 below, where material loss or damage is caused to any person or property on land or water by, or by a person in, or an article, animal or person falling from, an aircraft while in flight, taking off or landing, then unless the loss or damage was caused or contributed to by the negligence of the person by whom it was suffered, damages in respect of the loss or damage shall be recoverable without proof of negligence or intention or other cause of action, as if the loss or damage had been caused by the wilful act, neglect, or default of the owner of the aircraft.

3. Where material loss or damage is caused as aforesaid in circumstances in which —

   a) damages are recoverable in respect of the said loss or damage by virtue only of subsection 2 above, and

   b) a legal liability is created in some person other than the owner to pay damages in respect of the said loss or damage,

   the owner shall be entitled to be indemnified by that other person against any claim in respect of the said loss or damage.

4. Where the aircraft concerned has been bona fide demised, let or hired out for any period exceeding fourteen days to any other person by the owner thereof, and no pilot, commander, navigator or operative member of the crew of the aircraft is in the employment of the owner, this section shall have effect as if for references to the owner there were substituted references to the person to whom the aircraft has been so demised, let or hired out.

---

[83] For full text, see www.legislation.gov.uk/ukpga/1982/16 (accessed 28 April 2014)

CHAPTER 6

Regulation of commercial spaceplane flight operations

This chapter considers the overarching regulatory framework that will be necessary for commercial spaceplane operations in the UK. It explains in more detail what safety regulation is and examines the regulatory frameworks for both aviation and space operations that are currently in use worldwide. It then looks at different types of spaceplane operations and recommends the priority aspects of an appropriate regulatory framework for each.

Introduction

6.1 Over the past hundred years, commercial aviation has evolved from a somewhat risky endeavour into a safe, reliable mode of transport – and regulation has played a vital part in that evolution. Standards have been developed for all aspects of operations – from the aircraft themselves to aerodromes and to the types of operation that are allowed in different locations and under different conditions. Many of these are globally agreed and are monitored and managed internationally.

6.2 Clearly, the ultimate goal for commercial space operations should be the same. However, at this stage, that cannot be expected. The commercial spaceplane industry is new; the safety performance of spaceplanes is largely unknown; and there are no international certification standards available for spaceplanes. Furthermore, with the very diverse nature of spaceplane designs, there has been little opportunity to develop standardised operating procedures.

6.3 Nonetheless, it is clearly critical for all – regulators, operators, spaceflight participants and not least the uninvolved general public – that some form of regulation is put in place to define the safety standards required for all aspects of spaceplane operations. Operators themselves want this: it is their priority to achieve safe and repeatable spaceplane flights.

6.4 The regulatory task is therefore to identify what standards would be appropriate – in particular in the early stages of operations – and how these can best be introduced and monitored. The aim will be to create a flight operations regulatory framework that encompasses all the regulatory disciplines within a single set of achievable and manageable requirements.

6.5 This chapter focuses on the regulation of operations. It touches on other aspects of regulation, including airworthiness, spaceports and flight crew licensing. However, these are considered in full in separate chapters of the report.

Defining regulation

6.6 To assess the options for the regulation of the commercial spaceplane industry, it is important first to understand what is meant by 'regulation' and 'safety'. The Oxford English Dictionary defines regulation as 'a rule or directive made and maintained by an authority' and safety as 'the condition of being protected from or unlikely to cause danger, risk, or injury'.

6.7 In the context of commercial spaceplane operations, the aim of regulation will be to provide an acceptable level of safety assurance, by the establishment of rules and guidance material in order to promote a culture of safety management, safe spaceplane design and manufacture, and safe operation.

6.8 Therefore an appropriate regulatory framework for commercial spaceplane operations should follow government principles of good regulation, as set out in the Legislative and Regulatory Reform Act 2006:[84]

> '(a) regulatory activities should be carried out in a way which is transparent, accountable, proportionate and consistent;
>
> (b) regulatory activities should be targeted only at cases in which action is needed.'

6.9 These principles have been developed further in the *Regulators' Code*,[85] which emphasises the importance of carrying out regulatory activities in a way that supports regulated organisations to comply and grow, and the need to base regulatory activities on risk. In particular, the *Regulators' Code* makes it clear that 'regulators should take an evidence based approach to determining the priority risks in their area of responsibility'.[86]

6.10 The first crucial decision to be taken is about prioritisation – determining:

- whom the regulatory framework is designed to protect and what level of safety assurance that person or persons should reasonably expect; and
- what level of regulation is required, by when.

6.11 The challenge is to arrive at a suitable, permissive regulatory framework for each type of spaceplane operation. Such a permissive framework should be risk-based and deliver an acceptable level of safety, without being so burdensome that it stifles the development of this emerging industry. Such a framework should be compatible with existing spaceplane operations, but also flexible enough to allow for regulatory development in the future.

---

[84] Legislative and Regulatory Reform Act 2006, part 2, section 21, www.legislation.gov.uk/ukpga/2006/51/pdfs/ukpga_20060051_en.pdf (accessed 8 May 2014)

[85] Better Regulation Delivery Office (2014) *Regulators' Code*, www.gov.uk/government/uploads/system/uploads/attachment_data/file/300126/14-705-regulators-code.pdf (accessed 8 May 2014)

[86] ibid, section 3.1

Anticipated timeline for the development of commercial space operations in the UK

6.12 To help determine what level of regulation is required by when, this section provides an anticipated timeline for the development of commercial space operations – including spaceplanes – in the UK.

6.13 It is based on both publicly available information and information given to the Review team by the space industry, and is included to help define regulatory priorities. Much of it is conjecture and liable to change; it should not be taken as a guarantee of either operator readiness or commercial or technical progress.

Short term: 2014–20

6.14 In this period, the first commercial spaceplane operations are expected. As of May 2014, it is understood that:

- Virgin Galactic's commercial operations using its sub-orbital spaceplane are anticipated to begin in the US by the end of 2014;
- XCOR Aerospace intends to start commercial operations using its sub-orbital spaceplane in the US during 2015/16;
- the first use of both these spaceplanes will be for spaceflight experience, closely followed by the carriage of scientific payloads; and
- both operators have expressed an interest in commencing commercial operations on a small scale outside the US by 2018 or earlier – and the UK is a potential location.

6.15 Within Europe, Swiss Space Systems (S3) has indicated that its first commercial operations using its unmanned Sub-Orbital Aircraft Reusable (SOAR) spaceplane will take place between 2017 and 2020. These initial operations will be for the orbital launch of small satellites. S3 has stated that it would be interested in operating from the UK.

6.16 To enable any of these commercial spaceplane operations from the UK, a suitable launch location within the UK would need to be identified and a 'spaceport' developed. Given the potential time required for any planning permission and construction involved, the selection of a suitable site is a priority, if the UK is to be ready to allow launches by 2018 or earlier. If this cannot be achieved, then a temporary location may provide a suitable short-term solution. Analysis and a feasibility study would need to be undertaken in parallel to identify a permanent spaceport location.

6.17 In addition, a regulatory framework for sub-orbital spaceplane operations would be required within this timeframe. To give operators sufficient time to ensure compliance, and the regulator sufficient time to be satisfied that the spaceplane operation meets the regulatory requirements, a permissive regulatory regime would need to be established by 2016.

Recommendation
In order for sub-orbital spaceplane operations to take place from the UK by 2018 or earlier, a permissive regulatory framework needs to be established and be functioning at least one year in advance of planned operations.

6.18 Reaction Engines is one of the leaders in the development of single-stage to orbit technology. It plans to start testing a prototype SABRE (Synergetic Air-Breathing Rocket Engine) engine which is designed to enable single-stage to orbit operations, by 2020. Based on this, single-stage to orbit spaceplane operations are not expected to take place from the UK in the short term.

6.19 Currently there is no known development of intercontinental very high speed travel designs. Studies such as the European Space Agency's Long-Term Advanced Propulsion Concepts and Technologies (LAPCAT) programme have indicated that, while the technology could be developed, costs would be considerable. It is therefore extremely unlikely that any operations will occur in this period.

6.20 Vertical launch technology is already advanced, and so vertical launches could take place in the short term. However, this would require the development of a greenfield launch site at a suitable location. No such site has yet been selected. The geographical location of the UK is best suited to polar orbit insertion, and therefore a launch site with a clear sea track to the north would be the most favourable.

Medium term: 2020–26

6.21 During this period, the use of sub-orbital spaceplanes is expected to become more widespread and the frequency of operations to increase. This is expected to result in a reduction in ticket prices for spaceflight experience and for the carriage of scientific payloads. However, costs are unlikely to be reduced to a point where spaceflight experience is affordable for all.

6.22 The UK spaceport should be fully operational, catering for different types of spaceplanes and operations, including spaceflight experience, scientific payloads and orbital launch of small satellites.

6.23 As demand grows, it is possible that spaceplane operators and the general public may require more flexibility in launch locations. Better understanding of spaceplane safety performance and operating requirements could mean operations can take place from temporary spaceports or smaller regional spaceports.

6.24 The launch of small satellites into orbit from conventional aircraft and sub-orbital spaceplanes is also expected to become more common. The increasing availability of such systems, driving down costs, may well make small satellite launch using expendable vertical launch systems appear expensive and inflexible.

6.25 Development of single-stage to orbit spaceplanes, such as SKYLON, could begin in this period. Depending on the operating requirements of such a spaceplane, development test flights could take place from a UK spaceport.

6.26 The development of a spaceplane suitable for intercontinental very high speed travel could begin in this period; S3 has stated that it intends to use its SOAR spaceplane for this purpose. However, commercial operations in the medium term are thought to be unlikely on account of the anticipated length of the test and development programme.

6.27 If the UK decides to develop a vertical launch capability, it is expected that by this time there could be a market for up to 10 launches per year to meet current needs. This could be achieved with third party launch vehicles or UK-designed and manufactured systems. However, the advent of successful, low-cost air-launched orbital operations may make this option unnecessary.

Long term: 2026 onward

6.28 Predicting the shape of the commercial spaceplane industry beyond 2026 is difficult as much will depend on the success of earlier spaceplane operations and the level of funding that is available.

6.29 It can be anticipated, however, that spaceflight experience and scientific payloads could be available at a substantially reduced cost. Competition between air launch and conventional expendable launch vehicles could mean lower orbital launch costs for small satellites.

6.30 Single-stage to orbit operations could become a reality in the latter part of the 2020s. This would be a 'game-changer' in terms of access to space, with launch costs substantially lower than currently available. However, the large payloads that would be carried by such a spaceplane would be more suited to an equatorial launch site so operations from the UK are expected to be minimal.

6.31 Intercontinental very high speed travel could be a possibility from 2030 onwards, though this will depend on the development of suitable engine technology.

Implications for the UK

6.32 It is clear from the above timeline that the priorities for the UK should be the development of a permissive regulatory framework for sub-orbital spaceplane operations and the selection of a suitable site for a UK spaceport. For operations to commence by 2018 or earlier, the regulatory framework will need to be established by 2016, and the spaceport developed so that it is ready for operations in 2018 or earlier. A regulatory framework for the spaceport will also be required.

6.33 Air-launched orbital, single-stage to orbit and intercontinental very high speed travel operations are all possible from the UK. Therefore the respective regulatory frameworks will also need to be established. However, these operations are not likely in the short term, so this is not yet a priority.

6.34 Vertical launch vehicle operations may be possible from a few locations within the UK. Again a launch site would have to be selected and a suitable regulatory framework established. The decision on whether or not to support this may well be a commercial one.

Current aviation and space regulatory frameworks and organisations

6.35 As a starting point in defining the regulatory framework, this section examines existing regulatory frameworks that are in place worldwide. Some are based on aviation and others are intended purely for space operations, while some are not (strictly speaking) regulation by government but are based on industry standards and best practice. It also considers those organisations that do not have a direct space regulatory role, but have influence within the spaceflight community and may set industry safety standards and best practice.

International Civil Aviation Organization

6.36 A specialised agency of the United Nations, the International Civil Aviation Organization (ICAO) was created in 1944 to promote the safe and orderly development of international civil aviation throughout the world. It sets standards and regulations necessary for aviation safety, security, efficiency and regularity, as well as for aviation environmental protection. ICAO serves as the forum for co-operation in all fields of civil aviation among its 191 member states.[87]

6.37 ICAO was established with the signing of the Convention on International Civil Aviation,[88] also known as the Chicago Convention, in Chicago, Illinois, on 7 December 1944. Member states must ensure that their own national aviation legislation complies with the principles of the Chicago Convention and the Standards and Recommended Practices (SARPS) as stated in the 19 Annexes to the Chicago Convention.

6.38 Under the Chicago Convention, each state has complete and exclusive sovereignty over the airspace above its territory. However, 'freedom of the high seas' includes freedom of overflight, and therefore the airspace above the high

---

[87] For full details of ICAO's membership and responsibilities, see www.icao.int (accessed 8 May 2014)

[88] Full text of the Convention on International Civil Aviation at www.icao.int/publications/pages/doc7300.aspx (accessed 10 April 2014)

seas is beyond the jurisdiction of any state. Article 12 of the Chicago Convention ensures that such airspace is controlled by the 'Rules of the Air', established by ICAO and given in Annex II to the Convention on International Civil Aviation, widely known simply as 'ICAO Annex 2.'[89]

6.39 In assessing the applicability of the articles of the Chicago Convention to spaceplanes, it is worth noting that while the Chicago Convention itself does not directly define the term 'aircraft', the Annexes do. The definition is as follows:

> 'An aircraft is any machine that can derive support in the atmosphere from the reactions of the air other than the reactions of the air against the Earth's surface.'[90]

6.40 As explained in Chapter 5, spaceplanes meet this definition, and therefore the articles of the Chicago Convention and the ICAO Annexes would appear to apply to their operation. However, spaceplanes are also designed to operate outside the Earth's atmosphere; ICAO regulation does not cover this.

6.41 At the first Regulation of Emerging Modes of Aerospace Transportation (REMAT) meeting, held at McGill University in Montreal in 2013,[91] ICAO acknowledged the absence of a common international safety regulatory system for spaceplane operation, and agreed to establish a work group to look at how the commercial spaceplane industry could best be regulated. This would examine regulatory options and look to publish guidance for the future operation of spaceplanes.

United Nations Committee on the Peaceful Uses of Outer Space

6.42 The Committee on the Peaceful Uses of Outer Space (COPUOUS) was set up by the UN General Assembly in 1959 under Resolution 1472 (XIV).[92] Its remit was to review the scope of international co-operation in peaceful uses of outer space, to devise programmes in this field to be undertaken under United Nations auspices, to encourage continued research and the dissemination of information on outer space matters, and to study legal problems arising from the exploration of outer space.

6.43 There are 76 member states of COPUOUS, which also has two standing subcommittees – the Scientific and Technical Subcommittee and the Legal Subcommittee.

6.44 COPUOUS and its two subcommittees meet annually to consider questions put before them by the UN General Assembly, review reports submitted to

---

[89] Full text of Annex 2 can be found at www.icao.int/Meetings/anconf12/Document%20Archive/an02_cons[1].pdf (accessed 8 May 2014)

[90] ICAO – *Annex 1 to the Convention on Civil Aviation, Annex 6 Part I. Montreal, ICAO*. Available to order from www.icao.int

[91] See www.icao.int/Meetings/remat/Pages/default.aspx (accessed 8 May 2014)

[92] See www.oosa.unvienna.org/oosa/SpaceLaw/gares/html/gares_14_1472.html (accessed 8 May 2014)

them and address issues raised by the member states. Working on the basis of consensus, each then makes recommendations to the General Assembly.

6.45 The United Nations Office for Outer Space Affairs (UNOOSA) implements the decisions of the General Assembly and COPUOUS. UNOOSA has the dual objective of supporting the intergovernmental discussions in COPUOUS and its subcommittees, and of assisting developing countries in using space technology for development. In addition, it follows legal, scientific and technical developments relating to space activities, technology and applications, in order to provide technical information and advice to member states, international organisations and other UN offices.

The European Union

6.46 Within the EU there are two key regulatory bodies that are of relevance to spaceplanes: the European Aviation Safety Agency (EASA) and the European Space Agency (ESA).

EASA

6.47 EASA aims to promote the highest common standards of safety and environmental protection in civil aviation. It is the centrepiece of a new regulatory system which creates a single European market in the aviation industry. It is based in Cologne, Germany, and was created on 15 July 2003. Under the terms of EU Regulation 216/2008[93] – known as the EASA Basic Regulation – EASA is responsible for the development of European aviation legislation.

6.48 EASA's responsibilities include:

- providing expert advice to the EU for drafting new legislation;
- implementing and monitoring safety rules, including inspections in the Member States;
- type certification of aircraft and components, as well as the approval of organisations involved in the design, manufacture and maintenance of aeronautical products;
- authorisation of third country (non-EU) operators; and
- safety analysis and research.

6.49 Recently, EASA has also assumed responsibility for the development of safety regulations for airports and Air Traffic Management systems.

6.50 In practice, this means that EASA is directly responsible for the certification of aircraft. However, for most other disciplines, enforcement of regulations is

---

[93] See http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02011R1178-20120408 (accessed 7 April 2014)

devolved to the national competent authority for aviation in each EU Member State. National aviation authorities (NAAs) are designated as the competent authority to enforce and ensure compliance with the regulations developed by EASA within their respective state and national industry. In developing the regulations and associated guidance material, EASA consults fully with the NAAs and other stakeholders. EASA regulations are intended to be fully compliant with the ICAO Annexes to the Chicago Convention.

6.51 EASA regulations are published as implementing rules (IRs) and certification specifications (CSs), both of which have a defined status within European law. There is some flexibility in how these can be achieved: IRs set out acceptable means of compliance, but alternative means of compliance could be developed to satisfy a particular need, if that were thought necessary.

6.52 Recently EASA has engaged with the EU to seek permission to commence the development of regulations for sub-orbital spaceplanes. It presented eight options for the EU to consider. However, it is thought unlikely that the EU will agree on a way forward until at least 2016.

European Space Agency

6.53 The European Space Agency (ESA) is an intergovernmental organisation. It was established in 1975 and has its headquarters in Paris.

6.54 As stated on its website,[94] ESA's purpose is:

> 'to provide for, and to promote, for exclusively peaceful purposes, cooperation among European States in space research and technology and their space applications, with a view to their being used for scientific purposes and for operational space applications systems:
>
> - by elaborating and implementing a long-term European space policy, by recommending space objectives to the Member States, and by concerting the policies of the Member States with respect to other national and international organisations and institutions;
> - by elaborating and implementing activities and programmes in the space field;
> - by coordinating the European space programme and national programmes, and by integrating the latter progressively and as completely as possible into the European space programme, in particular as regards the development of applications satellites;

---

[94] See www.esa.int/About_Us/Welcome_to_ESA/ESA_s_Purpose (accessed 8 May 2014)

- by elaborating and implementing the industrial policy appropriate to its programme and by recommending a coherent industrial policy to the Member States.'

6.55 ESA's membership consists of 20 European states, and its programmes include successful expendable vertical launch vehicles such as Ariane. It has a varied orbital and interplanetary missions programme and an established human spaceflight programme, largely linked with the International Space Station. ESA's main launch site is at Kourou in French Guiana, and its main operations centre is at Darmstadt in Germany.

6.56 ESA is not a regulatory authority; however, it does set standards for space safety (see European Cooperation for Space Standardization below). While ESA is the owner of the spaceport at Kourou, the safety regulation of all expendable rocket launches is through the French space agency, the Centre National d'Études Spatiales (CNES).

The European Cooperation for Space Standardization

6.57 The European Cooperation for Space Standardization (ECSS)[95] is an initiative established to develop a coherent, single set of user-friendly standards for use in all European space activities. Its members include national agencies and authorities and international organisations such as the UK Space Agency, CNES and ESA.

6.58 It was established in 1993 and works to improve standardisation within the European space sector. The ECSS frequently publishes standards, to which contractors working for ESA must adhere.

United Kingdom

Department for Transport

6.59 The Secretary of State for Transport has a general duty of organising, carrying out and encouraging measures for the development of civil aviation and the emerging commercial spaceplane industry, particularly in respect of sub-orbital flights, for the promotion of safety and efficiency in the use of civil aircraft and for research into questions relating to air navigation. The Secretary of State for Transport is supported in this by the Department for Transport (DfT).

6.60 The DfT's aims and objectives are developed and set out each year in its business plan. Specific objectives within that fall to relevant business units, including the Aviation Directorate, the Air Accidents Investigation Branch and the Maritime and Coastguard Agency (an executive agency of the DfT). The head of

---

[95] See www.ecss.nl (accessed 9 May 2014)

the Aviation Directorate of the DfT is assigned various policy responsibilities and takes on the title of the UK director general of civil aviation.

6.61 The Secretary of State and the DfT are responsible for developing and amending primary aviation legislation and for making secondary legislation, such as operating regulations, in areas covered by the Annexes to the Chicago Convention. Section 60 of the Civil Aviation Act provides that the Privy Council, subject to approval by Parliament, may make an Air Navigation Order (ANO) to implement the Annexes to the Chicago Convention and to regulate air navigation generally.[96] Under an agreement between the DfT and the Civil Aviation Authority (CAA), the responsibility for drafting the UK ANO rests with the CAA.

6.62 The Secretary of State appoints the board of the CAA and is accountable to Parliament for the activities of the CAA. He/she may also issue directions to the CAA in certain circumstances, for example to ensure compliance with international obligations.

6.63 Separately, as part of the overall aviation security regime, the Secretary of State for Transport, through the DfT, is responsible for aviation security policy, and exercises powers under the Aviation Security Act 1982 (as amended by the Aviation and Maritime Security Act 1990)[97] in relation to aviation security. The Secretary of State for Transport has conferred various aviation security functions on the CAA within the Civil Aviation Act 2012,[98] including the provision of advice and assistance to the Secretary of State on this matter, as well as inspection and enforcement powers.

6.64 Responsibility for civil aeronautical and maritime search and rescue (SAR) policy rests with the DfT. As such, the DfT is responsible, through the UK SAR Strategic Committee, for setting the criteria and for assessing the adequacy of UK civil aeronautical and maritime SAR resources, response and co-ordination.

6.65 For the provision of air navigation services, the principal legislation is the Transport Act 2000.[99] This Act places objectives on both the Secretary of State and the CAA to exercise their functions so as to maintain a high standard of safety in the provision of air navigation services.

Civil Aviation Authority

6.66 The Civil Aviation Authority (CAA) was established in 1972 under the terms of the Civil Aviation Act 1971.[100] It is responsible for the regulation of aviation

---

[96] See www.legislation.gov.uk/ukpga/1982/16/contents (accessed 26 May 2014)

[97] See www.legislation.gov.uk/ukpga/1990/31/contents (accessed 26 May 2014)

[98] See www.legislation.gov.uk/ukpga/2012/19/contents/enacted (accessed 26 May 2014)

[99] See www.legislation.gov.uk/ukpga/2000/38/contents (accessed 26 May 2014)

[100] See www.legislation.gov.uk/ukpga/1971/75/contents/enacted (accessed 26 May 2014)

activities in the UK. The CAA regulates aviation through the articles of the Air Navigation Order (ANO).[101]

6.67 However, as the UK is an EU Member State, it is subject to EU law and EU aviation legislation. Therefore most aviation in the UK is now regulated by the CAA using the EASA implementing rules. The exception is any aircraft or aviation activity which, under the EASA Basic Regulation, is exempt from EU law: this is then regulated wholly under the articles of the ANO.

UK Space Agency

6.68 The UK Space Agency is an executive agency of the Department for Business, Innovation and Skills (BIS) and is at the heart of UK efforts to explore and benefit from space. It was officially launched on 23 March 2010 and became a full executive agency of BIS on 1 April 2011. On this date, responsibility for all space activities was transferred from a number of bodies, including government departments, research councils and non-departmental public bodies.

6.69 The UK Space Agency does not currently regulate space safety, but it manages the statutory duties of HM Government under the Outer Space Act 1986[102] (discussed further in Chapter 5) and develops space regulation policy that supports economic growth.

France

6.70 The CNES is the French government agency responsible for shaping and implementing France's space policy in Europe. Established in 1961, its headquarters are located in central Paris and it is under the supervision of the French Ministries of Defence and Research. The CNES takes a collaborative approach to space exploration and has helped to shape the Ariane programme.

6.71 It is also responsible for the safety regulation of spaceflight operations from French territory, including the Kourou spaceport in French Guiana. Its regulations are published in a set of Technical Instructions to the French Outer Space Act. Compliance with these Technical Regulations has been mandatory since 10 December 2010 for space operations by French space operators and for space operations conducted on French territory.

6.72 The Technical Regulations include the requirement for an operator safety management system (SMS) and the study of risks to third parties. The first version of the Technical Regulations was published in March 2011 and is devoted to unmanned space systems.

---

[101] See full text of the Air Navigation Order and its Regulations at www.caa.co.uk/docs/33/10107-CAA-CAP%20393%20Updated%203.pdf (accessed 8 June 2014)

[102] Full text at www.gov.uk/government/uploads/system/uploads/attachment_data/file/295760/outer-space-act-1986.pdf (accessed 23 June 2014)

United States

Federal Aviation Administration

6.73 The regulation of aviation in the US is the responsibility of the Federal Aviation Administration (FAA).

6.74 The FAA is responsible for:

- aviation safety – the regulation of aviation crews and operations;
- airports – ensuring compliance with federal airports legislation; planning, construction and operation of airports;
- air traffic – the operation and regulation of the National Airspace System, including control towers and radar systems; and
- commercial space transportation – delegated to the FAA's Office of Commercial Space Transportation (FAA AST).

6.75 The FAA's regulations are all published in the Federal Register and are available on the FAA website.[103] The principles are very similar to the regulations developed by EASA: high-level legal requirements are stated in the Federal Aviation Regulations (FARs), while advisory circulars (ACs) and guidance provide detail on how to comply with the FARs.

FAA Office of Commercial Space Transportation

6.76 The FAA is seen as the most advanced commercial space regulatory organisation in the world, having overseen more than 220 US commercial space launches since 1989 and developed laws and regulations for expendable and reusable launch vehicles. That is why 'an analysis of the applicability of the procedures and requirements utilised by the US Federal Aviation Administration Office of Commercial Space Transportation (FAA AST) to the UK' was included within the mandate for this Review. A description of the procedures is therefore provided later in this chapter. This section describes the organisation and its responsibilities.

6.77 In 1984, the US Congress passed the Commercial Space Launch Act,[104] in order to regulate the commercial space launch of expendable rockets and spaceports. Authority for regulation was given to the Department of Transportation (DoT). To enact this authority, the DoT established the Office of Commercial Space Transportation (OCST). In 1995 the OCST transferred to the FAA as the AST.

6.78 The Commercial Space Launch Act (CSLA) has been amended several times, with notable amendments in 1988 and in 2004[105] that effectively gave the FAA AST

---

[103] See www.faa.gov/regulations_policies/ (accessed 26 May 2014)

[104] See www.gpo.gov/fdsys/pkg/STATUTE-98/pdf/STATUTE-98-Pg3055.pdf (accessed 8 May 2014)

[105] For the 1988 amendment, see www.gpo.gov/fdsys/pkg/STATUTE-102/pdf/STATUTE-102-Pg3900.pdf; for the 2004 amendment, see www.faa.gov/about/office_org/headquarters_offices/ast/media/PL108-492.pdf (accessed 8 May 2014)

regulatory authority over reusable launch vehicles (RLVs), such as spaceplanes. The 2004 amendment also granted the FAA AST (through the DoT) the authority to implement regulations for commercial human spaceflight and create the experimental permits regime. The CSLA is now included within the US Code, under Title 51 – National and Commercial Space Programs, Chapter 509.[106]

6.79 The FAA AST issues licences and permits for commercial launches of orbital rockets and sub-orbital rockets. The first US-licensed launch was a sub-orbital launch of a Starfire vehicle on 29 March 1989. Since then, the FAA AST has licensed over 220 launches and 35 permit launches,[107] all conducted without any fatalities, serious injuries or property damage to the general public.

6.80 Since 1996, the FAA AST has also issued licences for the operation of non-federal launch sites, or 'commercial spaceports'. Currently there are eight FAA-licensed spaceports, with more in development.

6.81 The FAA AST manages its licensing, regulatory work and promotional work through the Office of the Associate Administrator, along with its five divisions: the Space Transportation Development Division, the Licensing and Evaluation Division, the Regulations and Analysis Division, the Safety Inspection Division, and the Operations Integration Division. Although the FAA AST is part of the FAA, the bulk of its organisation is operated separately.

6.82 The FAA AST has published regulations for commercial space transportation under the authority of the CSLA. These regulations are the Commercial Space Transportation Regulations, in Title 14 of the Code of Federal Regulations, parts 400–1199.[108]

The National Aeronautics and Space Administration

6.83 The National Aeronautics and Space Administration (NASA) is the US government agency responsible for the nation's civilian space programme and for aeronautics and aerospace research. The agency became operational on 1 October 1958. It has several key locations across the US, including the Armstrong Flight Research Center, Edwards Air Force Base, California.[109]

6.84 Since it was founded, NASA has led most US space exploration efforts, including the Apollo moon-landing missions, the Skylab space station, and later the space shuttle. Currently, NASA is supporting the International Space Station (ISS) and is overseeing the development of the Orion multi-purpose crew vehicle, the space launch system and commercial crew vehicles. It is also responsible for

---

[106] See http://uscode.house.gov/view.xhtml?path=/prelim@title51/subtitle5/chapter509&edition=prelim (accessed 8 May 2014)

[107] As of 8 May 2014. For latest details, see www.faa.gov/about/office_org/headquarters_offices/ast/ (accessed 8 May 2014)

[108] See www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title14/14tab_02.tpl (accessed 24 June 2014)

[109] The Center was formerly known as the Dryden Flight Research Center, but was renamed in March 2014.

the Launch Services Program which provides oversight of launch operations and countdown management for unmanned NASA launches.

6.85 NASA has also for many decades operated and tested a number of experimental and research aircraft, known as the X-planes. These are a series of experimental aircraft used to test and evaluate new technologies and aerodynamic concepts, including reusable spaceplanes. It has also undertaken research into hypersonic flight, which many believe will lead to intercontinental very high speed transport aircraft.

6.86 NASA uses the term 'human rated' to describe any spacecraft or launch vehicle certified as suitable for the transportation of humans. Hence in spaceflight, a human rating certification is the assurance that the space system accommodates human needs, effectively utilises human capabilities, controls hazards with sufficient certainty to be considered safe for human operations, and provides, to the maximum extent practical, the capability to recover the crew safely from hazardous situations.

6.87 Many of the NASA safety requirements can be found in safety directives and safety standards as part of the NASA Technical Standards Program. NASA's Procedural Requirement NPR 8705.2B – Human Rating Requirements for Space Systems[110] defines the certification process and a set of technical requirements to be applied to its crewed space systems. These are in addition to the standards and requirements that are mandatory for all NASA's spaceflight programmes.

6.88 The development of the space shuttle and the ISS both pre-date the NASA human rating requirements. Following the Challenger and Columbia accidents,[111] the criteria used by NASA for human rating spacecraft have been made more stringent.

6.89 NASA's Commercial Crew Program aims to facilitate development of a US commercial crew space transportation capability, with the goal of achieving safe, reliable and cost-effective access to and from Low Earth Orbit (LEO) and the ISS.

6.90 At the end of 2013, the FAA and NASA signed an agreement to co-ordinate standards for commercial space travel by government and non-government astronauts to and from LEO and the ISS. The two agencies will collaborate to expand efforts that provide a stable framework for the US space industry, avoid conflicting requirements and multiple sets of standards, and advance both public and crew safety. The Memorandum of Understanding (MoU) signed by the two agencies establishes policy for operational missions to the space station. Commercial providers will be required to obtain a licence from the FAA AST for

---

[110] See http://nodis3.gsfc.nasa.gov/npg_img/N_PR_8705_002B_/N_PR_8705_002B_.pdf (accessed 8 May 2014)

[111] In well-known and publicised incidents, space shuttle Challenger broke apart shortly after take-off in 1986; space shuttle Columbia disintegrated during re-entry in 2003. NASA provides a detailed description of the two incidents – for Challenger at www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-51L.html and for Columbia at http://spaceflight.nasa.gov/shuttle/archives/sts-107/index.html (accessed 8 May 2014)

public safety. Crew safety and mission assurance will be NASA's responsibility. This approach allows both agencies to incorporate experience and lessons learned as progress is made. It also ensures that the two agencies will have compatible processes for ensuring public safety.

Commercial Space Transportation Advisory Committee

6.91 The Commercial Space Transportation Advisory Committee (COMSTAC) was established in 1984. Since that time, it has provided information, advice and recommendations to DoT and the FAA on issues facing the US commercial space transportation industry.

6.92 COMSTAC has established working groups that provide information, reports and recommendations to the full Committee for adoption. It currently has four working groups: systems, business/legal, operations, and export controls. The Committee also establishes ad hoc working groups or special task groups to address specific issues, as needed.

6.93 The primary goals of COMSTAC are to:

- evaluate economic, technological and institutional developments relating to the US commercial space transportation industry;
- provide a forum for the discussion of problems involving the relationship between industry activities and government requirements; and
- make recommendations to the Administrator on issues and approaches for federal policies and programmes regarding the industry.

6.94 COMSTAC membership consists of senior executives from the commercial space transportation industry; representatives from the satellite industry, both manufacturers and users; state and local government officials; representatives from firms providing insurance, financial investment and legal services for commercial space activities; and representatives from academia, space advocacy organisations and industry associations. The economic, technical and institutional expertise provided by COMSTAC members has been invaluable to this Review's work in developing effective regulations that ensure safety during commercial launch operations and policies that support international competitiveness for the industry.

Rest of the world

6.95 There are many other nations throughout the world that have active and successful space programmes, including Russia, China, Japan and India. This Review has not considered their regulatory frameworks, in part due to the limited amount of information available in the public domain. However, further analysis of them could play a part in developing future regulations for commercial spaceplane operations in the UK.

Industry standards

6.96 The development of international standards for spaceplane safety is in its infancy. While organisations such as NASA and ESA have adopted standards for space safety, very few are designed specifically for spaceplane operations.

6.97 To date, the International Organization for Standardization (ISO) has adopted a handful of standards that create a foundation for further progress. These standards include the basic space safety policy found in ISO 14300[112] and the further standards for:

- ISO 14620: Space Systems Safety Requirements;[113]
- ISO 17666: Space Systems Risk Management;[114] and
- ISO 14624: Safety and Compatibility of Materials.[115]

6.98 However, these are generic and not designed for spaceplane operations.

6.99 The International Association for the Advancement of Space Safety (IAASS) is at the forefront of the development and publication of voluntary space safety standards. The IAASS was established in 2004 in the Netherlands and is a non-profit organisation dedicated to furthering international co-operation and scientific advancement in the field of space systems safety. In 2004, IAASS became a member of the International Astronautical Federation, and in 2010 it was granted observer status at COPUOUS.

6.100 While such codes and standards are undoubtedly of value, and should be promoted, they are unlikely to be sufficient for the regulation of commercial spaceplane operations, especially given the significant risk that spaceplanes could present to the public. However, it is acknowledged that industry has an important role to play in developing standards for the future, which may later be developed into regulation.

Procedures and requirements used by the FAA AST

6.101 As stated above, all commercial space launches in the US, including those carried out by US organisations outside the US, are regulated and licensed by the FAA AST under authority devolved from the US Secretary of Transportation. The FAA AST is therefore responsible for meeting the statutory requirements set out in the Commercial Space Launch Act (CSLA) to:

- authorise launch and re-entry and the operation of launch and re-entry sites as carried out by US organisations or within the US;

---

[112] See www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=45342 (accessed 8 May 2014)

[113] See www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=29766 (accessed 26 May 2014)

[114] See www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=33149 (accessed 26 May 2014)

[115] See www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=28953 (accessed 26 May 2014)

- exercise this responsibility consistent with public health and safety, safety of property, national security and foreign policy interest of the US; and
- encourage, facilitate and promote commercial space launches and re-entries by the private sector.

6.102 Within these statutory requirements, any person or organisation must obtain a licence to:

- launch a launch vehicle from the US;
- operate a launch site or re-entry site in the US; or
- re-enter a re-entry vehicle in the US.

6.103 As of 8 May 2014, only four licensed re-entries had been made.

6.104 Also a US citizen or an entity organised or existing under US law must obtain a licence to:

- launch a launch vehicle outside the US;
- operate a launch site or re-entry site outside the US; or
- re-enter a re-entry vehicle outside the US.

6.105 The FAA AST licensing system is built on the CSLA, and within it and the supporting regulations there are several key definitions.

- ‘Sub-orbital rocket’ means a vehicle, rocket propelled in whole or part, intended for flight on a sub-orbital trajectory, and the thrust of which is greater than its lift for most of the rocket-powered portion of its ascent.
- ‘Launch vehicle’ means a vehicle built to operate in, or place a payload or human beings in, outer space or a sub-orbital rocket.
- ‘Launch site’ means the location on Earth from which a launch takes place and necessary facilities at that location.
- ‘Launch’ means to place, or try to place, a launch vehicle or re-entry vehicle and any payload, crew or spaceflight participant from Earth:
  - in a sub-orbital trajectory;
  - in Earth orbit in outer space; or
  - otherwise in outer space.

  This includes activities involved in the preparation of a launch vehicle or payload for launch, when those activities take place at a launch site in the United States.

- 'Space-flight participant' means an individual, who is not crew, carried within a launch vehicle or re-entry vehicle.

6.106 The FAA AST uses these definitions to underpin its regulatory structure for re-entry vehicles, including RLVs. A rocket-propelled spaceplane falls under the definition of a 'sub-orbital rocket,' and is thus classified as a launch vehicle, rather than an aircraft. It is therefore not subject to aviation legislation. Instead, a spaceplane, as a launch vehicle, will need a 'launch licence'.

6.107 The use of the term 'space-flight participant' for any non-crew individuals carried within a launch vehicle means that people who pay to travel on board a launch or re-entry vehicle are not passengers; hence passenger rights as given in aviation legislation do not apply. Participants who pay for a spaceflight experience also have to provide written 'informed consent' to participate in the launch and re-entry, and written certification of compliance with any applicable regulations issued by the Secretary of Transportation. As stated in Chapter 5, the requirements for informed consent for spaceflight are set out in the Code of Federal Regulations Part 460.[116] In short, they mean the holder of a launch licence must inform flight crew and any spaceflight participants in writing that the US Federal Government has not certified the launch vehicle as safe for carrying crew or spaceflight participants. An RLV operator must also inform spaceflight participants in writing about the risks of the launch and re-entry, including the safety record of the launch or re-entry vehicle type. The Secretary of Transportation must inform the spaceflight participants in writing of any relevant information related to the risk or probable loss during each phase of flight.

6.108 For a commercial space launch, typically two licences may be required: one for the vehicle or the operator, and a separate one for the launch site operations (ie spaceport). However, if there is a site with a sole user, FAA safety regulations can be handled under the launch licence. Some vehicles, such as those launched by Sea Launch from the Pacific Ocean or air-launched Pegasus vehicles, do not require a site licence. Vehicle or operator licences are granted on the basis of acceptance of a detailed written application. Operators have to provide information on financial responsibility, payload, environmental impact and, crucially, safety – giving comprehensive details of the launch schedule and trajectory, as well as of the systems being used.

Considerations for granting a launch licence

6.109 During the UK Government technical visit to the US, the FAA AST explained the considerations involved in reviewing applications for a launch licence. The minimum requirements are summarised below.

---

[116] Code of Federal Regulations, Title 14, part 460.45, at www.ecfr.gov/cgi-bin/text-idx?rgn=div5&node=14:4.0.2.9.24#14:4.0.2.9.24.2.30.3 (accessed 28 April 2014)

- Policy: it will be considered whether a proposed launch or re-entry will jeopardise US national or foreign policy interests, or international obligations. An interagency review involving the Department of Defense, the Department of State and NASA is an integral part of this process.
- Payload review: the review looks at payload safety issues and classes of payload (NB the FAA AST does not review government payloads except for safety issues).
- Environmental: the applicant must provide enough information for the FAA AST to analyse the environmental impacts associated with the proposed launches and re-entries. It is also recommended that the prospective applicant prepare the environmental review documents in advance of applying, as it can take about one year for a full environmental impact assessment to be carried out by the FAA AST in compliance with the US National Environmental Policy Act.
- Safety review: this is a comprehensive review looking at:
  - launch description, including trajectory and staging events;
  - safety organisation, including identified safety official;
  - flight safety;
  - ground safety;
  - launch plans;
  - launch schedule, including generic processing schedule;
  - computer systems and software;
  - unique safety policies and practices;
  - flight safety system design and operational data;
  - flight safety system test data;
  - flight safety crew data;
  - safety management at the end of launch;
  - accident investigation plan; and
  - agreements for notification with appropriate air traffic and marine authorities.
- Financial responsibility: proof of financial responsibility is required. This is usually fulfilled by the purchase of liability insurance to a value based on a Maximum Probable Loss determination, which covers third parties and government property.

6.110 The overall process can take a significant amount of time. Once an application is determined to be complete enough to start review, the FAA AST has a maximum of 180 days to review each formal licence application. Furthermore, prior to applying for a launch licence, there is a mandatory consultation period. This allows the prospective applicant to familiarise the FAA with its proposal.

Experimental permits

6.111 As well as launch licences, the FAA AST also issues experimental permits. The CSLA Amendments Act 2004 established an experimental permit regime for reusable sub-orbital rockets (eg spaceplanes) that are flown:

- for research and development;
- to show compliance prior to obtaining an operating licence; or
- for crew training purposes.

6.112 Compensation for hire is not allowed, and nor is the carriage of participants. Legislative direction indicates that an experimental permit should be granted more quickly, and with fewer requirements, than a licence. This would be more like granting an aircraft a special airworthiness certificate in the experimental category.

Safety approvals

6.113 The FAA AST can also establish procedures for safety approvals of launch vehicles, reentry vehicles, safety systems, processes, services, or personnel that may be used in conducting licensed commercial space launch or re-entry activities. Licensees using an element for which a safety approval has been issued would need only to demonstrate that its use does not exceed its approved envelope. The decision to apply for a safety approval is voluntary on the part of an eligible applicant.

Operator licences

6.114 Once an operator has been granted a licence for a specific type of flight using a specific type of reusable vehicle (such as a spaceplane), it may be easier for that operator to gain licences for future launches with slightly different payloads or trajectories. Alternatively, by gaining an operator licence, the operator can conduct multiple launches or re-entries of the same or similar type, from the same site. Operator licences remain in effect for two to five years from the date of issue.

Requirements for occupant safety

6.115 The FAA AST does not certify the launch vehicle. Nor does it directly address safety standards for vehicle occupants, other than those necessary to ensure the safety of third parties on the ground. It has, however, been granted authority to develop requirements for occupant safety, but cannot enact these until October 2015. The FAA AST has published draft established practices for occupant safety.[117]

6.116 The stated goals of the draft practices are to:

- protect occupants from avoidable risks;
- leverage existing knowledge of human spaceflight safety;
- be easily understood;
- be performance based where possible;
- be applicable to all known system designs and uses;
- not restrict innovation;
- minimise cost to industry; and
- be easily updated.

6.117 However, the draft does not cover:

- how and where the new regulations will be integrated into the current regulations;
- certification;
- specific loss of crew probability thresholds; or
- security (criminal intent).

Safety inspections

6.118 In addition to licensing activities, the FAA AST carries out safety inspections. The Safety Inspection Division is responsible for: safety inspection, incident response, safety inspector training and enforcement. The Division inspects any FAA AST-regulated activity, including:

- licensed/permitted operations;
- licensed site operations;
- re-entry operations;
- pre-launch safety and readiness meetings;
- flight safety system related tests;

---

[117] FAA AST (2013) *Draft Established Practices for Human Space Flight Occupant Safety*, www.faa.gov/about/office_org/headquarters_offices/ast/media/draft_established_practices_for_hsf_occupant_safety_with_rationale.pdf (accessed 8 May 2014)

- public safety related procedures;
- rehearsals and exercises;
- production and manufacturing facilities;
- safety approval holders; and
- contractor and sub-contractor facilities.

6.119 Accident/incident investigation would normally be carried out by the National Transportation Safety Board (NTSB); however, each launch site is required to have its own accident/major incident investigation plan. This must include:

- immediate notification to the FAA Washington Operations Center;
- submission of a written report to the FAA within five days of any accident;
- a response plan which ensures that the consequences of a launch site accident are contained and minimised;
- co-operation with FAA or NTSB investigations; and
- identification of preventive measures to avoid recurrence.

6.120 In carrying out its normal role of safety inspection, the Division also has the power to enforce compliance with the regulations. If a violation is suspected, it will:

- plan and co-ordinate any investigation;
- conduct the investigation and collect evidence; and
- recommend a course of action, which could be:
  - informal;
  - administrative, ie a warning notice or letter of correction;
  - issuance of an emergency or restriction order;
  - suspension or revocation of licence/permit; or
  - a civil penalty.

6.121 Clearly, the full regulatory duties of the FAA AST are more detailed than are summarised above. However, this description covers its major responsibilities, and highlights several important factors that will need to be considered in the development of a regulatory framework for commercial spaceplane operations in the UK.

What safety standards can be expected of commercial spaceplanes?

6.122 Over the past hundred years, commercial aviation has evolved to the extent that, for public transport, operations involving ICAO-certified aircraft achieve a catastrophic failure rate better than $1x10^{-7}$. This means that catastrophic failure takes place less than once in every 10 million hours of flight.

6.123 For general aviation, the standards are typically between 1 in 10,000 and 1 in 100,000 – less stringent than for public transport, but still deemed an acceptable level of safety, given the nature of the activity.

6.124 The commercial spaceplane industry is new and the safety performance of spaceplanes largely unknown. Furthermore, the total number of commercial spaceplane flights before 2018 is likely to be very small; it is likely that meaningful safety data about commercial spaceplanes will only be accumulated some years thereafter. Previous spaceplane operations have used experimental vehicles operated largely by government agencies and, although some safety data is available, it may not be applicable to commercial operations.

6.125 The majority of spaceplane operations have so far occurred in the US. These have been either government operated (ie by NASA) or regulated by the FAA AST. In order to understand better the options for the UK, it is worth examining their approach to safety more closely.

6.126 During its technical visit to the US, the UK Government team was informed by NASA that it considered a target level of safety of 1 in 1,000 to be achievable for orbital operations, and 1 in 10,000 for sub-orbital operations in the future. These figures are understood to be broadly in line with ESA targets as well as with the draft safety standards being developed by the IAASS. However, it is worth highlighting that historically, orbital operations have experienced approximately 1 catastrophic failure every 100 launches (ie $1x10^{-2}$).

6.127 Both the US Government and the FAA AST have made it clear that they accept that spaceflight is a high-risk activity; hence their regulatory approach is to focus on the protection of the uninvolved general public (also known as third parties). This differs from normal commercial aviation, where the focus is on protection of passengers and crew, and works on the basis that if the risks to passengers and crew are minimised, then the public is inherently protected, too. The FAA AST has set a target level of safety of $30x10^{-6}$ for third party risks to collective members of the general public, and $1x10^{-6}$ for a risk to an individual. In plainer terms, this means that the acceptable risk of third party casualties is 0.00003 per mission, or 3 casualties in every 100,000 missions. Missions which cannot demonstrate that they should meet this target will not be granted a launch licence.

6.128 The FAA AST has not set, and currently has no intention of developing, any certification standards for spaceplane operations. It only sets high-level requirements within the Code of Federal Regulations (CFR 460)[118] concerning such items as crew training, qualifications and the maintenance of an adequate atmosphere within the spaceplane. These requirements are simply intended to protect the uninvolved general public by ensuring that the operating crew is able to control the spaceplane in all stages of flight.

6.129 As there are no certification standards, and only limited safety requirements, an FAA AST-licensed spaceplane operator will normally achieve the required safety standards by launching from locations where population levels are extremely low – hence the risk of casualties among the uninvolved general public is minimised. In practice, this means that all FAA AST-licensed launch sites are in areas that have very low levels of population – specifically either desert or coastal locations.

6.130 For spaceplane occupants – flight crew and participants – there is no federal assurance of the safety standards of the spaceplane. Instead, operators will apply the principles of informed consent before flight, as set out in Chapter 5 – informing each spaceflight participant in writing about the risks of the launch and re-entry, and requiring them to provide consent in writing to participate.

6.131 This is a fundamentally different approach to that used by NASA, which wishes to achieve a level of mission assurance and therefore sets strict safety standards for the design and operation of their spacecraft. (This is the human rating discussed above.) While falling short of a full aviation certification, the process ensures that spacecraft design takes into account the safety of the occupants, using engineering best practice and lessons learned from past failures.

6.132 It is clear that FAA AST and NASA have different requirements and a different approach to safety assurance. Neither, however, adopts a full certification process for spaceplanes – without which there can be no quantified safety assurance for spaceplane occupants.

6.133 Ultimately, the ideal solution would be for the UK's regulatory framework for spaceplanes to follow the same principles as commercial aviation regulation, which includes certification. However, as explained in more detail in Chapter 7, it is clear that commercial spaceplanes cannot currently achieve the same safety standards as commercial aviation, and may never be able to.

6.134 Insisting that spaceplane designs must meet the certification standards required for public transport would result in commercial spaceplane operations being delayed, possibly for many years, until both suitable airworthiness codes are developed and new spaceplanes designed and manufactured that meet the standards specified in those codes. Yet, for as long as activity levels are low,

---

[118] Code of Federal Regulations, Title 14, part 460, www.ecfr.gov/cgi-bin/text-idx?c=ecfr&sid=e11cee34fe5087a8cba8d252ec7327b3&rgn=div5&view=text&node=14:4.0.2.9.24&idno=14 (accessed 7 April 2014)

safety standards acceptable both to participants and to uninvolved persons may be achievable without such an approach.

6.135 Therefore, given the desire to enable commercial spaceplane operations to commence from the UK by 2018 or earlier – which is key to maximising the commercial opportunities set out in Chapter 3 – an alternative approach must be found. As the timeline earlier in this chapter indicates, the spaceplanes that could be operated in the UK within this timescale are likely to be sub-orbital and to hold an FAA AST launch licence.

6.136 However, as they will hold no Certificate of Airworthiness, operations will inherently present a far higher degree of risk than commercial aviation. Before allowing such operations, the Government must understand and accept this risk. If this risk is accepted, then protecting the uninvolved general public, rather than participants and crew, should become the underlying regulatory priority.

Recommendation

In order to allow spaceplane operations from the UK by 2018 or earlier, the Government must accept that spaceplane operations carry a higher degree of risk than most normal aviation activities, and that protecting the uninvolved general public should be its highest safety priority.

6.137 This is essentially the same approach taken by the FAA AST, and without certification this protection can best be achieved through such actions as:

- selection of launch sites away from densely populated areas;
- restriction of operations so that they only take place within segregated airspace; and
- using the principles of safety management to help ensure that spaceplane operations achieve the highest level of safety that is reasonably practicable.

6.138 These will therefore all form a significant part of the overall regulatory framework recommended by this Review – and are discussed in more detail in the chapters that follow.

Towards a single integrated regulatory framework for commercial spaceplane operations

6.139 The different regulatory frameworks outlined above indicate that there are several potential options for, and approaches to, the regulation of spaceplane operations. Furthermore, any regulatory framework must also take into account the complex legal landscape, discussed in Chapter 5, and the different operators and operating models described in Chapter 2. Some spaceplane operations will be subject to the Outer Space Act 1986, and some will not. Some – including those operators that have expressed the strongest desire to commence operations in the UK – will be subject to the US export control regime; others, developed elsewhere, may not. Some will carry participants as well as flight crew; others will be remotely piloted. Therefore one regulatory framework may not be suitable for all the different spaceplane operations within the scope of this Review.

6.140 Nonetheless, there is a strong case – in the interests of clarity and transparency – to find as much common ground as possible, not only across the regulatory frameworks proposed for different operations, but also with existing regulatory frameworks.

6.141 It is envisaged that, at some point in the future, the EU – through EASA – will introduce a regulatory framework for commercial spaceplane operations that would apply across Europe, including the UK. However, as was stated in Chapter 5, it has not yet done so, and indeed there are strong indications that any such rulemaking will not commence before 2016. In practical terms, this would mean that it is highly unlikely that regulations would be in place by 2018 – the potential date for the first commercial spaceplane launch from the UK.

6.142 In the absence of any EU regulation, the UK could regulate spaceplanes under national law – and the simplest approach, given the nature and provenance of the expected initial operations, could simply be to adopt the FAA AST regulatory framework for all commercial spaceplane activities.

The advantages and disadvantages of applying the FAA AST framework in the UK

6.143 The advantages of such an approach would be that:

- it would be focused on the safety of the uninvolved general public, as per the stated priority for the UK;
- it would apply to all operations within the scope of the Review (including expendable launch vehicles);
- it would facilitate initial FAA AST-licensed operations;
- US operators would not need to comply with a different regulatory framework;
- UK regulations could be drafted quickly, with regulators benefiting from the expertise of counterparts within the FAA AST; and
- it could potentially assist with challenges around export controls.

6.144 However, there are also some significant disadvantages, such as:

- adopting the FAA AST framework could necessitate changes to UK primary legislation, including the adoption of the US definition of a sub-orbital spaceplane into UK law;
- a separate organisation, similar to the FAA AST, would need to be established to administer the regulatory framework; and
- it could leave the UK out of step with any developing EU legislation – which the UK would then have to adopt.

6.145 Above all, however, the FAA AST framework assumes that spaceplanes are not aircraft; this view is not shared by CAA and Department for Transport lawyers, who have made it clear that spaceplanes meet the internationally accepted definition of an aircraft. This means that any future EU spaceplane legislation is likely to be based on aviation principles. This is further reflected by the fact that ICAO itself has established a working group to start looking at spaceplane operations. While the terms of reference for this group have yet to be published, the fact that ICAO has agreed to include spaceplanes in its future work programme further endorses the view that spaceplanes are aircraft, and the articles of the Chicago Convention would therefore apply to them.

6.146 Therefore, although the FAA AST regulatory system could be used by the UK for the safety regulation of both spaceplane operations and expendable launch vehicles, by following this route the UK would risk being out of step with its own legal opinion and with future EU and international regulatory developments.

Recommendation

Due to the risk of being out of step with future EU regulation and the UK legal view that spaceplanes are aircraft, the UK should **not** apply the FAA AST system as a whole for the regulation of commercial sub-orbital spaceplane operations.

Applying aviation legislation to spaceplanes

6.147 Strict application of the legal view that spaceplanes are aircraft would suggest that the full weight of EU aviation legislation would apply to all UK spaceplane operations, and that the CAA, as the competent authority for aviation regulation in the UK,[119] would also be the competent authority for spaceplanes.

6.148 Furthermore, any operations that carry, or propose to carry, paying participants or cargo would be deemed to be public transport under EASA regulation.

6.149 However, as was made clear in Chapter 5, spaceplanes cannot comply with the requirements of EU aviation legislation; if it were enforced, they essentially would not be able to operate. This has led to the recommendation that sub-orbital spaceplanes are classified as 'experimental aircraft' and treated as

---

[119] A competent authority is any person or organisation that has the legally delegated or invested authority, capacity or power to perform a designated function.

Annex II aircraft under the EASA Basic Regulation – thus enabling regulation to be managed at a national level, through exemptions and special conditions to the Air Navigation Order (ANO). Some potential exemptions and conditions are considered in subsequent sections of this chapter.

6.150 In the medium to long term, it may be possible to establish a certification process for spaceplanes. The emerging European spaceplane industry wishes for certification codes to be developed, and EASA supports this view. In 2008 EASA published an abstract entitled 'Accommodating sub-orbital flights into the EASA regulatory system'.[120] A major part of the paper was a discussion of how EASA certification could apply to sub-orbital spaceplanes, and it concluded that a restricted type certificate (RTC) could be a suitable way forward. Such an RTC could be based on the principles of EASA Certification Standards CS-23[121] or CS-25,[122] and would deliver safety requirements broadly in line with general aviation safety standards.

6.151 As is discussed in more depth in Chapter 7, there would be significant challenges in adapting the certification codes to cover unique systems such as reaction control systems and rocket engines.

6.152 From the framework point of view, however, the key issue is that with certification, a spaceplane would no longer be thought of as experimental and would be regulated solely as public transport or EASA commercial air transport. It is recognised that the flight profile and operating environment of spaceplanes is different from conventional aviation, and therefore the EU would have to develop a suitable operational regulatory framework at the same time as establishing the certification process.

Additional regulatory requirements

6.153 Even if regulated under aviation law, spaceplane operations conducted by UK companies may also be subject to the Outer Space Act 1986. Any sub-orbital or orbital operations using non-winged vehicles – ie vertical launch vehicles – cannot be regulated under aviation law, and an alternative method of safety regulation, such as that provided by the FAA AST, would need to be established.

6.154 This multiplicity of different regulatory requirements may lead to a level of regulatory complexity and burden that industry feels to be undesirable, particularly for orbital operations. While orbital operations are not expected

---

[120] J-B Marciacq, Y Morier, F Tomasello, Zs Erdelyi and M Gerhard (2008) 'Accommodating sub-orbital flights into the EASA regulatory system', EASA conference paper, https://getinfo.de/app/Accommodating-Sub-Orbital-Flights-into-the-EASA/id/BLCP%3ACN072087298 (accessed 29 May 2014)

[121] EASA (2012) *Certification Specifications for Normal, Utility, Aerobatic, and Commuter Category Aeroplanes*, CS-23, Amendment 3, http://easa.europa.eu/system/files/dfu/CS-23%20Amdt%203.pdf (accessed 7 May 2014)

[122] EASA (2013) *Certification Specifications and Acceptable Means of Compliance for Large Aeroplanes*, CS-25, Amendment 14, http://easa.europa.eu/system/files/dfu/2013-033-R-Annex%20to%20ED%20Decision%202013-033-R.pdf (accessed 7 May 2014)

during the initial stages of spaceplane operations from the UK, it is important that the challenges of regulating them are considered as soon as possible. For example, up to three different regulatory frameworks may apply to some operations:

- conventional carrier aircraft may be regulated under aviation law;
- The Outer Space Act would apply, as the orbital vehicle will have to be registered as a 'space object' and licensed by the UK Space Agency; and
- a new regulatory framework would be needed for orbital insertion and re-entry.

6.155 Currently there is no safety regulation of orbital launch systems in the UK. If the market develops as projected, the ideal solution ultimately will be to establish a regulatory framework to address all the regulatory requirements under a single competent authority, which would also be the competent authority for spaceplanes. The competent authority could be the CAA, the UK Space Agency or a new, separate organisation, working alongside other bodies such as the Health and Safety Executive. However, the creation of a new organisation would probably only be justified if regular orbital launch operations were taking place.

Recommendation

To ensure the safety of the uninvolved general public, and provide a single, clear regulatory framework for spaceplane and spaceflight operators, the Government should appoint a single competent authority for the safety regulation of all spaceflight operations.

Recommended regulatory frameworks for different types of spaceplane operations

6.156 The most transparent and consistent approach to regulation of spaceflight would be to have a single overarching framework, under a single competent authority. However, within this there would need to be slight differences in the specific regulations applied to different types of spaceplane operation – reflecting differences in flight profile and purpose, as well as launch method. The following sections examine the spaceplane operations that are within scope of the Review. Mindful of overall safety requirements, the legal view, the likely timeline and the regulatory options available, they also make recommendations for the most appropriate regulatory framework for the UK.

Sub-orbital spaceplanes for spaceflight experience/the carriage of scientific payloads

6.157 As set out in the timeline earlier in this chapter, sub-orbital spaceplanes for spaceflight experience and the carriage of scientific payloads are likely to be the first spaceplane operations in the UK. The regulatory framework outlined below would apply to EU-developed sub-orbital spaceplanes, as well as to FAA AST-licensed sub-orbital spaceplanes and any other third country operation taking place in the UK.

6.158 The proposed approach to allowing sub-orbital spaceplane operations in the short term is to consider them as experimental aircraft under Annex II of the EASA Basic Regulation. They would therefore be regulated under the Articles of the ANO, with appropriate exemptions and special conditions applied to reflect the characteristics and risks appropriate to the individual spaceplane flight profiles.

6.159 Any special conditions attached to the ANO for the regulation of sub-orbital spaceplanes will also help mitigate the risks to the uninvolved general public and, where possible, identify and mitigate the risks to spaceplane occupants. These special conditions should be based on industry best practice, if available; be derived from aviation regulation, where applicable; and use suitable space safety regulation, where appropriate and available.

6.160 It is acknowledged that initial UK spaceplane operations are likely to use US-designed and manufactured spaceplanes. As was set out in Chapter 4, US export controls mean that they will most likely operate under an FAA AST launch licence. Any UK regulatory requirements will apply in addition to the requirements of that launch licence.

6.161 The following is a sample list (but not exhaustive) of typical flight operations requirements that are addressed under ICAO, the EASA Basic Regulation and the ANO. (Requirements for flight crew licensing, medical assessment and airworthiness are covered in more detail in other chapters of this Review.)

- Public transport operators must hold an Air Operator Certificate.
- All operators must have a management system, including a safety management system (SMS), an operations manual and an emergency response plan.
- Operations must follow internationally agreed crew requirements, responsibilities and privileges, as well as standard operating procedures (SOPs).
- Operators must adhere to normal and non-normal checklist handling and regulations on what and who can be carried on an aircraft.
- Operators must provide a comprehensive flight plan, including fuel planning and in-flight fuel handling, in-flight procedures and navigation/communication and data link requirements.
- Any operations involving passengers must provide a passenger emergency briefing.

- Operators must confirm mass and balance.
- Operators must carry all equipment on the minimum equipment list.
- Operators must carry appropriate manuals and complete logs and records.
- Operators must state and adhere to operating limitations of the aircraft, including weather limitations.
- Operators must comply with aircraft performance and environmental protection requirements.
- All aircraft must hold proof of airworthiness, either through a Certificate of Airworthiness or a Permit to Fly.
- Suitable and sufficient onboard safety equipment must be carried.
- Operators must conduct a pre-flight inspection.
- Operators and flight crew must comply with guidance on operating personnel fatigue and rostering.
- All guidance on aircraft, personnel and data security must be strictly followed.

6.162 To assess how these flight operations regulatory requirements may be adapted to regulate spaceplane operations, the following sections look at some of the key requirements in a little more detail. Further development of regulations and the associated guidance material would need to be the subject of future regulatory activity and would need to be developed in close consultation with the spaceplane industry.

Recommendation

To develop the regulatory framework further, and to help mitigate the risks to the uninvolved general public and spaceplane flight crew and participants, the Government should task the CAA with the detailed assessment of risks, and with the development of appropriate exemptions and special conditions to the ANO for sub-orbital spaceplanes.

Air Operator Certificate

6.163 All aviation public transport[123] operators are required to hold an Air Operator Certificate (AOC). This ensures that public transport operations are only carried out by organisations that have satisfied their national regulatory authority that they are capable of delivering the operation safely. The exact details of the

---

[123] Public transport is defined in the Air Navigation Order as 'any flight on which is carried one or more passengers or cargo where valuable consideration has been given or promised for the carriage. A passenger is defined as meaning anyone who is not a member of the flight crew or cabin crew.' CAA (2010) *Summary of the Meaning of Commercial Air Transport, Public Transport & Aerial Work*, sections 1.1 and 1.2, www.caa.co.uk/docs/1428/SummaryOfCATPTAWANO2009May2010.pdf (accessed 9 May 2014)

requirements for holding an AOC may vary from country to country, but are likely to include the following:

- the operator will need to prove to the regulatory authority that it has sufficient financial integrity to fund its proposed operation;
- the operator will need to hold suitable liability insurance for the type of operation;
- the operator must have sufficient ground infrastructure to support its operation;
- the operator must have appointed all key accountable staff, eg safety, training, operations and maintenance, and have sufficient staff to support the operation;
- the operator must have suitable aircraft for the type of operation – all of which must hold a valid Certificate of Airworthiness; and
- the operator must have an operations manual.

6.164 Spaceplane operators could not directly comply with the requirements of an AOC, as no current sub-orbital spaceplanes hold a Certificate of Airworthiness, and nor are they likely to in the short term. While there may be no requirement for an experimental aircraft operator to hold an AOC, given the nature of sub-orbital spaceplane operations, some form of operating licence would be appropriate. This could be based on the AOC principles modified to fit the operation, or even built up from first principles, as appropriate.

Safety management system (SMS)

6.165 Any organisation carrying out public transport[124] operations must document how it manages the safety risks inherent in its operation. The methodology for doing this is given in ICAO Annex 19. With the increased risks inherent in spaceplane operations and spaceflight in general, it is imperative that such operations also follow the principles of safety management. Each operator should be required to publish a safety policy and to identify a person within its organisation who holds responsibility for the co-ordination of its SMS.

Recommendation
All spaceplane operators should be required to identify a person within their organisation who holds responsibility for the co-ordination of their safety management system.

---

[124] See www.icao.int/safety/SafetyManagement/Pages/Annex-19,-1st-Edition---Executive-summary.aspx (accessed 9 May 2014)

6.166 The recently published FAA AST *Draft Established Practices for Human Space Flight Occupant Safety* includes in section 1.5 requirements for the establishment and documentation of an operator's SMS.[125] These requirements follow the same principles as those for aviation.

6.167 A key part of an SMS is the identification of hazards, assessing the associated risks and how these risks are mitigated. With the hazards and risks inherent in spaceflight and spaceplane operations, it may be impossible to mitigate adequately all of the risks. It is therefore important that the prospective participant is informed of these risks, and this information is likely to form a major part of the informed consent process.

Management system

6.168 Section 3.1.1 of the FAA AST *Draft Established Practices for Human Space Flight Occupant Safety* states that 'clear lines of communication and approval authority within a program are necessary to avoid confusion and lessen the chance that safety issues will be missed'.[126] In European aviation law,[127] this is the role of the operator's management system.

6.169 A management system is a fully documented description of key aspects of an operator's organisation and approach. It should include as a minimum:

- identification of the key accountable personnel within the organisation;
- the organisation's safety policy;
- the SMS;
- processes for compliance monitoring;
- processes for management of change; and
- an emergency response plan.

6.170 The management system should correspond to the size of the operator and the nature and complexity of its activities, taking into account hazards and associated risks inherent in these activities.

6.171 It would seem wholly appropriate to require sub-orbital spaceplane operators to have a management system, available for review by the competent authority.

---

[125] FAA AST (2013) *Draft Established Practices for Human Space Flight Occupant Safety*, www.faa.gov/about/office_org/headquarters_offices/ast/media/draft_established_practices_for_hsf_occupant_safety_with_rationale.pdf (accessed 8 May 2014)

[126] ibid

[127] EASA Implementing Rules ORO.GEN.200, https://easa.europa.eu/system/files/dfu/04%20Part-ORO%20(AMC-GM)_Amdt2-Supplementary%20document%20to%20ED%20Decision%202013-019-R.pdf (accessed 7 June 2014)

Emergency response plan

6.172 All aviation operators should, in co-operation with other stakeholders, develop, co-ordinate and maintain an emergency response plan (ERP) that ensures orderly and safe transition from normal to emergency operations, and also the return to normal operations. The ERP should detail the actions to be taken by the operator or specified individuals in an emergency and should reflect the size, nature and complexity of the activities performed by the operator. The operator's ERP should also be included within the management system.

6.173 Due to the potential risk involved in sub-orbital spaceplane operations, it is essential for all operators to develop and maintain an appropriate ERP. As part of the management system, this would be available for review by the competent authority.

Operations manual

6.174 The purpose of the operations manual (OM) is to provide personnel involved in the preparation and execution of flight operations with all the information they need to carry out their task. For public transport operations, guidance on the structure and content of the OM is given by ICAO and EASA.[128]

6.175 Sub-orbital spaceplane operators should be required to develop a suitable OM for personnel working on their operations. For operations conducted under a wet lease type arrangement (see Chapter 4), it may be appropriate to have an adapted version of the OM that covers role-relevant information, without infringing export control regulation.

Passenger emergency briefing

6.176 Passengers on commercial aircraft are accustomed to receiving a safety brief/demonstration from the cabin crew prior to take-off. The fact that this brief is standardised and short is because all public transport aeroplanes comply with a standard set of safety requirements including requirements for safety equipment carriage.

6.177 Spaceplanes are different: they have no standard airworthiness or safety equipment requirements. They will operate in a much more hostile environment and, unlike passengers on a commercial aircraft, spaceflight participants may be required to assist the crew or carry out specific actions in the event of an emergency. This may mean that participants will need a significant period of dedicated safety training before the flight. Clearly, it will be entirely in the operator's interests to ensure that this is provided.

---

[128] The CAA has produced a detailed operations manual template, based on the EASA guidance. See www.caa.co.uk/docs/620/20140106EASAOperationsManualTemplateAeroplanes.pdf (accessed 9 May 2014)

6.178 The specific syllabus for this training will have to be developed by operators, and may vary considerably depending on the type of spaceplane operation.

Operating crew fatigue/flight time limitations

6.179 The flight time limitations (FTL) placed on flight crew in commercial aviation are designed to manage fatigue and ensure that the crew is adequately rested before undertaking any duty. As technology has progressed and automation has advanced, so crew fatigue and its effect on safety have been highlighted as increasingly important in the industry. Operators that employ crew involved in spaceflight will have to give extra consideration to factors that already exist in conventional aviation, but also to new factors that will affect the fatigue and stress placed on the crew when carrying out such a demanding task. Initially, the small number of flights may mean that crew fatigue is not an issue. However, as the industry matures and flight frequency and pilot duty increase, due consideration will need to be given to this.

6.180 As spaceflights will involve tasks that are not usual in standard commercial aviation, risk assessments will need to be carried out to consider some of the following areas:

- number of sectors[129] flown in a duty;
- duration of flight duty period (which will, of course, include any pre-flight and post-flight phase);
- automation level of the flight deck/procedures flown;
- task-related fatigue;
- biological effect (such as the impact of high G); and
- radiation exposure.

6.181 When formulating flight time limitations for the crew, the operator will have the responsibility of taking into account all aspects of their specific operation and of identifying key safety issues. Comprehensive risk assessments, both initially and as an ongoing process, will be needed to address the anticipated stresses and effects of high-altitude flight to provide a sufficient level of safety for the crew – and also, therefore, for any participants.

6.182 These issues are considered further in Chapters 11 and 12 of this Review.

Accident and incident investigation

6.183 Any UK accident or serious incident caused by a sub-orbital spaceplane will merit investigation. The Review recommends that the Air Accidents

---

[129] In commercial aviation, a sector lasts from a take-off to a landing. Long-distance flights – eg London to Sydney – which land at a mid-point during the journey are deemed to consist of two sectors.

Investigation Branch of the DfT carry out such investigations as part of its routine responsibilities.

Recommendation

The Government should task the Air Accidents Investigation Branch of the DfT with the investigation of any accidents or serious incidents involving sub-orbital spaceplanes.

Operating location

6.184 It is clear that the risks and complexities of spaceplane operations will necessitate operations taking place from a suitable launch location, or spaceport. The necessary criteria for a launch location are examined in detail in Chapter 9.

6.185 However, one key requirement – given both this Review's stated priority of protecting the uninvolved general public and the fact that initial operations are expected to take place under the terms of an FAA AST launch licence – is that the launch location will be in an area of low population density.

6.186 To date, to meet this requirement the FAA AST has only licensed launches from desert or coastal locations. There are no suitable desert locations in the UK, so this would imply that a UK spaceport would best be established at a coastal location. In future, with a better understanding of sub-orbital spaceplane safety performance and the possibility of the development of suitable certification codes, it may be possible to relax this coastal location requirement.

6.187 A spaceport will also require suitable airspace in which spaceplanes can operate. Again in line with the priority of protecting the uninvolved general public, it is likely that initial operations will need to take place within segregated areas of Special Use Airspace. This is considered further in Chapter 8.

6.188 This airspace will need to be monitored by radar to ensure that the spaceplane's location is known throughout its flight. Suitable radio frequencies will also be needed for voice communication and data link.

Unmanned aircraft systems

6.189 A number of the sub-orbital spaceplane designs are unmanned. Regulation of unmanned aircraft systems (UAS) is currently under development. Initial standards are scheduled for adoption by the ICAO during the first quarter of 2018, although those enabling full integration into the total aviation system are unlikely to be available until 2028.[130] EU regulatory development plans follow a similar timeframe,

---

[130] For further information, see ICAO Aviation System Block Upgrade (ASBU) programme, www.icao.int/Meetings/anconf12/Pages/Aviation-System-Block-Upgrades.aspx (accessed 9 May 2014)

with 'initial operations' starting from 2018, 'integration' progressing from 2023, with 'evolution' towards full airspace access by about 2028.[131]

6.190 These requirements are still open to a great deal of discussion and differing opinion, and therefore any approval for UAS operations (whether for spaceflight or traditional aviation) will in the short term be made on a case-by-case basis.

6.191 In the majority of cases, the specific challenges of operating in an unmanned capacity do not differ between atmospheric flight and spaceflight. Consequently, the same considerations surrounding the development of unmanned aircraft will be directly relevant for unmanned spaceplanes.

6.192 Both within the UK and internationally, an unmanned aircraft is still considered to be an aircraft, and is therefore subject to aviation rules. As a result, therefore, in the majority of cases, UAS will need to be designed, constructed and operated in a manner that will provide equivalence to the regulatory requirements set for manned aviation. This does not mean that the processes and/or procedures should be identical to those found in manned aviation, but simply that they should provide equivalent capability, so that UAS operations can be safely integrated with the rest of the aviation (and space) system. Where such equivalence cannot be achieved, additional procedures/constraints will need to be imposed, not only on UAS/unmanned spaceplane operations, but also on the remaining aviation system, so that an appropriate level of safety can be assured.

6.193 When examining the requirements for UAS operations, the key factor clearly is to cater for the absence of an onboard pilot. All manned aircraft are flown with a 'pilot-in-command' (ie a competent person who is directly responsible for the safe conduct of the flight) who can make appropriate decisions to maintain aircraft safety, should circumstances change as the flight progresses. Unmanned aircraft can be remotely piloted (by a competent person) or be autonomous. At present, both the ICAO and the EU only intend to develop global standards for remotely piloted aircraft systems (RPAS); all the indications are that UAS operations that do not include a remote pilot (other than possibly in the simplest of scenarios) will not be seriously considered for many decades.

6.194 For the foreseeable future, therefore, real-time, direct human responsibility will be required for all unmanned aircraft flights, particularly if the potential exists for any interaction with manned aircraft or for the overflight of populated areas. This would naturally include unmanned spaceplanes.

6.195 The term 'remote pilot' is used when describing the person in command of a UAS flight. While the location of the pilot is different, the function is essentially the same for manned and unmanned aviation: both involve managing an aircraft's

---

[131] European RPAS Steering Group (2013) *Roadmap for the Integration of Civil Remotely-Piloted Aircraft Systems into the European Aviation System*, http://ec.europa.eu/enterprise/sectors/aerospace/files/rpas-roadmap_en.pdf (accessed 9 May 2014)

flight through the air and both need to operate in the same airspace, with the same weather and under the same rules. Thus, there is clearly a need for equivalence with regard to any interactions with manned aviation.

6.196 This does not mean that all of the traditional 'pilot' skills will be required; however, a remote pilot of an unmanned spaceplane will be expected to possess the equivalent 'airmanship' skills required to be able to manage the flight safely, including the appropriate reactions to system failures or emergencies. The current intention internationally is that a new licence will be developed, known as the Remote Pilot's Licence, which will act as the UAS equivalent to the current pilot licensing regimes. This would seem applicable to spaceplane operations.

6.197 ICAO Annex 2 states that, as a guiding principle, a remotely piloted aircraft 'shall be operated in such a manner as to minimize hazards to persons, property or other aircraft'.[132] Therefore, the main purpose of UAS/RPAS regulations is to protect society from:

- uncontrolled crash, which may lead to injuries or fatalities on the ground (including a crash after a mid-air collision between two remotely piloted aircraft (RPA) or between an RPA and an obstacle); and
- mid-air collision with manned aircraft.

6.198 A UAS comprises a set of configurable elements, including the aircraft/spaceplane itself, its associated remote pilot station (the location where the remote pilot is operating the aircraft from), the required command and communication data links (C2 links) and any other system elements that may be required at any point during the flight operation, such as:

- software, eg flight management system and autopilot;
- system health monitoring, to keep the remote pilot informed about the status of the RPAS, in order to initiate emergency procedures, for example in case of C2 link failure;
- Air Traffic Control (ATC) communications equipment;
- flight termination system to perform the intentional and deliberate process of ending the flight in a controlled manner in the event of an emergency; and
- launch and recovery elements – any special devices required to assist remote take-off and landing, whether on board the aircraft or located externally.

6.199 These systems will be particularly important for sub-orbital spaceplane operations, which will clearly be conducted beyond visual line of sight.

---

[132] Full text of Annex 2 can be found at www.icao.int/Meetings/anconf12/Document%20Archive/an02_cons[1].pdf (accessed 8 May 2014)

A significant amount of data will need to be transferred between the spaceplane and the remote pilot station, so that the flight can be properly managed remotely (as opposed to being managed by a pilot on board). In order to achieve this, a stable and reliable C2 link is necessary. The required performance parameters of the C2 link will be dependent on the type of control interface used and will need to be defined by the unmanned spaceplane manufacturer/operator. However, the potential minimum requirement for unmanned spaceplanes would be that loss of the C2 link must not directly lead to a hazardous or catastrophic event.

6.200 Under international aviation rules, 'special authorisation' is required to be issued by each state over whose territory (including out to the 12 nautical mile limit) an unmanned aircraft is flown. This stems from the basic requirement to take into account the sovereignty of individual states when conducting international flights, and is governed by the requirements of Article 8 of the Chicago Convention (which is entitled 'Pilotless aircraft').[133] This special authorisation must be obtained prior to departure, and the precise details required could vary between states. As international experience with UAS operations grows, such special authorisation could evolve into blanket approval for specific operators. However, until a satisfactory level of operational experience has been reached, individual states are likely to require an authorisation for each flight.

6.201 To obtain such authorisation, a large amount of information must be provided to the regulatory authority of each state well in advance of the flight. This includes:

- copies of all remote pilot licences, certificates of registration and the Certificate of Airworthiness of the RPA, and the copies of any alternative certificates;
- a noise certificate;
- a full description of the RPA and its performance characteristics (eg type, maximum take-off mass, number and type of engine(s), dimensions, operating and cruising speed, typical and maximum climb and descent rates, endurance and other relevant performance data);
- details of communications, navigation and surveillance capabilities (including alternative means of communication between the remote pilot stations and the air traffic service);
- point of departure and destination, duration and frequency of flight, plus deployment of safety personnel during take-off and landing phases;
- route co-ordinates in World Geodetic System 1984 (WGS84) format, with any restrictions or limitations on overflying populated areas;
- payload information and description;

---

[133] See www.icao.int/publications/Documents/7300_orig.pdf (accessed 26 May 2014)

- C2 link description, with evidence that the link(s) used are safe, secure and compliant with state spectrum-management legislation;
- emergency procedures to deal with:
    - failure of ATC communications;
    - failure of C2 data link (partial or total), eg automatic flight and landing or activation of the flight termination plan;
    - other emergencies, eg loss of thrust, fuel leak, safety-related technical failures;
- security measures associated with the RPAS operation, both the physical security of the remote pilot station and the security of the C2 data link, eg against jamming, protecting the frequency band with encryption, frequency hopping, agility, diversity and polarisation change;
- proof that adequate insurance and liability coverage has been obtained;
- previous operations experience, including unsuccessful operations; and
- the detect and avoid capability (if equipped).

6.202 The same information requirements would logically apply to unmanned spaceplanes.

6.203 While initial sub-orbital operations in the UK are likely to take place within UK airspace only, the intended purpose of some of the unmanned spaceplanes under development would mean that they may cross into the airspace of multiple states. This would therefore involve seeking authorisation from all states involved. The additional planning and administrative requirements involved in obtaining multiple special authorisations, or indeed the possibility that some states may refuse to grant an authorisation, will clearly have an effect on the available routeing options for unmanned spaceplanes – and in particular for future intercontinental very high speed travel.

Air-launched orbital operations

6.204 Air-launched orbital operations involve the use of a carrier aircraft. This will either be a conventional aircraft or a sub-orbital spaceplane.

Conventional aircraft (with an ICAO Certificate of Airworthiness) used as carrier aircraft

6.205 Conventional aircraft that are modified for use as carrier aircraft will be regulated under aviation law. The aircraft should hold an ICAO-compliant Certificate of Airworthiness and operate as public transport, but it may have special conditions attached due to the nature of the operation. These conditions would relate to any specific airworthiness requirements for the launch/release system and any special operational requirements.

Conventional aircraft (no ICAO Certificate of Airworthiness) used as carrier aircraft

6.206 There is the potential for an orbital launch carrier vehicle to be designed and manufactured without a Certificate of Airworthiness. Consequently, it would need to be treated as an experimental aircraft in a similar manner to sub-orbital spaceplanes, ie regulated under the terms of the ANO with exemptions and special conditions.

Sub-orbital spaceplane used as carrier aircraft

6.207 The use of a sub-orbital spaceplane to launch an orbital upper stage – such as launching a satellite into LEO – is being considered by several operators. This has the advantage of launching at a higher speed and altitude than a conventional carrier aircraft, resulting in a smaller upper stage. However, the size of payload may be smaller because of the spaceplane’s limited lift capability.

6.208 Clearly, all regulations applicable to sub-orbital spaceplanes would apply to those used as carrier aircraft for orbital operations.

Orbital vehicle

6.209 The orbital stage of the system is usually a multi-stage expendable launch vehicle. As it will be launched at a high altitude, and is not designed to derive lift from the atmosphere, aviation regulation does not apply. Here the overriding safety priority is still to protect the uninvolved general public, and a suitable regulatory framework for this will need to be found.

6.210 Worldwide there have been relatively few launches of this kind, and most have been regulated by the FAA AST. Its framework is ideally suited to the safety regulation of expendable launch vehicles and is used to regulate both the carrier aircraft and launch vehicle until they separate; once they separate, the carrier aircraft is regulated by the FAA (aviation).

6.211 In the short term, any air-launched orbital operations in the UK are likely to take place under an FAA AST launch licence. The UK Government could choose to accept that the FAA AST licensing requirements for the expendable orbital upper stage are sufficient to protect the UK general public, and therefore a separate air-launched orbital UK regulatory framework is not needed. However, a UK launch licence would still be required.

6.212 In this case, the Review recommends that the UK sign an initially non-binding Memorandum of Co-operation with the FAA AST in order to understand better its licensing process and requirements. This is likely to lead to a more formal and binding Memorandum of Understanding (MoU) in due course. This would have the added benefit of developing UK expertise, which could assist the UK in setting up its own regulatory framework in the longer term.

6.213 It is anticipated that the Outer Space Act 1986 would also apply to any such operations launched by a UK company, meaning that the orbital vehicle will have to be registered as a 'space object' and licensed by the UK Space Agency.

Single-stage to orbit operations

6.214 A single-stage to orbit reusable spaceplane such as SKYLON will probably be a game-changer. Frequent operations into orbit with little 'downtime' should result in true low-cost access to space. A vehicle such as this, however, presents many regulatory and safety challenges.

6.215 For example, such a spaceplane may have the capability to launch from one country, dock with a space asset of another country or commercial organisation, and then land in a third country. Following a short turnaround, it could then begin another mission to another destination, potentially after only a couple of days of maintenance and then integration of the next payload. Accordingly, it would only take a small number of such spaceplanes to bring a level of international operating complexity that would require a regulatory framework as detailed and globally recognised as that of ICAO for aviation.

6.216 Repeated operations will also markedly increase overall exposure to space debris, and may require a unified system of 'space traffic control', with complete tracking, communications and data link capability. A decision would then have to be made about who would be responsible for such a system.

6.217 Coping with the establishment of such a regulatory framework and operational system on the necessary global scale is outside the scope of this Review and would probably fall to an organisation such as the UN or ICAO.

6.218 In the absence of a universal system, one option for the medium term (ie while any operations of such spaceplanes are still at the testing/development stage) would be to apply existing frameworks. For instance, the SKYLON concept fundamentally meets the ICAO definition of an aircraft – albeit a large and complex aircraft. Therefore, EASA civil aircraft certification processes, such as those provided by CS-25 and CS-E, could be applicable, though new requirements may need to be added. At the same time, it is a remotely piloted UAS, so any regulations around UAS would also potentially apply. Finally, if used for the carriage of spaceflight participants or ISS-bound astronauts, it would essentially be a human rated spacecraft, and an organisation such as ESA or NASA should be in a position to assess and help shape the space safety requirements for space certification.

6.219 This indicates that a large body of regulation would apply to a spaceplane such as SKYLON – and in the absence of a single certification process and internationally agreed regulatory framework, that is almost certainly the case. However, given the priority of protecting the uninvolved general public, this would remain necessary until a single framework was developed.

6.220 Such a single framework would provisionally bring together the most appropriate aspects of both aviation and space safety design and construction. It could also help reduce the liability requirements under the Outer Space Act.

6.221 Once the total certification process is understood, the operating requirements can be established, and this would then shape the necessary regulatory framework for the future.

Intercontinental very high speed travel

6.222 As set out in the timeline earlier in this chapter, it is anticipated that in the long term, spaceplanes could be used to provide intercontinental very high speed travel. The capability to operate at hypersonic speeds over long ranges would further 'shrink the globe' and be very attractive to those who regularly travel such distances.

6.223 There are two proposed methods of providing intercontinental very high speed travel, and they pose differing regulatory challenges.

Conventional aviation

6.224 This would involve a largely conventional aeroplane design, operating at hypersonic speeds within the atmosphere and following a conventional aeroplane flight profile. This would appear to be very similar to Concorde but operating at a much higher altitude and speed.

6.225 Regulation would also be possible using principles similar to those that were used to regulate Concorde. EASA commercial air transport regulations would apply, together with certification under CS-25 and CS-E, with special conditions attached to cover novel systems. Operating procedures, Air Traffic Control, aerodrome, airspace and frequency-spectrum requirements would need to be developed once the actual aeroplane characteristics are known.

Using a spaceplane

6.226 Several spaceplane operators have stated their intention to develop spaceplanes that could be used for intercontinental very high speed travel at a sub-orbital trajectory.

6.227 There are, however, potential issues with this approach. For example, the experience of being a 'passenger' on such an operation would be totally unlike conventional aviation. The high G climb, microgravity coast and high G re-entry would be the same as for spaceflight experience, and so such an operation may not be appropriate for regular mass-market travel. If this does become possible, a regulatory framework would need to be established.

6.228 Such a framework could mirror that used for spaceflight experience; however, this would not be appropriate for the carriage of normal 'passengers', particularly across international boundaries. Therefore such an operation should also comply with normal aviation legislation and use a spaceplane that has undergone an internationally accepted certification process.

6.229 Such a certification process could be developed in the medium term, as outlined in Chapter 7. Again operating procedures, Air Traffic Control, aerodrome, airspace and frequency-spectrum requirements would need to be developed once the actual spaceplane characteristics are known.

Recommendations

6.230 This chapter has made the following high-level and further recommendations.

- In order for sub-orbital spaceplane operations to take place from the UK by 2018 or earlier, a permissive regulatory framework needs to be established and be functioning at least one year in advance of planned operations. (*Recommendation 5 in summary report*)
- In order to allow spaceplane operations from the UK by 2018 or earlier, the Government must accept that spaceplane operations carry a higher degree of risk than most normal aviation activities, and that protecting the uninvolved general public should be its highest safety priority. (*Recommendation 4 in summary report*)
- Due to the risk of being out of step with future EU regulation and the UK legal view that spaceplanes are aircraft, the UK should not apply the FAA AST system as a whole for the regulation of commercial sub-orbital spaceplane operations.
- To ensure the safety of the uninvolved general public, and provide a single, clear regulatory framework for spaceplane and spaceflight operators, the Government should appoint a single competent authority for the safety regulation of all spaceflight operations. (*Recommendation 8 in summary report*)
- To further develop the regulatory framework, and help mitigate the risks to the uninvolved general public and spaceplane flight crew and participants, the Government should task the CAA with the detailed assessment of risks, and development of appropriate exemptions and special conditions to the ANO for sub-orbital spaceplanes. (*Recommendation 6 in summary report*)

- All spaceplane operators should be required to identify a person within their organisation who holds responsibility for the co-ordination of their safety management system.
- The Government should task the Air Accidents Investigation Branch of the Department for Transport with the investigation of any accidents or serious incidents involving sub-orbital spaceplanes.

CHAPTER 7
Airworthiness

This chapter considers the challenges of confirming the airworthiness of spaceplanes. It provides an overview of how airworthiness is assessed, globally, within aviation and how different states have, to date, sought to assess the airworthiness of space vehicles. It acknowledges the practical and commercial difficulties in certifying spaceplanes and recommends that a safety management system approach, covering design, manufacture and operation, be adopted in the short term. This could be replaced by certification codes and specifications in the longer term.

Introduction

7.1 A vital element of safe operations is ensuring that each spaceplane is airworthy whenever it is flown – ie that it is designed, manufactured and maintained to be fit for its intended purpose at all times.

7.2 In commercial aviation, airworthiness assurance is founded on certification of the aircraft, and approval of the organisations that work on it, through the licensing of their personnel and approval of their processes. It requires the aircraft and organisations to meet various standards that embody the lessons of significant experience in securing airworthy operations.

7.3 As spaceplane operations develop, such an approach will become as appropriate as it is to today’s commercial aircraft operations. However, spaceplane operations are still in their infancy, and the standards expected of commercial aircraft are not fully compatible with spaceplane technology. An alternative approach is therefore needed. This Review advocates that such an approach be based on direct systematic management of the safety of the spaceplane by those who operate it.

Scope

7.4 The scope of this section of the Review is to look at the background to existing airworthiness certification principles for fixed-wing aircraft,[134] and to assess the most appropriate regulatory regime for the airworthiness oversight of spaceplane operations in both the short and the longer terms.

7.5 It does not cover other aspects of aircraft certification (eg noise certification) and their applicability to spaceplanes. Environmental issues, including noise, are considered in Chapter 10.

---

[134] There are separate airworthiness requirements for rotorcraft, but as no proposed spaceplane design is based on rotorcraft, these are not considered here.

Background to airworthiness requirements and the ICAO Annex 8 Certificate of Airworthiness

7.6 When aviation was in its infancy, much as commercial space transport is today, it was recognised that the activity would transcend national borders. As international travel became more widespread, it became necessary to formalise the procedures for ensuring that aircraft meet certain minimum airworthiness standards that are acceptable to all countries.

7.7 The organisation responsible for this international agreement is the International Civil Aviation Organization (ICAO). ICAO's airworthiness standards are defined in Annex 8 to the Convention on International Civil Aviation.[135]

7.8 A Certificate of Airworthiness provides globally accepted confirmation that an aircraft meets ICAO airworthiness standards.

7.9 In order to qualify for this, a new design must be shown to comply with an individual state's code of airworthiness requirements – which itself must be compliant with Annex 8. This qualification process is called 'type certification', and it has become an internationally agreed process, intended to ensure a high level of manufacturing and operational integrity in design, development and production.

7.10 In addition to type certification, the aircraft must be manufactured to certain established standards, to ensure that every production aircraft conforms to the standards established by the type-certificated prototype(s). The way that countries generally maintain these standards is through design and manufacturing approvals – literally approving the organisations involved in carrying out aircraft design and manufacture.

7.11 Finally, aircraft in service must be supported by an organisation with sufficient knowledge and expertise to maintain the levels of airworthiness established by the type certification. This is referred to as 'continued airworthiness' and is an important part of the system of airworthiness management, as it ensures that the airworthiness standards established during aircraft certification are maintained throughout the life of the aircraft. Without type certification, no such references would exist.

7.12 These principles apply to all aircraft with ICAO Annex 8 Certificates of Airworthiness, from small light aircraft to large transport aircraft, such as the Airbus A380. The only differences are of scale.

---

[135] ICAO – *Annex 8 to the Convention on Civil Aviation*. Montreal, ICAO. Available to order from www.icao.int

Legal context for airworthiness certification and flexibility in requirements

7.13 Across the entire EU, the UK included, airworthiness certification is predominantly managed through the European Aviation Safety Agency (EASA), which since 2003 has been responsible for the airworthiness and environmental certification of all aeronautical products, parts and appliances designed, manufactured, maintained or used by persons under the regulatory oversight of EU Member States.

7.14 The Civil Aviation Authority (CAA) has the power to regulate aircraft that are not covered by EASA regulations, and thus has a legal duty to be satisfied that all aircraft under its jurisdiction are airworthy and safe to operate.

7.15 However, the **criteria** on which the CAA establishes satisfaction – ie the certification requirements it sets – are not written in law. Failure to comply with these requirements does not constitute a criminal offence; the only consequence is that the approval or certificate cannot be issued. The CAA is thus free to specify alternative requirements, such as special conditions or alternative means of compliance, to suit the particular application.

7.16 This is of particular relevance to spaceplanes, not only because most designs are still untested within their operating environment, but also on account of the considerable differences in design and intended flight profile. Therefore, it may be appropriate for spaceplane airworthiness requirements to be made modular, so that parts of the code could be selected or deselected, according to their relevance to a particular type of spaceplane.

Organisational approval in the UK/EU

7.17 As well as certification of the aircraft themselves, today's accepted international approach to civil airworthiness oversight also includes the formal approval of the design and production organisations that manufacture them. For UK oversight, the legal framework for achieving this is specified in section A of the British Civil Airworthiness Requirements,[136] and, for organisations that come under EASA's responsibility, in Commission Regulation (EU) No. 748/2012.[137]

Other forms of airworthiness approval

7.18 Aircraft that do not qualify for ICAO Annex 8 Certificates of Airworthiness may qualify for another form of airworthiness approval, and in Europe this is the Permit to Fly.

---

[136] CAA (2013) *BCAR Section A: Airworthiness Procedures where the CAA has primary responsibility for type approval of the product*, CAP 553, www.caa.co.uk/application.aspx?catid=33&pagetype=65&appid=11&mode=detail&id=220 (accessed 7 May 2014)

[137] See http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:224:0001:0085:EN:PDF (accessed 7 May 2014)

7.19 Most countries use a lesser form of Certificate of Airworthiness such as this, but the pivotal aspect of them is that they are, in general, only valid within the airspace of the issuing country.[138]

7.20 The Permit to Fly does not have the same privileges as an ICAO Annex 8 Certificate of Airworthiness. In the UK, the additional limitations mean that aircraft with a Permit to Fly:

- can typically only operate during daylight and under visual meteorological conditions (VMC);[139]
- are not allowed to fly over built-up areas; and
- cannot be used for public transport or aerial work.

7.21 There are, however, important advantages to the Permit to Fly system, most notably the fact that it allows maintenance to be carried out by non-approved organisations or personnel, although it must be signed off by a suitably qualified inspector.

7.22 Depending upon the manufacturing organisation process and the number of aircraft produced, aircraft operating under the Permit to Fly system can be treated as prototypes or as series production aircraft. Where production rates are low, there can be substantial differences between individual aircraft, even if they are built to an established design; and so the prototype approach is justified. As rates increase, but still remain small in the overall context, aircraft can be treated as series production aircraft, but still only qualify for Permits to Fly because of their certification basis.

How airworthiness requirements have developed

7.23 The conventional approach to drafting aircraft airworthiness requirements starts with defining the required level of safety. This is measured as the probability of a fatal accident being directly attributable to an airworthiness cause. From this, it is possible to assign numerical values to the safety margins that would secure the required level of safety; designs must then meet or exceed these safety margins to obtain airworthiness certification.

7.24 The simplest approach would naturally be to set a very high level of safety across all aircraft, through the use of high safety margins. However, such requirements would be costly to comply with and would potentially inhibit the development of lower-cost aircraft. Therefore, certification requirements are based on establishing a rational balance between stringency (safety) and cost of

---

[138] There are some exceptions to this. See CAA (2014) *Mandatory Requirements for Airworthiness*, CAP 747, www.caa.co.uk/application.aspx?catid=33&pagetype=65&appid=11&mode=detail&id=6098 (accessed 7 May 2014)

[139] These are defined as conditions in which visual flight rules (VFR) operations are permitted – in other words, conditions in which pilots have sufficient visibility to fly their aircraft safely.

compliance. As technology and knowledge improve over time, so improvements in safety become technically feasible and commercially cost-effective, and it becomes possible to prescribe higher levels of safety through progressive revisions to the requirements.

7.25 This rulemaking activity has been conducted nationally by individual states (eg the UK) or across a number of states (eg by EASA). It is important to note that while national requirements leading to type certification would only be valid in an individual state, EASA rulemaking would bring further commercial benefits for operators and manufacturers that hold a pan-European type certificate. The requirements may be no higher, but the commercial market is much larger.

7.26 In recent years, the process of rulemaking has evolved, and industry plays a much more proactive role in developing technical requirements in conjunction with regulatory authorities. This has helped to develop requirements that deliver the appropriate level of safety and are commercially and technically achievable in a more efficient fashion.

Harmonisation of airworthiness requirements

Airworthiness code development was historically undertaken independently by various contracting ICAO states with aircraft or engine manufacturers under their jurisdiction. Although this led to ICAO Annex 8-compliant aircraft certifications, there were inevitable differences in certification standards between states, and so to approve an aircraft in another country sometimes meant lengthy and costly re-certification to the airworthiness code of the importing state. To avoid this additional burden, there has been a determined effort over the past 40 years or so to harmonise airworthiness requirements between states and thus drive down the costs of additional certification between countries.

In Europe, this started with the formation of the Joint Aviation Authorities (JAA) in 1970. Originally its objectives were only to produce common airworthiness certification codes for large aeroplanes and for engines. This was in order to meet the needs of European industry – particularly for products manufactured by international consortia, such as Airbus. From 1987, its remit extended to operations, maintenance, licensing and certification/design standards for all classes of aircraft. As well as introducing harmonisation within Europe, the JAA also sought to work with US and Canadian industry and authorities to harmonise various codes too, thus reducing intercontinental barriers within the industry.

In 2002, a new regulatory framework was created by the European Parliament and the Council of the European Union through the formation of EASA. Subsequently, in September 2003, this Agency took over responsibility for airworthiness and environmental certification across the EU. As such, products so approved are universally accepted by each Member State without further investigation.

Overview of current aircraft certification requirements

7.27 As set out above, airworthiness certification is based on a balance between stringency and cost of compliance, with different codes applied internationally to different classes of aircraft. The relevant code is determined in relation to the aircraft's size in terms of passenger capacity and weight. This in turn determines the intended level of safety that will be required in service: the larger or more complex a craft, the higher the degree of airworthiness assurance required.

7.28 For the majority of aircraft types operated today in the UK, airworthiness standards are defined by EASA's certification specifications.[140] Compliance with one of these leads to an EASA type certificate being issued. With increasing weight and payload capacity come more demanding requirements of airworthiness stringency.

7.29 For smaller aircraft, Certification Specification (CS)-23 addresses the certification of normal, utility, aerobatic and commuter aeroplanes.[141] To qualify for certification, normal, utility and aerobatic aeroplanes are limited to a maximum take-off weight of 5,670 kilograms and nine passengers, and may be single-engined. Commuter aeroplanes must be multi-engined; they have an upper weight limit of 8,670 kilograms and can carry up to 19 passengers. Because of their increased size, commuter aircraft have a commensurately higher level of intended safety.

7.30 At the upper end of the range, there are multi-engined 'large aeroplanes' which are certificated under CS-25 but are not limited to a maximum take-off weight (MTOW) or passenger capacity.[142] This standard is appropriate for projects such as SKYLON, which is proposing an MTOW of 325,000 kilograms.

7.31 A crucial factor in the certification of large aeroplanes is that a forced landing should not be necessary if an engine fails during flight. This is specifically required in ICAO Annex 8. Commuter aeroplanes are expected to achieve a similar, though slightly reduced, standard of safety, but should nevertheless be able to meet the same performance standard. Although these aircraft are thus expected to have a continued flight capability following engine failure, this does not necessarily mean that they can complete the flight as originally planned. (Diversion to an alternative aerodrome is normally assumed.) Small, twin-engined aeroplanes, on the other hand, certificated in accordance with CS-23, have a performance level such that a forced landing may be necessary following engine failure.

7.32 Lastly, aircraft certification requirements dictate the use of certificated, type-approved engines. For EASA certification, this would require the use of the CS-E

---

[140] See http://easa.europa.eu/document-library/certification-specifications (accessed 7 May 2014)

[141] EASA (2012) *Certification Specifications for Normal, Utility, Aerobatic, and Commuter Category Aeroplanes*, CS-23, Amendment 3, http://easa.europa.eu/system/files/dfu/CS-23%20Amdt%203.pdf (accessed 7 May 2014)

[142] EASA (2013) *Certification Specifications and Acceptable Means of Compliance for Large Aeroplanes*, CS-25, Amendment 14, http://easa.europa.eu/system/files/dfu/2013-033-R-Annex%20to%20ED%20Decision%202013-033-R.pdf (accessed 7 May 2014)

specification.[143] The engine installations and their effects on the airframe are subject to further review as part of the aircraft certification process.

7.33 For fixed-wing aeroplanes, both CS-23 and CS-25 contain safety analysis requirements which define the safety objective to ensure an acceptable safety level for equipment and systems as installed on the aeroplane (paragraphs CS-23.1309 and CS-25.1309, respectively). A logical and acceptable inverse relationship must exist between the probability of occurrence and the severity of the effect. In other words, the more severe a failure would be, the less likely it must be to happen – and the greater the responsibility on the aircraft manufacturer/operator to demonstrate that its systems will be safe.

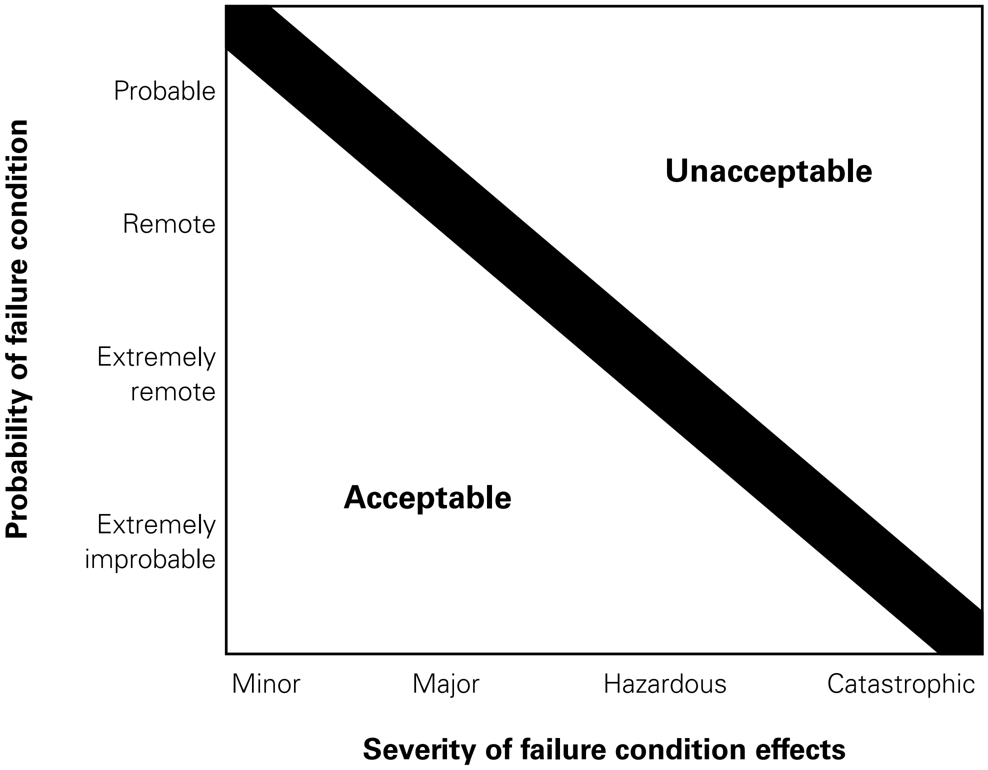


Figure 7.1: The relationship between probability and severity

7.34 This relationship between probability and severity is generic and is applicable to a wide range of certification applications. It would be equally applicable to spaceplane operations.

---

[143] EASA (2010) *Certification Specifications for Engines*, CS-E, Amendment 3, http://easa.europa.eu/system/files/dfu/CS-E_Amendment%203.pdf (accessed 7 May 2014)

Overview of current space industry regulations

7.35 Just as ICAO is the UN agency responsible for the conventional aircraft international certification framework, so the United Nations Office for Outer Space Affairs (UNOOSA) is responsible for promoting international co-operation in the peaceful uses of outer space.

7.36 UNOOSA serves as the secretariat for the General Assembly's only committee that deals exclusively with international co-operation in the peaceful uses of outer space. It was established in 1962 and maintains a Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space (the 'Outer Space Treaty').[144] The following 19 states have notified UNOOSA of their various national space laws: Argentina, Australia, Belgium, Canada, Chile, China, France, Germany, Japan, Kazakhstan, the Netherlands, Norway, Republic of Korea, Russian Federation, South Africa, Spain, Sweden, Ukraine and the United Kingdom.

7.37 The Outer Space Treaty provides the basic framework on international space law, and specifies that states shall be responsible for national space activities, whether carried out by governmental or non-governmental entities. Consequently, each state undertaking space operations has its own approach to regulatory oversight: there are no international standards as such and no harmonisation of the various approaches taken.

7.38 Nevertheless, as will be seen from the following brief overview of the more relevant and significant overseas systems, all seem to take the broadly similar approach that the national framework should encourage and promote spaceplane operations, while mitigating as far as possible any risks to public safety, property and national interests.

US

7.39 In the US, oversight is governed by the Federal Aviation Administration Office of Commercial Space Transportation (FAA AST). Its mission is to protect the public, property, and the national security and foreign policy interests of the US during commercial launch or re-entry activities, and to encourage, facilitate and promote US commercial space transportation.

7.40 As was discussed in Chapter 6, the FAA AST requirements do not comply with any international standards and they are not designed for regular, ongoing operations using the same vehicle (as airworthiness certification fundamentally is). There are two types of reusable launch licences – vehicle licences and operator licences. A vehicle licence authorises one or more launches of one model or type of reusable launch vehicle (RLV) from launch sites approved for

---

[144] Full details of this treaty can be found at www.unoosa.org/oosa/en/SpaceLaw/treaties.html (accessed 3 March 2014)

the mission. An operator licence authorises a series of missions of a designated family of RLVs within authorised parameters, including launch sites and trajectories, transporting specified classes of payloads to any re-entry site or other location designated in the licence.

7.41 Airworthiness is effectively considered within the licensing process, inasmuch as the FAA AST will not issue either a vehicle or an operator licence without assessing the safety of the vehicle for its mission. This is discussed in more detail in paragraphs 7.68–7.77 below.

France

7.42 Founded in 1961, the Centre National d'Études Spatiales (CNES) is the government agency responsible for shaping and implementing France's space policy. On 23 May 2008, the French parliament passed a new act covering space operations. To accommodate the arrival of operators from the private sector, a new legal framework translated into French law the provisions of international treaties and accords ratified since the late 1960s.

7.43 The French system establishes the appropriate legal safeguards for public and private players in space. Its chief objective is to ensure that the technical risks associated with space activities are properly mitigated, without compromising private contractors' competitiveness.

Australia

7.44 Likewise, the Australian model, through its Space Licensing and Safety Office implements the regulatory and safety regime for space activities in Australia and by Australians overseas. It ensures that civil space activities do not jeopardise public safety, property, the environment, Australia's national security, foreign policy or other international obligations.

Challenges around airworthiness certification of spaceplanes

Description of vehicles

7.45 One of the challenges of ensuring the airworthiness of spaceplanes is the wide variety of configurations under consideration. For example, the two most advanced projects, both from the US, use different launch concepts.

- Virgin Galactic utilises a specially designed carrier aircraft to carry the rocket-powered spaceplane to high altitude before releasing the spaceplane to begin its rocket-powered ascent to space. Its spaceplane SpaceShipTwo will feature a novel tail 'feathering' system as the primary control of the vehicle's speed and angle of descent during re-entry to the Earth's atmosphere. This provides an automatically stabilised re-entry capability that does not require any pilot input.

- XCOR Aerospace uses a much smaller spaceplane, which takes off from a runway in conventional aircraft manner, before ascending to space. It relies on its own fully reusable rocket propulsion system and a more conventional (for a space vehicle) reaction control system based on jets of hot-fired gas to enable the pilot to control manually the re-entry into the atmosphere.

7.46 Both of these vehicles use reasonably conventional reusable rocket engines for their propulsion systems.

7.47 In the future, a British project – SKYLON – intends to use an air-breathing rocket for its propulsion system, while taking off from a runway, rather than using a carrier aircraft. Airbus Defence and Space, meanwhile, is developing a spaceplane to be powered by two turbojet engines for normal flight and a rocket engine for the sub-orbital trajectory.[145]

7.48 Though there will be some areas of commonality between the designs, it is clear that a uniform assessment of airworthiness will be highly complex.

Assessing spaceplane-specific technologies

7.49 While many technologies employed in spaceplane designs (such as composite structures, advanced alloys, electrically signalled aerodynamic flying controls, electronic instrument displays) are used conventionally in civil aviation, there are some spaceplane technologies – notably rocket-based propulsion systems – which, on account of their current levels of reliability and failure modes, do not lend themselves to being assessed and approved according to current civil aviation regulatory practice. Practices can be developed to accommodate them, but this will take time. In the short term, an alternative means of determining airworthiness assurance is required, and this will still need to cover the same areas of concern.

Rocket powerplant

7.50 The biggest engineering challenge to airworthiness comes from the rocket powerplant, as this is a novel feature for civil and commercial aircraft application. Rocket-powered aircraft have been developed for sporting purposes, notably by XCOR Aerospace.

7.51 The existing EASA engine Certification Specification CS-E caters for engine failure modes which are ‘hazardous’. However, the probabilities of failure built into the CS-E code at present are based upon many years of experience – and millions of hours of operation – with gas turbines of conventional design. This experience and the criteria within the specification can be applied by manufacturers to meet these requirements, but these would not be applicable for a radically new rocket engine. In fact, the failure rates of modern turbine

---

[145] More details of these operators, including images, can be found in Chapter 2.

engines are now so low that it is statistically unlikely that any individual aircraft will experience an engine failure during its service life.

7.52 An important principle of CS-E certification is that engine failure cannot have automatically catastrophic consequences for the aircraft. There are various measures which can be taken at the aircraft design level, such as separation of essential services, to ensure that this is the case; but for typical spaceplane powerplant applications it is evident that the propulsion system has been the major contributor to catastrophic failure up to now. This indicates that the principle would be difficult to realise for spaceplanes.

7.53 The definition of 'critical parts' (ie those whose failure could prevent continued safe flight and landing, or which would result in reduced safety margins, degraded performance, or loss of capability to conduct certain flight operations) would probably have to evolve, and acceptable failure rates would have to be agreed. These rates would be dependent on an acceptable loss rate for the overall vehicle, which would also have to be agreed.

7.54 Furthermore, the guidance material associated with the CS-E safety analysis requirements states that engine failures involving complete loss of thrust or power can be expected to occur in service, and that an aircraft should be capable of controlled flight following such an event.[146] For the purpose of the engine safety analysis and engine certification, engine failure with no external effect other than loss of thrust and services is regarded as a failure with a 'minor' effect. This assumes that either:

- there is sufficient thrust available from the other engines to allow continued safe flight and landing; or
- for single-engined aircraft the crew training, flight conditions (eg daylight, visual flight rules (VFR)), crew procedures and/or ability to carry out a forced landing are such that the craft can be landed safely.

7.55 Thus a 'minor effect' is one which can be expected to occur several times in an individual aircraft's service life. It would not significantly reduce aeroplane safety, and would require additional actions by the crew that are well within their capabilities. In practice, however, the standards now achieved by aircraft powerplant are such that certification authorities would be concerned about engine reliability at this rate; operators would almost certainly not tolerate higher failure rates because of the commercial impact. Hence engine reliability standards for aviation are, in all probability, higher than those mandated in the EASA specification.

---

[146] EASA (2010) *Certification Specifications for Engines*, CS-E, section 510, Safety analysis, http://easa.europa.eu/system/files/dfu/CS-E_Amendment%203.pdf (accessed 7 May 2014)

7.56 Most aircraft used for public transport have multiple turbine engines. This means that they have genuine redundancy and can be flown safely even if one engine is out of operation.

7.57 For a spaceplane, if multiple rocket engines are required to deliver the thrust necessary for a given trajectory, and loss of one engine means that the trajectory is no longer achievable, then these assumptions may no longer apply. In such cases, a higher level of reliability might be necessary than that implied by the CS-E regulations.

7.58 On the other hand, rocket technology is reasonably well understood, as many rockets have been developed for military use and for the exploration of space. The biggest challenge with rocket engines has been their reliability: they operate close to the limits of materials technology and other technical knowledge, such as thermodynamics, fluid mechanics and acoustics.

7.59 To address rocket engines fully within regulation, significant amendments to CS-E requirements would be needed. As an example, section CS-E 740 sets out a test for engine endurance, which is based on simulating repetitive flight cycles. For a spaceplane, this would mean testing both the air-breathing and the non-air-breathing part – a complex and costly process. Part of the test would logically require demonstrating repeated burns in liquid oxygen fuel mode for a period of time, simulating typical flights. However, CS-E does not yet cater for non-air-breathing powerplants, meaning that this aspect would have to be comprehensively covered.

7.60 Similarly for vibration surveys – set out under section CS-E 650 – it would be necessary to include the combustion chambers used for the rocket part of the mission, to ensure that any vibration in the combustion chambers is acceptable: it is known that vibration destroyed a number of early rockets. Special conditions would again probably be needed.

Reaction control systems

7.61 Another novel design feature that would have to be addressed is the use of reaction control systems (RCS). These have not yet been used in civil aviation, though they are used on some military aircraft such as the Harrier and the F-35. Therefore they are not fully covered by existing certification specifications.

7.62 It is understood that in the Harrier, the RCS was treated as a primary flying control and was designed to offer a similar ‘feel’ to that of civil flying controls, inasmuch as it is similar to the cyclic control of a helicopter. It is understood that experience of the system has been excellent. Though spaceplane RCS are likely to use either a mono-propellant or bi-propellant system (whereas the Harrier system used hot-air engine bleeds), it would seem prudent to require spaceplane RCS to achieve a similar level of reliability to that achieved by the Harrier RCS. The only other consideration would be whether each thruster element of the reaction control system should be treated as an engine or a flight control system.

Flight controls

7.63 Possibly the most hazardous part of any spaceflight is the re-entry to the Earth's atmosphere and maintaining stability and control. As stated above, there are different approaches to this currently being proposed.

7.64 Virgin Galactic intends to use a novel 'feathering' mechanism for SpaceShipTwo. The tail of the vehicle rotates to a position roughly 65 degrees to the vehicle's horizontal fuselage datum: this enables the vehicle to behave like a 'shuttlecock' on encountering the air, ensuring the correct orientation of the vehicle and enabling it to cope with the loads and heating of the airflow around the vehicle at hypersonic speed.

7.65 XCOR Aerospace will initially use reaction controls on its Lynx spaceplane, supported by aerodynamic controls as these become effective. These altitude control features are critical to the success of any flight beyond the atmosphere. Therefore the systems, including the flight control systems used to blend reaction control and aerodynamic control together, would need to have a failure rate of 10^{-7} and 10^{-8} per flight hour to be satisfactory.

7.66 A more general challenge for any spaceplane concept involving a carrier aircraft is the difficulty of achieving a clean separation of the two. Military experience shows that the clean separation of 'stores' (bombs, missiles etc) from a launch aircraft needs careful assessment. The carrier aircraft/spaceplane combination will need to be evaluated thoroughly, especially with regard to the emergency procedures to be used if a release is not achieved as intended. While both CS-23 and CS-25 contain requirements that aircraft must be able to make a smooth transition from one flight condition to any other flight condition without exceptional piloting skill, alertness or strength, the specifications may need to be expanded to cover this issue.

7.67 The issues considered above represent significant challenges for the development of appropriate airworthiness assessment for spaceplanes.

How airworthiness is assessed within the FAA AST system

7.68 As was noted earlier, while there is no internationally harmonised framework of international spaceplane operations, individual states have developed their own space operations frameworks. All have taken a similar approach, in that their regulations fundamentally seek to protect the uninvolved general public, as well as property and national security and foreign policy interests. At the same time, all seek to encourage and facilitate commercial space operations.

7.69 The most advanced space operations framework is that applied in the US. Given that those spaceplane operators expected to commence operations in the UK in the short term are all US-based, it is proposed that the UK should align itself with the US regulatory philosophy for initial airworthiness assurance. This will provide a practical way forward.

7.70 As was explained in Chapter 6, the FAA AST system recognises that space transport is inherently less safe than conventional air travel, and the future of the commercial human spaceflight industry will depend on its ability to improve its safety performance incrementally. In the meantime, the public interest is served by creating a clear legal, regulatory and safety regime for commercial human spaceflight; the regulatory standards governing human spaceflight must evolve as the industry matures, so that regulations neither stifle technology development nor expose crew or spaceflight participants to avoidable risks.

7.71 Thus the FAA AST requirements have purposely been established to encourage innovation in commercial space operations. This allows the industry to design, build and experiment while under a regime that does not have the more stringent requirements of civil aviation. This approach has been collectively agreed by all involved – the regulators, representative groups, bodies and industry, together with the federal government – and it has a very clear and common focus.

7.72 An important part of the FAA AST safety assessment of the spaceplane is that the applicant uses a System Safety Process to identify the hazards and to assess the risks to the uninvolved general public and the safety of property associated with all aspects of the mission, including normal and abnormal operation and flight of the vehicle and payload. Such a system of safety analysis identifies and assesses the probability and consequences of any reasonably foreseeable hazardous event and of any safety-critical system failures that could occur, and focuses on the consequential risk to the public.

7.73 To do this, it defines an acceptable risk in terms of the expected average number of third party casualties for an individual mission. This is set at a quantitative value of 0.00003 (30×10^{-6}) casualties per mission to the public, together with the risk to an individual of 0.000001 (1×10^{-6}). This establishment of a target level of safety is consistent with the approach for the development of certification requirements, described earlier: the important differences here are that the FAA AST is concerned with the third party risk only, and the aircraft certification target safety rates are defined in terms of fatal accident rates per flight hour.

7.74 The System Safety Process review includes identifying all safety-critical systems, conducting a hazard analysis and risk assessment, and performing a validation and verification (V&V) analysis. The safety V&V process is intended to determine that the correct safety-critical system is being built (validation) and that the design solution has met all the safety-critical requirements (verification).

7.75 The verification process produces tangible evidence that the design meets the safety requirements. There are four conventional verification methods by which safety requirements are shown to have been met: analysis, test, demonstration and inspection. These are all methods which are considered 'acceptable', as used in aircraft certification procedures today.

7.76 It is likely that in the short term, spaceplane operations in the UK will involve spaceplanes designed and manufactured in the US, operating under a wet lease type arrangement. This would mean that they require an FAA AST launch licence.

7.77 Given that the application process for an FAA AST launch licence includes assessments of safety standards and operating procedures, the most appropriate way to assess airworthiness in the short term may be to develop a methodology that verifies the FAA AST assessments. This methodology would need to be based on a deeper understanding of the FAA AST process and, specifically, the extent to which occupants and third parties are protected from an accident or serious incident occurring, and the extent to which the effects of a vehicle failure or break-up are mitigated.

Recommendation
Work should be commissioned to develop, within the airworthiness assessment approach, a methodology for giving due recognition to FAA AST licensing system assessments.

7.78 However, there is a challenge with this approach. As was discussed in Chapter 4, US export controls limit the amount of information that can be obtained by UK regulators about the FAA AST licensing process, and in particular the safety performance of the spaceplanes themselves. Therefore, as part of discussions around export controls and their applicability to commercial spaceplane operations, it will be important to agree a means of gaining greater insight into the assessments made by FAA AST.

Recommendation
In order to obtain a better understanding of the FAA AST licensing process and the safety performance of any US sub-orbital spaceplanes that are likely to operate in the UK, the Department for Transport should sign a Memorandum of Understanding with the FAA AST.

The case for a safety management system approach to airworthiness assessment

7.79 At the time of writing, any airworthiness assessment of spaceplanes which are already in development could only be against the existing certification specification codes, in particular CS-23 or CS-25 and CS-E.

7.80 These existing codes may be appropriate for the spaceplane carrier aircraft (albeit with additional criteria peculiar to the spaceplane carriage and release aspects), since these are classified as aircraft.[147] However, based on information about designs viewed to date, the codes are not suitable to cater for the spaceplane vehicle itself. For these, although CS-23 may be appropriate as regards the size and capacity of smaller spaceplanes under consideration, the level of safety expectations may be more closely aligned to that provided by CS-25, particularly where paying participants are involved.

7.81 Ultimately, however, no existing certification specification is truly suitable for application to spaceplane technology at the moment. Instead, for spaceplanes under development at the time of writing, a pragmatic approach to airworthiness approval needs to be found.

Airworthiness assessment under an Experimental Permit to Fly

7.82 A consequence of this absence of an available certification basis for spaceplanes is that the conventional Certificate of Airworthiness will not be an available option. It has already been seen that there are 'lesser' forms of permission available, such as the Permit to Fly concept, which is already an internationally recognised means of approval. It is proposed to take this a stage further for initial spaceplane operations, by recognising that these are still very much at the experimental stage of their operational development. In accordance with the EASA Basic Regulation, this renders them a national responsibility.

7.83 To secure safe initial UK operations, it is therefore recommended in Chapter 5 that sub-orbital spaceplanes are classified as 'experimental aircraft' and are regulated at a national level, through suitable amendments to the UK Air Navigation Order (ANO). It is envisaged that such spaceplanes would be issued with an Experimental Permit to Fly on the basis of an airworthiness assurance gained from oversight of the combined operator/manufacturer organisational arrangements that will need to be in place.

7.84 The issue of an Experimental Permit to Fly in the UK would not be based on the same criteria as the issue of an experimental permit under the FAA AST system. The FAA AST system utilises an experimental permit concept for a limited scope of activities, namely:

---

[147] As set out in Chapter 5, spaceplanes meet the ICAO definition of an aircraft: 'any machine that can derive support in the atmosphere from the reactions of the air other than the reactions of the air against the earth's surface.'

- for research and development;
- to show compliance to obtain an operating licence; or
- for crew training purposes.

7.85 The carriage of property or human beings for compensation or hire is prohibited under an FAA AST experimental permit. A launch licence is required for this, and additional flight requirements are applicable.

The safety management system approach

7.86 It is apparent that initial sub-orbital operations are being undertaken by operators who:

- have commissioned a bespoke spaceplane design; and
- will remain intimately engaged throughout the design and production process.

7.87 Therefore, it is considered entirely possible for the operator to develop the knowledge, and have access to the data, necessary to assess competently and fully the risks to its operation, as required for FAA AST licensing. Such an operator should, therefore, be capable of including the management of such risks within a formalised safety management system (SMS) approach and should be afforded the opportunity to do so, as an alternative to being required to follow the commercial aviation airworthiness assurance process. This approach is considered appropriate and manageable for the airworthiness oversight and approval of spaceplanes produced in small numbers.

7.88 This approach lends itself to the situation that exists, for example, between the spaceplane operator Virgin Galactic and its spaceplane design and production organisations, Scaled Composites and The Spaceship Company. Recognising that Virgin Galactic's aircraft are essentially being designed and manufactured in small numbers for its sole use, it is envisaged that a holistic SMS, covering the initial, continued and continuing airworthiness, could be established by the operator. Virgin Galactic has been working very closely with Scaled Composites and is well placed to gain access to the necessary compliance information that any regulator would normally require as part of a conventional certification.

7.89 Such a system would then be used by the operator to manage the airworthiness risks of its spaceplane operations and to demonstrate the required level of safety to the CAA (or other competent authority).

Recommendation

In the short term, spaceplanes currently under development should be regulated in the UK in accordance with an overall safety management system framework, to be specified by the CAA and managed by the operator.

7.90 Safety management is an organisational function, which ensures that all safety risks have been identified, assessed and satisfactorily mitigated. Safety management applies a set of principles, a framework, processes and measures to prevent accidents, injuries and other adverse consequences. It exists to assist in the design of the operational system and its implementation either through the prediction of deficiencies before errors occur, or through the identification and correction of the system's deficiencies by analysis of safety occurrences.

7.91 Safety management implies a systematic approach to safety, including the necessary organisational structure, accountabilities, policies and procedures.

7.92 Application of such an approach would be cost-effective, without being overly burdensome for spaceplanes, as the approach is firmly based within the civil aviation safety system.

7.93 However, to assure not only regulators, but also participants and the uninvolved general public, it is imperative that spaceplanes currently under development should be required (and seen to be required) to achieve the highest level of safety that is **reasonably** practical, through the application of an SMS approach.

7.94 That would mean following industry best practices, working to existing civil aviation requirements as far as possible, and ensuring that the manufacture and maintenance of spaceplanes is of a high standard. This approach applies to both manned and unmanned spaceplanes.

Recommendation

Spaceplanes currently under development should be required (and seen to be required) to achieve the highest level of safety that is reasonably practical.

Quality management and safety management

There are clear parallels between this proposed SMS and existing quality management systems (QMS). An operator or manufacturer's QMS is focused on compliance with prescriptive regulations and requirements to meet customer expectations and contractual obligations, while an SMS is focused on safety performance. The objectives of an SMS are to identify safety-related hazards, assess the associated risk and implement effective risk controls. In contrast, a QMS focuses on the consistent delivery of products and services that meet relevant specifications.

Both systems use similar risk management and assurance processes. This is a further reason why it is believed that introducing a requirement for operators to manage airworthiness through an SMS would not be too onerous.

Carriage of participants: informed consent

7.95 As was stated above, spaceplane operations should be required (and be seen to be required) to achieve the highest level of safety that is reasonably practical. Within this there is implicit acknowledgement that, although operators should be required to implement all the best practices of the industry, work to existing requirements as far as possible, and ensure that their spaceplanes are manufactured and maintained to a high standard, spaceplanes will **not** be able to deliver the level of safety that the public have come to expect from conventional aviation.

7.96 This is one of the reasons why it has been recommended, in Chapter 5, to apply the principle of informed consent to permit the carriage of participants and cargo on sub-orbital spaceplanes. As part of the process of seeking informed consent, it will be essential to articulate the fact that spaceplanes have not attained airworthiness certification under international standards, and to explain the approach taken to assessing airworthiness.

Airworthiness assessment for intercontinental very high speed travel

7.97 As was discussed in Chapter 2, one of the potential uses of spaceplanes is to enable intercontinental very high speed travel. This could involve spaceplanes which remain within the Earth's atmosphere for the entire flight, travelling at hypersonic speeds (eg Mach 5), or fractional orbital airliners, achieving near orbital velocity before re-entering the Earth's atmosphere prior to landing at their destination.

7.98 Such possibilities are still theoretical – and are likely to remain so for some years to come. Even if such spaceplanes are successfully developed, they are not likely in the foreseeable future to be realistic or cost-effective alternatives for mass-market travel.

7.99 However, should they be developed, it is expected that these types of operations would be too large and complex for the SMS approach to be used as a means of achieving airworthiness assurance.

7.100 Besides, given that such operations are not anticipated to begin until after 2020, it is proposed that these projects should be managed through a permanent, more conventional approach, in line with normal aircraft certification procedures. There is sufficient time available for certification requirements to be developed and for certification bases to be defined.

7.101 Spaceplanes that remain within the Earth's atmosphere for the entire flight clearly lie within the ICAO definition of an aircraft, since they rely on the reaction from the atmosphere for their lift. As such, they would theoretically be subject to the normal aircraft airworthiness oversight process and procedures.

7.102 However, the design conditions and operating envelope of the prospective designs go beyond those envisaged by the existing certification requirements and would therefore necessitate the development of new requirements.

7.103 The nature of this task is analogous to the challenges posed by the certification of Concorde, which similarly presented the need for additional supersonic transport requirements, in addition to those already established for subsonic aircraft. In the same way, any changes in requirements to address the nature of spaceplane operations should not set out to increase the overall compliance burden for these vehicles. Instead, wherever possible existing requirements should be adapted to reflect the design features and anticipated operating characteristics of spaceplanes operating at such speeds and altitudes. This approach is consistent with what is understood to be the intention of the National Aeronautics and Space Administration (NASA) – that the aviation regulation model should be used for the regulation of any A to B commercial spaceplane operations.[148]

7.104 Indeed, this same principle is one that could usefully apply to the development of any codes.

Recommendation
The target level of safety to be applied in the development of the regulatory framework for commercial spaceplane operations should be equivalent to the prevailing standards for conventional commercial transport operations.

---

[148] Views shared during UK Government technical visit to US, 2013.

Assuring airworthiness in a maturing spaceplane industry: aligning with the commercial aircraft certification approach

7.105 Many technologies employed in spaceplane designs, such as composite structures, advanced alloys, electrically signalled aerodynamic flying controls and electronic instrument displays, are used conventionally in civil aviation, and their reliability and safety levels can be assessed through current airworthiness processes and procedures. However, as was stated above, certain spaceplane technologies do not lend themselves to being assessed and approved according to current civil aviation regulatory practice.

7.106 The most obvious of these, as acknowledged earlier, is the rocket powerplant. As was stated above, the commercial aircraft certification standards for engines require that an engine failure must not directly cause the loss of the aircraft. This drives not only the design of the propulsion system, in terms of reliability, containment of engine debris etc, but also the design of the aircraft itself – such as fuel systems, flight deck controls and the aerodynamic handling qualities that assure continued controllability of the aircraft, for example.

7.107 As the spaceplane industry matures, it should be possible to develop certification codes and technical requirements for objective airworthiness regulations. Discussions with European spaceplane manufacturers have indicated a preference for certification to be developed, and EASA supports this view.

7.108 Given the vast range of technologies involved, codes should be modular, so that parts of the code could be selected or deselected according to their relevance to a particular project and 'Special Conditions' (Certification Review Items) derived for the unique parts of the certification code. This modular approach would offer a level of transparency, but also flexibility. For example, a module on rocket nozzles may apply to all rocket engines; however, a module on compressors would be applicable to the air-breathing rocket engine being developed by Reaction Engines Ltd (the SABRE engine), but not to hybrid rocket designs.

7.109 It has been suggested that the existing European certification codes of CS-25 (for the airframe) and CS-E (for the engines) would be suitable starting points for the initial configuration design of these vehicles and powerplants, with airframe and engine codes specifically developed for these aerospace craft during the period to 2020. If development of codes were to start during 2015, with suitable staffing and funding it should be possible to produce draft codes by 2018 – of significant potential value to operators and manufacturers, as well as to regulators.

Recommendation

The UK should further engage with and encourage the EU to start the development of EU spaceplane regulation and certification. Once such regulations are mature, it is anticipated that they will replace the UK regulatory framework.

7.110 The resources needed to develop these requirements should not be underestimated. As a minimum, separate rulemaking groups would need to be established for each technical discipline addressed in the existing aircraft and engine codes, including: flight (performance and handling), structures, design and construction, powerplant, equipment, operating limitations and information. As suggested earlier, these would draw on expertise from industry, as well as from the regulatory authorities.

Recommendations

7.111 This chapter has made the following recommendations.

- Work should be commissioned to develop, within the airworthiness assessment approach, a methodology for giving due recognition to FAA AST licensing system assessments. (*Recommendation 10 in summary report*)
- In order to obtain a better understanding of the FAA AST licensing process and the safety performance of any US sub-orbital spaceplanes that are likely to operate in the UK, the Department for Transport should sign a Memorandum of Understanding with the FAA AST. (*Recommendation 9 in summary report*)
- In the short term, spaceplanes currently under development should be regulated in the UK in accordance with an overall safety management system framework, to be specified by the CAA and managed by the operator. (*Recommendation 11 in summary report*)
- Spaceplanes currently under development should be required (and seen to be required) to achieve the highest level of safety that is **reasonably** practical. (*Recommendation 12 in summary report*)
- The target level of safety to be applied in the development of the regulatory framework for commercial spaceplane operations should be equivalent to the prevailing standards for conventional commercial transport operations.
- The UK should further engage with and encourage the EU to start the development of EU spaceplane regulation and certification. Once such regulations are mature, it is anticipated that they will replace the UK regulatory framework. (*Recommendation 13 in summary report*)

CHAPTER 8
Airspace

Every spaceplane that launches from the UK will fly through UK airspace – one of the busiest areas of airspace in the world. This chapter looks at how spaceplane and other commercial space operations could be managed within UK and indeed European airspace. It looks at both safety issues and the impact of spaceplane operations on other airspace users. It explains how airspace is currently designed and managed, and recommends a practical means of integrating space operations within that context.

Introduction

8.1 UK airspace is busy, complex and facing increasing demand for access. It incorporates an extensive route structure (mainly used by commercial air traffic), 145 Danger Areas of various volumes and other training areas to support military activity, and 32 control zones to support flights to and from some of the 141 licensed airfields in the UK. In 2013, almost 2.2 million flights and 220 million passengers transited through UK airspace.[149]

8.2 To ensure that these flights can take place safely and as scheduled, airspace must be carefully constructed and constantly managed. It is currently designed and managed using systems based on international standards – such as the International Civil Aviation Organization (ICAO) Airspace Classification System and European Airspace Management (ASM) guidance.

8.3 Under the Transport Act 2000, the Civil Aviation Authority (CAA) has a statutory duty to exercise its air navigation functions in the manner it thinks best to:

- secure the most efficient use of airspace;
- satisfy the requirements of all airspace users; and
- take account of the interests of any person in relation to the use of any particular airspace or the use of airspace generally.[150]

8.4 Spaceplanes, and indeed all commercial space operations, present a challenge here. The number of spaceplane operations – at least in the next few years – will be very small; however, due to the nature of the operations, if they are to be managed safely and in line with the underlying priority of minimising the risk to the uninvolved general public, it is likely that they will require a significant volume of airspace and will create disruption to other airspace users.

---

[149] Official National Air Traffic Services (NATS) figures, as cited in 'NATS sees increase in air traffic in 2013', news release, 17 January 2014, www.nats.aero/news/nats-sees-increase-air-traffic-2013/ (accessed 23 April 2014)

[150] UK Transport Act 2000, section 70(1), www.legislation.gov.uk/ukpga/2000/38 (accessed 29 April 2014)

8.5 However, it is essential that this challenge is overcome. The inability to access space is viewed as a barrier to growth for UK companies.[151] The Space Innovation and Growth Strategy highlights the economic and social benefits to the UK accrued through the allocation of scarce national resources, such as spectrum and orbit slots.[152] Airspace is a similarly finite resource and must be allocated equitably to sustain and promote broader commercial growth and opportunity, as well as to support activity necessary for national defence and security.

The principles of Airspace Management

8.6 The purpose of Airspace Management (ASM) is to ensure the safety of all airspace users, as well as the safety and integrity of the operation itself.

8.7 ASM is a planning function, with the primary objective of providing the most efficient use of airspace, based on actual need. Across Europe, airspace is managed under the Flexible Use of Airspace (FUA) concept.[153] This works on the fundamental principle that airspace should not be designated as either military or civil airspace, but should be considered as a joint, shared resource.

8.8 However, it is recognised that some types of operation will need to take place within segregated airspace. The application of the FUA concept aims to ensure that, through the daily allocation of flexible airspace structures, any necessary segregation of airspace is based on real usage within a specific time period and airspace volume.

8.9 Effective airspace solutions also necessarily incorporate the requirements for failure modes for each type of operation. For unusual aerial activities, this may entail additional airspace safety measures.

Airspace usage in Europe

8.10 European and UK/Ireland air traffic is forecast to increase. By 2019, it is anticipated that there will be 10.8 million aircraft movements in Europe, nearly 14 per cent more than in 2012. Growth across Europe is patchy, and all the top five states – based on numbers of air traffic movements – recorded fewer total flights in 2013 than in 2012, except for the UK, where the figure was 0.6 per cent higher.[154] While the growth in percentage terms is much weaker in the more mature markets of Western Europe, it is still the busiest states (Germany,

---

[151] UKSpace (2013) *Space Innovation and Growth Strategy 2014–2030: Space growth action plan*, p14, www.gov.uk/government/uploads/system/uploads/attachment_data/file/298362/igs-action-plan.pdf (accessed 23 June 2014)

[152] ibid, p12

[153] Eurocontrol (2013) *European Route Network Improvement Plan (ERNIP) – Part 3: Airspace Management Handbook*, pxix, www.eurocontrol.int/publications/european-route-network-improvement-plan-ernip-part-3-airspace-management-handbook (accessed 29 April 2014)

[154] Eurocontrol (2013) *EUROCONTROL Seven-Year Forecast September 2013: Flight Movements and Service Units 2013–2019*, p10, www.eurocontrol.int/sites/default/files/content/documents/official-documents/forecasts/seven-year-flights-service-units-forecast-2013-2019-sep2013.pdf (accessed 29 April 2014)

followed by France, Italy and the UK) that will see the greatest number of extra flights per day between now and 2019.[155]

8.11 It is anticipated that air traffic in UK/Ireland airspace will grow on average by 1.8 per cent per annum up to 2019.[156] The demand for air travel is not spread evenly across the UK: it is at its highest levels in the South East, where approximately 60 per cent of air passengers and 50 per cent of all flights use a London aerodrome.[157]

8.12 The predicted increase in air traffic numbers, the extension of the arrivals management planning and the implementation of free route operations together mean that spaceplane operations launched from the UK will be taking place in an increasingly complex airspace environment.

How airspace is divided

8.13 The airspace from the surface to flight level (FL) 245 (24,500 feet) above the UK and surrounding waters is divided into two Flight Information Regions (FIR): the London FIR, which covers most of England and Wales, and the Scottish FIR, which covers Scotland, Northern Ireland and a small part of northern England. The airspace above the FIR is known as the Upper Flight Information Region (UIR).

Figure 8.1: London and Scottish Flight Information and Upper Flight Information Regions

---

[155] ibid, p12

[156] ibid, p15

[157] L Butcher (2014) 'Aviation: London Heathrow Airport', Standard Note to the House of Commons SN1136, p4, www.parliament.uk/briefing-papers/sn01136.pdf (accessed 29 April 2014)

8.14 The airspace within the FIR/UIR is divided into different types using the ICAO Airspace Classification System. This defines seven classes of airspace, each with minimum air traffic service (ATS) requirements and different services provided.

8.15 The UK has adopted the ICAO system, although only six classes are utilised. Classes A, C, D and E are controlled airspace. Airspace around busy aerodromes, routes to and from those aerodromes and above FL 195 in the UK is designated controlled airspace. The remaining airspace is designated either Class F or G.[158] Appendix 8A contains a full matrix of UK airspace classifications.

The case for using segregated airspace

8.16 Some activities conducted in UK airspace require segregation from other general air traffic. This may be because the aircraft are unable to comply with standard procedures, or because the nature of the planned operation would not be compatible with other airspace use. Managing this entails creating segregated areas of Special Use Airspace (SUA), usually notified as Danger Areas. Segregation of airspace is the basis for the current approach to the management of unmanned aircraft system (UAS) flights in the UK.[159]

8.17 Figure 8.2 illustrates the complexity of the UK's airspace. It shows the air traffic route structure, existing Danger Areas (shaded red) and other military training areas (shaded blue).

---

[158] CAA (2013) 'Policy statement – the application of ICAO airspace classifications in UK Flight Information Regions', www.caa.co.uk/docs/33/20130805ApplicationOfAirspaceClassificationInUKPolicyV4.pdf (accessed 29 April 2014)

[159] CAA (2012) *Unmanned Aircraft System Operations in UK Airspace – Guidance,* CAP 722, section 2, chapter 1, p1, www.caa.co.uk/docs/33/CAP722.pdf (accessed 29 April 2014)

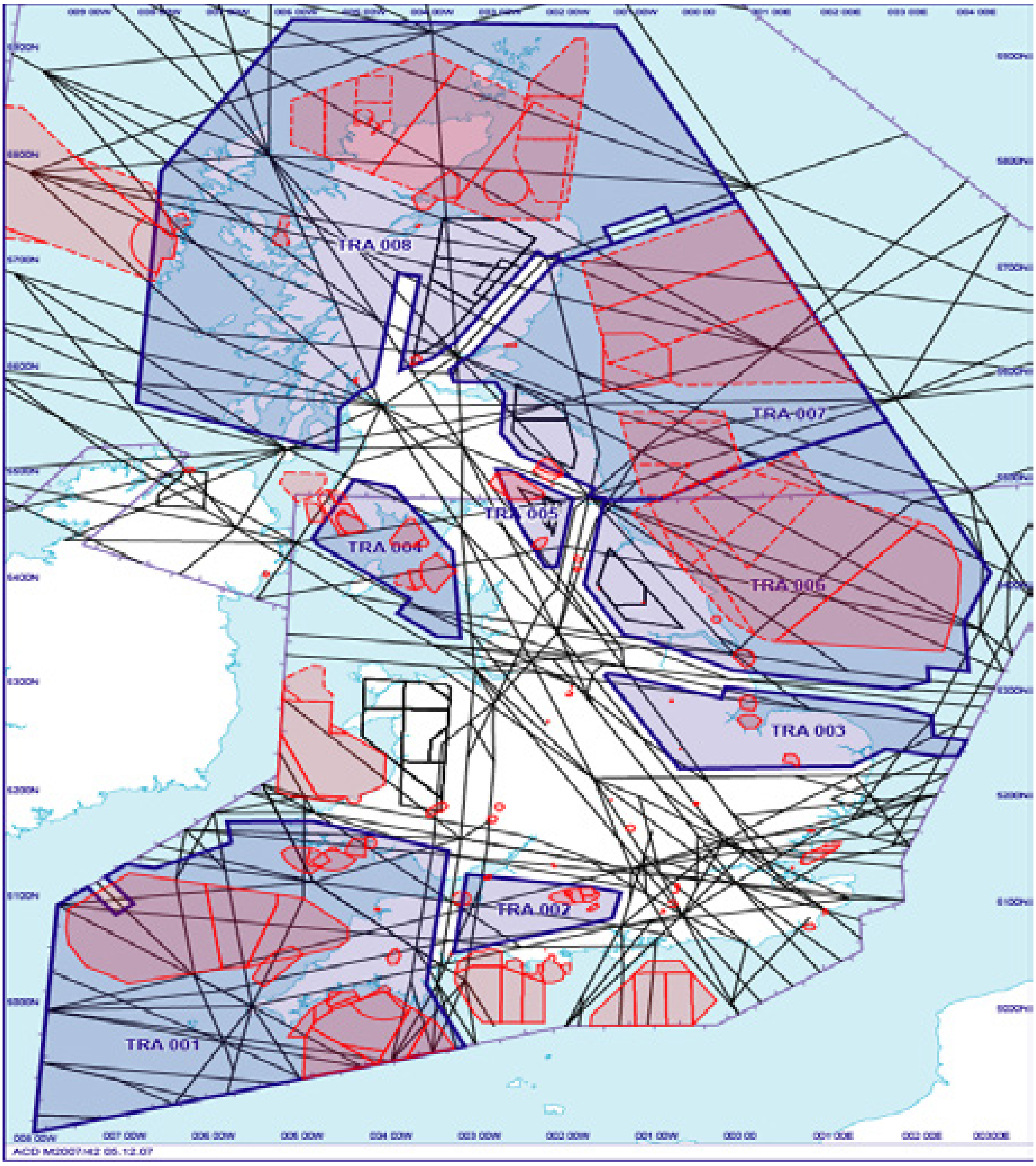


Figure 8.2: The London and Scottish FIR/UIRs, showing the air traffic route structure, Danger Areas (shaded red), Temporary Reserved Areas (marked TRA) and other military training areas (shaded blue)

8.18 Spaceplane operations will be an unusual aerial activity and will be a challenge to integrate through normal Air Traffic Management (ATM) means for a number of reasons. The Rules of the Air[160] – essentially the airspace equivalent of the Highway Code for flight in the UK[161] – govern the flight of all aircraft in the UK, and all aircraft are expected to comply with them. However, several of the spaceplane designs considered in this Review will effectively be unable to comply with those Rules: once take-off or launch commences, they would be committed to a planned trajectory and unable to take instructions to enable separation from other general air traffic.

8.19 Some operations – such as those proposed in the US by Virgin Galactic and XCOR Aerospace – may be able to comply with the Rules of the Air in certain circumstances, and therefore appear to be compatible with flight in Class G airspace. However, given the safety concerns discussed in previous chapters, it will be desirable – at least in the short term – to keep spaceplane launches away from other airspace users.

8.20 Therefore, it can be anticipated that, in the short term, airspace segregation to support and contain space access operations will be a necessary first step. ASM solutions would need to be designed to reflect the operation and flight profile. For some types of operation and flight profile, this may need to continue; for others, as the operation matures and as confidence builds, there may be potential for the evolution of such airspace measures.

Recommendation

In the short term, spaceplane launches and recovery of unpowered vehicles should take place only within areas of segregated airspace.

8.21 This approach is in line with that taken in the US,[162] where extensive tracts of military SUA are being exploited for the launch and recovery of spaceplane test flights. In the US, all spaceplane and vertical launch operations to date have utilised segregated airspace to ensure the safety of other airspace users. All licensed US spaceports have significant, existing, collocated, restricted military airspace within which much of the activity can occur, including any corridors necessary for departure and recovery. Interaction with general air traffic is limited.

Practical challenges of airspace segregation

8.22 There are significant differences between the US and UK environments. The sheer scale of the US landmass; existing US operations, including test facilities;

---

[160] Rules of the Air Regulations, section 2, p5, www.legislation.gov.uk/uksi/2007/734/pdfs/uksi_20070734_en.pdf (accessed 29 April 2014)

[161] The Rules of the Air are to be replaced by the Standardised European Rules of the Air, which will be adopted in the UK with effect from 4 December 2014.

[162] As explained to the UK Government delegation during the technical visit to the US, 2013.

large test ranges; and favourable weather conditions that do not hamper flying – all of these mean that spaceplane operations are more easily supported and facilitated. A good example is Spaceport America (New Mexico), which has significant portions of the existing White Sands Missile Range restricted airspace within which to operate safely.

8.23 In the UK, however, such large expanses are not so readily available, and specifically designed airspace constructs may add to already complex and congested airspace. Even in the relatively less-congested airspace to the north of Scotland, the upper air routes are busy with traffic transiting to and from the US; the addition of SUA in this area may impede access to the North Atlantic Organized Track System (NAT OTS).

Forthcoming changes to ASM

Increasingly dynamic and flexible solutions are being developed which will be better able to respond to the airspace requirements to support spaceplane and other commercial space operations.

Advanced Flexible Use of Airspace (AFUA) solutions are designed to fulfil operator needs and better share airspace constraints across user communities. The Single European Sky ATM Research (SESAR) Joint Undertaking is developing processes and services to deliver network capacity improvements through the exploitation of AFUA.

Variable Profile Area (VPA) is an airspace design principle based on flexible allocation and management of fixed, predefined modules (or building blocks) of airspace. These modules would be designed to fulfil airspace users' needs individually or as a combination of modules, depending on the specific mission profile to be supported. The employment of VPA in the design of airspace for spaceplane and other commercial space operations would allow the establishment of an airspace structure capable of supporting a variety of mission profiles. Each profile would be supported by an associated pre-determined VPA construct.

The concept of Dynamic Mobile Areas (DMA) enables temporary mobile airspace segregation with defined lateral and vertical dimensions and timeframe allocations, but with a variable geographical location along a defined trajectory. This principle seeks to minimise the impact on the network, while satisfying the needs of airspace users.

The DMA concept has the potential to reduce significantly the need for fixed airspace structures. It would be sufficiently dynamic to respond to spaceplane operators' requirements and would be fully integrated into the air traffic route network, and so would limit the constraints on other airspace users.

During space shuttle operations, a specific process for the protection of commercial air traffic under the shuttle's flight path was used. If a similar UK procedure proved necessary, DMA offers a potential airspace solution, if supported by the appropriate procedures and software tools.

Further details of the SESAR programme can be found in Appendix 8B.

Using existing areas of Special Use Airspace

8.24 The UK has relatively large areas of existing SUA – or Danger Areas – that have been established to contain specific military aviation activity. Depending on the location of a spaceport, it may be possible to use some of these Danger Areas for sub-orbital and orbital flights. This would require an airspace-sharing agreement to be reached between the civilian sponsor of a space access operation and the Ministry of Defence (MOD). There are existing examples of such partnering arrangements between the MOD and other entities which enable the sharing of SUA, subject to the MOD retaining primacy of use.

8.25 A change to the type of activity conducted in SUA may, in some circumstances, require an airspace change proposal to be conducted to ensure that the airspace design is sufficient to contain the new activity. In addition, even an airspace-sharing agreement, making use of existing SUA, would need to take into account the potential impact of UK spaceplane operations on air traffic capacity.

8.26 For example, the South West Managed Danger Area complex EGD 064A–C is situated off the north Cornwall coast and is bisected by several Conditional Routes (CDRs): these can be used by general air traffic when the Danger Area complex is not in use. It is shown in Figure 8.3 below. Although not an indication of future availability, in recent times this has generally been made available by the MOD to other general air traffic, allowing commercial aircraft almost constant access to the airspace. Based on 2013 data, approximately 37,000 aircraft (1.7 per cent of annual flights through UK airspace) flew along the seven CDRs that penetrate EGD 064.

8.27 Any airspace-sharing arrangement in this area would naturally have an impact, as the area would be increasingly segregated due to spaceplane operations: the affected CDRs would be required to close, at least during the period allocated to spaceplane launches. This would require the re-routeing of aircraft and may have a wider impact on the air traffic route network, delaying other aircraft, as those re-routed aircraft fill the capacity in adjacent Air Traffic Control (ATC) sectors.

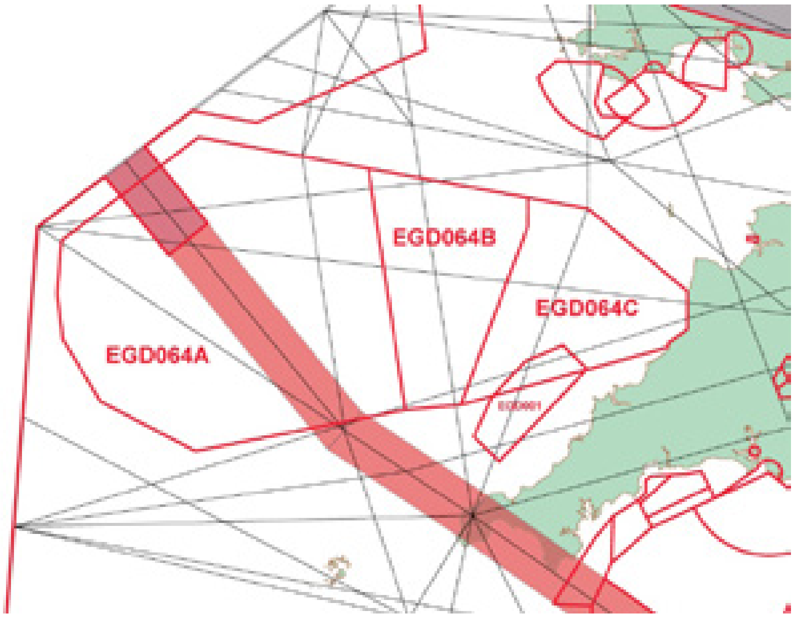


Figure 8.3: The South West Managed Danger Area EGD 064 complex upper air traffic route centrelines (grey) and lower air traffic airway (shaded red)

8.28 The Southern Managed Danger Area complex EGD 323A–F off the north coast of East Anglia is far more heavily utilised by military operators; in 2013, despite this heavy usage, approximately 20,000 commercial aircraft (nearly 1 per cent of the annual flights through UK airspace) transited along CDRs through this intensively used area. Access to the routes affected by EGD 323 is limited to a far greater extent by military activity, with availability for general air traffic mainly restricted to overnight and weekends.

8.29 Despite the greater numbers of aircraft routeing through the EGD 064 complex, the increased segregation of the EGD 323 complex would be likely to have more effect on capacity and route efficiency than the segregation of the EGD 064 complex, due to its significant effect on the entire North Sea route structure. Furthermore, the sharing of existing SUA in these circumstances would necessarily compete with MOD priorities and may require negotiation, depending on NAT OTS access requirements.

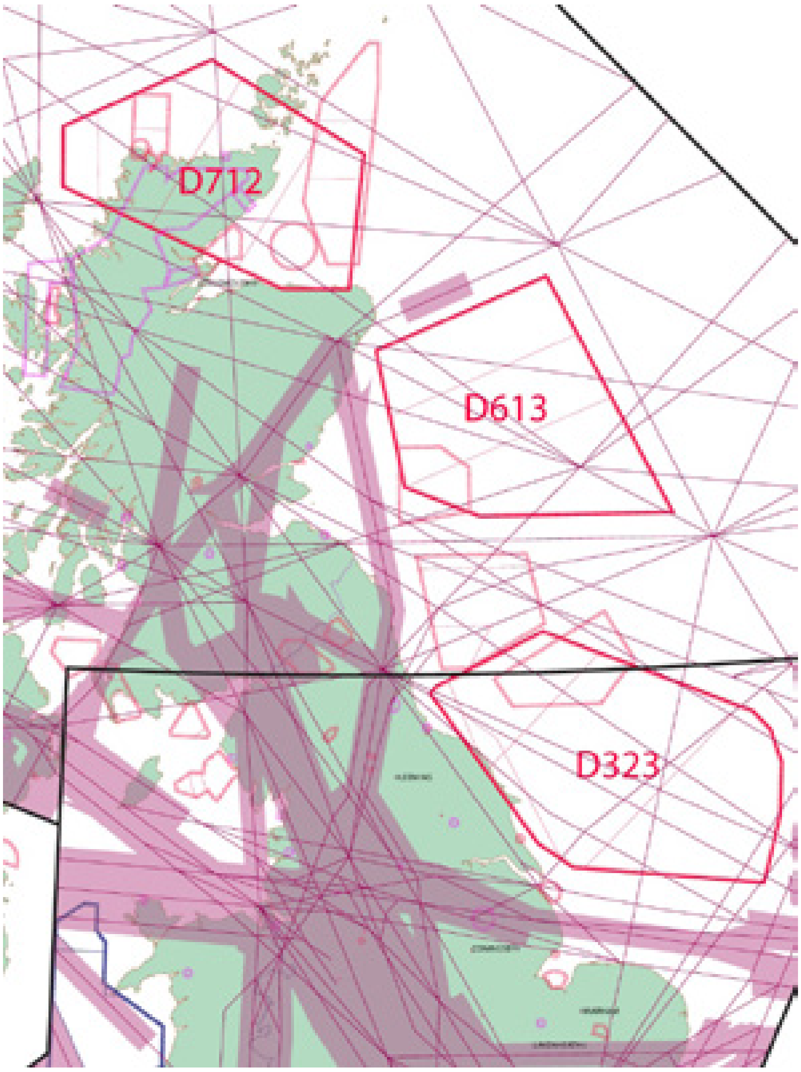


Figure 8.4: The North and East Coast Managed Danger Areas including the EGD 323 complex, Danger Areas (red borders), upper air traffic route centrelines (purple) and lower air traffic airways (shaded purple)

8.30 Additional activation of either SUA complex would have an impact on capacity and route efficiency, depending on the frequency and duration of segregation to support spaceplane operations.

Recommendation
Depending on the chosen location(s) of a spaceport to support spaceplane operations, the CAA should undertake initial discussions with the MOD and NATS to scope the options for using existing military-managed segregated SUA for spaceplane operations in the medium term, with a view to ensuring the establishment of effective governance and oversight arrangements.

8.31 Sharing SUA may also lead to issues, depending on existing levels of utilisation by the military. Clear agreements and protocols on priorities for use would need to be agreed with military stakeholders, as well as with air navigation service providers (ANSP). For example, at Spaceport America there have been ongoing discussions with the US Army White Sands Missile Range and the Federal Aviation Administration's Albuquerque Center on airspace procedures.[163]

8.32 The view of the Federal Aviation Administration Office of Commercial Space Transportation (FAA AST), expressed during the UK Government technical visit to the US, was that spaceports and aerodromes could potentially co-exist, but that there may be a need to align those elements which are common to both, as well as to accommodate any additional requirements that may be needed for an aerodrome to be a spaceport. In terms of airspace, this may require a hybrid solution or, for an existing aerodrome with controlled airspace, the addition of controlled airspace or segregated SUA volumes to ensure that the activity is entirely contained. For example, the Mojave Air and Spaceport is protected by Class D airspace from the surface to 18,000 feet and Danger Area airspace above. Co-ordination takes place with the military when entry to the airspace is required.

Creating bespoke areas of SUA

8.33 Alternatively, bespoke SUA may need to be established to support sub-orbital and orbital spaceplane operations. This would involve the development of an airspace change proposal (see paragraphs 8.44–8.49 below) that sets out the size of the proposed Danger Area around a spaceport and its proposed level of usage, as well as identifying suitable alternative routes around the segregated area.

8.34 In principle, a bespoke area of SUA should be as small as possible to minimise the impact on other airspace users, but as large as necessary to contain the operations safely.

8.35 In the UK, the MOD uses safety traces, based on the maximum ballistic effect of ammunition and weapons systems (including rocket-propelled systems), in the design of SUA to ensure containment of a particular activity. For spaceplanes, a similar approach could be used, taking into account the profiles and capabilities of particular aircraft, spaceplane and vertical launch systems and the key characteristics of an operational spaceport and/or test site, as well as the nuances of operating from specific locations which may impact upon the air traffic route network.

---

[163] See http://spaceportamerica.com/newsletters/spaceport-america-newsletter-march-2014 (accessed 20 May 2014)

Planning considerations

8.36 A degree of flexibility would be required in any solution designed to accommodate launch system test and evolution. Today in the US, each launch is considered to be unique and, as was explained during the UK Government technical visit to the US, very few generic lessons have been learned so far, on account of the small number of launches.

8.37 Equally, the Airspace Management process designed to support this activity must be sufficiently dynamic to enable SUA to be activated and deactivated in time to support the airspace solution. The initial low-frequency activity, as is currently the case in the US, would not warrant extended periods of SUA activation; instead, closely defined, relatively short periods of SUA activation would be sufficient. There is an established process for activating SUA, described in paragraphs 8.50–8.56 below, though the dynamic management of airspace in Class G poses a particular challenge.

8.38 Airspace solutions should also take into account and accommodate any contingency requirements, such as diversion of the spaceplane to an alternative aerodrome or landing site. This may require the establishment of a pre-planned airspace solution at short notice or of SUA in parallel to the primary area to support any contingency operation.

8.39 In addition, airspace solutions may be required in order to protect other airspace users from debris in case of a catastrophic spaceplane failure away from the established SUA. Procedures and tools were developed by the Federal Aviation Administration (FAA) to mitigate the hazards presented by such a failure in the aftermath of the Columbia space shuttle accident in February 2003. In this case, a dedicated tool – the Shuttle Hazard Area to Aircraft Calculator – was developed and has evolved over time. The tool was able to model the extent of the debris field and dynamically map a potential airspace restriction, which could be established at very short notice in the event of an accident, thereby negating the need to establish contingency airspace restrictions in order to mitigate the risks associated with a catastrophic failure.[164]

---

[164] D Murray and M Mitchell (2010) 'Lessons learned in operational space and Air Traffic Management', p2, in *Proceedings of the 48th AIAA Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition, Orlando, Florida, 7–10 January 2010*

The need for legislation

8.40 If deemed appropriate, any necessary SUA segregations may be supported by associated legal instruments or statutory instruments. However, such instruments would only be valid over mainland UK and up to the 12 nautical mile limit for territorial waters. Segregations over the high seas (ie beyond the 12 nautical mile limit) can be established. In the UK, in accordance with ICAO, such airspace would be designated as a Danger Area; in the US, the airspace would be designated as a Temporary Flight Restriction (TFR).

8.41 However, in general, legislation is not needed to create segregated SUA.

Designating a sponsor

8.42 Ordinarily, Danger Areas are established to contain defence-related activities. Accordingly, the MOD provides regulatory, safety and management oversight of Danger Area airspace on behalf of the CAA. Each Danger Area must be allocated to a sponsor, and that sponsor will act as the Danger Area Authority. The Danger Area Authority should have processes and procedures in place to ensure the safe and efficient management of the Danger Area airspace for which responsibility has been allocated.[165]

8.43 In circumstances where a sponsor other than the MOD is appointed, governance arrangements would need to be established to ensure that the associated responsibilities are discharged. Precedent in this case may be drawn from the oversight of EGD 314 Harpur Hill, which is sponsored by the Health and Safety Laboratory, with oversight exercised through the MOD-led Danger Area Airspace Steering Group.

The airspace change process

8.44 In accordance with its statutory duties,[166] the CAA must exercise its air navigation functions in the manner it thinks best. In practice, this requires that any proposed changes to the structure of UK airspace, maintaining consistency with the CAA's Future Airspace Strategy,[167] should be developed within the framework set out in the CAP 724 Airspace Charter[168] and CAP 725 Guidance on the Application of the Airspace Change Process.[169] These detail the processes by which changes to the dimensions, classification or use of UK airspace may be carried out.

---

[165] CAA (2013) 'Policy Statement: Danger Areas', www.caa.co.uk/docs/33/20130201DAPolicyFinal.pdf (accessed 29 April 2014)

[166] UK Transport Act 2000, section 70(1), www.legislation.gov.uk/ukpga/2000/38 (accessed 29 April 2014)

[167] CAA (2011) *Future Airspace Strategy for the United Kingdom 2011 to 2030*, www.caa.co.uk/docs/2065/20110630FAS.pdf (accessed 29 April 2014)

[168] CAA (2012) *Airspace Charter*, CAP 724, www.caa.co.uk/docs/33/cap724.pdf (accessed 29 April 2014)

[169] CAA (2007) *CAA Guidance on the Application of the Airspace Change Process*, CAP 724, www.caa.co.uk/docs/33/CAP724.PDF (accessed 29 April 2014)

8.45 Under CAP 725, any changes to the lateral or vertical dimensions of Danger Areas, restricted or prohibited airspace and Temporary Reserved Areas, or significant changes in their operational use, require the development of an airspace change proposal (ACP). An ACP can be initiated by any organisation; in practice, it is normally initiated and sponsored by an aerodrome operator or/and an ANSP.

8.46 The development of any ACP will follow a seven-stage process,[170] which draws together the relevant operational and environmental assessments to provide assurance of the safe and efficient use of the airspace. It also includes public and stakeholder consultation – normally of 12 weeks' duration.

8.47 Having taken into account consultation input, the proposal is then submitted to the CAA for regulatory review. A timescale for completion of the full process cannot be pre-determined; however, the CAA has set a timeframe for the regulatory decision stage of up to 16 weeks.

8.48 The amount of resources that a change sponsor would need to devote to proposal development, consultation, adaptation and documentation may be considerable, and would invariably affect the duration of the development process, as would the scale, complexity and sensitivity of the proposal. In addition, the nature of a consultation may require an iterative process of 'consult–refine–consult' to be employed; this would need to be considered when planning implementation timescales.

8.49 Overall, it is to be expected that from initiation, a large-scale ACP of this nature may take more than two years to complete. This timing must be taken into account when considering the stated aim of allowing spaceplane operations to take place from the UK by 2018 or earlier.

Recommendation
An airspace change proposal should be initiated as soon as an aerodrome is selected for spaceplane operations. To enable spaceplane operations to take place in the UK before 2018, this would need to happen within the next few months.

---

[170] ibid, p5

Managing airspace on a day-to-day basis

8.50 The Airspace Management Cell UK (AMC UK) is responsible for many of the flexible airspace structures and Conditional Routes (CDRs) in the UK. It would be an integral part of the ASM system, configured to enable spaceplane and other space access operations.

8.51 The AMC UK, in consultation with the Military Airspace Booking and Coordination Cell, collects and analyses all airspace requests and, after co-ordination, promulgates the airspace allocation.

8.52 In the US, airspace closures are notified by Notices to Airmen (NOTAMs); in the UK, in addition to NOTAM, the process utilises the Airspace Use Plan (AUP), with subsequent periodic updates promulgated via the Updated Airspace Use Plan (UUP). The AUP and UUP are messages of equivalent status to a NOTAM, notifying the daily plan for the temporary allocation of the airspace for a specific time period.

8.53 This process, carried out via the Eurocontrol Network Management Operations Centre (NMOC), is the primary means of notifying all airspace users of the daily airspace allocation, and would be the most likely method employed for the notification of airspace constructs established to support spaceplane and other space access operations.

8.54 However, some changes to the process may be required to accommodate the nuances of orbital and sub-orbital launch operations from the UK.

8.55 For example, to ensure a robust process for the activation and deactivation of airspace, it will be important to understand the timeframe necessary for the notification of spaceplane launch and recovery, and whether operators have the ability to offer flexibility within those launch/recovery times. It is understood that spaceflights will be weather dependent (ie subject to cloud, visibility and crosswind limitations); therefore, an element of flexibility would be required.

8.56 In the US, launch determination in terms of time, location and airspace is decided by the operator, in consultation with the FAA AST and the FAA's Air Traffic Control (ATC). Temporary Flight Restrictions (TFRs) – the equivalent of segregated SUA – are employed to segregate the airspace on the day of operation, but are promulgated in advance. Similar consultation with operators is likely to be required for spaceplane launches in the UK, though decisions themselves would not be made by the operators.

Recommendation

Airspace Management notification procedures should be reviewed in full at a time appropriate to the development of the initial anticipated spaceplane operations from the UK.

Airspace and Air Traffic Control

8.57 There will be a requirement for the launch operator/spaceport operator to ensure that the required airspace/ATC procedures are in place. These arrangements should include the allocation of appropriate radio frequencies for communication, for example with ATC. The frequencies would be allocated by the relevant aviation authority, through international agreement, for operations extending into outer space. A system for this is already in place through ICAO, in a manner that will ensure compliance with the International Telecommunication Union radio regulations.[171]

8.58 ATC is considered in more detail in Chapter 9.

Analysis of airspace solutions for different types of space operation

Sub-orbital operations

8.59 Sub-orbital operations to and from the same spaceport are likely to be delivered through a variety of spaceplane systems, operating in different ways, flying a spectrum of profiles and requiring various airspace solutions to support such operations. Specific ASM solutions would need to be designed on a case-by-case basis, taking into account particular system requirements and, in some cases, perhaps with each system operating in different modes.

8.60 Systems such as those under development by Virgin Galactic and XCOR Aerospace currently operate under visual flight rules (VFR)[172] and, within certain parameters, have a degree of autonomy to manoeuvre the spaceplane during certain portions of the flight. This indicates that some systems will have the potential to comply with the Rules of the Air, and may be able to integrate and interact with other air traffic. The ability of systems such as the XCOR Lynx or Virgin Galactic's WhiteKnightTwo (the carrier aircraft) to accept trajectory deviations may enable a more flexible integration into the airspace system in the future: this may facilitate more flexible airspace design solutions.

8.61 However, at the very least in early phases of the operation, and certainly during system testing, it can be anticipated that segregated SUA will be necessary to support such operations. Virgin Galactic's is the only sub-orbital system currently flying in the US and does so supported by a combination of segregated airspace and agreements with the FAA to operate in the United States National Airspace System. Until there is a high degree of confidence in such operations, the interaction of general air traffic and sub-orbital flights in the same airspace

---

[171] J-B Marciacq, Y Morier, F Tomasello, Zs Erdelyi and M Gerhard (2008) 'Accommodating sub-orbital flights into the EASA regulatory system', EASA conference paper, https://getinfo.de/app/Accommodating-Sub-Orbital-Flights-into-the-EASA/id/BLCP%3ACN072087298 (accessed 29 May 2014)

[172] For a definition of these, see CAA (2014) *Air Navigation – Rules of the Air Regulations*, CAP 393, section 2, p14, www.caa.co.uk/docs/33/10107-CAA-CAP%20393%20Updated%203.pdf (accessed 8 June 2014)

should not be permitted . The extent of any airspace segregation is likely to vary depending on the exact nature of the operation.

8.62 It can be anticipated that, in some cases, the spaceplane departure and recovery profile will allow other air traffic to operate above and/or beneath any stepped segregated SUA, at various stages of the spaceplane flight.

8.63 It is possible that a cylinder of segregated SUA with a radius of 10–20 nautical miles would be sufficient to contain a typical launch and recovery profile, avoiding the necessity for large volumes of SUA. The flight profile of XCOR Lynx, for example, will likely include a gradual circling descent – unlike the space shuttle, which flew a steep straight-in approach, operating at an 18–20 degree angle on final approach.

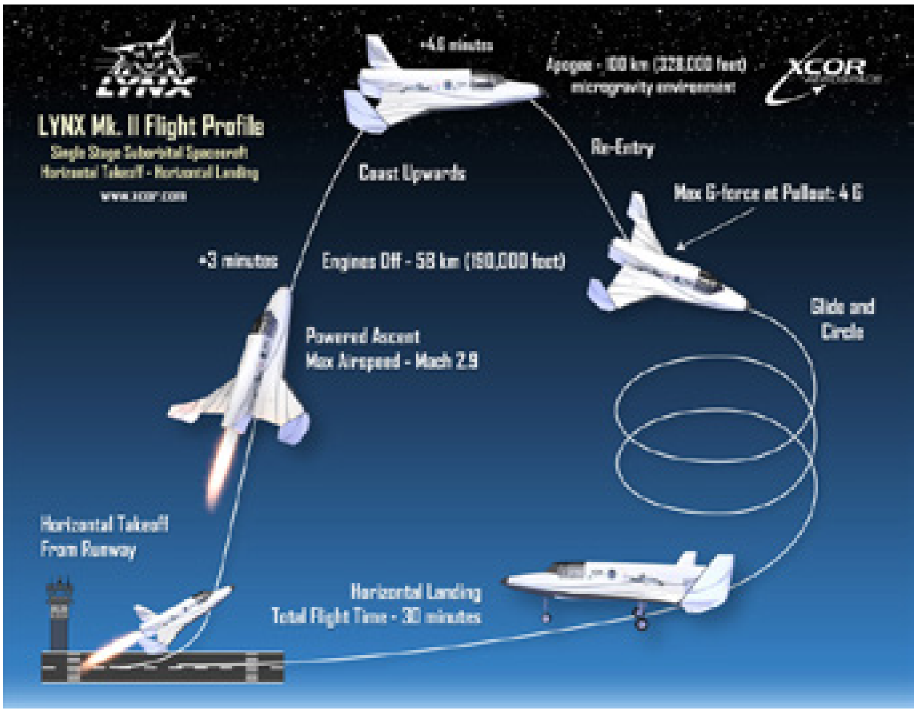


Figure 8.5: XCOR Lynx flight profile (courtesy of XCOR Aerospace)

8.64 Flexible activation and deactivation of airspace structures will be essential, given the likely duration and frequency of proposed spaceflights. For example, XCOR has indicated that it intends to conduct several flights per spaceplane per day, each lasting 30 minutes, when at full operating capability.

8.65 Based on an analysis of the limited information available regarding proposed spaceplane operations, it can be concluded that:

- airspace to support sub-orbital operations will necessarily be designed on a case-by-case basis, exploiting the FUA concept and, in future, AFUA solutions;

- the airspace will be modular, allowing airspace solutions to be configured according to the type of operation and, as a spaceport evolves, enabling ‘add-ons’ as increasing volumes of airspace are required to support other operations, orbital or sub-orbital;
- the airspace will be managed dynamically, allowing the exploitation of the airspace by other users when it is not being utilised for sub-orbital test, launch and recovery operations. This is particularly important during low-frequency operations, anticipated in the early stages of development; and
- the airspace would be managed by the AMC UK at the Swanwick Area Control Centre (ACC) and co-ordinated through the Eurocontrol NMOC, ensuring complete air traffic route network integration.

Single-stage to orbit operations

8.66 For the purposes of this Review, the exemplar single-stage to orbit operation is considered to be delivered through SKYLON. As a large, remotely piloted system, SKYLON, in keeping with the current unmanned aircraft systems (UAS) regulatory regime, would not interact with other air traffic and would be required to operate in segregated SUA. Routinely, SKYLON would be expected to operate into and out of the same spaceport, but it would also be possible to land at an alternative spaceport that offers adequate facilities (such as a sufficiently long runway).

8.67 Because of its predicted flight characteristics, it is likely that SKYLON would require very large volumes of segregated SUA in which to operate, especially to support system failure modes and off-nominal operations, such as single-engine operations, when radius of turn can be expected to be even greater. These abort events can occur within the air-breathing mode, during transition to rocket mode, during the rocket mode within the atmosphere and finally an abort to orbit could be carried out; hence the different abort modes have different operating requirements and these will need to be considered.

8.68 An additional significant factor affecting the airspace design solutions for SKYLON relates to safety in the event of catastrophic failure. Due to its size and large fuel load, SKYLON would pose more risk to other airspace users in the event of a catastrophic failure than smaller sub-orbital spaceplanes. Consequently, the size of the airspace required to cater for such an event is likely to be significantly greater. For certain portions of the flight, air traffic activity beneath the SKYLON flight path might need to be restricted.

8.69 The space shuttle was probably the operation most closely aligned to that anticipated for SKYLON – certainly in terms of its speed and unpowered glide re-entry/recovery profile. The FAA initiated a work programme in 2005 which focused on space shuttle re-entry and recovery, and the use of existing ATM tools to establish TFRs to protect aircraft from the potential hazards of a space shuttle failure during the planned re-entry. However, given the complexity, cost and capacity penalties of large airspace restrictions, the FAA determined that the airspace below a re-entering shuttle would remain open for air traffic operations, so long as an operational plan was in place to notify airspace users in advance and to provide air traffic controllers with the necessary information to address a potential accident appropriately.[173]

8.70 While these space vehicles may present a safety risk to air traffic, the FAA demonstrated, through this approach to the space shuttle, that normal operations can continue in the airspace. That said, if it was determined that the risk of under-flight by general air traffic was significant, it is possible that evolving AFUA concepts and tools could be adapted to provide the requisite dynamic and flexible airspace restrictions which may be required beneath the SKYLON flight path.

Recommendation

Given the potential hazard to other airspace users from debris in the event of a catastrophic high-altitude system failure, a review should be undertaken – at a time appropriate in the development of SKYLON – to assess the risk to general air traffic activity beneath the SKYLON flight path and, in turn, to identify potential ASM solutions to mitigate any associated risk.

8.71 The segregated SUA designed to support SKYLON operations will necessarily exploit the AFUA processes and procedures in much the same way as sub-orbital flights. The ASM solutions will be flexible and dynamic, allowing airspace to be utilised to the fullest extent. Given that the volume of segregated SUA required is likely to be more extensive than that for sub-orbital operations, the impact of such restrictions is likely to be far greater and, therefore, the exploitation of AFUA processes and procedures will be even more critical. A combination of careful spaceport selection, utilisation of typically low air traffic density airspace, low-frequency operations and the employment of AFUA procedures and processes would mitigate to some extent the potential impact of extended tracts of segregated SUA.

Intercontinental very high speed travel

8.72 As was explained in Chapter 2, intercontinental very high speed travel at sub-orbital level is still purely theoretical. With no operating example – even in the test environment – the level of information regarding airspace requirements is minimal. However, it is likely that controlled airspace would be required to contain and protect associated bespoke instrument flight procedures (IFP).

---

[173] D Murray and R VanSuetendael (2006) 'A tool for integrating commercial space operations into the national airspace system', AIAA Atmospheric Flight Mechanics Conference and Exhibit, Keystone, Colorado, 21–24 August

8.73 As with other space access operations, the airspace solution appropriate to support such operations will depend on the nature of the system employed. Compatibility with existing ATM arrangements will be a key factor in the approach to the development of an airspace solution.

8.74 If operating from an existing aerodrome – in particular a busy commercial operation – integration with general air traffic, without the need to employ segregated SUA, would be essential. Flights would operate A to B rather than A to A, generating a need for en-route deconfliction. However, beyond the terminal departure and approach phases, deconfliction with other en-route traffic would not be necessary, due to the altitude at which such a system is likely to operate.

8.75 If integration with traffic in the terminal environment can be achieved, no SUA would be necessary. However, should segregation be required, careful consideration should be given to the launch/departure locations of such operations.

8.76 Although there is currently no articulated requirement for IFP design or the containment of any such procedures, future requirements for IFPs would need to be considered. For example, it seems likely that if intercontinental very high speed travel were to operate from existing aerodromes, some form of instrument flight capability would be required. It is unlikely, however, that current IFP guidance would be applicable to such aircraft.[174]

Recommendation

A review of instrument flight procedure (IFP) design requirements should be conducted at a time appropriate to the development pathway of an aircraft or spaceplane capable of intercontinental very high speed flight, with the aim of determining whether existing guidance can be applied or if new IFP design criteria need to be developed specifically to support such operations.

Vertical launch vehicles

8.77 As was discussed in Chapter 3, there is a clear global demand for additional vertical launch capability for satellites, and the development of a vertical launch capability in the UK could act as an attractor to business and accelerate the overall economic benefits of commercial space operations. Therefore, while vertical launch vehicles are not the core focus of this Review, it is important to assess the airspace requirements of vertical launch vehicles.

8.78 The launch of rockets in the UK is currently conducted in accordance with the Air Navigation Order (ANO).[175] The purpose of ANO Article 168 is to ensure the effective integration of any rocket launch (usually a recreational/amateur

---

[174] ICAO (2006) *Procedures for Air Navigation Services – Aircraft Operations*, Document 8168, vol II, Montreal, ICAO

[175] CAA (2014) *Air Navigation – The Order and the Regulations*, CAP 393, Article 168 – Regulation of Rockets, www.caa.co.uk/docs/33/10107-CAA-CAP%20393%20Updated%203.pdf (accessed 8 June 2014)

activity) into UK airspace and so ensure the safety of all airspace users. The ANO is not concerned with the rocket itself, nor with the execution of the rocket launch, which is subject to other regulation (ie health and safety legislation). The supporting CAA process requires the sponsor of a large rocket launch to obtain permission in accordance with the ANO.

8.79 The CAA process is configured for the oversight of recreational and amateur rocket launches and may lack the appropriate structure, depth and detail to allow sufficiently effective and robust oversight of large-scale complex commercial operations involving orbital and sub-orbital payload launches.

Recommendation

Given the potential for change in the nature and scale of rocket launches in the UK, the CAA Large Rocket Launch Permission process should be reviewed to ensure the establishment of an effective framework for the oversight of future orbital and sub-orbital rocket launches in the UK.

8.80 As with other orbital and sub-orbital operations, vertical launch systems would require the support of segregated SUA. The volumes required are likely to be significantly less than for a single-stage to orbit vehicle, but perhaps comparable to those for sub-orbital systems. In addition to the principles applied to sub-orbital spaceplane operations, a segregated corridor of airspace may be required for the release of the various rocket stages of a launch system or for contingency in the case of a system malfunction.

8.81 Airspace to support vertical operations will be designed to exploit the FUA concept through AFUA solutions. A modular airspace design may be necessary to allow airspace solutions to be configured according to the type of operation and system employed. The airspace would then be managed dynamically, allowing exploitation of the airspace by the network when not being utilised for vertical launches.

8.82 In order to reduce the need for fixed airspace structures, and thus minimise the impact on the air traffic route network, the Dynamic Mobile Areas (DMA) concept would support the release of any rocket stages. These DMAs would enable temporary mobile airspace segregation with defined lateral and vertical dimensions and allocated timeframes, but with a variable geographical location along a defined trajectory.

8.83 It should be borne in mind, however, that this airspace segregation is for the safety of other airspace users and does not imply segregation on land or sea for the protection of the uninvolved general public. In the US, Spaceport America is located in a very remote area with low population levels and has significant portions of existing White Sands Missile Range restricted airspace within which to operate safely. Potential locations for a UK vertical launch site are considered in Chapter 9.

8.84 The airspace would be managed by the AMC UK and co-ordinated through the Eurocontrol NMOC, ensuring complete air traffic route network integration.

Managing satellites in orbit

8.85 Currently, there are 1,071 operational satellites in orbit around the Earth. Approximately 50 per cent of these are in Low Earth Orbit. These geocentric orbits, which include the International Space Station, the Hubble Space Telescope and many Earth observation satellites, range in altitude from 160 kilometres to 2,000 kilometres above mean sea level. About 50 – generally global positioning satellites used for navigation – are in Medium Earth Orbit at approximately 20,000 kilometres altitude. A small handful are in elliptical orbits, where they move closer to and further from the Earth, and the remainder are in geo-stationary orbit, at an altitude of almost 36,000 kilometres.[176]

8.86 Integration into the sub-orbital range (ie 100 kilometres to below 200 kilometres) is not viewed as an issue that need be addressed in this paper, as this is considered a volume of relatively 'clean air'. The sub-orbital altitudes are well above the standard operating altitudes of conventional aircraft – including some specialist military systems which operate at higher altitudes – and well below the lowest orbiting systems which aim to achieve an orbital access at approximately 700 kilometres. Therefore, it is considered that no deconfliction would be required with other existing operators in this altitude range, excepting those operating similar operations at the same or similar locations.

Notification for defence and security purposes

8.87 Orbital payload launch operations are co-ordinated with North American Aerospace Defense Command (NORAD) by the satellite launch sponsor, and thus no deconfliction is required in this respect. Notification to the UK military will be required for both vertical and sub-orbital launch activity. All activity will need to be co-ordinated with extant UK military structures through the National Air Defence Operations Centre (NADOC) and the UK Space Operations Coordination Centre (SpOCC).

Recommendation
In order to support UK defence and security objectives, a robust system for notification and co-ordination with UK military structures should be established.

---

[176] C Fraser (2013) 'How many satellites are in space?', *Universe Today*, 24 October 2013, www.universetoday.com/42198/how-many-satellites-in-space (accessed 23 April 2014)

Conclusion

8.88 Airspace and ASM solutions will be essential elements of any regulatory solution developed to enable the safe integration of spaceplane and commercial space operations from the UK. The ASM solutions described in this chapter are in many cases currently available or are part of existing ASM and AFUA developments.

8.89 Airspace solutions will necessarily be developed to support specific types of operation and any associated failure modes. Segregated SUA will likely be required to support all types of orbital and sub-orbital operations, at least initially, until system developments achieve an appropriate level of maturity and consequently enable some limited integration with the air traffic route network.

8.90 The exploitation of a segregated airspace construct, tailored to accommodate specific operational requirements and managed through a robust and dynamic process synchronised with the European air traffic route network, will maintain the integrity of the space access operation, ensure the safety of all airspace users and mitigate the constraints introduced into the network by the establishment of segregated SUA.

Recommendations

8.91 This chapter has made the following recommendations.

- In the short term, spaceplane launches and recovery of unpowered vehicles should take place only within areas of segregated airspace. (*Recommendation 14 in summary report*)
- Depending on the chosen location(s) of a spaceport to support spaceplane operations, the CAA should undertake initial discussions with the MOD and NATS to scope the options for using existing military-managed segregated SUA for spaceplane operations in the medium term, with a view to ensuring the establishment of effective governance and oversight arrangements. (*Recommendation 16 in summary report*)
- An airspace change proposal should be initiated as soon as an aerodrome is selected for spaceplane operations. To enable spaceplane operations to take place in the UK before 2018, this would need to happen within the next few months. (*Recommendation 15 in summary report*)
- Airspace Management notification procedures should be reviewed in full at a time appropriate to the development of the initial anticipated spaceplane operations from the UK. (*Recommendation 17 in summary report*)

- Given the potential hazard to other airspace users from debris in the event of a catastrophic high-altitude system failure, a review should be undertaken – at a time appropriate in the development of SKYLON – to assess the risk to general air traffic activity beneath the SKYLON flight path and, in turn, to identify potential ASM solutions to mitigate any associated risk.
- A review of instrument flight procedure (IFP) design requirements should be conducted at a time appropriate to the development pathway of an aircraft or spaceplane capable of intercontinental very high speed flight, with the aim of determining whether existing guidance can be applied or if new IFP design criteria need to be developed specifically to support such operations.
- Given the potential for change in the nature and scale of rocket launches in the UK, the CAA Large Rocket Launch Permission process should be reviewed to ensure the establishment of an effective framework for the oversight of future orbital and sub-orbital rocket launches in the UK.
- In order to support UK defence and security objectives, a robust system for notification and co-ordination with UK military structures should be established.

APPENDIX 8A

UK airspace classifications

APPENDIX 8B

The SESAR programme

The Single European Sky ATM Research (SESAR) Joint Undertaking is developing processes and services to deliver air traffic network capacity improvements through the exploitation of Advanced Flexible Use of Airspace (AFUA) concepts. Through these developments, increasingly dynamic and flexible solutions are being developed, which will be better able to respond to the airspace requirements to support spaceplane and other commercial space operations.

In particular, they will support flexible construction, to provide the necessary volumes of segregated airspace and the dynamic activation of airspace volumes to provide sufficient time for spaceplane operations. These factors will mitigate the impact of spaceplane operations on other airspace users.

Variable Profile Area

Variable Profile Area (VPA) is an Airspace Management design concept based on flexible allocation and management of fixed predefined modules (or building blocks) of airspace. These modules would be designed to fulfil airspace users' needs individually or as a combination of modules to form a particular Airspace Reservation (ARES),[177] depending on the specific mission profile to be supported. The employment of VPA in the design of airspace for spaceplane and other commercial space operations would allow the establishment of an airspace structure capable of supporting a variety of mission profiles. Each profile would be supported by an associated pre-determined VPA construct.

In the VPA concept, modules are flexibly configured, matching operational needs by requesting the number of modules appropriate to the individual mission, and negotiated through a collaborative decision-making process (CDM). VPAs may be employed in both a free-route and a fixed-route network environment, by both civil and military airspace users.

The principles for the definition of VPA are as follows:

- The construction of the ARES modules shall allow the maximum of flexibility and offer a variety of combinations that can fit the individual airspace user's needs.
- Smaller module volumes (ie 15x15 nautical miles) allow more flexibility – particularly useful in areas of high-density traffic.
- Vertical limits will be adaptable, depending on the mission type, mission objectives and aircraft capabilities.
- ARES will be designed such that any combination of modules should be possible.

---

[177] SESAR terminology encompassing segregated and reserved airspace volumes.

- The ARES airspace status will be automatically defined as a Temporary Segregated Area (TSA), although varying degrees of permeability would be possible.
- The ARES design will take into account the route network in the vicinity to enable capacity to be optimised and to provide for different airspace allocation and re-routeing options.

The conditions for the primacy of use will be defined and protocols established for the allocation and management of the ARES and the associated route network. The VPA modules will be requested by the airspace user and negotiated with the Airspace Managers through a CDM process. The best possible ARES configuration will be allocated to accommodate both mission requirements and air traffic flow demand.

Dynamic Mobile Area

The concept of Dynamic Mobile Areas (DMA) will enable temporary **mobile** airspace segregation with defined lateral and vertical dimensions and timeframe allocations, but with a variable geographical location, potentially along a defined trajectory. Again this concept aims to minimise the impact on the network, while satisfying the needs of airspace users. The DMA concept has the potential to reduce significantly the need for fixed airspace structures.

DMA will be sufficiently dynamic to respond to spaceplane operators’ requirements and will be fully integrated into the route network, and so will be expected to mitigate to an extent the constraints on other airspace users.

A DMA is a VPA by design, with its volume and shape optimised for one individual mission. This concept envisages DMA types 1, 2 and 3, based on VPA design principles. For the purposes of spaceplane operations initially only DMA types 1 and 3 are considered; the timeframe for initial implementation of both is 2016.

DMAs were developed conceptually to support military missions, which often involve several tasks at different locations and different levels (eg air-to-air refuelling and a separate air combat exercise). It is not always possible to allocate a single ARES that encompasses a series of different tasks, as it would represent a significant portion of the airspace and therefore would have too big an impact on the network.

Type 1 DMA is an area of defined lateral and vertical dimensions and a timeframe allocation at a variable geographical location, which is negotiated through a CDM process. The use of type 1 DMAs allows the network manager to propose the location of the requested SUA in order to minimise the impact on the expected commercial traffic, while keeping the transit time between the SUA and the spaceport below the maximum threshold defined by the airspace user. During its activation no change to volume and shape would occur. The use of type 1 DMA could be based on predefined areas as a potential initial evolutionary process to start with, or designed ad hoc.

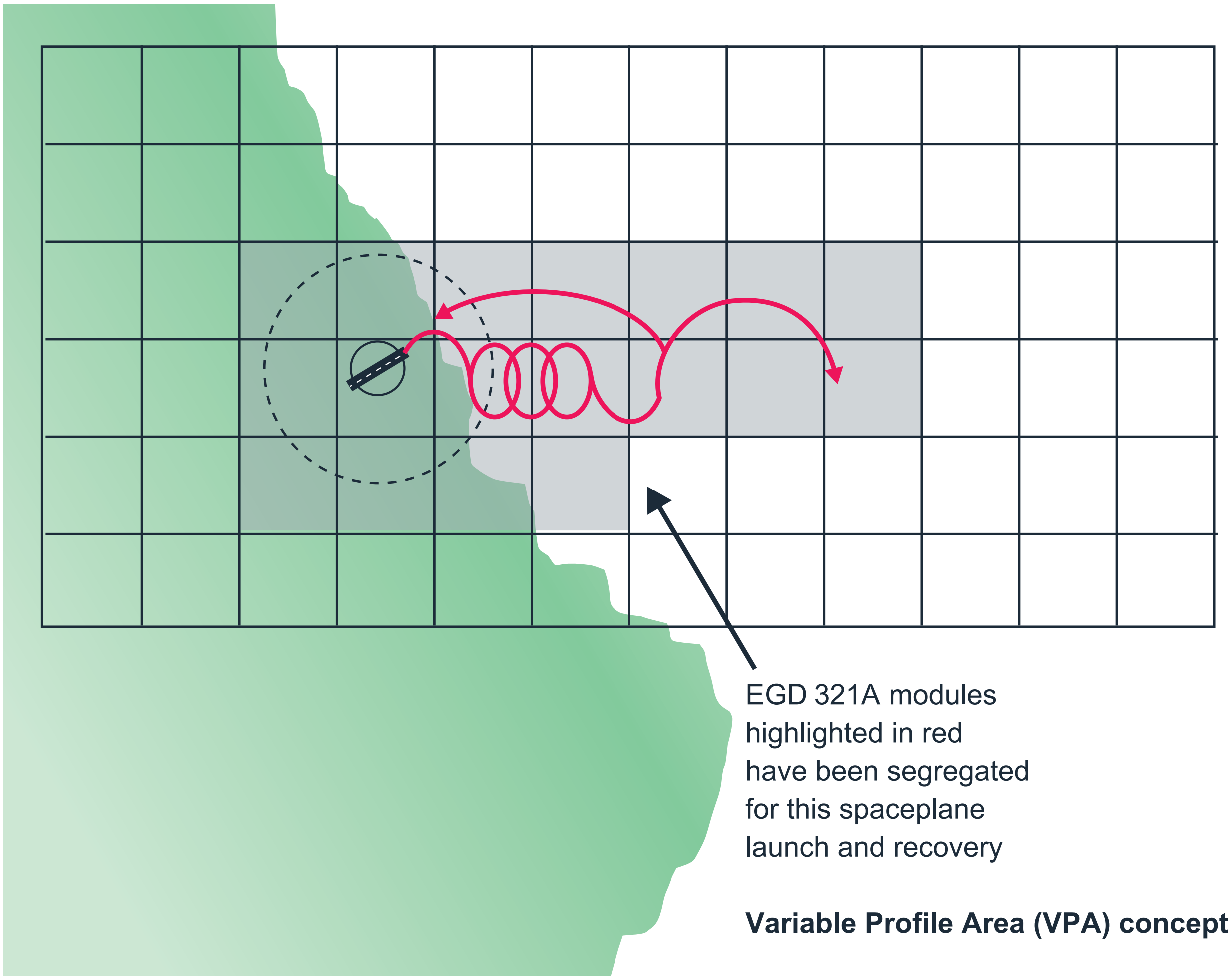


Figure 8.6: Variable Profile Area (VPA) concept

Type 3 DMA is an area with defined lateral and vertical dimensions around a moving activity that requires extra lateral and vertical separation from other trajectories. A type 3 DMA is in effect an airspace ‘bubble’ that moves with the aircraft to maintain its separation from other traffic. This type of DMA not only minimises airspace segregation, and in so doing limits the impact on the route network, but is also beneficial to the airspace user, by increasing flexibility.

During the space shuttle operation, a procedure for the protection of commercial air traffic under the shuttle’s flight path was employed. If a similar procedure proved necessary in the UK, the type 3 DMA offers a potential solution.

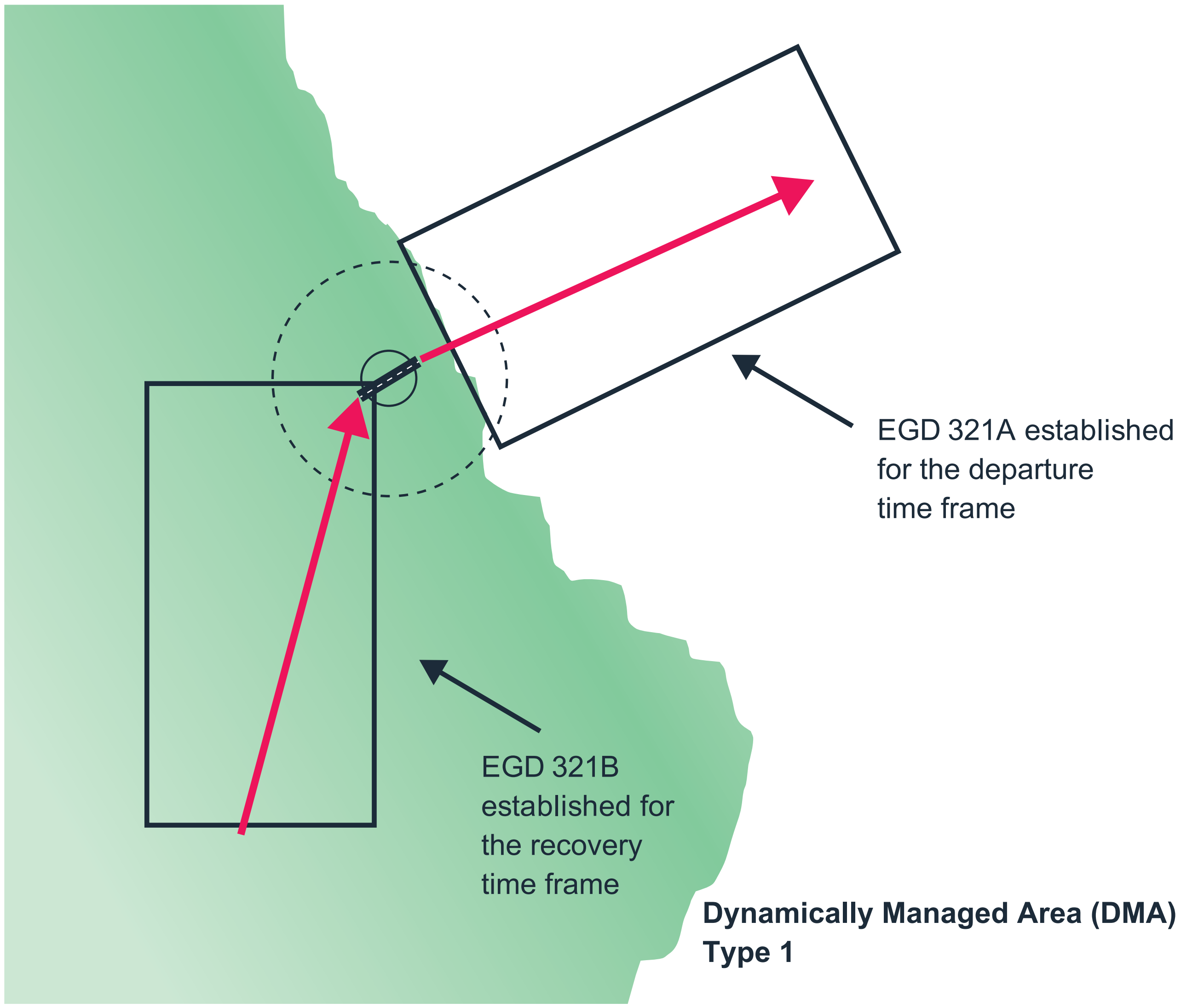
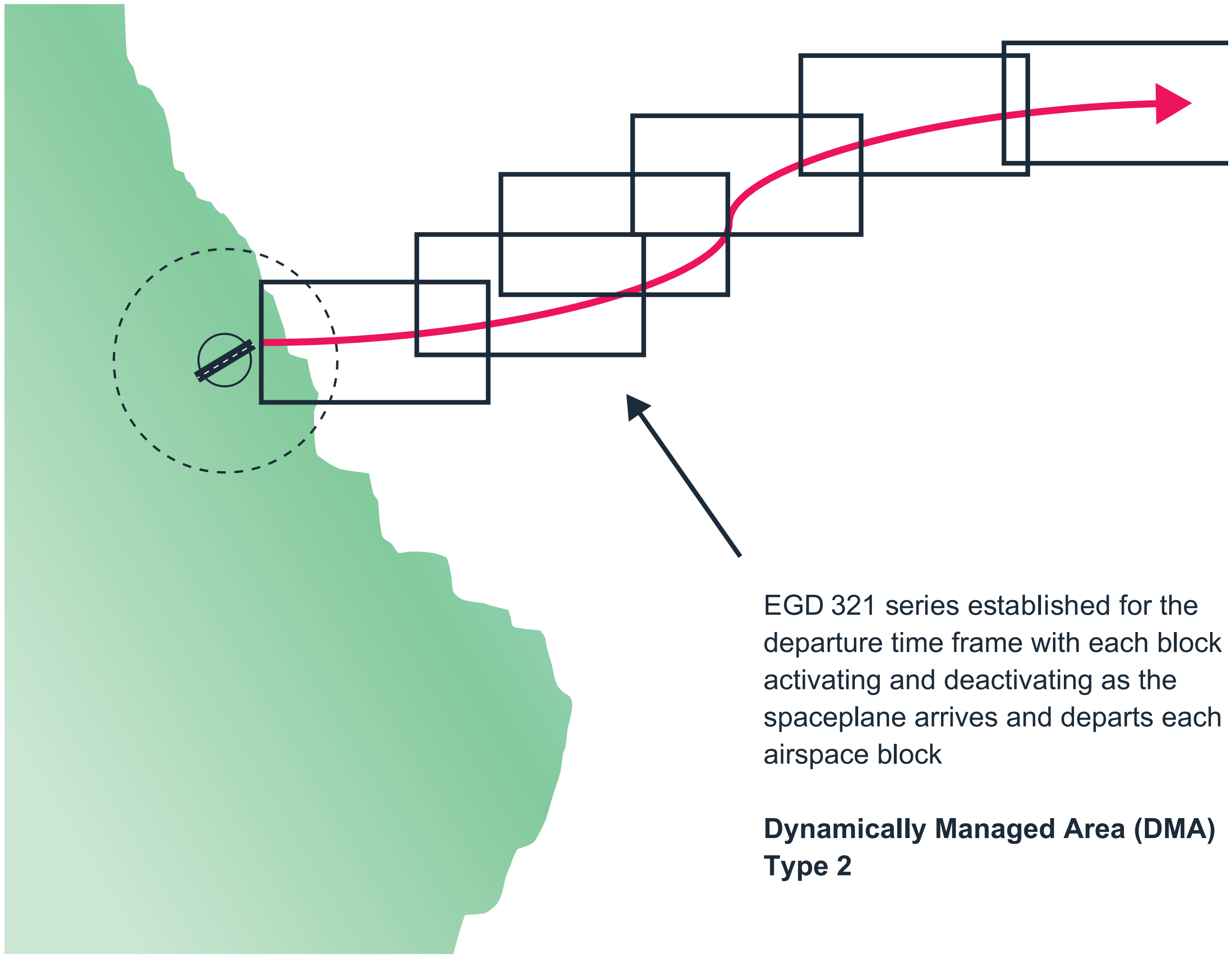


Figure 8.7: Example of a type 3 DMA for an air-to-air refuelling sortie



EGD 321 series established for the departure time frame with each block activating and deactivating as the spaceplane arrives and departs each airspace block

Dynamically Managed Area (DMA) Type 2

Figure 8.8: Example of a DMA type 2

CHAPTER 9

Spaceports and Air Traffic Management

This chapter sets out the key operational requirements for a UK spaceport. It then uses these as criteria to make an initial assessment of existing UK aerodromes to identify which might be suitable locations for a spaceport to allow operations to begin by 2018 or earlier. It provides a shortlist of eight aerodromes which meet the criteria, and indicates the further factors that should be considered in choosing a location for initial spaceplane operations. It also looks at the requirements for a spaceport for vertically launched operations and how these differ. It looks, too, at the requirements for regulating a spaceport, including for Air Traffic Control (ATC).

Overview

9.1 The UK Government's *Plan for Growth* stated that it wanted 'the UK to be the European centre for space tourism and will work with regulatory authorities to define regulations applicable for novel space vehicles that offer low cost access to space'.[178] As was set out clearly in Chapter 3, this fundamentally requires the UK to have a space launch capability: a spaceport. As well as allowing spaceplanes to launch from the UK, hence encouraging operators to consider the UK, the spaceport could also become a hub for the UK space industry and related high-technology industries.

9.2 In its Civil Space Strategy 2012–2016, the UK Space Agency stated 'we will work with the Civil Aviation Authority (CAA) and the European Aviation Safety Agency (EASA) to ensure the right regulatory framework is in place to facilitate UK launch capabilities and space tourism'.[179] The CAA's Strategic Plan 2011–16[180] includes commercial space operations under the strategic objective of enhancing aviation safety, with the need to assess new risks and ensure that the right mitigations can be developed. The CAA Future Airspace Strategy[181] also acknowledged the need to address the regulatory requirements to enable sub-orbital flights in the UK and to exploit existing airspace measures or develop novel Flexible Use of Airspace arrangements to accommodate commercial space operations. This was then followed by a statement in the Innovation and Growth Strategy 2014–2030,[182] where the UK Space Agency indicated that it will work

---

[178] HM Government (2011) *The Plan for Growth*, www.gov.uk/government/uploads/system/uploads/attachment_data/file/31584/2011budget_growth.pdf (accessed 26 May 2014)

[179] UK Space Agency (2012) *Civil Space Strategy 2012–2016*, p18, www.bis.gov.uk/assets/ukspaceagency/docs/uk-space-agency-civil-space-strategy.pdf (accessed 26 May 2014)

[180] CAA (2011) *Civil Aviation Authority Strategic Plan 2011 to 2016*, p15, www.caa.co.uk/docs/1743/CAA%20Strategic%20Plan%202011-16%20v2.pdf (accessed 26 May 2014)

[181] CAA (2011) *Future Airspace Strategy for the United Kingdom 2011 to 2030*, p50, www.caa.co.uk/docs/2065/20110630FAS.pdf (accessed 26 May 2014)

[182] UKspace (2013) *Space Innovation and Growth Strategy 2014–2030: Space growth action plan*, p14, www.gov.uk/government/uploads/system/uploads/attachment_data/file/298362/igs-action-plan.pdf (accessed 23 June 2014)

with the CAA, the Department for Business, Innovation and Skills (BIS) and the Department for Transport (DfT) to establish a suitable framework for safe commercial space operations, with the intention of establishing a spaceport by 2018.

9.3 The mandate for this Review specifically asked the CAA to provide:

- an analysis and recommendations regarding the appropriate regulatory requirements for spaceport operations; and
- recommendations as to the most suitable locations for a spaceport in the UK.

This chapter fulfils those requirements.

Regulatory requirements for spaceport operations

9.4 The UK does not presently have a 'spaceport', and has little or no recent indigenous experience with rocket launch procedures. There is, however, a considerable body of knowledge, expertise and many years of experience in the regulation of aerodromes, Air Traffic Management, Flexible Use of Airspace and Danger Area operation. It is anticipated that much of the regulation that applies to these 'routine' aviation activities will also necessarily apply to spaceplane operations and spaceport management.

9.5 While this chapter deals specifically with spaceport/aerodrome issues, there are strong links and close associations with Chapter 8, which covers airspace and other restricted airspace operations. A growing body of operational expertise is also developing with regard to the use of remotely piloted aircraft systems in segregated airspace, and this will help inform the overall debate.

Recommendations as to the most suitable locations for a spaceport in the UK

9.6 In addition to the regulatory regime, this chapter also assesses possible UK regions and potential locations for their suitability to host spaceplane and vertical launch operations. To do so, it considers several critical factors, including local population density, airspace complexity and regional weather. These would be essential criteria in any decision on where a UK spaceport should be located.

9.7 The first two of these are in line with the stated regulatory priority of protecting the uninvolved general public. Population density is a key factor: in the US, to minimise the risks to the uninvolved general public, the Federal Aviation Administration Office of Commercial Space Transportation (FAA AST) has to date only granted launch licences for proposed launches from either a desert or a coastal location, where population density is lower. Given the likelihood – as set out in Chapter 6 – that the first spaceplane operations in the UK may well take place under an FAA AST launch licence, it is clearly essential that the issue of population density is addressed in the selection of a suitable location for a spaceport.

Finding a location where operations can commence by 2018 or earlier

9.8 However, there is a further critical factor in this Review: the desire to enable sub-orbital spaceplane operations to commence by 2018 or earlier. To meet this demand, it is likely that an interim spaceport solution will need to be found: a new aerodrome could not be built in such a short timescale, since even if construction could be accelerated, the planning and approval process necessarily takes a long time. Therefore, designation and construction of a new, purpose-built spaceport is not a realistic option in the short term.

9.9 Instead, the short-term requirement can best be addressed if spaceplane operations can be allowed to take place from an existing aerodrome. As was discussed in Chapter 2, the majority of spaceplane designs studied to date involve either launch from a carrier aircraft, or take-off (in the manner of an aircraft) from a runway. Therefore some existing aerodromes should be suitable.

9.10 Our assessment therefore applies the three critical factors above – local population density, airspace complexity and regional weather – to UK aerodromes that meet a fourth critical factor: they have a runway that is sufficiently long to enable spaceplane operations, or that could potentially be extended to meet the requirement.

A shortlist of suitable locations

9.11 This chapter does not recommend a single, specific location for a UK spaceport. Instead, it provides a shortlist of existing UK aerodromes that, based on the assessment conducted, could be suitable for spaceplane operations. The CAA Review team has not approached any of the operators of these technically suitable aerodromes to discuss the possibility of its becoming a spaceport.

Vertical launch and economic factors

9.12 A number of technical and economic studies of existing spaceports, and of potential new sites, emphasise the need to cater for both vertical and horizontal launch capabilities. These include a report by the British National Space Centre (BNSC)[183] and one by Surrey Satellite Technology Limited (SSTL).[184] The combination of both vertical and horizontal operations assists in making the economic case for a spaceport more viable.

---

[183] British National Space Centre (2009) *A UK Spaceport – A timely investment in the future*, Report No. 08/09-BNSC 5-16, p68

[184] Surrey Satellite Technology Ltd (2013) ‘Towards a UK launch infrastructure’, p44. Unpublished study, part of the Space Collaborative Innovation Team Initiative (Space CITI) programme within the UK Space Agency’s National Space Technology Programme (NSTP)

9.13 As was made clear at the outset, vertical launch operations are not the primary focus of this Review. However, the economic factors mean that it is important to ask the question of whether suitability for vertical launch should also be a factor in the selection of a UK spaceport site.

9.14 The geographical requirements for vertical launches and for sub-orbital spaceplane operations are different. A number of existing studies – including the two cited above – indicate that, due to its northerly latitude, the UK is only suitable for vertical launch to polar orbit. This has therefore led to the recommendation across these reports (and others) that the area of the UK most suited to a vertical launch site would be the north coast of Scotland – possibly around Dounreay.

9.15 This practical restriction does not exist for sub-orbital spaceplane operations. These could, therefore, potentially take place from a wider set of locations than vertical launch operations.

9.16 Given the goal of enabling spaceplane operations to commence by 2018 or earlier, and the facts that (a) spaceplanes could operate from some conventional aerodromes and (b) a vertical launch facility would have to be built as new, the Review team does not feel it is necessary to delay sub-orbital operations until a combined site could be created. However, this may need further consideration in the future, as and when a vertical launch site is planned.

9.17 In this chapter, the requirements for horizontal and vertical launch scenarios are separated as far as practical. The bulk of the information deals with sub-orbital operations for spaceflight experience and scientific research. Some detail and location information is also provided for vertical launch to orbit.

9.18 The requirements for a single-stage to orbit operation such as SKYLON demand further examination on account of the much larger scale of ground infrastructure and airspace anticipated to be needed, together with other safety aspects, which are expected to differ significantly from early sub-orbital flights.

9.19 Intercontinental very high speed transport, either within the atmosphere or sub-orbital, is many years in the future and will require a very detailed analysis of the operational requirements for this hybrid type of operation.

9.20 The early years of operation of the initial sub-orbital and vertical launch operations will inform the development of future regulatory requirements.

Characteristics of, and considerations for, a spaceport

9.21 The spaceports visited in the US as part of the UK Government technical visit in June 2013, those operational around the world and those specified in spaceport location studies all have identifiable fundamental characteristics, which include:

- a relatively large site with a very long and wide runway;

- a location adjacent to significant volumes of segregated airspace;
- a location in an area of very low population density or near the coast;
- a location in a region with conducive local meteorological conditions.

9.22 Based on the information the Review team has received on spaceplane designs, a spaceport will need to have a runway that is at least 3,000 metres (9,800 feet) long for sub-orbital operations. A substantially longer runway, of the order of 5,000 metres (16,500 feet), may be required for single-stage to orbit operations, again based on information received to date. It is anticipated that runway widths of the order of 45–60 metres will be necessary.

9.23 UK aerodromes have developed over time, and their design, land take and operation vary considerably in terms of size, complexity and intensity. Similarly, existing global spaceports have developed historically, mainly under government control, and again vary greatly in size and operation. It is therefore difficult to indicate what a UK spaceport might physically look like: its design and layout will depend on whether it is built on a greenfield site or utilises an existing aviation site. A spaceport's initial operation would be expected to grow over time, and therefore it may be necessary to safeguard a significant portion of land for future growth. There will also be the requirement to provide suitable 'safety zones' around the location to deal with variable volumes of stored fuels or other explosive materials required for the spaceplane/rocket operation.

9.24 The need for segregated airspace is considered in Chapter 8 of this Review. Suffice it to say here that the complexity and use of nearby airspace is a vital determining factor in selecting a spaceport site, as spaceplane operations are likely to disrupt normal aviation considerably. The need for segregated airspace specifically reflects our stated priority of protecting the uninvolved general public: it minimises the risk of mid-air collision.

9.25 As was highlighted above, this same priority is why local population density is vital in deciding where a spaceport could be located. Population data, based on 2011 Census data (updated for 2013) as supplied by CACI Information Services Ltd, indicates that certain areas may not be suitable for a spaceport, due to high local populations or the presence of built-up areas where people live or work under any proposed flight paths. Further investigation is required to ascertain whether a UK site could meet the FAA AST criteria for safety of the uninvolved public.

9.26 Meteorological conditions across the UK are very variable in terms of cloud cover, wind speed, rain and temperature. Specific conditions, such as strong crosswinds or heavy cloud, may hamper operations or restrict the number of days when sub-orbital flights or rocket launches can take place, thus reducing the economic viability of a spaceport in a particular region. Limited information from potential operators is available about the capability of their spaceplanes to operate in cloud, under instrument meteorological conditions (IMC). Limited information is also available with regard to the issue of spaceplane icing.

9.27 Ultimately, a balance will need to be struck that takes account of all these factors and that will inform the overall economic case for a particular location. For example, an additional factor seen at many existing spaceports is a coastal location. This has the benefits of a suitably low population density and reasonable remoteness, and so meets safety requirements. However, it may mean that the location suffers from weather conditions that are not conducive to spaceport operations, or that the area does not have good transport links by land, sea and air to cater for the general logistics of staff and visitors.

9.28 The UK Institute of Directors (IoD) identified the same issues in its 2012 report, which attempted to identify a location for a spaceport.[185] Similar findings were presented to the BNSC in 1995 by AEA Technology.[186]

Applying existing aerodrome regulation

9.29 Significant changes will occur to aerodrome regulation in the UK during 2014, with EASA requirements beginning to take effect and continuing until the end of 2017. The Military Aviation Authority (MAA) currently regulates military aerodromes and MAA oversight and assurance processes will cover any proposed military site. Based on proposed timescales for sub-orbital operations, there are a number of possible regulatory scenarios for a spaceport within what will be the new aerodrome regulatory structure:

- a sub-orbital operation (permanent or temporary) at an existing EASA-certificated aerodrome;
- a sub-orbital operation (permanent or temporary) at an existing CAA-licensed aerodrome;
- a sub-orbital operation (permanent or temporary) at an existing UK unlicensed or private aerodrome;
- a sub-orbital operation at an existing UK military aerodrome; or
- operations taking place at a purpose-built spaceport, either on a greenfield site or an ex-military facility for either, or both, sub-orbital and vertical launch.

9.30 Regardless of which of the above possible scenarios is used, the requirement for restricted or segregated airspace and for third party safety remains the same, irrespective of spaceport type. If EASA or CAA aerodrome requirements are used, then an existing, well-understood process of oversight can be applied at

---

[185] Institute of Directors (2012) *Space: Britain's new infrastructure frontier*, pp20–21, www.iod.com/mainwebsite/resources/document/space-britains-new-infrastructure-frontier-may12.pdf (accessed 14 April 2014)

[186] AEA Technology (1995) *Dounreay Small Satellite Launch Facility*, AEA Technology, Space and Defence Systems (SDS) Department, Culham, England.

these locations. Any additional commercial spaceflight activity can be viewed as an 'add on' to the day-to-day aerodrome operation, with a specific safety case for the operation.

9.31 The basic structure of the EASA certification or the CAA licensing regimes should be used, together with an additional process for rocket or sub-orbital operations, as this will need to be a unique and bespoke procedure related to the specific location. There will be a future training requirement for existing CAA aerodrome and air traffic service (ATS) personnel to become familiar with the characteristics of sub-orbital operations, both on the ground and in the airspace, to provide adequate oversight.

9.32 If a spaceplane operation took place at an unlicensed or private site, then the CAA would have little oversight of the ground operations. However, the airspace and Air Traffic Management (ATM) safety procedures would still be required to ensure the safety of third parties in the air and on the ground.

Recommendation

Sub-orbital operations should commence, either on a permanent or a temporary basis, from one (or more) of the following:

- an existing EASA-certificated aerodrome;
- an existing CAA-licensed aerodrome; and/or
- an existing UK military aerodrome, subject to approval from the MOD.

Recommendation

In order to make maximum use of existing infrastructure, the location should still be active but at a low level of aircraft movements. It should have existing and appropriate ground infrastructure/facilities and Air Traffic Control.

9.33 Whichever region and specific location is chosen, the overriding safety requirement will be the safety of the uninvolved general public. This will be directly related to ground blast zones, restricted airspace and any stage drop zone requirements or down-range non-nominal occurrences. A regulatory framework of some kind will still be required in this case.

Assessing the suitability of UK aerodromes

9.34 The Review team has assessed UK aerodromes against the critical factors identified above. The first part of the assessment is an analysis of whether an aerodrome meets the fundamental requirement of runway length.

9.35 Declared distances for UK licensed aerodromes are published in the UK Aeronautical Information Publication (AIP)[187] and other documents, such as

---

[187] See www.nats-uk.ead-it.com/public/index.php.html (accessed 14 April 2014)

Pooley's Flight Guide.[188] Information on military aerodromes was obtained from the En-Route Supplement, British Isles and North Atlantic.[189] In all, 46 aerodromes in the UK were identified either as meeting the requirement for runway length (ie having a runway of at least 3,000 metres, or a runway of at least 2,000 metres that could be extended). Actual runway condition or suitability at the suggested locations has not been assessed at this stage.

9.36 A number of aerodromes are listed which do not have the runway length required for initial spaceplane operations at the time of writing, but may have the possibility to extend their runway in the future, as part of a wider spaceport operation. Runway extension and aerodrome expansion will need to be carried out through the normal development and planning procedures and the timescales related to those procedures.

9.37 Consideration will also have to be given to the indirect costs of disruption to the normal operations, during the runway extension engineering works, which could take several months to complete.

9.38 Table 9.1 indicates initial potential sites in England, Scotland, Wales and Northern Ireland, with the main runway length shown in metres for civil and military aerodromes – with the longest first. For each of these 46 aerodromes, a general assessment of airspace issues and local population density was carried out (using data from CACI Ltd on residential populations within specific distances of each aerodrome) and a broad conclusion reached about the aerodrome's potential suitability for hosting spaceplane operations. Full details of the population data are shown in Appendix 9B.

9.39 It is important to underline that this initial assessment is simply about whether or not an aerodrome would be technically suitable for spaceplane operations, and whether or not essential criteria could be met. It has not investigated the operational requirements for diversion aerodromes.

Location	Runway length (metres)	Airspace/ATM	Population density	Site potential
London Heathrow Operator: Heathrow Airport Ltd	3,901	The UK's busiest airport, operating close to capacity. Very complex airspace in the London terminal manoeuvring area (TMA).	Large areas of dense population in the vicinity.	Not a realistic site for a sub-orbital operation.

---

[188] R Pooley, R Patel and S Pooley (eds) (2011) *Pooleys Flight Guide 2012*, 50th edition, Elstree, Pooley's Flight Equipment Ltd

[189] No1 Aeronautical Information Documents Unit, *En-Route Supplement: British Isles and North Atlantic* (effective 1 May 2014), available to order at www.aidu.mod.uk/Milflip/ (accessed 23 May 2014)

Location	Runway length (metres)	Airspace/ATM	Population density	Site potential
London Gatwick Operator: Gatwick Airport Ltd	3,316	The UK's second busiest airport. Very complex airspace in the London TMA.	Large areas of dense population in the vicinity.	Not a realistic site for a sub-orbital operation.
Boscombe Down Ministry of Defence (MOD) site operated by QinetiQ.	3,182	Located close to Danger Areas of Salisbury Plain, but with restricted levels. Familiarity with test flight operations.	Relatively close proximity to Salisbury and Andover.	Possible site, with MOD/QinetiQ agreement. Additional airspace protection required. Further research required.
RAF Brize Norton	3,050	Active military airfield, located close to the Daventry control area (CTA) and major airways to/from North Atlantic. Very busy Swanwick sector.	Some medium population density in the vicinity.	Possible site, with MOD agreement Additional airspace protection required. Further research required.
London Stansted Airport Operator: Stansted Airport Ltd	3,050	London's third airport, busy traffic, complex airspace structures.	Relatively built-up areas in the vicinity.	Not a realistic site for a sub-orbital operation.
Manchester Airport Operator: Manchester Airport plc	3,050	Busy airport, complex airspace structures of Manchester TMA.	Large areas of dense population in the vicinity.	Not a realistic site for a sub-orbital operation.
Campbeltown Airport (Machrihanish) Operator: Highlands and Islands Airports Ltd (HIAL)	Potential 3,049 – currently operated as 1,750	Very low traffic levels. Large areas of water over which to operate. Large areas of Class G airspace (uncontrolled): would therefore require additional protection.	Situated near the coast on the Mull of Kintyre. Very low population density.	Possible site, agreement needed from HIAL. Further research required.

Location	Runway length (metres)	Airspace/ATM	Population density	Site potential
RAF Fairford	3,046	Standby airfield located close to RAF Brize Norton and the Cotswold CTA and major airways to/from North Atlantic and Southern Ireland, very busy sector.	Relatively low population density in the vicinity.	Possible site, MOD agreement needed. Additional airspace protection required. Further research required.
Bruntingthorpe	3,000	Unlicensed aerodrome used for vehicle testing, aircraft storage and as a museum. Located close to very busy airspace and airports.	Some medium population density in the vicinity.	Not a realistic site for a sub-orbital operation.
Glasgow Prestwick Airport Operator: Glasgow Prestwick Airport Ltd	2,987	Large aerodrome, close to the coast with low traffic levels.	Relatively low population density to the north and east, but quite built up close to the airport.	Possible site but new restricted airspace would be required. Further research required.
East Midlands Airport Operator: East Midlands International Airport Ltd	2,893	Located beneath very busy airspace of the Daventry sector.	Relatively built-up areas in the vicinity.	Not a realistic site for a sub-orbital operation.
Doncaster Sheffield Airport Operator: Peel Airports	2,893	Situated close to busy civil and military airspace.	Relatively built-up areas in the vicinity.	Possible site but new restricted airspace required. Further research required.
RAF Mildenhall	2,810	Active airfield currently operated by US Air Force (USAF). Situated in close proximity to several other military airfields. Large areas of Class G airspace.	Relatively low population density in the vicinity.	Possible site, MOD agreement needed. Additional airspace protection required. Further research required.

Location	Runway length (metres)	Airspace/ATM	Population density	Site potential
RAF Marham	2,783	Active military airfield. Situated in close proximity to several other military airfields. Large areas of Class G airspace.	Relatively low population density in the vicinity.	Possible site, MOD agreement needed. Additional airspace protection required.
Belfast Aldergrove Airport Operator: Belfast International Airport Ltd	2,780	Busy civil aerodrome in Northern Ireland. Belfast TMA is a complex airspace due to upper ATS routes and North Atlantic Track Structure interaction.	Relatively low population density in the vicinity.	Not a realistic site for a sub-orbital operation.
RAF Wittering	2,759	Active military airfield. Situated in close proximity to several other military airfields. Large areas of Class G airspace. Also close to the Daventry CTA.	Relatively low population density in the vicinity.	Possible site, MOD agreement needed. Additional airspace protection required. Further research required.
RAF Lossiemouth	2,755	Active military airfield. Close to large Danger Areas.	Relatively low population density in the vicinity. Coastal location.	Possible site, MOD agreement needed. Additional airspace protection required.
Manston Airport Operator: Skyport Ltd	2,752	Situated beneath very complex and busy airspace of the Worthing CTA.	Some medium population density in the vicinity.	Not a realistic site for a sub-orbital operation.
Newquay Cornwall Airport Operator: Cornwall Airport Ltd	2,744	Located in Class G airspace close to the coast and relatively close to Danger Area (DA) 064 complex, which extends up to FL660 (approx. 66,000 feet)	Relatively low population density in the vicinity.	Possible site, some additional segregated airspace required to join DA 064. Further research required.

Location	Runway length (metres)	Airspace/ATM	Population density	Site potential
RAF Coningsby	2,744	Active military airfield. Situated in close proximity to several other military airfields. Large areas of Class G airspace. Busy military training areas in vicinity.	Relatively low population density in the vicinity.	Possible site, MOD agreement needed. Additional airspace protection required. Further research required.
RAF Waddington	2,743	Active military airfield. Situated in close proximity to several other military airfields. Large areas of Class G airspace. Busy military training areas in vicinity.	Relatively low population density in the vicinity.	Possible site, MOD agreement needed. Additional airspace protection required. Further research required.
RAF Lakenheath	2,743	Active airfield currently operated by USAF. Situated in close proximity to several other military airfields. Large areas of Class G airspace.	Relatively low population density in the vicinity.	Possible site, MOD agreement needed. Additional airspace protection required. Further research required.
RAF Scampton	2,740	Active military airfield. Situated in close proximity to several other military airfields. Large areas of Class G airspace.	Relatively low population density in the vicinity.	Possible site, MOD agreement needed. Additional airspace protection required. Further research required.
Glasgow Airport Operator: Glasgow Airport Ltd	2,665	Busy civil aerodrome within the Scottish TMA.	Large areas of dense population in the vicinity.	Not a realistic site for a sub-orbital operation.
Birmingham Airport Operator: Birmingham Airport Ltd	2,599	Busy civil aerodrome, complex airspace structures overhead.	Large areas of dense population in the vicinity.	Not a realistic site for a sub-orbital operation.

Location	Runway length (metres)	Airspace/ATM	Population density	Site potential
RAF Leuchars	2,585	Active military airfield. Coastal location. Close to Scottish TMA. Large areas of Class G airspace.	Relatively low population density in the vicinity.	Possible site, MOD agreement needed. Additional airspace protection required. Further research required.
Edinburgh Airport Operator: Edinburgh Airport Limited	2,556	Busy civil aerodrome within the Scottish TMA.	Large areas of dense population in the vicinity.	Not a realistic site for a sub-orbital operation.
RAF Wyton	2,515	Active military airfield. Situated in close proximity to several other military airfields. Large areas of Class G airspace. Also close to the Daventry CTA.	Relatively low population density in the vicinity.	Possible site, MOD agreement needed. Additional airspace protection required. Further research required.
Farnborough Airport Operator: TAG Farnborough Airport Ltd	2,440	Busy civil aerodrome, complex airspace structures overhead with London TMA.	Large areas of dense population in the vicinity.	Not a realistic site for a sub-orbital operation.
Warton Operator: BAE Systems	2,422	Active test flight centre. Close proximity to the Manchester TMA.	Large areas of dense population in the vicinity.	Not a realistic site for a sub-orbital operation.
Cardiff Airport Operator: Cardiff International Airport Ltd	2,392	Regional airport with relatively low traffic levels. Situated close to two major airways and busy airspace.	Relatively low population density in the vicinity.	Not a realistic site for a sub-orbital operation.
RAF Cottesmore	2,383	Inactive military airfield. Situated in close proximity to several other military airfields. Large areas of Class G airspace. Also close to the Daventry CTA.	Relatively low population density in the vicinity.	Possible site, MOD agreement needed. Additional airspace protection required. Further research required.

Location	Runway length (metres)	Airspace/ATM	Population density	Site potential
RAF Honington	2,379	Situated in close proximity to several other military airfields. Large areas of Class G airspace. Busy military training areas in vicinity.	Relatively low population density in the vicinity.	Possible site, MOD agreement needed. Additional airspace protection required. Further research required.
Kinloss Barracks	2,344	Military barracks used as relief landing ground for RAF Lossiemouth.	Relatively low population density in the vicinity.	Possible site, MOD agreement needed. Additional airspace protection required. Further research required.
Newcastle Airport Operator: Newcastle International Airport Ltd	2,329	Relatively busy regional airport. Possible access to North Sea Danger Areas.	Large areas of dense population in the vicinity.	Possible location. Further research required.
Stornoway Airport Operator: HIAL	2,315	Very low traffic levels. Large areas of water over which to operate. Class G airspace would require additional protection.	Situated near the coast on the Isle of Lewis. Very low population density.	Possible location. Further research required.
RNAS Yeovilton	2,292	Active Naval Air Station. Class G airspace.	Relatively low population density in the vicinity.	Possible location. Further research required.
Durham Tees Valley Airport Operator: Durham Tees Valley Airport Ltd	2,291	Regional airport with relatively low traffic levels. Possible access to North Sea Danger Areas.	Large areas of dense population in the vicinity.	Possible location. Further research required.
RAF Leeming	2,289	Active RAF station. Class G airspace, very busy military flying area.	Relatively low population density in the vicinity.	Possible location. Further research required.

Location	Runway length (metres)	Airspace/ATM	Population density	Site potential
Llanbedr Airport Operator: Llanbedr Airfield Estates LLP	2,289	Disused since 2004, previous use as test flying site. Coastal location adjacent to Danger Area in Cardigan Bay.	Relatively low population density in the vicinity.	Possible location, further research required.
Liverpool Airport Operator: Liverpool Airport Ltd	2,285	Regional airport with relatively low traffic levels.	Large areas of dense population in the vicinity.	Not a realistic site for a sub-orbital operation.
Bournemouth Airport Operator: Bournemouth International Airport Ltd	2,271	Regional airport with relatively low traffic levels. Busy airspace sector above.	Large areas of dense population in the vicinity.	Not a realistic site for a sub-orbital operation.
Leeds Bradford Airport Operator: Leeds Bradford International Airport Ltd	2,250	Regional airport with relatively low traffic levels. Busy airspace sector above.	Large areas of dense population in the vicinity.	Not a realistic site for a sub-orbital operation.
Humberside Airport Operator: Eastern Group	2,196	Regional airport with relatively low traffic levels. Class G airspace and busy military training in the vicinity.	Large areas of dense population in the vicinity and large-scale industrial areas.	Not a realistic site for a sub-orbital operation.
London Luton Airport Operator: Abertis	2,160	Busy London airport, very busy London TMA.	Large areas of dense population in the vicinity.	Not a realistic site for a sub-orbital operation.
RAF Lyneham	2,070	Disused RAF airfield. Positioned beneath very busy airways connecting London/ Europe to the North Atlantic.	Relatively low population density in the vicinity.	Not a realistic site for a sub-orbital operation.

Table 9.1: Spaceport operational criteria and possible locations

Analysis

9.40 The assessment of the 46 potential sites in Table 9.1 indicates that there are just nine UK aerodromes with runways in excess of 3,000 metres. Of these, four (Heathrow, Gatwick, Stansted and Manchester) are not realistic on account of:

- existing high-intensity commercial air transport operations;
- high population density; and
- complex airspace in their vicinity.

9.41 Of the remaining five locations, three (Boscombe Down, RAF Brize Norton and RAF Fairford) are existing operational military aerodromes. **Campbeltown** is a very quiet aerodrome on the West Coast of Scotland, which possesses a runway in excess of 3,000 metres. However, the full runway has not been used operationally for some years. Bruntingthorpe is a disused aerodrome in the Midlands, situated beneath very busy airspace and therefore not considered suitable.

9.42 There are 19 locations with runways between 2,500 and 3,000 metres which could potentially be utilised if runway extensions were provided. Of these 19 locations, six (East Midlands, Belfast Aldergrove, Manston, Glasgow, Birmingham and Edinburgh) are initially considered unrealistic for sub-orbital operations for the same reasons noted above. Thirteen locations in this group (**Glasgow Prestwick, Doncaster Sheffield, RAF Mildenhall, RAF Marham, RAF Lossiemouth, RAF Wittering, RAF Leuchars, Newquay Cornwall Airport, RAF Coningsby, RAF Waddington, RAF Lakenheath, RAF Wyton** and **RAF Scampton**) are considered possible locations, subject to runway extensions and provision of appropriate segregated airspace.

9.43 Fifteen locations have also been identified as having runway lengths between 2,200 and 2,499 metres, of which eight (**RAF Cottesmore, Kinloss Barracks, Newcastle, Stornoway, RNAS Yeovilton, Durham Tees Valley, RAF Leeming** and **Llanbedr**) are potential sites where more significant runway extensions, additional airspace protection and additional local analysis and research may allow sub-orbital operations to take place. Three further locations have a runway of between 2,000 and 2,199 metres, but none are considered realistic sites.

9.44 Therefore, of the original 46 potential locations, identified from a runway length perspective and shown in Table 9.1, 20 can be removed as inappropriate for sub-orbital operations either because of their proximity to urban areas or existing busy airspace, or because they are busy military aerodromes, where sub-orbital flights may not be compatible with military operations. This leaves 26, as shown in Figure 9.1.

Recommendation

To allow sub-orbital operations in the near future, possible locations should be selected from the identified list and further investigations carried out as to their viability. Government will need to agree a process for how sites would be selected.

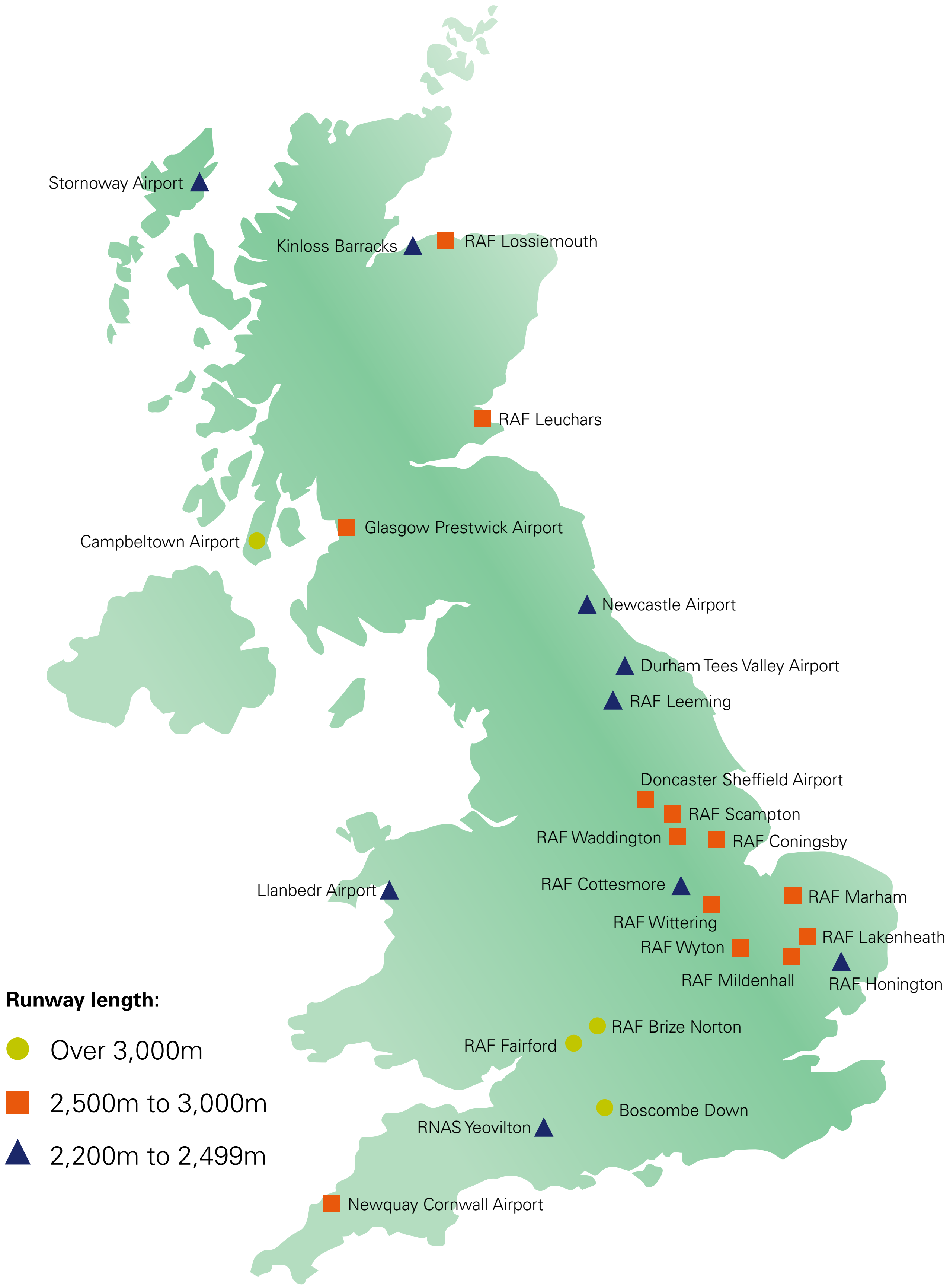


Figure 9.1: Locations of UK civil and military aerodromes which could potentially host sub-orbital operations

The requirement for a coastal location

9.45 As was set out earlier in this Review, it is anticipated that initial spaceplane operations in the UK may take place under a wet lease type arrangement, in which a US operator is wholly responsible for the entire operation, which would be conducted under licence from the FAA AST. In such circumstances, it is expected that the FAA AST would require operators to meet certain safety criteria, and in particular to carry out an expected casualty analysis. The result of this analysis, which is based on the possible impact of an incident and how many people would be affected, needs to demonstrate that operations are safer than the minimum standards stated by the FAA AST. To date, this has resulted in the FAA AST licensing operations only in areas of very low population density, such as desert or coastal locations. This would imply that the site for initial UK spaceplane operations should also be a coastal location.

Recommendation

In order to ensure the safety of the uninvolved general public and to enable initial operations under a wet lease type arrangement to take place in line with FAA AST launch site licensing requirements, the Review strongly recommends that a UK spaceport should be established at a coastal location.

9.46 Following this recommendation, the list of potential sites from which sub-orbital operations could occur would be reduced to eight, as can be seen on the map in Figure 9.2 below.

9.47 Of these eight:

- one, Campbeltown Airport, has a runway potentially over 3,000 metres long;
- four – Glasgow Prestwick Airport, Newquay Cornwall Airport, RAF Leuchars and RAF Lossiemouth – have a runway between 2,500 metres and 3,000 metres long, so would require a runway extension to allow spaceplane operations; and
- the other three have a runway between 2,200 metres and 2,500 metres long. Each would, therefore, need a significant runway extension that would require considerable investment. One of these, Llanbedr, is unlicensed at the time of writing, so – if the recommendations set out earlier in this chapter were followed – it would also need to apply for a CAA licence or EASA certification, so that appropriate aerodrome safety regulation could be provided. This might necessitate some changes to ensure that the aerodrome meets the required standards for licensing/certification.

9.48 While the initial 46 have been reduced to eight, there is always the possibility that a discounted site could be re-instated following a more detailed operational and safety analysis in the future. It should be reiterated that while eight possible locations have been identified in this Review, no detailed discussions have taken place with existing civil or military aerodrome or site operators to ascertain their appetite for sub-orbital operations.

9.49 As part of the selection process, it would be appropriate to carry out an expected casualty analysis, using the FAA AST criteria, to ensure that any sites proposed would meet the required standards.

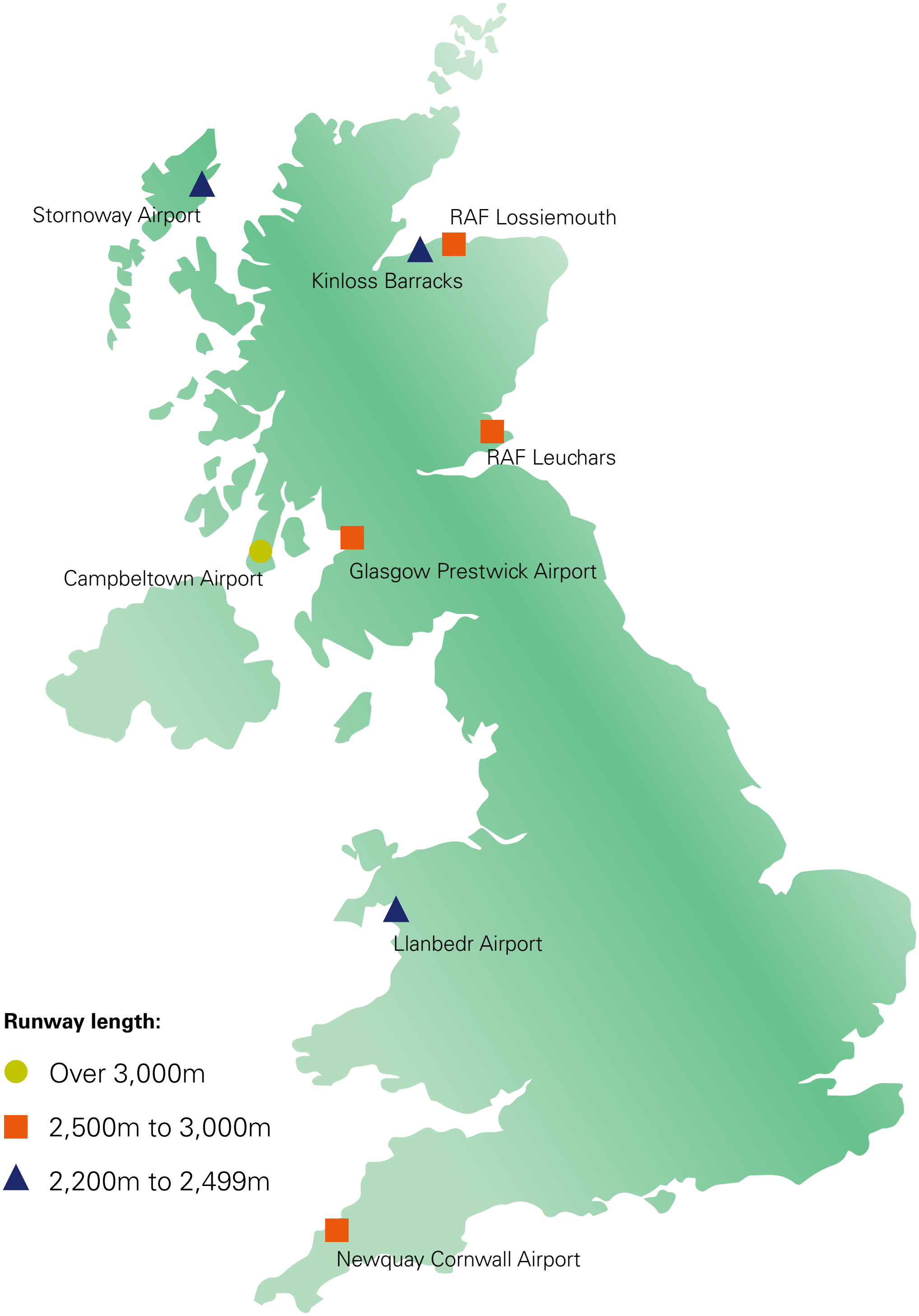


Figure 9.2: Locations of UK coastal civil and military aerodromes which could potentially host sub-orbital operations

Spaceports at a UK Overseas Territory

9.50 Consideration has also been given to the possibility of a spaceport location at one of the United Kingdom's Overseas Territories. The UK has 14 Overseas Territories spread across the world.[190] As in the investigation above, the initial criterion was a runway in excess of 2,500 metres, preferably 3,000 metres. Using this criterion, aerodromes at the following locations are also potential locations for spaceport operations:

- British Indian Ocean Territory (Chagos Islands/Diego Garcia) (3,659 metres);
- Ascension Island (3,054 metres); and
- Falkland Islands (2,590 metres).

9.51 Thanks to their proximity to the equator, both Diego Garcia and Ascension Island would also be suitable for vertical launches to orbit. Both of these aerodromes are in use by the MOD, and are therefore active airfields with some existing facilities. Initial investigation of the weather conditions for both Ascension Island and Diego Garcia indicates that they could be acceptable for both vertical and horizontal launch operations. No other assessment of suitability has been undertaken.

Recommendation

To provide more clarity and begin the development of future capability, further detailed consideration should be given to a limited number of locations in the UK and its Overseas Territories, where more detailed analysis could be carried out to assess their suitability for sub-orbital, vertical launch or single-stage to orbit operations.

Infrastructure and facility requirements for spaceports

9.52 Irrespective of the type of spaceport and its regulatory regime, a number of facilities, operational capabilities, activities and infrastructure requirements will be needed to support any potential operations.

9.53 Existing aerodromes will have facilities such as runways, taxiways, aprons and hangars that can be utilised. A sub-orbital operation at an existing aerodrome will, however, require a set of new procedures and agreements to allow the operation to be integrated into existing flight schedules.

9.54 Existing aerodromes may not require any additional land take, unless a runway extension is considered necessary. A simple vertical launch site may also be a relatively small area, but will require bespoke ground facilities.

---

[190] See www.gov.uk/government/policies/protecting-and-developing-the-overseas-territories (accessed 14 April 2014)

9.55 Any future expansion and major development will require a much larger facility footprint. The unpublished SSTL study indicates that a simple, single vertical launch site for small launch vehicles would have a land take of about 5 square kilometres.[191] Future expansion with multiple vertical launch pads and a runway of significant length (3,000–5,000 metres) should also be safeguarded, suggesting a land take of approximately 65 square kilometres. As a direct comparison, London Heathrow Airport is approximately 12 square kilometres, and both London Gatwick and London Stansted are approximately 8 square kilometres. Spaceports, due to the safety distances required, could, in the future, potentially be very large sites.

9.56 Examples of potential spaceport layouts and land take are shown below in Figures 9.3, 9.4 and 9.5.

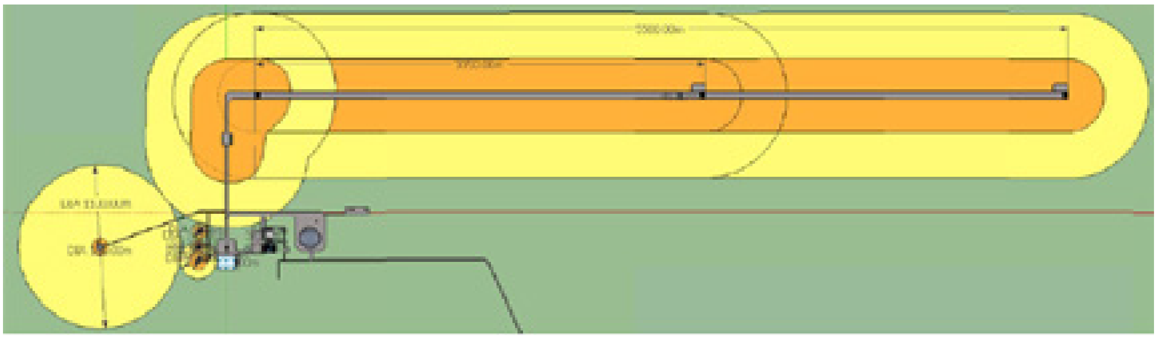


Figure 9.3: Indicative horizontal launch site, approx. 16 square kilometres (courtesy of SSTL)

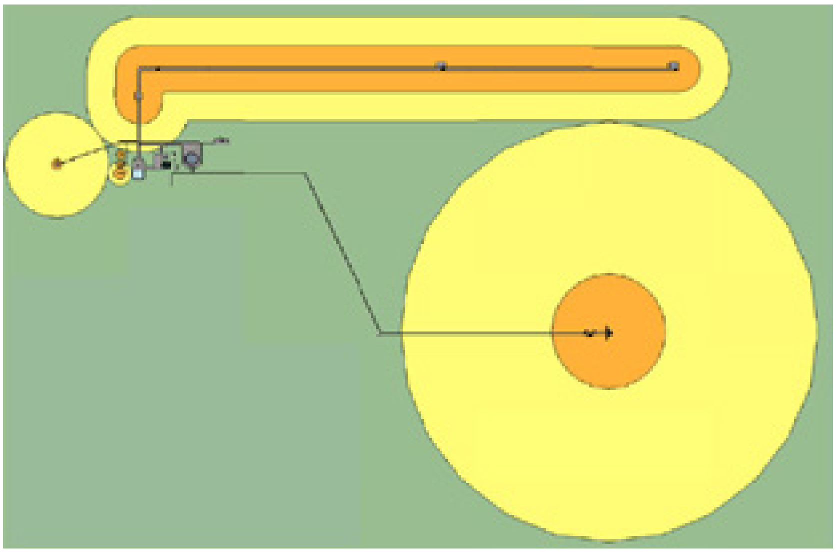


Figure 9.4: Indicative horizontal and single vertical launch site, approx. 45 square kilometres (courtesy of SSTL)

---

[191] Surrey Satellite Technology Ltd (2013) 'Towards a UK launch infrastructure', p90. Unpublished study

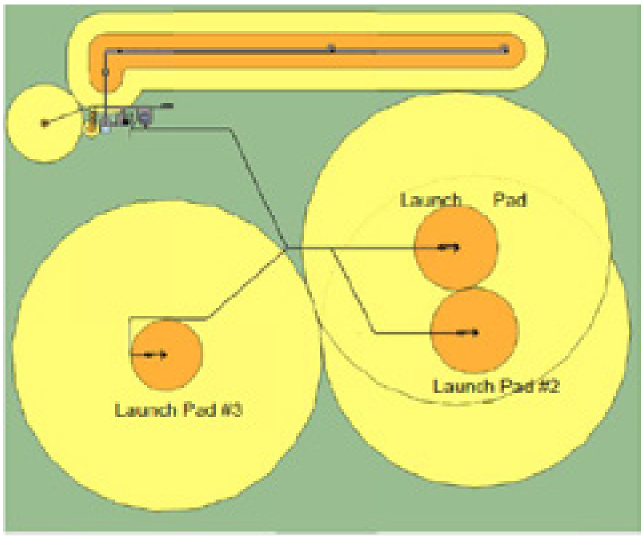


Figure 9.5: Indicative horizontal and multiple vertical launch site, approx. 65 square kilometres (courtesy of SSTL)

Meteorological considerations

9.57 As was stated in paragraph 9.6 above, meteorological conditions will be a vital determinant in the selection of suitable locations for spaceplane operations, and can indeed aid selection of a specific site from those shortlisted where the fundamental operating criteria are met.

9.58 The Review has therefore used regional meteorological information, sourced directly from the Met Office website, as an indicator of typical weather conditions experienced in each region.[192] The data is factual and obtained over many decades. However, before selecting a site, it may need further investigation, taking into account local weather conditions at each of the potential locations.

9.59 There will be differences in the acceptable meteorological conditions for each commercial space operator and their respective launch vehicles. These criteria will differ with respect to cloud cover, wind speed, precipitation and temperature. For example, early indicators (which need to be confirmed) suggest that initial spaceplane operations will have limiting crosswind requirements. In addition to low-level wind speeds, upper-air wind speeds are also important for flight planning purposes. Obviously there will also be differences here between vertical launch and those launches requiring a runway.

9.60 In addition to wind speed, the orientation of the location runway will also be an important factor. A runway oriented into the prevailing wind (typically from the south-west in the UK) will allow more opportunities to operate.

---

[192] See http://metoffice.gov.uk/climate/uk/regional/ (accessed 14 April 2014)

9.61 Early entrants to the sub-orbital market are expecting to offer the 'view from space' as part of the spaceflight experience, and will therefore require weather conditions appropriate to providing that experience. Sub-orbital flights with a scientific payload may have less restrictive weather criteria. Future intercontinental very high speed flights should be expected to operate in a similar mode to current-day commercial flight operations.

9.62 Therefore the key meteorological data we have gathered include hours of sunshine (as an indicator of cloud cover), wind speed and rainfall. These are included as the main factors that could affect safe visual flight rules (VFR) operations and adversely affect the spaceflight experience.

9.63 The number of hours of bright sunshine is controlled by the length of day and cloudiness.

9.64 Typically in summer, the northern part of the country experiences more hours of daylight (sunrise to sunset) than the southern half. This effect is reversed in the winter, with the northern part of the UK experiencing much shorter days than the south. For example, Inverness at the summer solstice (21 June) experiences approximately 18 hours from sunrise to sunset (0415–2215), while Truro in Cornwall experiences approximately 16 hours 20 minutes (0510–2130). During the winter solstice (21 December) the length of daytime is approximately 6 hours 30 minutes in Inverness (0900–1530), compared to 8 hours in Truro (0815–1615).

9.65 In addition to the normal aviation meteorological reporting, sub-orbital operations will require details of high-level wind speeds over the launch site, in order to assess drift at high altitudes. It is also likely that information on space weather activity will be required prior to the launch.

9.66 A region-by-region review of the data is included as Appendix 9A at the end of this chapter.

Summary of meteorological factors

9.67 As would perhaps be expected, there is considerable variation in the local weather conditions of the UK regions where potential locations have been identified for sub-orbital operations. In general, for sub-orbital flights that are limited by cloud cover and wind speeds, locations in Scotland are likely to offer fewer hours of potential flight operations than are locations further south in the UK. In the north of the UK, generally hours of sunshine are fewer (cloud cover greater), rainfall is higher and wind speeds are greater.

9.68 The more challenging meteorological environment in these locations is therefore very likely to impact the economic potential and viability of operations in these locations. In short, locations in the southern part of the UK have more conducive meteorological conditions than those in the north of the UK.

9.69 Once sub-orbital operators have confirmed their meteorological operating criteria further, in-depth investigation of these aerodromes can take place, particularly of the eight locations in Figure 9.2.

Spaceport safety management

9.70 When considering the early adoption of sub-orbital operations in the UK, it is very likely that these flights will take place from an existing aviation facility. In this context, it may not be necessary to define or designate this facility as a spaceport, but as an aerodrome at which sub-orbital operations occur. There are existing safety management requirements for aerodromes, derived from the International Civil Aviation Organization (ICAO), EASA and the CAA. They are tried and tested, and have been central to the UK aerodromes' good safety record over many years. The MOD also utilises its own safety management system and has introduced a requirement for aerodromes to nominate an aerodrome operator, who would be responsible for ensuring a safe operating environment is maintained.

9.71 The International Association for the Advancement of Space Safety (IAASS) also suggests the use of existing civil aviation safety management systems (SMS) processes and procedures.[193] Should a site be identified as a result of this Review, considerable co-ordination and liaison will be required between all stakeholders prior to operations to ensure that all new hazards are identified and any residual risks (identified through a full risk assessment process) mitigated. The spaceport SMS requirements should not generate a need for a separate set of documents, but should complement the existing aerodrome requirements. The spaceport elements should follow the existing SMS components of safety policy and objectives; safety risk management; safety assurance; and safety promotion.

9.72 Stakeholders will include the aerodrome operator, the local air navigation service provider (ANSP); the aerodrome rescue and fire fighting services (RFFS); local authority emergency services, including search and rescue and specialist medical facilities; the national ANSP and military authorities; and the sub-orbital operator. In addition to existing aerodrome safety management requirements, the following specific issues and topics will need to be reviewed, and the processes, procedures and plans set out in a local 'concept of operations' or safety plan. This list of considerations is not definitive, and the safety management issues to be covered will, of necessity, be related to the local environment. The list is, however, applicable to operations on a full-time basis, seasonal flights or a short-duration sequence of flights.

---

[193] IAASS Suborbital Safety Technical Committee, Operations Group – Standards (2013) 'Spaceport safety management systems', pp4–11. Document is not publicly available.

- Typically ICAO Annex 14,[194] EASA Aerodrome Regulations[195] and CAA CAP 168 aerodrome design requirements[196] should be applicable, given the type of spaceplanes currently being suggested for sub-orbital operations. Any unusual or bespoke infrastructure designs will need to be understood and integrated into the existing manoeuvring area design.
- A full safety and risk assessment of the proposed operation and its possible interaction with existing aviation activity will be required, with agreed procedures for ensuring the safety of existing aircraft operations on the aerodrome.
- Assurance will be needed that all UK occupational health and safety requirements have been catered for, as well as any storage of dangerous goods.
- Detailed procedures must be developed for the total launch operation, in conjunction with the aerodrome operator and the ANSPs, to cover all phases of the flight – fuelling, movement to the runway, take-off, ATM procedures during the flight, standard procedure for re-entry and landing, recovery of the aircraft from the runway after landing and post-flight operations.
- A communications plan will be needed to ensure that all other airspace users and relevant parties are aware that sub-orbital operations are taking place. This will include Notices to Airmen (NOTAMs) and other safety advisories. Procedures for the activation of Danger Areas and any additional temporary restricted airspace should be established, and the procedures for its promulgation followed. The communications plan should include warnings to existing airspace and/or maritime users of the proposed launch window and of any associated hazards under the flight path or downrange from the launch site, including chemical cloud dispersal and any sonic boom generation.
- Emergency and contingency plans will be required for abortive take-offs, fuel leaks, aircraft ditching or early return to aerodrome with fuel on board. Also details of any specialist equipment required for crash recovery on or off the aerodrome should be confirmed. There will be a further need for liaison and training with aerodrome and local authority RFFS and other emergency services, to ensure that responders understand any emergency procedures that are unique to the sub-orbital aircraft, its equipment and crew.

---

[194] See www.icao.int/safety/ism/ICAO%20Annexes/Forms/AllItems.aspx (accessed 20 April 2014)

[195] See http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2014:044:0001:0034:EN:PDF (accessed 21 May 2014)

[196] CAA (2011) *Licensing of Aerodromes,* CAP 168, www.caa.co.uk/docs/33/CAP168.PDF (accessed 20 April 2014)

- Procedures should be put in place for emergency evacuation and transport of crew and passengers to local hyperbaric chamber sites, following emergency decompression at high altitude, or for any other medical condition resulting from the sub-orbital flight. Further details of the medical aspects can be found in Chapter 12.
- The Aerodrome Manual and the Manual of Air Traffic Services Part 2 will require additional material to cater for the sub-orbital operation and will need to detail all local procedures and agreements with other agencies.
- Procedures must be agreed for the co-ordination between ATC and any ground or mission control operation, both local and en route.
- Hangars and aprons will be required for storage, maintenance and security of the aircraft and any other equipment used in flight preparation.
- Safety distances must be identified for the storage of fuel or other flammable or exotic materials required for the operation.
- Confirmation will be needed of any normal and special radio telephony frequencies and equipment to be used for aerodrome, approach, area and sub-orbital communications with ATC and any ground control station, including telemetry (radio, radar or optical). An assessment of any potential interference from telemetry ground equipment to existing aerodrome surveillance, navigation and communication systems should be conducted.
- Procedures for taxiway access from the refuelling area to the runway will need to be defined. This may be by towing or under the aircraft's own power, depending on the operator. Ground movement plans post-landing and assisted recovery from the runway should also be agreed.
- Many other aviation-related processes, such as site security, public access, media relations and passenger-handling facilities, will be required, but it is likely that processes will already be in place and can be adapted, if necessary.

Recommendation
Local authorities should establish contingency plans for major incidents in advance of the commencement of spaceplane operations from a spaceport.

Health and safety considerations of spaceports

9.73 The Health and Safety Executive (HSE) and the CAA have agreed guidelines setting out their respective responsibilities for enforcing occupational health and safety in relation to public transport aircraft while on the ground and in the air. These guidelines are contained in a general Memorandum of Understanding

(MoU) and a number of annexes covering more specific areas.[197] The MoU sets out key interfaces between the HSE and the CAA Safety and Airspace Regulation Group, and establishes a framework for liaison to ensure effective co-ordination of policy issues, enforcement activity and investigation within their respective responsibilities for safety in aviation and its environs. Examples of annexes to the MoU that are likely to be applicable to commercial space operations are:

- Annex 2 – Aerodromes;
- Annex 3 – Dangerous Goods;
- Annex 5 – Aircraft Maintenance;
- Annex 6 – Recreational Flying;
- Annex 7 – Air Traffic Services; and
- Annex 8 – Occupational Health and Safety.

9.74 The Health and Safety at Work etc Act 1974 sets out the general duties on employers and employees.[198] Under the Act, employers such as sub-orbital spaceplane operators have a legal responsibility to ensure, so far as is reasonably practicable, the health and safety of their employees while at work. They are also under a duty to prevent, so far as is reasonably practicable, non-employees who may be affected by their undertaking from being exposed to risks as a result. Employees also owe duties to themselves and each other.

9.75 Regulations made under the Act (some of which implement European health and safety directives) provide more explicit requirements in relation to certain categories of worker, industry or activity. The Management of Health and Safety at Work Regulations 1999 represent the UK's transposition of many European occupational safety and health requirements under the Framework Directive (89/391/EEC).[199] The main requirement on employers is to carry out a suitable and sufficient risk assessment that reflects the particular characteristics of the workplace. They also incorporate the 'principles of prevention' to be applied when considering measures to deal with risks in the workplace.

9.76 Irrespective of the overall regulatory framework described in this Review, there will still be an overriding requirement for the operation of sub-orbital spaceplane and vertical launch operations to be conducted safely. The HSE has produced guidance and approved codes of practice to assist duty holders in complying with health and safety legislation. The following is a list of some key pieces of health and safety legislation that will apply to commercial space operations at an existing aerodrome or a new vertical launch facility:

---

[197] See www.caa.co.uk/default.aspx?catid=17&pagetype=68&gid=1046 (accessed 14 April 2014)

[198] See www.legislation.gov.uk/ukpga/1974/37 (accessed 21 May 2014)

[199] See www.legislation.gov.uk/uksi/1999/3242/contents/made (accessed 20 April 2014)

- **Management of Health and Safety at Work Regulations 1999**: these require employers to carry out risk assessments, make arrangements to implement necessary measures, appoint competent people and arrange for appropriate information and training;
- **Control of Substances Hazardous to Health Regulations 2002 (COSHH)**: these require employers to assess the risks from hazardous substances and take appropriate precautions;[200]
- **Control of Major Accident Hazards Regulations 1999**: these require those establishments at which dangerous substances are present, or above threshold levels, to take all measures necessary to prevent major accidents and limit their consequences for humans and the environment. The Regulations put in place a detailed regime that operators of establishments are required to comply with. Those establishments where dangerous substances are present at a higher (top-tier) threshold have greater duties;[201]
- **Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR)**:[202] these set minimum requirements for the protection of workers from fire and explosion risks related to dangerous substances and potentially explosive atmospheres. DSEAR complements the requirement to manage risks under the Management of Health and Safety at Work Regulations 1999. DSEAR put into effect requirements from two European directives: the Chemical Agents Directive (98/24/EC) and the Explosive Atmosphere Directive (99/92/EC). Dangerous substances are materials or mixtures of substances (called 'preparations' in DSEAR) that could create risks to people's safety from fires and explosions. Many of these substances can also create additional risks, and these are covered under separate health and safety law, such as the Control of Substances Hazardous to Health Regulations. In general, it is envisaged that spaceplane flight preparations will take place in a 'remote' and secure location on an aerodrome, where they can be conducted safely without hindering other flight operations. This location would also need a site that can be identified for fuelling and that will comply with national requirements for storage, transfer and use of explosive or exotic materials. Safe blast distances will need to be identified and will be dependent on the volumes of fuels stored on site. Due care will need to be paid to the primary legislation applying to the control of substances that can cause fires and explosions in the workplace. Under DSEAR, employers are required to assess the risks of fires and explosions that may be caused by dangerous substances in the workplace. These risks must then be eliminated or reduced as far as is reasonably practicable.

---

[200] See www.legislation.gov.uk/uksi/2002/2677/pdfs/uksi_20022677_en.pdf (accessed 20 April 2014)

[201] See www.legislation.gov.uk/uksi/1999/743/contents/made (accessed 20 April 2014)

[202] See www.legislation.gov.uk/uksi/2002/2776/contents/made (accessed 20 April 2014)

9.77 The operation and ground servicing of the spaceplane will require a full assessment of risk to employees and third parties; control and mitigation measures to be put in place to control the risks; and emergency plans and procedures to be produced and tested. Particular reference will need to be made to the separation distances required for the storage of liquid oxygen and nitrogen and to the avoidance of bituminous surfaces in storage areas. In the early years of operations, it is likely that relatively small amounts of fuels and other hazardous liquids will be stored at the locations. However, as operations increase and the amounts of material increase, further advice will need to be obtained from the HSE. While fuels such as liquid oxygen and liquid hydrogen have mutually exclusive safe blast distances for storage, there will be additional and more demanding requirements when they are placed together on a space vehicle.

9.78 Further liaison will be required between key HSE departments and the CAA as additional information on the full nature of each proposed operation becomes clearer. Clarification will need to be sought with regard to the relationships between non-UK-registered companies operating at UK sites (eg in relation to any operations conducted under wet lease type arrangements). In particular, it will be important to understand whether FAA AST launch and re-entry licence requirements are being adhered to, and how these relate to health and safety requirements.

Recommendation

To ensure the health and safety of all parties concerned in commercial space operations, the CAA and the HSE should ensure a full understanding of the different proposed operational concepts and how existing Memoranda of Understanding would apply to these operations.

Launch and recovery flight corridors

9.79 In the US, one of the main ways in which the safety of the uninvolved general public is protected during spaceflight operations is by ensuring that spaceflights only take place within specific flight corridors, under which population density is lower. The FAA AST defines a flight corridor as ‘an area on the Earth’s surface estimated to contain the hazardous debris from nominal flight of a launch vehicle, and non-nominal flight of a launch vehicle assuming perfectly functioning flight termination system or other flight safety system’.[203]

9.80 Flight corridors will consist of two main sections: an Overflight Exclusion Zone and a Launch and Downrange Area. There is no absolute threshold value for population density in a flight corridor in the FAA AST regulations. The measure of

---

[203] See www.faa.gov/about/office_org/headquarters_offices/ast/licenses_permits/media/Part_400_Compilation.pdf (accessed 20 April 2014)

population density is simply one factor included in the computation of expected casualties (ie collective risk to the public posed by the launch operation). The other factors are: probability of failure of the vehicle, probability of impact of the vehicle or its debris within a particular area (which is sometimes itself expressed as a function of the vehicle's probability of failure) and casualty area of the vehicle or its debris.

9.81 There is a threshold value of expected casualty in the FAA AST regulations (Code of Federal Regulations, Title 14, chapter III)[204] of $30x10^{-6}$ per mission. From there, for a particular vehicle with a particular, known failure rate and a particular, known casualty area, it is possible to compute a maximum allowable population density. However, there is generally some variability/uncertainty in those parameters, including the potential for the vehicle to fail in multiple ways that produce different casualty areas (eg one for an in-flight explosion, one for an aerodynamic break-up, one for an intact impact etc). The FAA AST utilises sophisticated tools to perform the expected casualty computations to ensure that a proposed operation does not exceed the threshold. Depending on the launch site location, additional flight safety through Danger Area management and active monitoring will be required to ensure that the flight does not interfere with other aircraft and ships. It is anticipated that the sub-orbital vehicle flight corridor can be encompassed within the more demanding orbital corridor.

9.82 The UK does not currently have requirements for such flight corridors or airspace restrictions. Further investigation is required into such requirements and then their use at the specific locations identified above. The design of flight corridors, together with the population density data, will again limit or restrict the potential of the identified sites. The flight corridors and any stage drop zones will also have a significant effect on the vertical launch site location.

9.83 There will be a requirement to develop agreed processes to identify both the ground buffer zone and the aircraft buffer zone to protect the public and aircraft, respectively. Consideration will need to be given to existing procedures already in use by the FAA AST and described by Gonzales and Murray.[205] FAA AST safety distances and buffers on the ground and in the air are conservative and based on experience with reusable launch vehicles (RLVs). There may be an opportunity to reduce these dimensions once their reliability is established and a vehicle component or debris catalogue is available.

---

[204] FAA AST, Title 14 of the Code of Federal Regulations, www.faa.gov/regulations_policies/handbooks_manuals/aircraft/amt_handbook/media/FAA-8083-30_Ch12.pdf (accessed 20 April 2014)

[205] E Gonzales and D Murray (2011) 'FAA's approach to ground and NAS separation distances for commercial rocket launches', in *Proceedings of the 48th AIAA Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition, Orlando, Florida, 4–7 January 2010*

Identifying a vertical launch location

9.84 As indicated in this Review, it is very likely that there will be a requirement to prepare for sub-orbital flights in the near future, prior to any demand for a vertical launch facility. While there are obvious synergies between differing launch services, the more imminent timing for sub-orbital operations may preclude a common vertical and horizontal launch site being identified as the UK spaceport. Certainly in the first few years of operation, catering for both horizontal and vertical launch at the same location may not be possible.

9.85 In its 2013 study,[206] SSTL indicated that the UK would benefit from a small vertical launch capability at a UK spaceport. The report suggests that a common launch site would be preferred on account of the economies of scale and common use of ground facilities and services, and could initially cater for four to six launches per year.

9.86 The SSTL study identifies several regional launch locations but, because of the requirement for launch over the sea and the need to have launch vehicle stage drops away from land masses, it concluded that the north coast of Scotland was preferable. This is similar to the findings of an earlier study by AEA Technology, which recommended the area around Dounreay as suitable for a launch facility for small satellites.[207] However, in line with the meteorological analysis, this may not be the most suitable location for spaceplane operations.

9.87 Should a solely vertical launch site be identified, that facility would fall outside the traditional oversight of the CAA. The requirement to consider the safety of the uninvolved general public and other airspace users would, however, remain. A decision would need to be made as to what regulatory regime should cover this site and whether it could be regulated by the CAA or another body. This future regulatory regime should cover both UK and Overseas Territory locations.

Recommendation

A separate vertical launch site should be identified which, due to the restricted operational criteria for vertical launch to orbit, should be on the north coast of Scotland.

Air Traffic Control/Management considerations

9.88 If, as indicated above, sub-orbital spaceplane operations occur at an existing aerodrome with its own ATC provider, then, as with aerodrome infrastructure, these facilities can be used with the addition of bespoke procedures for the spaceplane flights. Procedures will need to be developed for each stage of the

---

[206] Surrey Satellite Technology Ltd (2013) 'Towards a UK launch infrastructure', Executive Summary, p7. Unpublished study

[207] AEA Technology (1995), Dounreay Small Satellite Launch Facility

sub-orbital flight. In addition to the local ATC, there will also be a need to develop procedures and interfaces with national civil and military ATM providers.

9.89 There may also be requirements to notify national or regional military and search and rescue authorities of the impending departure of the spaceplane.

9.90 The following items are indicative of the detailed written procedures that will be required, and are based on typical ATM certification requirements.

- The sub-orbital operator must inform the aerodrome operator and the ANSP of the proposed dates and times of flights.
- NOTAMs or other aeronautical information and warnings to airspace and maritime users must be promulgated in advance.
- On the day of launch, flight details must be confirmed, reflecting the weather conditions and aircraft serviceability.
- The sub-orbital operator must inform the aerodrome operator, the RFFS and ANSP when spaceplane fuelling begins, and ensure that any specific safety or security requirements are activated.
- Details must be agreed for safe passenger loading.
- Movement of the spaceplane from hangar to fuelling location must be fully planned. This is likely to be a towed movement.
- Movement of the spaceplane from the fuelling area to the runway must also be fully planned: this could be either a towed movement or involve the spaceplane moving under its own power.
- Details must be supplied of RFFS standby requirements during ground movements.
- Details must be confirmed of: the transfer of information from local ATC to national ANSP as required, for warning of imminent departure of the spaceplane; the transfer of control from national ANSP controllers to local ATC; and the transfer of control procedures from local ATC to national ANSP or other civil or military ATC authority as agreed.
- Normal ATC operations for clearing a spaceplane for take-off will exist as part of ensuring safe management of all other traffic in the vicinity of the aerodrome during movements of the spaceplane.
- Suitable procedures must be agreed for liaison with the local/national sub-orbital mission control unit overseeing the sub-orbital flight, to confirm that the spaceplane is airborne.

- An arrangement must be put in place to ensure that the Airspace Reservation is protected from other traffic and to monitor the sub-orbital spaceplane to ensure that it remains inside its nominal flight profile and flight corridor.
- Procedures must be confirmed for warning appropriate civil and military ATM providers, should the spaceplane deviate from its nominal flight path and operate outside its normal flight parameters.
- Details of the flight procedures and any manoeuvres to be carried out by the spaceplane to reduce speed during the approach need to be agreed with the air traffic services provider in advance.
- Details must be confirmed of how the aerodrome runway will remain sterile for the spaceplane return approach and landing, thus ensuring that it is always available.
- Procedures must be agreed in advance of how the spaceplane will be recovered from the runway following the landing. This will include information on towing requirements, RFFS cover and any health and safety measures needed for the flight crew and the ground crew.
- Details must be confirmed of any post-flight decontamination, de-fuelling or other servicing requirements and their health and safety and RFFS cover needs.
- Details must be confirmed of any normal post-flight or emergency medical testing or other requirements, and how these will be met.
- Plans must be put in place for how any post-flight debriefing and lessons learned will be carried out and shared between appropriate stakeholders for future flights.

9.91 There will be a requirement prior to any sub-orbital flights to develop a UK-wide system to assess any hazard to other aircraft potentially flying beneath the sub-orbital spaceplane in departure and arrival phases. An operational tool was developed by NASA and the FAA for space shuttle operations. The Space and Air Traffic Management System was developed along with the Shuttle Hazard Area to Aircraft, used for shuttle re-entry following the space shuttle Columbia accident in 2003.

9.92 There will also be a safety requirement to continuously track the position of the spaceplane during its flight. Since proposed spaceplane flight levels are above those used in normal commercial air traffic, current civilian radar will not be able to track the spaceplane for all of its flight. Liaison with military or other space tracking systems and assets will be required. Particular co-ordination will be required with military space organisations such as the US Strategic Command (US StratCom) and its Space Control and Surveillance division. There will be a need to identify how full flight tracking up to 120 kilometres (360,000 feet) may be possible and could be built into the overall flight monitoring process. Accurate positioning and reporting of the spaceplane's position during the whole flight profile will be a requirement, as this will allow those monitoring the flight to determine whether or not its track in relation to an expected flight envelope is being maintained.

Recommendations

9.93 This chapter includes the following recommendations.

- Sub-orbital operations should commence, either on a permanent or a temporary basis, from one (or more) of the following:
  - an existing EASA-certificated aerodrome;
  - an existing CAA-licensed aerodrome; and/or
  - an existing UK military aerodrome, subject to approval from the MOD.

  (*Recommendation 18 in summary report*)
- In order to make maximum use of existing infrastructure, the location should still be active but at a low level of aircraft movements. It should have existing and appropriate ground infrastructure/facilities and Air Traffic Control. (*Recommendation 19 in summary report*)
- To allow sub-orbital operations in the near future, possible locations should be selected from the identified list and further investigations carried out as to their viability. Government will need to agree a process for how sites would be selected. (*Recommendation 20 in summary report*)
- In order to ensure the safety of the uninvolved general public and to enable initial operations under a wet lease type arrangement to take place in line with FAA AST launch site licensing requirements, the Review strongly recommends that a UK spaceport should be established at a coastal location. (*Recommendation 21 in summary report*)
- To provide more clarity and begin the development of future capability, further detailed consideration should be given to a limited number of locations in the UK and its Overseas Territories, where more detailed analysis could be carried out to assess their suitability for sub-orbital, vertical launch, or single-stage to orbit operations.
- Local authorities should establish contingency plans for major incidents in advance of the commencement of spaceplane operations from a spaceport. (*Recommendation 23 in summary report*)

- To ensure the health and safety of all parties concerned in commercial space operations, the CAA and the HSE should ensure a full understanding of the different proposed operational concepts and how existing Memoranda of Understanding would apply to these operations.
- A separate vertical launch site should be identified which, due to the restricted operational criteria for vertical launch to orbit, should be on the north coast of Scotland. (*Recommendation 22 in summary report*)

APPENDIX 9A

Regional meteorological information

This appendix includes the meteorological information used to support our analysis. All data and figures are sourced from the Met Office website.

Northern Scotland

This section looks at the meteorological factors likely to affect sites in northern Scotland, such as RAF Lossiemouth, Kinloss Barracks and Stornoway Airport.

Sunshine

In general, in northern Scotland December is the dullest month and May or June the sunniest. Sunshine duration decreases with increasing altitude, increasing latitude and distance from the coast. Local topography also exerts a strong influence and, in the winter, deep glens and north-facing slopes can be in shade for long periods. In northern Scotland, the sunniest places are close to the Moray Firth, where both RAF Lossiemouth and Kinloss are located, and in the southern Outer Hebrides, where the annual average approaches 1,300 hours per year. By comparison, the sunniest places on mainland UK are along the south coast of England, with over 1,750 hours per year on average.

Information for Inverness Aerodrome as an example is shown in Figure 9.6 below.

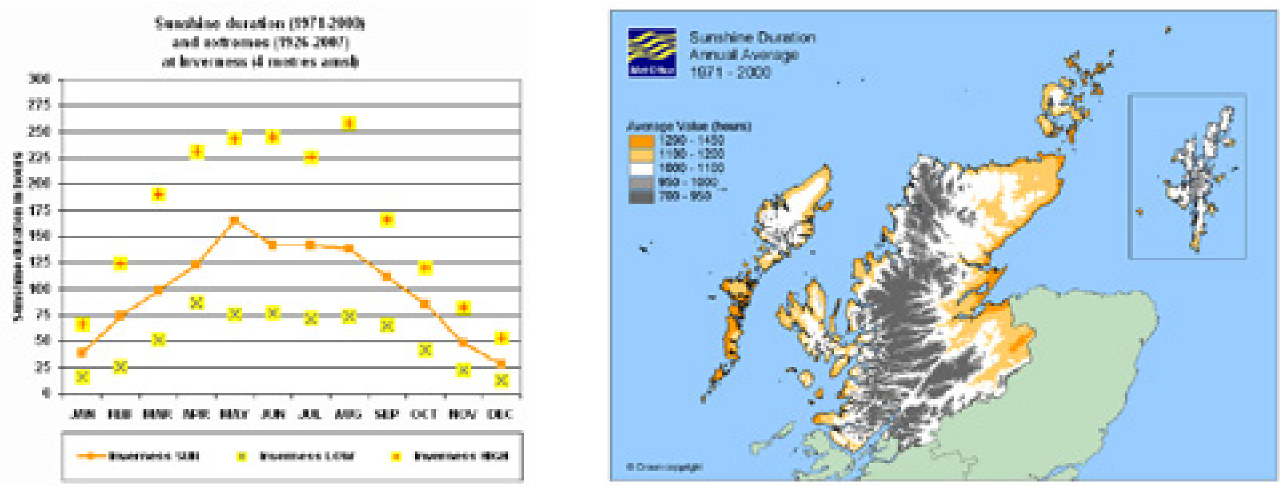


Figure 9.6: Average monthly hours of sunshine at Inverness and average annual hours of sunshine for northern Scotland 1971–2000

Rainfall

Much of northern Scotland is exposed to the rain-bearing westerly winds, particularly the Western Isles and the west coast. As a result, most of the western half of the region has an average annual rainfall of at least 1,700 millimetres. The highest average annual rainfalls occur over the higher, west-facing slopes, with the wettest area being to the north-west of Fort William (over 4,000 millimetres per year). Over the lower-lying islands, the average is less than about 1,600 millimetres, while near the Moray Firth, in the lee of the mountains, it is only about 700 millimetres per year. These values can be compared with annual totals around 500 millimetres in the driest parts of eastern England.

Rainfall is generally well distributed throughout the year. The frequency of Atlantic depressions is normally greatest during the autumn and winter, but, unlike other parts of the UK, Scotland tends to remain under their influence for much of the summer, too. In the western and northern areas, there is a clear peak in autumn/early winter, whereas places close to the Moray Firth tend to have a more even distribution through the year. Late spring and early summer is normally the driest part of the year. Over much of northern Scotland, the number of days with rainfall totals of 1 millimetre or more ('wet days') tends to follow a pattern similar to the monthly rainfall totals. In winter (December to February), there are fewer than 40 wet days on average close to the Moray Firth, rising to over 60 days in much of the western half of the region and Shetland. In summer (June to August), the Moray Firth area has about 30 wet days and the western areas over 45 days.

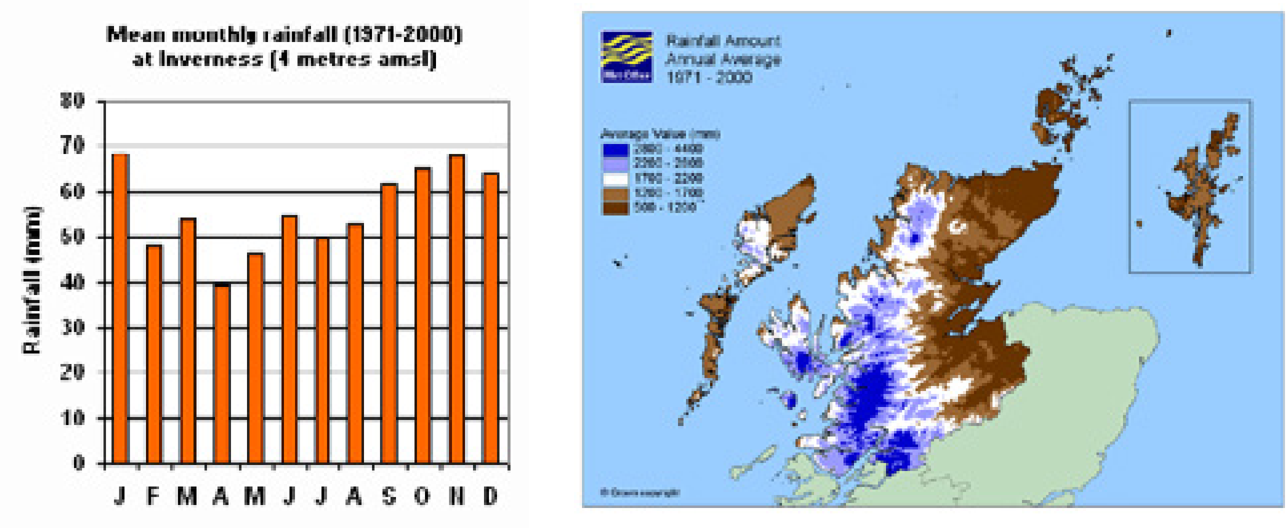


Figure 9.7: Average monthly rainfall at Inverness and average annual rainfall in northern Scotland 1971–2000

Winds

The western and northern parts of northern Scotland are, on average, the windiest in the UK, being fully exposed to the Atlantic and closest to the passage of areas of low pressure. The frequency and depth of these depressions is greatest from December to February, and this is when mean speeds and gusts (short-duration peak values) are strongest. However, spring tends to have a maximum frequency of winds from the north-east. This seasonal effect is due to a build-up of high pressure over Scandinavia at this time of year.

Figure 9.8 shows the annual wind rose for Lerwick in the Shetland Islands and the monthly wind speed plus gusts. This is typical for the Northern and Western Isles, with a prevailing south-west wind direction through the year and frequent strong winds. In the Highlands, winds are lighter and generally directed along valleys.

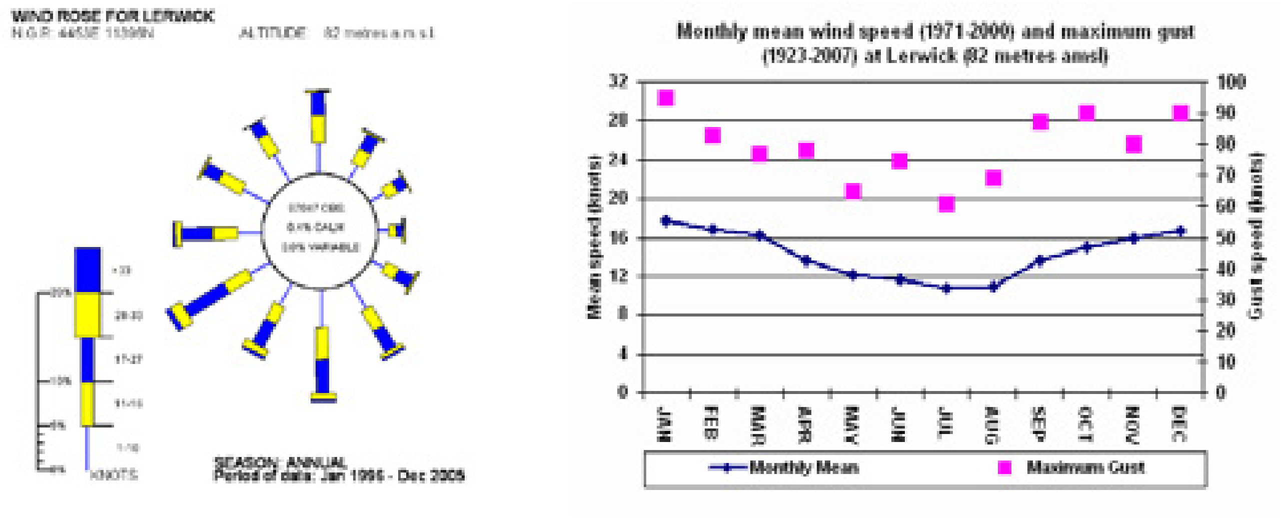


Figure 9.8: Average annual wind speed and direction at Lerwick 1996–2005 and average monthly wind speed at Lerwick 1971–2000

Eastern Scotland

This section looks at the meteorological factors likely to affect sites in eastern Scotland, such as RAF Leuchars.

Sunshine

Eastern Scotland includes the sunniest places in Scotland, such as the coast of Fife, where the average is about 1,500 hours per year. Other coastal places, for example in East Lothian, average more than 1,400 hours, but sunshine averages are lower elsewhere and are lowest over the Grampian mountains (less than 1,100 hours).

Figure 9.9 shows the average monthly sunshine totals for Dyce – Aberdeen Airport – together with the highest and lowest totals recorded in the stated periods. The sunniest month is May, because of the tendency for settled anticyclonic conditions in late spring, which is a feature of the weather over Scotland as a whole. However, this national trend is less marked and even reversed at places close to the east coast because of the occurrence of sea-fog (haar) in late spring.

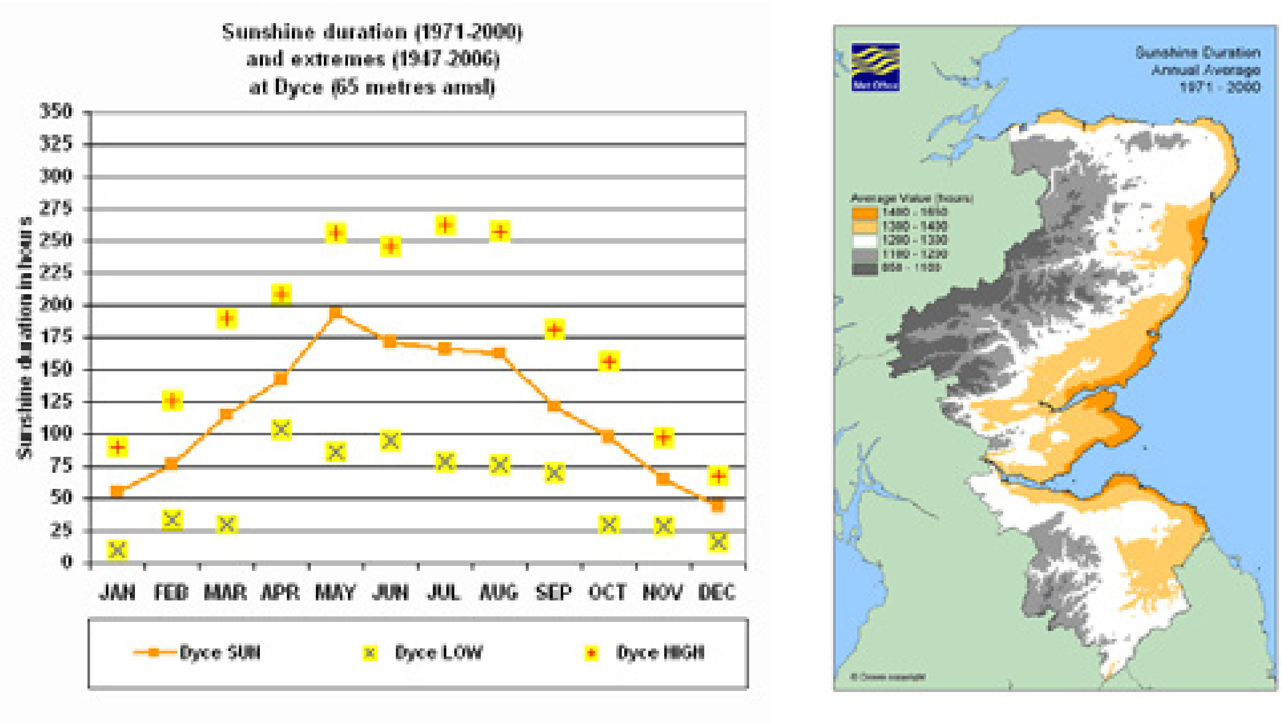


Figure 9.9: Average monthly hours of sunshine at Dyce and average annual hours of sunshine for eastern Scotland 1971–2000

Rainfall

Much of eastern Scotland is sheltered from the rain-bearing westerly winds. This shelter reaches its greatest potential along the coasts of East Lothian and Fife, which have average annual rainfall of less than 700 millimetres. In contrast, the wettest area of eastern Scotland is the southern Grampians, where average annual rainfall is over 1,500 millimetres. These values can be compared with annual totals of around 500 millimetres in the driest parts of eastern England and over 4,000 millimetres in the western Scottish Highlands.

Rainfall is generally well distributed throughout the year. The frequency of Atlantic depressions is normally greatest during the autumn and winter, but, unlike other parts of the UK, Scotland tends to remain under their influence for much of the summer, too. The wettest months tend to be in autumn and early winter, whereas late winter and spring is normally the driest part of the year.

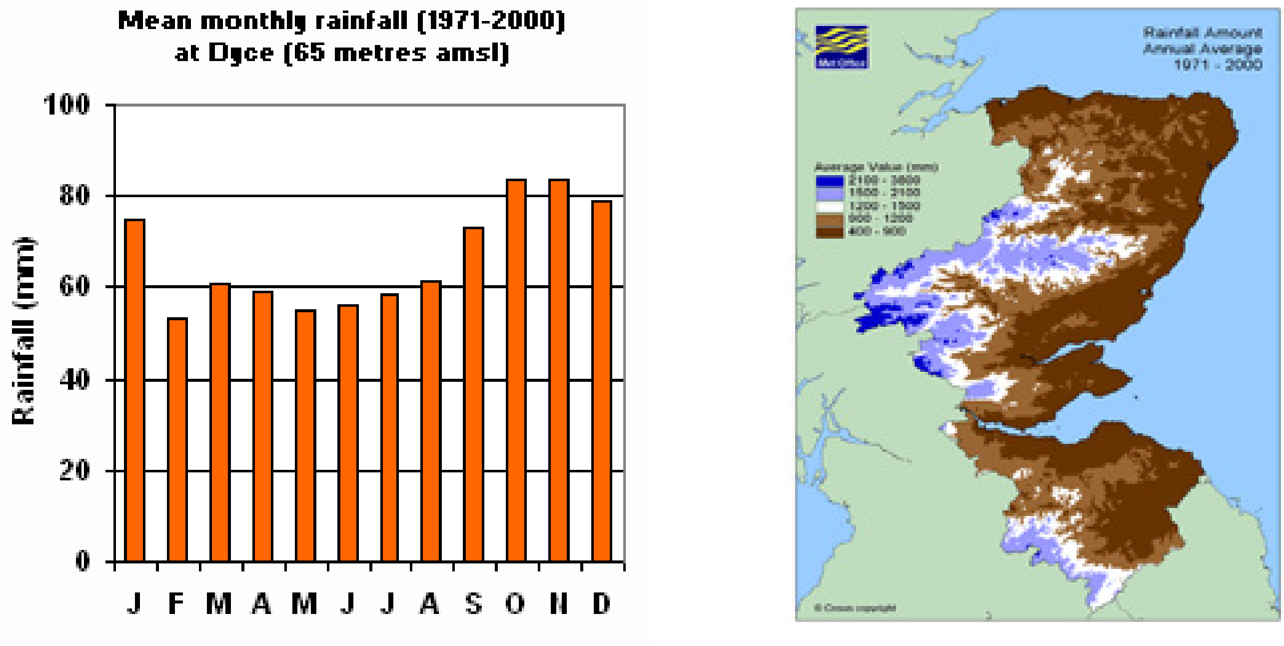


Figure 9.10: Average monthly rainfall at Dyce and average annual rainfall in eastern Scotland 1971–2000

Wind

Eastern Scotland is one of the more windy parts of the UK, being relatively close to the track of Atlantic depressions. The strongest winds are associated with the passage of deep areas of low pressure close to or across the UK. The frequency and strength of these depressions is greatest from December to February, and this is when mean speeds and gusts (short-duration peak values) are high.

Another measure of wind exposure is the number of days when gale force is reached. If the wind reaches a mean speed of 34 knots or more over any 10 consecutive minutes, then that day is classed as having a gale. Over most inland areas of the region, the average is around five days per year, but places sheltered to the west experience fewer than this, while exposed upland areas have over 20 days with a gale in an average year. Wind speed is sensitive to local topographic effects and land use. Spring time tends to have a maximum frequency of winds from the north-east. This seasonal effect is due to a build-up of high pressure over Scandinavia. In eastern Scotland, periods of very light or calm winds with no preferred direction vary from about less than 1 per cent of the year on the coast to about 5 per cent at sheltered places well inland.

The annual wind rose for Leuchars is typical of open, level locations across the Central Lowlands, with an enhanced south-westerly wind direction through the year associated with a large-scale funnelling effect.

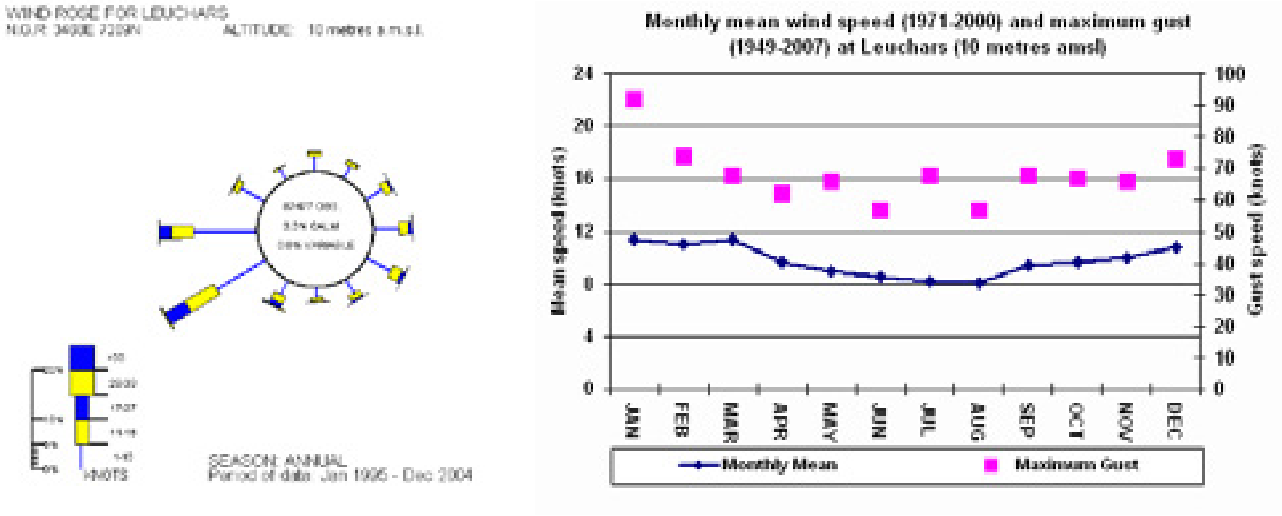


Figure 9.11: Average annual wind speed and direction 1995–2004 and average monthly wind speed at RAF Leuchars 1971–2000

Western Scotland

This section looks at the meteorological factors likely to affect sites in western Scotland such as Campbeltown Airport and Glasgow Prestwick Airport.

Sunshine

The sunniest parts of western Scotland are the Solway coast, Kintyre and the low-lying islands, where the average annual sunshine totals approach 1450 hours. Close to the other coasts, 1325 hours is typical, while the averages decrease with altitude and to the north so that the Southern Uplands receive less than 1200 hours and the West Highlands less than 1100 hours.

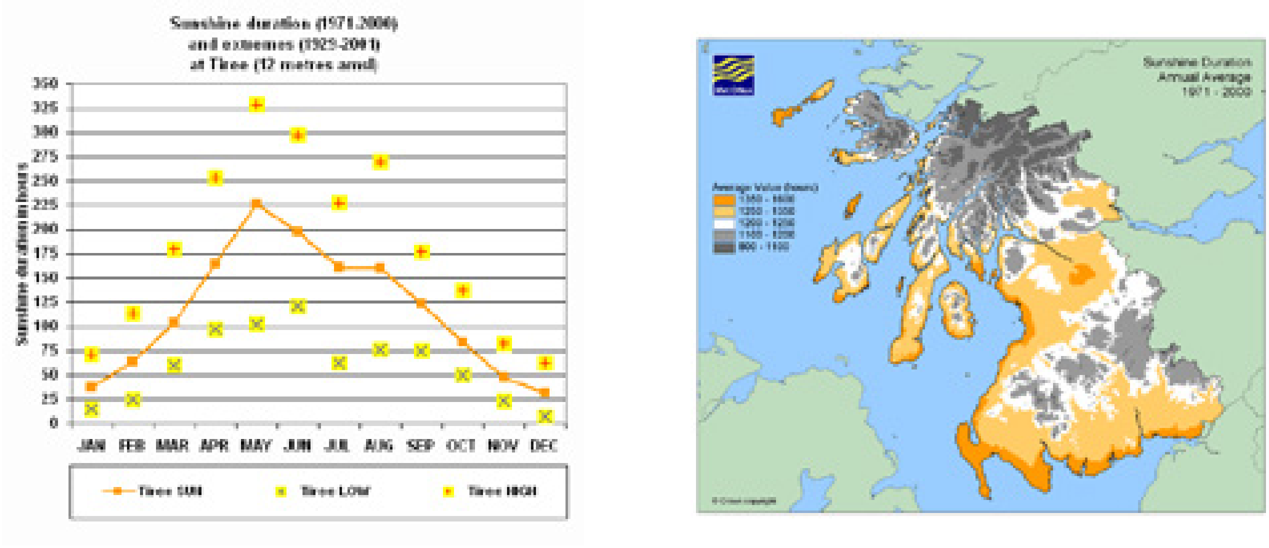


Figure 9.12: Average monthly hours of sunshine at Tiree and average annual hours of sunshine for western Scotland 1971–2000

Rainfall

Average annual rainfall totals range from less than 1,000 millimetres in the upper Clyde valley and along the coasts of Ayrshire and Dumfries and Galloway, to over 3,500 millimetres over the higher parts of the West Highlands, approaching the maximum values found in the UK (over 4,000 millimetres further north). These averages can be compared to annual totals of around 500 millimetres typical of the driest parts of eastern England.

Rainfall is generally well distributed throughout the year, but there is a marked seasonal variation. The frequency of Atlantic depressions is normally greatest during the winter, but, unlike other areas of the UK, Scotland tends to remain under their influence for much of the summer, too. Autumn and early winter are the wettest seasons, especially from October to January, and spring and early summer is normally the driest part of the year, especially from April to June.

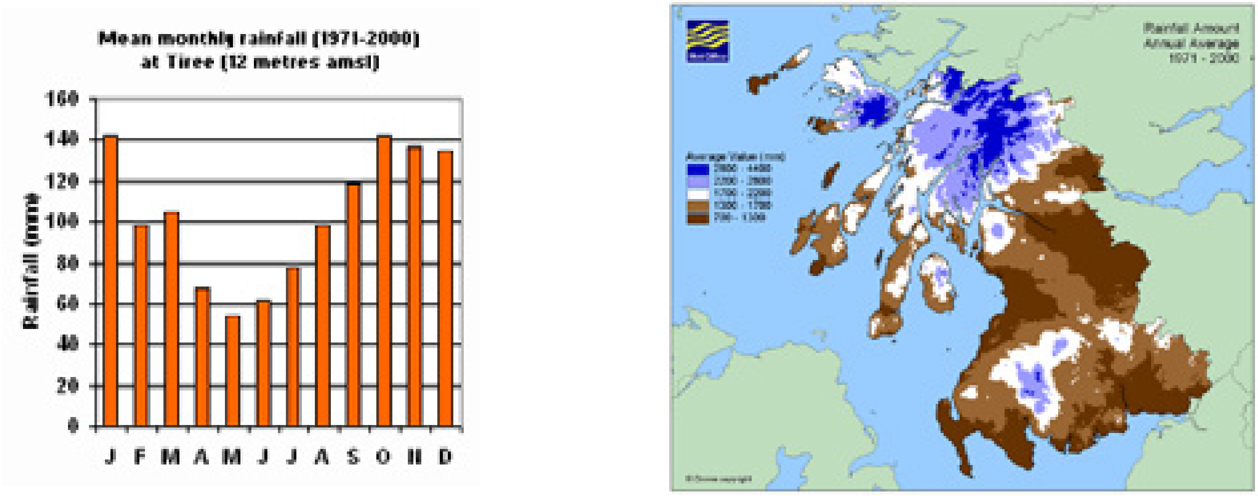


Figure 9.13: Average monthly rainfall at Tiree and average annual rainfall in western Scotland 1971–2000

Wind

Western Scotland is one of the more exposed areas of the UK, being close to the Atlantic. The strongest winds are associated with the passage of deep depressions close to or across the UK. The frequency and strength of depressions is greatest in the winter half of the year, and this is when mean speeds and gusts are strongest.

As Atlantic depressions pass by the UK, the wind typically starts to blow from the south or south-west, but later comes from the west or north-west as the depression moves away. The strongest winds nearly always blow from westerly directions. Spring time also tends to have a maximum of winds from the north-east, due to the build-up of high pressure over Scandinavia at this time of year.

Figure 9.14 shows a typical variation of the monthly mean speeds and highest gusts in Tiree, on the Inner Hebrides. The period November to March sees the highest mean speeds, and June to August the lightest winds.

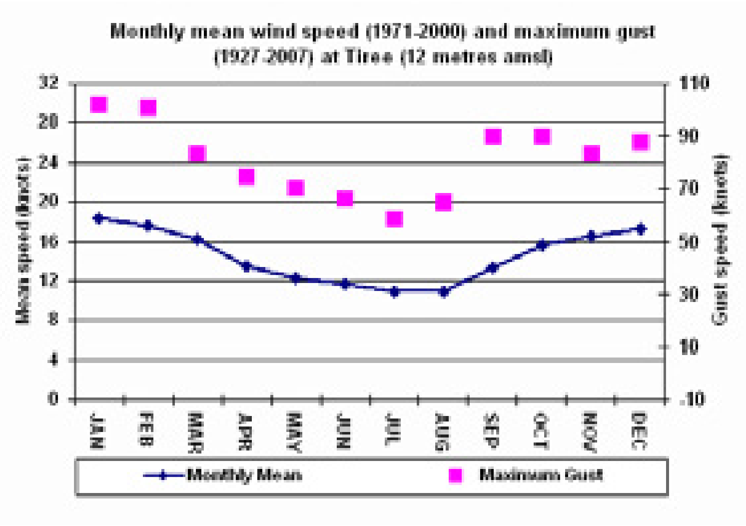


Figure 9.14: Average monthly wind speed at Tiree, western Scotland 1971–2000

Figure 9.15 shows the wind roses for Glasgow Prestwick Airport and Tiree. Glasgow Prestwick Airport is in the Central Lowlands, and the wind rose illustrates the typical frequency of speeds and directions during the year in this area; the wind comes predominantly from the south-west. In contrast, the wind rose for Tiree is typical of sites on the islands of western Scotland, with topographic features generally absent and frequent strong winds.

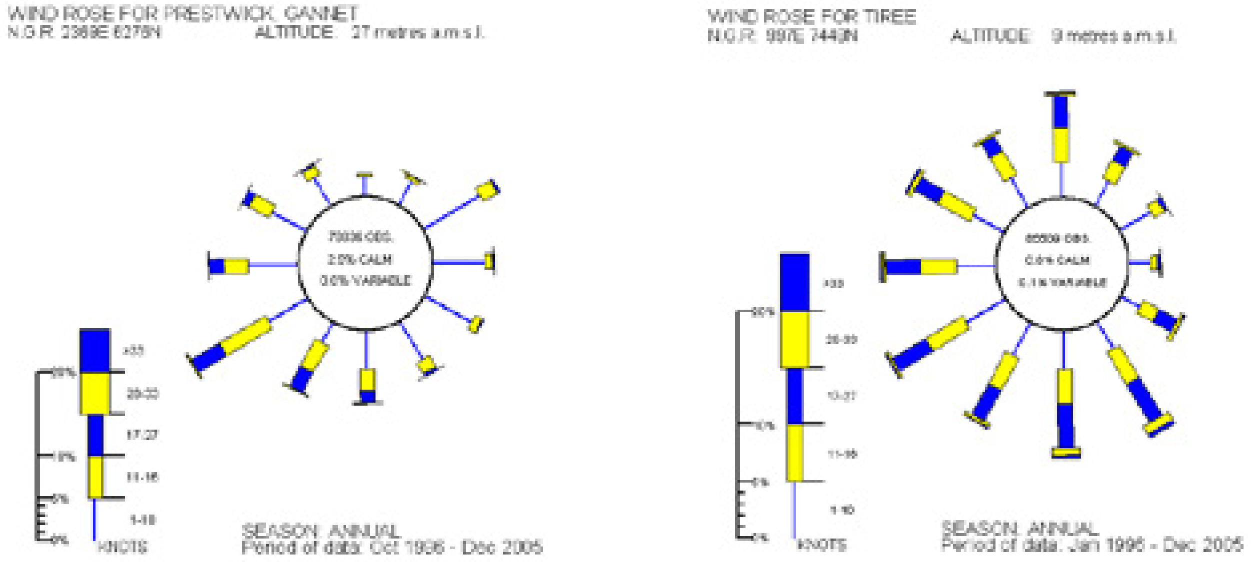


Figure 9.15: Average annual wind speed and direction, Glasgow Prestwick Airport and Tiree 1996–2005

North-east England

This section looks at the meteorological factors likely to affect sites in north-east England, such as Newcastle Airport, Durham Tees Valley Airport, Doncaster Sheffield Airport and RAF Leeming.

Sunshine

Overall, coastal sites are the sunniest because of the tendency for convective cloud to develop over inland areas in summer. However, day to day, changes can occur with wind direction, and easterly weather often brings dull conditions to coastal districts, especially in spring and early summer, when sea fog (known locally as 'fret') occurs. Average annual sunshine durations over north-east England range from almost 1,500 hours on the coast to less than 1,250 hours in the higher Pennines. These figures compare with values of less than 1,100 hours per year in the Shetland Islands to over 1,750 hours along the south coast of England.

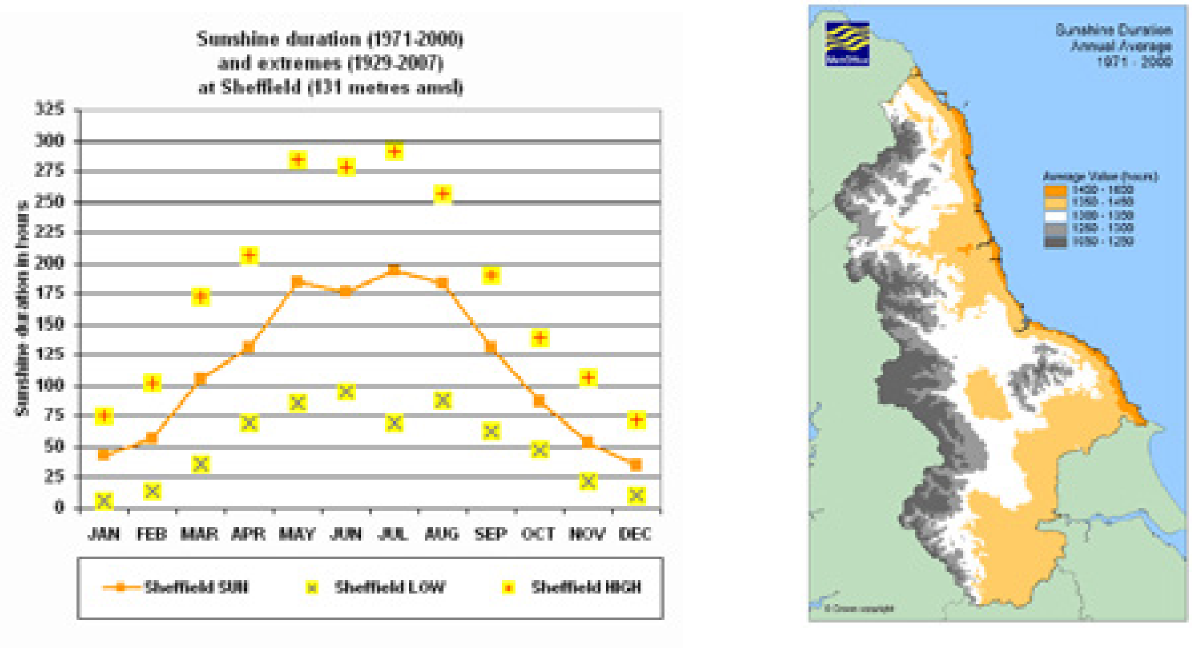


Figure 9.16: Average monthly hours of sunshine at Sheffield and average annual hours of sunshine for north-east England 1971–2000

Rainfall

Average annual rainfall exceeds 1,500 millimetres in the higher parts of the Pennines. There is a decrease as the land falls eastwards, and the north-east coast of England is one of the driest parts of the UK, with less than 600 millimetres in places such as Teesside and the Northumbrian coast. Relatively low averages are also found in the Vale of York. In contrast, the higher ground of the North York Moors experiences averages of over 1,000 millimetres in places such as Fylingdales.

While rainfall is generally well distributed through the year, there is a seasonal pattern. The driest season is spring, while there is an autumn/winter maximum, when the Atlantic depressions are at their most vigorous. This contrast is most pronounced in the wetter upland areas. At the lower sites and towards the coast the distribution is more even, with showery rainfall in summer contributing as much as the autumn/winter depressions. Over much of the region, the number of days with rainfall totals of 1 millimetre or more ('wet days') tends to follow a pattern similar to the monthly rainfall totals. In winter (December–February), 45–50 days is the norm, but this decreases to about 35 days in summer (June–August). In the drier areas closer to the coast, about 30 days in winter and about 25 days in summer are typical. Periods of prolonged rainfall are often associated with east or north-easterly winds on the northern flank of depressions passing to the south of the area.

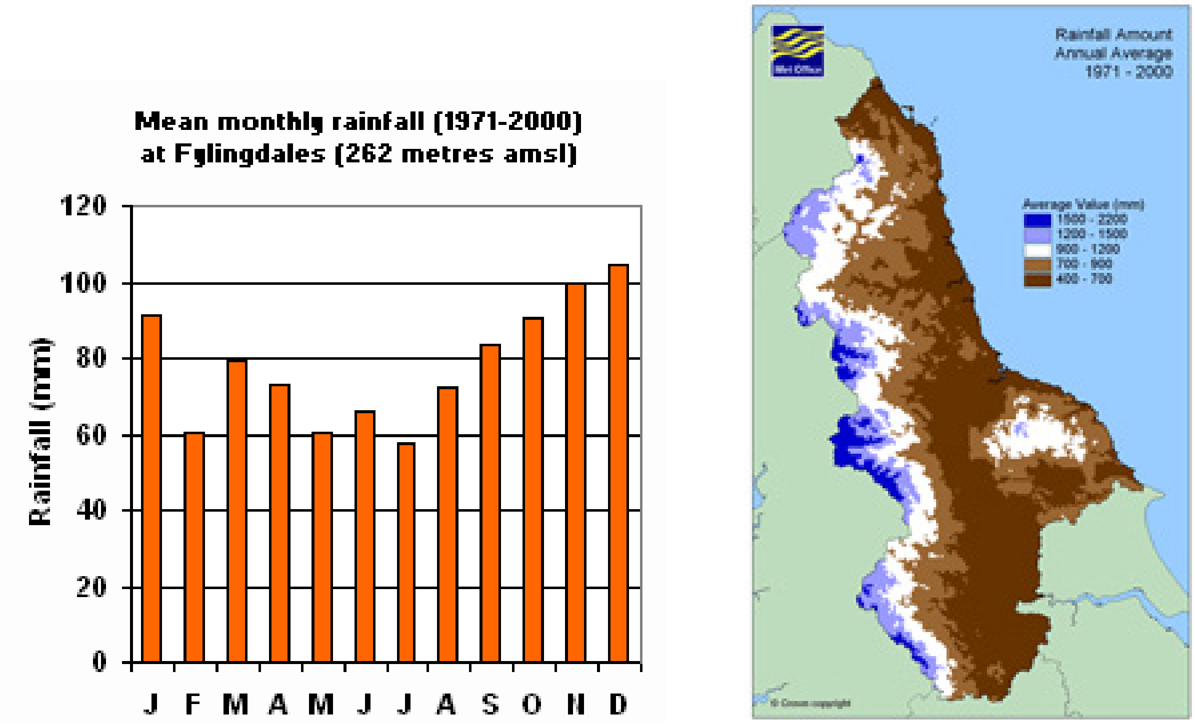


Figure 9.17: Average monthly rainfall at Fylingdales and average annual rainfall in north-east England 1971–2000

Wind

The strongest winds are associated with the passage of depressions close to or across the UK, with the frequency and depth of these areas of low pressure being greatest from December to February. This is when mean speeds and gusts (short-duration peak values) are strongest. The period November to March has the highest mean speeds and the peak gusts follow a similar pattern. Upland areas and coastal areas, particularly those exposed to the north, will experience stronger winds.

Another measure of wind exposure is the number of days when gale force is reached. If the wind reaches a mean speed of 34 knots or more over any 10 consecutive minutes, then that day is classed as having a gale. Over the highest points in the Pennines, there are about 15 gales per year, while along the coast gales occur on 5–10 days, while low-lying places inland experience fewer than five gales per year.

Wind speed is sensitive to altitude and local topographic effects. The area's western and eastern boundaries are the main influence on its climate. The high altitude of the Pennines creates an environment that is frequently cool, dull and wet, but the Pennines also cast a 'rain shadow' across the area through the shelter they afford from the prevailing westerly winds. The North Sea exerts a moderating control on coastal districts where, especially, it can keep summer conditions relatively cool. The annual wind rose for Boulmer in Northumberland is typical of open, level locations across the region, with a prevailing south-westerly wind direction through the year. However, there is a high frequency of north to north-east winds in spring.

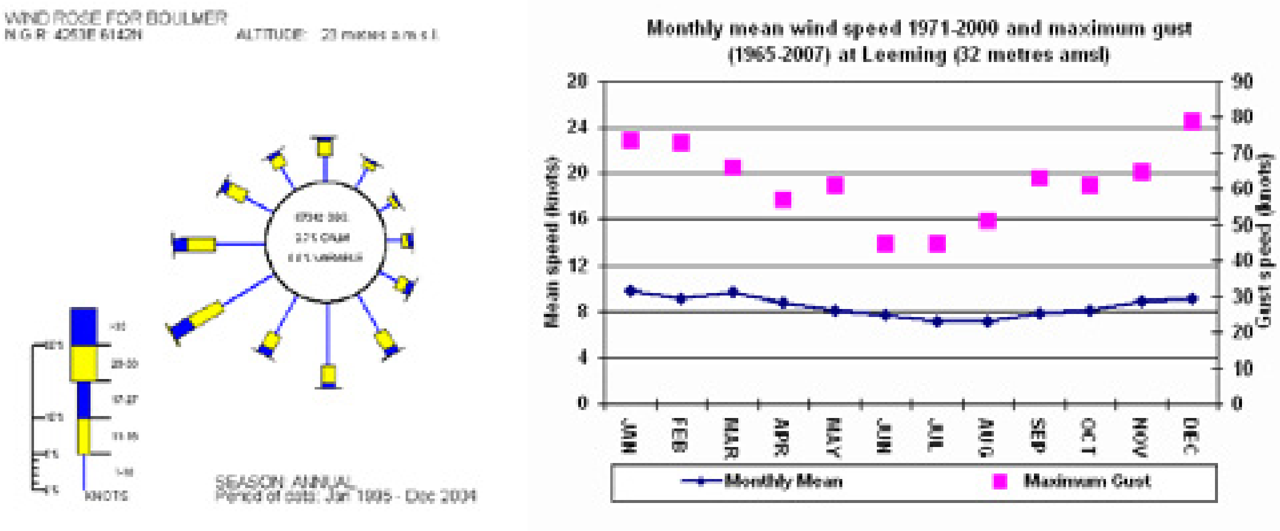


Figure 9.18: Average annual wind speed and direction at RAF Boulmer 1995–2004 and average monthly wind speed at RAF Leeming 1971–2000

Eastern England

This section looks at the meteorological factors likely to affect sites in eastern England, such as RAF Mildenhall, RAF Marham, RAF Wittering, RAF Honington, RAF Coningsby, RAF Waddington, RAF Lakenheath, RAF Scampton and RAF Wyton.

Sunshine

Compared to coastal resorts in south-west England, the Norfolk coast on the east has about 10 per cent fewer hours of sunshine per year. Low cloud from the North Sea can affect the coast, especially in spring and summer. Across the region, annual averages range from less than 1,450 hours over much of Lincolnshire and East Yorkshire to over 1,550 hours in eastern Suffolk and Essex.

Figure 9.19 shows the average monthly sunshine totals for RAF Waddington in Lincolnshire together with the highest and lowest totals recorded in the stated periods.

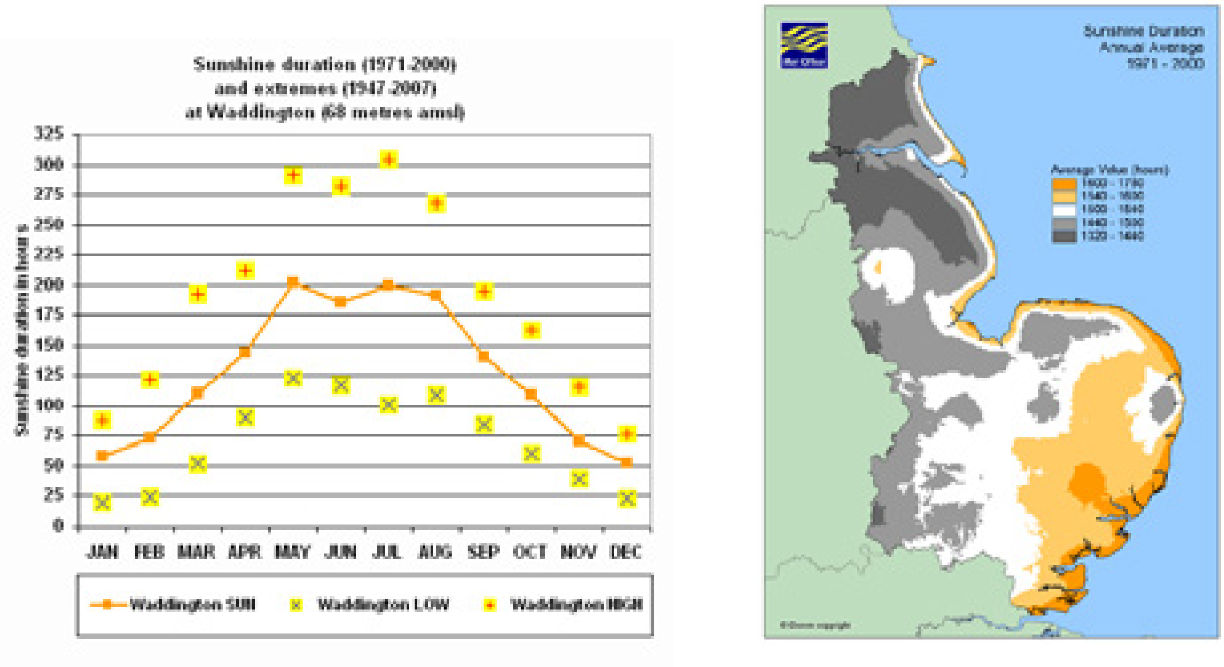


Figure 9.19: Average monthly hours of sunshine at RAF Waddington and average annual hours of sunshine for eastern England 1971–2000

Rainfall

Eastern England contains some of the driest areas in the country, and much of eastern England receives less than 700 millimetres of rainfall per year. The mean monthly rainfall for 1971–2000 is shown in Figure 9.20 below.

Eastern England also experiences a much more even distribution of rainfall throughout the year than most other parts of the UK. This is mainly due to a combination of the 'rain-shadow' effect for winter Atlantic depressions produced by the high ground to the west and a higher frequency of convective rainfall in summer. Across most of the region there are, on average, about 30 rain days (rainfall greater than 1 millimetre) in winter (December to February) and fewer than 25 days in summer (June to August) with the highest averages being at the higher altitude of the Wolds. The number of thunderstorms in a year can make a significant contribution to the total annual rainfall. They can occur at any time of year, but are more frequent during the summer months. Over East Anglia, Lincolnshire and Humberside the average number of days of thunder per year is about 15, although there is considerable variability from year to year.

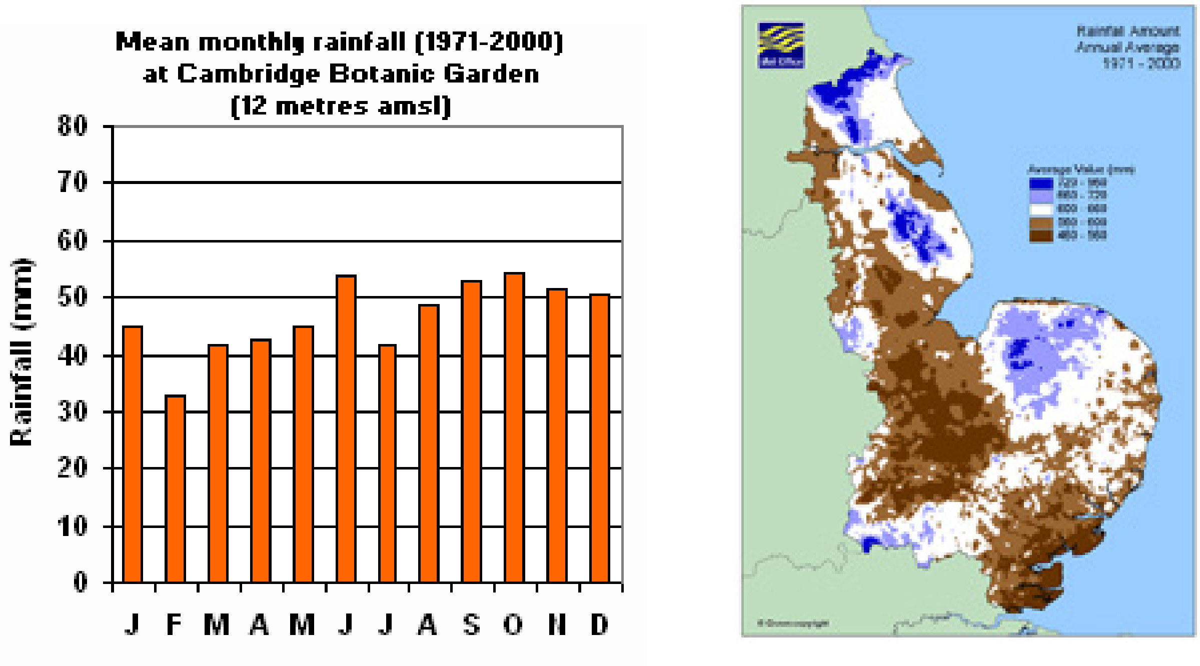


Figure 9.20: Average monthly rainfall at Cambridge and average annual rainfall in eastern England 1971–2000

Wind

Eastern England is one of the more sheltered parts of the UK, since the windiest areas are to the north and west, closer to the track of Atlantic storms. The strongest winds are associated with the passage of deep depressions across or close to the UK. The frequency of depressions is greatest during the winter months, so this is when the strongest winds normally occur. Figure 9.21 shows a typical variation of the monthly mean speeds and highest gusts for RAF Waddington.

The prevailing wind direction is from the south or north-west, and the strongest winds nearly always blow from these directions. Averaged across the year, the wind rose for RAF Coltishall in Norfolk shows that the prevailing wind direction is from the south-west (Figure 9.21).

Spring time also tends to have a maximum of winds from the north-east, due to a build-up of high pressure over Scandinavia at this time of year. In coastal areas, sea breezes are an important feature of the weather in late spring and summer, when the land is warming up and the sea still relatively cool. These start at the coast and then progress inland, bringing a drop in temperature. The inland penetration is dependent on the temperature difference between land and sea and the strength of convective activity.

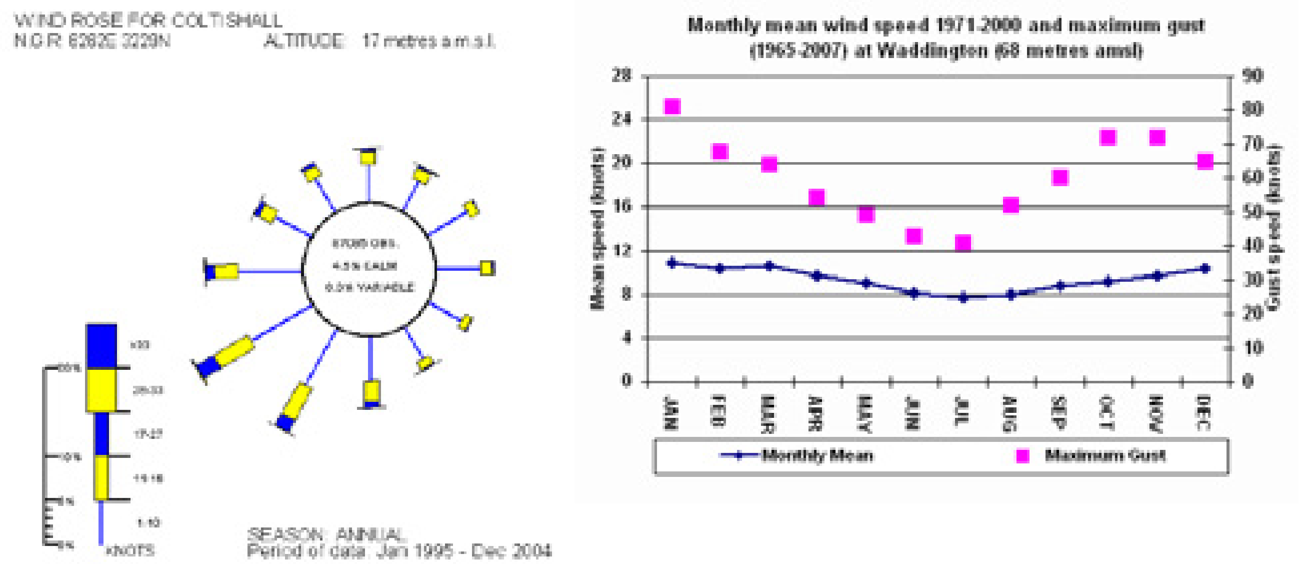


Figure 9.21: Average annual wind speed and direction at RAF Coltishall 1995–2004 and average monthly wind speed at RAF Waddington 1971–2000

Southern England

This section looks at the meteorological factors likely to affect sites in southern England, such as Boscombe Down, RAF Fairford and RAF Brize Norton.

Sunshine

Southern England includes the sunniest places in mainland UK, these being the coastal resorts of Sussex and Hampshire. The Isle of Wight also features in the list of high sunshine averages. On the coast, average annual sunshine durations can exceed 1,750 hours, but 1,550–1,600 hours is typical of most of the region, with a decrease towards the north (eg 1,450 hours over the higher Chilterns). The highest recorded monthly sunshine totals in the region are 314.7 hours at Brize Norton in Oxfordshire, in July 2006.

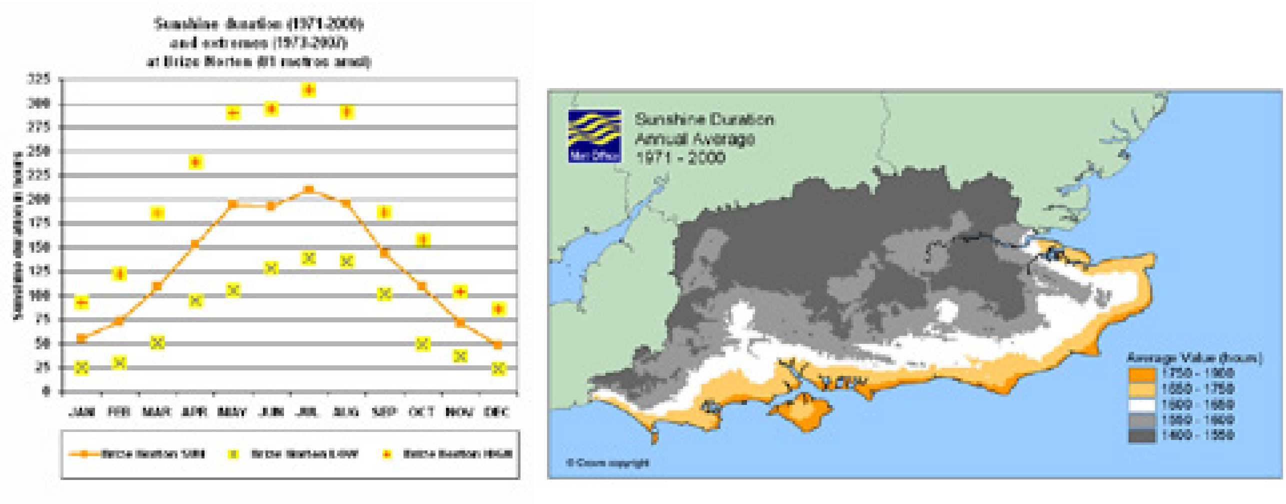


Figure 9.22: Average monthly hours of sunshine at RAF Brize Norton and average annual hours of sunshine for southern England 1971–2000

Rainfall

Much of southern England is relatively distant from the route of many Atlantic depressions, and towards the north-east of the region there is increasing shelter from rain-bearing south-westerly winds. This shelter reaches its greatest potential around the Thames Estuary. The wettest areas are therefore the South Downs and the higher parts of Dorset, with an average of over 950 millimetres per year. In contrast, the Thames Valley, London and the north Kent coast normally receive less than 650 millimetres of rain per year.

Rainfall is generally well distributed throughout the year, but with an autumn/early winter maximum that is more pronounced in counties bordering the English Channel. Further north, in London and the Thames Valley, there are also significant amounts in the summer associated with showery, convective rainfall. The course of mean monthly rainfall for 1971–2000 for Bracknell is shown below. Over much of southern England, the number of days with rainfall totals of 1 millimetre or more ('wet days') tends to follow a pattern similar to the monthly rainfall totals. In winter (December to February) there are 35–40 wet days on average over the Downs and the higher parts of the west, decreasing to fewer than 30 days around the Thames Estuary. In summer (June to August) there are about 25 wet days, with the North Downs and western areas being most prone. Southern England is susceptible to summer thunderstorms, especially at inland locations. The associated high-intensity rainfall can also result in flooding, but this is usually short-lived.

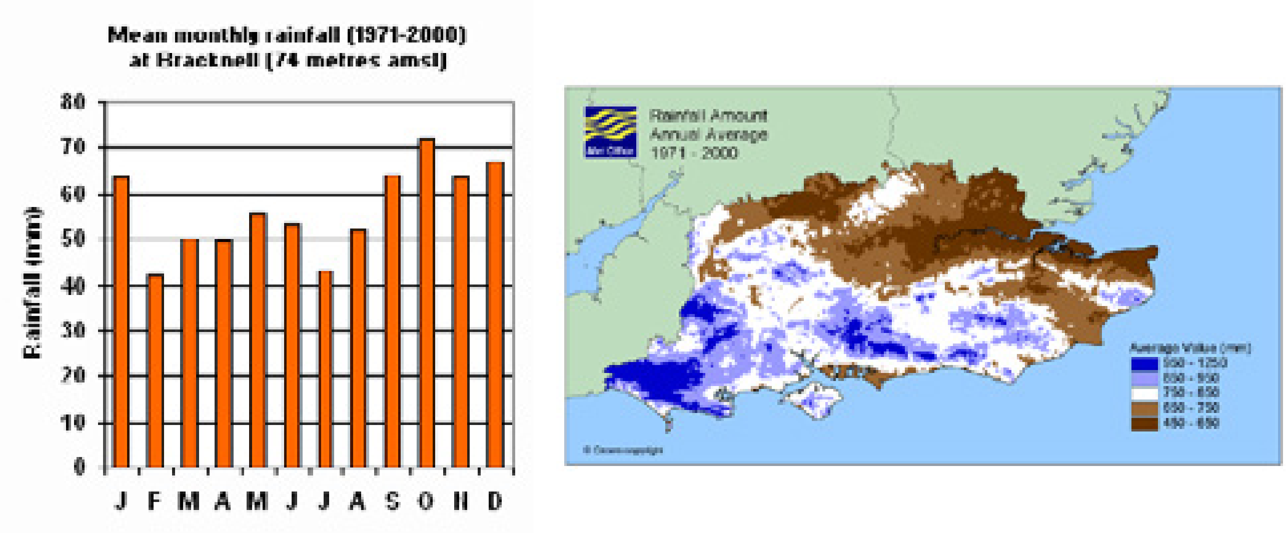


Figure 9.23: Average monthly rainfall at Bracknell and average annual rainfall in southern England 1971–2000

Wind

Southern England is one of the more sheltered parts of the UK, the windiest areas being in western and northern Britain, closer to the Atlantic. The strongest winds are associated with the passage of deep areas of low pressure close to or across the UK. The frequency and strength of these depressions is greatest from December to February, and this is when mean speeds and gusts (short-duration peak values) are strongest. Figure 9.24 shows a typical variation of the monthly mean speeds and highest gusts. The variation in monthly mean speeds (average of a continuous record) and highest gusts ('instantaneous' speed averaged over about three seconds) at Heathrow is shown below. The direction of the wind is defined as the direction from which the wind is blowing.

As Atlantic depressions pass the UK, the wind typically starts to blow from the south or south-west, but later comes from the west or north-west as the depression moves away. The strongest winds nearly always blow from westerly directions. Spring time tends to have a maximum frequency of winds from the north-east. This seasonal effect is due to high pressure building over Scandinavia at this time of year.

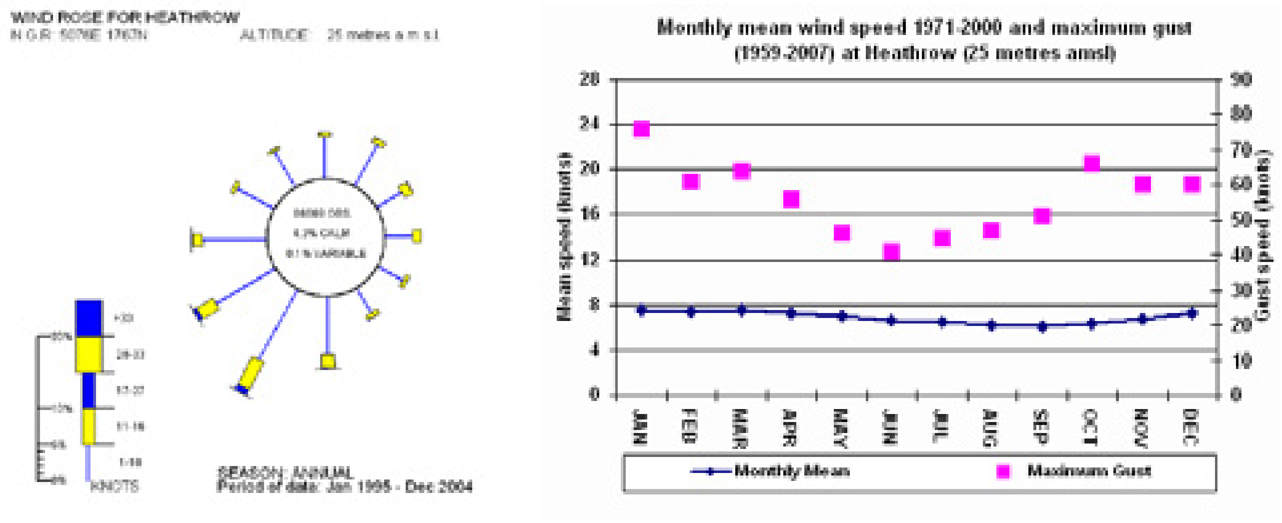


Figure 9.24: Average annual wind speed and direction at Heathrow Airport 1995–2004 and average monthly wind speed at Heathrow Airport 1971–2000

South-west England

This section looks at the meteorological factors likely to affect sites in south-west England, such as Newquay Cornwall Airport and RNAS Yeovilton.

Sunshine

Coastal areas in the south-west have average annual sunshine totals of above 1,600 hours, the south (English Channel) coast being more favoured than the north (Bristol Channel) coast. The Channel Islands are the sunniest part of the UK, with some places exceeding 1,900 hours per year (compared to 1,100 hours per year recorded on the Shetland Islands).

Inland, the annual sunshine totals are mainly between 1,400 and 1,600 hours. Figure 9.25 shows the average monthly sunshine totals for St Mawgan (the site of Newquay Cornwall Airport), together with the highest and lowest totals recorded in the stated periods.

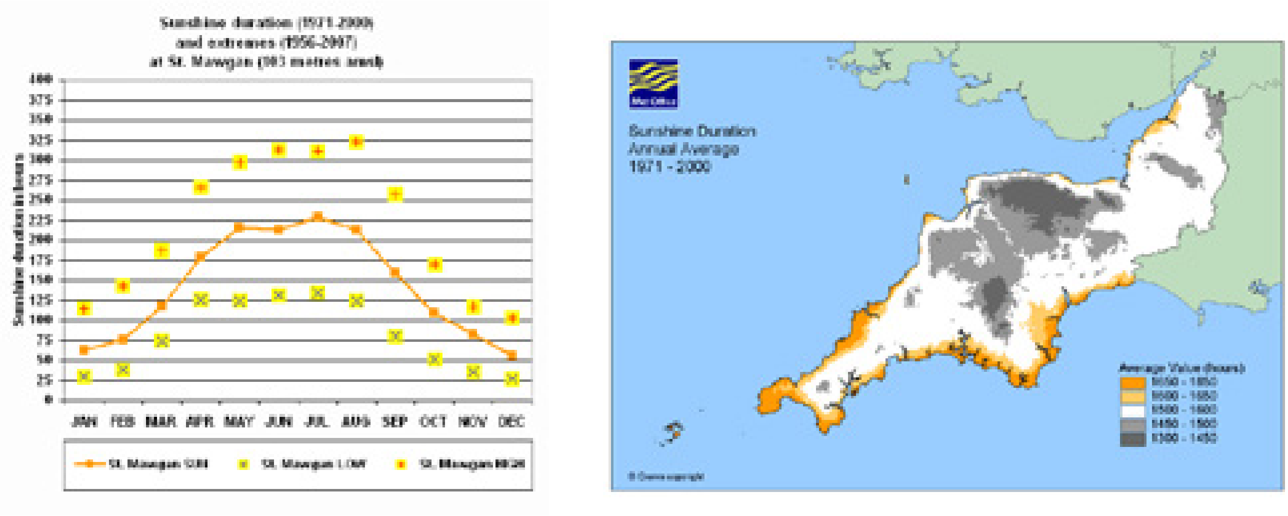


Figure 9.25: Average monthly hours of sunshine at St Mawgan and average annual hours of sunshine for south-west England 1971–2000

Rainfall

Annual rainfall totals are about 850–900 millimetres in the Scilly Isles. Most coastal areas of Cornwall and Devon have 900–1,000 millimetres, but up to double this amount falls on upland such as Dartmoor, Bodmin Moor and Exmoor. The highest rainfall is in December and January, when the sea is relatively warm and the Atlantic depressions are most vigorous. The months from April to July are the driest, when the sea is relatively cool and the Azores high-pressure system exerts more influence. August shows an increase in rainfall over July and starts the gradual rise in rainfall into the autumn and early winter.

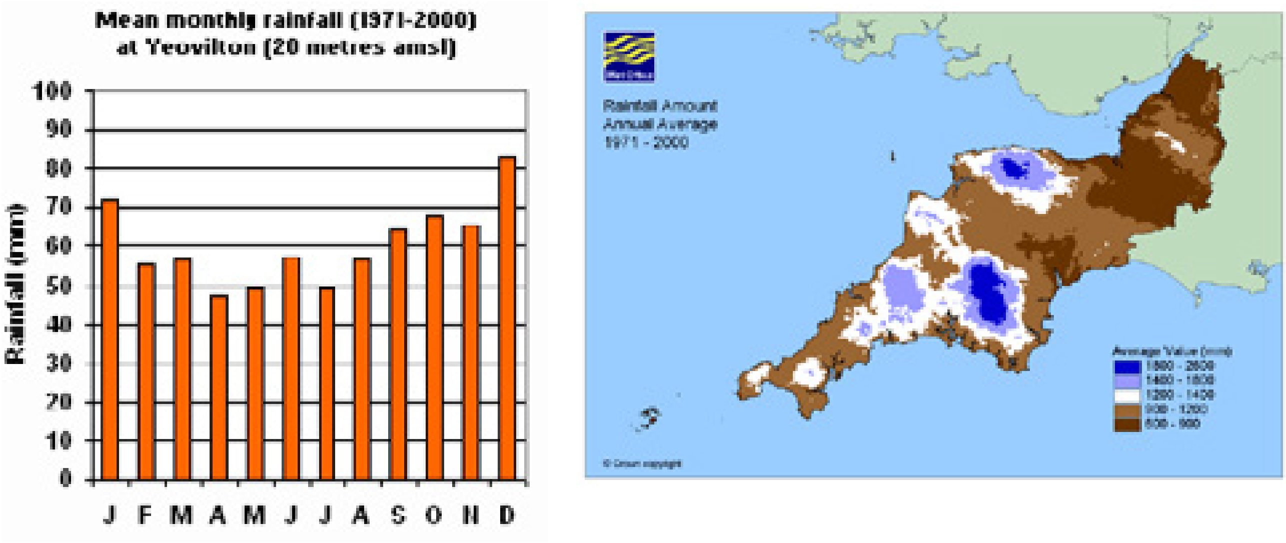


Figure 9.26: Average monthly rainfall at RNAS Yeovilton and average annual rainfall in south- west England 1971-2000

Wind

South-west England is one of the more exposed areas of the UK, with wind speeds on average only greater in western Scotland. The strongest winds are associated with the passage of deep depressions close to or across the British Isles. The frequency and strength of depressions is greatest in the winter half of the year, and this is when mean speeds and gusts are strongest. Figure 9.27 shows a typical variation of the monthly mean speeds and highest gusts. The variation in monthly mean speeds (average of a continuous record) and highest gusts ('instantaneous' speed averaged over about three seconds) at St Mawgan is shown below. The months from November to March have the highest mean speeds, with June to August having the lightest winds.

The peak gusts follow a similar pattern, and in the past 30 years both December and January have had gusts to over 80 knots.

Other coastal areas are similar to St Mawgan, though mean speeds generally decline towards the north-east of the region. Inland areas have lower speeds, which also decrease to the north-east. At Yeovilton in lowland Somerset, for example, the mean speeds are about two-thirds of those at St Mawgan.

Another measure of wind exposure is the number of days when gale force was reached. If the wind reaches a mean speed of 34 knots or more over any 10 consecutive minutes then that day is classed as having a gale. Exposed headlands and islands have the greatest frequency of days with a gale. In the Scilly Isles, the average is around 24 days per year, with a similar figure for exposed places in coastal Cornwall. The frequency is rather less to the north-east, especially inland. Plymouth (on the coast) has about 16 days per year, but Yeovilton in Somerset has seven and Long Ashton near Bristol only four.

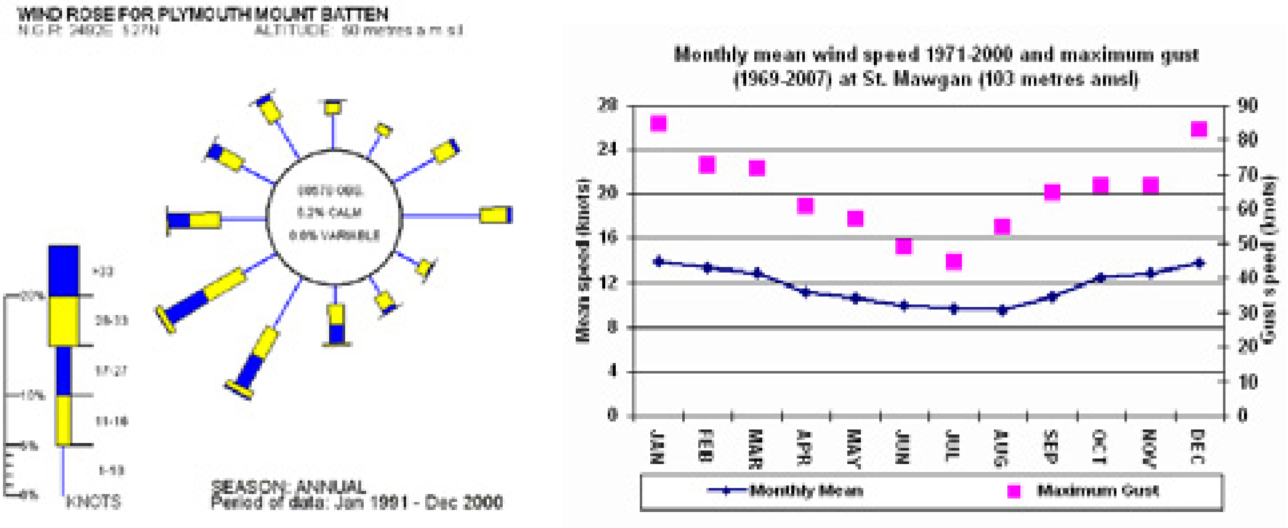


Figure 9.27: Average annual wind speed and direction at Plymouth 1991–2000 and average monthly wind speed at St Mawgan 1971–2000

Wales

This section looks at the meteorological factors likely to affect sites in Wales, such as Llanbedr.

Sunshine

Wales has an essentially maritime climate, characterised by weather that is often cloudy, wet and windy, but mild. However, the shape of the coastline and the central spine of high ground from Snowdonia southwards to the Brecon Beacons introduce localised differences. While some upland areas can experience harsh weather, the coasts enjoy more favourable conditions, and areas in east Wales are more sheltered and hence similar to neighbouring English counties. The hilly nature of the terrain in Wales and its proximity to the Atlantic tends to encourage cloud cover. Despite this, the south-western coastal strip of Pembrokeshire manages an average annual sunshine total of over 1,700 hours. Mean monthly sunshine totals reach a maximum in May or June, and are at their lowest in December. The key factor is, of course, the variation in the length of the day through the year, but cloud cover plays a part, too. Figure 9.28 shows the average monthly sunshine totals for RAF Valley in Anglesey, together with the highest and lowest totals recorded in the stated periods.

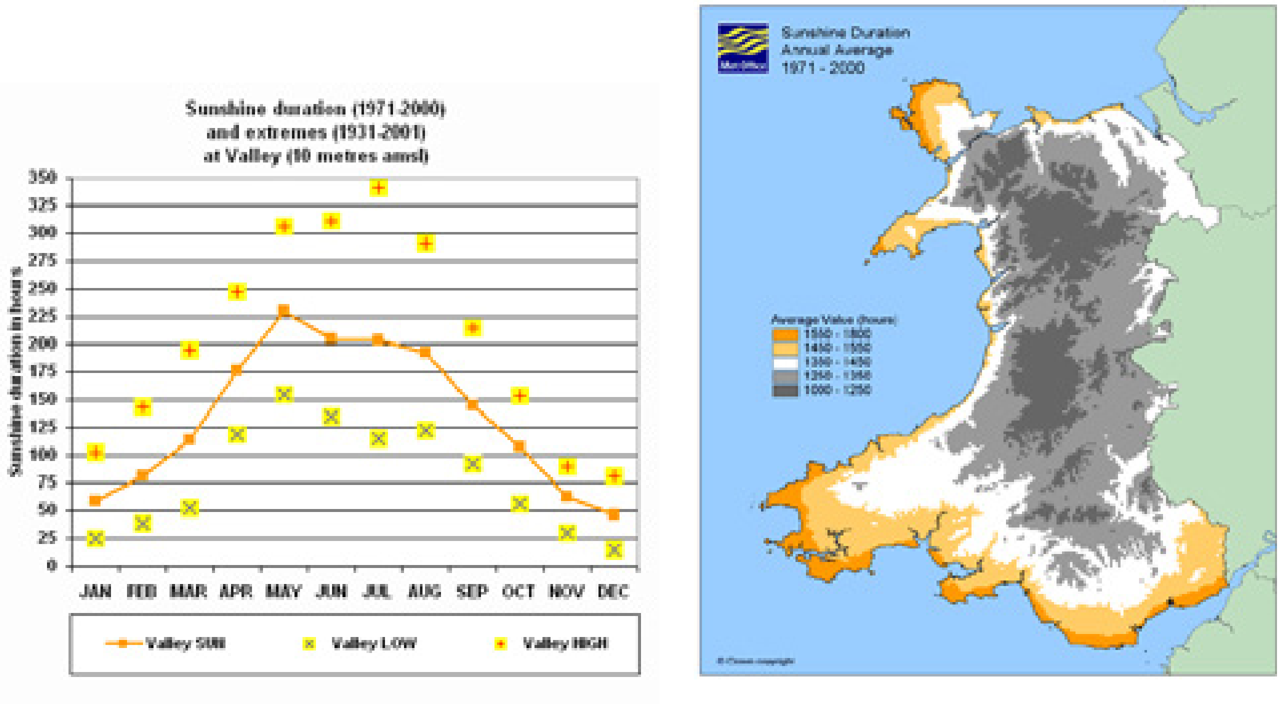


Figure 9.28: Average monthly hours of sunshine at RAF Valley and average annual hours of sunshine for Wales 1971–2000

Rainfall

Rainfall in Wales varies widely, with the highest average annual totals being recorded in the central upland spine from Snowdonia to the Brecon Beacons. Snowdonia is the wettest area, with average annual totals exceeding 3,000 millimetres, comparable to those in the English Lake District or the western Highlands of Scotland. In contrast, places along the coast, and particularly close to the border with England, are drier, receiving less than 1,000 millimetres per year.

Throughout Wales, the months from October to January are significantly wetter than those between February and September, unlike places in eastern England, where July and August are often the wettest months of the year. This seasonal pattern is a reflection of the high frequency of winter Atlantic depressions and the relatively low frequency of summer thunderstorms. Over much of Wales, the number of days with a rainfall total of 1 millimetre or more (‘wet days’) tends to follow a pattern similar to the monthly rainfall totals. In the higher parts, over 50 days is the norm in winter (December–February) and over 35 days in summer (June–August). In the driest areas of the east and south, about 40 days in winter and about 25 days in summer are typical. The combination of close proximity to active weather systems arriving from the Atlantic and the extensive areas of upland can lead to notable daily and monthly falls.

Figure 9.29 shows the mean monthly rainfall for 1971–2000 for RAF Valley. The pattern of rainfall shows the months from October to January as being the wettest, and the late spring and early summer months the driest.

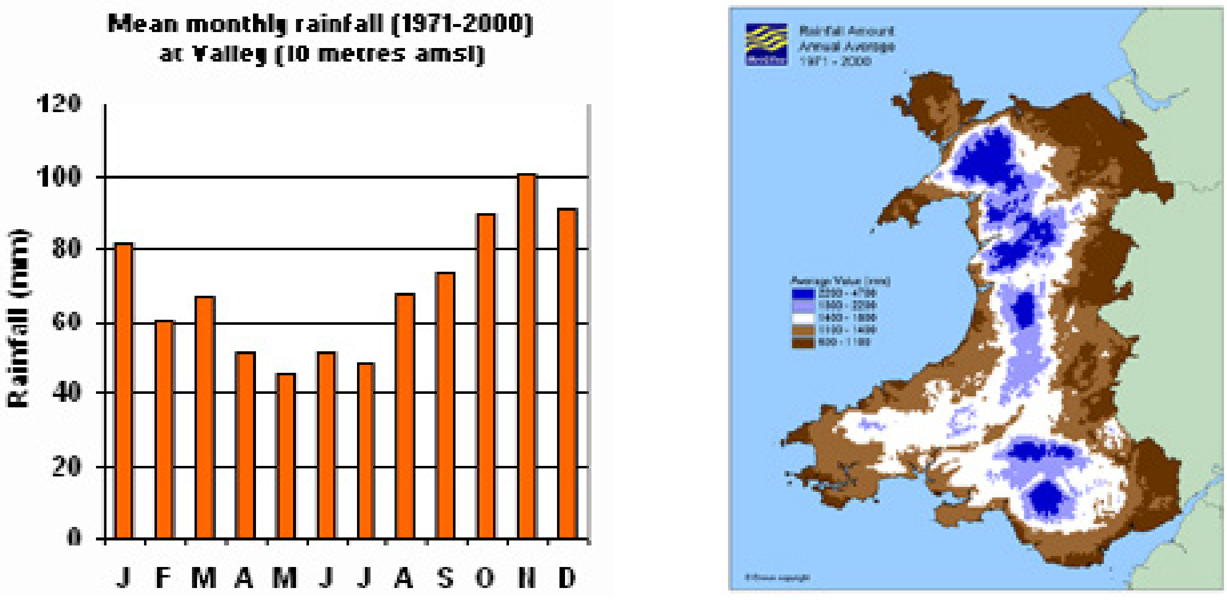


Figure 9.29: Average monthly rainfall at RAF Valley and average annual rainfall in Wales 1971–2000

Wind

Wales is one of the windier parts of the UK, with the windiest areas being over the highest ground and along the coasts, particularly those facing directions between north-west and south. The strongest winds are associated with the passage of deep areas of low pressure close to or across the UK. The frequency and strength of these depressions is greatest from November to February, and this is when mean speeds and gusts (short-duration peak values) are strongest. The variation in monthly mean speeds (average of a continuous record) and highest gusts ('instantaneous' speed averaged over about three seconds) at RAF Valley is shown in Figure 9.30 below.

Another measure of wind exposure is the number of days when gale force is reached. At low altitudes in Wales, gales occur most frequently in the south-west of Pembrokeshire, with about 30 days of gales on average. Other coastal areas average 15 days or more of gales each year, with the number of days decreasing inland to five days or fewer. The annual wind rose for Valley on Anglesey is typical of coastal locations in Wales, with a prevailing south-westerly wind direction through the year. However, there is a high frequency of north to north-east winds in spring.

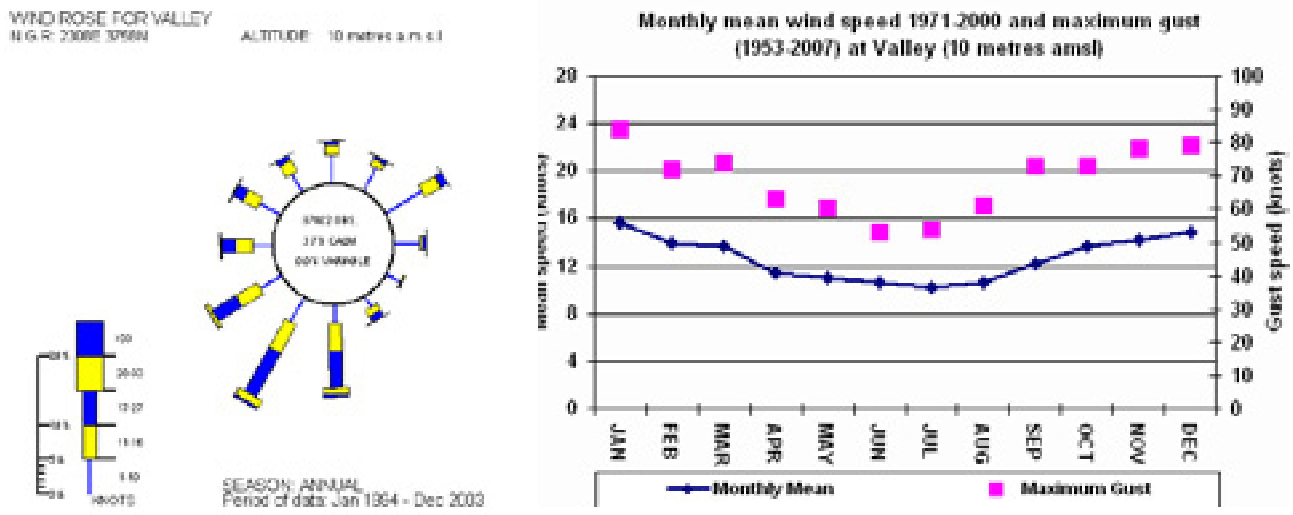


Figure 9.30: Average annual wind speed and direction 1994–2003 and average monthly wind speed at RAF Valley 1971–2000

APPENDIX 9B:

Population density data

Population data are based on 2011 Census data (updated for 2013) as supplied by CACI Information Services Ltd. Copyright: CACI Ltd 2013.

Airport	**Airport Code**	**Population resident within**				
		1 nautical mile (nm)	**2 nm**	**5 nm**	**7 nm**	**10 nm**
Belfast Aldergrove	EGAA	1,100	2,500	40,650	55,150	295,250
Birmingham	EGBB	10,300	89,400	577,800	983,650	1,835,400
Boscombe Down	EGDM	1,650	12,800	52,300	109,750	148,000
Bournemouth	EGHH	300	33,400	346,700	481,100	554,800
Bruntingthorpe	-	950	2,600	54,700	197,850	669,200
Campbeltown	EGEC	250	750	6,250	6,600	7,250
Cardiff	EGFF	6,050	11,400	75,700	163,450	459,550
Doncaster Sheffield	EGCN	1,450	9,350	101,100	224,650	416,550
Durham Tees Valley	EGNV	1,050	5,550	162,100	304,050	518,700
East Midlands	EGNX	5,350	11,850	130,400	381,650	947,200
Edinburgh	EGPH	1,250	9,050	223,000	533,850	809,800
Farnborough	EGLF	6,400	72,800	303,650	420,850	788,250
Glasgow	EGPF	4,200	65,150	459,450	758,200	1,086,000
Glasgow Prestwick	EGPK	7,400	18,300	89,450	143,800	241,250
Humberside	EGNJ	150	1,650	19,800	53,350	195,650
Kinloss Barracks	EGQK	1,600	2,850	16,250	20,200	52,800
Leeds/Bradford	EGNM	9,450	53,250	457,800	872,350	1,422,600
Liverpool	EGGP	11,300	33,600	377,850	787,600	1,477,900
Llanbedr	EGOD	50	1,800	4,550	8,500	23,100
London Gatwick	EGKK	250	46,100	184,150	309,200	521,300
London Heathrow	EGLL	5,250	68,650	739,650	1,423,050	2,827,600
London Luton	EGGW	6,600	58,300	275,100	455,600	902,450
London Stansted	EGSS	<50	12,550	74,850	113,100	237,250
Manchester	EGCC	1,150	45,400	435,050	857,500	1,504,850
Manston	EGMH	150	1,650	19,800	53,350	195,650

Airport	Airport Code	Population resident within				
		1 nautical mile (nm)	2 nm	5 nm	7 nm	10 nm
Newcastle	EGNT	1,250	23,750	335,350	597,900	1,032,300
Newquay Cornwall	EGHQ	800	2,600	37,200	55,600	102,900
RAF Brize Norton	EGVN	8,800	19,100	58,250	83,950	140,600
RAF Coningsby	EGXC	3,500	8,000	19,800	28,150	110,950
RAF Cottesmore	EGXJ	1,100	4,100	21,600	36,950	115,050
RAF Fairford	EGVA	600	5,200	36,250	145,200	324,650
RAF Honington	EGXH	1,800	3,050	40,600	93,100	151,300
RAF Lakenheath	EGUL	50	7,000	37,600	62,450	113,300
RAF Leeming	EGXE	2,950	7,700	31,900	47,900	111,650
RAF Leuchars	EGQL	2,900	3,700	34,250	127,400	230,350
RAF Lossiemouth	EGQS	250	7,850	35,050	39,250	48,300
RAF Lyneham	EGDL	3,050	6,450	49,450	121,550	349,900
RAF Marham	EGYM	2,900	4,000	14,850	42,400	120,450
RAF Mildenhall	EGUN	4,300	15,550	35,850	58,800	157,550
RAF Scampton	EGXP	1,250	2,200	70,650	145,950	215,150
RAF Waddington	EGXW	3,650	15,850	140,800	171,200	211,850
RAF Wittering	EGXT	0	5,000	39,250	63,000	282,500
RAF Wyton	EGUY	1,450	16,900	81,550	114,600	203,450
RNAS Yeovilton	EGDY	1,500	4,500	71,500	105,950	180,600
Stornoway	EGPO	1,150	6,700	10,850	12,250	13,300
Warton	EGNO	7,500	10,600	99,000	358,750	691,700

CHAPTER 10

Environmental impacts and considerations of spaceplane and spaceport operations

This chapter examines the potential environmental impact of spaceplane operations – and in particular, those relating to a spaceport. It uses the framework of existing environmental policy and legislation that applies to aviation, and considers its applicability to spaceplanes and spaceports. Based on this, it proposes criteria that may be used to aid selection of a potential spaceport site that would minimise its impacts on the surrounding area. It also considers what operational restrictions could be of value in minimising and mitigating any environmental impacts of spaceplane operations.

Environmental impact of aviation

10.1 In March 2013, the Government published its Aviation Policy Framework.[208] At its heart is the Government's primary objective of economic growth and how aviation can contribute to that. However, it recognises the need to maintain a balance between the benefits of aviation and its costs, particularly its contribution to climate change and noise.

10.2 To manage aviation's environmental impacts, the Aviation Policy Framework sets out three policies:

- to ensure that the aviation sector makes a significant and cost-effective contribution towards reducing global emissions;
- to limit, and where possible reduce, the number of people in the UK significantly affected by aircraft noise; and
- to achieve full compliance with European air quality standards.

10.3 All three policies are relevant to the development of commercial spaceplane operations within the UK, and in particular to the selection of a spaceport site. Given the opportunities for economic growth associated with commercial space operations, the goal – in line with the Aviation Policy Framework – has been to identify potential environmental risks around spaceplane and spaceport operations, and to pinpoint ways to minimise these and mitigate environmental impacts, without fundamentally impeding operations.

10.4 These three areas are therefore considered in turn, summarising the relevant legislation and then considering what this means for spaceplane operations.

---

[208] HM Government (2013) *Aviation Policy Framework*, Cm 8584, www.gov.uk/government/uploads/system/uploads/attachment_data/file/153776/aviation-policy-framework.pdf (accessed 22 April 2014)

Reducing emissions

10.5 As acknowledged in the Aviation Policy Framework, the aviation sector is responsible for about 1–2 per cent of worldwide greenhouse gas emissions and for about 6 per cent of the UK's total greenhouse gas emissions. The overwhelming majority of these are of carbon dioxide. Over recent years, there has been sustained effort by governments and the aviation industry to reduce emissions; for example the International Air Transport Association has set a target to cut net emissions in half by 2050, compared with the 2005 levels.[209]

10.6 Given that the majority of spaceplanes – and vertical launch vehicles – will emit carbon dioxide as an exhaust product, it is important to assess the potential impact of this on emissions targets.

Policy context

10.7 The Climate Change Act was passed in 2008 and established a framework to develop an economically credible emissions reduction path.[210] It also strengthened the UK's leadership internationally, by highlighting the role it would take in contributing to urgent collective action to tackle climate change under the Kyoto Protocol.

10.8 The Act commits the UK to reducing emissions by at least 80 per cent by 2050 from the 1990 levels. This target was based on a recommendation in the Committee on Climate Change report *Building a Low-carbon Economy*.[211] The 80 per cent target includes greenhouse gas emissions from the devolved administrations, which account for around 20 per cent of the UK's total emissions.

10.9 The Act requires the Government to set legally binding 'carbon budgets'. A carbon budget is a cap on the amount of greenhouse gases emitted in the UK over a five-year period. They are designed to provide a cost-effective, phased path to achieving the long-term objectives. The Committee provides advice on the appropriate level of each carbon budget. The first four carbon budgets have been put into legislation and run up to 2027.

Spaceplanes and carbon emissions

10.10 According to designs viewed to date, the overwhelming majority of spaceplanes and vertically launched vehicles will emit carbon dioxide as an exhaust product. There is therefore a need to assess whether the carbon emissions of a spaceport and its operations would significantly contribute to UK carbon emissions and conflict with already established carbon budgets and targets.

---

[209] See www.iata.org/policy/environment/Pages/climate-change.aspx (accessed 22 April 2014)

[210] See www.legislation.gov.uk/ukpga/2008/27/contents (accessed 22 April 2014)

[211] Committee on Climate Change (2008) *Building a Low-carbon Economy*, www.theccc.org.uk/publication/building-a-low-carbon-economy-the-uks-contribution-to-tackling-climate-change-2/ (accessed 22 April 2014)

10.11 There are two key factors here: first, the anticipated level of emissions from each operation, and secondly the total number of operations. With regard to the first, spaceplane designs – as far as they can be assessed – do not appear likely to generate substantially higher levels of carbon dioxide emissions than ordinary aviation. With regard to the latter, because the total number of operations is expected to be low, at least initially, the total volume of emissions from spaceplane activity will be insignificant, compared to that of other forms of aviation.

10.12 Therefore, other than following good practice to minimise carbon emissions from spaceplane operations and from the associated spaceport infrastructure, further restrictions are unlikely to be necessary.

Impacting the upper atmosphere

10.13 Most commercial aviation activity occurs in the troposphere and, to a secondary extent, the lower stratosphere. Commercial space access will result in activity in the upper stratosphere and also in the mesosphere and thermosphere.

10.14 Rocket exhaust emissions are known to result in stratospheric ozone depletion, predominantly as a result of particulate matter emissions from solid and hydrocarbon fuels.[212] Even water vapour emissions from liquid oxygen and liquid hydrogen fuels, widely considered to be inert, are known to contribute to ozone depletion. The stratosphere is very dry, and the emission of water into the upper stratosphere would cause a large perturbation, with potential warming consequences.

10.15 However, studies have consistently shown that **at current launch rates**, ozone depletion from rocket exhaust emissions is insignificant compared to other sources of ozone loss.[213]

10.16 Although research into rocket exhaust emission impacts has focused on ozone depletion, there is emerging evidence that some emission products may contribute to global warming at far greater rates than carbon dioxide (CO_2), although there is considerable uncertainty surrounding the potential magnitude of the effect. These include particulate matter from solid fuels and black carbon particulates from hybrid rocket fuels.[214] There is therefore a need to consider the additional radiative forcing effects in the upper atmosphere, in addition to those from carbon dioxide.

10.17 Commercial space access is expected to be dominated, at least initially, by sub-orbital spaceplanes, which use smaller rocket engines than are typically used by

---

[212] See World Meteorological Organization (2002) 'Scientific assessment of ozone depletion', www.wmo.int/pages/prog/arep/gaw/ozone_2002/ozone_2002.html (accessed 22 April 2014)

[213] ibid

[214] M Ross, M Mills and D Toohey (2010) 'Potential climate impacts of black carbon emitted by rockets', *Geophysical Research Letters*, 37, L24810, doi:10.1029/2010GL044548

existing vertical launch systems. However, spaceplanes are designed for reuse and could potentially conduct several operations in a single day; hence the total number of operations will increase. The potential benefit of lower emissions is therefore likely to be more than offset by the increased volume of operations. As existing regulations limiting ozone depletion from industrial sources reduce their impacts, it is possible that rocket exhaust emissions may become the dominating contributor to stratospheric ozone depletion and face pressure to be regulated.

10.18 None of this affects the choice of launch site or spaceport; however, the long-term climate impacts do require consideration.

Recommendation

The potential atmospheric impacts of sub-orbital and orbital commercial space operations should be studied further to ensure that a large number of operations would remain compatible with the UK's climate change objectives, and that specific risks identified could be mitigated.

Noise

10.19 Noise is understandably a prime concern around spaceplane operations, and particularly the selection of a spaceport site. Just as aircraft – particularly those with large or powerful jet engines – create a significant noise as they take off and pass overhead, so will spaceplanes. However, though the precise noise levels have yet to be fully determined, initial indications based on published characteristics are that noise from spaceplanes should not create more significant impact than noise from military fast jets.

10.20 Spaceplane operations in the UK are initially expected to take place from an existing civil-licensed or military aerodrome, where noise levels are already closely monitored. The total number of operations over the next few years is expected to be relatively low. As a result, it is anticipated that in the immediate term, spaceports will be able to comply with existing noise regulations. However, as spaceplane designs evolve and operations increase, noise impact will need to be kept under review. Furthermore, if a new spaceport were to be proposed at a greenfield site, noise would be a critical factor in the planning process.

Policy context

10.21 This section provides an overview of UK noise and planning policy.

National Planning Policy Framework

10.22 The National Planning Policy Framework (NPPF),[215] published in March 2012, represented a comprehensive revision of UK planning policy and guidance. With respect to noise, it replaced Planning Policy Guidance Note 24 (PPG 24), which was published in 1994 and provided prescriptive noise criteria regarding residential development near sources of noise. Instead, the NPPF introduced four high-level principles relevant to noise:

- avoid noise giving rise to significant adverse impacts on health and quality of life as a result of new development;
- mitigate and reduce to a minimum other adverse impacts on health and quality of life arising from noise from new development, including through the use of conditions;
- recognise that development will often create some noise, and that existing businesses wanting to develop in continuance of their business should not have unreasonable restrictions put on them because of changes in nearby land uses since they were established; and
- identify and protect areas of tranquillity which have remained relatively undisturbed by noise and are prized for their recreational and amenity value for this reason.

10.23 The definition of 'adverse impacts' is provided in the Noise Policy Statement for England (see below).

Noise Policy Statement for England

10.24 The Noise Policy Statement for England (NPSE) was published by the Department for the Environment, Food and Rural Affairs (Defra) in March 2010.[216] The noise policy aims to:

> 'Through the effective management and control of environmental, neighbour and neighbourhood noise within the context of Government policy on sustainable development:
>
> - avoid significant adverse impacts on health and quality of life
> - mitigate and minimise adverse impacts on health and quality of life, and

---

[215] Department for Communities and Local Government (2012) *National Planning Policy Framework*, www.gov.uk/government/uploads/system/uploads/attachment_data/file/6077/2116950.pdf (accessed 22 April 2014)

[216] Department for Environment, Food and Rural Affairs (2010) *Noise Policy Statement for England*, www.gov.uk/government/uploads/system/uploads/attachment_data/file/69533/pb13750-noise-policy.pdf (accessed 22 April 2014)

- where possible, contribute to the improvement of health and quality of life.'

10.25 The NPSE goes on to that state that 'the broad aim of noise management has been to separate noise sources from sensitive noise receivers and to "minimise" noise'.

10.26 Unlike for air quality, there are no European or national noise limits that have to be met, although there can be specified local limits for specific developments. Furthermore, sound only becomes noise (often defined as 'unwanted sound') when it exists in the wrong place or at the wrong time, so that it causes or contributes to some harmful or otherwise unwanted effect, like annoyance or sleep disturbance. Unlike many other pollutants, noise pollution depends not just on the physical aspects of the sound itself, but also on the human reaction to it.

10.27 With regard to 'significant adverse' and 'adverse' impacts as used in the NPPF, the NPSE states that there are two established concepts from toxicology that are applied to noise impacts by, for example, the World Health Organization. They are:

- NOEL – No Observed Effect Level: This is the level below which no effect can be detected. In simple terms, below this level, noise has no detectable effect on health and quality of life; and
- LOAEL – Lowest Observed Adverse Effect Level: This is the level above which adverse effects on health and quality of life can be detected.

10.28 The NPSE extends this concept further, to introduce the concept of a significant observed adverse effect level:

- SOAEL – Significant Observed Adverse Effect Level: This is the level above which significant adverse effects on health and quality of life occur.

10.29 The NPSE emphasises that it is not possible to have a single objective noise-based measure for SOAEL that is applicable to all sources of noise in all situations. Consequently, SOAEL is likely to be different for different noise sources, for different receptors and at different times. It acknowledges that further research is required to increase our understanding of what may constitute a significant adverse impact on health and quality of life from noise.

10.30 However, not having specific SOAEL values in the NPSE provides the necessary policy flexibility until further evidence and suitable guidance is available.

10.31 Relating the definitions of SOAEL and LOAEL to the aims of the NPSE, it states that:

- significant adverse effects on health and quality of life should be avoided, while also taking into account the guiding principles of sustainable development; and

- where noise impact lies somewhere between LOAEL and SOAEL, all reasonable steps should be taken to mitigate and minimise adverse effects on health and quality of life, while also taking into account the guiding principles of sustainable development.

10.32 Importantly, this does not mean that such adverse effects **cannot** occur.

Scotland

10.33 Noise and planning are devolved, with separate legislation set for Scotland.

10.34 The Scottish Government published a Planning Advice Note on Planning and Noise in March 2011.[217] This aims to provide advice on the role of the planning system in helping to prevent and limit the adverse effects of noise. During the preparation of a development plan, it highlights the need to consider:

- avoidance of significant adverse noise impacts from new developments;
- reasonable application of noise impact criteria;
- use of mitigation measures to manage noise impacts;
- protection of Quiet Areas; and
- avoidance of development significantly adversely affecting Noise Management Areas.

10.35 The terms Quiet Areas and Noise Management Areas (NMAs) were introduced through the Environmental Noise (Scotland) Regulations 2006,[218] which transposed the European Union Directive 2002/49/EC on Environmental Noise into Scottish law.[219] Quiet Areas are specifically those areas indicated within agglomerations. NMAs are those areas for which action plans are drawn up in order to manage noise exposure.

Wales

10.36 Noise and planning are also devolved for Wales, and have separate legislation. The Planning Policy Wales states that 'the objective of a policy for noise is to minimise emissions and reduce ambient noise levels to an acceptable standard'.[220] The Noise Action Plan for Wales aims 'to prevent and reduce environmental noise where necessary and preserve environmental quality where

---

[217] Scottish Government (2011) 'Planning Advice Note 1/2011: Planning and Noise', www.scotland.gov.uk/Publications/2011/02/28153945/0 (accessed 22 April 2014)

[218] See www.legislation.gov.uk/ssi/2006/465/made (accessed 22 April 2014)

[219] See http://ec.europa.eu/environment/noise/directive.htm (accessed 22 April 2014)

[220] Welsh Government (2014) 'Planning policy Wales', http://wales.gov.uk/topics/planning/policy/ppw/?lang=en (accessed 22 April 2014)

it is good'.[221] With regard to a potential spaceport, the relevant policy is to ensure 'that potentially noisy developments are located in areas where noise will not be such an important consideration or where its impact can be minimised'.

Assessing environmental noise exposure

10.37 The levels of individual noise events are required for many purposes, including aircraft noise certification. However, in order to assess environmental noise exposure, it is necessary to consider and take account of many events over a longer term – events which may differ in magnitude and be either repetitive or isolated.

10.38 Long-term noise exposure levels have been quantified in a variety of ways. They have been dictated partly by available instrumentation and partly by the nature of the events and their relationship to background levels, which are, in turn, controlled by other sources. One such measure is L_n, the sound level exceeded for n per cent of the measurement period. For example, in situations where the instantaneous sound level is continuously fluctuating, L_{90} and L_{10} can be used to characterise background and typical high levels, respectively. In the UK, a particular version of L_{10} is used to specify levels of exposure to road traffic noise.

10.39 Nowadays, the most commonly used noise exposure measure for all sources is the equivalent continuous noise level, L_{eq}. For transportation noise, including aircraft noise, this is in widespread use around the world. L_{eq} may be defined as the level of the hypothetical steady sound which, over the measurement period, contains the same (frequency-weighted) sound energy as the actual variable sound (see Figure 10.1).

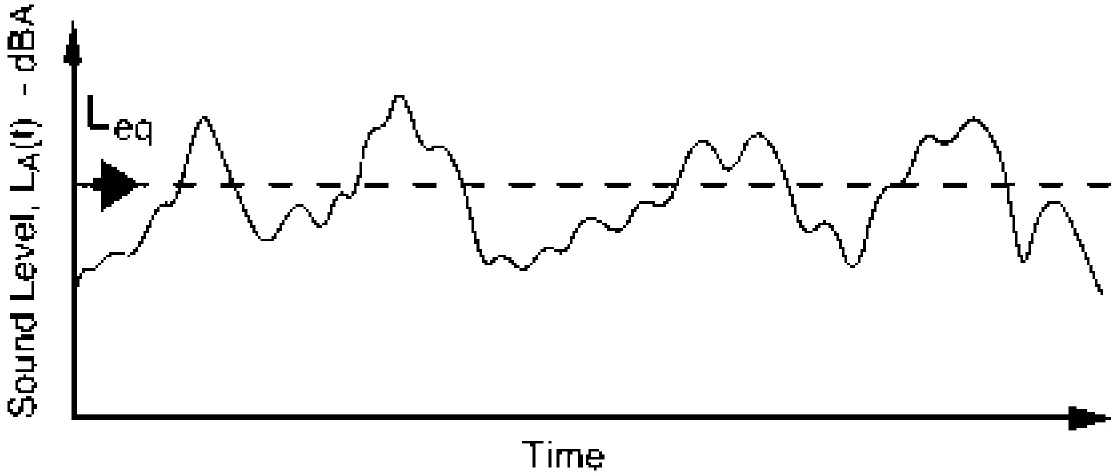


Figure 10.1: Measuring L_{eq} - Equivalent continuous noise level

---

[221] Welsh Government (2013) 'A noise action plan for Wales', http://wales.gov.uk/topics/environmentcountryside/epq/noiseandnuisance/environmentalnoise/noisemonitoringmapping/noise-action-plan/?lang=en (accessed 22 April 2014)

10.40 Usually a relatively long measurement period is specified. Theoretically, L_{eq} can be measured on any frequency-weighted scale, but in practice the A-weighted scale (L_A) is most widely used. (The corresponding L_{eq} is often abbreviated L_{Aeq}.)

10.41 As stated above, there are no defined levels of SOAEL and LOAEL associated with environmental noise in England. However, with regard to conventional civil airports, the onset of significant annoyance has been established as 57 dBA $L_{eq,\ 16\ hour}$, based on an average summer's day exposure.[222] $L_{eq,\ 16\ hour}$ is an equivalent continuous noise exposure level that contains the same noise energy as the fluctuating noise level over an average summer's day from 0700 to 2300.

10.42 Night-time noise exposure has historically been assessed using 48 dBA $L_{eq,\ 8\ hour}$ (2300–0700). Single-event Sound Exposure Level (SEL) is also used to estimate the risk of sleep disturbance from a single operation.

Applying environmental noise assessment criteria to a spaceport

10.43 One of the difficulties in defining noise criteria for a spaceport is the potential for a very wide range of noise exposure levels between different types of spaceplane. Those launched at altitude from a carrier aircraft are likely to be comparable to existing civil aircraft. However, those which launch from a runway using rocket engines are likely to be several times noisier than existing civil aircraft. To understand the difficulties this poses in setting policy criteria, it is necessary to understand the L_{eq} index better.

10.44 The L_{eq} index embodies the equal energy principle: in other words, it assumes that a small number (N) of noisier events has the same total noise energy as a greater number of quieter events. L_{eq} can be expressed mathematically as: $L_{eq} = SEL_{avg} + 10x\log_{10}N - constant.$

10.45 Applying the expression to typical values of SEL and N gives the results shown in Table 10.1.

SEL (dB)	N	$L_{eq,16hr}$
110	1	62.4
100	10	62.4
90	100	62.4
80	1000	62.4

Table 10.1: Variation of SEL and N for constant L_{eq}

---

[222] dBA means 'A-weighted decibels.' The A-weighting system means that the decibel values of sounds at low frequencies are treated as less disruptive than noises at higher frequencies. It is used because the human ear is less sensitive to sounds at low frequencies.

10.46 As the SEL decreases at a rate of 10 dB, the level of each noise event becomes half as loud. For the same total noise energy, the number of events increases by a factor of 10.

10.47 Theory and social and attitudinal survey results imply that all four scenarios in Table 10.1 should result in a similar noise annoyance response from an average individual. Across a wide range of aerodrome types, this relationship has been shown to work well. However, it does not apply so effectively to changes at the more extreme end of the spectrum – for example, when a new aerodrome is created where there was previously no aircraft noise, or to accurately reflect the noise impact of the withdrawal of Concorde operations at Heathrow. The noise of just one Concorde departure was equivalent to 55 Boeing 747-400 departures or almost 600 Airbus A320 departures.

10.48 Therefore, while some may argue that tolerance of a single noise event rises according to the energy relationship, it is generally accepted that L_{eq} is not an appropriate measurement for very loud and infrequent noise events.

10.49 A literature search was undertaken to investigate how noise is taken into account where there is potential for significant variation between noise event types. This highlighted a lack of evidence on which to define noise assessment criteria when ambient noise levels are punctuated with very infrequent, yet very noisy events.

10.50 For Spaceport America, the US relied on its noise policy for civil airports and assessed the impact of the change to the 65 dB Day Night Level (DNL – the US airport noise indicator) noise contour.[223] The only additional element was to check on the impact of the highest single-event noise levels (vertical launch) on the nearest residence, to confirm that there was no risk of hearing damage. The analysis highlighted the difficulty of using energy average metrics by showing that a vertical launch resulting in a peak noise level of 90 dBA for two minutes, every three days (125 times per year) would only contribute an additional 0.6 dB to the DNL level.

10.51 The Federal Aviation Administration (FAA) has further defined three DNL significance criteria.[224]

---

[223] FAA AST (2008) *Final Environmental Impact Statement for the Spaceport America Commercial Launch Site, Sierra County, New Mexico*, vols I and II, www.faa.gov/about/office_org/headquarters_offices/ast/environmental/nepa_docs/review/operator/spaceport_america_eis/ (accessed 22 April 2014)

[224] FAA (2004) *FAA 1050.E Policies and Procedures for Considering Significant Environmental Impacts*, www.faa.gov/regulations_policies/orders_notices/index.cfm/go/document.current/documentNumber/1050.1 (accessed 22 April 2014)

Base Level	Change	Level of Impact
>65 dB DNL	>1.5 dB	Significant
60–65 dB DNL	>3 dB	Slight to moderate
45–60 dB DNL	>5 dB	Slight to moderate

Table 10.2: DNL significance criteria

10.52 The DNL metric, like L_{eq}, is fundamentally insensitive to insignificant, yet very loud, events. This means that a large number of events can be accommodated at an existing airport without causing a significant impact within the significance criteria.

10.53 So if airport noise assessments are not wholly appropriate for assessing the potential noise impact of all spaceplane operations – potentially uncommon, yet very loud events – a useful parallel can perhaps be found by looking more widely. From a noise perspective, motor racing circuits and music concert venues could both be considered to be comparable situations. Both exhibit relatively low ambient noise levels, which are elevated for relatively infrequent, yet noisy, activities.

10.54 The motor racing circuit analogy is most appropriate, as circuits exhibit a wide range of noise levels, depending on what type of activity is being undertaken. Circuits typically define noisy days as those when unsilenced vehicles are operating, eg Grand Prix and GT racing, and quiet days as those when road vehicles engage in track days and similar hospitality events.

10.55 The recent environmental impact assessment (EIS) for the Silverstone Grand Prix circuit assessed quiet day activities and a club event activity, which encompassed 'competitive' and 'customer use' types of activities.[225] Both were assessed using the $L_{eq,\ 16\ hour}$ index. The EIS focused on the potential change in use if the circuit were to be developed, and thus defined large and significant change as being when noise increased from below 50 dBA L_{eq} to more than 55 dBA L_{eq}. A moderate change was defined as noise increasing from below 50 dBA L_{eq} to between 50 and 55 dBA L_{eq}, or from 50–55 dBA L_{eq} to more than 55 dBA L_{eq}.

10.56 The analysis shows that noise indicators such as L_{eq} would be suitable for identifying potential noise impacts, and could therefore be used to inform spaceport noise assessments. Because vertical launch operations would be significantly noisier than many spaceplane operations, consideration would need

---

[225] South Northamptonshire Council, Planning Application Display – S/2011/1051/MAO, Environmental Statement Appendix H: Noise and Vibration, http://snc.planning-register.co.uk/plandisp.aspx?recno=65299 (accessed 22 April 2014)

to be given to assessing both 'quiet days' and 'noisy days', as the noise exposure would be significantly different.

Noise impact of operations at night

10.57 While it may seem logical to restrict horizontal and vertical launch vehicles to operations during the daytime (as, for example, is done with motor racing), there may be airspace operational reasons that require operations to take place at night.

10.58 It is well known that noise at night can interrupt the sleeping process. Evidence already exists linking the risk of awakening to an individual noise event, and thus the effect and impact is much more straightforward to assess and quantify than daytime noise annoyance.

10.59 The UK 1992 field study of aircraft noise and sleep disturbance found that outdoor noise events below 90 dBA SEL were unlikely to disturb the average person's sleep.[226] However, at levels of 90–100 dBA SEL, the likelihood of the average person being woken by that noise event was found to be about 1 in 75. Thus, it is possible to calculate the approximate number of awakenings by combining knowledge of the population count within the 90 dBA SEL noise footprint for a launch vehicle, the number of operations of the different vehicle types and the probability of being awoken.

10.60 Based on noise measurement data of existing vertical launch vehicles[227] that are representative of proposed vertical launch concepts, the risk of sleep disturbance from a vertical launch would extend up to seven miles from the launch site. Populations living within seven miles could be very quickly estimated for a large number of candidate sites for vertical launch and the process could be readily used both to screen out certain sites, and to assess in more detail a shortlist of spaceport sites, taking into account noise from spaceplane operations, once the noise footprints for spaceplanes have been determined.

Noise management

10.61 In its 2008 Guidance on the Balanced Approach to Aircraft Noise Management,[228] the International Civil Aviation Organization (ICAO) introduced a four-pronged approach to managing aircraft noise, involving:

- reduction of noise at source;
- reduction of noise through operational measures;

---

[226] Department for Transport (1992) *Report of a Field Study of Aircraft Noise and Sleep Disturbance*, London, CAA

[227] FAA AST (2008) *Final Environmental Impact Statement for the Spaceport America Commercial Launch Site, Sierra County, New Mexico,* Vols I and II, www.faa.gov/about/office_org/headquarters_offices/ast/environmental/nepa_docs/review/operator/spaceport_america_eis/ (accessed 22 April 2014)

[228] ICAO (2008) *Guidance on the Balanced Approach to Aircraft Noise Management*, second edition, Montreal, ICAO

- reduction of noise through land-use planning; and
- as a last resort, restrictions on operations.

10.62 Reduction of noise at source means identifying ways to reduce the noise emission of a vehicle over time, through the design, manufacture and introduction of new technologies. It can involve setting long-term goals to support research and development of such technologies and standards to ensure that the best available technology is incorporated into designs.

10.63 Reduction of noise through operational measures includes, where possible, taking measures to minimise noise exposure through optimised departure and arrival operating procedures and using optimised flight paths that take into account population distributions in the vicinity of an airport.

10.64 Reduction of noise through land-use planning means selecting operational sites away from densely populated areas. Once sites are developed, measures can be taken to discourage population encroachment on the site, which could create future noise problems.

10.65 Finally, restrictions on operations might include limitations on operational times, the number of operations and limitations relating to wind direction. The specific types of vehicles that could be operated could also be restricted to mitigate impacts on a site-by-site basis.

10.66 Although conceived as a framework to manage subsonic aircraft noise at civil airports, the framework is equally applicable to spaceplane operations and spaceports. The only difference is that the specific measures that could be applied under each element may differ somewhat from those applicable to a conventional civil airport. The following sections discuss in more detail what role operational measures might play in minimising noise impacts.

Reduction of noise at source

10.67 As mentioned, this element seeks to ensure that the best available technology is incorporated into vehicle design to minimise noise emission. The basic requirements of sub-orbital and orbital flight and the fundamental physics mean that vehicle powerplants will be required to develop large amounts of thrust with high exhaust velocities: these lead to high levels of turbulent noise.

10.68 Spaceplane operations based on using a carrier aircraft may reduce these adverse effects.

10.69 For designs that do not use a carrier aircraft, international design standards to control noise do not exist at the time of writing, and in many cases it may not be appropriate to develop and introduce such standards. As such, this element is unlikely to play as big a role in the management of spaceport noise as it does for a conventional airport.

Reduction of noise through operational measures

10.70 For spaceplane operations based on using a carrier aircraft, it may be possible to mitigate noise impacts quite simply, through the application of appropriate departure and arrival flight procedures and by using departure and arrival flight paths that direct the carrier aircraft away from more densely populated areas.

Recommendation
For spaceplane operations that use a carrier aircraft, optimised flight procedures and flight paths should be considered as ways to mitigate the noise impact.

10.71 For spaceplanes that use rocket-powered propulsion from take-off, the propulsion system and high flight speeds may preclude the use of optimised departure procedures. This may also be the case for any vehicle that would also use rocket power for landing.

10.72 In the case of a vehicle that performs an unpowered landing, although propulsion noise may no longer be a determining factor, unpowered approach and landing will place complete priority on energy management to achieve a safe landing. This may result in limitations to the ground track that can be flown.

10.73 For vertical launch vehicles, it is unlikely that any form of operational measures could be used to reduce noise.

Reduction of noise through land-use planning

10.74 Appropriate siting of a spaceport, as far away as possible from population centres, is likely to be the most effective measure for reducing noise impacts associated with a spaceport. This reflects the principle set out above that noise pollution is only an issue when it causes or contributes to some harmful or otherwise unwanted effect, like annoyance or sleep disturbance.

10.75 Once a site is established, it will be essential that the area in the vicinity is appropriately zoned to prevent population encroachment on a spaceport.

Operating restrictions

10.76 While it is recognised that under ICAO guidance, operating restrictions should be considered a last resort, because of the wide range of noise levels between the different concept vehicles, restrictions could play a significant role in managing spaceport noise. Additionally, in the case of rocket-powered vehicles, restrictions on the number and time of day of operations may be the only effective way to manage their noise impacts.

10.77 The Spaceport America EIS assumed that no launches would take place at night, and it would seem an obvious measure to take to prevent night-time operations in the UK too.[229] However, the need to avoid interaction with other airspace users may prevent a complete curfew on night-time operations. This could be taken into account by considering potential night-time noise impacts as part of the site selection noise criteria, in addition to, and separate from, day-time noise impacts. This is the case for civil airports.

10.78 Nevertheless, it may still be necessary to impose restrictions on the numbers and types of operations that can take place at night, and also potentially limitations on the number of consecutive days and/or nights of operation, to provide some form of respite from noise impacts.

Recommendation

Where airspace considerations may require operations at night, the impacts should be minimised through assessing risk of sleep disturbance.

10.79 A review of motor racing circuit noise management plans identified examples where the number of days per year that the circuit can be used is restricted, depending on the noise output of the vehicle. Restrictions are also placed on the number of consecutive days, depending on the vehicle types operated, with further restrictions on weekend use.

10.80 For example, Donington Park racing circuit has developed a Noise Management Plan that specifically differentiates between four classes of vehicle.[230] It allows unlimited use of Class 1 vehicles that meet a specified noise level, based on a trackside noise test. Beyond that, the circuit is permitted up to 60 noisy days per year, which can be refined further, as follows:

- up to 60 race meetings for Class 2 vehicles (up to 108 dBA static noise test);
- up to 40 race meetings for Class 3 vehicles (up to 118 dBA static noise test); or
- up to 20 race meetings for Class 4 vehicles (unsilenced).

10.81 Thus, rather than express the wide variation in noise exposure between different types of use in a single noise exposure value, practical noise controls were instead developed around limiting the amount of use of each vehicle type. Such criteria are, however, most appropriate for operational control, once a site has been selected.

---

[229] FAA AST (2008) *Final Environmental Impact Statement for the Spaceport America Commercial Launch Site, Sierra County, New Mexico*, vols I and II, www.faa.gov/about/office_org/headquarters_offices/ast/environmental/nepa_docs/review/operator/spaceport_america_eis/ (accessed 22 April 2014)

[230] See www.donington-park.co.uk/about-donington/circuit-noise-restrictions/ (accessed 22 April 2014)

Recommendation

Measures to restrict the time of day and number of operations, like those employed to mitigate infrequent yet high noise in other circumstances, such as motor racing circuits, should be considered – in particular for rocket-powered vehicles – as this will be the only effective noise mitigation measure at a given site.

Sonic boom

10.82 All the launch vehicles considered here would operate at supersonic speeds and thus generate sonic booms. A sonic boom propagates along a cone of rays opening forward of the aircraft's velocity vector. For a supersonic aircraft in horizontal flight, this ray cone will eventually intersect with the ground at a future time, as the cone intersects with the ground to form the hyperbolic boom footprint.

10.83 The majority of vehicles operating from a spaceport on sub-orbital flights would not fly an orbital trajectory and, as a consequence, their trajectories would be vertical or near vertical, ie they would not 'pitch over' as in orbital types of launches. Consequently, during the ascent portion of a launch, the ray cone (and the corresponding sonic boom from the launch vehicle) would not intersect with the ground. Instead, it would propagate away from the Earth's surface and the corresponding sonic boom would not be heard.

10.84 While the possibility exists that a boom propagating into free space may reflect off the thermosphere and back to the ground (referred to as an 'over-the-top' boom), such booms are generally inaudible.

10.85 However, for spaceplanes such as SKYLON, which are designed for orbital insertion, flight trajectories would result in a sonic boom propagating back to ground level. Reaction Engines Ltd has indicated that SKYLON would become supersonic 23 kilometres after departure, at an altitude of 10,000 feet.

10.86 Sonic boom strength is proportional to mass and length to the power 1.5.[231] This would suggest that a SKYLON sonic boom would be greater than that of Concorde, which was generally regarded as unacceptable over land. Such a vehicle would therefore need to be operated from a coastal site to minimise the risk of sonic boom occurring over land.

Sonic boom control

10.87 There are no internationally agreed rules regulating civil supersonic flight in order to control sonic boom. ICAO is, at the time of writing, collating evidence on sonic boom propagation and impacts that may feed into Standards and Recommended Practices for the control of sonic booms associated with

---

[231] R Seebass and AR George (1972) 'Sonic boom minimization', Proceedings of the Second Sonic Boom Symposium, *Journal of the Acoustical Society of America*, 51(2-3): 686–694

supersonic flight. This work is, however, related to facilitating the development of supersonic business jets, and so will incorporate design features to reduce sonic boom signature, which may not be relevant to spaceplanes.

10.88 As a result, individual states have defined their own rules and regulations with regard to supersonic flight. These are generally maintained by military authorities, as they have almost exclusive access to supersonic aeroplanes. In the UK, supersonic flight regulations are defined by the Military Aviation Authority (MAA). Section RA 2310(1) states:

> **'Conduct and Positioning of Supersonic Flights in the UK FIR [Flight Information Region]**
> In the UK FIR, all supersonic flights should be conducted over the sea. Aircraft Commanders should ensure their aircraft is at least 10 nautical miles out to sea and along a line of flight at least 20° divergent from the mean line of the coast; the angle of dive should not exceed the minimum necessary to accelerate to supersonic flight. Supersonic flights with the aircraft pointing towards the land, turning or flying parallel to the coast should take place at least 35 nautical miles from the nearest coastline. Aircraft position should be accurately determined and if more than one radar unit is controlling within the same airspace, close co-ordination should be affected before any supersonic runs take place.'[232]

Recommendation
To minimise the impact of sonic boom over land, a coastal site should be chosen as the spaceport for orbital operations so that the sonic boom would take place over water.

Air quality

10.89 The Aviation Policy Framework specifically targets compliance with European air quality standards. These focus on the levels of air pollutants that impact public health, such as particulate matter (PM_{10} and $PM_{2.5}$) and nitrogen dioxide (NO_2).

10.90 Because of the fuel they use, many spaceplanes will not produce significant amounts of either particulate or NO_2 emissions: most rocket fuels produce primarily carbon dioxide and water when burned. The exceptions are spaceplanes that use solid fuel or kerosene. Solid fuel in particular is likely to produce high levels of $PM_{2.5}$. It also brings with it higher risk in the event of an incident.

10.91 A potential mitigation would be to strictly limit or even ban operations that use solid fuel: however, such a decision would need much more analysis. In the short

---

[232] See www.maa.mod.uk/linkedfiles/regulation/2000_series/ra2310.pdf (accessed 26 May 2014)

term, the amount of $PM_{2.5}$ generated by solid fuel-powered vehicles would be small, on account of the small number of launches expected.

Policy context

10.92 The Air Quality Standards Regulations[233] transposed into UK law the European Union Directive on Ambient Air Quality.[234] This Directive sets legally binding limits for concentrations in outdoor air of $PM_{10,}$ $PM_{2.5}$ and NO_2, as well as for some other major pollutants. As well as having direct effects, these pollutants can combine in the atmosphere to form ozone, a harmful air pollutant (and potent greenhouse gas) that can be transported great distances by weather systems.

10.93 These issues were recognised in the Air Quality Strategy for England, Scotland, Wales and Northern Ireland.[235] The strategy sets out air quality objectives and policy options to further improve air quality in the UK. It noted that there were three specific areas where targets were not being met:

- particulate matter (PM);
- ozone; and
- nitrogen dioxide.

10.94 With regard to PM, the Air Quality Strategy noted that, while legislative requirements focus attention on meeting EU air quality limit values and thus localised hotspots, there is no accepted threshold effect, ie no recognised safe level for exposure to fine particles ($PM_{2.5}$). It therefore adopted a policy of 'exposure reduction' for $PM_{2.5}$, regardless of exposure level, by seeking a 15 per cent reduction in average concentrations in urban background areas across the UK between 2010 and 2020.

10.95 In contrast to PM, there is no consensus on a lack of a threshold effect for NO_2, so the strategy aims to meet legally binding limits.

Applying air quality standards to spaceplane operations

10.96 All the proposed sub-orbital spaceplanes and vertical launch vehicles use rocket-based propulsion. However, there are many different rocket fuels, and spaceplane and vertical launch vehicle design concepts have been proposed using one or more of the following fuels:

- jet fuel;
- hydrocarbon fuel, eg kerosene-based rocket propellant;

---

[233] See www.legislation.gov.uk/uksi/2010/1001/pdfs/uksi_20101001_en.pdf (accessed 22 April 2014)

[234] See http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008L0050 (accessed 22 April 2014)

[235] Defra (2007) *The Air Quality Strategy for England, Scotland, Wales and Northern Ireland*, vol 1, www.gov.uk/government/uploads/system/uploads/attachment_data/file/69336/pb12654-air-quality-strategy-vol1-070712.pdf (accessed 22 April 2014)

- cryogenic propellants, eg liquid oxygen and liquid hydrogen, maintained at very low temperatures;
- solid propellants, eg powdered aluminium-based solid fuel; and
- hybrid propellants, eg mix of solid propellants with oxidisers such as liquid oxygen.

10.97 Of these, only those relying on solid fuel and kerosene – either in the spaceplane or vertical launch vehicle or in its carrier aircraft – would contribute to PM and NO_2 emissions. As discussed above, all other rocket fuels produce primarily carbon dioxide and water.

10.98 Solid fuel rocket engines generate aluminium oxide (Al_2O_3) as an exhaust product in the form of particulate matter of less than 2.5 microns in diameter, the concentrations of which are regulated through EU Directive. As noted above, UK policy is to reduce $PM_{2.5}$ exposure, regardless of exposure level, with a target of a 15 per cent reduction in average concentrations in urban background areas across the UK between 2010 and 2020.

10.99 Initially the amount of $PM_{2.5}$ generated by solid fuel-powered vehicles would be small, on account of the small number of launches expected. Hence it would have only a negligible impact on average concentrations. However, if the number of operations using solid fuel were to increase, that may change.

10.100 Furthermore, while all the rocket fuels listed above are considered to be hazardous materials, meaning that their transportation and storage are governed by existing regulations, the greatest risks are associated with solid propellants, specifically a launch pad-related explosion of a solid fuel rocket. Although an uncontained failure of a solid fuel rocket would reduce the rate of combustion as a result of the propellant grain being broken, combustion would generate large quantities of hydrogen chloride (HCl) and aluminium oxide (Al_2O_3). HCl would react with water to form hydrochloric acid, which would be a health risk not only within the immediate launch pad area but also downwind of the launch site. In the EIS for Spaceport America, the Federal Aviation Administration Office of Commercial Space Transportation (FAA AST) noted that this risk might extend 2–3 miles downwind of the launch pad.[236]

10.101 There are two immediate options for mitigating this risk. The first is to stipulate that vertical launches can only take place when the wind direction means that any emission cloud would disperse away from populated areas. The second, more radical, option is to consider restricting or even banning the use of solid fuels altogether.

---

[236] FAA AST (2008) *Final Environmental Impact Statement for the Spaceport America Commercial Launch Site, Sierra County, New Mexico*, vols I and II, www.faa.gov/about/office_org/headquarters_offices/ast/environmental/nepa_docs/review/operator/spaceport_america_eis/ (accessed 22 April 2014)

10.102 Such a decision would need further analysis, examining not only the potential environmental impact, but also the impact on the growth of the spaceplane and commercial space industry. It would be essential to ensure that a ban on solid fuels does not stifle the industry unnecessarily. Further research might ascertain whether those designs that propose to use solid fuels could be adapted to use other fuels, and what the consequence of such adaptation would be on launch dates.

Recommendation

Consideration should be given to supporting a research project to assess the impact on the environment and the emerging industry of banning the use of solid fuels.

Conclusions

10.103 This chapter has considered the primary environmental factors that would have a bearing on spaceplane operations and the location of a potential spaceport: noise, sonic boom, local air quality and environmental factors that could cause a risk to the uninvolved general public.

10.104 In general, existing international aviation environmental regulation for aircraft, aerodromes and airspace will apply, covering issues such as noise, air quality (including carbon emissions) and the storage of hazardous materials. However, with regard to noise assessment, the Review has identified a lack of established significance criteria. While existing airport noise criteria would help to identify potential impacts, the criteria do not fully reflect likely reactions to very infrequent, yet very loud, noise events.

10.105 Overall, the environmental characteristics and considerations are expected to vary between spaceplane types and individual designs. Environmental issues surrounding spaceplanes are also expected to be of significant public concern. To address these concerns, a full environmental impact assessment should be undertaken for each spaceplane type at each launch location. This is in line with FAA AST requirements, and would ensure that all appropriate mitigation can be put in place.

Recommendation

A full environmental impact assessment should be undertaken for each spaceplane type at each launch location.

10.106 Because environmental impact assessments can take some time to complete, it is important that any such assessment should begin as soon as an operator confirms its intention to launch from a given site.

Recommendations

10.107 This chapter has made the following recommendations.

- The potential atmospheric impacts of sub-orbital and orbital commercial space operations should be studied further to ensure that a large number of operations would remain compatible with the UK's climate change objectives, and that specific risks identified could be mitigated.
- For spaceplane operations that use a carrier aircraft, optimised flight procedures and flight paths should be considered as ways to mitigate the noise impact.
- Where airspace considerations may require operations at night, the impacts should be minimised through assessing risk of sleep disturbance.
- Measures to restrict the time of day and number of operations, like those employed to mitigate infrequent yet high noise in other circumstances, such as motor racing circuits, should be considered – in particular for rocket-powered vehicles – as this will be the only effective noise mitigation measure at a given site.
- To minimise the impact of sonic boom over land, a coastal site should be chosen as the spaceport for orbital operations so that the sonic boom would take place over water.
- Consideration should be given to supporting a research project to assess the impact on the environment and the emerging industry of banning the use of solid fuels.
- A full environmental impact assessment should be undertaken for each spaceplane type at each launch location. (*Recommendation 24 in summary report*)

CHAPTER 11

Flight crew competence and licensing

Clearly, commercial space operations will require fully trained pilots – including trained remote pilots for unmanned operations. However, with no existing commercial standards for spaceplane pilot training, it is imperative to establish the most effective ways of ensuring that spaceplane flight crew have the knowledge and experience required to support safe operations, in both the short and the longer term.

This chapter explores the challenges involved in the training, assessment and maintenance of competence of spaceplane flight crew. It examines flight crew licensing for aviation in the UK, including training and assessment, and spaceflight training to date in other jurisdictions, and considers whether and how these systems could be applied in the UK.

Background: spaceflight crew training to date

11.1 Manned spaceflight commenced on 12 April 1961, when cosmonaut Yuri Gagarin became the first human being to go into space and orbit the Earth. Gagarin was a USSR Air Force pilot, trained to fly fast jets. The second human in space, Alan Shephard, was a US Navy test pilot – again, highly trained and specially selected for the mission.

11.2 This process of selecting crews for space operations from the respective military services has continued for the majority of missions since then. This has meant that the overwhelming majority of spacecraft crew to date have been highly trained and physically fit, even before selection for a space mission.

11.3 As operations have evolved, and longer missions with larger crews have become possible, some specialised roles for crew members have developed. Recent Russian, US and European spaceflight programmes have used similar roles to ensure the safety of the mission. These roles consist of commander, mission specialist, flight engineer, payload specialist and researcher. The responsibility to ensure that space programme crew members are appropriately trained and competent rests with the respective space agencies.

The challenges of training for commercial spaceflight

11.4 However, in an era of commercial spaceflight, it can no longer be assumed that space agencies will take responsibility for flight crew training and competence. Nor can it be assumed that most of the crew will be drawn from the military.

11.5 From a regulatory perspective, given the stated goal of protecting the uninvolved general public, it is essential that regulators can be confident that spaceflight crew have the skills and knowledge required to operate their spaceplanes. This means that standards of competence for spaceflight crew need to be defined.

11.6 It is also essential that spaceflight crew are physically able to cope with the unique stresses of spaceflight. There is also a case for requiring crew to have experience in similar conditions to those on board a spaceplane, in advance of flight: this is considered further in Chapter 12, on medical requirements.

11.7 A spaceflight crew licensing model would need to address both technical competence and physical ability. This is in line with current flight crew licensing for commercial and private aviation.

Training of astronauts and cosmonauts by space agencies

11.8 As was stated above, virtually all spaceflight crew training to date has been led by national space agencies. It is appropriate, therefore, to look at what that training has involved.

11.9 Although the National Aeronautics and Space Administration (NASA), the European Space Agency (ESA), Russia and China all have mature and extensive astronaut and cosmonaut training programmes, details of these have been difficult to obtain.

11.10 Nonetheless, it is clear that astronaut and cosmonaut crew training has typically been built around five sequential phases:

- selection – a detailed and extensive selection process;
- basic training – general knowledge of space technology and science, and the basic skills related to future operational tasks;
- advanced training – knowledge and skills related to the operation of specific space systems, payloads, transport vehicles and their related interaction with the ground;
- mission-specific training – focused on ensuring that the flight crew and back-up crew have the specific knowledge and skills required to perform the mission-specific, and onboard tasks within their assigned roles; and
- onboard training – maintaining the proficiency of crew in critical skills while in orbit.

11.11 Often, crew members have also been required to maintain competence in other tasks, such as language skills, diving and traditional flight training.

11.12 As Figure 11.1 below shows, this means that the training of an astronaut can take up to four years.

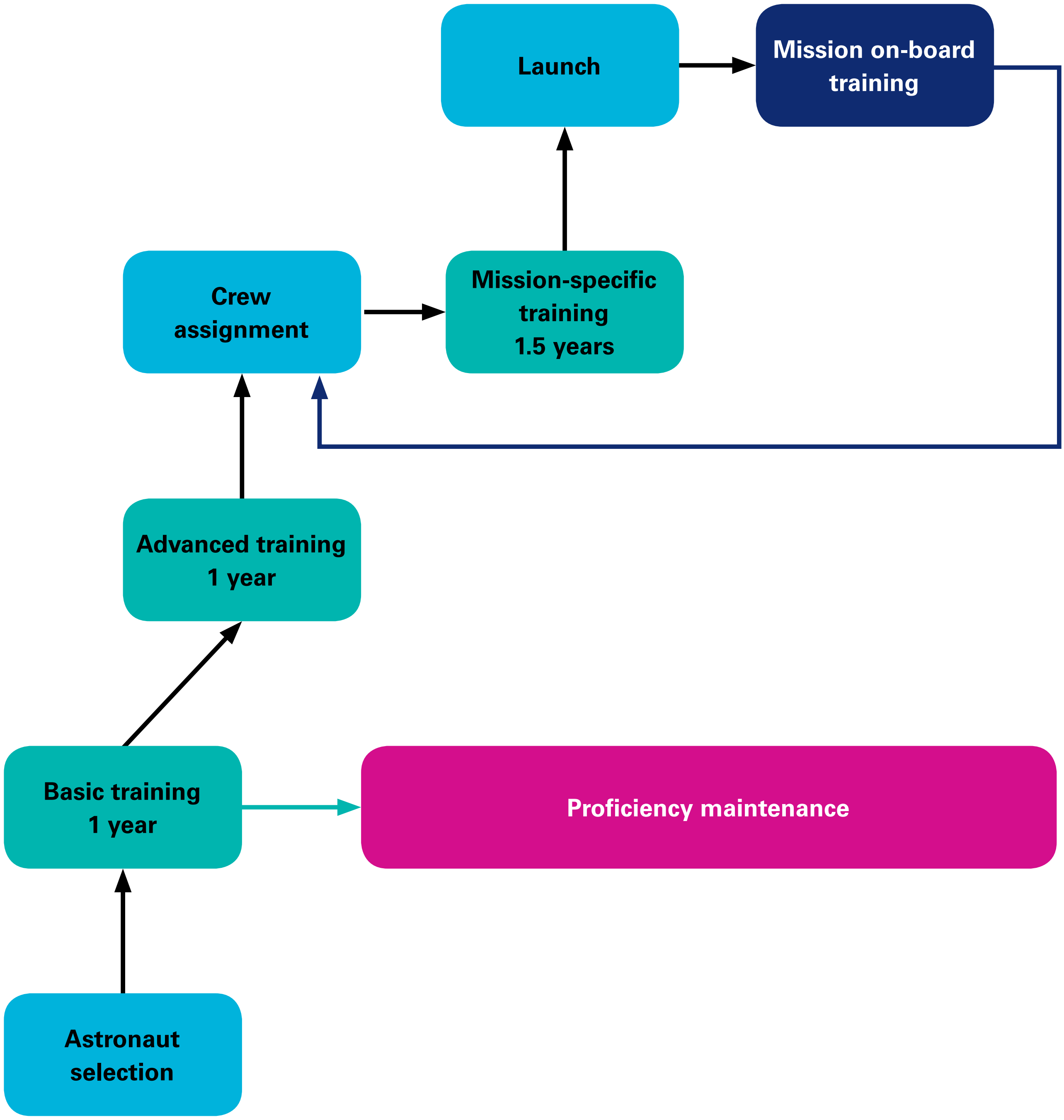


Figure 11.1: Overview of astronaut training[237]

---

[237] Adapted from G Musgrave, A Larsen and T Sgobba (2009) *Safety Design for Space Systems*, Amsterdam, Elsevier, chapter 25, figure 25.1

11.13 There are important differences between the extensive training programme as outlined above and the training for piloting a sub-orbital spaceplane. According to a book published by the International Association for the Advancement of Space Safety (IAASS), space agencies consider that the 'crew training program is designed to provide the systems familiarization and flight skills required to effectively, efficiently and safely control and operate the system as well as carry out mission tasks'.[238] In other words, training is focused on the practical use of space systems **before** a spaceflight, and on enabling the crew to operate these systems safely in simulated conditions.

11.14 However, these training programmes are for astronauts and long-term space orbits, which are very different missions from those envisaged for sub-orbital spaceplanes.

11.15 As discussed elsewhere in this report, the initial uses of spaceplanes are expected to be for sub-orbital spaceflight experience and delivery of satellites into Low Earth Orbit. Such missions would be far shorter than most of those run by space agencies – a matter of hours rather than days or weeks. They would also be more frequent: some operators have indicated they would potentially conduct multiple sub-orbital flights in a single day.

11.16 This has various implications for the training and licensing of spaceplane flight crew. Mission-specific training could potentially be shorter; however, there may be a need to consider the additional stresses on flight crew of multiple rapid ascents and descents over a short period of time.

11.17 What will not change is the requirement for flight crew to have the skills needed to effectively, efficiently and safely control and operate the spaceplane. The next question, therefore, is how competence has been assessed and defined to date for commercial spaceflight.

Approaches to commercial spaceflight crew licensing and competence

Spaceflight crew licensing and competence in the US

11.18 In the US, requirements for human spaceflight are set out in the Commercial Space Launch Amendments Act of 2004.[239] This Act includes rules on crew qualifications and training, and on informed consent for crew and spaceflight participants. In practice, these are managed and monitored by the Federal Aviation Administration Office of Commercial Space Transportation (FAA AST).

---

[238] ibid

[239] See www.faa.gov/about/office_org/headquarters_offices/ast/media/PL108-492.pdf (accessed 7 April 2014)

11.19 Flight crew licensing and competence are covered under the Human Space Flight Requirements for Crew and Space Flight Participants.[240] The relevant parts are Code of Federal Regulation (CFR) Parts 401, 415, 431, 435, 440 and 460.[241]

11.20 CFR 460 details the regulations for Human Space Flight Requirements. In line with its overall regulatory approach, CFR 460 places the responsibility for defining the training standards and ensuring spaceflight crew competence on the operator. Specifically, the operator must ensure that all members of the flight crew:

- have appropriate experience;
- are appropriately trained for their craft; and
- have demonstrated an ability to withstand the stresses of spaceflight, which may include high acceleration and deceleration, microgravity and vibration, and any abort or emergency procedures in sufficient condition to safely carry out their duties so that the vehicle will not harm the public.

The full text of CFR 460 is included as Appendix 11A to this chapter.

11.21 As part of an operator's application for a vehicle or operator licence, it is required to provide evidence that the flight crew has the necessary experience and that the training has achieved the defined standards to ensure the competence of the flight crew.

Spaceflight crew licensing and competence in Europe

11.22 In Europe, no organisation has yet been given a mandate to develop a regulatory framework for spaceflight crew licensing and competence. However, the two key European agencies, ESA and the European Aviation Safety Agency (EASA) have both indicated a broad position on spaceflight crew competence which differs from that of the FAA AST and is more in keeping with that set out above by the IAASS in its publication *Safety Design for Space Systems*.

11.23 The ESA approach is that summed up in paragraphs 11.10–11.13 above: a formal training process that can last four years.

11.24 EASA has set out its approach in a paper 'Accommodating sub-orbital flights into the EASA regulatory system'.[242] The paper states that: 'it is obvious that the flight crew of a spacecraft has to fulfil certain requirements for the initial training, proficiency, testing and medical fitness'.[243]

---

[240] See www.faa.gov/regulations_policies/faa_regulations/commercial_space (accessed 10 April 2014)

[241] Code of Federal Regulations, Title 14, part 460, www.ecfr.gov/cgi-bin/text-idx?c=ecfr&sid=e11cee34fe5087a8cba8d252ec7327b3&rgn=div5&view=text&node=14:4.0.2.9.24&idno=14 (accessed 7 April 2014)

[242] J-B Marciacq, Y Morier, F Tomasello, Zs Erdelyi, M Gerhard (2008) 'Accommodating suborbital flights into the EASA regulatory system', EASA conference paper, https://getinfo.de/app/Accommodating-Sub-Orbital-Flights-into-the-EASA/id/BLCP%3ACN072087298

[243] ibid, paragraph 5

11.25 EASA considers that within NASA and ESA there is sufficient scientific, operational and managerial experience for such operations. However, it raises concerns that this may not be the same in the commercial market:

> 'when looking however, at commercial space tourism operations carried out by private operators, the issue is not only whether crews possess sufficient knowledge, it is also necessary to ensure that:
>
> - Proper rules exist in order to clearly establish responsibilities and privileges for natural and legal persons;
> - Such rules are accompanied by Acceptable Means of Compliance (AMC) and published (example being training syllabi);
> - Mechanisms exist to oversee and enforce the application of the rules (example being the issuing, suspending and revoking of pilot licences).'[244]

11.26 As stated in Chapter 6, the Review has concluded that it is not appropriate in the long term for the UK to follow the FAA AST approach and devolve responsibility for safe operations to the operator – not least because of the importance for the UK of keeping in step with potential future developments in regulation within Europe, which would then apply to the UK. Therefore the requirements indicated by EASA in its paper must be given due consideration in the development of a UK spaceflight crew licensing system.

11.27 However, EASA's paper was published in 2008; the commercial space market has evolved considerably since then.

The commercial spaceflight training industry today

11.28 Throughout the world there are only a few space agencies that offer astronaut and cosmonaut training programmes. And, as explained above, these can take a number of years to complete. Following the US Commercial Space Launch Act 2004, an emerging market for commercial human spaceflight training organisations began to develop, offering training for sub-orbital and orbital spaceflight pilots and participants.

11.29 The FAA AST has given its approval to some of these organisations, including NASTAR Center, Black Sky Training and Space Expedition Corporation. All of these are based in the US, and have approached the FAA AST for safety approval of their facilities to meet the training requirements for commercial human spaceflight, both sub-orbital and orbital. NASA has also tried to stimulate private spaceflight training through such programmes as Commercial Crew Development and Commercial Orbital Transportation Services.[245]

---

[244] ibid

[245] See www.nasa.gov/offices/c3po/home/index.html (accessed 8 June 2014)

11.30 Programmes are typically vehicle-specific, and provide spaceplane pilots with the knowledge and skills necessary to ensure safe operation of the vehicle (and thus any potential paying participants) during flight.

11.31 Reflecting the fact that spaceplanes (unlike vertical launch spacecraft) share many characteristics with conventional aviation, most of the organisations offering spaceplane flight crew training programmes have done so by extending their successful conventional flight training programmes to address the requirements of spaceplane flight. Could the UK's flight training industry do the same?

The UK flight training industry

11.32 The UK has a highly successful flight training industry that has developed over a number of years from established training schools to supply the growing airline industry and the private general aviation community. At the end of 2013, there were more approved training organisations in the UK than in any other European country,[246] and worldwide only the US and Canada have a greater number of established flight training organisations.[247]

11.33 The industry trains pilots for licences and ratings in conventional light aircraft, such as Cessnas and Pipers, as well as for complex multi-pilot passenger-carrying aircraft. Indeed, a key part of the UK flight training industry's market is to supply pilots to many major European, Middle East and Asian airline operators. It therefore makes extensive use of full-motion synthetic training devices to simulate the operations of such aircraft.

11.34 The UK's success in this field is all the more notable given some significant disadvantages compared to other European states, such as the requirement that value added tax (VAT) must be paid on flight training, and the fact that the industry itself must contribute financially to the regulation, compliance monitoring and direct oversight conducted by the Civil Aviation Authority (CAA). In other EASA member states, neither of these requirements is in place, and so flight training can be provided at a lower cost.

11.35 This gives confidence that, even though there is as yet no training provision in the UK for prospective spaceplane flight crew, the experience and expertise that exists here could be applied to spaceplane operations, and UK approved training organisations could establish programmes for the training of spaceplane flight crew. This would first require the development of proportionate, risk-based rules and regulations for such training – applying all relevant aspects of existing flight training, as well as identifying training needs for each spaceplane and additional aspects that reflect the unique requirements of spaceplane operations.

---

[246] UK Civil Aviation Authority Standards Document 31, Version 115, List of Approved Training Organisations; and a comparison with comparable lists from other EASA member states, conducted in December 2013.

[247] Information from the Federal Aviation Administration and Transport Canada.

UK military flight training

11.36 As well as the civil aviation industry, the UK armed forces offer expertise in flight crew training. In particular, they have expertise in training fast jet pilots, applying techniques and systems designed to assist the flight crew in managing many of the physical and operational challenges to which pilots of sub-orbital and orbital spaceflight would be exposed. This expertise could be an invaluable asset in the development of spaceplane flight crew training programmes.

11.37 Becoming a fast jet pilot involves lengthy training and extensive performance assessment. Experience is built initially on single-engine, piston-powered aircraft. Candidates with acceptable performance are selected for basic fast jet pilot training on single-engine turbine aircraft. Successful candidates will then proceed on to the Hawk T2 and finally on to the Operational Conversion Unit (OCU) for either the Eurofighter Typhoon or the Tornado GR4. A significant percentage of OCU training is conducted in full-motion synthetic training environments.

Licensing requirements and training of aviation flight crew

11.38 The requirements for the licensing of flight crew for aviation are based on established international standards.

International Civil Aviation Organization Annex 1 Personnel Licensing

11.39 The International Civil Aviation Organization (ICAO) is the permanent body charged with administering the principles laid out in the Convention on International Civil Aviation, also known as the Chicago Convention.

11.40 One of ICAO's major duties is to adopt international Standards and Recommended Practices (SARPs) and to incorporate these into the Annexes to the Chicago Convention, and to publish internationally agreed Procedures for Air Navigation Services (PANS).

11.41 Annex 1 of the Chicago Convention covers personnel licensing, and a subsequent PANS document, *Procedures for Air Navigation Services – Training,*[248] provides further guidance on the uniform implementation of the training required for the pilot licences and ratings found in Annex 1. This document specifies the actual procedures to be applied by training organisations in providing training for aeronautical personnel.

EU Aircrew Regulations

11.42 All EU Member States (including the UK), plus Norway, Iceland, Liechtenstein and Switzerland, are implementing the EU Aircrew Regulations, in line with Commission Regulation (EU) 1178/2011.[249] This is the most significant regulatory

---

[248] ICAO (2010) *Procedures for Air Navigation Services – Training*, Doc 9868, Montreal, ICAO

[249] See http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02011R1178-20120408 (accessed 7 April 2014)

change for over a decade, setting out specific requirements for the issue of flight crew licences, ratings and certificates (Part-FCL) and the approval of training organisations (Part-ORA), the use of flight simulation training devices in crew training (Part-FSTD), cabin crew (Part-CC) and requirements for medical certificates and aeromedical centres (Part-MED). There are also requirements for the competent authorities in EASA member states (Part-ARA).

11.43 This transition is having a profound effect on the European flight training industry, in terms both of the courses available and of the technology being used to train student pilots. Though there is no reason to suggest that the transition will reduce the industry's capacity to provide spaceflight crew training, it may mean that its readiness and desire to do so decreases, due to the effort involved in meeting standards for more routine flight crew training.

Applying existing aviation flight crew regulations to spaceplane operations

11.44 In the short term, it is unlikely that existing aviation flight crew regulations can be applied to spaceplane operations. Such regulations are partially related to type certification of aircraft, and, as was set out in Chapter 7, no such certification is anticipated for some years. However, as was explained in Chapter 7 (and elsewhere in this report), it is expected that spaceplanes **will** be subject to certain aspects of existing aviation regulation.

11.45 An example of relevant existing aviation regulation is the requirement to hold a pilot's licence to operate an aircraft as pilot in command. This is set out in ICAO Annex 1, the EU Aircrew Regulations,[250] and the Air Navigation Order (ANO),[251] and would be expected to apply to all manned operations, including spaceplanes. EU Regulation 216/2008 – commonly known as the EASA Basic Regulation[252] – will also be of relevance to flight crew licensing requirements for spaceplanes.

11.46 One concept used in aviation that may be of use to the spaceplane industry in establishing flight crew training needs for new aircraft and spaceplane systems is that of Operational Evaluation Boards (OEBs), as defined in the pan-European Joint Aviation Requirements.[253] Under these, aircraft design organisations can apply to EASA to request that an OEB be convened to evaluate and define, among other things, the flight crew training requirements for an aircraft.

11.47 The OEB process produces reports that contain recommendations regarding the content of training courses. The reports include a general description of

---

[250] See http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02011R1178-20120408 (accessed 7 April 2014)

[251] Full text of the Air Navigation Order and its Regulations at www.caa.co.uk/docs/33/10107-CAA-CAP%20393%20Updated%203.pdf (accessed 8 June 2014)

[252] See http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:079:0001:0049:EN:PDF (accessed 7 April 2014)

[253] For more information on the Joint Aviation Requirements, see www.caa.co.uk/default.aspx/default.aspx?catid=49&pagetype=90&pageid=526 (accessed 27 May 2014)

the aircraft, initial training requirements, any differences between variants and specifications for particular emphasis during training.

11.48 It was envisaged by EASA that OEBs would be replaced by a new process called Operational Suitability Data, but this has been delayed. The OEB process therefore seems relatively well suited to defining spaceplane flight crew training requirements in the short to medium term.

Manned multi-stage spaceplanes, horizontally launched from a runway (including launched from a carrier aircraft)

11.49 This type of operation involves two separate aircraft: the carrier aircraft and the spaceplane which separates during the flight.

11.50 The carrier aircraft may either be a fully certificated complex multi-pilot aircraft and/or an aircraft designated as 'experimental' and treated as an Annex II aircraft under the EASA Basic Regulation. As this could be a new aircraft or a variant or modified existing aircraft type, the aircraft operator and manufacturer could be required to develop a process similar to the OEB to establish the training needs for future flight crew and the use of suitable synthetic training devices.

11.51 The separated spaceplane itself would either be a fully certified complex motor-powered high-performance aircraft and/or a spaceplane designated as 'experimental' and treated as an Annex II aircraft under the EASA Basic Regulation.

11.52 The aircrew regulation requirements for a complex motor-powered high-performance aircraft are stated in Subpart H of the Annex I (Part-FCL) in FCL.720.A of the EU Aircrew Regulations.[254] For the issue of a type rating for a complex high-performance aircraft, flight crew must have passed theoretical knowledge examinations at Airline Transport Pilot level and hold a valid multi-engine Instrument Rating.

11.53 In the absence of a formal type rating course and in co-operation, the spaceplane operator and manufacturer could develop a process similar to the OEB to establish the training needs for future flight crew, how competence of existing flight crew will be maintained and how suitable synthetic training devices will be used.

11.54 In the US, the relevant FAA AST regulations are the Human Space Flight Requirements for Crew and Space Flight Participants. These were initially published in draft for consultation, entitled the *Draft Guidelines for Commercial Suborbital Reusable Launch Vehicle Operations with Flight Crew*. Included in the draft guidelines was the proposal that spaceflight crew should hold a

---

[254] See http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02011R1178-20120408 (accessed 7 April 2014)

professional pilot's licence. There was considerable comment on the proposals, in particular questioning the need for flight crew to hold such a licence.

11.55 Following this, in December 2006, the FAA AST published its rules and regulations, along with the comments received on the draft proposals.[255] The published regulation for flight crew requires 'a minimum of possessing a pilot's licence with instrument rating' and 'extensive aeronautical knowledge'. This is justified in the response to the comments as follows: 'an instrument rating should ensure that pilots of launch and re-entry vehicles have acquired the skills of scanning cockpit displays, correctly interpreting the instruments, and responding with correct control inputs'.

11.56 The FAA expects that, regardless of the kind of vehicle used, there will be times when a pilot will be relying on instrument skills and competence.

Manned single-stage to orbit and single-stage to sub-orbit spaceplanes, horizontally launched from a runway

11.57 EASA would also consider spaceplanes launched in this way to be certified complex motor-powered high-performance aircraft and/or spaceplanes designated as 'experimental' and treated as Annex II aircraft under the EASA Basic Regulation.[256]

11.58 As already stated, the aircrew licensing requirements for such aircraft are set out in Subpart H of Annex I (Part-FCL) in FCL.720.A of the EU aircrew regulations.[257] For the issue of a type rating for a complex high-performance aircraft, flight crew must have passed theoretical knowledge examinations at Airline Transport Pilot level and hold a valid multi-engine Instrument Rating.

11.59 Again, in the absence of a formal type rating course, the OEB process (or similar) could be used to establish the training needs.

11.60 Again, as already mentioned, in the US the relevant FAA AST regulations state that for such spaceplanes, the minimum requirement for flight crew is 'possessing a pilot's licence with instrument rating' and having 'extensive aeronautical knowledge'.

11.61 From the perspective of developing UK regulations and assisting aircraft and spaceplane operators and manufacturers in developing training needs, it is essential to gain a detailed understanding of what standards and levels of competence the FAA AST used to establish these regulations.

---

[255] See www.gpo.gov/fdsys/pkg/FR-2006-12-15/pdf/E6-21193.pdf (accessed 11 June 2014)

[256] See http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:079:0001:0049:EN:PDF (accessed 11 June 2014)

[257] See http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02011R1178-20120408 (accessed 7 April 2014)

Intercontinental very high speed transport

11.62 As was stated in Chapter 2, it is not anticipated that intercontinental very high speed transport operations will commence for some years. However, looking ahead, it is envisaged that these operations would involve a fully certificated complex multi-pilot aircraft. As such, the full requirements of the EU Aircrew Regulations would apply, including the option for the aircraft operator and manufacturer to request an OEB to define the training needs for future flight crew. In co-operation with the aircraft/spaceplane manufacturer, an approved type rating course would need to be developed, using approved synthetic training devices.

11.63 Much more work would be required to establish standards and levels of competence for this kind of operation. This is not a priority at this stage, but these operations should be considered as part of the development of standards for all spaceplane operations.

Unmanned spaceplanes

11.64 The ‘piloting’ function is essentially the same for unmanned aircraft systems (UAS) as it is for manned aviation: both involve ‘managing’ an aircraft’s flight through the air and they need to operate in the same airspace, with the same weather and under the same rules. Thus, there is clearly a need for equivalence with regard to any interactions with manned aviation.

11.65 While this does not mean that all the traditional pilot skills will be required (although this will clearly depend on the type of control interface used), a remote pilot of an unmanned spaceplane will still be expected to possess the equivalent airmanship skills required to manage the flight safely, including the appropriate reactions to system failures or emergencies.

11.66 In general, therefore, the overall airmanship requirements (knowledge of flight procedures, airspace, Air Traffic Control procedures, aircraft captaincy etc) will be the same as for a manned spaceplane. Added to this, there will clearly be the requirement for knowledge of any UAS-specific subjects (such as command and communication (C2) data link management etc).

11.67 The current intention internationally is for a new licence to be developed, known as the Remote Pilot’s Licence, which will act as the UAS equivalent to the pilot licensing regimes. Once developed, such a licence would be expected to be required for unmanned spaceplane operations.

Assessing the requirements for spaceplane flight crew licensing

11.68 Identifying which existing regulations will apply to each type of spaceplane is an important starting point. However, in developing standards and licensing requirements for spaceplane operations, consideration will need to be given to the following:

- minimum flight crew experience requirements: should spaceplane flight crew be required to have more experience than flight crew for commercial air transport? For example, there could be a requirement to have both military and civil flight experience, experience as a test pilot, or experience operating other aircraft with similar handling characteristics to a spaceplane. Other criteria could be performance in a single-pilot environment or experience of unpowered approaches;
- minimum theoretical knowledge: again, should this be in line with commercial air transport or is it sufficient to operate within the rules of the airspace environment? Flight and theoretical training syllabi should include, as a minimum, the launch and re-entry acceleration and deceleration phases; use of reaction control systems; and emergency procedures covering all possible scenarios, such as system, engine or structural failures, loss of communications and spatial disorientation.

High G training

As well as theoretical training around the effects of high acceleration and deceleration forces (high G flight), it may also be appropriate to mandate practical training in a high G environment.

The effects of high G can impair even highly trained fast jet pilots; indeed, the service inquiry report into an accident on 20 August 2011 involving an RAF Aerobatic Team Hawk noted that 'The deviation from the aircraft's expected flight path shortly after exposure to high G raised the possibility that the pilot was subject to G induced impairment.'* The report then stated: 'the panel concluded that pilot incapacitation resulting from G induced impairment was a possible cause of the accident'.** It therefore recommended that the Deputy Chief of the Defence Staff (Capability), in consultation with the Chief of Staff (Health) and Operational Duty Holders should 'develop and fulfil the capability requirement for the future of UK High G Training'***

This incident and wider studies into the effects of high G led the Review to recommend that all spaceplane flight crew must be suitably trained in the effects of high acceleration and deceleration forces. This is explained in more detail in Chapter 12.

* Military Aviation Authority (2012) 'Service inquiry investigation into accident involving RAFAT Hawk T Mk1 XX179 on 20 Aug 2011', www.gov.uk/government/publications/service-inquiry-report-into-the-accident-involving-red-arrows-hawk-t-mk1-xx179-on-20-august-2011 (accessed 8 June 2014).

** ibid, paragraph 1.4.18.d

*** ibid, paragraph 1.5.4

Competence to fly

11.69 When it comes to flight skills, there will be different requirements for each different spaceplane. For example, for some spaceplanes it may be necessary to train flight crew on failure of glider guidance; others will require training on how to conduct a stable approach with a 'no go-around' option. This is a good illustration of where the OEB process can help operators and manufacturers to identify and define skills or aspects of training that require specific emphasis.

11.70 Training will need to take place in a synthetic training device or flight training simulator, where flight crew can demonstrate their competence in advance of operations. This has two further implications:

- there needs to be a suitable mechanism for establishing and evaluating competence. This means that before training spaceflight crew, agreed standards of competence must be set and instructors and examiners trained; and
- synthetic training devices need to be developed, which simulate the internal and (where possible) external environment of the specific spaceplane.

11.71 As potentially the first European country from which spaceplanes will operate, the UK is ideally placed to lead the development of competence standards for spaceplane flight crew. However, to help the emerging spaceplane industry benefit from a clear and consistent set of standards, such development should ideally include engagement with other competent authorities, in particular the FAA AST and EASA.

Recommendation
As soon as possible, the competent authority for spaceplane and spaceflight regulation should work with the FAA AST and EASA to develop standards and levels of competence for sub-orbital and orbital spaceflight crew, as well as for instructors and examiners. These should be followed by suitable training and guidance materials.

Recommendation
Operators should ensure that, where appropriate, flight training will be conducted in flight training simulators or training devices which simulate the internal and (where possible) external environment of the specific spaceplane.

11.72 In developing standards and levels of competence for spaceflight crew, instructors and examiners, it will also be essential to address some of the legal and regulatory factors that affect flight crew licensing. For example, work will be needed to define and establish:

- the privileges of sub-orbital pilots, instructors and examiners – how should concepts such as Pilot in Command and Pilot under Training be defined for sub-orbital and orbital operations?
- the structure of a pilot licensing or competence system – will a separate sub-orbital licence be required, or will existing licences be acceptable with type ratings?
- the legal permission to operate a sub-orbital vehicle in UK airspace: would operations be conducted under visual flight rules (VFR) or instrument flight rules (IFR)?
- the privileges to operate the appropriate two-way communications system required, if different from standard communications systems.

Considering a short-term solution

11.73 As may be apparent, there are a lot of factors to address before standards-based spaceplane flight crew training in the UK could **commence**. This work needs, therefore, to begin promptly. However, even if it were to begin immediately, and even if allowance were made for the fact that many potential spaceplane flight crew members would be experienced and trained pilots, it is highly unlikely that the UK competent authority would be able to license UK-trained spaceplane flight crew by 2018 – the prospective start date for spaceplane operations from the UK.

11.74 Therefore, if the UK is to allow spaceplane operations to begin before a licensing regime is put in place, an alternative approach must be found to determining flight crew competence.

11.75 It is highly likely that initial operations will take place under a wet lease type arrangement: the spaceplane and its crew will be from the US and will have to meet FAA AST licensing requirements. Therefore, as a means of facilitating spaceplane operations in the short term, until suitable training facilities and regulatory structures are in place, flight crew accepted by the FAA AST in accordance with CFR 460 could be validated. This would mean the CAA – as the competent authority in the UK for aviation regulation – confirming that it is content that any spaceplane flight crew members involved in a spaceflight from the UK have sufficient competence to conduct the specific operation.

11.76 The validation could be issued in accordance with Annex III to the Aircrew Regulations,[258] which require a pilot to:

- hold a valid ICAO-compliant licence;
- hold at least a Class 1 Medical Certificate issued in accordance with Part-MED; and
- have successfully completed a skill test on the appropriate aircraft or in a synthetic training device designed to replicate the operation of the aircraft, with an examiner designated by the competent authority. (This is not the same as an examiner being trained and licensed with a UK system.)

11.77 If spaceplanes are classified as experimental aircraft under Annex II of the EASA Basic Regulation, the competent authority could add further requirements if deemed appropriate.

11.78 Appendix 11B to this chapter provides full details of the Annex III validation process.

Recommendation

To allow spaceplane operations in the short term, the Government should agree to the CAA validating the FAA AST process around flight crew licensing.

---

[258] See http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02011R1178-20120408 (accessed 7 April 2014)

Conclusion

11.79 The training of astronauts is a complex and lengthy process, in which a significant portion of the training is mission-specific. The FAA AST has sought to anticipate potential commercial demands by approving spaceplane flight crew training programmes based on the training of traditional flight crew, and using the expertise and experience of the flight training industry in the US to develop courses and training programmes. While the UK does not have experience of training astronauts, it does have a mature flight training industry that is similar to that in the US.

11.80 There is, therefore, significant potential for the UK flight training industry to develop courses and training programmes to meet future commercial spaceplane flight crew training needs. However, these are medium- to long-term aspirations, and would need the development first of agreed competence standards. This process of development should begin as soon as possible.

11.81 To facilitate spaceplane operations from the UK in the short term, there is the possibility of validating the FAA AST process to ensure that all flight crew are competent to undertake the flights.

Recommendations

11.82 This chapter has made the following recommendations.

- As soon as possible, the competent authority for spaceplane and spaceflight regulation should work with the FAA AST and EASA to develop standards and levels of competence for sub-orbital and orbital spaceflight crew, as well as for instructors and examiners. These should be followed by suitable training and guidance materials. (*Recommendation 26 in summary report*)
- Operators should ensure that, where appropriate, flight training will be conducted in flight training simulators or training devices which simulate the internal and (where possible) external environment of the specific spaceplane.
- To allow spaceplane operations in the short term, the Government should agree to the CAA validating the FAA AST process around flight crew licensing. (*Recommendation 25 in summary report*)

APPENDIX 11A
CFR 460

The following is an extract from CFR 460 – Human Space Flight Requirements.

Subpart A – Launch and reentry with crew

460.1	Scope
460.3	Applicability
460.5	Crew qualifications and training
460.7	Operator training of crew
460.9	Informing crew of risk
460.11	Environmental control and life support systems
460.13	Smoke detection and fire suppression
460.15	Human Factors
460.17	Verification program
460.19	Crew waiver of claims against US Government

Subpart B – Launch and reentry with a space flight participant

460.41	Scope
460.43	Applicability
460.45	Operator informing space flight participant of risk
460.49	Space flight participant waiver of claims against US Government
460.51	Space flight participant training
460.53	Security

(a) Each crew member must–

  (1) Complete training on how to carry out his or her role on board or on the ground so that the vehicle will not harm the public; and

  (2) Train for his or her role in nominal and non-nominal conditions. The conditions must include –

    (i) Abort scenarios; and

    (ii) Emergency operations.

(b) Each member of a flight crew must demonstrate an ability to withstand the stresses of space flight, which may include high acceleration or deceleration, microgravity, and vibration, in sufficient condition to safely carry out his or her duties so that the vehicle will not harm the public.

(c) A pilot and a remote operator must –

  (1) Possess and carry an FAA pilot certificate with an instrument rating.

  (2) Possess aeronautical knowledge, experience, and skills necessary to pilot and control the launch and reentry vehicle that will operate in the National Airspace System (NAS). Aeronautical experience may include hours in flight, ratings and training.

  (3) Receive vehicle and mission specific training for each phase of flight by using one or more of the following –

    (i) A method or device that simulates the flight;

    (ii) An aircraft whose characteristics are similar to the vehicle or that has similar phases of flight to the vehicle;

    (iii) Flight Testing; or

    (iv) An equivalent method of training approved by the FAA through the licenses or permit process.

  (4) Train in procedures that direct the vehicle away from the public in the event the flight crew abandons the vehicle during flight; and

  (5) Train for each mode of control or propulsion, including any transition between modes, such that the pilot or remote operator is able to control the vehicle.

(d) A remote operator may demonstrate an equivalent level of safety to paragraph (c)(1) of this section through the license or permit process.

(e) Each crew member with a safety-critical role must possess and carry an FAA second-class airman medical certificate issued in accordance with 14 CFR part 67, no more than 12 months prior to the month of launch and re-entry.

APPENDIX 11B

Process for Annex III validation requirements of third country ICAO-compliant licences

The validation requirements are set out in Annex III to the EU Aircrew Regulations.[259]

CONDITIONS FOR THE ACCEPTANCE OF LICENCES ISSUED BY OR ON BEHALF OF THIRD COUNTRIES

A. VALIDATION OF LICENCES

General

1. A pilot licence issued in compliance with the requirements of Annex 1 to the Chicago Convention by a third country may be validated by the competent authority of a Member State.

   Pilots shall apply to the competent authority of the Member State where they reside or are established, or, if they are not residing in the territory of the Member States, where the operator for which they are flying or intend to fly has its principal place of business.

2. The period of validation of a licence shall not exceed 1 year, provided that the basic licence remains valid.

   This period may only be extended once by the competent authority that issued the validation when, during the validation period, the pilot has applied, or is undergoing training, for the issuance of a licence in accordance with Part-FCL. This extension shall cover the period of time necessary for the licence to be issued in accordance with Part-FCL.

   The holders of a licence accepted by a Member State shall exercise their privileges in accordance with the requirements stated in Part-FCL.

Pilot licences for commercial air transport and other commercial activities

3. In the case of pilot licences for commercial air transport and other commercial activities, the holder shall comply with the following requirements:

   (a) complete, as a skill test, the type or class rating revalidation requirements of Part-FCL relevant to the privileges of the licence held;

---

[259] See http://eur-lex.europa.eu/LexUriServ/LexUriServ do?uri=OJ%3AL%3A2011%3A311%3A0001%3A0193%3AEN%3APDF (accessed 11 June 2014)

(b) demonstrate that he/she has acquired knowledge of the relevant parts of Part-OPS and Part-FCL;

(c) demonstrate that he/she has acquired knowledge of English in accordance with FCL.055;

(d) hold a valid Class 1 medical certificate, issued in accordance with Part-Medical;

(e) in the case of aeroplanes, comply with the experience requirements set out in the following table:

Licence held	**Total flying hours experience**	**Privileges**	
(1)	(2)	(3)	
ATPL(A)	> 1 500 hours as PIC on multi-pilot aeroplanes	Commercial air transport in multi-pilot aeroplanes as PIC	(a)
ATPL(A) or CPL(A)/ IR (*)	> 1 500 hours as PIC or co-pilot on multi-pilot aeroplanes according to operational requirements	Commercial air transport in multi-pilot aeroplanes as co-pilot	(b)
CPL(A)/IR	> 1 000 hours as PIC in commercial air transport since gaining an IR	Commercial air transport in single-pilot aeroplanes as PIC	(c)
CPL(A)/IR	> 1 000 hours as PIC or as co-pilot in single-pilot aeroplanes according to operational requirements	Commercial air transport in single-pilot aeroplanes as co-pilot according to Part-OPS	(d)
ATPL(A), CPL (A)/IR, CPL(A)	> 700 hours in aeroplanes other than TMGs, including 200 hours in the activity role for which acceptance is sought, and 50 hours in that role in the last 12 months	Exercise of privileges in aeroplanes in operations other than commercial air transport	(e)
CPL(A)	> 1 500 hours as PIC in commercial air transport including 500 hours on seaplane operations	Commercial air transport in single-pilot aeroplanes as PIC	(f)
(*) CPL(A)/IR holders on multi-pilot aeroplanes shall have demonstrated ICAO ATPL(A) level knowledge before acceptance.			

Pilot licences for non-commercial activities with an instrument rating

4. In the case of private pilot licences with an instrument rating, or CPL and ATPL licences with an instrument rating where the pilot intends only to exercise private pilot privileges, the holder shall comply with the following requirements:

   (a) complete the skill test for instrument rating and the type or class ratings relevant to the privileges of the licence held, in accordance with Appendix 7 and Appendix 9 to Part-FCL;

   (b) demonstrate that he/she has acquired knowledge of Air Law, Aeronautical Weather Codes, Flight Planning and Performance (IR), and Human Performance;

   (c) demonstrate that he/she has acquired knowledge of English in accordance with FCL.055;

   (d) hold at least a valid Class 2 medical certificate issued in accordance with Annex 1 to the Chicago Convention;

   (e) have a minimum experience of at least 100 hours of instrument flight time as pilot-in-command in the relevant category of aircraft.

Pilot licences for non-commercial activities without an instrument rating

5. In the case of private pilot licences, or CPL and ATPL licences without an instrument rating where the pilot intends only to exercise private pilot privileges, the holder shall comply with the following requirements:

   (a) demonstrate that he/she has acquired knowledge of Air Law and Human Performance;

   (b) pass the PPL skill test as set out in Part-FCL;

   (c) fulfil the relevant requirements of Part-FCL for the issuance of a type or class rating as relevant to the privileges of the licence held;

   (d) hold at least a Class 2 medical certificate issued in accordance with Annex 1 to the Chicago Convention;

   (e) demonstrate that he/she has acquired language proficiency in accordance with FCL.055;

   (f) have a minimum experience of at least 100 hours as pilot in the relevant category of aircraft.

Validation of pilot licences for specific tasks of limited duration

6. Notwithstanding the provisions of the paragraphs above, in the case of manufacturer flights, Member States may accept a licence issued in accordance with Annex 1 to the Chicago Convention by a third country for a maximum of 12 months for specific tasks of limited duration, such as instruction flights for initial entry into service, demonstration, ferry or test flights, provided the applicant complies with the following requirements:

   (a) holds an appropriate licence and medical certificate and associated ratings or qualifications issued in accordance with Annex 1 to the Chicago Convention;

   (b) is employed, directly or indirectly, by an aeroplane manufacturer.

   In this case, the privileges of the holder shall be limited to performing flight instruction and testing for initial issue of type ratings, the supervision of initial line flying by the operators' pilots, delivery or ferry flights, initial line flying, flight demonstrations or test flights.

CHAPTER 12

Medical requirements for spaceplane flight crew and participants

Just as the fitness of flight crew is assessed and certificated for ordinary aviation, so there will need to be a system for assessing the fitness of spaceplane flight crew to cope with the specific medical risks of the spaceplane environment. Some of these risks will also affect participants – who will not necessarily have the same levels of health and fitness as the flight crew. This chapter examines the potential health risks of space travel and considers how best to prepare, assess and certificate flight crew for spaceplane operations. It also discusses the issue of participant health and operators' responsibilities. More broadly, it then looks at the requirement for wider involvement of the medical profession and medical knowledge in spaceplane design and spaceplane and spaceport operations.

The challenges of defining medical requirements for spaceplane operations

12.1 In UK aviation regulation, all pilots require some form of medical certificate or declaration. This is based on the principle that the fitness of the flight crew to handle the aircraft and cope with the likely conditions experienced in flight has to be assured. When it comes to spaceflight, it is only logical that this same principle should apply – not only for the protection of flight crew and any participants, but also to protect, as far as possible, the uninvolved general public.

12.2 Space and spaceplane environments pose hazards not encountered in everyday life on Earth, or in normal aviation. Human physiology has evolved for terrestrial habitation: travelling into space is only possible for humans using a specially created environment. This therefore means that space vehicles and personal protective equipment have to be designed on the basis of what is known about the physiological parameters that humans can tolerate comfortably, and considering all potential routine and emergency scenarios.

12.3 This applies not only to flight crew, but also to potential paying participants. Many airlines require confirmation from passengers that they are fit to fly. For spaceflight experience, this will also be essential. Risks to participant health need to be considered in advance of flight, with mitigations put in place where appropriate.

12.4 A wide variety of spaceflight profiles has been proposed, and these will vary considerably from one operation to another. Some medical effects are likely to impact on a significant number of participants (eg motion sickness), while other effects, as yet unknown, may be novel and unique to spaceplane operations. Individual assessment of flight crew and participants will therefore be a key part of the successful introduction of spaceplane operations.

12.5 Initially, in addition to regular medical screening, it may be appropriate to assess each member of the flight crew pre-flight. Regular monitoring of the health parameters of crew and participants will be important to ensure that any changes that result from frequent exposure to this new environment are detected early. This aspect should be included in an operator's safety management system, along with all other potential medical risks.

12.6 Aviation and space medicine expertise is essential not only for the assessment of the medical fitness of crew and participants, but for all aspects of human spaceflight participation – from the design of the spaceplane, to development of equipment such as life support systems, to helping define pre-flight preparation requirements. The UK has a successful history of contributing to the design, test, development and introduction to service of aircraft where oxygen and life support systems for the crew are required. This expertise could prove a significant opportunity for the UK to support the development of commercial spaceplane operations.

12.7 In the initial approach to spaceplane activities, it is recognised that there has to be an appropriate balance between prescriptive regulation and guidance, including medical requirements, so that early activities can be nurtured and encouraged within a suitable safety oversight system without stifling innovation.

Scope

12.8 This Review considers all types of sub-orbital spaceplane operations, including spaceflight experience, scientific research and very high speed intercontinental travel. Sub-orbital flights are likely to be used as a platform for research, particularly for life and physical sciences.

12.9 Most information about the medical effects of spaceflight has been gleaned from long-duration missions, such as the International Space Station (ISS), and it is uncertain how this will translate to occasional or more frequent sub-orbital flights.

12.10 Potential orbital operations are considered briefly and separately. Orbital 'holidays' in space hotels, extra-vehicular activity, 'round the moon' trips and the potential extreme sport activity of space-diving are not covered. Additional medical considerations for lunar exploration or potential flights to Mars are also out of scope.

Medical risks of spaceflight

12.11 Medical assessments for spaceplane operations need to take into account the different physiological environments likely to be encountered. These will vary according to the type of operation. However, they may include:

- reduced ambient pressure (hypobaric environment);
- a reduced oxygen level (hypoxic environment);
- microgravity;
- high noise levels;
- increased radiation exposure;
- vibration; and
- thermal extremes.

12.12 Potential exposures are largely theoretical at the time of writing, as commercial spaceplane operations have yet to commence. Whereas aviation medical experience has been gained during the past century of manned flight, during which billions of people have experienced flying in an aircraft, space medical experience has resulted from voyages to the moon and projects such as the ISS, and is limited to fewer than 600 people in total. There has been no experience of frequent, sub-orbital missions, and it remains to be determined whether there may be any unforeseen effect on health or flight crew performance from this activity.

12.13 However, through sub-orbital flight test programmes and military high-altitude operations, it is possible to identify likely exposures.

12.14 Further factors to consider in a medical assessment include psychological wellbeing, propensity to motion sickness and the ability to withstand high acceleration and deceleration forces.

12.15 The health risks of some of the main exposures are considered in more detail below. These, in turn, inform the recommendations later in the chapter regarding medical assessment and preparation for spaceplane operations.

Reduced ambient pressure and reduced oxygen levels

12.16 Sub-orbital flights will take occupants to altitudes of over 100 kilometres, well above the 35,000 feet cruising altitude of most commercial aircraft. At such an altitude, the lack of oxygen in the air would be fatal. A pressurised cabin is therefore essential.

12.17 The cabin of a commercial aircraft is usually pressurised to an equivalent of 6,000–8,000 feet. This reduced pressure results in a slightly lower than ground level oxygen availability, but it has little or no adverse effect on healthy people. Virgin Galactic has indicated that its SpaceShipTwo will operate with a cabin pressure similar to that of a normal commercial aircraft.

12.18 The key risk here is what happens if the pressurisation systems fail, or if for any reason the integrity of the spaceplane cabin is breached. The effects of loss of cabin pressure would vary according to the altitude at which the depressurisation occurs, the difference between internal cabin and external pressure, and the rate of change of pressure.

12.19 However, depressurisation at high altitude carries the following risks:

- **lack of oxygen (hypoxia)**, which can cause rapid loss of consciousness, depending on the altitude at which the depressurisation occurs;[260]
- **decompression illness (DCI)** at ambient altitudes over 18,000 feet. In some types of high-altitude aviation, pre-breathing oxygen is used as a preventive strategy against DCI. However, it is unlikely to be practical or commercially acceptable for spaceplane operations, and at altitudes of above 50,000 feet it is unlikely to offer effective protection, unless individuals are also wearing suitable protective clothing;[261]
- **ebullism**, the spontaneous change of liquid water to water vapour in body tissues at an ambient pressure of at or below 47 mmHg. In a body with a temperature of 37 °C, this can occur at altitudes over approximately 63,000 feet and rapidly lead to damage to the lungs and surrounding tissues.[262] In an unpressurised environment, a reliable full pressure suit is required to prevent ebullism. If the integrity of a pressurised cabin is breached, it is essential to maintain the pressure sufficiently high to prevent ebullism and to ensure that the gas composition maximises the chances of injury-free survival. The risk increases with the area of the breach and is greater with smaller cabin volumes; and
- **barotrauma**, which is damage to body tissues from a change in pressure. If a cabin depressurises rapidly, the pressure differential between gas in the cabin and gas in the lung could become so great that it may tear lung tissue. This would mean air would leak into the chest (pneumothorax or pneumomediastinum) and gas could get into the tissues (mediastinal emphysema) or circulation, known as arterial gas embolism.

---

[260] D Gradwell (2006) 'Hypoxia and hyperventilation', in DJ Rainford and D Gradwell (eds) *Ernsting's Aviation Medicine*, fourth edition, London, Hodder Arnold

[261] JT Webb, AA Pilmanis and RB O'Connor (1998) 'An abrupt zero-preoxygenation altitude threshold for decompression sickness symptoms', *Aviation, Space and Environmental Medicine* (*ASEM*), 69(4): 335–340

[262] DH Murray, AA Pilmanis, RS Blue et al (2013) 'Pathophysiology, prevention, and treatment of ebullism', *ASEM*, 84(2):89–96

12.20 As is clear from the above risks, loss of cabin pressurisation or other life support system failure could be potentially catastrophic. Back-up systems and equipment, together with training in their use and in emergency procedures, will be essential. Even in the case of a non-catastrophic in-flight depressurisation, there will still be a need for supplemental oxygen and rapid descent.

12.21 In the event of a depressurisation, medical personnel trained in the treatment of the consequences of decompression at high altitudes would need to be available on the ground to assess and treat any affected individuals immediately on landing, and specialist medical equipment may be required.

12.22 The use of 100 per cent oxygen is essential treatment in the initial management of decompression illness and may be required for a variety of other conditions. Serious casualties may require ventilator and cardiac support.

12.23 Lung barotrauma may require emergency relief of tension pneumothorax or the insertion of chest drains prior to transfer to hospital. In the management of lung injury caused by ebullism, specialist ventilator support is required. DCI requires oxygen therapy and, depending on the altitude and rate of the decompression, and duration of exposure, may require immediate transfer to a hyperbaric recompression facility.[263] Sufficient hyperbaric chamber space needs to be available to accommodate multiple casualties. For those in need of critical care, this would have to be in a category 1 chamber.[264] If there has been lung damage, individual assessment is essential and chamber treatment may be contraindicated.

High acceleration and deceleration forces (high G)

12.24 Spaceplane flight crew and any participants will be exposed to high levels of long-duration (ie >2 seconds) acceleration forces (expressed in multiples of gravity known as 'G') at launch or during the ballistic phase of the flight, and even higher forces on re-entry to the atmosphere. The main acceleration forces (G levels) will run from head to toe (known as Gz) and chest to back (Gx). Gy (lateral) forces may also be experienced.

12.25 As was discussed in Chapter 11 of this report, the effects of high G can impair even highly trained fast jet pilots, so the potential impact on spaceplane flight crew and participants will need to be considered fully in devising medical criteria.

12.26 Predicted G levels for Virgin Galactic's SpaceShipTwo include, for the flight crew, a maximum of 5 Gz on re-entry;[265] they will be exposed to a level above 4 Gz for up to 15 seconds. Participants' seats will reposition for boost and will be reclined

---

[263] A list of such facilities is available from the British Hyperbaric Association, www.hyperbaric.org.uk (accessed 10 April 2014)

[264] Personal communication from RDS Wylie and SM Phillips to SE Evans, 2 December 2013. See also MJ Johnston (2008) 'Loss of cabin pressure in a military transport: a mass casualty with decompression illnesses', *ASEM*, 79(4): 429–432

[265] Interview with J Vanderploeg, Virgin Galactic, 31 July 2013

for re-entry, and they are expected to experience up to 3.5 Gz during boost and 5 Gx on re-entry. Predicted Gz levels for XCOR's Lynx Mark II are between 3 and 4 Gz for up to 40 seconds on re-entry.

Medical input to spaceplane design

12.27 There is an important role for aviation and space medicine expertise in spaceplane design and development. In particular the design of life support systems, both built-in and 'carry-on', is crucial for the safety of any manned operation. Aspects such as impact protection, seat design and crash resistance will also need to be considered for any design which could potentially be manned in the future, even if initial operations are to be unmanned.

12.28 Information about the life support and emergency life support systems, cabin temperature, rate of cabin pressure changes, likely noise and vibration exposure and radiation protection is not readily available for the spaceplanes under development at the time of writing. However, to address in part the risks of depressurisation discussed above, in the event of a depressurisation at high altitude, spaceplane flight crew and participants, if not wearing full pressure suits, would have to be able to don close-fitting face masks supplying 100 per cent oxygen within seconds – ideally within five seconds for the crew. This contingency supply of oxygen would need to be immediately available in bottled form, as drop-down masks would not be effective above 30,000 feet cabin altitude. Pressure suits with their own oxygen supply would provide an alternative method of protection.

12.29 Aspects of design will also need to be considered in relation to potential in-flight aeromedical emergency scenarios, emergency egress devices for different stages of flight and post-crash survival aids. Emergency egress systems for use during launch have not historically been included in space shuttle missions. If they are to be included, they will need to be planned during the early concept and design phases, as it may not be possible to retrofit such features once a spaceplane is in production.

12.30 Medical and human factors aspects of personal protective equipment, clothing and life support systems should be considered during development, testing and introduction to service. The UK has considerable knowledge of, and expertise in, the design, development and testing of aviation systems, particularly life support systems and equipment, high-altitude flight, aircraft design and vehicle manufacture, and companies could be encouraged to diversify into the space market. The knowledge of the UK's defence companies and armed forces in these aspects of protection against the adverse effects of extreme altitude – such as the expertise gained by the RAF and QinetiQ in the development of systems for the Typhoon and Joint Strike Fighter aircraft[266] – are likely to be able to contribute towards the development of protective equipment for use in the spaceplane environment.

12.31 This may therefore be a significant opportunity for the UK, and consideration should be given to how the UK can best benefit from it.

Recommendation

To maximise the potential commercial opportunity for the UK, the Government should encourage discussions and partnerships between designers/manufacturers of spaceplanes and designers/manufacturers of UK life support systems and training/emergency equipment, and consider seed funding for UK technology and design companies to consider diversifying into the space market.

12.32 Human factors elements will be important for life support system design and operation. If, as anticipated, the initial pilots of spaceplanes are recruited from the fast jet, military or astronaut pool, they are likely to be used to highly automated systems and controls. To date, spaceplane designs in general have less automation and more basic systems, involving large physical controls. These factors need to be considered in the design of systems and translation of skills to spaceplane operations.

12.33 Both the National Aeronautics and Space Administration (NASA)[267] and the European Space Agency (ESA) have a 'human rating' concept which covers technical requirements for space systems to ensure the safety of personnel, both occupants and ground crew. This approach encompasses a holistic overview of any aspect of the design that could affect the safety of people on board. It covers a broad range of considerations to ensure the safety of operations, including human interactions with the systems, routine and emergency life support systems and capabilities to safely recover crew in an emergency.

Recommendation

The competent authority for spaceplane operations should ensure that consideration is given in a European regulatory framework to establishing a 'human rating' approach to design and operational requirements for spaceplanes, particularly those that will be travelling to Low Earth Orbit (LEO) and beyond.

---

[266] D Connolly (2013) 'Lung volumes, pulmonary ventilation, and hypoxia following rapid decompression to 60,000ft', *ASEM*, 84(6): 551–559

[267] NASA (2008) 'Human-rating requirements for space systems', www.hq.nasa.gov/office/codeq/doctree/87052.htm (accessed 10 April 2014)

Recommendation

Spaceplane manufacturers and operators should be strongly encouraged to work with physiology experts in the development of their life support systems and emergency egress requirements.

Medical responsibilities of spaceplane operators

12.34 Spaceplane operators have individual discretion to put in place and oversee the aviation and space medical support required to assure the health, wellbeing and physical and mental performance of their flight crew. In practice, the medical standards of operators are likely to be far higher than those that any regulation would mandate, as operators will want to be assured of career-long fitness for their flight crew and will not wish to jeopardise the success of early operations through any flight crew medical risk or incident that could lead to adverse publicity.

12.35 The initial pool of spaceplane flight crew is likely to be drawn from pilots with current or past astronaut experience or military service: both groups will have undergone considerable medical selection and have had to conform to high fitness standards.

12.36 Standard operating procedures will be required to describe actions to be taken if there is incapacitation of a member of the crew or a participant medical event.

Health and safety requirements

12.37 The health and safety of pilots and other crew on board aircraft are covered by UK health and safety legislation, under the Civil Aviation (Working Time) Regulations 2004 (as amended).[268]

Recommendation

The Health and Safety Executive should be consulted on whether the scope of existing UK health and safety legislation, including that pertaining to the aircraft environment, should be extended to include protection for flight crew involved in the operation of spaceplanes, other crew and spaceflight participants.

Medical requirements for flight crew

12.38 Throughout the world, periodic medical surveillance is undertaken of pilots operating international and domestic commercial flights. As the UK is one of the contracting states to the International Convention on Civil Aviation[269] (also

---

[268] See www.legislation.gov.uk/uksi/2004/756/contents/made (accessed 21 May 2014). This item of legislation is currently only available in its original format.

[269] Full text of the Convention on International Civil Aviation at www.icao.int/publications/pages/doc7300.aspx (accessed 10 April 2014)

known as the Chicago Convention) and a Member State of the European Union, UK-licensed pilots require an EU Class 1 medical certificate to undertake public transport operations.[270]

12.39 The medical assessment for the issue of a certificate includes consideration of future incapacitation risk and functional ability to act as a pilot. The incapacitation risk has to be predicted as <1 per cent per year for Class 1 certificate issue to fly multi-pilot operations, and in the order of <0.5 per cent per year to fly single-pilot operations.

12.40 It would seem appropriate to assume that these medical standards should apply equally to spaceplanes. But should further criteria also apply?

Initial spaceplane operations

12.41 For initial spaceplane operations, it is likely that flight crew recruitment will be largely from individuals with experience as astronauts or as pilots in military service. Medical selection requirements for these two categories are stringent, and it is unlikely that candidates will have major pre-existing medical conditions.

12.42 Astronaut fitness standards are evaluated and set by international consensus. The Multilateral Medical Policy Board established by the partners of the ISS programme agrees on standards for ISS astronauts.[271] Astronaut medical requirements have traditionally been set at a high level, with a view to ensuring continuous career-long fitness to minimise flight safety risk and maximise the return on the extensive financial investment in their training.

12.43 Currently, there is no organisation overseeing the safety of occupants of **commercial** sub-orbital spaceplanes. In the US, the Federal Aviation Administration Office of Commercial Space Transportation (FAA AST) is addressing this, through an ongoing initiative to develop safety guidelines for human spaceflight, both sub-orbital and orbital, with a maximum duration of two weeks.[272] In line with the FAA AST's overall regulatory remit to protect the safety of uninvolved third parties from hazards associated with spaceplane operations, rather than focusing on the protection of the crew, the flight crew medical standards set in this draft are lower than those set by NASA for its own employees, and those set for the ISS.

12.44 The European Aviation Safety Agency (EASA) has started to consider medical requirements for spaceplane operations in the context of European

---

[270] The requirements for this are set out in EASA Basic Regulation 216/2008 and Aircrew Regulation 1178/2011, both at http://easa.europa.eu/regulations

[271] E Messerschmid, J-P Haignere, K Damian and V Damann (2000) 'EAC training and medical support for International Space Station astronauts', www.esa.int/esapub/bulletin/bullet104/messers104.pdf (accessed 10 April 2014)

[272] FAA AST (2013) *Draft Established Practices for Human Space Flight Occupant Safety*, www.faa.gov/about/office_org/headquarters_offices/ast/media/draft_established_practices_for_hsf_occupant_safety_with_rationale.pdf (accessed 10 April 2014)

Regulations.[273] Although there are parallels with aviation, the medical requirements for space travel demand separate consideration, and it may not be appropriate to assign space medical requirements to classes of medical certification developed for air travel.

12.45 Medical literature to date has not sought to recommend specific medical requirements for spaceplane flight crew, but rather to provide an evidence base on the medical risks of spaceflight to emphasise how these can be mitigated. The exception is the Commercial Spaceflight Working Group of the Aerospace Medical Association, which has published recommendations for flight crew members participating in sub-orbital spaceflight.[274]

12.46 It is clear, therefore, that while there has been consideration of the necessary medical requirements for spaceplane flight crew, there are currently no common standards that apply. Given the Review's stated regulatory priority of protecting the uninvolved general public, it is imperative that UK regulators should be satisfied that spaceflight crew are physically fit to undertake operations safely. Therefore, to enable spaceplane operations to commence in the UK by 2018 or earlier, this gap needs to be addressed promptly. If initial operations in the UK are to take place under FAA AST licence, the medical standards of each individual operator should be reviewed in advance of the commencement of operations, to ensure that they comply with or exceed the UK medical requirements, or drafts thereof, for spaceplane flight crew.

12.47 The standards required for spaceplane flight crew need to be confirmed as soon as possible, so that training of aeromedical examiners can take place. This will then mean that examiners are ready to certificate spaceplane flight crew before operations commence.

12.48 The UK has an established network of aeromedical examiners and aeromedical centres. With minimal additional training (possibly a one-week training course), these medical practitioners could undertake medical assessments of spaceplane flight crew and paying participants.

Recommendation

The Government should ensure that medical requirements for spaceplane crew are developed at least a year before spaceplane operations commence in the UK, by international experts experienced in both aviation and space medicine, and that aeromedical examiners are trained to undertake the required medical assessments.

12.49 In the longer term, it will be important to develop international regulation in this area. This could involve the adoption of (or be based on) current aviation

---

[273] J-B Marciacq and A Ruge (2013) 'Sub-orbital and orbital pilots licensing and passengers medical screening/training', International Astronautical Association (IAA) 19th Humans In Space Conference, Cologne, July

[274] Aerospace Medical Association Commercial Spaceflight Working Group (2011) 'Position paper: sub-orbital commercial spaceflight crewmember medical issues', *ASEM*, 82(4): 475–484

medical requirements, or the creation of new bespoke standards. With a shift in emphasis from experimental space exploration to routine space travel, there will be an expectation of safe passage that requires a merging of existing space and aviation approaches to safety management.

12.50 For example, as spaceplane operations become more common, it will be necessary to increase the number of flight crew – so some eligibility standards may need to be reviewed. Consideration will need to be given as to whether prospective spaceflight crew with medical conditions that are permissible for commercial or military aviation pilots, but not for astronauts, could be allowed to become spaceplane flight crew. This may, in part, be a decision for operators as to whether or not they are willing to accept flight crew with such conditions.

12.51 Bodies that currently set and review standards for astronauts will need to be included in the discussions with the organisations involved with international standard setting in the field of civil aviation, to create medical requirements for spaceflight.

Medical criteria for spaceplane flight crew

12.52 At the time of writing, the FAA AST requires all spaceplane flight crew to hold, as a minimum, a Second Class Airman Medical Certificate.[275] However, a research project conducted by the FAA Center of Excellence for Commercial Space Transportation (COE-CST) has suggested that a Second Class certificate is inadequate and gives medical guidelines for spaceplane operators to use and adjust according to the particular profile of their operation.[276] The report suggests that a First Class certificate should be required, along with a full assessment by an aeromedical examiner with specialist knowledge of space medicine.

12.53 For operations that launch from a UK spaceport, as indicated above, it would be reasonable to apply existing flight crew medical criteria, such as a requirement to hold an EU Class 1 medical certificate,[277] and to demonstrate compliance with International Civil Aviation Organization (ICAO) Class 1 medical provisions, as the basic criteria prior to applying for a spaceplane flight crew medical certificate, unless there is good evidence to do otherwise. However, it is likely to be necessary to add further medical requirements to ensure that all spaceplane flight crew can tolerate, and not be harmed by, the environmental hazards and physiological stressors likely to be encountered. It is reasonable for these requirements to be developed further in the light of the experience of initial

---

[275] FAA (2006) Human Space Flight Requirements for Crew and Space Flight Participants. Code of Federal Regulations, Title 14, parts 401, 415, 431, 435, 440 and 460, www.faa.gov/regulations_policies/faa_regulations/commercial_space/ (accessed 4 June 2014)

[276] R Jennings, J Vanderploeg, M Antunano, J Davis et al (2012) 'Flight crew medical standards and spaceflight participant medical acceptance guidelines for commercial space flight', www.ispcs.com/files/ww/files/ISPCS%202012/2012.08.06%20Task%20183-UTMB%20Final%20Report.pdf (accessed 10 April 2014)

[277] The requirements for this are set out in EU Regulation 216/2008 (EASA Basic Regulation) and EU Aircrew Regulation 1178/2011, http://easa.europa.eu/regulations (accessed 8 June 2014)

commercial spaceplane operations. The requirements should ideally be developed on an international basis, with the ambition of worldwide acceptance. Individual states would utilise their existing aviation and space medicine expertise to oversee the regulatory requirements and train personnel to undertake medical assessments.

Recommendation

The competent authority should ensure that medical assessment guidelines are reviewed once information has been gained from operational experience.

Recommendation

In the medium term (3–8 years), the competent authority should seek to work with EASA and other regulators to develop consistent pan-European medical requirements, and also work with ICAO to develop medical provisions and international Standards and Recommended Practices for spaceplane flight crew.

12.54 Sub-orbital spaceflight involves rapid transitions from high levels of acceleration to none and vice versa, potentially several times in one day. This is an important difference from spaceflight to date. It will be a new physiological experience and has the potential to cause effects not seen before, including problems with the circulatory system, disorientation or vertigo.

12.55 This is an important risk to address: for early spaceplane operations it may be best managed by conducting brief medical checks before each flight to endorse individual fitness, and after each flight to determine any issues that may have arisen during the flight.

12.56 Initially operators may wish to have ‘standby’ crew available in case of unexpected medical problems, so that if any one member of the spaceflight crew is deemed to be unfit for the next flight, a replacement can simply slot in. (It is unclear as yet whether operators that plan to run several sub-orbital spaceflights in a day plan to use the same flight crew for all of them.)

Recommendation

The competent authority should ensure that individual fitness is considered in the context of each proposed operational scenario; initially this may need to be endorsed before each flight.

12.57 Clearly, any medical assessment of spaceplane flight crew must be conducted by trained professionals who understand the risks and are aware of all potential signs of impairment.

Recommendation

All medical assessments for spaceplane flight crew should be undertaken by aeromedical examiners who are experienced in Class 1 assessments, and have undertaken further training in the additional medical considerations for spaceplane flight.

12.58 Appeals against adverse regulatory decisions on crew fitness for spaceplane flight should be handled by existing national processes established for appeals against decisions regarding the fitness of commercial flight crew.

Flight crew complement

The medical risk to a flight from the incapacitation of a pilot is greatly reduced by the presence of a second flight crew member. Some spaceplane operators propose to have two pilots; others just one.

The substantial increase in risk presented by having only one pilot on the flight deck, rather than a multi-pilot crew, may be considered acceptable for spaceplane operations that, for the next few years, will be pioneering. However, if spaceplane operations develop into a realistic alternative to long-haul air travel, a multi-pilot crew, will almost certainly be required as part of maintaining the level of safety that would then be expected.

Medical training requirements for spaceplane flight crew

12.59 Spaceplane pilots will require training to understand the physiological effects of the environments they are likely to encounter, and to learn how to counter these effects. This training would almost certainly need to include:

- parabolic flight to experience microgravity;
- experiencing hypoxia under controlled conditions in an altitude chamber; and
- centrifuge training to experience high G.

12.60 Hypoxia training is best undertaken in an altitude chamber, and availability of this facility is limited. ‘Man rated’ altitude chambers include those operated by the Ministry of Defence (MOD) at RAF Henlow and QinetiQ at MOD Boscombe Down. Ground-based hypoxia simulation, using a gas mixture lacking in oxygen, can be used as an alternative and is safer, as there is no risk of DCI because it does not replicate the low-pressure environment at altitude.

12.61 If pressure suits are worn to provide a tolerable cabin environment or to mitigate the risks of cabin depressurisation, it will be important that full training is given. Although pressure suits are not currently in use in the UK, the aviation medicine expertise is available and training could be readily set up in an altitude chamber with the appropriate oxygen system installed.

12.62 Drawing on the experience of the UK military in training fast jet pilots, one essential element will be to ensure that spaceplane flight crew are prepared for the effects of high acceleration and deceleration forces (high G). As well as physical experience – through centrifuge runs to the maximum G force they may experience in normal and emergency situations – this should include awareness training around the potential dangers of high G loads, particularly G-induced loss of consciousness. Experience of how to perform an effective anti-G straining manoeuvre will be essential.

Recommendation

All spaceplane flight crew must be suitably trained in the effects of high acceleration and deceleration forces.

12.63 The only ground-based training for high G in the UK is a long-arm centrifuge located at Farnborough, which is used mainly by the MOD. Other states in Europe and beyond have centrifuge facilities available. However, given the goal of building a UK spaceplane operation capability, it is imperative that appropriate training facilities are in place in the UK. A modern long-arm centrifuge facility should therefore be established in the UK at the same location as other spaceplane training facilities. This would streamline training and medical assessment, and enable knowledge-sharing around high G flight and other factors.

12.64 These same facilities could also be used on a commercial basis to provide spaceflight participants with experience of high G flight. It would be up to individual spaceplane operators, and potentially even individual participants, whether to make this a pre-spaceflight requirement. By having all training and assessment facilities at the same location, it would improve the individual customer experience for the participants.

Recommendation

The Government should explore with industry how sufficient and appropriate facilities can be made available to support the pre-spaceflight training of spaceplane flight crew in the long term – and in particular ensure that a modern long-arm centrifuge is available and accessible in the UK.

12.65 Details of emergency egress provisions are not widely available and need to be established. There will have to be training in emergency egress, and in how to assist participants to make an emergency egress. More generally, spaceplane flight crew may need specific education in aviation and space medicine to ensure an adequate understanding of the spaceflight environment, as well as training in land and water survival and first aid.

Medical criteria for cabin crew

12.66 None of the spaceplane operations considered in Chapter 2 of this Review plan to have cabin crew on board. However, further in the future – and particularly if spaceplane operations develop into a realistic alternative to long-haul air travel – cabin crew may be needed.

12.67 Cabin crew may, in the future, be carried to attend to passengers with specific medical or other needs, to ensure that passengers are strapped in when necessary (especially prior to re-entry) and to provide assistance with emergency egress.

12.68 If cabin crew are carried, operators will want to assure themselves that all crew members are fit to undertake their duties and free of any medical condition that could result in a medical event during the flight or that could pose a risk to the health of other occupants.

Medical criteria for other personnel

12.69 Spaceflights may involve other personnel in their operation, including engineers and members of the rescue and fire fighting service. Where there is existing national and international legislation governing medical standards for these individuals, there is no obvious reason to alter these for spaceplane operations.

Medical criteria for operators of unmanned/remotely piloted spaceplanes

12.70 Several of the spaceplanes considered within this Review are designed to be remotely piloted. Therefore it is important to consider the medical requirements for a remote pilot of a spaceplane.

12.71 The acceptable risk of incapacitation of the operator will vary according to the level of autonomy of the operation. Medical requirements for remote pilots of unmanned spaceplanes can be derived from air traffic control officer (ATCO) medical requirements once the scope of the remote pilot's function is established. General requirements related to being fit for duty, not under the influence of alcohol, and not suffering adverse effects of medication or drugs would apply.

12.72 A US report has recommended that remote pilots of spaceplanes require the same level of medical certification as spaceflight crew.[278] However, as remote pilots are not exposed to the same environment and physical stressors, it seems reasonable that there should be a difference in medical assessment and requirements.

---

[278] R Jennings, J Vanderploeg, M Antunano, J Davis et al (2012) 'Flight crew medical standards and spaceflight participant medical acceptance guidelines for commercial space flight', www.ispcs.com/files/ww/files/ISPCS%20 2012/2012.08.06%20Task%20183-UTMB%20Final%20Report.pdf (accessed 10 April 2014)

Recommendation

The competent authority should ensure that medical requirements are developed for remote pilots of unmanned spaceplanes.

Medical requirements for spaceflight participants

12.73 As discussed above, all human spaceflight has been undertaken by trained and medically assessed individuals. In a commercial era, this can no longer be taken for granted. Prospective participants may have chronic medical conditions, or conditions that could deteriorate rapidly within the space environment. Spaceplane flights will expose people to hazards not encountered in commercial air transport, and, as has been made clear, there is simply not the body of evidence about the effect of such hazards on human physiology that there is for mainstream aviation: many potential problems or adverse effects are theoretical at the time of writing.

12.74 Nonetheless, commercial air operations may provide the most appropriate model for managing medical requirements for participants. There is no UK or European regulation governing medical requirements for passengers in commercial air operations, but most individual operators have a medical advisory service for passengers with medical conditions and will determine whether they consider these passengers fit to travel. Given that any spaceflight participants will be making an active choice to participate, spaceplane operators are likely to take a similar approach, requiring participants to give specific, written, informed consent to their carriage on board a spaceplane, and their acceptance of the inherent risks. This is the intended practice in the US, and a similar approach is proposed in the UK, as is set out in Chapters 5 and 6.

12.75 However, as discussed in Chapter 5, which deals with the legal context, it will be important to determine what level of information about the medical risks is required to enable participants to give informed consent. The potential liabilities of the operator and physician who give information about risk to each participant need to be explored.

Recommendation

The competent authority should ensure that guidance is developed to assist operators in providing sufficient, appropriate information for potential participants to be able to give informed consent for their carriage.

12.76 Within an informed consent model, only people with the most serious conditions or with conditions that could present a risk to others are likely to be excluded by operators.[279] However, operators are likely to wish to apply some kind of medical screening, so that, at the very least, they can consider the potential effect of the

---

[279] SM Grenon, J Saary, G Gray et al (2012) 'Can I take a space flight? Considerations for doctors', *BMJ*, 345:e8124

spaceflight on the individual. Such screening should be conducted by a suitably knowledgeable medical advisor.

12.77 Risks include the occurrence of a sudden medical emergency which cannot be treated during a spaceplane flight (which, in the worst-case scenario, could result in an in-flight death), the lack of any possibility of diverting the craft to treat a condition urgently, the recurrence or exacerbation of a pre-existing condition because of the physiological stressors, and future development of a medical condition due to exposure to environmental hazards, such as radiation. There is also a risk of traumatic injury when someone is not strapped in and is able to move freely about the cabin.

Recommendation

The competent authority should require spaceplane operators to have a management system in place that specifies overall strategy for the management and mitigation of the medical risks to crew and participants and a medical advisory capability for individual risk management.

12.78 Participant assessment is recommended at least twice: initially within six months of the intended flight and again shortly before the flight. This two-stage approach means that significant health risks can be identified early on, and those with the most serious conditions can be excluded well in advance of the flight. It also means that, should a participant's health have changed in any important way in the intervening period, the operator is able to identify this – and, where appropriate, recommend or request that the participant does not fly, or simply refuse to carry them.

Risks to safe continuation

12.79 As a participant medical event is unlikely to present a risk to the safe continuation of a spaceflight, and hence to the uninvolved general public, it is doubtful that regulation will be required in this area. An exception could be if there is only one participant and a single pilot, and if that participant is seated close enough to the pilot to be able to interfere with the flight controls, either wilfully or involuntarily in conjunction with a medical event. The psychological and mental fitness of the participant will be particularly important in this situation. A medical event such as a panic attack could present a risk to flight safety if there is no supervision or restraint of participants, and no barrier separating the flight crew from the participants.

Tolerance of high acceleration and deceleration forces

12.80 One of the major concerns surrounding participants in spaceflight is their ability to tolerate high acceleration and deceleration forces (high G). As long ago as 2006, the FAA published guidance on the medical screening of spaceflight participants.[280] This guidance is divided into two distinct sections: sub-orbital flight or flights where less than 3 Gz will be experienced; and orbital flights or flights where the Gz force is likely to exceed 3. It also identifies the fact that individual operators may need to set specific guidelines, including anthropometric requirements such as height or weight constraints.

12.81 The COE-CST guidelines consider sub-orbital accelerations not to exceed +6 Gx, ± 1 Gy, and +4 Gz: they recommend that if these limits are likely to be exceeded, enhanced medical screening should be undertaken.[281]

12.82 Centrifuge studies have been conducted on a cross-section of the general population and suggest that most individuals will be able to tolerate the acceleration forces likely to be encountered in commercial spaceflight.[282] Virgin Galactic is evaluating the effect of high G on individuals with known medical conditions (hypertension, heart disease, diabetes, pulmonary disease and cervical spine problems) to determine whether individuals with these conditions may be carried as participants on SpaceShipTwo.[283]

12.83 Given these concerns, it may be desirable for participants to experience high G in advance of space flight, but this would be a matter of personal and/or operator preference. The sensation and effects of high G can be realised in a centrifuge or an aerobatic aircraft. Centrifuge experience may be useful to determine physiological tolerance of high acceleration forces and psychological tolerance of a challenging and confined environment. It will be essential if anti-G measures such as the anti-G straining manoeuvre are likely to be needed to counteract the acceleration forces that will be experienced.

12.84 There is no need for G training if the levels of G are unlikely to go above those that would require positive countermeasures to prevent adverse physiological effects.

12.85 Parabolic flight will enable prior experience of weightlessness or 'microgravity' if desired. This may be useful as part of advance medical assessment for individuals with known medical conditions, as it may alert the individual to the possibility of motion sickness, facilitating appropriate preparation. It also

---

[280] MJ Antunano, DL Baisden, J Davis et al (2006) 'Guidance for medical screening of commercial aerospace passengers', Federal Aviation Administration, DOT/FAA/AM-06/1, Office of Aerospace Medicine, Washington, DC

[281] R Jennings, J Vanderploeg, M Antunano, J Davis et al (2012) 'Flight crew medical standards and spaceflight participant medical acceptance guidelines for commercial space flight', www.ispcs.com/files/ww/files/ISPCS%20 2012/2012.08.06%20Task%20183-UTMB%20Final%20Report.pdf (accessed 10 April 2014)

[282] RS Blue, JM Riccitello, J Tizard et al (2012) 'Commercial spaceflight participant G-force tolerance during centrifuge-simulated sub-orbital flight', *ASEM*, 83(10): 929–934

[283] Interview with J Vanderploeg, Virgin Galactic, 31 July 2013; 'Subjects support the future of spaceflight', www.etcusa.com/etc-newsletter/medical-standards-for-commercial-spaceflight (accessed 10 April 2014)

provides practical training in how to strap back into the seats after a microgravity experience. There may be no need to experience microgravity if the total duration of zero G is only a few minutes, particularly if all paying participants will remain strapped into their seats.

12.86 Participants intending to travel in one of the smaller spaceplanes, where room may be limited, may wish to assure themselves and the operator that they are not subject to claustrophobia, by exhibiting tolerance of being in a confined space, eg underwater pod, for a period of time.

12.87 Experience of hypoxia in an altitude chamber may be useful.

12.88 All participants should receive practical training in how to escape from the spaceplane in an emergency. This should be an operator responsibility.

12.89 Food will not be provided on the initial sub-orbital flights, but limited amounts of water will need to be carried. Procedures and equipment will be required to address in-flight vomiting and toilet needs.[284] Onboard toilets are not envisaged in sub-orbital spaceplanes; participants will need to be advised to void urine in advance and to eat a non-fibrous diet for a period before the flight to reduce in-flight toileting needs.

Future operations: orbital flights and very high speed intercontinental travel

12.90 The considerations set out above are for initial spaceplane operations – in particular sub-orbital spaceflight experience. Potential future operations, such as orbital flights and intercontinental very high speed travel would have different requirements.

12.91 Orbital flights for tourism or long-distance travel purposes may be of several hours' duration, and the medical risks of repeated periods of orbital flight for an hour or more are unknown.

12.92 Consequences of more prolonged spaceflight, based on experience of astronauts, could include fluid shifts, muscle atrophy, bone loss, immunosuppression, visual problems and back pain. There may also be intolerance of standing on returning to ground level. Radiation protection would require attention, particularly for frequent crew exposure. Space motion sickness is likely to be more of an issue for orbital flights, as it typically occurs after an hour or so of weightlessness.[285]

12.93 There may need to be additional medical requirements if the flight is likely to last for more than a few days, including psychological fitness and assurance of good

---

[284] HA Wichman (2005) 'Behavioural and health implications of civilian spaceflight', *ASEM*, 76 (Supplement 1): B164–171

[285] WE Thornton and F Bonato (2013) 'Space motion sickness and motion sickness: symptoms and etiology', *ASEM*, 84(7): 716–721

dental health. Training in countermeasures to prevent deconditioning, in how to re-acclimatise on return to Earth, and in land and water survival will also usually be necessary, and consideration would need to be given at the design stage to the provision of a radiation shelter.

12.94 Given this wider range of risk factors, more intensive health screening is considered necessary for orbital flights. Both the COE-CST and the medical community of the ISS have published recommended participant medical screening guidelines for orbital flights.[286]

12.95 It is important to note that if a crew member or participant develops a medical problem during an orbital flight, the time to landing and access to definitive medical treatment will be much longer.

Recommendation
In the longer term (10 years plus) the competent authority should work with EASA and other regulators to develop European medical requirements for orbital spaceplane operations, and with ICAO to develop medical provisions and international Standards and Recommended Practices for flight crew of orbital spaceplane operations.

12.96 Future very high speed intercontinental operations involving spaceplanes would present similar public health risks to long-haul travel and could act as a rapid disease vector. Hygiene issues, toileting and the provision of food and water would be important, given that the sectors would be considerably longer than are anticipated for space tourism experiences. It is probable that cabin crew would be carried on these operations, and the staffing ratio related to the number of participants would need to be determined.

12.97 Proposals considered to date include one operation that flies sub-orbitally with a cabin pressure equivalent to 8,000 feet altitude, and another that is orbital for about an hour. Further details of those would be needed to determine potential medical issues.

Dealing with in-flight medical incidents

12.98 Standard operating procedures will be needed in the event of a medical incapacitation affecting a member of the flight crew. Although rare, even astronauts have been known to become incapacitated while in space.

---

[286] R Jennings, J Vanderploeg, M Antunano, J Davis et al (2012) 'Flight crew medical standards and spaceflight participant medical acceptance guidelines for commercial space flight', www.ispcs.com/files/ww/files/ISPCS%20 2012/2012.08.06%20Task%20183-UTMB%20Final%20Report.pdf (accessed 10 April 2014); V Bogomolov, F Castrucci, JM Comtois et al (2007) 'International Space Station medical standards and certification for space flight participants', *ASEM*, 78(12): 1162–1169; and MJ Antunano, MD Gerzer et al (2009) 'Medical safety considerations for passengers on short-duration commercial orbital space flights', International Academy of Astronautics Study Group, http://iaaweb.org/iaa/Studies/sg26finalreport.pdf (accessed 14 April 2014)

12.99 Operators will want to avoid cancellation or early return of the spaceplane, but flight crew would need to consider a rapid return to the spaceport (or a diversion spaceport) in the event of participant illness. Unlike commercial aircraft, spaceplanes are unlikely to be able to divert in a medical emergency, and operators therefore may want access to a ground-based in-flight medical advice service. This should be achievable with high-frequency and very high-frequency radio and satellite communication systems, with the only loss of communication being a short interval (seconds to minutes) during re-entry.

12.100 The provision of first aid or medical kits may be required on board for minor or more serious medical emergencies affecting participants. A personalised kit for each participant may be appropriate, and prophylactic medication to counter motion sickness may be appropriate for susceptible individuals, though space sickness is known to affect those not normally afflicted on the ground.

12.101 In commercial aviation, basic medical kit requirements are mandated by law according to the number of passenger seats on the aircraft and the potential length of time the aircraft could be away from a location where medical assistance is available.[287] The use of extended medical kits on larger, long-haul aircraft is controlled by cabin crew, and the lack of cabin crew may be a limitation on their use on spaceplanes. The use of a Universal Precaution Kit to minimise the risk of contamination from spilt body fluids may similarly not be possible in the absence of cabin crew.

12.102 NASA has a risk management system for human spaceflight that can be used to consider the different medical events that could occur.[288] This approach could be used to determine how to mitigate and manage the risks associated with these events.

12.103 Some operators may choose to carry a medical assistant, if one or more participants are at higher than normal risk of a medical event. An in-flight death of a participant would be handled in the same way as in commercial aviation, securing the body in situ until after landing and transporting it to the nearest medical facility for death to be confirmed.

Recommendation
The competent authority should ensure that all spaceplane flight crew receive training in procedures to be followed in the event of the medical incapacitation of a member of the flight crew or of an onboard medical incident affecting a participant.

---

[287] Current regulations include: Commission Regulation (EC) No 859/2008 of 20 August 2008 (EU-OPS) 1.745 (First aid kits) and 1.755 (Emergency medical kit) and associated Acceptable Means of Compliance (AMCs). Future EASA regulations include: Commission Regulation (EU) No 965/2012 of 5 October 2012 (Ops Regulation, implemented in UK October 2014) CAT.IDE.A.220 (First aid kit) and CAT.IDE.A.225 (Emergency medical kit), plus associated AMCs.

[288] J Law, CH Mathers, SR Fondy et al (2013) 'NASA's human system risk management approach and its applicability to commercial spaceflight', *ASEM*, 84(1): 68–73

Incident/accident reporting and investigation

12.104 There will be a need for medical advice to be available to the investigators of any spaceplane accident or incident. The Air Accidents Investigation Branch (AAIB) has the remit to investigate UK aviation accidents and would need additional expertise to expand its function to the investigation of spaceplane accidents. From a medical perspective, there would need to be pathology and space medicine expertise to assist in any AAIB investigation.

12.105 Incidents should be reported under a mandatory scheme similar to the Mandatory Occurrence Reporting Scheme in use for air operations.

Radiation

12.106 The risks of radiation exposure increase with altitude,[289] especially above 15 kilometres, where the protection of the Earth's atmosphere ends: levels of radiation can exhibit quite wide variation above this.[290] Radiation doses are also higher with increasing latitude. Occasionally the sun can suddenly emit a high level of radiation lasting for minutes to hours or even days. These eruptions comprise solar particle events (SPE), solar flares and/or coronal mass ejections. The emission of high-energy protons presents a biological threat to humans above the Earth's atmosphere.

12.107 There is as yet no effective SPE forecasting capability, although certain environmental conditions make solar radiation storms much more likely. If an SPE occurs and radiation is emitted towards Earth, it is unlikely to be recognised until detected by ground monitoring stations several minutes later.

12.108 If the SPE is detected before flight, or environmental conditions are known to increase the likelihood of solar sunspot eruptions, take-off could potentially be delayed or rescheduled. An active radiation monitor with a warning function to indicate radiation above a certain threshold can be carried on board. Carriage of 'equipment to measure and indicate continuously the dose rate of cosmic radiation being received … and the cumulative dose' with 'the display unit … readily visible to a flight crew member' is an ICAO requirement for flights intended to be operated over 49,000 feet.[291] If the radiation threshold is reached during flight, it would be important to minimise the risk to spaceplane occupants and descend as soon as possible. Standard operating procedures would need to be developed to manage this situation, and the flight crew trained appropriately.

12.109 Astronauts are radiation workers, but are not recognised or classified as such in the same way as those in terrestrial occupations where radiation exposure is

---

[289] International Commission on Radiological Protection (ICRP) (2007) *The 2007 Recommendations of the International Commission on Radiological Protection*, ICRP Publication 103, vol 37, Oxford, Pergamon Press

[290] M Bagshaw and FA Cucinotta (2008) 'Cosmic radiation', in JR Davis, R Johnson, J Stepanek et al (eds) *Fundamentals of Aerospace Medicine*, fourth edition, Philadelphia, Lippincott Williams & Wilkins

[291] ICAO Annex 6; 6.12

possible, whose employers are responsible for establishing guidance on limits for annual and career radiation exposure. Astronaut radiation exposure limits are higher than for any other occupation, and NASA uses a value of 3 per cent Radiation Exposure-Induced Death for its flight crews.[292] The limits vary with age and gender, and work is continuing to define these limits.[293]

12.110 European legislation imposes requirements relating to the assessment and limitation of aircrew members' exposure to cosmic radiation and the provision of information on the effect of cosmic radiation.[294] In the UK, the Air Navigation Order (ANO) encompasses the relevant articles of the European Council directive,[295] and provides for the monitoring and mitigation of cosmic radiation exposure for commercial aircrew. It is likely that legislation will be needed to cover potential radiation exposure of spaceplane pilots.

Recommendation

The Cosmic Radiation Advisory Group (CRAG), including representatives of the public health authorities, the Health and Safety Executive and the CAA, should consider whether the ANO should be revised to cover potential radiation exposure of spaceplane crew.

12.111 The FAA COE-CST report recommends that participants should not be exposed to a radiation dose of >1 milliSievert/year.[296] Operators are required to have a system of record keeping regarding radiation: this is prescribed in legislation.[297]

12.112 For commercial aviation there are a number of models available to predict likely radiation exposure for each flight; however, these models do not predict exposure for very high-altitude flights. It is possible that a similar model could be developed for spaceplane flight once sufficient measurements have been obtained from initial data.

Recommendation

The CRAG should consider a legislative requirement for operators to maintain records regarding radiation exposure associated with spaceplane operations.

---

[292] G Dietze, DT Bartlett, DA Cool, FA Cucinotta (2013) *Assessment of Radiation Exposure of Astronauts in Space*, ICRP Publication 123, Ann. ICRP: 42(4)

[293] MA Frey (2013) 'Research progress reports from the NASA Human Research Programs', *ASEM,* 84: 75–76

[294] Article 42 of the Euratom Directive – Council Directive 96/29/EURATOM of 13 May 1996, laying down basic safety standards for protection of the health of workers and the general public against the dangers arising from ionising radiation, Official Journal of the European Communities 39, L159, 29 June 1996.

[295] Air Navigation Order and its Regulations, Article 148, at www.caa.co.uk/docs/33/10107-CAA-CAP%20393%20Updated%203.pdf (accessed 8 June 2014)

[296] R Jennings, J Vanderploeg, M Antunano, J Davis et al (2012) 'Flight crew medical standards and spaceflight participant medical acceptance guidelines for commercial space flight', www.ispcs.com/files/ww/files/ISPCS%202012/2012.08.06%20Task%20183-UTMB%20Final%20Report.pdf (accessed 10 April 2014)

[297] See Air Navigation (Cosmic Radiation) (Keeping of Records) Regulations 2000 [SI 2000/1380] and ICAO Annex 6; 4.2

Recommendation

The CRAG should consider whether active radiation monitoring equipment should be carried on board all manned spaceplanes, so that immediate action can be taken to mitigate the radiation risk from a solar particle event, or whether individual dosimetry should be used to assess the doses to which occupants are exposed.

Recommendation

The CRAG should consider other radiation monitoring, avoidance and protection measures for spaceplane crew and participants and the need for long-term data collection, analysis and risk assessment.

Health surveillance

12.113 As was made clear earlier in this chapter, compared to aviation medicine, space medicine is still in its infancy. Therefore it is essential that processes are put in place to gather data about the health of flight crew and participants of spaceflights. This will help monitor changes in their health on an individual level, but will also build knowledge about the impacts of spaceflight on human physiology. In particular, data-gathering around participants and any medical events experienced will be crucial to ensure that any early trends in adverse medical incidents are recognised.

Recommendation

The competent authority should ensure that in-flight crew medical event monitoring and reporting systems are established and that similar medical event monitoring and reporting systems are established for participants while experience is being gained of these types of operations.

12.114 As spaceplane environments (Gz, Gx, cabin air quality, cabin pressurisation) and flight profiles will vary, it will be important to ensure that there is collaboration between the medical advisors to the different companies involved, so that there can be mutual exchange of medical findings. Open reporting and international co-operation will be important and should be encouraged. The establishment of a confidential reporting system independent of operators and regulators could be considered, but this is unlikely to be practicable until spaceplane activity is more common.

Recommendation

The competent authority should ensure that data is captured from any medical events pertaining to flights. A reporting scheme should be put in place for this purpose.

Recommendation

The Government should establish central co-ordination of spaceplane medical event data collection (to include all medical events, not just those that could have jeopardised the safety of the flight) with particular attention to the monitoring and study of long-term health. It should also consider funding spaceplane medical event data recording and analysis. An international group could be established to review the medical data of spaceflight crew and in-flight medical events affecting flight crew and participants.

12.115 Further into the future, it is unknown whether spaceplane pilots undertaking very high speed intercontinental travel will be subject to disruption of circadian rhythms, sleep disruption and fatigue that long-haul commercial aircrew may experience. Theoretically it is probable that very high speed travel between several time zones will cause ‘jet lag’, though whether the symptoms will be similar to, or more pronounced than, those that develop after air travel through many lines of longitude remains to be determined. Exposure to high G on a regular basis may also lead to physiological stress and fatigue not seen in current air operations. Countermeasures similar to, or adapted from, those used by astronauts to counteract loss of bone mass and muscle atrophy may be required, but this will not be known until data becomes available from the first spaceplane operations. Again, this will need to be monitored as and when such operations commence.

12.116 Long-duration space missions are known to result in loss of bone and muscle mass, neurovestibular, visual and cardiovascular changes, as well as having some effects on the immune system and psychological wellbeing. When pilots begin to operate frequent short-duration spaceflights, studies should be undertaken to see whether similar effects occur and whether physical training is required before, during or post-flight to counter these effects.

Health considerations at spaceports

12.117 Chapter 9 of this report discusses the selection requirements for a UK spaceport. Once a location is identified, there are a number of health-related issues that would need to be considered in spaceport design and operation. These include aspects of public health, occupational and environmental health, health and safety considerations and emergency medical service provision.

Health and safety

12.118 Planning for a spaceport requires consideration of the supply, storage and handling of traditional rocket fuels, including liquid oxygen and liquid hydrogen, aviation fuel and other chemicals such as liquid nitrogen (used for its cryogenic properties). Health and safety requirements for a spaceport are considered in full in Chapter 9; here, the specific medical issues for workers and around major incident planning are examined.

12.119 Under current UK regulation, the Health and Safety Executive (HSE) is responsible for enforcement of the Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR), which place duties on employers to eliminate or control the risks from explosive atmospheres in the workplace. This is the legislation by which the United Kingdom implements the European Directive on controlling explosive atmospheres (99/92/EC – also known as the 'ATEX Workplace Directive') which aims to reduce the risk of a fatality or serious injury resulting from a 'dangerous substance' igniting and potentially exploding. The requirements in DSEAR apply to most workplaces where a potentially explosive atmosphere may occur.

12.120 The HSE is also responsible for oversight of the Control of Major Accident Hazards (COMAH) Regulations, which require businesses to take all necessary measures to prevent major accidents involving dangerous substances and to limit the consequences for people and the environment of any major accidents that do occur.

12.121 In line with these duties, the HSE is responsible for the ground safety of vertical launches, including the demarcation of exclusion areas. This contrasts with the US approach of giving responsibility to a specific aviation body, the FAA AST, to create rules designed to protect the safety of third parties on the ground.

12.122 The health and safety of aviation personnel working on the ground are covered by current UK health and safety legislation. Because spaceplanes may involve toxic substances not normally encountered in commercial aviation, particular attention may need to be paid to the potential exposure of these personnel to such substances.

Recommendation

The HSE should be consulted on whether the scope of current UK health and safety legislation, including that pertaining to environmental hazards and control of toxic substances, should be extended to include protection for ground crew involved in the operation of spaceplanes.

Major incident planning

12.123 As part of major incident planning around spaceports, medical aspects should be considered. This will require consultation and planning with local health services, particularly the nearest National Health Service general hospital/trauma centre. This is in line with the recommendation, made in Chapter 9, that local authorities should establish contingency plans for major incidents in advance of the commencement of spaceplane operations from a spaceport.

12.124 The local emergency plan would need to consider onsite care of casualties and transport to the nearest emergency department. Scenarios could include a spaceplane accident close to or at the spaceport, an onboard system failure with casualties, a terrorist attack, or an explosion or chemical leak of toxic materials. There may need to be a national plan put in place to cover such scenarios, with input from the health service in the devolved administrations likely to be affected.

12.125 Guidance based on the emergency medical plan for Spaceport America is available.[298]

Spaceport medical facilities

12.126 Appropriate first aid or medical services should be provided at a spaceport for staff, along with access for emergency services. This is in line with the HSE First Aid Regulations.[299]

12.127 While these impose requirements on employers with respect to first aid provision for employees, there is no requirement for the provision of first aid to the public, and no regulatory requirement for an aerodrome to provide medical services. Given that a UK spaceport is likely to be a major tourist attraction and a large number of visitors may be anticipated, first aid provision for visitors may need to be considered.

12.128 A spaceport medical director would be needed to provide medical support for flight crew, participants and ground crew, and to ensure that resources and facilities are prepared and tested to cope with large spectator events or mass casualties.

12.129 Depending on the type of chemicals used by the spaceplanes as fuel or for other purposes, there is likely to be a need for ongoing occupational health provision for any individuals who could be exposed to these substances. Pre-employment screening, observation and monitoring may be required. The local population may also require protection from noise, debris and pollutants.

Public health

12.130 Public health responsibilities at a spaceport would include advising on a strategic framework and priorities for health protection, the effectiveness of health protection-related emergency plans and major epidemic/pandemic plans; the capacity to prevent and respond to communicable disease and environmental hazards which present a risk to public health; and assessing and advising on major risks to public health, associated risk perception and communication issues.

12.131 As spaceplane operations develop, and options such as very high speed intercontinental travel become feasible, it will be necessary to consider port health controls for food standards, food safety and water quality, the import

---

[298] J Law and J Vanderploeg (2012) 'An emergency medical planning guide for commercial spaceflight events', *ASEM*, 83(9): 890–895

[299] HSE —The Health and Safety (First-Aid) Regulations 1981

of food and products of animal origin, and infectious disease. At ports of entry into the UK, the local authority has responsibility for port health, and the local centre for disease control has responsibility for public health, including control of communicable disease. The structure of public health organisations varies between the devolved countries of the UK, and so would vary according to the site of a spaceport.

Development of aviation and space medicine expertise

12.132 As is clear from this Review, specialists in aviation and space medicine will be needed to advise commercial spaceplane companies on all medical aspects of spaceplane design, through to manufacture, equipment, trials and operations. Training and experience in aviation and space medicine will be essential to this process: facilitating and encouraging the training of a cadre of specialists will support the future requirements of operators for advice and medical input.

12.133 Key to this will be the formal recognition of a specialty of aviation and space medicine. This is being progressed at the time of writing. The Department of Health confirmed in July 2012 that the four UK chief medical officers had approved the first stage of application for recognition of training in this specialty, and the second stage is progressing. The training curriculum has been fully developed and, it is anticipated, will be submitted to the General Medical Council (GMC) for approval by mid-2014.

12.134 Governmental, corporate and military support for the aviation and space medicine specialty is essential to ensure sufficient provision of consultant-level expertise in the future for spaceplane operations. Medical input will be needed for the selection, monitoring and medical fitness assessment of flight crew, assessment of participants' fitness to fly, assessment of the health of other personnel, support for medical emergencies in flight and in the event of emergencies at or near the spaceport.

Recommendation

The Government should lend support to the formal recognition by the General Medical Council of the medical specialty of aviation and space medicine.

12.135 Existing centres of excellence in aviation and space medicine in the UK include: King's College London (KCL), University College London (UCL), the Royal Air Force Centre of Aviation Medicine (RAF CAM), QinetiQ, the UK Centre for Astrobiology at the University of Edinburgh and the CAA. Facilities, structure, support, funding and research are subject to the individual objectives of the differing organisations. Hence these vary widely and are not co-ordinated.

12.136 The facilities available and the scale of practice of space medicine in the UK are very small indeed, compared to the facilities available, the volume of research undertaken and the number of employees at DLR, Germany, where the medical screening of astronauts is undertaken for the European Space Agency. Other European centres of aerospace medicine exist, such as the Netherlands National Aerospace Laboratory in Amsterdam. Having dedicated centres of excellence puts these organisations in a prime position to tender for international research in the field of aviation and space medicine.

12.137 The Centre of Human and Aerospace Physiological Sciences at KCL provides a range of basic, advanced and diploma courses in aviation medicine, a Postgraduate Certificate in Aeromedical Sciences and an MSc course in Aviation Medicine. The diploma course includes teaching from the medical directors of Virgin Galactic and the Red Bull Stratos 'Edge of Space' parachute record holder, as well as from the European Space Agency. Science graduates may undertake a Space Physiology and Health MSc course.

12.138 The Centre for Space Medicine at UCL runs an undergraduate course in altitude, space and external environment medicine as a component of its physiology and medical degree courses. It has a particular interest in translating findings from space medicine research into practical applications for clinical medical practice.

12.139 RAF CAM undertakes training in aviation, occupational, environmental and related sciences to support current and future air operations, and has expertise in life support systems, acceleration, escape systems, personal protective equipment testing and aeromedical training.

12.140 QinetiQ is involved in aviation and space medicine research, development, trials and assessment, flight trials and release to service of products. It operates the only long-arm UK centrifuge at Farnborough, as well as altitude (hypobaric), hyperbaric and climatic chambers at Boscombe Down.

12.141 The CAA has a cadre of specialists in aviation and space medicine and authorises several hundred aeromedical examiners (AMEs) who have undertaken training in aviation medicine to conduct medical assessments of pilots and other aviation personnel. With minimal further training, as discussed above, AMEs could undertake medical assessments of spaceplane crew and participants.

Recommendation

The Government should consider funding trainees for the space medicine element of specialist medical training in aviation and space medicine, as no UK employer currently provides this support.

Recommendation

During the development of, and preparation for, initial spaceplane operations, the Government should sponsor and encourage partnerships between UK specialists in aviation medicine who have some (perhaps limited) space experience and practitioners who have international space expertise, to build UK expertise and experience in space medicine.

Medical research

12.142 Increasingly the potential of space research – particularly experiments conducted under microgravity – to provide benefits for terrestrial healthcare is being realised. The radiation and isolation aspects of the space environment can also be exploited to answer physical and life science questions that cannot be investigated on Earth, and several UK universities are undertaking ground-breaking research in this area.[300]

12.143 UK universities are particularly strong in the fields of life science and biomedicine. Sub-orbital spacecraft are being marketed as cheaper platforms to enable experimental work in microgravity for a matter of minutes.

12.144 The potential benefits of experiments conducted in the space environment include:

- enhancing fundamental knowledge of physics, astrochemistry and biology;
- increasing understanding of the ageing process, muscle wasting, skin and bone metabolism and repair mechanisms, sleep disturbance, balance disorders, the ability of simple organisms to withstand extreme conditions; and
- producing and exploring applications for new materials.

12.145 Space biomedical research has improved remote medical monitoring and care, diagnosis and treatment. It has led to the development of precision robotics for use in surgery and to the creation of diagnostic ultrasound technology, while information gained from satellites has helped to address low water supply issues for remote communities. In space, the muscle groups surrounding the spine, the stabiliser muscles, atrophy quickly and significantly. Rehabilitation is required on return from space; however, the methods used to date are sub-optimal. Northumbria University has developed a new technique and a device that appears to rehabilitate stabiliser muscles more effectively than any existing system. Though the initial research focused on astronauts, the findings could

---

[300] S Evetts and I Whiteley (2013) 'Space biomedicine: UK research for health in space', *A Global Village*, Imperial College, 11: 23–27

potentially be used to provide effective treatment for lower back pain for many more people.

12.146 Clearly, spaceplane operations from the UK would make it easier for UK universities and researchers to conduct space research – an important potential benefit.

12.147 However, there are some important issues to be addressed before this could take place. Space environments research may involve the transport of people to conduct research or may involve research on people flying. Ethical committee approval may need to be granted before some of these experiments are undertaken. Many research councils in the UK are currently unable to accept bids for space research because of their constitution and remit.

Recommendation
The Government should discuss with the Medical Research Council and the national public health services how research in the fields of space medicine and space biomedical science can be developed and encouraged, and how national integration of space medicine research may be achieved.

Taking a strategic approach to space medicine research

12.148 Space medicine research in the UK is fragmented. The UK Space Biomedicine Consortium (UKSBC) has grown out of a student-led association and aims to bring together all parties interested in space biomedicine research. Membership now includes more than 30 organisations and it is supported by the UK Space Agency. The UKSBC has a five-strand strategy:

- benefit terrestrial healthcare;
- enhance UK innovation and economic growth;
- prepare the UK to participate effectively in future human spaceflight activities;
- benefit/serve the interests of UKSBC members; and
- contribute to, and benefit from, international collaboration.

12.149 The UK Space Agency also supports a Space Environments Working Group that facilitates work associated with the European Space Agency’s Life and Physical Sciences in Space programme of space research and development.[301] International and commercial collaboration are key to success in this area.

---

[301] See www.esa.int/esapub/br/br183/br183.pdf (accessed 10 April 2014)

12.150 A national space biomedicine strategy would complement well the Strategy for UK Life Sciences,[302] but has yet to be firmly established. There are many committed space scientists in the UK. A UK strategy supported by government would assist in providing them with organisational resources and support.

Recommendation
The Government should establish a national space biomedicine strategy.

Recommendation
The Government should fund and support an academic institution to act as a central focal point for UK aviation and space medicine research.

Recommendations

12.151 This chapter has made the following recommendations.

- To maximise the potential commercial opportunity for the UK, the Government should encourage discussions and partnerships between designers/manufacturers of spaceplanes and designers/manufacturers of UK life support systems and training/emergency equipment, and consider seed funding for UK technology and design companies to consider diversifying into the space market.
- The competent authority for spaceplane operations should ensure that consideration is given in a European regulatory framework to establishing a ‘human rating’ approach to design and operational requirements for spaceplanes, particularly those that will be travelling to Low Earth Orbit (LEO) and beyond.
- Spaceplane manufacturers and operators should be strongly encouraged to work with physiology experts in the development of their life support systems and emergency egress requirements.
- The Health and Safety Executive should be consulted on whether the scope of existing UK health and safety legislation, including that pertaining to the aircraft environment, should be extended to include protection for flight crew involved in the operation of spaceplanes, other crew and spaceflight participants.

---

[302] Department for Business, Innovation and Skills and Office for Life Sciences (2011) *Strategy for UK Life Sciences*, www.gov.uk/government/uploads/system/uploads/attachment_data/file/32457/11-1429-strategy-for-uk-life-sciences.pdf (accessed 10 April 2014)

- The Government should ensure that medical requirements for spaceplane crew are developed at least a year before spaceplane operations commence in the UK, by international experts experienced in both aviation and space medicine, and that aeromedical examiners are trained to undertake the required medical assessments. (*Recommendation 27 in summary report*)
- The competent authority should ensure that medical assessment guidelines are reviewed once information has been gained from operational experience. (*Recommendation 30 in summary report*)
- In the medium term (3–8 years), the competent authority should seek to work with EASA and other regulators to develop consistent pan-European medical requirements, and also work with ICAO to develop medical provisions and international Standards and Recommended Practices for spaceplane flight crew.
- The competent authority should ensure that individual fitness is considered in the context of each proposed operational scenario; initially this may need to be endorsed before each flight.
- All medical assessments for spaceplane flight crew should be undertaken by aeromedical examiners who are experienced in Class 1 assessments, and have undertaken further training in the additional medical considerations for spaceplane flight.
- All spaceplane flight crew must be suitably trained in the effects of high acceleration and deceleration forces. (*Recommendation 28 in summary report*)
- The Government should explore with industry how sufficient and appropriate facilities can be made available to support the pre-spaceflight training of spaceplane flight crew in the long term – and in particular ensure that a modern long-arm centrifuge is available and accessible in the UK. (*Recommendation 29 in summary report*)
- The competent authority should ensure that medical requirements are developed for remote pilots of unmanned spaceplanes.
- The competent authority should ensure that guidance is developed to assist operators in providing sufficient, appropriate information for potential participants to be able to give informed consent for their carriage.
- The competent authority should require spaceplane operators to have a management system in place that specifies overall strategy for the management and mitigation of the medical risks to crew and participants and a medical advisory capability for individual risk management.

- In the longer term (10 years plus) the competent authority should work with EASA and other regulators to develop European medical requirements for orbital spaceplane operations, and with ICAO to develop medical provisions and international Standards and Recommended Practices for flight crew of orbital spaceplane operations.
- The competent authority should ensure that all spaceplane flight crew receive training in procedures to be followed in the event of the medical incapacitation of a member of the flight crew or of an onboard medical incident affecting a participant.
- The Cosmic Radiation Advisory Group (CRAG), including representatives of the public health authorities, the Health and Safety Executive and the CAA, should consider whether the ANO should be revised to cover potential radiation exposure of spaceplane crew.
- The CRAG should consider a legislative requirement for operators to maintain records regarding radiation exposure associated with spaceplane operations.
- The CRAG should consider whether active radiation monitoring equipment should be carried on board all manned spaceplanes, so that immediate action can be taken to mitigate the radiation risk from a solar particle event, or whether individual dosimetry should be used to assess the doses to which occupants are exposed.
- The CRAG should consider other radiation monitoring, avoidance and protection measures for spaceplane crew and participants and the need for long-term data collection, analysis and risk assessment.
- The competent authority should ensure that in-flight crew medical event monitoring and reporting systems are established and that similar medical event monitoring and reporting systems are established for participants while experience is being gained of these types of operations.
- The competent authority should ensure that data is captured from any medical events pertaining to flights. A reporting scheme should be put in place for this purpose.
- The Government should establish central co-ordination of spaceplane medical event data collection (to include all medical events, not just those that could have jeopardised the safety of the flight) with particular attention to the monitoring and study of long-term health. It should also consider funding spaceplane medical event data recording and analysis. An international group could be established to review the medical data of spaceflight crew and in-flight medical events affecting flight crew and participants.

- The HSE should be consulted on whether the scope of current UK health and safety legislation, including that pertaining to environmental hazards and control of toxic substances, should be extended to include protection for ground crew involved in the operation of spaceplanes.
- The Government should lend support to the formal recognition by the General Medical Council of the medical specialty of aviation and space medicine.
- The Government should consider funding trainees for the space medicine element of specialist medical training in aviation and space medicine, as no UK employer currently provides this support.
- During the development of, and preparation for, initial spaceplane operations, the Government should sponsor and encourage partnerships between UK specialists in aviation medicine who have some (perhaps limited) space experience and practitioners who have international space expertise, to build UK expertise and experience in space medicine.
- The Government should discuss with the Medical Research Council and the national public health services how research in the fields of space medicine and space biomedical science can be developed and encouraged, and how national integration of space medicine research may be achieved.
- The Government should establish a national space biomedicine strategy.
- The Government should fund and support an academic institution to act as a central focal point for UK aviation and space medicine research.

Glossary

Aerodrome	A defined area intended to be used either wholly or in part for aircraft to take off from or land at. Used in preference to airport or airfield etc, as these latter terms are associated with having met certain regulatory requirements.
Air Navigation Order (ANO)	Overarching regulation for air navigation in the UK, in line with the Chicago Convention on International Civil Aviation.
Air navigation service provider (ANSP)	An organisation that manages flight traffic on behalf of a company, region or country. In the UK, the ANSP is NATS.
Airspace change process	The process by which changes to the dimensions, classification or use of UK airspace must be carried out. It requires the submission of an airspace change proposal, which must be assessed according to published criteria and opened to public consultation.
Airspace Management (ASM)	A planning function that aims to provide the most efficient use of airspace based on actual need.
Air Traffic Control (ATC)	The specific guidance from ground-based controllers to direct aircraft on the ground and through controlled airspace.
Air Traffic Management (ATM)	The overarching processes and procedures used to ensure that aircraft are safely guided in the skies and on the ground. ATM includes ATC, ASM and Air Traffic Flow and Capacity Management.
Air traffic service (ATS)	Any one of several services provided by ANSPs to aircraft – such as meteorological information. Different ATS are provided in different classes of airspace.
Airworthy	An aircraft that is designed, manufactured and maintained to be fit for its intended purpose is described as airworthy, and can be awarded a Certificate of Airworthiness.
C2	A command and communication data link – a means of connecting an aircraft with monitoring systems on the ground. Particularly important for unmanned aircraft systems.

Catastrophic failure rate	A catastrophic failure is a sudden and total failure of some system from which recovery is impossible. Catastrophic failure rate is the highest on a scale of failure classifications, which has been used for some years to assess the safety of aviation, particularly within airworthiness assessment. It is measured as the likelihood of a catastrophic failure occurring within a given number of flight hours, ie a catastrophic failure rate of better than 1×10^{-7} means that the likelihood of catastrophic failure taking place is less than 1 in every 10 million hours of flight. Different classes of aircraft must meet different catastrophic failure rates.
Centrifuge	A centrifuge is a training device used to produce the effects of high acceleration and deceleration forces, such as will be encountered on a spaceplane. It spins at high speeds, enabling those on board – typically pilots of jet aircraft or astronauts – to learn about the effects of high G and how to counteract these effects.
Certification specification (CS)	A CS is the specification which an aircraft, or component part of an aircraft (eg an engine), must meet to obtain EASA type certification.
Civil Aviation Authority (CAA)	The UK's specialist aviation regulator.
Competent authority	Any person or organisation that has the legally delegated or invested authority, capacity or power to perform a designated function. For example, the CAA is the competent authority in the UK for aviation regulation.
Danger Area	An area of segregated airspace within which activities that are potentially dangerous to the flight of aircraft may take place, at specified times.
European Aviation Safety Agency (EASA)	An EU agency, which regulates civil aviation across Europe – supporting a single European market in the aviation industry.
Expected casualty analysis	In the US, applicants for a launch licence are required to undertake an expected casualty analysis for their proposed launch. For example, the **maximum** acceptable average is 0.00003 (30×10^{-6}) casualties among the general public per mission.

Experimental	Under Annex II of the EASA Basic Regulation, some categories of aircraft are excluded and remain subject to national regulation. These include 'aircraft specifically designed or modified for research, experimental or scientific purposes'. To allow initial spaceplane operations to be regulated at the national level, we have recommended that spaceplanes are classified initially as experimental aircraft.
Experimental permit	The FAA AST can grant experimental permits to allow the launch of reusable sub-orbital rockets (eg spaceplanes) for research and development; to show compliance prior to obtaining an operating licence; or for crew training. The criteria for granting an experimental permit are lower than for a full launch licence.
FAA AST	The US Federal Aviation Administration Office of Commercial Space Transportation – the organisation responsible for regulating commercial space launches in the US.
Flexible Use of Airspace (FUA)	An Airspace Management approach, based on the fundamental principle that airspace should not be designated as either military or civil airspace, but should be considered as a joint, shared resource.
High G	High acceleration and deceleration forces, expressed in multiples of gravity known as 'G'. The effects of high G can include loss of vision and loss of consciousness.
High Earth Orbit (HEO)	An orbital path around the Earth that takes place entirely above 35,786 kilometres.
Horizontal launch	Taking off from a runway, like an aircraft.
Human rating	A term used by NASA to assess whether a spacecraft or launch vehicle is suitable for the transportation of humans.
Informed consent	Before taking part in a spaceflight, spaceplane flight crew and participants will have to be informed of the inherent risks, including to their health, and of the spaceplane's known safety record. They will then sign to say they have received this information; this is known as giving informed consent.

Intercontinental very high speed travel	Umbrella term used within this report to describe passenger flight between two destinations at a sub-orbital trajectory, or using engine technology developed for spaceplanes. It is also known as hypersonic flight. It is seen as one of the main potential benefits of commercial space travel, with projections of travel time between, for example, New York and Tokyo being reduced to just a couple of hours or less. However, no such travel has yet been accomplished.
International Civil Aviation Organization (ICAO)	A UN specialised agency that works with all signatory states to the Chicago Convention and global industry and aviation organisations to develop international Standards and Recommended Practices for aviation.
ITAR	US International Traffic in Arms Regulations, designed to restrict the sharing of any information and material concerning items on the US Munitions List with anyone outside the US.
L_{eq}	Equivalent continuous noise level. This is a commonly used measure of noise exposure. It means the average sound level for a specific location over a defined measurement period – for instance the aircraft noise over one village between 7am and 11pm.
Launch licence	The FAA AST issues licences and permits for commercial launches of orbital and sub-orbital vehicles. Licences are granted based on acceptance of a detailed written application.
Low Earth Orbit (LEO)	An orbital path around the Earth at an altitude of between 160 kilometres and 2,000 kilometres. Most remote sensing satellites and many weather satellites are in LEO.
Microgravity	Very small amounts of gravity – but not quite zero. A microgravity environment can be experienced in LEO. This lack of gravity means objects are effectively weightless.
Microsatellite	A satellite weighing between 10 kilograms and 100 kilograms.
Nanosatellite	A satellite weighing between 1 kilogram and 10 kilograms.
Orbital	An orbit is the curved path of an object around a point in space – such as a planet. An orbital flight around Earth would therefore complete a full path around Earth.

Outer space	There is no internationally agreed boundary for where outer space begins. However, it is commonly considered to commence 100 kilometres above the Earth's surface.
Participant	In this Review, a participant is anyone other than flight crew who participates in spaceflight. This could be a paying participant.
Reusable launch vehicle	A type of spacecraft that can be used for more than one launch. Most rockets to date have been expendable; spaceplanes are designed to be reusable.
Rocket	Generally understood as a vertical launch vehicle, powered by a rocket engine.
Rocket engine	Conventionally, a type of engine that operates by burning fuel and oxidiser carried with the engine. Unlike gas turbine or piston engines, which are used in most conventional aircraft, a rocket engine does not require air – which is why it can work in space.
Safety management system (SMS)	A systematic approach to ensuring that all safety risks have been identified, assessed and satisfactorily mitigated.
Single-stage to orbit	A description for a type of mission which reaches orbit (as opposed to a sub-orbital level) without the orbital vehicle needing to split from a carrier craft or launch vehicle. The majority of orbital flights to date have involved multi-stage vehicles, with some parts – or stages – being jettisoned at a certain altitude before orbit is reached.
Sound Exposure Level (SEL)	A means of measuring the impact of a single noise. An SEL footprint shows the geographical area in which a particular SEL is reached from a single noise incident – such as a plane taking off.
Spaceflight experience	Umbrella term used within this Review to describe the relatively short sub-orbital spaceflights that are expected to be available to paying participants in the near future. Such flights will allow participants to experience spaceflight and a microgravity environment. The term is used in preference to 'space tourism'.
Spaceplane	A winged vehicle that acts as an aircraft while in the atmosphere and as a spacecraft while in space.
Spaceport	A launch site for space operations.

Space object	A term used in the five UN Treaties which form the basis of international space law. Under these treaties, 'space object' includes component parts of a space object as well as its launch vehicle and parts thereof.
Special Use Airspace (SUA)	Areas of airspace that are segregated for a specific purpose. While airspace is designated SUA, there are very strict limits on other aircraft using the area.
Strategic	When used to describe a missile or weapon system, strategic means a system that has the capability to cause mass destruction in a single strike. It generally refers to ballistic missile systems. Importantly, the term includes not only the explosive device itself, but also the entire delivery system.
Sub-orbital	A sub-orbital spaceflight reaches space, but does not complete an 'orbit' of the Earth.
Type certificate	A type certificate is issued to signify the airworthiness of an aircraft manufacturing design. Once a type certificate has been awarded, the design cannot be changed; any changes would require reassessment.
Unmanned	An aircraft, or spaceplane, that has no onboard flight crew and is remotely piloted from another location.
Vertical launch	Taking off from a vertical launch pad, like a space rocket.
Wet lease	In aviation, an arrangement in which an operator leases an aircraft, together with its flight crew and its maintenance staff, to another operator. Within this Review, wet lease type arrangement refers specifically to an arrangement which would allow a US spaceplane operator to conduct operations from the UK (or any other country outside the US); the spaceplane would have to be wholly crewed and maintained by the operator's staff. This would ensure that the operation was in compliance with ITAR. This cannot be a true wet lease because wet leasing can only be conducted if the aircraft system has an Air Operator's Certificate, and initial spaceplane operations are not expected to have an AOC.

Acknowledgements

This report was written by a cross-government team including Andrew Badham (CAA); Andy Sinclair (CAA); Bob Waters (UK Space Agency); Charles Prophet (CAA); Dr Darren Rhodes (CAA); Gerry Corbett (CAA); Graham Owers (CAA); Jeremy Stubbs (CAA); Justin Willcocks (CAA); Paul Cremin (DfT); Robin Allan (CAA) and Dr Sally Evans (CAA). The Review project was managed by Lynn Oates. Further editorial review and direction was provided by Liz Cox (UK Space Agency); Padhraic Kelleher (CAA); Wg Cdr Rayna Owens (MOD); Pete Stockel (DSTL) and Simon Wragg (Siluri Integration Ltd), along with other members of the National Spaceflight Coordination Group and the CAA Safety Leadership Team.

The authors would like to thank all those who have contributed to the report, including:

- all those the UK Government team met on its technical visit to the US in 2013 at the Federal Aviation Administration (FAA) and its Office of Commercial Space Transportation (FAA AST), the National Aeronautics and Space Administration (NASA), the Commercial Space Transportation Advisory Committee (COMSTAC), State Department, the Commercial Spaceflight Federation, New Mexico Spaceport, Spaceport Mojave, Kirtland Air Force Base, NASA Dryden Flight Research Center and the Aerospace Corporation;
- representatives of spaceplane operators Airbus Defence and Space, Bristol Spaceplanes, Orbital Sciences Corporation, Reaction Engines, Swiss Space Systems, Virgin Galactic and XCOR Aerospace;
- all those who attended the industry days co-ordinated by the CAA as part of its research;
- colleagues at EASA and ESA; and
- staff of DfT, MOD, UK Space Agency, the Health and Safety Executive and other UK government agencies.

In addition, the authors would like to thank a number of individuals who helped them in their research. These include Sqn Ldr Pete Hodkinson, Cliff Whittaker, Dr MCJ Blokpoel, Capt Dave Riley and Capt Ian Wrathall.