HEALTH & SAFETY LABORATORY

Human Factors in Air Displays:

Transfer of Behaviours and Error Path Study

Author(s):

Colleen Butler, BA MSc PhD

Julie Bell, BSc MSc, FIEHF

William M H Dean, BSc

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Report approved by:	Ed Corbett, MSc, CPsychol, AFBPsS, HSE Science Division, Head of Human & Organisational Performance
Report authorised for issue to Civil Aviation Authority by:	Charles Oakley, CEng FIMechE BSc(Eng), HSE Science Division
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Lead Author:	Colleen Butler BA MSc PhD, HSE Science Division, Human Reliability Team
Contributing Author(s):	Julie Bell BSc MSc, FIEHF, HSE Science Division, Human Reliability Team, William M H Dean, BSc, Aviation Safety Specialist
Customer:	Kevin Sawyer, Civil Aviation Authority
Technical Reviewer(s):	Tony Wynn, BSc, MSc, PhD, C.ErgHF MCIEHF, CPsychol, AFBPsS
Editorial Reviewer(s):	Rosemary Whitbread, BSc, HSE Science Division Kevin Hallas, BSc(Hons), PgDip, HSE Science Division
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A number of display pilots and expert stakeholders contributed to this study by making themselves available for consultation through interview. Their open and committed involvement has made this study possible. These included:

Single-Engine Piston aeroplane and Jet-Powered aeroplane display pilots, Flying Display Directors (FDDs), Display Authorisation Evaluators (DAE), and representatives from the Civil Aviation Authority's General Aviation Unit (CAA GAU), the British Air Display Association (BADA) and the Historic Aircraft Association (HAA).

The authors of this report would also like to thank Marcian Tessin, an Air Traffic Controller Officer with expertise in safety leadership and incident management and Christian Bjursten Carlsson, a Commercial Pilot and Human Factors Specialist, for their technical reviews and insightful comments on a draft summary report of this work.

EXECUTIVE SUMMARY

The Civil Aviation Authority (CAA) commissioned the Health and Safety Executive's Science Division, the Health and Safety Laboratory (HSL) to carry out a study to explore human factors in air displays.

The aim of this research was to enhance understanding of the error paths that lead to flying display accidents, including the potential for negative transfer of behaviours between aircraft. An error path is defined as the weaknesses in safety 'barriers' that, when aligned, can result in an unwanted outcome; safety barriers are conceptualised at the individual, job and organisational level. A research requirement was to use the research findings to develop human factors training for the display community.

Method

The scope was narrowed to focus on Single-Engine Piston (SEP) and Jet-Powered (JP) aeroplanes, and was divided into three phases: (i) desk-based collation and review of relevant theory, industry guidance and accident reports; (ii) consultation with the display community and analysis of findings and (iii) reporting of findings and provision of human factors training programme.

Main Findings

Display pilots are flying in a highly dynamic, time critical, evolving environment. They are generally operating at the automatic, skill-based level of human cognition, where the human error potential is generally related to slips and lapses, and where the transfer of behaviour between aircraft can increase error potential. Why transfer occurs, and what causes skills acquired in one setting to impact another has been extensively researched within the discipline of cognitive psychology and neuroscience, and is experienced by experts across all industrial sectors and in all skilled activities. The processes related to the assurance of the competence of air display pilots was a recurring contributory factor highlighted in accident reports. These included training, supervision, practical experience and assessment.

Consultation with pilots and the wider display community provided a rich source of potential error path data. The main findings were:

- there are important operating and handling differences between and within types and categories of SEP and JP aeroplanes that could impact safety;
- there is potential for negative transfer of behaviours between types and categories of aeroplanes;
- there are numerous error pathways that cannot be entirely eliminated, but problems arising from negative transfer of behaviours were perceived as a) often recoverable and b) as being normally mitigated by a number of measures;
- many pilots have developed strategies for minimising the likelihood of error (including those caused by negative transfer);
- currency on aeroplane, time pressures, distractions on display day (e.g. weather), stress and pressures to display were all considered factors that could influence pilot performance on the day of display.

Wider issues were also highlighted and included:

- The role of the Display Authorisation Evaluator (DAE) and the Display Authorisation Evaluation process to ensure display pilots were suited to display flying in terms of their attitude, skills, behaviour and knowledge;
- Flying Display Directors (FDDs) activities, roles, and responsibilities including the variation in content and delivery of display briefs;
- Event organisation and how it can vary significantly in terms of how well pilots' needs are considered, which in turn can impact safety and performance;
- The role of the regulator, their relationship with the display community and how information is shared.

Conclusion

Design changes to aircraft are the most effective way of reducing the likelihood of slips and lapses caused by negative transfer, but this is not generally an option for aeroplanes in display flying. Pilots have, instead, developed their own strategies for minimising errors, which include minimising errors due to negative transfer. The research identified many excellent strategies used by pilots, who may not necessarily realise that they are managing human factors' related risk. The strategies that they have developed to safely manage and adapt to aeroplane type changes promote moving between System 1 fast thinking (automatic processing) and System 2 slow thinking (controlled processing). Whether or not a pilot can employ these strategies is not only dependent on the individual but also on wider display community processes and structures in place to support them.

There appeared to be variation in how extensively human factors expertise was utilised in accident investigations. Applying human factors resource to a wider range of incidents will likely help strengthen industry learning on error reduction/ performance enhancement. Such an investigation approach should be applied to high potential incidents, as well as those resulting in near misses, or less serious incidents. This would help to ensure that there is consideration of not only individual factors, but broader task and organisational/sector factors. It would also enable deeper and broader learning to help reduce the likelihood of high consequence events. There is a need at all levels of the display community to promote practices to ensure a positive health and safety culture, including a 'just' culture. It is important that pilots and other personnel can speak openly and honestly following an incident. Such openness and honesty enables learning and safety improvement.

The human factors principles and research data discussed in this report are applicable to all aircraft types where there are sufficient similarities in contextual information for negative transfer to occur. It is recommended that all pilots and operators consider how it might occur and be addressed in their aircraft. The research highlights that PIFs extend beyond those associated with negative transfer of behaviour and therefore, the proposed training programme is applicable to all.

Recommendations

A key requirement was to use the error path findings from this study to develop human factors training for display pilots, training that the CAA will require holders of Display Authorisations (DAs) to undertake. The authors of this study are aware that experts make errors irrespective of training and experience or how motivated they are to do things correctly and therefore, training forms part of a number of recommendations for consideration.

1. CAA should work with FDDs to improve the quality and quantity of reporting and feedback provided by FDDs following airshows. CAA should also consider ways in which this information can be shared across the display community. Sharing information from FDD reports on why incidents occurred and actions that have been, or can be, taken to prevent further similar incidents would be of benefit to the entire display community.

2. CAA and the Air Accident Investigation Branch (AAIB) should promote more consideration of human factors in accident investigations through application of human factors expertise. This would enable deeper and broader learning to help reduce the likelihood of high consequence events.

3. CAA should develop a human factors training programme based on knowledge sharing techniques to ensure there is an exchange of expertise across the display community. Engaging with the display community as a resource could bring about improvements in safety practices far beyond traditional training.

4. CAA should consider a blended learning solution comprising a combination of self-taught learning and reflection, online learning and face-to- face training, delivered in a modular format.

5. All display pilots, not just those flying multiple aircraft, should be required to participate in the proposed training programme. This includes pilots seeking initial display authorisation and display authorisation renewal. The inclusion of other critical support and management roles in training is also recommended in order to support a more holistic / systematic approach to enhancing safety for air displays.

6. To further facilitate the transfer of learning, the CAA should work to set up a community of practice to help ensure that the taught elements of the training are embedded into long term practice and delegates can share their own expertise. This could serve as a repository for human factors references and relevant information.

7. CAA should use face-to-face sessions in human factors training to activate the expertise within the display community. Face-to-face sessions should include further identification and discussion of PIFS and mitigation measures to optimise pilot performance. The outputs of such sessions could be defined as recommended safe practices which could be extracted and published in the community of practice.

8. CAA should work with FDDs to standardise the inclusion of human factors in FDD briefs and debriefs.

9. CAA should consider how to effectively engage with the display community, including DAEs, FDDs, event organisers, and other stakeholders (e.g. British Air Display Association, Historic Aircraft Association) to improve safety and regulatory compliance.

10. CAA should consider the pace of change of regulation and the timing of changes and how that may impact pilots in the display season.

CONTENTS

1 INTRODUCTION

1.1 STUDY CONTEXT

The Civil Aviation Authority (CAA) commissioned HSE's Science Division, the Health and Safety Laboratory (HSL) to carry out a study on human factors in air displays. Specifically, the study required exploration of the potential for negative transfer of pilot behaviour between aircraft types and identification of the potential for error and factors that have and could contribute to air display accidents.

The motivation for the current project was the investigation into the accident to Hawker Hunter T7, G-BXFI that crashed near Shoreham Airport on the 22nd August 2015. Following the extensive investigation carried out by the Air Accident Investigation Branch (AAIB), a number of recommendations were made. This work seeks to enable the CAA to address two of these recommendations:

i. AAIB Recommendation 2016-041**:**

It is recommended that the Civil Aviation Authority require a Display Authorisation to be renewed for each class or type of aircraft the holder intends to operate during the validity of that renewal.

In response to Recommendation 2016-041, the CAA agreed to:

Review the list of different categories of aircraft relevant to pilot Display Authorisation renewal and assess the impact of operating differences between each category. The CAA will expand this work to include a study of the potential for negative transfer of behaviours between aircraft types. The CAA will consider introducing any relevant findings into the ongoing training and assessment requirements for display pilots, including the requirements for Display Authorisation renewal.

ii. AAIB Recommendation 2017-006:

It is recommended that the Civil Aviation Authority undertake a study of error paths that lead to flying display accidents and integrate its findings into the human factors training it requires the holders of display authorisations to undertake.

In response to Recommendation 2017-006, the CAA agreed to:

Work with external experts to understand the influence of human factors on air displays. The CAA will expand this work to include a study of error paths that lead to flying display accidents and integrate the findings into the human factors training it requires the holders of display authorisations to undertake.

1.2 AIMS AND OBJECTIVES

The aim of this study was to enhance understanding of the error paths that lead to flying display accidents including consideration of the potential for error resulting from the negative transfer of behaviours between aircraft types. A further requirement was to use the error path findings from this study to develop human factors training for display pilots, training that the CAA will require holders of display authorisations (DAs) to undertake.

To address the aims and requirements of this study, the following key objectives were formulated:

i. Identify the scope of the categories / groups of aircraft to focus on in order to maximise study outcomes;
ii. Review key industry guidance and 'negative transfer of learning' literature;
iii. Analyse a sample of accident / incident reports of UK flying display accidents / incidents;
iv. Collate examples on negative transfer from other industries;
v. Adopt a task analysis approach to enrich understanding of potential error paths that lead to flying display accidents;
vi. Develop research materials (e.g. semi-structured interview guides, images of aircraft cockpits) informed by the findings from (i) – (v);
vii. Collate error path data from the display community (to include display pilots, Flying Display Directors, Display Authorisation Evaluators and key stakeholders e.g. British Air Display Association, Civil Aviation Authority's General Aviation Unit and the Historic Aviation Association);
viii. Analyse the data to propose a draft training programme;
ix. Write up a draft summary report informed by results from i-viii;
x. Produce a final training programme following discussions with the Civil Aviation Authority's General Aviation Unit;
xi. Deliver findings in a final report; and,
xii. Deliver training materials and associated testing process and records informed by the final report.

2 METHODS

This study involved three phases: (1) desk-based data collation (2) consultation and analysis and (3) reporting and provision of a training programme with associated materials. Figure 1 provides an overview of the three stages of the study with associated activities, project timeline (March 2018 to September 2018) and milestones.

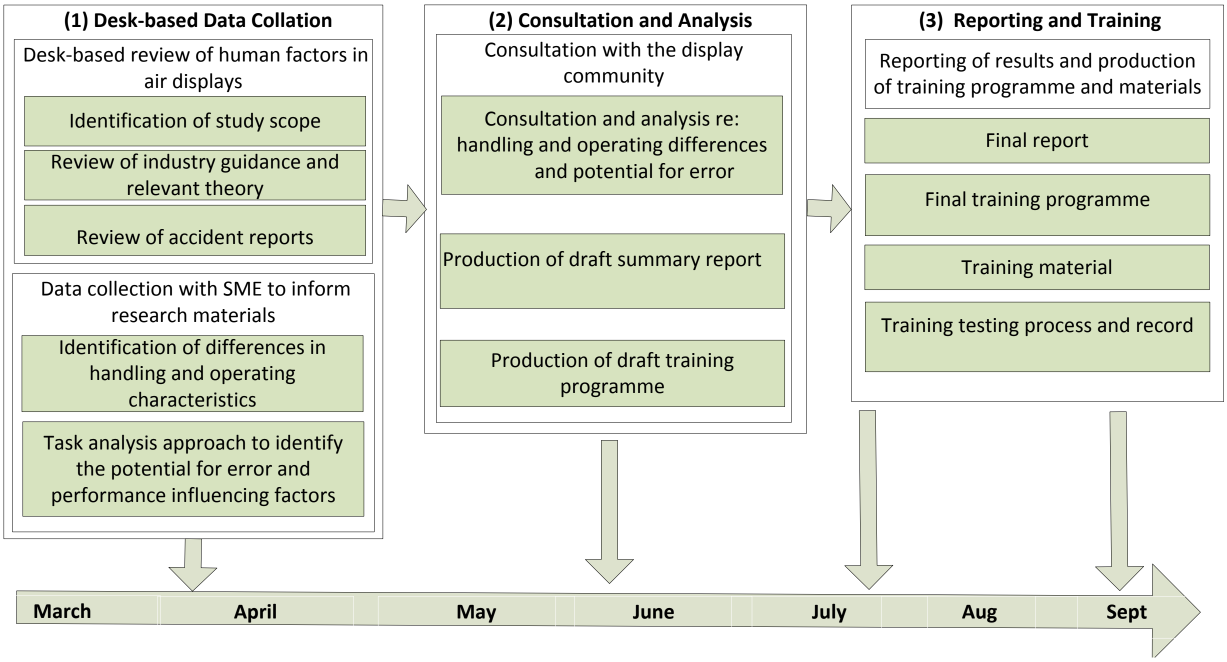

Figure 1 Project timeline and key activities

2.1 DESK-BASED DATA COLLATION

2.1.1 Study Scope

A pilot can seek authorisation to display an aircraft in 23 different categories of aircraft, as defined in the CAA's recently revised regulatory document referred to as CAP 403, Edition 15 (Civil Aviation Authority, 2018). These are divided into eight groups of aircraft:

- Single-Engine Piston aeroplanes;
- Multi-Engine Piston aeroplanes;
- Jet-Powered aeroplanes;
- Turbo-Prop Powered aeroplanes;
- Helicopters and Gyroplanes;
- Gliders, Hang Gliders and Paragliders;
- Microlight aeroplanes; and,
- Powered Parachutes, Powered Paragliders and Powered Hang Gliders.

In order to maximise the research outcomes, the scope of this study was narrowed to focus on five categories of aeroplanes: Single-Engine Piston (SEP) aeroplanes, categories A, B and C and Jet-Powered (JP) aeroplanes, categories G1 and G2 as defined in CAP 403, Edition 15 (Civil Aviation Authority, 2018).

The type of aircraft, group and category of aeroplane was determined by an analysis of the DA database, Subject Matter Expert (SME) opinion, and research knowledge of how negative transfer can occur. Analysis of the 443 current DAs showed that the majority of DAs are for SEPs only (approximately 60%) and for SEPs and JPs (approximately 10%). Table 1 in Appendix A provides further information. The potential for negative transfer is greatest within the groups selected because of the similarities in aeroplane characteristics. As defined:

> *"When two situations have similar (or identical) stimulus elements but different response or strategic components, transfer will be negative…"* (Wickens et al., 2013, p.227)

In addition, the SME confirmed these groups of aircraft (SEPs and JPs) were most likely to be involved in high-energy manoeuvres during air displays and are, therefore, of most relevance to the project.

Conversely, the potential for negative transfer is reduced by increasing the differences between stimuli,

> *"…if the responses for two systems are different and incompatible… the amount of negative transfer may be reduced by actually increasing the differences… the operator confronting two control levers with incompatible motion directions will have few problems if the appearance of the handles (both visual and tactile stimulus elements) is quite distinct"* (Wickens *et al.*, 2013 p.227)

This means that the contextual and functional differences between, for example, SEPs and helicopters, or gliders and Multi-Engine Piston aeroplanes are sufficient to exclude them from the current work, as negative transfer is less likely to occur.

The principles identified in this research will be applicable to the operating differences between any of the aircraft categories. However, by limiting the scope, it was possible to 'deep dive' into issues, providing a much richer understanding of human factors issues linked to transfer of behaviours and error paths within the air display sector.

Section 3 provides more information about the background theory to human performance in air display, and is the basis of the rationale for narrowing the research scope.

2.1.2 Data Collation

Phase one (desk–based data collation) involved collation and review of key documents / information including:

- Data from the CAA e.g. Display Authorisation (DA) database; Flying Display Director (FDD) reports;
- Collation of examples of transfer from other industries;
- A sample of Flying Display Director (FDD) reports and AAIB reports;
- SME views on operating and handling characteristics of aircraft;
- Industry guidance (e.g. CAP 403, Edition 15) and 'transfer of learning' literature; and,
- Training material from a number of sources.

2.1.3 Design of Research Materials

A walk-through talk-through task analysis approach was used with the Subject Matter Expert (SME) in this study to gain a greater understanding of display pilot actions and decisions when conducting a flying display. This involved the SME commentating through a hypothetical scenario highlighting key display pilot activities and decisions leading up to a display and during a display. To facilitate this discussion, large-scale images of cockpits and different types of aeroplane were used to prompt discussion and memory recall of key actions and decisions. The aim of this task analysis exercise was to inform the development of interview question guides that could be used with display pilots and other key stakeholders in this study.

Two sets of question guides were developed. These were informed by the output of the task analysis exercise, SME views on operating and handling characteristics of aircraft and a high level review of a sample of accident reports. The first question guide for display pilots was designed to enable exploration of the following topics:

- Display flying experience and aeroplane type;
- Operating and handling differences between different types of aeroplane;
- Views on the potential for all error, including the potential for error due to negative transfer of behaviours between aeroplanes; and,
- Factors considered likely to influence error.

A second question guide was developed for other expert stakeholders in this study (see Section 2.2.1 for a description of stakeholder consultation). This included a high level discussion on the topics above with additional questions relating to the organisational aspects of display flying. For example, questions relating to stakeholder views on currency requirements[1], the Display Authorisation Evaluation (DAE) process, the role of the FDD and any other views on the safety of airshow organisation.

2.2 CONSULTATION WITH THE DISPLAY COMMUNITY

Phase two involved recruitment of experts in the display community, consultation with the display community and analysis of findings.

2.2.1 Recruitment of Experts from the Display Community

A purposive sampling approach was used to recruit interview participants for the study. This approach focuses on particular characteristics of a population that are of interest and can best

[1] In CAP 403, Edition 15, the minimum currency requirement preceding a flying display (that includes a standard aerobatic skill level) is to complete three display routines within 90 days of the date of display and one display routine within 30 days of the date of display. The one display within 30 days must be in the specific category of aircraft being displayed. For intermediate, advanced and unlimited aerobatic skill levels, three displays within 90 days must be in the specific category of aircraft being displayed with one within 30 days in that category. CAP 403 also highlights that currency requirements should be viewed as a minimum and "*that pilots are encouraged, particularly during the winter months or pre-season work up, to undertake sufficient practice to ensure that a sufficiently high standard of safety is maintained*".

address the research aims and objectives (Ritchie and Lewis, 2003). A key criterion for display pilot participation in this study was that display pilots held a current or recent DA. A DA is a national document detailing the types or groups of aircraft in which a pilot is authorised to display, together with any limitations and any specific endorsements.

A second criterion for display pilot participation in this study was that display pilots who held a current or recent DA were authorised to fly either SEP aeroplanes and / or JP aeroplanes. The rationale for this criterion was that the work focused on aeroplanes and, specifically, SEP aeroplane categories A, B and C, and JP aeroplanes, categories G1, and G2, as defined in CAP 403 (Civil Aviation Authority, 2018).

A third key criterion for participation in this study was to include expert stakeholders from a number of organisations who play key roles in informing the safety of air display. This included FDDs. FDDs are responsible to the CAA for the safe conduct of a flying display. A DAE was consulted, this is a CAA authorised person qualified to conduct examinations and tests for the award of DA. The CAA requested consultation with representatives from the Civil Aviation Authority's General Aviation Unit (CAA GAU), the British Air Display Association (BADA) and the Historic Aircraft Association (HAA).

Table 1 provides information on the number of interviews and who was consulted. It shows that consultation included seven pilots who display or have displayed SEP aeroplanes, three pilots who display or have displayed JP aeroplanes and six expert stakeholders. The majority of interviewees had extensive flying experience as a display pilot and as a commercial pilot or a military pilot. Furthermore, the majority of interviewees had received some form of formal human factors training and receive regular human factors refresher training as a commercial pilot or a military pilot. It was not evident that pilots had received any formal human factors training specifically in the context of air display. Some interviewees commented that they attended the pre-season and post-season symposiums arranged by the CAA and the Military Aviation Authority (MAA) and that human factors presentations can form part of these.

Table 1 Number of expert display pilots and expert stakeholders consulted

Roles / organisation relevant to study scope	**Number of Interviews**
Single-Engine Piston (SEP) aeroplane pilots	7
Jet-Powered (JP) aeroplane pilots	3
Flying Display Director (FDD)	1
Display Authorisation Evaluator (DAE)	1
British Air Display Association (BADA) and FDD	1
Historic Aircraft Association (HAA)	1
Civil Aviation Authority's General Aviation Unit (CAA's GAU)	2
Total Number of Interviews	**16**

2.2.2 Semi-Structured Interviews

Semi-structured interviews were particularly well suited for this study as they combine structure with flexibility, thus allowing researchers to be responsive to what the interviewee was expressing and to capture any relevant additional information.

Two HSL researchers conducted the telephone and face-to-face interviews between May and June 2018. Each interview lasted approximately sixty minutes. At the start of each interview, details about the purpose of the research and assurances about anonymity and confidentiality were reiterated to participants. All interviews were audio recorded (with participants' consent), and transcribed for the purposes of data analysis.

2.3 DATA ANALYSIS OF INTERVIEWS

A thematic approach to analysis was adopted to identify the main themes from interviews. It involved the following steps:

- familiarisation with interview notes and audio recordings in order to obtain an initial understanding of the information and begin to formulate emerging themes;
- development of an analytical framework specifying a set of key themes drawing on the broad topics that were covered in the interviews;
- transfer of key themes onto a spreadsheet divided by discipline;
- population of the spreadsheet, which involved going through the interview notes and audio recordings; and,
- summarising the key issues that emerged for each theme in the relevant cells within the spreadsheet.

2.3.1 Considerations for interpretation of data

The findings that emerged from the qualitative data (the interview data) reflect the range and diversity of expert display pilots and expert stakeholders consulted in this study and therefore represent a good spectrum of views and experiences. Whilst views are wide and varied, this study used a small sample of display pilots and stakeholders (16 in total) relative to the display community population and therefore is not statistically representative of the display community. As the results are indicative only, it is not possible to comment on how far the results can be extrapolated across the display community. Given the main data collection method was via interviews, which tend to be more subjective, there may be additional performance influencing factors that impact on display pilots that have not been identified in this study. However, Subject Matter Experts who reviewed this work consider the findings to be representative of air display in practice. HSL researchers also noted that the expert interview participants were keen to participate, and actively engaged in interview discussions.

3 BACKGROUND THEORY: HUMAN PERFORMANCE IN AIR DISPLAYS

This section provides a high level introduction to relevant theory for non-human factors professionals.

3.1 EXPERT BEHAVIOUR

Air display pilots are experts; in an air display they are operating in a highly dynamic time critical evolving environment. The airborne time during an air display is approximately seven to ten minutes. In this time, the display pilot is continuously monitoring parts of the system, shifting their attention from the inside to the outside of the aeroplane throughout the flight, managing risks, anticipating future conditions, reacting to threats, and responding to all sensory inputs.

When flying a display, pilots are generally operating at the skilled, automatic end of human behaviour. Daniel Kahneman's description of human behaviour usefully simplifies complex cognitive processes and therefore is a helpful model to use in this context. Kahneman describes skilled automatic behaviour as 'System 1: fast thinking', this end of human behaviour has a number of characteristics - it executes skilled responses and generates skilled intuitions after adequate training, it operates quickly (in milliseconds) with little or no effort, with no sense of voluntary control (Kahneman, 2011). When people operate at this automatic, skill-based level the human error potential is related to slips and lapses, and the transfer of behaviour between aircraft can increase this error potential.

At times, a pilot may move between automatic processing and controlled processing. Controlled processing, also referred to as 'System 2: slow thinking', is effortful and includes greater conscious processing. System 1 can be programmed by System 2 to mobilize attention when a particular pattern is detected (Kahneman, 2011).

If a pilot moves to controlled processing he / she may exhibit rule-based behaviours and even knowledge-based behaviours (e.g. when facing something unexpected). Figure 2 illustrates the stages of skill acquisition and how mental effort changes when pilots operate at skilled, rule and knowledge-based behaviour levels.

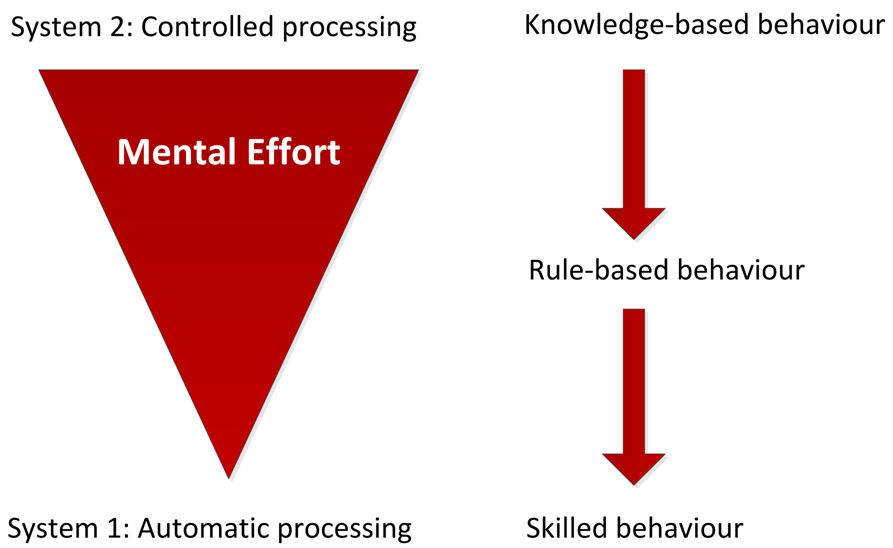

Figure 2 Rasmussen's stages of skill acquisition (adapted from Rasmussen, 1986)

At these different levels of behaviour, different types of error occur. Table 2 provides a summary of the basic error types associated with skill-based, rule-based and knowledge-based behaviour.

Table 2 Generic Error Modelling System (Adapted from Reason, 1990)

Level of Performance	Basic Error Type	Description
Skill-based Behaviour	Slips and lapses	Automated unconscious failures of automatic processing (attention / memory) during routine actions which are detected fairly rapidly.
Rule-based Behaviour	Rule-based mistakes	Errors of ruled-based behaviour e.g. applying the wrong rule for a given situation.
Knowledge-based Behaviour	Knowledge-based mistakes	Errors of cognitive (knowledge-based) processing whereby a problem is not analysed correctly (or not at all) and results in an error.

3.1.1 Slips and Lapses

Slips are failures in carrying out the actions of a task. They are described as 'actions-not-as-planned'. Typical slips might include:

- doing the right thing but on the wrong object (e.g. switching the wrong switch);
- carrying out the wrong check but on the right item (e.g. checking a dial but for the wrong value);
- transposing digits when copying out numbers;
- performing an action too soon or leaving it too late;
- omitting a step or series of steps from a task; and,
- performing the action in the wrong direction (e.g. particularly with equipment that works differently to what the individual is familiar with).

Lapses cause us to forget to carry out an action, to lose our place in a task or even to forget what we had intended to do.

It should be noted that slips and lapses are errors which tend to occur in highly practised, well-trained behaviours, are by definition, not prevented by further training. They are best prevented by design but can be reduced by rigorous checking supported by mitigation measures such as use of checklists. In some cases, there may be an opportunity to enhance individual or team skills in order to more assertively reduce distractions/interruptions, but such approaches are likely less reliable then more preventative design measures. Preventative design measures include:

- ensure consistency in controls e.g. up always means off;
- layout controls so that those operated in sequence occur in that sequence and those which should not be operated in sequence are located separately;
- involve end users in designing the layout of controls and instrumentation;
- design in warnings and alarms which help people detect errors; and,
- design in features to prevent inadvertent operation.

The above list refers to cockpit design. Recognising that the aircraft being flown in air displays cannot generally be modified or redesigned, this study is focused on identifying mitigation measures used by display pilots to recognise the potential for error and mitigate against it (with a focus on error due to transfer of behaviours between aircraft). Mitigation measures are discussed in Section 4.3.2.

3.1.2 Mistakes

Mistakes are a more complex type of human error where a person does the wrong thing believing it to be right. They are decision-making failures and involve failures in how we plan, assess intentions, and judge consequences (Health and Safety Executive, 1999). Mistakes might include not following the correct procedure because the individual is unaware of it or using a commonly used, familiar procedure when it is not suitable for the particular circumstances of the task. Mistakes tend to occur in situations where the person does not know the correct way of carrying out a task either because the task is new to the person or unexpected, or he / she has not been properly trained (Health and Safety Executive, 2018).

Rule-based mistakes

Rule-based mistakes occur when our behaviour is based on remembered rules or familiar procedures. We have a strong tendency to use familiar rules or solutions even when these are not the most convenient or efficient.

Knowledge-based mistakes

In unfamiliar circumstances we have to consciously determine goals, and develop the plans and procedures to help us achieve them. Planning or problem solving needs us to reason from first principles or use analogies. Misdiagnoses and miscalculations can result when we use this knowledge-based reasoning and these are referred to as knowledge-based mistakes.

Rule-based mistakes and knowledge-based mistakes often result from poor training in safe working procedures. These are often labelled as violations but if the employee or contractor is not aware of the safe working procedures in the circumstances and situation of the task, then this is a mistake rather than a deliberate violation.

3.1.3 Violations

A violation is an intentional deviation from rules, procedures, instructions and regulations, and is usually motivated by a desire to get the job done. For a violation to occur, the person must be aware of the existence of the rules, otherwise it could be a mistake due to lack of knowledge or awareness of the correct rule or procedure. Violations are a significant cause of many accidents and incidents and are very common in both work environments and our everyday lives. Driving a car on the motorway is often given as an example to illustrate how many of us commit violations in our everyday life. Surveys of driving behaviour show that a large percentage of experienced and fully licenced (trained) drivers admit to routinely not keeping to the speed limit on motorways, despite being fully aware of what the speed limit is (Health and Safety Executive, 1999). Violations are also sometimes encouraged by peer and organisational pressures / norms, as well as unforeseen organisational incentives. For example, not reporting an injury at work might be associated with staff rewards associated with achieving safety targets / goals.

3.1.4 Performance Influencing Factors

Slips, lapses, mistakes and violations are more likely to occur under certain circumstances. A simplistic way to consider these circumstances is to think about three aspects: that is the individual, the job and the organisation and how they impact on people's health and safety related behaviour. These three aspects influencing human performance are often referred to as performance influencing factors (PIFs). Optimising performance influencing factors will reduce the likelihood of all types of human failure. A further description of PIFs and suggestions of PIFs in the context of air display safety is provided below:

- **Individual factors -** People bring to their job personal attitudes, skills, habits and personalities which can be strengths or weaknesses depending on the demands of the task. Individual characteristics influence behaviour in complex and significant ways. Their effects on task performance can be negative and may not always be mitigated by job design. Some characteristics such as personality are fixed and cannot be changed. Others, such as skills and attitudes, may be changed or enhanced. In the context of air display, these individual factors can include the display pilot's attitude, the display pilot's motivation to display, their experience, their physical and mental health and their level of alertness.

- **Job factors -** Tasks should be designed in accordance with ergonomic principles to take into account limitations and strengths in human performance. Matching the job to the person will ensure that they are not overloaded and that the most effective contribution to the business results. A physical match includes the design of the work environment. A mental match involves the individual's information and decision-making requirements, as well as their perception of the tasks and risks. Mismatches between job requirements and people's capabilities provide the potential for human error. In the context of air display, these job or task characteristics include the aircraft type, cockpit design and characteristics of the working environment such as temperature levels in the cockpit, noise or vibration.

- **Organisational factors -** Organisational factors have the greatest influence on individual and group behaviour, yet they are often overlooked during the design of work and during investigation of accidents and incidents. Organisations need to establish structures and systems which support human performance e.g. competence assurance systems, team structures and supervision. They also need to develop their own positive health and safety culture including a 'just' culture. A 'just' culture enables personnel to speak openly and honestly following an incident. Such openness and honesty enables learning and safety improvement. The culture needs to promote involvement and commitment at all organisational levels. In the context of air display safety, organisational influences are the wider influences on the pilot and the display activities e.g. the regulations, the competence assurance system within which the display pilot sits, maintenance, the environmental conditions and pre-event planning activities.

The framework of PIFs referred to above is simply that - a framework for understanding the factors that can influence human performance. Any one performance influencing factor does not necessarily fall under 'individual', 'job' or 'organisation' but often has elements of all three. One example of this is the topic of work 'transfer of behaviour between aircraft types'. The potential for transfer of behaviour between aircraft types may be influenced by numerous factors including:

- the competence of the display pilot (that is the knowledge, skill, attitude and behaviour of the pilot);
- the aircraft type and the extent of challenge presented by a change in aircraft type; and,
- wider organisational structures and systems which may influence the competence of the display pilot such as the level and nature of pilot supervision and the prevailing safety culture.

3.1.5 Error Paths

The definition of error paths used in this study is the Swiss Cheese Model as shown in Figure 3 (Reason, 2008). This proposes that in any safety system, 'barriers' are placed between the hazard and an unwanted outcome. The 'barriers' are at the individual, job and organisational level, and the better optimised they are to minimise the potential for error, the stronger they are. Weaknesses in barriers cannot be totally eradicated and these are represented by the holes. A 'hole' in each 'barrier' may not on its own result in an unwanted outcome, but if the 'holes' align then an unwanted outcome can occur. The route through the 'holes' represents the error path.

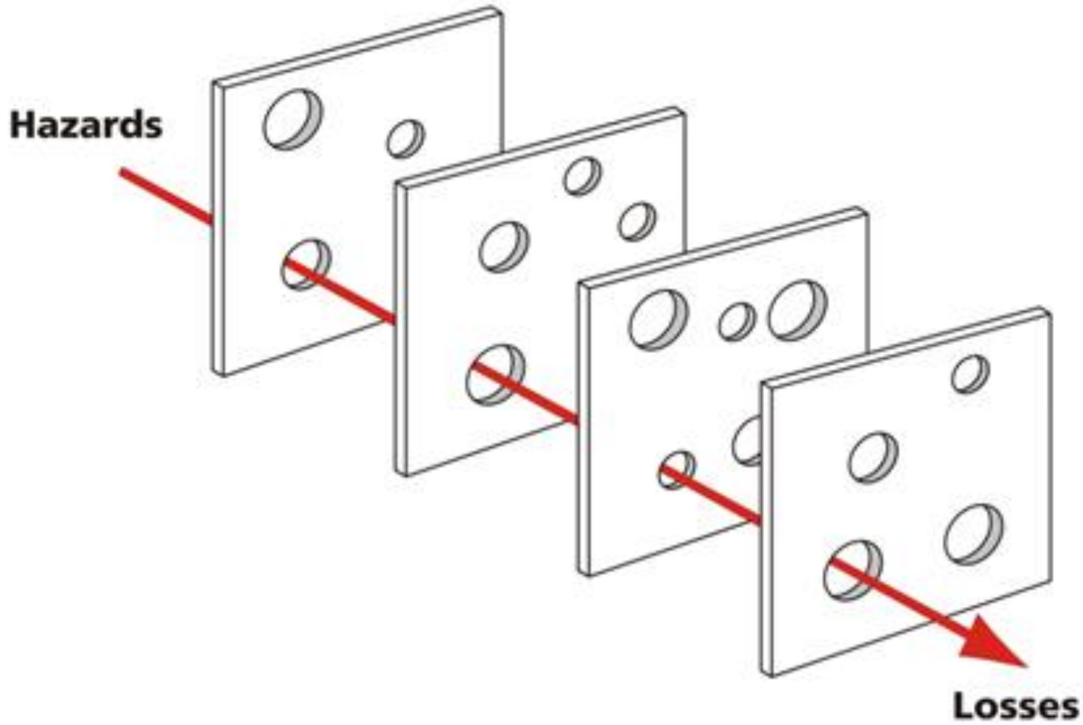

Figure 3 A representation of Reason's Swiss Cheese Model

3.2 NEGATIVE TRANSFER OF BEHAVIOUR

The potential for error resulting from the negative transfer of behaviours between aircraft types is a focus of this study. Why transfer of behaviour occurs, whether this is positive transfer or negative transfer, has been extensively researched within the discipline of cognitive psychology and neuroscience. This section illustrates that the recommendations made in research and industry guidance are often focused on managing error due to negative transfer solely by design. It seeks to recognise that, whilst design changes are not necessarily possible in the context of flying displays, actions can still be taken to minimise error from negative transfer. The actions that can be taken involve the use of strategies that promote a combination of System 1 thinking and System 2 thinking in the management and adaptation to aeroplane type changes.

3.2.1 Positive and negative transfer of behaviour

Transfer of behaviour may be defined as follows:

> *"… all learning but particularly the learning of skills is subject to the effects of transfer of training (effects of past learning on present learning). Equipment and tasks should be designed to provide for as much positive transfer as possible and to avoid the possibility of negative transfer.*" (Morgan *et al*., 1963, p. 28)

Transfer is considered to be positive when there are savings in learning e.g. information in the training period is carried over to the effective performance or learning of the target task; the rate of learning is accelerated, e.g. use of a simulator for training pilots assumes positive transfer. Negative transfer of behaviour can result in learning being slowed but, importantly for the purposes of this study, this transfer or habit interference can result in incorrect operation, accidents and incidents (Wickens *et al.,* 2013).

> *"Relatively small flight deck differences to which the crews were not accustomed…. Differences in controls and displays caused habit interference or negative transfer which resulted in crew errors."* (Braune *et al*., 1989, p.2)

3.2.2 Industry guidance reference to negative transfer

The CAA flight crew human factors handbook (CAP 737) (CAA, 2016a) provides an explanation of negative transfer in the area of aircraft and aviation accident potential. While the focus of this work is air displays, the information provided in CAP 737 is pertinent to all pilots, all types of aircraft and all operational circumstances because, fundamentally, it is about how humans interact with their environment and the influences on their performance. CAP 737 also explains that the first line of defence against error is the system designer:

> *"Work in the 1940s and 1950s by scientists such as Paul Fitts and Alphonse Chapanis helped to establish the idea that aviation design should account for human vulnerabilities. The classic example of that work is the placement and shapes of the gear and flap levers, intended to defend against the human error slip of selecting the wrong lever. Although established over seventy years ago this work is still apparent in all modern air transport aircraft, and is driven by regulation. Other methods of preventing skill-based errors are control guards (e.g. over hydraulic cut off switches), interlocks (gear lever in ground-mode), different shapes and feel of controls (e.g. on autopilot control panels), making controls more difficult to operate (having to pull a switch before changing its selection) and putting controls out of reach where possible (e.g. the IRS mode selectors on an aft overhead panel). Despite such work, errors can still occur… For this reason, as well as attempting to prevent skill-based errors, designers put devices in place to mitigate or alert of consequences. These include alerts, warnings and automatic recovery functions such as reversionary modes." (*Civil Aviation Authority, 2016a, p.49)

In addition to design, operating procedures can be used to alleviate the need for heavy knowledge-based processing (decision making). Procedures can provide a framework of steps for actions or tasks (whether written checklists or memorised mnemonics) but can suffer from rule-based mistakes as well as skill-based errors; for example if a checklist is interrupted and the pilot returns to the wrong place. This has occurred in many accidents, not just aviation accidents. CAP 737 notes that due to the infinite number of situations that can occur, there cannot be an operating procedure to protect against every potential error.

3.2.3 Why transfer occurs

The critical conditions for negative transfer are related to stages of cognitive processing and resource saving (Wickens *et al.,* 2013). From a human performance point of view, it is desirable to be at the skill stage (System 1) due to the reduced attentional demands. At this stage, the less attentional resources the air display pilot has to allocate to the detailed execution of an individual task (e.g. managing energy), the more attentional resources will be available for any other tasks (e.g. attention to the display line). The drawback for having reached this stage of performance level (i.e. being able to perform a task without paying close attention to it) makes the pilot vulnerable to errors if the task is changed in subtle but critical ways (Braune *et al*., 1989). The subtle but critical ways are explained in the following quote:

> *"Classic analysis of transfer reveals that the "red flag" inviting negative transfer results when the similar displays and circumstances between the "old" and "new" system, and also similar, but not identical actions, whereby the latter have very different consequences in the old from the new systems."* (Lyall and Wickens, 2005, p.45)

A classic example of a subtle but critical change may be a change of aeroplane type: when a pilot's autonomous skill has developed or been recently practiced on one aeroplane and the 'new' aeroplane is similar enough to lead to the 'old' skill being used in error (Civil Aviation Authority, 2016a). Negative transfer of behaviour is also more likely to happen when the unexpected occurs such as an engine failure during a display. In such circumstances, pilots may use the wrong gliding speed or use the speed from an aeroplane he / she flies more often.

3.2.4 What can be done to mitigate against error due to negative transfer

Changes in aeroplane type require a pilot to move between System 1 thinking (automatic processing) and System 2 thinking (controlled processing) to help manage and adapt to aeroplane type changes. This is first managed and learnt during the planning and pre-flight of the display. Pilots may exhibit negative transfer of behaviour (e.g. choose wrong speeds and heights) when adapting to a 'new' aeroplane if System 1 thinking only is applied. A main cause of negative transfer of behaviours is when pilots use too much System 1 thinking. Therefore, any strategies that promote moving between System 1 thinking (automatic processing) and System 2 thinking (controlled processing) to help manage and adapt to aeroplane type changes appear to be where there is greatest potential for mitigating against error due to negative transfer from change in aeroplane type. These strategies may be individual strategies employed by the pilot but may also have dependencies on 'organisational' processes/structures being in place to support them.

3.2.5 Impact of Negative Transfer in other Industries

The safety issues associated with negative transfer are not specific to pilots and aircraft. The examples below from other industries suggest that the potential for negative transfer can be reduced by standardisation of design, experience and training and 'slowing down', from System 1 thinking to System 2 thinking.

The impact of negative transfer on human action has been quantified as part of the research underpinning the Human Error Assessment and Reduction Technique (HEART) (Williams, 1985; Bell and Williams, 2017). HEART is a human reliability assessment technique developed to help risk analysts and designers identify and quantify the major influences on human performance and the likelihood of error, in a systematic and repeatable way. It is based on the general principle that for each task in life there is a basic probability of failure that can be assessed within probabilistic limits. Affecting each of these tasks are varying levels of Error Producing Conditions (EPCs) (similar to PIFs) that can influence human reliability. Since its development in the 1980s, HEART has been used to provide meaningful insight into human error in the healthcare, rail, aviation, nuclear, process and offshore engineering industries.

The method has been consolidated recently by drawing on the last 30 years' Human Factors Literature (Bell and Williams, 2017). HEART indicates that a person can be:

- up to six times more likely to make an error if they have to unlearn one technique and apply another (e.g. a light switch in the UK works in entirely the opposite way to a light switch in the USA), and
- up to approximately eight times more likely if the spatial and functional information provided does not conform to stereotypical function (e.g. the universal expectation that by pushing a joystick to the right, a user would produce a rightwards movement of some sort).

Both 'technique unlearning' and the 'conveying spatial and functional information' are forms of negative transfer.

Construction and general access

Investigation of and research into the operating characteristics of mobile elevated work platforms (MEWPs) has highlighted the impact of negative transfer based on learned behaviours (HSE, 2013). MEWPs are used across all sectors, particularly for temporary work at height such as construction and maintenance activities; incorrect operation by users can result in serious injury and death, by entrapment. Previous experience with a particular model of MEWP and its control configuration, can impact the use of a similar but different MEWP.

Slips in MEWP operation have included selecting the wrong control on the panel or moving the control in the wrong direction to that intended. Lapses have included forgetting to operate the toggle between drive and height modes on a scissor lift. Slips and lapses in the context of MEWPs are typically associated with a demand on attention elsewhere, such as concentrating on a particular obstruction or focusing on the work location. The researchers stress the importance of effective training to address, for example, incorrect operation of controls, not just on a class of machines but on specific models, given the variation in designs. A key recommendation was to reduce accident potential by using a standardised ergonomics approach to user interface design amongst manufacturers. This was to help the novice operator learn with fewer errors and help the experienced operator to adjust between different machines.

Medical

A published collection of stories from health care providers, describes incidents of medical error to illustrate how the systems approach serves as an effective tool for understanding errors and accidents in health care. One example is of a fully trained, experienced and motivated anaesthesiologist, who, 'lost' a patient in an emergency situation, in part because they were unfamiliar with the specific anaesthesia machine; they were unaware that the auditory alarms had been disabled (Bogner and Mahwah, 2004).

Road

In driving behaviour, general abilities are considered basic prerequisites for the safe manoeuvring of a vehicle including; ability to turn a steering wheel and operate pedals with speed, strength and precision. However, the driving of a vehicle in traffic demands a complicated interplay between sensory, motor, intellectual and other higher mental functions. Much of driving is characterised by activities involving basic control of the vehicle, such as maintaining appropriate speed, headway, and lane position within surrounding traffic. These activities require relatively few mental resources and allow drivers to engage in other mental activities simultaneously without noticeable detriment to the driving task (Ranney *et al.,* 2000).

Examples of negative transfer often arise when moving from one type of car to another. Most European cars have the direction indicator and light controls to the left of the steering wheel with the windscreen wiper switches on the right. On Japanese cars these locations tend to be reversed. Drivers tend to 'slow down' (move to System 2 thinking) and notice such contextual changes so that they do not prove detrimental to the driving task.

4 FINDINGS: HUMAN PERFORMANCE IN AIR DISPLAYS

4.1 INCIDENT REPORTS

The ‘incidents’ information collated in this study took the form of a sample of FDD reports sent to the CAA in 2017. A review of these reports showed that in 2017 there were a total of seven ‘too low’ calls, seven ‘too close’ calls and two ‘terminate calls’ across five different airshow locations.

It was evident from the further information provided by FDDs in the reports that deviation from expected minimum height requirements occurred across a number of different sites / locations and was not an uncommon occurrence. The information provided in FDD reports was variable. Many reports had very little information. One report that provided further explanation on why an incident may have occurred explained that misunderstandings may have taken place due to differences between CAA and Military Aviation Authority (MAA) regulations. Provision of explanations as to why incidents may have occurred makes it possible for safety improvements to be made.

4.2 ACCIDENT REPORTS

A high level review of a sample of accident reports was conducted to identify any common human factors issues that have contributed to air display accidents. Table 2 in Appendix B shows some of the human factors contributory factors noted in accident report analyses / conclusions for a sample of fatal or serious air display accidents between 2007 and 2015.

The processes related to the assurance of the competence of air display pilots was a recurring factor highlighted in previous accident report analyses / conclusions. A number of different aspects related to competence assurance have been highlighted. These included:

- training, guidance and development (e.g. the guidance and training received by the Hawker Hunter pilot in relation to escape manoeuvres);
- supervision or mentoring (e.g. in the North American Rockwell accident and the Extra 300 accident). Comments in one report highlighted how not being part of a larger organisation can be a disadvantage for mentoring or supervision opportunities;
- current practical experience (e.g. currency on type in the Hawker Hunter accident and the Folland Gnat accident);
- requirements and guidance related to the assessment and reassessment of competence associated with the issue and renewal of DAs (e.g. in the North American Rockwell accident and the Extra 300 accident).

The performance influencing factors of fatigue, stress, workload and pressure were also raised as possible factors that have influenced accidents. The importance of clarity of communication in pre-event planning and briefing was also highlighted.

It is of note that, in the small sample of accident investigations reviewed in this study, there appeared to be variation in how extensively human factors expertise was utilised. The Hawker Hunter accident report contained a separate human factors study (Air Accident Investigation Branch, 2017). This report was the only report (in the sample of reports reviewed in this study) to raise the possibility of negative transfer of behaviours as being a possible contributory factor. It included hypotheses that (i) the visual scan pattern used during the incident may have been influenced by the pilot's experience in other aircraft and (ii) the gate heights used by the pilot may have been influenced by the pilot's experience in other aircraft (Air Accident Investigation Branch, 2017). Other reports explained that human factors experts were consulted (Air Accident Investigation Branch, 2011) or did not refer to human factors expertise in the report (Air Accident Investigation Branch, 2014).

4.3 PERFORMANCE INFLUENCING FACTORS IN AIR DISPLAY: CONSULTATION WITH THE DISPLAY COMMMUNITY

As previously described, a simplistic way to consider the circumstances which influence the likelihood of error during air display is through consideration of individual, job and organisational factors that may influence the performance of the air display pilot. Optimising performance influencing factors will reduce the likelihood of all types of human failure.

One of the key influencing factors considered in this work was aircraft type and the potential for transferring behaviours between aircraft type. Given this was a key objective of this work, this factor will be discussed first. Section 4.3.1 provides a summary of findings from interviews with the display community when they were asked about operating and handling differences between different types of aircraft and the potential for negative transfer of behaviours. Section 4.3.2 provides a summary of findings on the individual mitigation measures employed by pilots. Section 4.3.3 summarises errors and other key performance influencing factors described in interviews with the air display community.

In order to maximise the research outcomes, the work focused on aeroplanes and, specifically, Single-Engine Piston (SEP) aeroplanes, categories A, B and C and Jet-Powered (JPs) aeroplanes categories G1, and G2, as defined in CAP 403 (Civil Aviation Authority, 2018, see Table 4).

Table 4 Categories and Groups of SEPs and JPs as defined in CAP 403 (Civil Aviation Authority, 2018)

Category	Group
	Single-Engine Piston (SEP) Aeroplanes
A	Less than 200 hp
B	Between 200 and 600 hp
C	Exceeding 600 hp
	Jet-Powered (JP) Aeroplanes
G1	Straight wing single engine jet aeroplanes specified by type
G2	Swept wing single engine jet aeroplanes specified by type

Findings from interviews identified handling and operating differences between and within these aeroplane types and categories.

4.3.1 Aeroplane Type – Handling and Operating Differences

Handling Differences

Findings from interviews indicated some examples of differences in handling between aeroplane types and categories, primarily due to energy management.

There were a number of examples provided of differences in handling between types within the SEP category C, aeroplanes exceeding 600 hp. For example, one pilot described differences between a Sea Fury (SEP C) and Harvard Texan (SEP C): there was a need to maintain energy in the Harvard ("*it's an aeroplane that is losing energy*") and this was not required for the Sea Fury. One of the implications of this was that there were manoeuvres carried out in the Sea Fury that were not carried out in the Harvard. Another pilot described differences between a Spitfire Mark 5 and Spitfire Mark 9. The differences between two types of Spitfire were described as being mostly about engine husbandry - the Spitfire Mark 5 overheated twice as quick (given it only had one radiator) whereas the Spitfire Mark 9 had two radiators and this meant less energy management was required.

There were a number of examples provided of differences in handling between aircraft in different categories within the SEP aeroplane group. For example, differences between a Chipmunk (SEP A) and a Spitfire (SEP C) were described by one pilot as follows - handling in the Chipmunk was easier and there was less to go wrong in the Chipmunk relative to the Spitfire. The Chipmunk was described as being "*all about energy management*" whereas in the Spitfire the pilot described being focused on not losing height. Another pilot described handling differences between a Piston Provost (SEP B) and a Harvard (SEP C), and talked about how the Provost, with lower horsepower, took a lot more energy management: "*it is very draggy and loses height during the display so you are limited to two vertical manoeuvres, maybe three..*" whereas it was considered easier to maintain vertical manoeuvres in the Harvard.

Similarly, in the JP group, differences in handling between types of aeroplane within the G1 category (straight wing single engine piston aeroplanes specified by type), were described. One pilot described differences between a Jet Provost Mark 3 (G1), a Jet Provost Mark 5 (G1) and a Strikemaster (G1). With a Jet Provost Mark 3, the pilot described that the throttle can be set to 95% and left there. Whereas with a Jet Provost Mark 5 and a Strikemaster, the pilot explained that it was important to bring the throttle back and that it was not possible to select fixed power with the Strikemaster and a Jet Provost Mark 5.

A number of pilots also discussed how differences in handling were required because of the use of different metrics within and across aeroplane types and categories – these may be in miles per hour (mph), nautical miles per hour (knots), or kilometres per hour (km/h). This was not viewed as problematic for them. One pilot commented that when learning to fly the Spitfire, they had not noticed any impact of a change in units between the 'old' and 'new' aeroplane given the similarity between knots and km/hour until it was highlighted by a colleague.

A number of pilots explained how the principles in handling were essentially the same regardless of aeroplane category or type and that the differences that were required were due to energy management for a particular aeroplane and achieving the required parameters (e.g. speed on entry, height on entry etc.) specific to that aeroplane.

Operating Differences

Findings from interviews indicated some examples of differences in operating between aeroplane types and categories due to different aeroplane design.

There were a number of examples provided of operating differences between types within the SEP category C, aeroplanes exceeding 600 hp. A number of pilots discussed a key operating difference when converting to the Spitfire. Pilots commented that throttle friction was a key operating difference given the need to change hands. Some pilots described how checklists/flight communication cards highlighted that throttle friction needed to be "*done up tight for take-off to trap the problem*". A second example of an operating difference between the different types of aeroplane within the same category (SEP C) related to a Hawker Hurricane and a Spitfire Mark 5. One pilot explained that with these two aeroplanes "*the landing gear goes down at different times*" - at the beginning of the downwind leg for the Hawker Hurricane and the end of the downwind leg for the Spitfire Mark 5.

Another example of an operating difference between aeroplane types was discussed by a pilot who flew a Spitfire Mark 9 and wanted to re-familiarize with a Spitfire Mark 19. The Spitfire Mark 9 was a training variant and had a second seat and there were variations between the aeroplane types related to cockpit layout. In particular, there were differences in the flap position between the Mark 9 and the Mark 19. Following a flight with the Mark 19, the pilot described that upon landing, they had intended to raise the flaps but raised the undercarriage instead. The pilot explained that one possible reason for this choice of action may have been related to prior experience with the Chipmunk. In the Chipmunk the flap control was in the same position, however having not flown the Chipmunk for several months was unsure whether this factor played a part. The pilot explained that other reasons for these actions may have been related to arousal levels and increased stress due to noise from an ill-fitting helmet.

Views on operating differences were also apparent between SEP B (Yak 50) and SEP C (Mustang). For example, one pilot spoke about a key operating difference related to canopy design. The pilot described how this difference was highlighted when engine failure occurred in the Mustang. The pilot "*did the procedure for the Yak in terms of what to do with the canopy which is not what you are supposed to do in the Mustang*."

Comment on the potential for negative transfer of behaviours between aeroplanes

The display community were asked about their views regarding the potential for transfer of behaviours between aeroplanes, based on their extensive display flying experiences. It is noteworthy that several interviewees had experience of flying numerous types of aeroplane (i.e. some had experience of flying over 100 different types of aeroplane because of their background as test pilots). Findings are summarised below.

There is potential for negative transfer of behaviours between types and categories of aircraft – all interviewees perceived that there was always the potential for negative transfer of behaviours between types and categories of aircraft simply based on the observation that all human behaviour is subject to error at any time due to a number of potential influencing factors. Some interviewees highlighted that the potential for negative transfer of behaviours may be greatest under certain conditions:

- with aeroplanes of the same type (and therefore aeroplanes that are most similar in design) and / or
- when the unexpected occurs (e.g. an engine failure) and/or

- in the phases of take-off and landing because of operational differences between categories and types of aeroplanes.

Whilst all interviewees acknowledged the potential for negative transfer of behaviours and were mindful that flying different aeroplane types adds complexity, they also added that was not necessarily an issue because problems arising from negative transfer of behaviours were (a) often recoverable and (b) normally mitigated by a number of measures.

4.3.2 Mitigation measures for negative transfer of behaviours between aircraft

Display pilots and stakeholders described numerous mitigation measures that they employed to reduce the probability of any human error including negative transfer of behaviours between aeroplanes. Throughout all discussions, the importance of attitude and mindset pre-display, during display and post display was highlighted. This was described as a "*rigorous attitude on the part of the pilot*" or being "*thirsty for knowledge*" on display day. Others, particularly those with a military background, talked about how beneficial it was to have been taught to have a "*critical mindset".* The individual mitigation measures employed by pilots may be categorised as pre-display day, during display and post-display measures though there was some overlap on when these measures were employed.

Pre-display day mitigation measures

Maintenance of currency to ensure aeroplane familiarisation
A number of pilots talked about the importance of currency to ensure familiarisation with aeroplane type pre-display day. In doing so, pilots talked about the importance of using their practice display to deliberately mishandle some aerobatics and practice engine failures in order to remind themselves what steps to take if they experienced an engine failure or they inadvertently mishandled the aeroplane (e.g. mistakenly "*pull too hard*") during a display. One pilot talked about the importance of doing touch drills for all phases of the flight and not just a phase that they were most concerned about. Views on currency are further discussed in Section 4.3.3.

The importance of refreshing on aeroplane limitations was highlighted by several pilots. This was carried out by many the night before and / or again on the day of the display and recognised as a key element to help pilots with their recent experience on that aeroplane. Some pilots mentioned use of a self-administered essential knowledge quiz (EKQ) which was used as a reminder of aeroplane limitations and to help to ensure emergency drills did not get crossed over between aeroplanes.

Peer review / Supervision and discussion of display practice
Supervision of display was mentioned as a critical factor by some. One pilot highlighted that this was particularly important as it helped to mitigate against a pilot getting into risky behaviour without realising it. Another pilot commented on the value of peer to peer critiques of their routines; it forced them to consider aspects of their display that they may not have done otherwise.

Another pilot made a point of talking through any handling differences with a senior colleague contrasting any handling differences between the aeroplane being displayed and the aeroplane flown in their day job.

Planning and Assessment – time and weather considerations

All pilots talked about the importance of their own planning in advance of display day, weeks ahead and the night before their display event. This involved numerous considerations and actions including ensuring communications with the FDD, highly specific plans around scheduling, assessment of weather considerations, the potential impact of weather on their planned display and the planning of specific manoeuvres appropriate to aircraft type.

Display day mitigation measures

Ensuring sufficient quiet time pre-display

Several pilots talked about the importance of having enough quiet time alone (e.g. *"a 40-minute bubble"*) pre-display that was free of distractions (e.g. phones or greeting others) to allow them to think through their display.

Visualisation / Walkthroughs

Almost all pilots talked about using visualisation of their display or 'walking through' their display the night before and / or on display day before the display. Some described this as going out into the hangar to walk through their display, others described sitting under their aeroplane and closing their eyes. Visualisation involved thinking through a number of aspects:

- the intended aerobatic sequence;
- the display line, and
- the avoids.
- potential emergencies *("the what ifs"*);
    - what to do in the event of engine failure;
    - visualising where would be the worst place in a sequence to fail;
    - what to do to get back on the ground safely; and
    - going through escape manoeuvres for every aerobatic manoeuvre.

Cockpit re-familiarisation, checks and adaptations

Some pilots talked about how they routinely did a cockpit scan from left to right as standard practice to check instrument location and ensure gauges can be read and interpreted correctly. For some, this was also followed by use of mnemonics. Some pilots mentioned use of what they referred to as a standard aviation mnemonic, 'BUMPFITCH', for pre-take off checks, downwind checks and landing checks. One pilot described using this mnemonic but adapting it slightly for different aeroplanes:

- B for brakes (hydraulic and pneumatic pressure);
- U for undercarriage;
- M for mixture (one of the controls on the engine) and M for magnetos (to make sure they are on);
- P for propeller;
- F for fuel flaps;
- I for instruments (altimeter and engine instruments);
- T for trim, throttle friction and tail wheel lock;
- C for carb heat, cowl flaps and coolant; and,
- H for hatches and harness.

Aspects such as tail wheel lock and coolant were added when moving from flying one aeroplane type to a second type of aeroplane. Throttle friction was also an addition and that was included for the bigger engine aeroplanes.

One pilot remarked on how modern cockpits have limitations marked on them with different colours but older cockpits did not. To assist with remembering aeroplane limitations and parameters, this pilot described using a red wax pencil to draw limitations on instruments (e.g. glide speed if the engine stops).

Use of kneeboards / flight communication cards (also referred to as flight reference cards)
A number of pilots explained that they used A5 size kneeboards with checklists or flight communication cards with safety critical information easily accessible to them during their display.

Some interviewees described how their organisation produced their own flight reference cards / checklists on kneeboards for all aeroplane types and that these were made available on Dropbox for all pilots to access. These checklists contained various information; the front page contained information that the pilot may refer to during flight if required and included all engine and aeroplane limitations for that specific aeroplane along with appropriate operating air speeds and vital actions before take-off. The second page included a cockpit brief and provided initial settings describing where the controls were, how they work and how controls were labelled and a starting procedure. Other information included hints and tips on the performance of that aeroplane, a summary of handling qualities and if the aeroplane was cleared for aerobatics, key display parameters such as entry speeds were also included.

Situation awareness - visual, kinaesthetic and auditory sensory feedback
In the descriptions provided by interviewees of operating and handling differences between aircraft types and categories, pilots described how fundamental differences in visual, auditory and kinaesthetic sensory feedback between different aeroplane types and categories provided them with continuous feedback on their situational awareness.

A number of interviewees explained that during their display their flying technique involved use of various external visual references - pilots explained that they looked out of the window much of the time eyeballing height and line with occasional glances into the cockpit to pick up instrument readings (e.g. airspeed, altimeter). Pilots commented on the importance of this external visual feedback particularly when learning to display new aeroplane types (e.g. learn that "*ground closure is much faster*" in the Spitfire relative to the Yak). Comments were also made in relation to altimeters and how reliance on them would be misinformed as they are not always accurate.

Pilots talked about the importance of kinaesthetic feedback, feeling the gravitational force (G) of an aeroplane during the display and how it was possible, with experience, to make good estimates on how much G you are pulling without a G-meter. The physical effort required to fly an aeroplane was also mentioned with some aeroplanes perceived as requiring light physical effort ("*almost by fingertip*") and others "*a bit hard work*" and this aspect was perceived by one pilot as "*an immediate discriminator*" between aeroplanes.

Auditory feedback was also described as key to sensory feedback – several pilots commented on how some aeroplanes were much noisier (e.g. the Spitfire was considered a much noisier aeroplane relative to other SEPs) or how a change in headset means that perception of noise was altered and required time to adapt to this altered sensory feedback.

Post-display Mitigation Measures

Reviewing your own the display for continuous improvement
One pilot made a point of filming all their displays. The purpose of this was to enable review of the films afterwards to check positioning of the aeroplane, identify any deviations from the intended plan, and to understand how to rectify that for future displays.

4.3.3 Insight into errors and performance influencing factors in air display

Display pilots were asked for their general views and comments on any errors they had experienced during displays (not necessarily errors that perceived as only being related to a transfer of behaviours issue) and the factors they consider are most likely to influence error.

Examples of errors

A number of different errors were mentioned that have occurred within display time and during take-off and landing. In relation to errors during display time, these included the following:

- Some pilots mentioned that they have, on occasion, not checked instruments (for gate height and speed) at points in their display and gave different reasons for this. One pilot commented that he was aware there have been times when he should have checked instrumentation more and commented that the reasons for not doing so was because he knew the aeroplane "*by feel and from looking outside whether the picture was right*". Another pilot commented that on occasion when a gate height had not been checked the reason for this was because the entry at manoeuvre had been so high on energy that it didn't seem necessary to check;
- Some pilots commented that they have had to reposition during a display. The reasons given for this were because they had over-rotated, or the aeroplane "*doesn't feel right*";
- One pilot commented that misreadings do happen but they are rare and one would have to misread on more than one instance for it to have a critical impact.

In relation to errors during take-off / landing, these included:

- Mis-setting the pressure setting on the altimeter. One pilot commented that they did not perceive that as particularly problematic because he was not relying solely on one instrument;
- Upon take-off, some pilots commented that they had not got the throttle friction set up high enough but were able to recover from this without it proving to have much impact;
- One pilot commented that when landing they found themselves thinking "*Did I put the gear down?*" Given they could not be certain they "*put the power on and went around again*".

Performance Influencing Factors in Air Display

It was evident from interviews with both display pilots and expert stakeholders that they perceived that display pilot performance in how to respond, monitor, learn and anticipate during a flying display was influenced by numerous contextual factors, that is, numerous organisational, job and individual PIFs. A number of factors were highlighted by interviewees from the display community as possible contributors to error and these included:

Currency

Currency was regarded by many interviewees (display pilots and expert stakeholders) as one of the most significant factors influencing the likelihood of error in display flying. As one pilot commented, "*insufficient rehearsal could lead to anything*". A number of important points were raised by interviewees in relation to currency:

- It was evident that a number of interviewees perceived the minimum regulatory requirements on currency as a bare minimum and commented that a sensible person would do more than the minimum requirements, as highlighted in CAP 403. Those who commented on this were very mindful of the practicalities and cost associated with this i.e. getting access to aeroplanes and the cost of doing so. Some commented on how certain organisations and airshows required their pilots to do more than the minimum requirements with some stipulating that there was a requirement to be observed displaying and tracked, without the crowd present, the week before certain airshows;
- Many interviewees highlighted how military display requirements were more strict relative to civilian display requirements and how military rules become more stringent if military display pilots did not meet certain currency requirements i.e. they had to raise their base height when they displayed;
- A number of interviewees highlighted the importance of having recent experience. One interviewee highlighted that a key factor was whether a pilot had flown an aeroplane recently proportionate to their understanding of that aeroplane and that this was not necessarily a straightforward judgement to make. Some pilots suggested that it may be advantageous to increase the number of required displays in the four to six weeks before an actual display but keep the overall minimum requirements (i.e. three complete displays within 90 days of display date) the same;
- Another point, made by many related to what a pilot does to achieve currency. For example, one pilot commented "*when is a display a display, you can get airborne, land and claim a display*…" Other interviewees highlighted that the currency discussion was often too focused on hours flown and that this was not necessarily a good indication of experience, the most important consideration was the actual experience in those hours;
- Challenges associated with checking the validity of currencies declared by display pilots was mentioned. For example, when a pilot declared a recent airshow that was cancelled (e.g. due to poor weather), the airshow organiser / FDD had to check back on whether the declared currency was still valid.

Time pressure

Time pressure on display day was a factor mentioned by many display pilots; the need to meet your take-off time, display slot time and landing times, and fuel being late, were all cited as influences. Some pilots commented on how time can become pressurised because people want to greet you at airshows and talk about your aeroplane. One pilot commented that with greater experience, management of time had become easier because they had learnt to be more assertive with those looking for attention just before a display. Time planning was described as particularly critical by jet pilots because of a need to be extremely fuel conscious.

Managing distractions

Pilots described numerous distractions that need to be managed during display flying. A key source of distraction may be changes in weather. Several pilots emphasised the importance of planning and reviewing their display in relation to the weather with wind being a significant factor requiring consideration pre display, particularly an aerobatic display. Distractions can be numerous and related to people wanting to talk to you pre display, changes in the airshow programme, a poor briefing, and loose articles in the cockpit.

Allocation of attention during display – stresses and compliance pressures

Some pilots talked about the potential influence of stress during a display and how that may impact on their ability to allocate attention in display time. A number of sources of pressures and stresses were mentioned relating to personal stress and due to physiological conditions in the cockpit (e.g. hot cockpits in warm weather, issues with auditory feedback due to ill-fitting headsets). Some pilots highlighted that there were anxieties in the display world particularly related to compliance pressures due to a number of recent changes in display flying rules. One pilot commented that because of the pace and timing of regulation changes, pilots are now so worried about breaking the rules (e.g. breaking the display line, going below height) that this could be detrimental to safety.

The 'thousandth hour mark'

A small number of interviewees remarked on the dangers of the "thousand hour mark" on an aeroplane; at this point a pilot may have become very competent and comfortable on type and "*knows everything about this aeroplane*" so may start to relax to the point where slips and lapses occur.

Pressure to display

Some interviewees commented that pilots may feel pressure to display. This may be from pilots putting pressure on themselves or pressure from various other external sources. Interviewees explained it can be related to whether the pilot was being paid to display, whether they owned the aeroplane and / or whether they fly for a particular organisation. A couple of different scenarios were described by interviewees and these represented variations in safety culture across the display community.

In one scenario, display pilots were described as volunteers who fly for an organisation and because there they had no financial interest in the aeroplane, they did not feel under pressure to display the aeroplane. In such organisations, it was understood that a pilot did not have to display and they were rewarded if they raised safety concerns. Furthermore for pilots visiting such organisations, were given the same clear messages and if they did not display, for whatever reason, on the day, they would still be paid.

The other scenario described was where pilots own their aeroplane, and may put pressure on themselves and / or they may feel pressure from other sources to display despite concerns regarding weather or otherwise. As one interviewee commented, "*there are examples of pressurising pilots to fly when they are not comfortable to fly".*

Pilots may, particularly in earlier stages of their career, feel that they don't want to let people down, they may not get paid and / or they don't want to get a reputation for not turning up for fear they may not be asked to display again. The financial 'agreement' between the pilot and the airshow organiser was described as often being based on trust and an expectation that the pilot will be paid after the event.

Potential for bias to influence display manoeuvres
Some pilots commented that display manoeuvres performed in a display may be subject to a continuation bias; the inherent desire to complete a manoeuvre as planned.

Performance influencing factors relating to the wider display community

Expert stakeholders were also asked for their views on some wider organisational aspects of display flying including the DAE, the FDD's role and responsibilities and any other views on airshow event organisation. Perceptions on these aspects were wide and varied and are summarised below:

DAE activities, roles and responsibilities
The role of the Display Authorisation Evaluator and the Display Authorisation Evaluation process was described as a key role in ensuring display pilots were suited to display flying in terms of their attitude, skills, behaviour and knowledge.

Some interviewees commented on how recent changes to the process whereby a display pilot was not permitted to have the same DAE conducting their revalidation for more than two consecutive years, were good changes for the industry. Interviewees commented that this provided more rigour to the process and helped avoid the potential conflict of interest that may be present when a DAE and a display pilot know one another. However, some highlighted that this can present challenges and one of these was that it can be difficult to find an available DAE. Another pilot highlighted that this process meant they could be examined by someone who had less knowledge of the aeroplane type. Questions were raised as to whether it was better to be evaluated by someone who is known to the pilot and has good knowledge of the aeroplane type, or one that is not known to the pilot but has less knowledge of the aeroplane type.

It became evident in interviews, that significant changes to the responsibilities of a DAE were being considered by the regulator. A DAE standards document, recently produced by the CAA has set down new expectations regarding the responsibilities of the DAE. This document was sent to DAEs for comment. Whilst the document was described by one interviewee as "*well-intended*", it has raised a number of questions. One question related to the benefits of the proposed change in the role of the DAE i.e. that there will be a requirement for DAEs to grade display pilots and share this information with the CAA. There was a lack of clarity about whether DAEs were expected to work in accordance with this document - it was issued as a draft but there was a lack of clarity about whether it was applicable in this display season. As part of this discussion, one interviewee suggested that a potential improvement to the DAE standards document would be to require one DAE to train a pilot and a separate DAE to evaluate the pilot.

FDD activities, roles, and responsibilities
Interviewees thought that the recent requirement for FDDs to gain accreditation through training and demonstrate currency requirements were beneficial changes. Some interviewees highlighted that they would like to see more opportunities for new FDDs to be mentored and include more practical elements into the training course e.g. applying the theory learnt on the training course to the practice of the FDD role at an airshow.

Some interviewees perceived that there was quite a variation in the content and delivery of display briefs provided by FDDs. One interviewee suggested that there may be benefit to standardisation of the brief to ensure all pilots get the same information albeit different in depth and quality of delivery. There was also reported variability in the use of a post display debrief and whether it was on a formal or informal basis.

Event Organisation

A number of interviewees commented that events can vary considerably in how well they are organised and how much consideration is given to ensuring pilots feel at ease on display day. These included a number of considerations: making sure pilots have plenty of rest, that pilots have rest areas, that transportation is appropriately considered. These elements were considered by interviewees to have the potential to influence the pilots' mindset and therefore pilot performance on display day.

Role of the Regulator

Some comment was made on the role of the regulator and how changes could help to reduce the organisational role in error paths. One interviewee suggested that the display community should have a delegated role in administering safety regulations because specialist knowledge is required and this expertise was not available within the CAA. Under a delegated system of administration and responsibilities for display authorisation, a structured system could be introduced; the introduction of specific safety management systems would be a way for the display community to demonstrate to the regulator that they are managing safety. This suggestion is one of many that the CAA could consider as part of a continued consultation with the display community.

5 ANALYSIS

This study has provided insight into human factors issues associated with air display accidents with a focus on the potential for negative transfer of behaviours between aeroplane types. It has drawn on findings from incident (FDD) reports, accident reports and interviews with the display community including display pilots and expert industry stakeholders. This section provides analysis and a list of recommendations. The rationale for each recommendation is provided throughout this section. The ten key recommendations from this study are highlighted.

5.1 INCIDENT REPORTS

Analysis of FDD reports showed that in 2017 there were a total of seven 'too low' calls, seven 'too close' calls and two 'terminate calls' across five different airshow locations.

It was evident from the further information provided by FDDs in the reports that deviation from expected minimum height requirements occurred across a number of different sites / locations and was not an uncommon occurrence. The information provided in FDD reports was variable. Many reports had very little information. One report that provided further explanation on why an incident may have occurred explained that misunderstandings may have taken place due to differences between CAA and Military Aviation Authority (MAA) regulations.

It is noteworthy that the provision of further information in FDD reports, on why incidents occurred, can enable lessons to be learnt. This underlines the importance of FDD discussions with pilots post display, provision of feedback and reporting from air displays.

Recommendation 1: CAA should work with FDDs to improve the quality and quantity of reporting and feedback provided by FDDs following airshows. CAA should also consider ways in which this information can be shared across the display community. Sharing information from FDD reports on why incidents occurred and actions that have been, or can be, taken to prevent further similar incidents would be of benefit to the entire display community.

5.2 ACCIDENT REPORTS

The processes related to the assurance of the competence of air display pilots was a recurring factor highlighted in previous accident report analyses / conclusions. Table 2 in Appendix B shows the human factors contributory factors noted in accident report analyses / conclusions for a sample of fatal or serious air display accidents within the last 11 years in the UK. A number of different aspects of competence development have been highlighted. These included:

- training, guidance and development;
- supervision or mentoring (comments in one report highlighted how not being part of a larger organisation can be a disadvantage for mentoring or supervision opportunities);
- current practical experience;
- requirements and guidance related to the assessment and reassessment of competence associated with the issue and renewal of DAs.

The PIFs of fatigue, stress, workload and pressure were raised as possible factors that have influenced accidents. The importance of clarity of communication in pre-event planning and briefing was also highlighted.

Based on the small sample of reports reviewed in this study, there appeared to be variation in how extensively human factors expertise was utilised in accident investigations. Some reports included reference to the use of human factors expertise and others did not. Applying human factors expertise to a wider range of incidents will likely help strengthen industry learning on error reduction/ performance enhancement. Such an investigation approach should be applied to high potential incidents, as well as those resulting in near misses, or less serious incidents. This would enable deeper and broader learning to help reduce the likelihood of high consequence events.

From a human factors perspective, it is considered good practice to promote a 'just' culture, which enables openness and honesty during the investigation process. This same principle is advocated for all levels of the display community. It is important that pilots and other personnel can speak openly and honestly following an incident. This would support learning and safety improvement.

Recommendation 2: CAA and AAIB should promote more consideration of human factors in accident investigations through application of human factors expertise. This would enable deeper and broader learning to help reduce the likelihood of high consequence events.

5.3 OPERATING AND HANDLING DIFFERENCES

Based on interview findings, it was evident that there were a number of operating and handling differences identified between and within types and categories of SEP and JP aeroplanes. Consistent with the scientific literature, pilots reported the potential for negative transfer of behaviours is greatest under certain conditions:

- with aeroplanes of the same type (and therefore aeroplanes that are most similar in design) and / or
- when the unexpected occurs (e.g. an engine failure) and / or
- in phases of take-off and landing because of operational differences between categories and types of aeroplanes.

There were only two examples of incidents, described by pilots, which could be attributed to negative transfer of behaviours. One example related to the raising of the undercarriage rather than flaps and another related to actions taken in response to an engine failure.

All interviewees acknowledged the potential for negative transfer of behaviours and perceived that, whilst flying different aeroplane types adds complexity, it was not necessarily considered an issue. Many perceived that problems arising from negative transfer of behaviours were a) often recoverable and b) normally mitigated by a number of measures.

It was evident that there is extensive knowledge within the display community (that includes display pilots, FDDs and DAEs) in relation to operating and handling differences between aeroplanes in the context of air display. New human factors training could play an important role in providing an opportunity to enable this sharing of knowledge and experience. Given there is limited opportunity for the community to meet and share experiences in learning, it would likely be beneficial if this training included various methods of learning / knowledge sharing e.g. online and face-to-face methods. It is noteworthy that other critical support roles and management roles would also benefit from human factors training, in order to support a more holistic / systematic approach to enhancing safety for air displays.

Recommendation 3: Implementation of human factors training - CAA should develop a human factors training programme based on knowledge sharing techniques to ensure there is an exchange of expertise across the display community. Engaging with the display community as a resource could bring about improvements in safety practices far beyond traditional training.

Recommendation 4: Methods for human factors training - CAA should consider a blended learning solution comprising a combination of self-taught learning and reflection, online learning and face-to-face training, delivered in a modular format.

Recommendation 5: Training participants – All display pilots, not just those flying multiple aircraft, should be required to participate in the proposed training programme. This includes pilots seeking initial display authorisation and display authorisation renewal. The inclusion of other critical support and management roles in training is also recommended in order to support a more holistic / systematic approach to enhancing safety for air displays.

Recommendation 6: Processes to keep training current and maintain involvement - To further facilitate the transfer of learning, CAA should work to set up a community of practice to help ensure that the taught elements of the training are embedded into long term practice and delegates can share their own expertise of undertaking piloting displays. This could serve as a repository for human factors references and relevant information.

5.4 STRATEGIES TO REDUCE ERROR POTENTIAL

In order to reduce the potential for error (including error due to negative transfer of behaviours between aeroplane types), pilot attitude and mindset, and the planning and preparation phase of an air display are critical. Interviewees stated that planning and preparation involved a number of strategies that were used months and weeks before display day, on display day and post display to reduce the likelihood of error. The analysis in this study has identified the following as particularly valuable measures / strategies; they represent good practice in the promotion of safe air displays, including reducing the likelihood of negative transfer:

- Maintenance of currency;
- Supervision / peer review of practice displays;
- Planning and assessment – time; weather; communication with FDD;
- Visualisation / walkthroughs of display sequence and escape manoeuvres;
- Refreshing on aircraft limitations;
- Cockpit familiarization techniques and use of mnemonics;
- Use of visual, kinaesthetic and auditory sensory feedback;
- Use of kneeboards with accessible aircraft information and checklists; and,
- Reflection post-display to identify improvements for future displays.

In the theory section of this report (Section 3), it was noted that managing and adapting to changes in aeroplane type required a pilot to move between automatic processing (System 1; fast thinking) and controlled processing (System 2: slow thinking). The strategies used by pilots are ways of helping them to achieve this. For example, the use of a visualisation technique is akin to the practice of mindfulness. Mindfulness is defined as the qualities of attention: focus, stability, sustainability, filtering and vividness. It is not simply about paying more attention. It is about continually refining and updating expectations, assumptions and beliefs and holding a rich awareness of discriminatory details and a capacity for action (Weick and Sutcliffe, 2007). Pilots may use too much System 1 thinking if the mitigation measures identified above are not employed.

It appeared that many of the strategies had been developed by display pilots themselves over time and with great experience. It was also evident that many strategies were dependent on other supporting factors. For example, maintenance of currency, supervision and peer review appeared to be easier to facilitate when pilots were in the military or part of a larger organization. Financial considerations, access to aircraft and more opportunities for discussion with peers/supervisors were considered important issues. Similarly, it was evident that flight communication cards were made available to pilots who flew as part of a larger organisation. The sharing of this good practice and lessons learnt (e.g. mitigation measures / individual strategies, knowledge of operating and handling differences) would bring benefits across the display community.

5.4.1 Performance influencing factors in air display

Based on interview findings, numerous individual, job and organisational factors are likely to influence the performance of a pilot while displaying an aeroplane. These included the following:

- insufficient currency;
- time pressures;
- distractions (e.g. due to weather, changes on display day);
- mental and/ or physiological stresses;
- possible increased potential for slips / lapses due to hours on type;
- pressures to display (e.g. personal pressures, perceived compliance pressures); and
- physical cockpit conditions.

Challenges or difficulties experienced by pilots in employing the strategies discussed in Section 5.4 also have the potential to influence pilot performance. For example, a lack of opportunity for supervision / peer review of practice displays could negatively impact a pilot’s performance; they have limited opportunity to notice and address unsafe practices, and to be given timely feedback to adjust their performance.

It was evident that there is extensive knowledge, experience and insight within the display community in relation to mitigation measures and performance influencing factors. The main data collection method in this study was via interviews, which tend to be more subjective, there may be additional performance influencing factors that impact on display pilots that have not been identified in this study.

Recommendation 7: Training content - Use face-to-face sessions in human factors training to activate the expertise within the display community. Face-to-face sessions should include further identification and discussion of PIFS and mitigation measures to optimise pilot performance. The outputs of such sessions could be defined as recommended safe practices which could be extracted and published in the community of practice.

5.4.2 Regulatory Changes

It is evident that numerous regulatory actions have been taken in relation to the management of competence since the accidents reviewed in this study (CAA, 2016b). These have included the following:

- there is now a requirement for display pilots authorised to perform at standard level aerobatics in multiple categories to renew in those categories at least every two years;
- display pilots must be assessed by a different DAE every two years; and
- there are requirements for FDDs to be accredited through training.

Interview findings indicated these were considered, by many, to be beneficial changes. It was also evident that there were a number of ongoing changes (e.g. associated with the roles and responsibilities of the DAE) that appeared to require further discussion between regulator and industry to identify solutions and improvements collaboratively. Suggested improvements included:

- providing further opportunities for mentoring of new FDDs;
- including more practical elements into the FDD training course;
- standardisation of information provided in FDD briefs;
- ensuring that any debriefs (following displays) are more of a formalised common practice;
- improvements in the facilities provided for pilots at airshows;
- having one DAE train a pilot and a separate DAE to evaluate the pilot.

It is of note that FDD debriefs provide another opportunity to promote discussion of error and positive practices enabling a 'just' culture. Ideally a mechanism to capture learning points would also be applied, so that these can be shared more widely, integrated into training, or other measures to support safety.

It is evident that effective engagement with the display community can bring further improvements to safety and regulatory compliance. It would also help the regulator to gain buy-in to changes in regulation, manage expectations and provide opportunities for clarification of new regulations.

Recommendation 8: CAA should work with FDDs to standardise the inclusion of human factors in FDD briefs and debriefs.

Recommendation 9: CAA should consider how to effectively engage with the display community, including DAEs, FDDs, event organisers, and other stakeholders (e.g. BADA, HAA) to improve safety and regulatory compliance.

Recommendation 10: CAA should consider the pace of change of regulation and the timing of changes and how that may impact pilots in the display season.

5.4.3 Error paths

Based on the findings from this study, and as with any highly skilled safety critical activities involving dynamic systems, numerous error paths are possible and could lead to flying display accidents. Figure 4 provides a summary of the PIFs that can influence display pilot performance. As highlighted previously, many of the PIFs described cannot necessarily be assigned to 'individual', 'job' or 'organisation' categories, but have elements of all three. For the purposes of illustration only, these are categorised in Figure 4 as organisational, job and individual factors.

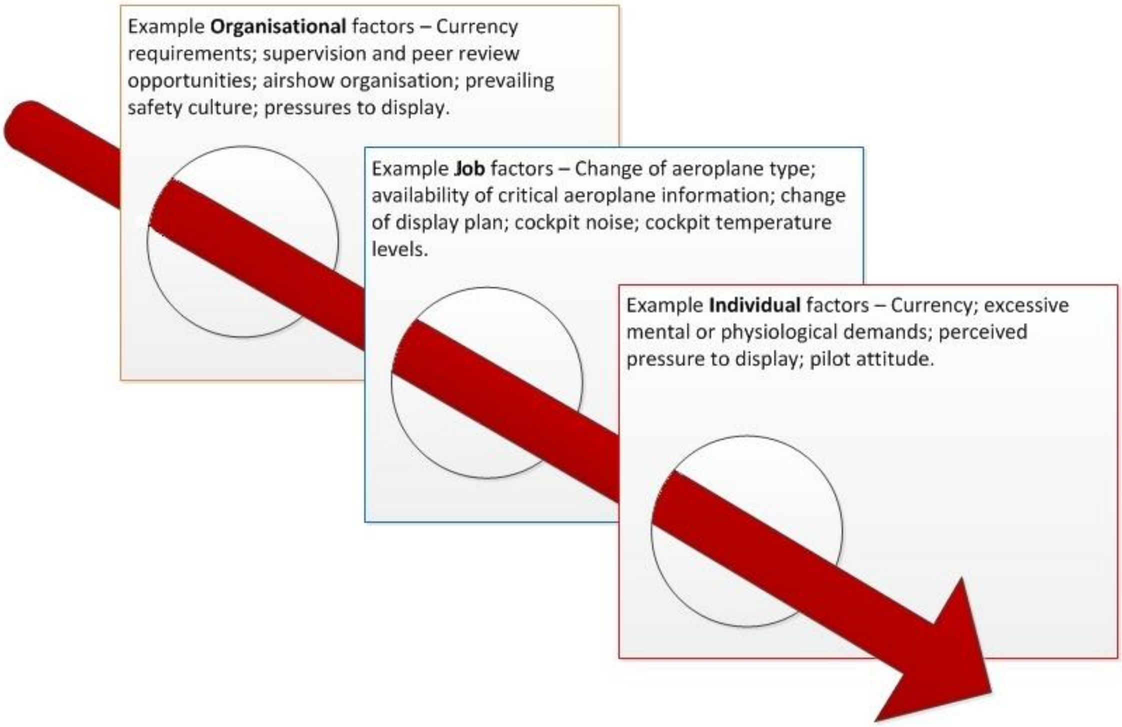

Figure 4 A summary of performance influencing factors that can influence display pilot performance.

The research shows that PIFs extending beyond those associated with negative transfer of behaviour are prevalent in display activities. The human factors and research principles are applicable to all pilots and the display community as a whole will need to engage with the training recommendations in this report.

6 CONCLUSIONS

There are important operating and handling differences between and within types and categories of SEP and JP aeroplanes that could impact safety, and there is potential for negative transfer of behaviours. There are numerous error pathways that cannot be entirely eliminated, but problems arising from negative transfer of behaviours were perceived as a) often recoverable and b) as being normally mitigated by a number of measures.

Design changes to aircraft are the most effective way of reducing the likelihood of slips and lapses caused by negative transfer, but this is not generally an option for aeroplanes in display flying. Pilots have, instead, developed their own strategies for minimising errors, which include minimising errors due to negative transfer. The research identified many excellent strategies used by pilots, who may not necessarily realise that they are managing human factors' related risk. The strategies that they have developed to safely manage and adapt to aeroplane type changes promote moving between System 1 fast thinking (automatic processing) and System 2 slow thinking (controlled processing). Whether or not a pilot can employ these strategies is not only dependent on the individual but also on the wider display community processes and structures being in place to support them.

The human factors principles and research data discussed in this report are applicable to all aircraft types where there are sufficient similarities in contextual information for negative transfer to occur. It is recommended that all pilots and operators consider how it might occur and be addressed in their aircraft. The research highlights that PIFs extend beyond those associated with negative transfer of behaviour and therefore, the proposed training programme is applicable to all.

There is a need at all levels of the display community to promote practices to ensure a positive health and safety culture, including a 'just' culture being promoted across the community. A culture that encourages speaking openly about error is much more likely to encourage openness and honesty during investigations, and therefore enable greater learning.

7 RECOMMENDATIONS

A key requirement was to use the error path findings from this study to develop human factors training for display pilots, training that the CAA will require holders of DAs to undertake. The authors of this study are aware that experts make errors irrespective of training and experience or how motivated they are to do things correctly and therefore, training forms part of a number of recommendations for consideration.

1. CAA should work with FDDs to improve the quality and quantity of reporting and feedback provided by FDDs following airshows. CAA should also consider ways in which this information can be shared across the display community. Sharing information from FDD reports on why incidents occurred and actions that have been, or can be, taken to prevent further similar incidents would be of benefit to the entire display community.

2. CAA and AAIB should promote more consideration of human factors in accident investigations through application of human factors expertise. This would enable deeper and broader learning to help reduce the likelihood of high consequence events.

3. CAA should develop a human factors training programme based on knowledge sharing techniques to ensure there is an exchange of expertise across the display community. Engaging with the display community as a resource could bring about improvements in safety practices far beyond traditional training.

4. CAA should consider a blended learning solution comprising a combination of self-taught learning and reflection, online learning and face to face training, delivered in a modular format.

5. All display pilots, not just those flying multiple aircraft, should be required to participate in the proposed training programme. This includes pilots seeking initial display authorisation and display authorisation renewal. The inclusion of other critical support and management roles in training is also recommended in order to support a more holistic / systematic approach to enhancing safety for air displays.

6. To further facilitate the transfer of learning, the CAA should work to set up a community of practice to help ensure that the taught elements of the training are embedded into long term practice and delegates can share their current knowledge and expertise. This could serve as a repository for human factors references and relevant information.

7. CAA should use face-to-face sessions in human factors training to activate the expertise within the display community. Face-to-face sessions should include further identification and discussion of PIFS and mitigation measures to optimise pilot performance. The outputs of such sessions could be defined as recommended safe practices which could be extracted and published in the community of practice.

8. CAA should work with FDDs to standardise the inclusion of human factors in FDD briefs and debriefs.

9. CAA should consider how to effectively engage with the display community, including DAEs, FDDs, event organisers, and other stakeholders (e.g. BADA, HAA) to improve safety and regulatory compliance.

10. CAA should consider the pace of change of regulation and the timing of changes and how that may impact pilots in the display season.

8 GLOSSARY

Term	Definition
Automatic processing	Also referred to as System 1: fast thinking. This is the automatic execution of skilled responses with little or no effort.
Competence	The knowledge, skill, attitude and behaviour of the person doing the task (a PIF). For pilots this will include currency.
Controlled processing	Also referred to as System 2: slow thinking. This is effortful thinking to execute actions.
Currency	Skill deteriorates and needs to be refreshed. Currency is about whether a pilot has flown an aeroplane recently proportionate to their understanding of that aeroplane. CAP 403 has specific requirements to demonstrate currency.
Display Authorisation Evaluation (DAE)	A Civil Aviation Authority authorised person qualified to conduct examinations and tests for the award of a Display Authorisation.
Display authorisations (DA)	A national document detailing the types or groups of aircraft in which a pilot is authorised to display, together with any limitations and any specific endorsements.
Energy management	Actions by the pilot to ensure that the aircraft's total kinetic and potential energy are sufficient for safe flight and to successfully complete planned display manoeuvres.
Error paths	The weaknesses in safety 'barriers' that, when aligned, can result in an unwanted outcome. The safety barriers are conceptualised at the individual, job and organisational level.
Flying Display	Any flying activity deliberately performed for the purpose of providing an exhibition or entertainment at an event that has been advertised and is open to the public.
Flying Display Director (FDD)	The person responsible to the Civil Aviation Authority for the safe conduct of a flying display.
Generic Error Modelling System (GEMS)	An error classification method to illustrate how behaviours can be skill-based or automatic rule based behaviour and rule or knowledge-based decision making.
Human Factors	The organisational, job factors, and individual characteristics, which influence behaviour in a way that can affect individual, team and organisational performance.
Individual factors	What an individual brings to their job (skills, knowledge, behaviours, personality etc.) and the task they are undertaking.
Job factors	The characteristics of the job, or task that is being undertaken.

Term	Definition
Lapses	Forget to carry out an action, to lose track of a task or to forget a stage of a task; they unconscious failures of automatic processing during routine actions.
Mindfulness	The qualities of attention: focus, stability, sustainability, filtering and vividness.
Mistakes	Mistakes are a more complex type of human error where a person does the wrong thing believing it to be right. They are decision-making failures and involve failures in how we plan, assess intentions and judge consequences.
Negative transfer	When a learned behaviour from one setting is used in a contextually similar setting, but with key differences that could impact performance.
Organisational factors	The work environment and associated systems in which the individual is working to complete a task.
Performance influencing factors (PIF)	The circumstances that can make it more or less likely that an error occurs during task performance
Skills, rules, knowledge (S-R-K)	Classification of behaviours to illustrate the level of information processing required and how that relates to error types. Based on GEMS.
Slips	Described as 'actions-not-as-planned', these are unconscious failures of automatic processing during routine actions.
Swiss Cheese Model	The representation of the barriers between a hazard and an unwanted outcome as layers of Swiss Cheese, with each hole in the cheese representing a weakness in the barrier.
System 1: fast thinking	Executes skilled responses with little or no effort, and no sense of voluntary control.
System 2: slow thinking	Also referred to as controlled processing, this is effortful thinking to execute actions.
Transfer of behaviour	Behaviour learned in one setting is transferred to other settings, particularly those that are contextually similar.

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10 APPENDIX

10.1 APPENDIX A: ANALYSIS OF DISPLAY AUTHORISATION DATABASE

Table 1 Analysis of Display Authorisation database

No. of Groups a pilot has authorisations in	**Groups Authorised**	**Number of Display Authorisations in this group**	**Percentage of Display Authorisations in this group**
Authorised to fly in one group only	Single-Engine Piston (SEP) Aeroplanes only	266	60.04%
	Multi-Engine Piston (MEP) Aeroplanes only	8	1.81%
	Jet-Powered (JP) Aeroplanes only	4	0.90%
	Microlight Aeroplanes only	2	0.45%
	Helicopters and Gyroplanes only	1	0.23%
Authorised to fly within two groups	SEP and MEP	61	13.76%
	SEP and JP	42	9.48%
	SEP and Gliders	11	2.48%
	SEP and Microlight Aeroplanes	5	1.13%
	SEP and Helicopters	3	0.67%
	JP and Helicopters	3	0.67%
	SEP and Turbo-Prop Powered Aeroplanes	1	0.23%
	JP and Turbo-Prop Powered Aeroplanes	1	0.23%
Authorised to fly within three groups	SEP, MEP and JP	12	2.71%
	SEP, MEP and Turbo-Prop	7	1.58%
	SEP, JP and Turbo-Prop	4	0.90%
	SEP, MEP and Gliders	2	0.45%
	SEP, JP and Gliders	2	0.45%
	SEP, Helicopters and Gliders	1	0.23%
	SEP, JP and Helicopters	1	0.23%
	SEP, Gliders and Microlight Aeroplanes	1	0.23%
	SEP, Turbo-Prop Powered Aeroplanes and Microlight	1	0.23%
	SEP, MEP and Helicopter	1	0.23%
Authorised to fly within four groups	SEP, MEP, JP and Turbo-Prop Powered Aeroplanes	2	0.45%
	SEP, MEP, JP and Gliders	1	0.23%
	Total	443	100%

10.2 APPENDIX B: ANALYSIS OF A SAMPLE OF UK FLYING DISPLAY ACCIDENTS (2007-2015)

Table 2 A high level analysis of a sample of fatal / serious accidents at UK flying displays (2007-2015)

No.	Accident Date	Aircraft Type(Aircraft Category as per CAP 403, 2018)	What Happened	Some Contributory Human Factors Noted in Accident Report Analysis/Conclusions	References Used
1	22/8/2015	Hawker Hunter (G2)	Insufficient height to complete looping manoeuvre	• Specific human factors analysis on one manoeuvre (i.e. the bent loop) within the display sequence showed that a number of possible errors and performance influencing factors (PIFS) may have contributed to the accident. These included: ○ The altimeter may not have been seen or read at the apex of the loop; ○ An inaccurate perception of aircraft height may have been obtained; ○ The minimum height required at apex may have been recalled incorrectly; ○ An escape manoeuvre may have not been selected as a result of the limited time available to select and implement the action, and the guidance and training that the pilot received with regard to performing an escape manoeuvre at the apex of a loop in the Hunter. • An analysis of pilot experience and task practice was considered important to include (however not included in the RAFCAM report due to timescales of AAIB report publishing); • Specific reference is made to evidence that other pilots do not always check or perceive correctly that the required height has been achieved at the apex of manoeuvres; • PIFS considered in the RAFCAM analysis included scan pattern, workload, allocation of attention and visual limitations. It is hypothesised that the scan pattern used may have been influenced by the pilot's experience in other aircraft suggesting a negative transfer of behaviour issue.	Royal Air Force Centre of Aviation Medicine (RAFCAM) study cited in Appendix M (Air Accident Investigation Branch, 2017).
2	1/08/2015	Folland Gnat T Mk 1(G2)	Loss of control rolling manoeuvre	• The pilot's experience and currency were considered to be contributory factors, e.g. the pilot had not flown high performance, swept wing jet aircraft before converting onto the Gnat and at the time of the accident was of intermediate experience according to CAP 632 criteria.	(Air Accident Investigation Branch, 2016).

No.	Accident Date	Aircraft Type(Aircraft Category as per CAP 403, 2018)	What Happened	Some Contributory Human Factors Noted in Accident Report Analysis/Conclusions	References Used
3	01/07/2012	North American Rockwell OV-10B Bronco (J)	Loss of control rolling manoeuvre	• The pilot had demonstrated his flying display to a Display Authorisation Evaluator (DAE) as part of the evaluation and renewal process but there was no evidence that his display had been evaluated separately, or that there had been any mentoring, other than on those occasions. Thus, if a problem had developed with the way a particular manoeuvre or display was being conducted, it may not have been detected and an opportunity to address it may have been missed. • Secondly, there is no requirement for mentoring during the process to extend the privileges of a display authorisation, as required for an initial Display Authorisation. The accident pilot was the only person flying this aircraft regularly and was not part of a larger organisation. Consequently, the opportunity for mentoring may have been limited. Within a larger organisation there tends to be a natural and, in some cases, required element of oversight by other pilots.	(Air Accident Investigation Branch, 2014).]
4	19/6/2010	Extra 300 (SEP B)	Did not recover from spin manoeuvre with sufficient height	• The human factors expert considered that the pilot's judgement may have been affected by fatigue and life stresses. He also considered that any tendency the pilot may have had towards impulsive behaviour was unlikely to have been checked by as they were awarded the highest category of aerobatic DA at their first assessment. • The DA process was followed correctly, but the existing guidance to DAEs given in CAP 403 did not preclude a relatively inexperienced pilot being awarded an Unlimited category authorisation on first assessment for an aerobatic DA. There may be circumstances in which this would be appropriate, but the forgoing discussion suggests that it should not be the norm. • The accident pilot had not had an experienced colleague critique his flying display, or any of his practices, during the 2010 season. The human factors expert considered that a process that requires an element of mentoring and supervision until a reasonable amount of experience has been accrued may help a pilot improve his judgement.	(Air Accident Investigation Branch, 2011).]
5	15/09/2007	Hawker	Loss of	• There was no record of the pilot having completed the currency training	(Air Accident

No.	Accident Date	Aircraft Type(Aircraft Category as per CAP 403, 2018)	What Happened	Some Contributory Human Factors Noted in Accident Report Analysis/Conclusions	References Used
		Hurricane Mk XII (IIb) (SEP C)	control during rolling manoeuvre	requirements as specified in the operator's Organisational Control Manual; • The pilot had stated on a number of occasions prior to the display that they would not be rolling the aircraft, but in the event, did so; • Whilst the lead Hurricane pilot and the display sequence organisers were satisfied from the briefings and the pilot of G-HURR's comments that they were clear about the manoeuvres they would be performing, there action of attempting the rolling manoeuvre suggested otherwise; • The intended display sequence had not been practised; • The pilot had not demonstrated similar manoeuvres in an aircraft in the same category when his DA was last renewed.	Investigation Branch, 2009).]

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Health and Safety Laboratory
Harpur Hill
Buxton
Derbyshire
SK17 9JN
UK
www.hsl.gov.uk

T : +44 (0)20 3028 2000
E: hslinfo@hsl.gsi.gov.uk