Safety Regulation Group

Civil Aviation Authority

CAA PAPER 2010/01

The SBAS Offshore Approach Procedure (SOAP)

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The SBAS Offshore Approach Procedure (SOAP)

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Foreword

The research reported in this paper was funded under the European Union 6th Framework GIANT project, and was performed by Helios Technology Ltd. except for the simulator trials which were conducted by Eurocopter in Marignane, France. The work follows on from the research into the use of Differential GPS to provide guidance for helicopters approaching offshore installations reported in CAA Papers 2000/5, 2003/2 and 2003/7, and the safety assessments of the use of GPS for offshore helicopter operations reported in CAA Paper 2009/06. In turn, this work was commissioned in response to the findings of the Helicopter Human Factors Working Group reported in CAA Paper 87007 (Recommendations 4.1.1 and 4.2.1). The Helicopter Human Factors Working Group was formed in response to Recommendation 1 of the Helicopter Airworthiness Review Panel (HARP Report – CAP 491).

UK CAA Safety Regulation Group offers the following comments on the work reported in this paper:

SBAS Offshore Approach Procedure (SOAP) Design and Simulator Trials

The intial design of the procedure was based on the ealier offshore approach trials work reported in CAA Paper 2000/5. The final agreed version of the procedure emerging from the simulator trials differed from the initial version mainly in terms of detail; the basic approach design remained substantially unchanged suggesting that the procedure is robust. It was notable that there was very good agreement between all six pilots that participated in the simulator trials in terms of the final approach design. CAA considers that these results provide a solid basis for taking the work forwards, initially to demonstrator trials and then to in-service trials.

SOAP Safety Assessment

By their nature, safety assessments cannot provide definitive answers, but are able to give a general 'ball park' indication of the level of safety achieved. They can also enable comparisons to be made, and the fact that the safety assessment reported here shows SOAP to reduce three conflict scenarios from 'tolerable' to 'negligible' compared to the GPS-assisted approach described in CAA Paper 2009/06, demonstrates the improved safety inherent in SOAP. The addition of the maritime Automatic Identification System (AIS) to provide an additional, independent means of locating uncharted obstacles and charted obstacles contained in the aircraft's navigation database, is expected to reduce all conflict scenario risks to negligible. This would represent the ideal result.

EGNOS Data Collection and Analysis, and Availability Assessment

This section of the work has identified that typical existing GPS antenna installations are unlikely to be suitable for SOAP. However, CAA considers that no insurmountable problems were identified. Antennas with improved gain characteristics at low angles of elevation are understood to be available, and an additional antenna could be mounted on the nose of helicopters using SOAP which could be either manually or automatically switched as a function of approach heading.

Further work is now in progress at Helios Technology Ltd. under a European Union 7th Framework project. This project, named HEDGE (Helicopters Deploy GNSS in Europe), will develop prototype avionics and conduct demonstration flights of the new EGNOS/SBAS guided approach procedure. Four 'add-on' work packages have been identified which CAA hopes to be able to arrange funding for. One of these packages, the addition of an AIS receiver to the demonstration system, has already been contracted under funding provided by CAA Norway, Oil & Gas UK and Shell Aircraft.

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Executive Summary

This document reports on the development and assessment of a new type of offshore approach procedure called SOAP (SBAS Offshore Approach Procedure). The work was undertaken as part of the GIANT project, sponsored by the GNSS Supervisory Authority (GSA), and this report has been produced for the UK Civil Aviation Authority (CAA) who participated in and part funded the work.

Offshore helicopter operations in support of the oil and gas industry have for many years made use of an Airborne Radar Approach (ARA) procedure for low-visibility offshore approaches. The ARA relies on the aircraft's weather radar for guidance and as a means of detecting obstacles in the approach and overshoot paths. The use of the weather radar was borne of necessity since no other equipment was available to support these operations. Although this situation has existed for a number of years and the safety record has generally been reasonable, the weather radar is neither designed nor certificated for the task. Furthermore, a safety assessment of the ARA has identified a number of weaknesses that need to be addressed [Ref. 1].

The European Geostationary Navigation Overlay System (EGNOS) is the European Satellite Based Augmentation System (SBAS) that will become operational in 2010. When combined with GPS, it will offer users a very high accuracy and integrity navigation capability. Following earlier research into the use of differential GPS (DGPS) for performing offshore approaches, conducted by the UK CAA and reported in CAA Papers 2000/5 [Ref. 5], 2003/02 [Ref. 6] and 2003/07 [Ref. 7], it was believed that the SBAS capability provided by EGNOS had significant potential to provide a practical differential GPS offshore approach guidance system and address the limitations of the existing ARA procedures.

To investigate this potential, a new SBAS Offshore Approach Procedure (SOAP) has been developed and evaluated. SOAP is based on the new Approach with Vertical Guidance (APV) defined by ICAO, and uses angular display sensitivity similar to the well-established Instrument Landing System (ILS). By providing both horizontal and vertical instrument guidance, it is intended to reduce pilot workload during manually flown approaches and allow modern helicopters to make use of their Automatic Flight Control Systems (AFCS) and fly coupled approaches.

Some aspects of the SOAP need further study. For example, the navigation database content required needs to be confirmed. This report has assumed that an obstacle radius and the helideck height for each destination waypoint could be included in the database. The obstacle radius would be used to determine the correct offset distance for the horizontal approach track, and the helideck height would be used to establish the correct datum for the vertical profile of the approach path.

The feasibility of the SOAP procedure has been assessed from the following perspectives:

- Flight simulations have been performed to assess the flyability of the procedure.
- An assessment has been conducted to ensure the safety of the procedure.
- Data collection (via flight trials) and subsequent data analysis have been undertaken to establish EGNOS reception characteristics on helicopters and estimate system availability.

The flight simulations were conducted in Eurocopter's R&D Simulator, located in Marignane, France. About 80 approaches were flown using pilots from offshore helicopter operators and from the UK CAA. The simulations found the new procedure to be very flyable, and confirmed several operational parameters.

The safety assessment was conducted in two parts:

- a success case, which considers the safety of the approach when no pilot errors occur and all equipment functions correctly, and
- a failure case, which considers the safety of the approach when pilot errors occur or equipment fails.

The success case showed that the lateral and vertical accuracy was sufficient for the operation.

The failure case found that, for most system failures, the risk is 'negligible'. However, in several cases the risk was found to be 'tolerable', meaning that measures should be sought to reduce the frequency of these events. A particular risk contributing to two of these events is the detection and avoidance of uncharted obstacles in the approach and overshoot paths. A potential mitigation is considered to exist in the use of the Automatic Identification System (AIS), which is a maritime system that provides the location and identity of any vessel large enough to present a hazard to a helicopter. It is known that some search and rescue (SAR) helicopters already use this system to assist the location of vessels. It is recommended that the feasibility of displaying AIS information to the flight crew is investigated further. It is also noted that an automatic collision warning system, such as TAWS A, could be adapted to make use of the AIS data which could also reduce crew errors. The analysis suggests that using AIS data for display and collision avoidance could make all probabilities 'negligible'.

The EGNOS data collection and analysis found generally good reception of EGNOS and GPS signals on the test helicopter (a Eurocopter Super Puma AS332L). However, the antenna installation was found to be sub-optimal for SOAP operations. Consequently, it is recommended that consideration be given to re-siting the antenna or adding a secondary unit on this aircraft in particular, and that similar exercises be performed on other helicopter types to ensure adequate reception characteristics for SOAP. It is also recommended that alternative antennas with higher gain at lower angles of elevation be considered.

Using the data collected, an assessment was also made of the likely availability of the SOAP procedure for the specific GNSS antenna installation on board the test helicopter. On the basis of the actual wind conditions experienced in the North Sea over the period 2000 through 2008, it is estimated that the availability of SOAP would be in the region of 93%. This level of availability suggests that, for the SuperPuma, it would be worth expending the effort to improve the antenna installation prior to the commencement of SOAP operations. The reception characteristics on other helicopter types should also be evaluated and improved as necessary before they are used for SOAP operations.

Report

1 Introduction

1.1 Overview

1.1.1 This document reports on the development and assessment of a new type of offshore approach procedure called SOAP (SBAS Offshore Approach Procedure). It has been produced by a joint industry working group[1], headed by Helios, for the Safety Regulation Group (SRG) of the UK Civil Aviation Authority (CAA) and formed part of the GIANT project, which is co-funded by the European GNSS Supervisory Authority (GSA).

1.2 General

1.2.1 Offshore helicopter operations in support of the oil and gas industry have for many years made use of an Airborne Radar Approach (ARA) procedure for low-visibility offshore approaches. This procedure relies on the aircraft's weather radar for guidance, and as a means of detecting obstacles in the approach and overshoot paths. The use of the weather radar was borne of necessity since no other equipment was available to support these operations. Although this situation has existed for a number of years and the safety record has generally been reasonable, the weather radar is neither designed nor certificated for the task. Furthermore, a safety assessment of the ARA [Ref.1], has identified a number of weaknesses that need to be addressed.

1.2.2 The European Geostationary Navigation Overlay System (EGNOS) is the European Satellite Based Augmentation System (SBAS) that will become operational in 2010. When combined with GPS, it will offer users a very high accuracy and integrity navigation capability. Following earlier research into the use of differential GPS (DGPS) for performing offshore approaches, conducted by the UK CAA and reported in CAA Papers 2000/5 [Ref. 5], 2003/02 [Ref. 6] and 2003/07 [Ref. 7], it was believed that the SBAS capability provided by EGNOS had significant potential to provide a practical differential GPS offshore approach guidance system and address the limitations of the existing ARA procedures.

1.2.3 To investigate this potential, a new SBAS Offshore Approach Procedure (SOAP) has been developed (described in Section 2), and this document contains the results of the following work to investigate its feasibility:

- Simulations to assess the flyability of the procedure (described in Section 3).
- A safety assessment (described in Section 4).
- Data collection (via flight trials) and analysis (described in Section 5).
- EGNOS availability assessment (described in Section 6).

1.3 Acknowledgements

1.3.1 Helios would like to thank the UK CAA, the Norwegian CAA, Eurocopter, Bristow Helicopters, Bond Offshore Helicopters and CHC Scotia Helicopters for their assistance with the work reported in this document.

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[1] The working group comprised representatives from Helios Technology, Eurocopter, the UK CAA, CAA Norway, Bristow Helicopters, CHC Scotia Helicopters, Bond Offshore Helicopters, CHC Helicopter Service and Nosrke Helicopters.

2 The SOAP procedure and EGNOS

2.1 Introduction

2.1.1 This section contains a description of the SOAP procedure, and a description of EGNOS and its potential suitability for this application. It also contains a list of relevant avionics standards.

2.1.2 The SOAP procedure was based on earlier research and trials performed for the UK CAA and reported in CAA Papers 2000/5 [Ref. 5], 2003/02 [Ref. 6] and 2003/07 [Ref. 7], and developed in consultation with the offshore helicopter operators. Some of the parameters proposed in the procedure were validated during the subsequent flight simulator trials, and this is highlighted and discussed where appropriate.

2.2 The SOAP procedure

2.2.1 General

2.2.1.1 The procedure comprises a 'straight-in' approach providing a minimum lateral separation from the approach track to the nearest part of the destination platform structure. It does not include any course reversal, race track or arc procedure, or any turn or change of course.

2.2.1.2 The procedure is automatically generated by the aircraft's avionics equipment following input of the destination (the destination platform is defined as a waypoint) and selection of the final approach track (direction and left or right offset) by the flight crew, entered during the en-route phase. Fixed approaches may be desirable at some locations to assist air traffic management. These may be implemented by procedurally limiting flight crew choice of approach track, or by programming the approach procedure(s) into the aircraft's navigation database.

2.2.1.3 An obstacle radius which circumscribes the extent of the destination platform will be defined, which will be used to calculate the offset distance. It is expected that the obstacle radius will be held in the navigation database. The details of the database coding for the destination and obstacle radius need to be defined.

2.2.1.4 Since the datum for the vertical approach profile (i.e. the MDA) is dependent on the height of the helideck, it is anticipated that this information will be added to the navigation database entry for each platform. This would most appropriately be GPS height (in WGS84 format) as both lateral and vertical guidance is to be provided by GPS.

2.2.1.5 The EGNOS approach procedure consists of four segments, each of which is described separately below and illustrated in Figure 2.1.

2.2.2 Arrival Segment

2.2.2.1 The Arrival Segment commences at the last en-route navigation fix and ends at the Initial Approach Fix (IAF).

2.2.2.2 During the Arrival Segment, the aircraft descends to 1500 ft, the Minimum Safe Altitude (MSA), as indicated by the barometric altimeter, and prepares for the approach.

2.2.2.3 Standard en-route obstacle clearance criteria should be applied to the Arrival Segment.

2.2.3 Initial Approach Segment

2.2.3.1 The Initial Approach Segment commences at the IAF, and ends at the Final Approach Fix (FAF).

2.2.3.2 The distance of the FAF from the Missed Approach Point (MAP) varies depending on the length of the descent segment, but the Initial Approach Segment should not be less than 2 NM in length.

2.2.3.3 The Initial Approach Segment is flown at a constant altitude of 1500 ft (i.e. the MSA), as indicated by the barometric altimeter set at QNH. The EGNOS height is calibrated using the radio altimeter during this segment in order to provide the flight crew with a valid cross check of height above the sea surface during the remainder of the approach.

2.2.3.4 The purpose of the Initial Approach Segment is to align and prepare the helicopter for the Final Approach. During the Initial Approach Segment, the aircraft should finalise its heading and decelerate to the final approach airspeed. The Final Approach airspeed should be between 60 and 80 kt IAS.

2.2.3.5 The destination should be identified on the weather radar, and the Final Approach and Missed Approach areas generated by the system should be identified and verified to be clear of obstacles, i.e. radar returns.

2.2.4 Final Approach Segment

2.2.4.1 General

a) The Final Approach Segment commences at the FAF and ends at the MAP.

b) The Final Approach Segment consists of two parts: the descent segment and the level segment.

c) The Final Approach Segment will be protected against charted (fixed) obstacles by sloped Obstacle Assessment Surfaces (OAS) as for APV approaches. This will be achieved by ensuring that the avionics will not allow an approach direction to be selected that includes charted obstacles that impinge on the OAS.

2.2.4.2 Descent Segment

a) At the FAF, the aircraft enters the descent segment and begins to descend at a constant airspeed and a fixed glide path angle of 4° until it reaches the Minimum Descent Altitude (MDA). A steeper glide path angle of 6° may be used (e.g. to avoid obstacles), provided that the descent can be flown at a groundspeed of 60 kt or less in order to constrain the descent rate for reasons of passenger comfort.

b) During this segment, vertical separation from the offshore fixed charted obstacle environment is maintained by the use of the OAS. Within the final approach area, the MDA will provide separation from the sea. In addition, it is necessary to check that the approach and overshoot paths are clear of weather radar returns prior to commencing the descent. This provides a check for uncharted obstacles.

c) The length of the descent segment, and thus the distance from the FAF to the MAP, varies depending on the MDA.

d) Lateral guidance on the slope will be provided by EGNOS.

e) Lateral guidance sensitivity during the descent will be angular and the full scale deflection will be fixed at a value of 2°. The guidance will be focused at a point on the approach heading 10,000 ft beyond the destination. The lateral guidance sensitivity is illustrated in Figure 2.2.

f) Vertical guidance on the slope is provided by EGNOS but with the radio altimeter and AVAD system providing an independent 'safety net'. As the aircraft approaches the MDA it starts to level off. Fairing of the transition to the level segment will prevent undershoot of the MDA.

g) Vertical guidance sensitivity during the descent will be angular and the full scale deflection will be fixed at a value determined by the Glide Path Angle divided by four (GPA/4). The glide path will originate from a point 200 ft below the MDA to give a fixed, standardised vertical sensitivity at the level off point. The level off point will move as the MDA of different platforms varies with helideck height and by time of day (i.e. day/night). The vertical guidance sensitivity is illustrated in Figure 2.3.

2.2.4.3 Level Segment

a) The altitude of the level segment is the MDA. Both lateral and vertical guidance are provided by EGNOS.

b) Vertical guidance sensitivity on the level segment will be linear, fixed at the value at the level off point.

c) Lateral guidance on the level segment will have the same angular sensitivity as during the descent, up to the point abeam of the destination, beyond which the scaling will be linear, fixed at a full scale deflection value of ± 0.3 NM (see Figure 2.2.

d) During the level segment, the crew will attempt to make visual contact with the destination. Once contact is made, a visual approach and landing is made.

e) The MAP is defined as the closest point to the destination from which it is safe to make a decision to land, and thus the distance from the MAP to the destination is the Minimum Decision Range (MDR). Under normal circumstances the MDR will be 0.75 NM, and the maximum groundspeed at the MAP will be 80 kt. However the MDR may be shortened to 0.5 NM if the groundspeed at the MAP can be constrained to 60 kt.

f) To achieve 60 kt groundspeed at the MAP, decelerating from 80 kt to 60 kt along the level segment is possible provided that adequate AFCS (Automatic Flight Control System) performance is available. In the case of AFCS degradation or limited AFCS performance, the entire approach must be flown at 60 kt groundspeed in order to use a MDR of 0.5 NM.

g) The angle between the approach track and the heading of the destination at the MAP is the offset angle, which must not exceed 30°.

h) The length of the level segment is fixed at 0.75 NM regardless of the MDA.

i) The MDA will be 200 ft or helideck height + 50 ft (whichever the higher) by day and 300 ft by night as measured by the EGNOS system. A higher MDA could be applied in some circumstances (e.g. to ensure adequate cuing for transition from the instrument to the visual segment at the MAP), and the benefits/disadvantages of this need further analysis.

2.2.5 Missed Approach Segment

2.2.5.1 The Missed Approach segment commences at the MAP and ends when the helicopter reaches MSA.

2.2.5.2 If visual contact is not made with the destination by the MAP, then a missed approach is initiated. A missed approach will also be initiated at any point on the approach if any fault is detected with the approach guidance system, or if either the horizontal deviation exceeds one dot or if the vertical deviation exceeds half a dot.

2.2.5.3 The missed approach manoeuvre comprises a straight ahead, 'wings level' climb at the fastest safe rate until the helicopter is at or above the MSA. Straight ahead guidance is provided for the climb out with the crew then able to select guidance to either attempt a further approach or to fly to an alternate destination.

2.2.5.4 The missed approach area to be used will have been identified and verified as clear of obstacles on the radar display during the Initial Approach segment.

2.2.5.5 The angular lateral guidance sensitivity of the Final Approach segment will continue to be used beyond the MAP until the point abeam of the destination, after which a linear lateral guidance sensitivity equating to a full scale deflection of ± 0.3 NM will be used until the aircraft passes above the MSA when the guidance will cease.

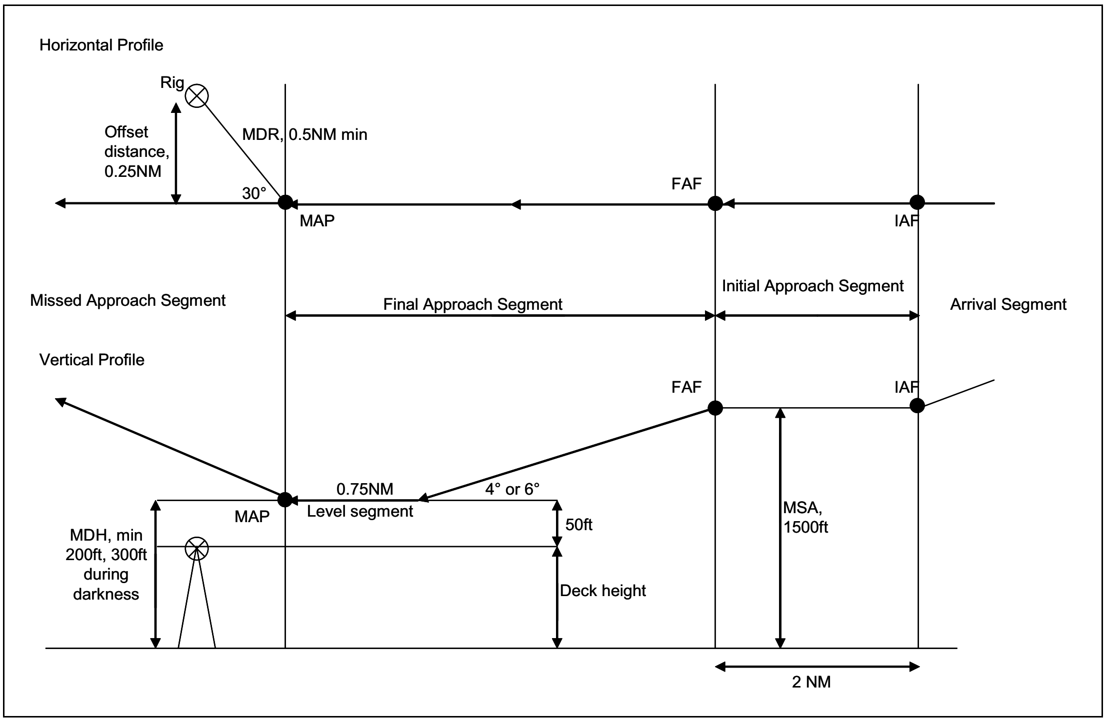


Figure 2.1 Overview of approach parameters

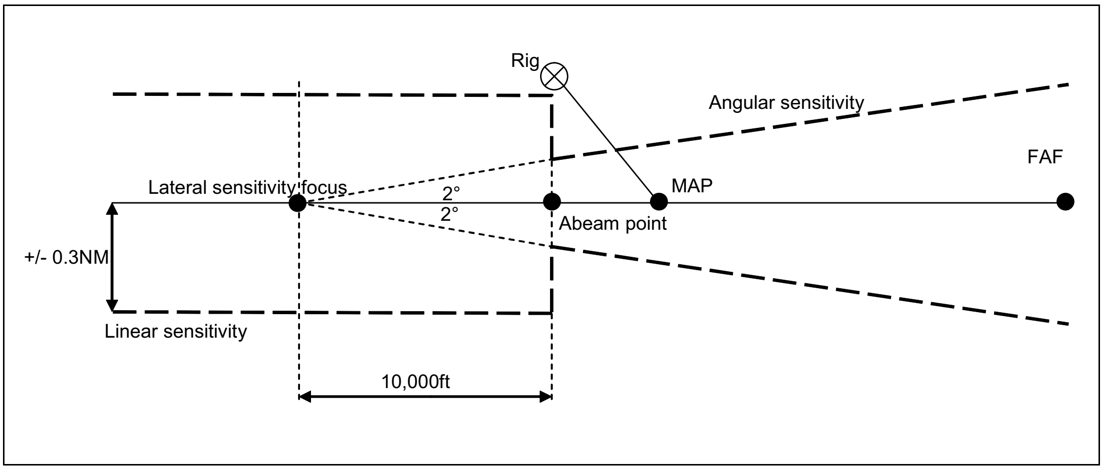


Figure 2.2 Lateral sensitivity

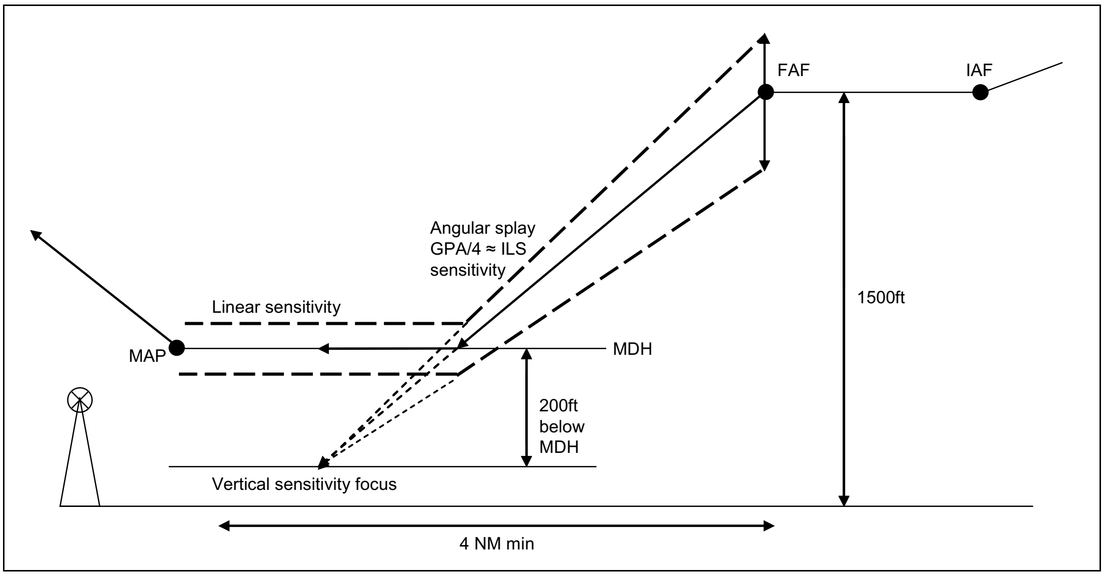


Figure 2.3 Vertical sensitivity

2.3 EGNOS

2.3.1 The EGNOS system has a space segment composed of three Geostationary satellites located above the equator. Currently these are the Inmarsat Atlantic Ocean Region – East (AOR–E 15.5° W), Inmarsat Indian Ocean Region – West (IOR–W 25° E) and the ESA ARTEMIS (21.4° E) geostationary satellites. The Inmarsat satellites are of the 3rd generation of geostationaries and were launched in 1996 and 1998 respectively. Their primary purpose is to carry voice and data communications. ARTEMIS is a multi-functional test satellite developed by the European Space Agency (ESA) and supports various experimental technologies in addition to its navigation and communications payloads. It was launched in 2001. The coverage of these satellites with a 5 degree mask angle is shown in Figure 2.4 below.

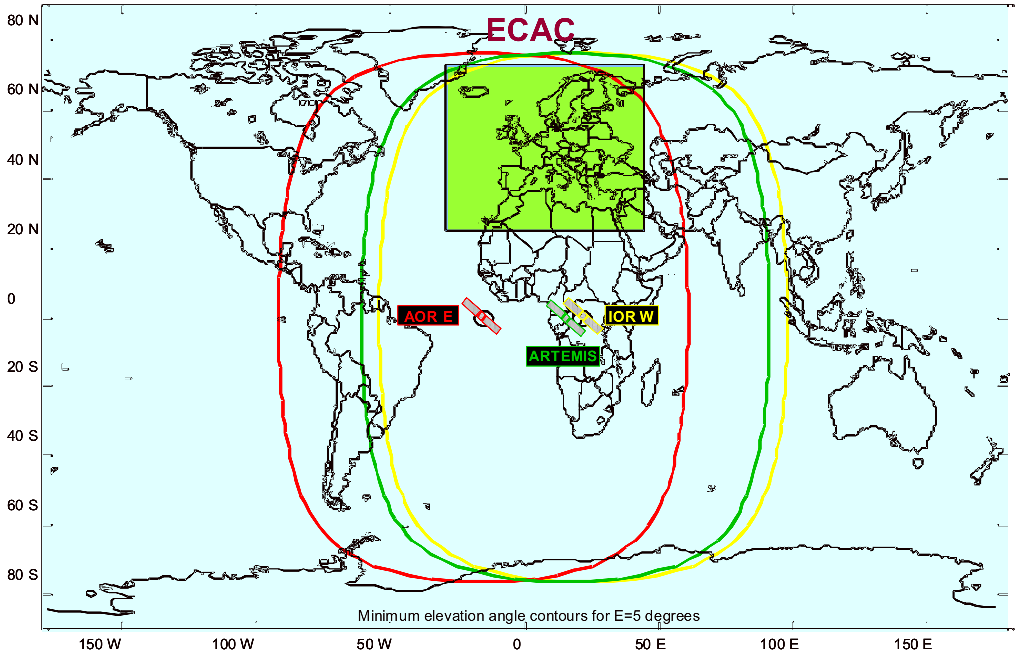


Figure 2.4 EGNOS GEO coverage

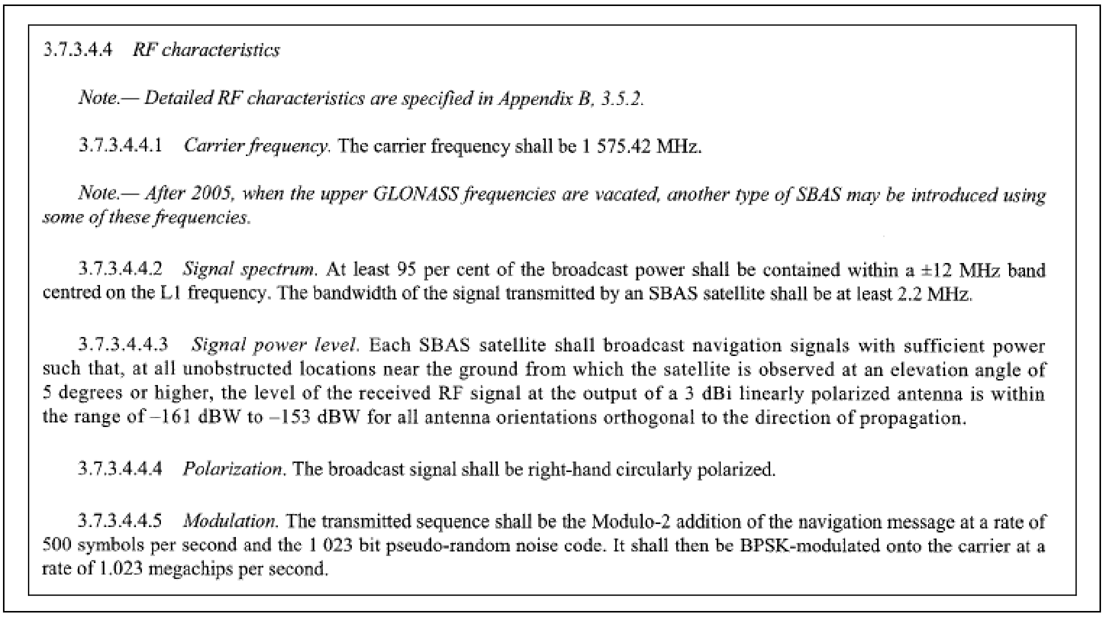
2.3.2 Clearly, within the North Sea offshore environment it could be expected that a user would be able to track all three EGNOS satellites, albeit at low elevation angles. For a user at Aberdeen, for example, the satellites will appear marginally above 20° elevation to the local horizon – all to the south (Table 2.1). ARTEMIS is currently being used for industry test purposes and its availability is consequently sporadic. However, good signals can be received from both Inmarsat satellites. As the IOR–W satellite is sufficiently close to ARTEMIS it can be expected that any results relating to it could be directly applicable to ARTEMIS.

Table 2.1 Location of EGNOS GEOs relative to Aberdeen user

PRN	Satellite	Elevation	Azimuth	Notes
120	Inmarsat AOR–E	23.9°	200.1°	Currently in test mode broadcasting Message Type 0/2
124	ARTEMIS	21.7°	156.9°	Artemis is currently under use for industry testing of the EGNOS system. Its availability cannot be guaranteed.
126	Inmarsat IOR–W	20.7°	152.9°	Currently in test mode broadcasting Message Type 0/2

2.3.3 The satellites are all bent-pipe repeaters - that is, they only frequency shift and rebroadcast messages uplinked from the EGNOS ground segment. Unlike GPS satellites, they have no capability to operate autonomously without the ground uplink for any duration at all.

2.3.4 The received power levels from these satellites are constrained by ICAO SARPs Annex 10 (see Figure 2.5):



3.7.3.4.4 *RF characteristics*

Note.— Detailed RF characteristics are specified in Appendix B, 3.5.2.

3.7.3.4.4.1 *Carrier frequency.* The carrier frequency shall be 1 575.42 MHz.

Note.— After 2005, when the upper GLONASS frequencies are vacated, another type of SBAS may be introduced using some of these frequencies.

3.7.3.4.4.2 *Signal spectrum.* At least 95 per cent of the broadcast power shall be contained within a ±12 MHz band centred on the L1 frequency. The bandwidth of the signal transmitted by an SBAS satellite shall be at least 2.2 MHz.

3.7.3.4.4.3 *Signal power level.* Each SBAS satellite shall broadcast navigation signals with sufficient power such that, at all unobstructed locations near the ground from which the satellite is observed at an elevation angle of 5 degrees or higher, the level of the received RF signal at the output of a 3 dBi linearly polarized antenna is within the range of −161 dBW to −153 dBW for all antenna orientations orthogonal to the direction of propagation.

3.7.3.4.4.4 *Polarization.* The broadcast signal shall be right-hand circularly polarized.

3.7.3.4.4.5 *Modulation.* The transmitted sequence shall be the Modulo-2 addition of the navigation message at a rate of 500 symbols per second and the 1 023 bit pseudo-random noise code. It shall then be BPSK-modulated onto the carrier at a rate of 1.023 megachips per second.

Figure 2.5 SBAS RF characteristics from ICAO SARPS

2.3.5 In order to achieve these power levels the Effective Isotropic Radiated Power (EIRP) levels at the edge of coverage is in the range 29–30dBW for the Inmarsat satellites and > 27dBW for ARTEMIS. Inmarsat and ESA monitor the received power levels from the navigation payloads in real time and adjust the satellites radiated power levels to ensure that the signals are compliant with the Annex 10 requirements.

2.4 Suitability of EGNOS standards for approach procedure

2.4.1 The safety assessment assumes that the equipment used for the EGNOS–enabled offshore approach procedure will be compliant with the requirements of the industry standard MOPS (RTCA DO–229D, Ref. 3).

2.4.2 However, the procedure requires functionality beyond that currently available within the MOPS. The additional functions include the ability to calculate the approach, while airborne, accepting inputs from the flight crew in terms of the final approach track (direction and left or right offset) and destinations selected from a database. This functionality will likely be provided by the aircraft's flight management system (FMS), mechanised via a dedicated approach page on the CDU. In addition, a radio altimeter input to the FMS will be required. The safety assessment assumes that the current specified failure rate performance will be maintained following these additions.

2.4.3 The assessment also assumes that the approach system and the weather radar information are combined on a single integrated navigation display. The assessment assumes that this display unit will have similar performance to current individual displays.

2.5 Relevant avionics standards

2.5.1 Information on equipment standards has been obtained during previous work through consultation with the helicopter operators and equipment manufacturers.

2.5.2 The RDR–1400 weather radar is certified and manufactured to the following standards:

- FAA TSO C63b – (Airborne Weather and Ground Mapping Radars);
- FAA TSO C102 – (Airborne Radar Approach and Beacon Systems for Helicopters).

2.5.3 Information obtained from Honeywell on the Primus 700 indicates that this weather radar is certified and manufactured to the following standards:

- FAA TSO C63b – (Airborne Weather and Ground Mapping Radars);
- FAA TSO C102 – (Airborne Radar Approach and Beacon Systems for Helicopters);
- RTCA DO 178B Level B – (Software Considerations in Airborne Systems and Equipment Certification).

2.5.4 Information obtained from Rockwell Collins on their products indicates that these are certified and manufactured to the following standards:

- Collins ALT 50 radio altimeter.
    - FAA TSO C87 – (Airborne Low Range Radio Altimeter);
    - EUROCAE ED –14c – (Environmental Conditions and Test Procedures for Airborne Equipment);
    - RTCA DO 178B Level A – (Software Considerations in Airborne Systems and Equipment Certification).

2.5.5 The Thales TRT AHV8 radio altimeter is certified to RTCA DO – 138 (Environmental Conditions and Test Procedures for Airborne Electronic/ Electrical Equipment and Instruments) which has been superseded by DO –160/ED –14.

2.5.6 For all EGNOS receiver and display equipment that are used on board the aircraft the following standards are applicable:

- RTCA DO – 229D – (Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment).
- FAA TSO C145b – (Airborne Navigation Sensors Using The Global Positioning System Augmented By The Satellite Based Augmentation System).
- FAA TSO C146b – (Stand-Alone Airborne Navigation Equipment Using The Global Positioning System Augmented By The Satellite Based Augmentation System).

3 SOAP flight simulation

3.1 Scope

3.1.1 This section reports on the piloted simulation trials that were performed to assess the SOAP concept. It includes descriptions of the trials design and the simulation facility used, and also presents the results and conclusions.

3.2 Simulation objectives

3.2.1 The SOAP concept includes features that are novel in the context of offshore approaches such as an ILS look-alike vertically guided descent segment and a fixed lateral offset. A complete description of the procedure is presented in Section 2. The objectives of the piloted simulation trials were to assess the flyability of the new procedure in a representative scenario, and to evaluate the influence of some design parameters. Also, as a result of the involvement of pilots from the offshore industry, initial feedback on the acceptability of the procedure to the helicopter operators was expected.

3.3 Simulation environment

3.3.1 Simulation facility

3.3.1.1 The simulator trials were performed using the Eurocopter R&D simulator (SPHERE) located in Marignane, near Marseilles, in France. The main features of the SPHERE flight simulator are:

- Fixed-base platform.
- Side-by-side experimental cockpit (NH90-like).
- Spherical image projection in 8 m diameter dome (Field-of-view: 180° H x 80° V).
- 80 x 80 km database representing the Marignane area.
- Reconfigurable cockpit controls and displays.
- Various Eurocopter helicopter models (civil and military).
- Adjustable atmospheric conditions:
  - o Wind, speed and direction.
  - o Cloud ceiling.
  - o Horizontal visibility.

3.3.1.2 For the purposes of the offshore approach scenario, an offshore installation model was added to the marine area of the visual database. The layout of the offshore installation visual model is presented in Figure 3.1.

3.3.2 Helicopter simulation model

3.3.2.1 A simulation model of the Eurocopter EC225 was used for the trials. The EC225 is a modern transport helicopter (11 tons / 19 passengers) which is currently used by many operators in the North Sea. It includes a 'glass cockpit' with Electronic Flight Instruments (EFIS) and an advanced Automatic Flight Control System (AFCS).

3.3.2.2 The EC225 simulation model that was used for the trials is representative of the real helicopter in terms of:

- Flight mechanics.
- Control grips, travels and forces (Force Feel System).
- Primary Flight Display (PFD) and Navigation Display (ND) information.
- Automatic Flight Control System (AFCS) stabilisation and upper-modes.

3.3.2.3 Weather radar information is not displayed; the offshore installation is presented as a waypoint on the ND.

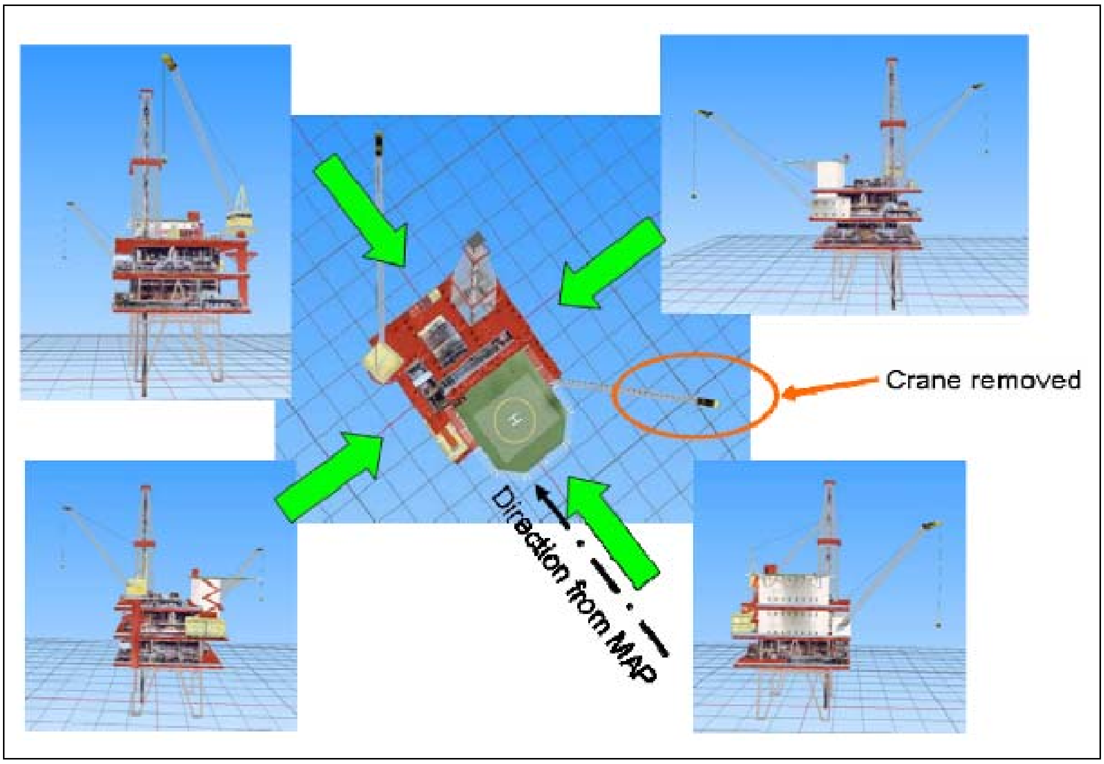


Figure 3.1 Overview of simulator offshore installation model

3.3.3 AFCS model

3.3.3.1 The EC225 AFCS is a 4-axis auto-pilot designed to relieve pilot workload both in 'hands-on' and 'hands-off' conditions. In nominal (basic) mode, it provides long term 'hands-off' pitch / roll attitude retention and extended fly-through capabilities, including command decoupling, throughout the whole flight envelope.

3.3.3.2 In hover and low speed (below 40 Kt airspeed), the AFCS provides heading hold and trim follow-up. In forward flight (above 40 Kt airspeed), the AFCS provides automatic turn co-ordination.

3.3.3.3 The EC225 AFCS also provides upper-modes that can be coupled to the Flight Management System (FMS):

- ALT, barometric altitude hold.
- IAS, air speed hold.
- HDG, heading hold.
- ALT.A, barometric altitude acquire.
- VS, vertical speed hold.
- NAV, navigation computer steering roll follow-up.
- VOR, V.O.R. course capture and track.
- LOC, localiser beam capture and track.
- G/S, glide slope beam capture and track.
- BC, back course.
- GA, go around.
- CR.HT, cruise radio altimeter height.

3.3.3.4 In the context of the offshore approach procedure simulation, the following upper-modes were used: ALT, IAS, HDG, ALTA and VS. Coupling with the FMS was not available in the simulation, so all approaches were flown manually either by using the upper modes or, in few cases, by using only the basic AFCS mode.

3.3.4 Guidance displays

3.3.4.1 Primary Flight Display (PFD)

a) Lateral and vertical guidance were displayed on the PFD. The course deviation was displayed on the HSI located below the attitude indicator (artificial horizon), as on the actual aircraft and is illustrated in Figure 3.2.

b) Lateral display sensitivity was based on the DO – 229D standard applicable to SBAS receivers and is illustrated in Figure 3.3. The full scale deflection angle of ± 2° provides a lateral sensitivity similar to a conventional ILS Course Deviation Indicator (CDI).

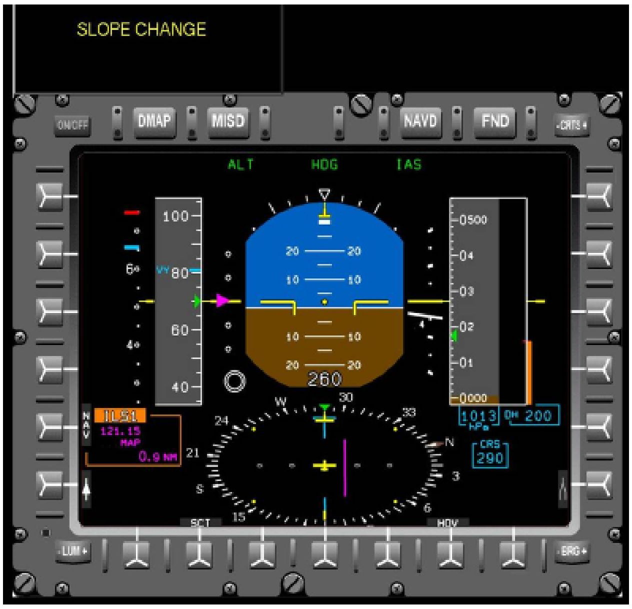


Figure 3.2 View of Primary Flight Display

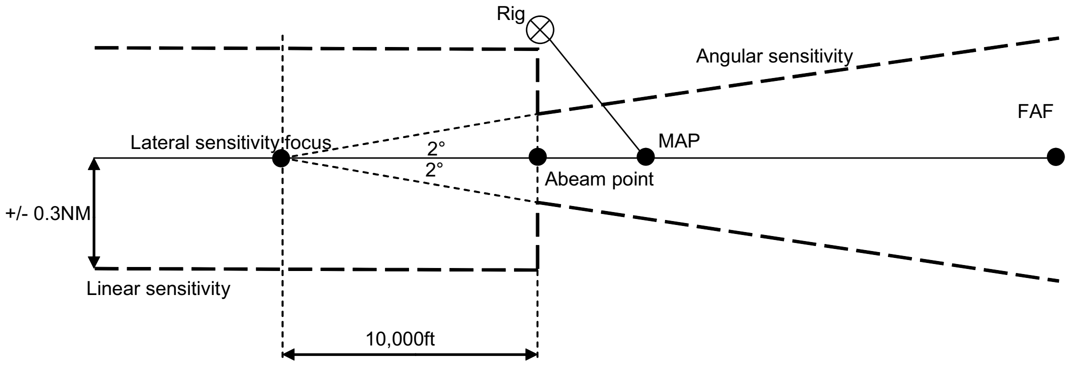


Figure 3.3 Lateral display sensitivity

c) For vertical guidance, two options were defined for assessment:

- Procedural guidance[2]: An ILS look-alike glide slope was provided for the descent segment. A vertical deviation scale (magenta bug) was located to the left of the attitude indicator, as on the actual aircraft. Full scale angular deviation depends on the Glide Path Angle (slope) and is equal to ± GPA/4.

  This angular scaling is consistent with DO – 229D requirements and provides a vertical sensitivity similar to a conventional ILS Glide Slope Deviation Indicator (GSI).

  No vertical guidance was provided along the level segment. Upon approaching the MDA, the pilot levels off and then maintains altitude (200 ft ASL) using the radio altimeter indicator.

- Full ILS-like guidance: In addition to the ILS-like glide slope on the descent segment, a linear vertical deviation scale was provided for the level segment as illustrated in Figure 3.3. Vertical sensitivity on the level segment was ± 50 ft, which is consistent with the pseudo-glide slope sensitivity at 200 ft, the nominal MDA.

  No fairing between the angular and the linear scale was implemented due to time constraints. When approaching the MDA, the pilots were instructed to depart from the glide slope guidance for few seconds in order to smooth the level-off. To assist anticipation of this manoeuvre, a flashing "SLOPE CHANGE" alpha-numeric indication was presented on the PFD at 200 ft above MDA.

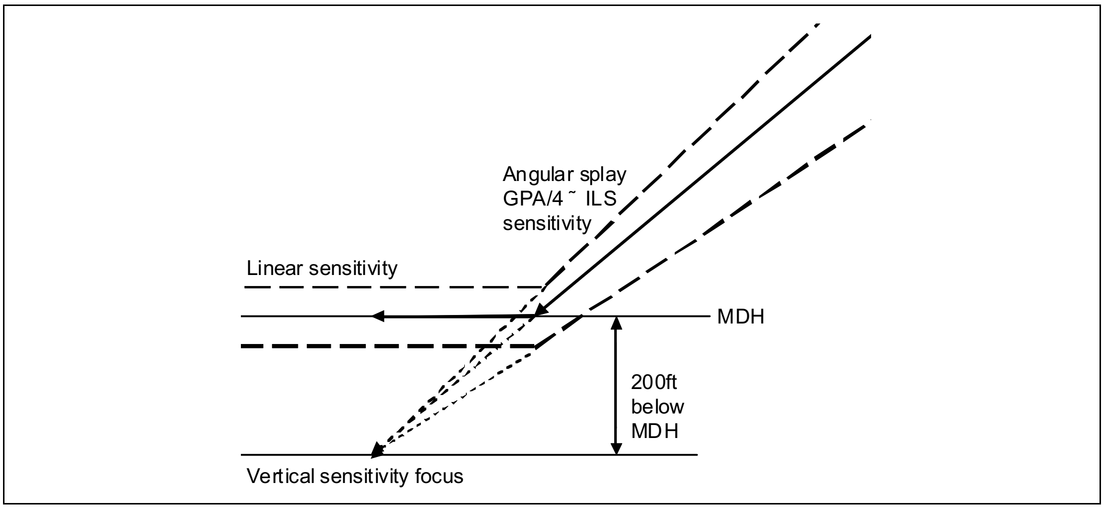


Figure 3.4 Vertical display sensitivity

d) At the bottom left of the PFD, either Distance-to-MAP or Distance-to-Rig was displayed in alphanumeric format (see Section 3.4.5, Principal Testing Parameters).

3.3.4.2 Navigation Display (ND)

a) The position of the helicopter in the horizontal plane was presented on the Navigation Display (see Figure 3.5) located to the left of the PFD. In addition to the approach waypoints, which were displayed conventionally, the beginning of the level segment (identified as "D") and the destination position were also presented. The scaling of the display could be adjusted using the RNG keys on the left side of the display.

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[2] It should be noted that the original plan for the procedural guidance was to use the ALT.A AFCS mode to descend from MSA to MDA at the FAF, i.e. there was to be no vertical guidance per se. The motivation for this was that CAA Norway was planning to implement an interim solution using GPS for lateral guidance only. The procedural guidance actually implemented was the result of a misunderstanding.

b) Other relevant information, such as alphanumeric indications of course, distance / time to next waypoint and groundspeed (G/S) were also presented.

Figure 3.5 View of Navigation Display

3.4 Scenario and test matrix

3.4.1 Off-shore approach procedure

3.4.1.1 An approach procedure representative of the new concept described in Section 2 was defined for the purpose of the simulator trials. The procedure comprised a straight-in track from the Initial Approach Fix (IAF) to the Missed Approach Point (MAP). The procedure comprised the following four segments:

- Initial segment (IAF to FAF): Level segment at 1500 ft / Course 290° / Length 2 NM (baseline).
- Descent segment (FAF to Level-off at 200 ft MDA): Straight-in descent / Course 290° / two slope options: 4° (baseline) and 6°.
- Level segment (to MAP): Course 290° / Height 200 ft / Length 0.75 NM (option: 0.5 NM).
- Visual segment (MAP to Destination): Course 320° (30° geometric offset) / 200 ft (also 50 ft above helideck) / two length (MDR) options: 0.5 NM and 0.75 NM.

3.4.1.2 A view of the vertical profile of the procedure, for 0.5 NM MDR, is shown in Figure 3.6 below .

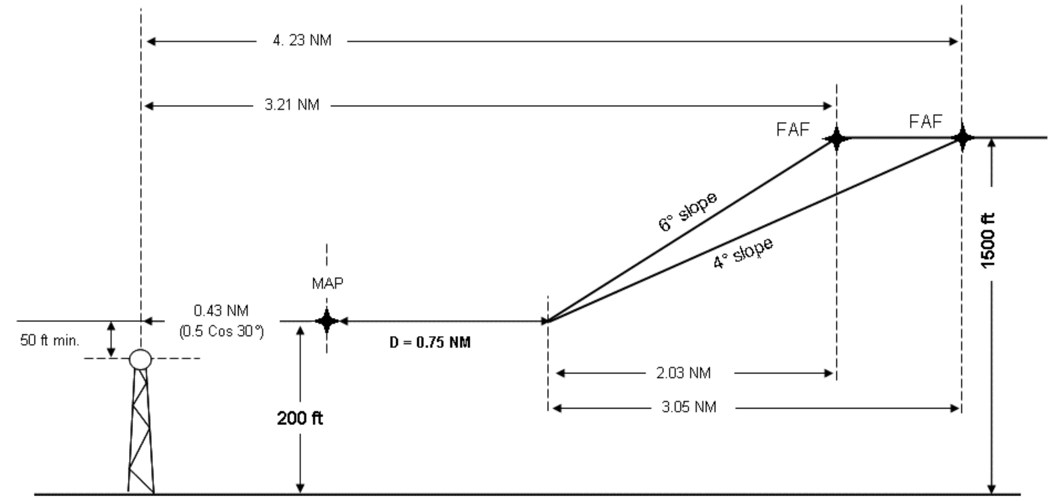

Figure 3.6 Vertical profile of the SOAP

3.4.2 Visual environment

3.4.2.1 A daylight degraded visual environment was selected for the trials. The cloud ceiling and met visibility were adjusted to reproduce the most demanding condition for the final approach; i.e. when visual contact with the destination can be established just prior to the MAP. To achieve this condition, the met visibility was set to MDR + 0.1 NM.

3.4.3 Wind conditions

3.4.3.1 Most of the trials were conducted without wind. However, for some test cases, a constant wind was introduced to generate critical or specific conditions.

3.4.3.2 Initially, it was planned to introduce a left crosswind (200°) to increase the offset angle to 45° (22/16 kt wind speed for 80/60 kt airspeed respectively). This option, which requires the final visual segment (course 320°) to be flown with a strong tail wind component, was judged irrelevant by all the pilots and consequently discarded from the test matrix. However, left crosswinds of a smaller magnitude (15/10 kt) were included to assess the acceptability of a light tail wind component during the deceleration to the destination. Right crosswind conditions (020°) were judged the most representative for the approach layout (destination on the right side of the approach course) and were introduced to assess the impact on the final deceleration during the visual segment.

3.4.4 Initialisation settings

3.4.4.1 All runs were initialised at a distance of 4 NM from the IAF. Helicopter altitude and heading were set to 2000 ft and 260°, respectively. Initial airspeed was set to 80 kt. To intercept the final approach course shortly before the IAF, the pilots had to maintain the initial heading (260°) while initiating a descent to 1500 ft altitude.

3.4.4.2 As no specific speed constraint was imposed at the IAF, the initial airspeed was retained during most of the runs throughout the initial descent to the IAF.

3.4.5 Principal test parameters

3.4.5.1 A set of principal parameters to be tested were defined before the trials and then used to build a test matrix.

- Minimum Decision Range (MDR): This parameter represents the distance of the MAP from the destination and, hence, is the length of the visual segment. Two values were considered: 0.5 NM and 0.75 NM. The latter value (0.75 NM) corresponds to the MDR which is currently used for ARA approaches. The main objective of the trials was to assess the maximum groundspeed at the MAP for achieving a smooth deceleration to hover near the helideck for each MDR.
- Distance presented on Primary Flight Display: Two options were proposed: 'MAP' or 'helideck'. Presenting the distance to the destination helideck is consistent with the current ARA approach where the pilot continuously monitors the remaining distance to the destination as it appears on the display and was the preferred option in the earlier work [Ref. 5]. Displaying the distance to the MAP is consistent with standard on-shore non-precision approach (NPA) GPS point-in-space (PINS) procedures where distance to next waypoint, including the MAP, is presented to the pilot.
- Vertical guidance display: Two options were presented: 'Full ILS look-alike' or 'procedural'.
- Angle of descent slope (glide path angle): A 4° slope was selected as the baseline. A 6° slope was proposed as an option as a steeper slope could be beneficial in an obstacle rich environment, e.g. in a field comprising several offshore installations.

- Maximum offset angle: The geometric offset angle (i.e. the bearing of the destination from the approach track at the MAP) was set to 30°. A test option of a 45° offset angle was contrived by introducing a left cross wind.
- Met Visibility: The met visibility was always set to the appropriate minimum for the MDR. Although simulation of a visibility less than MDR was considered in order to assess go around conditions, this option was discarded by the pilots because they judged it to be of little interest.
- Final approach airspeed: The baseline was set at 80 kt and used for most of the approaches. An airspeed of 60 kt was also proposed as an option, in particular in order to limit the descent rate when flying 6° descent slope approaches.

3.5 Control strategy

3.5.1 The control strategy (i.e. the way the pilot uses the autopilot functions) has a major impact on pilot workload and consequently had to be clearly identified before the trials. It should be noted that all the pilots selected the same strategy for flying the instrument segments of the approaches, and this common strategy appeared to be the best adapted to take benefit of the autopilot upper-modes available.

3.5.2 For the visual segment (MAP to destination), some differences in control strategy were noticed. One pilot initiated the deceleration before starting the turn towards the destination whereas others preferred to complete the turn first.

3.5.3 The control strategy employed by the pilots during the trials is presented by approach phase in Table 3.1.

Table 3.1 Control strategy per phase of the approach

Phase of Approach	Altitude / Height control	Track control	Speed control
Initialisation point ➡ IAF (descent from 2000 to 1500 ft and approach course capture)	ALT or ALTA 1500 ft altitude selection and capture	HDG Final course (290°) interception and capture	IAS
Initial approach: IAF ➡ FAF	ALT DA preset (200 ft) before FAF ALTA engagement shortly before G/S interception	HDG Adjustments of heading reference to keep track when necessary	IAS Airspeed reduction to meet desired speed at FAF
Descent: FAF➡ Level-Off	ALTA VS reference adjustment to match required descent rate and maintain G/S	HDG Adjustments of heading reference to keep track when necessary	IAS

Table 3.1 Control strategy per phase of the approach (Continued)

Phase of Approach	Altitude / Height control	Track control	Speed control
Level segment: Level-Off ➡ MAP	ALTA ➡ ALT Automatic switch to ALT 300 ft above DA Automatic levelling at DA	HDG Adjustments of heading reference to keep track when necessary	IAS If required, airspeed reduction to meet desired groundspeed at MAP
Visual segment: MAP ➡ Destination Right turn towards destination and deceleration to hover)	ALT ➡ manual Keep DA, then shallow climb to achieve hover > 50 ft above helideck	HDG or manual Right turn through heading reference adjustment	IAS ➡ manual Deceleration to 30 kt then manual control

3.6 Results overview

3.6.1 Pilots feedback on simulation quality

3.6.1.1 The quality of the simulation was generally judged to be good and well suited to the objectives of the trials. The lack of motion cues (the simulator was fixed base) was somewhat disturbing when trying to hover and land on the helideck, but this manoeuvre was peripheral to the scope of the trials.

3.6.1.2 The fidelity of the EC225 model was judged to be adequate, in particular by those having real flight experience of this helicopter type. However, a few minor discrepancies with respect to the actual aircraft concerning information displayed and AFCS interface were highlighted. These discrepancies were not significant in the context of the trials except, perhaps, the absence of the track vector indication on the HSI.

3.6.1.3 The visual scenery was also judged to be generally adequate. However, one pilot complained about the lack of stereoscopic (3-D) perception when flying towards the destination, increasing the difficulty in controlling the deceleration to the hover alongside the helideck.

3.6.2 Pilot feedback on test parameters

- **MDR / Groundspeed at MAP trade-off:** The final deceleration to the destination was confirmed as being the most critical phase of the approach.
  - For the 0.5 NM MDR, a groundspeed (G/S) of 80 kt at the MAP was judged much too high. A maximum groundspeed of 60 kt at MAP was judged adequate for achieving a smooth and safe deceleration to the hover alongside the helideck. A 50 kt G/S was judged even more comfortable as it provided more time margin for performing the deceleration.
  - For the 0.75 NM MDR, the deceleration was easier to achieve and a maximum G/S at the MAP of 80 kt was judged acceptable.
- **Distance presented on the Primary Flight Display:** The pilots were unanimously in favour of displaying only the distance to the MAP on the primary flight display. Displaying distance to the destination was judged of little interest, even after passing the MAP because the MAP-to-destination distance is fixed by the

procedure and supposed to be known by the pilot. Moreover, the final deceleration is flown visually and the installation position remains displayed on the navigation display.

- **Vertical guidance display:** The first team of three pilots judged the 'procedural' display very adequate to fly the approach when all the required AFCS upper-modes were available, ALTA in particular which provides automatic level-off and altitude hold. Consequently, the first team of three pilots flew almost all approaches with the 'procedural' display. The lack of a vertical guidance display along the level segment was not a concern except in the case of AFCS degradation in the vertical axis (e.g. collective trim failure). In such a case, the vertical guidance (± 50 ft linear scale) provided by the 'Full ILS look-alike' display was judged helpful to accurately maintain altitude.

  The second team of three pilots preferred the 'Full ILS look-alike' display in all circumstances and consequently flew most of the approaches using this display configuration. However, they also recognised that the 'procedural' display was adequate when the AFCS was fully operative.

  For each display concept ('procedural' or 'Full ILS look-alike'), remarks were made about the implementation in the simulator:

- **Procedural display:** The glide slope indication should disappear at the start of the level-off manoeuvre. Otherwise, displaying a descent indication when flying the level segment (still in IMC) was considered very disturbing.
- **Full 'ILS look-alike' display:** For the simulation trials, there was no fairing between the descent slope and the level segment. This resulted in a downward transient of the glide slope index when initiating the level-off manoeuvre. This transient was judged disturbing by all the pilots. Consequently, if the 'Full ILS look-alike' display configuration is selected for a future application, the need for fairing between the decent and level segments is definitely confirmed.
- **Angle of descent slope (glide path angle):** The 4° slope (baseline) was judged acceptable for passenger comfort when flown at 80 kt; the descent rate is approximately 560 ft/min for 80 kt G/S. In the case of a headwind component (the most likely situation), G/S and therefore descent rate will be lower.

  For the 6° slope, the descent rate at 80 kt G/S was judged to be definitely too high (850 ft/min); this both for passenger comfort and pilot workload during the descent. However, a clean (without overshoot) levelling off manoeuvre was still achievable by using the ALTA mode. A 60 kt G/S resulted in a descent rate of 650 ft/min which was judged to be acceptable.

- **Maximum offset angle:** It appeared during the trials that, even for the 30° offset baseline, the heading change required significantly exceeded 30°. Performing the turn at the MAP takes some distance which needs to be compensated for by increasing the heading change. As it is related to the turn radius, the additional heading change increases with G/S. Finally, taking this effect into account, all the pilots considered the 30° offset angle to be the maximum acceptable. Regardless of the tail wind issues, the few runs that were performed with a left crosswind to generate a larger effective offset angle (45°) were judged unacceptable both in terms of visual acquisition of the destination (the pilot's view of the destination may be obstructed by the front window strut), and the required heading change at the MAP.
- **Final approach airspeed:** This parameter is strongly correlated to the descent slope angle and to the MDR due to descent rate and deceleration constraints respectively. Both constraints are, in fact, related to groundspeed which means that the final airspeed to be acquired prior to the FAF must be adjusted depending

on the wind conditions to ensure that the G/S doesn't exceed 80 kt (60 kt for 6° slope) along the descent segment and at the MAP (60 kt for MDR reduced to 0.5 NM).

For a standard slope (4°) and 0.5 NM MDR, the pilot has two options. He can either fly the entire approach at 60 kt G/S or fly the descent at 80 kt G/S and then to decelerate to 60 kt G/S during the level segment. Although theoretically possible, decelerating in the descent segment is not recommended due to the increase in pilot workload.

The first option is the easiest to fly but leads to wasted time in the descent segment where 80 kt G/S could be used while still meeting the maximum descent rate constraint.

The second option is more efficient and was also assessed by the pilots during the trials. The unanimous opinion is that decelerating from 80 to 60 kt along the level segment is easily achievable by decreasing the IAS reference by 20 kt while letting the ALT mode maintain height during the deceleration. However, when no upper modes are available, flying such a deceleration manually at a low height over sea level was judged to be too demanding. Consequently, in the event of AFCS unavailability or degradation, the entire approach should be flown at 60 kt G/S.

- **Length of level segment:** This length was set to 0.75 NM for all the scheduled test cases and was considered to be adequate by all the pilots. A reduced length of 0.5 NM was also assessed by one pilot to see whether this could be acceptable, in particular when performing a deceleration from 80 to 60 kt during the level segment. The pilot concluded that, with upper AFCS modes engaged, a 0.5 NM length was sufficient to level off and to perform the deceleration without excessive workload. That means a level segment of 0.5 NM could be considered as a possible option to shorten the approach, if required, but would need to be subject to further assessment.
- **FAF-to-destination distance:** The approaches were designed with the objective of keeping at least 4 NM distance between the FAF and the destination in keeping with the current ARA. This objective could be met for the 4° slope approaches whatever the MDR, but not for the 6° slope without raising the altitude of the initial segment.

3.6.2.1 Finally, the pilots concluded that the overall length of the final approach, from FAF to destination, is not a relevant parameter for this type of procedure where all segments are defined by specific design constraints.

3.7 Flight parameters survey

3.7.1 To keep traceability of the experiment, almost all the simulation runs performed were recorded. The following flight parameters were of interest:

- From FAF to MAP (instrument flight):
  - Vertical profile throughout the descent segment.
  - Vertical profile throughout the level-off manoeuvre and DA capture.
  - Lateral deviation with respect to the approach track.
  - Airspeed and vertical speed.
- From MAP to Installation (visual flight):
  - Vertical profile.
  - Trajectory in the horizontal plane.
  - Groundspeed.
  - Deceleration rate.

3.7.2 It is not possible to present all the cases evaluated in this document. Only a few typical examples are described in the following paragraphs.

3.7.3 FAF to MAP segments

3.7.3.1 Figures containing the simulation results are presented in Annex B.

3.7.3.2 **Test cases 2 & 3 (Figures B.1 & B.2):** Covering the flight paths achieved for the nominal test case (4° slope / no wind), with 'ILS look-alike' and 'Procedural' guidance respectively. The tracking accuracy looks good in both cases. The type of guidance display is not a factor as the level off manoeuvre was performed automatically using the ALT mode (after having preset ALTA at 200 ft) in both cases.

3.7.3.3 **Test case 5a (Figure B.3):** Covering the 4° slope approach with a 22 kt cross wind from the right (020°). Although, there was no track vector indication, drift correction (to 15°) is managed fairly well and the resulting tracking accuracy is still good.

3.7.3.4 **Test case 4 (Figure B.4):** Covering the 6° slope approach flown at 80 kt IAS in zero wind conditions. Although, the average descent rate is considered definitely too high by the pilots, the ALT mode is still able to level off at the 200 ft preset altitude without noticeable overshoot.

3.7.3.5 **Test case 15a (Figure B.5):** Covering the 4° slope approach flown with 16 kt cross wind from the right (020°) in which the pilot achieved an airspeed reduction from 80 kt to 60 kt during the level segment. Despite the need to adjust the drift correction while speed is reducing, a fair tracking accuracy is achieved. Altitude is also well maintained during deceleration along the level segment.

3.7.3.6 **Test case 11b (Figure B.6):** Covering the 6° slope approach flown in zero wind conditions and all AFCS modes disengaged. The flight path tracking performance is somewhat degraded but is nevertheless still within the allowed boundaries, in particular within the ± 50 ft vertical corridor in the level segment.

3.7.4 MAP to Installation segment

3.7.4.1 **Test case 4 (Figure B.7):** Covering the 0.5 NM MDR / no wind case. When starting from 80 kt G/S at the MAP, the pilot could not decelerate to less than 40 kt IAS in the vicinity of the destination.

3.7.4.2 **Test case 5a (Figure B.8):** Covering the 0.5 NM MDR / 22 kt wind from 020° case. Turning into the wind allows the pilot to decelerate to 20 kt G/S close to the destination, which is considered appropriate for initiating a landing sequence (not performed during this run).

3.7.4.3 **Test case 7a (Figure B.9):** Covering the 0.5 MDR / no wind case. The reduced speed at the MAP (60 kt G/S) allows the pilot to decelerate to a low G/S close to the destination and then land on the helideck.

3.7.4.4 **Test case 8 (Figure B.10):** Covering the 0.75 MDR / no wind case. As a result of the longer MDR, deceleration to the destination is no longer an issue even with 80 kt G/S at the MAP. 40 kt G/S is reached at 0.3 NM before the destination which is appropriate for initiating a landing sequence (not performed during this run).

3.8 Conclusions

3.8.1 The simulation trials allowed the flyability of the new offshore approach procedure based on EGNOS guidance to be assessed. Almost 80 simulation runs were performed over 4 days, divided between two sessions (1.5 and 2.5 days). Referring to the analysis of the results and to the feedback of the 6 pilots involved in the trials, the main conclusions are summarised below:

- The simulation environment (visual scenery and EC225 helicopter model) provided by the Eurocopter SPHERE flight simulator was judged to be sufficiently representative for the purposes of the trials.
- The procedure was judged easy to fly due, in particular, to the efficient upper modes of the EC225 AFCS (Airspeed Hold, Altitude Hold, Altitude Acquire & Hold, and Vertical Speed Hold). The most demanding task was definitely the deceleration to destination during the final visual segment.
- 'ILS look-alike' guidance on the descent segment is clearly an improvement compared to the current laterally only guided procedures.
- In nominal, conditions, the 'procedural' approach flown to a minimum radio altimeter height was judged to be sufficient, particularly when flown coupled. However, 'ILS look-alike' guidance on level segment is beneficial, both in normal day to day operation as well as in the case of AFCS degradation on the vertical axis (e.g. collective trim failure) or when the crew choose to manually fly the approach.
- The distance to MAP display was preferred over the distance to destination.
- A 4° descent slope is acceptable at 80 kt Ground Speed (G/S) in terms of passengers comfort and flyability. A 6° slope is acceptable only if the G/S reduced to 60 kt.
- The maximum acceptable installation offset angle is 30°.
- For a 0.75 NM MDR, the maximum acceptable G/S at the MAP is 80 kt.
- For a 0.5 NM MDR, the maximum acceptable G/S at the MAP is 60 kt.
- To achieve 60 kt at the MAP, decelerating from 80 to 60 kt along the level segment appears to be a good option provided that all AFCS modes are available. In the case of AFCS unavailability or degradation, the entire approach must be flown at 60 kt G/S, i.e. 60 kt IAS in zero wind.
- A length of 0.75 NM for the level segment is a good compromise but a reduction to 0.5 NM, if necessary for obstacle clearance, could still be acceptable but would need to be subject to further assessment.
- Tailwind conditions in the final visual segment (MAP to destination), are definitely not acceptable. There is therefore a need to define several approach courses for each platform to cope with different wind directions.
- With the ‘procedural’ approach, the glide slope guidance should be removed at the level-off point.

4 SOAP safety assessment

4.1 Introduction

4.1.1 This section contains the safety assessment of the SOAP procedure.

4.2 Methodology

4.2.1 The methodology used in the safety assessment employs a two-part approach, analysing both the success and failure cases of the procedure. These are defined as follows:

- Success case: In the success case, all equipment that is used during the procedure operates according to the design specifications. Additionally, the flight crew involved follow all procedures, operate the aircraft and equipment correctly, and fully observe and react correctly to all external factors.

- Failure case: In the failure case, one or more hazards occur resulting in a potential conflict. An assessment of the likely probability and severity of the consequence of the hazard is made for each of the failure cases.

4.2.2 The success case

4.2.2.1 Analysis of the success case is required as the EGNOS-enabled offshore approach (SOAP) represents a new procedure, and the performance of the equipment while operating correctly has not previously been assessed. The success case is described in Section 4.4.

4.2.3 The failure case

4.2.3.1 The analysis of the failure case is based on the criteria of JAA AMC 25.1309 as for the hazard assessments previously conducted and reported in CAA Paper 2009/06 [Ref. 1]. Although this is normally applied to airborne operations, the study also considers the Air Traffic Management (ATM) risks that encompass air and ground systems.

4.2.3.2 The study began with a hazard identification. The hazards result from human, equipment or procedural failures. The potential consequences of each of the hazards were also identified at this stage to aid with the development of the conflict scenarios.

4.2.3.3 The hazards were consolidated, eliminating duplicate and overlapping hazards, and were associated with conflict scenarios. A conflict scenario represents an operational consequence of a hazard.

4.2.3.4 Each conflict scenario was then assessed for its severity. The risk classification scheme used in the hazard analysis was taken from JAA AMJ 25.1309-25 [Ref 8]. The JAA severity classification is reproduced in Table 4.1.

Table 4.1 JAA AMJ 25.1309 severity classification

Severity	Description
Catastrophic	Failure conditions that would prevent continued safe flight and landing.
Hazardous	Failure conditions that would reduce the capability of the aircraft or the ability of the crew to cope with adverse operating conditions to the extent that there would be: - a large reduction in safety margins or functional capabilities, – physical distress or higher workload such that the flight crew cannot be relied upon to perform their task accurately or completely, or – serious injury or fatal injury to a relatively small number of the occupants.
Major	Failure conditions which would reduce the capability of the aircraft or the ability of the crew to cope with adverse operating conditions to the extent that there would be, for example: – a significant reduction in safety margins or functional capabilities, – a significant increase in crew workload or in conditions impairing crew efficiency, or – discomfort to occupants, possibly including injuries.
Minor	Failure conditions which would not significantly reduce aircraft safety, and which involve crew actions that are well within their capabilities. Minor failure conditions may include, for example: – slight reduction of safety margins, – slight increase in crew workload, or – some inconvenience to occupants.

4.2.3.5 The probability classification, both quantitative and qualitative, is also based on JAA AMJ 25.1309 and is reproduced below.

Table 4.2 JAA AMJ 25.1309 probability classification

Frequency category	Qualitative description	Quantitative description
PROBABLE	Anticipated to occur one or more times during the entire operational life of each aeroplane.	Failure condition frequency is more than 10^{-5} per aircraft flight hour.
REMOTE	Unlikely to occur to each aeroplane during its total operational life but which may occur several times when considering the total operational life of a number of aeroplanes of the type.	Failure condition frequency is between 10^{-7} and 10^{-5} per aircraft flight hour.
EXTREMELY REMOTE	Unlikely to occur when considering the total operational life of all aeroplanes of the type, but nevertheless, has to be considered as being possible.	Failure condition frequency is between 10^{-9} and 10^{-7} per aircraft flight hour.
EXTREMELY IMPROBABLE	So unlikely that they are not anticipated to occur during the entire operational life of all aeroplanes of one type.	Failure condition frequency is less than 10^{-9} per aircraft flight hour.

4.2.3.6 The severity and probability classifications for each conflict scenario were combined to determine the corresponding risk for comparison with the JAA AMJ 25.1309 risk matrix reproduced below.

Table 4.3 JAA AMJ 25.1309 matrix

		Severity			
		Catastrophic	**Hazardous**	**Major**	**Minor**
Frequency	**Probable**	UNACCEPTABLE	UNACCEPTABLE	UNACCEPTABLE	TOLERABLE
	Remote	UNACCEPTABLE	UNACCEPTABLE	TOLERABLE	NEGLIGIBLE
	Extremely remote	UNACCEPTABLE	TOLERABLE	NEGLIGIBLE	NEGLIGIBLE
	Extremely improbable	TOLERABLE	NEGLIGIBLE	NEGLIGIBLE	NEGLIGIBLE

4.2.3.7 In the JAA AMJ 25.1309 assessment procedure, an operation is deemed to be safe if all the risks are negligible. Tolerable risks are acceptable subject to review and/or mitigation. If any risk is found to be unacceptable, then additional systems and/or procedures should be defined to reduce the risk to no worse than tolerable.

4.2.3.8 For this study, the term 'tolerable' has been interpreted to mean 'acceptable in the short/medium term'. It is assumed that a longer-term solution will be sought to reduce the chance of any such hazards to 'negligible'.

4.2.3.9 Although there is no 'negligible' category for catastrophic failures in AMJ 25.1309, a frequency of less than 10^{-11} per flight hour has been assumed for this safety assessment.

4.2.3.10 The AMJ 25.1309 matrix is also ambiguous in respect of the severity to be assigned at the boundaries between the different frequency categories (i.e. 10^{-5}, 10^{-7}, 10^{-9} or 10^{-11}). Clearer boundaries have therefore been defined, and the modified risk matrix is shown in Table 4.4.

4.2.3.11 It is important to note that the results of the hazard analyses contained in this report should be used as a guide and not interpreted literally. Expert judgement has inevitably been required in the analysis and there is consequently a degree of uncertainty in the figures produced. In general, the study has taken a conservative view and it is possible that a marginally 'unacceptable' risk may in fact be considered 'acceptable' or vice-versa.

Table 4.4 Adapted risk matrix

		Severity			
		Catastrophic	**Hazardous**	**Major**	**Minor**
Frequency	**Probable ($f > 10^{-5}$)**	UNACCEPTABLE	UNACCEPTABLE	UNACCEPTABLE	TOLERABLE
	Remote ($10^{-5} \geq f > 10^{-7}$)	UNACCEPTABLE	UNACCEPTABLE	TOLERABLE	NEGLIGIBLE
	Extremely remote ($10^{-7} \geq f > 10^{-9}$)	UNACCEPTABLE	TOLERABLE	NEGLIGIBLE	NEGLIGIBLE
	Extremely improbable ($10^{-9} \geq f > 10^{-11}$)	TOLERABLE	NEGLIGIBLE	NEGLIGIBLE	NEGLIGIBLE
	Less than extremely improbable ($f \leq 10^{-11}$)	NEGLIGIBLE	NEGLIGIBLE	NEGLIGIBLE	NEGLIGIBLE

4.3 Systems in use

4.3.1 For this procedure, and in compliance with the requirements of JAR OPS 3, this safety assessment assumes that the following equipment is available for operational use on board the aircraft:

- EGNOS receiver and associated CDI, FD or equivalent.
- Weather radar.
- Barometric altimeter.
- Radio altimeter.
- Displays.
- Compass.

4.3.2 In the case of the EGNOS receiver, the equipment deemed operational within this hazard analysis is assumed to be generically compliant with the standards and specifications contained in RTCA DO–229D.

4.3.3 In the case of the weather radar, previous work [Ref 1] has determined that the Bendix RDR–1400 weather radar system is typical of airborne weather radars in terms of performance and specification.

4.4 Analysis of success case

4.4.1 General

4.4.1.1 The analysis within this section assumes that all avionics systems operate according to design limits and specifications, and that the flight crew correctly operate all equipment and follow standard operating procedures. The analysis establishes whether, given the design limits of the equipment and the procedures, the safety limits of the procedure are acceptable and whether there is any likelihood that a helicopter flying the procedure would be placed in danger.

4.4.1.2 The analysis considers:

- Navigation System Error (NSE): the performance of the EGNOS system for horizontal and vertical guidance accuracy.
- Flight Technical Error (FTE): the ability of the flight crew / aircraft to fly accurately along the track that the EGNOS system specifies.

4.4.1.3 The analysis estimates a likely closest point of approach in the lateral and vertical profiles considering the contributions from the EGNOS system, the radio altimeter and the flight crew in maintaining the intended flight path.

4.4.2 Navigation System Error (NSE)

4.4.2.1 General

a) The equipment that is to be carried by the aircraft for conducting the SOAP procedure and the standards to which the equipment is manufactured are listed in Section 2.5.

b) The EGNOS and associated equipment is required to maintain the aircraft on the defined approach. Whether the aircraft is flown manually or coupled will not have any effect on the NSE. The general performance requirements are summarised in the Table 4.5 extracted from [Ref 2].

Table 4.5 EGNOS Mission Requirements Document performance parameters

	Open service	En-route / NPA	APV I
Lateral accuracy	3 m	220 m	16 m
Vertical accuracy	4 m	N/A	20 m
Integrity	–	1-10^{-7} / hour	1-2x10^{-7} / 150s
Time To Alarm	–	10 s	10 s
HAL	–	0.3 NM	40 m
VAL	–	N/A	50 m
Continuity	–	1-10^{-5} / hour	1-8x10^{-6} / 15s
Global availability	0.99	0.999	N/A
Local Availability	–	N/A	0.99

c) The EGNOS equipment is to be certified initially for an accuracy of 20 meters vertically and 16 meters horizontally, both with a 95% confidence level [Ref 2]. However, typical performance will be much better than this.

4.4.2.2 **Display requirements**

a) The full scale deflection (FSD) requirements for the display during the final approach are as follows:

- Vertical FSD: 0.25 x GPA, where GPA equals the descent slope, and ± 15 meters during the level segment. The FSD at each is 2.5 dots.
- Horizontal FSD: ± 2 degrees. The FSD at each is 2.5 dots.

b) The display requirements drive the performance of the Flight Technical Error (FTE).

4.4.2.3 **Alerting requirements**

a) For the LPV type approach procedures it is a requirement of the MOPS [Ref. 3] that the Horizontal Alert Limit (HAL) and the Vertical Alert Limit (VAL) be encoded as part of the FAS data block. The HAL and the VAL are defined broadly as:

- Horizontal Alert Limit: The HAL is the radius of a circle in the horizontal plane (the local plane tangent to the WGS–84 ellipsoid), with its centre being at the true position, that describes the region which is required to contain the indicated horizontal position with the required probability for a particular navigation mode.
- Vertical Alert Limit: The VAL is half the length of a segment on the vertical axis (perpendicular to the horizontal plane of WGS–84 ellipsoid), with its centre being at the true position, that describes the region which is required to contain the indicated vertical position with the required probability for a particular navigation mode.

b) In practice, for SOAP the per-approach probability of exceeding the VAL or HAL when integrity is being provided by EGNOS is 4.8×10^{-7} (in each dimension assuming an exposure time of 360 seconds[3]).

c) Different alert limits can be applied depending on the procedure being flown. A smaller (more accurate) alert limit will reduce the availability of the EGNOS service and vice-versa. Typical alert limits are shown in Table 4.6.

Table 4.6 ICAO Annex 10 typical operational alert limits

Typical approach operation	Horizontal alert limit	Vertical alert limit
NPA	556 m (0.3 NM)	N/A
APV–I	40 m (130 ft)	50 m (164 ft)
APV–II	40.0 m (130 ft)	20 m (66 ft)
Category I precision approach	40.0 m (130 ft)	15.0 to 10.0 m (50 ft to 33 ft)

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[3] For a final approach segment of 4NM flown at 60 KIAS with a 20 knot headwind.

d) In this analysis a 40 m horizontal limit and a 35 m vertical limit[4] has been assumed. These are expected to provide good compromise between service availability and accuracy, but this will need to be confirmed in future work.

4.4.2.4 Radio altimeter accuracies

a) The accuracy of the radio altimeter varies with model. The Collins ALT–50 used in the North Sea operations has a display that indicates ground clearance from 0-2000 ft with a system accuracy of ± 2%. For the success case, the accuracies are:

- During the initial approach segment (IAF to FAF): 1500 ft x 0.02 = ± 30 ft;
- During the level segment (level off point to MAP): 250 ft x 0.02 = ± 5 ft.

4.4.3 Flight Technical Error (FTE)

4.4.3.1 Lateral FTE

a) The lateral FTE is comparable with the ability of the pilot or autopilot to comply with the guidance that is provided by the navigation sensors. In this case it is noted that the flight crew will not proceed with an approach that is one dot or more left or right off the centre line. The guidance that is provided along the approach is angular and the variation of the Full Scale Deflection (FSD) along the track is shown in Table 4.7.

Table 4.7 Lateral FSD FTE at significant procedure points

	m	ft	NM
IAF	494	1620	0.27
FAF	365	1200	0.20
MAP	135	440	0.07
Abeam point	106	350	0.06

b) As the procedure will be aborted by the flight crew when the approach is one dot or more away from the centre, the applicable maximum FTE at the various points of the approach is shown in Table 4.8.

Table 4.8 Lateral FTE at which procedure will be abandoned

	m	ft	NM
IAF	198	650	0.11
FAF	146	480	0.08
MAP	54	180	0.03
Abeam point	43	140	0.02

4.4.3.2 Vertical FTE

a) The flight crew will not proceed with an approach that is 0.5 dots or more high or low displaced from the vertical approach path. The guidance that is provided along the approach is angular until the level segment, after which the guidance is linear.

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[4] This figure, whilst currently more stringent than the EGNOS design target, represents the target figure that the EGNOS designers are seeking to justify for the use of the system in aviation. It is likely that this will represent the ultimate figure used by fixed wing aviation.

b) Along the level segment, which includes the MAP and the abeam point, the guidance at FSD is ± 15m. The vertical FTE at which the procedure will be abandoned is therefore ± 3m (± 10 ft).

4.4.4 Conclusions

4.4.4.1 Table 4.9 summarises the assumed errors contributed by the equipment and the flight crew at the MAP.

Table 4.9 Total System Error for success case

	Lateral	Vertical
EGNOS alarm limits	± 131 ft (40 m)	± 115 ft (35 m)
FTE	± 177 ft (54 m)	± 10 ft (3 m)
TOTAL SYSTEM ERROR (TSE)	**± 308 ft (94 m)**	**± 125 ft (38 m)**

4.4.4.2 Assuming that the operation of the EGNOS equipment and procedure is within limits at the commencement of the level segment on final approach, the lateral TSE provides sufficient clearance since the smallest offset distance is 0.25 NM (463 m).

4.4.4.3 The MDA of concern is 200 ft[5], which means that in a worst case scenario the helicopter could descend to 75 ft above the sea (although this would be a very unusual situation – accuracy will be much better plus the AVAD would alarm). The vertical performance is therefore sufficient to keep the aircraft clear of the sea.

4.4.4.4 If the aircraft goes below the AVAD alarm limit (which may be between 100 and 160ft depending on helicopter operator configuration) it will trigger and cause the aircraft to discontinue the approach. Tidal variations (expected to be a few metres) could also contribute to some unnecessary but infrequent AVAD alarms. Although this is undesirable, it is not expected to occur very often and could be mitigated by raising the minimum height of the level segment to a figure greater than the present 200 ft.

4.5 Failure case

4.5.1 Hazard identification

4.5.1.1 This section identifies and qualitatively assesses the hazards that are associated with the SOAP procedure conducted in accordance with the description presented in Section 2.

4.5.1.2 The hazards were identified through a HAZID session within Helios on the basis of previous work [Ref 1]. The hazards were merged into a consolidated list which is summarised in Table 4.10.

Table 4.10 Consolidated list of hazards

ID	Hazard
ID1	Guidance system displays incorrect information
ID2	Aircraft database is incorrect
ID3	Weather radar provides incorrect information
ID4	Radio altimeter displays incorrect information
ID5	Wrong wind or other information from installation

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[5] This figure is conservative since, in practice, the MDA is the higher of 200 ft or the helideck height + 50 ft by day and 300 ft or helideck height + 50 ft by night.

Table 4.10 Consolidated list of hazards (Continued)

ID	Hazard
ID6	Miscommunication between flight crew or between flight crew and installation
ID7	Flight crew error – misinterpretation of information
ID8	Flight crew error – incorrect selection/operation of equipment
ID9	Flight crew error – distraction/inattention/disorientation

4.5.1.3 Note that the hazard of total failure of the EGNOS receiver, weather radar or altimeters are not included since these would be detected by the flight crew who would, if necessary, terminate the approach.

4.5.2 Guidance system displays incorrect information (ID1)

4.5.2.1 This hazard occurs when the guidance system displays incorrect information to the flight crew. This could result from a partial or unannunciated failure of the guidance system. Failures in the guidance system are deemed to be caused through a combination of failures of the EGNOS receiver, display, or the EGNOS signals in space.

4.5.3 Aircraft database is incorrect (ID2)

4.5.3.1 This hazard occurs when the information presented by the system database for the location of installations or obstacles is incorrect. This information may be incorrect due to corruption of the navigation database or the database being out of date, either through use of the previous AIRAC cycle and the warning being ignored by the flight crew, or an installation has been moved and the NOTAM update has not been incorporated.

4.5.3.2 It is assumed within the analysis that installation locations will be published through the standard AIRAC cycle for traceability and ease of regulation. The way in which installation locations are determined and the point of survey of the installations for publication are yet to be defined.

4.5.4 Weather radar provides incorrect information (ID3)

4.5.4.1 This hazard occurs if the information displayed to the flight crew by the weather radar is incorrect. It results from a partial or unannunciated failure of the weather radar and causes incomplete, inaccurate or partial data to be displayed.

4.5.5 Radio altimeter displays incorrect information (ID4)

4.5.5.1 This hazard occurs if the height information presented to the flight crew is incorrect. This hazard occurs due to partial or unannunciated failure of the radio altimeter(s) in the final approach segment.

4.5.5.2 As described in Section 2, the final approach level segment is flown using height from the EGNOS system cross-checked with the radio altimeter. The barometric altimeter is available for use prior to the FAF and a failure of the barometric altimeter after this point would not affect the approach. On some aircraft types (e.g. EC225) the barometric and radio altimeter strip gauges are adjacent which aids the cross-check. For a sensible cross-check of the baro and radio altimeters, the baro altimeter must be set to the local pressure (QNH).

4.5.5.3 The AVAD system works in association with the radio altimeter and provides automatic height warnings at a fixed and a pilot selectable height. Some aircraft also have dual radio altimeters, each with these height warnings.

4.5.5.4 The most critical failure of a radio altimeter would be a 'stuck' height reading on an aircraft with only a single radio altimeter while the aircraft is flying at low height in low visibility.

4.5.6 Wrong wind from installation (ID5)

4.5.6.1 In this hazard the flight crew are provided with incorrect wind information prior to commencing the approach to the platform. The wind information is used by the flight crew to select the heading for the final approach. Hence, the operational consequence of this hazard is that the approach could have a significant cross-wind and the crew not be aware of it.

4.5.6.2 Note that the reported wind information can be cross-checked against the wind information provided by the GNSS receiver.

4.5.6.3 Some approaches are intentionally executed with a significant cross-wind due to obstacle restrictions. So a cross-wind approach is not necessarily a hazard in itself.

4.5.6.4 A significantly out-of-wind approach can also be detected by the aircrew if the approach is being flown manually by the need to continually make corrections to the aircraft's heading. This would provide the crew with an indication that the reported wind was not correct. During a coupled approach the flight crew may be unaware of significant differences between the forecast and the actual wind.

4.5.6.5 An unexpected cross-wind is most significant in the final visual landing phase where the helicopter is manoeuvring close to the installation and at the MAP where the destination may not appear where expected.

4.5.7 Miscommunication between flight crew or between platform and flight crew (ID6)

4.5.7.1 This hazard occurs if there is a mistake in the communication between the flight crew themselves, or between the flight crew and the destination installation. In this hazard, even if correct information is passed from the installation, the flight crew may mis-read or mis-transpose it.

4.5.8 Flight crew error – misinterpretation of information (ID7)

4.5.8.1 In this hazard the flight crew misidentify or mis-locate the destination installation, or fail to detect or mis-locate an obstacle, possibly as a result of the navigation display becoming cluttered due to the overlay of track and weather radar information.

4.5.9 Flight crew error – incorrect selection/operation of equipment (ID8)

4.5.9.1 In this hazard the flight crew make an error in the operation of equipment, for example:

- Incorrect adjustment of the weather radar (discussed in 4.5.9.2 and 4.5.9.3 below).
- Selection of the incorrect destination on the guidance system equipment.
- Selection of the incorrect final approach track (direction and/or offset).
- Incorrect adjustment of pressure setting on the baro altimeter. This hazard is less relevant since the final approach is flown using EGNOS height with the radio altimeter providing an independent cross-check and safety net.

4.5.9.2 During the SOAP procedure, the weather radar serves as an obstacle detector. The weather radar must be adjusted to provide the optimum picture for the approach. This adjustment includes gain, tilt and mode (map or weather) and will vary according to the sea state. Incorrect setting – especially of gain or tilt – could make obstacles or the destination less visible on the weather radar display.

4.5.9.3 Although the radar is usually set to map mode, at least one operator flies it in weather mode. The differences between the modes appear to be equipment specific. For the RDR 1400, the differences are in display colours and sensitivity (the map mode has adjustable sensitivity).

4.5.10 Flight crew error – distraction/inattention/disorientation (ID9)

4.5.10.1 In this hazard the flight crew makes an error through distraction, inattention or disorientation, and could result in the helicopter approaching the wrong installation or coming into conflict with an obstacle or the sea.

4.6 Conflict scenario analysis

4.6.1 General

4.6.1.1 Conflict scenarios have been used to analyse the operational impact of the hazards identified. A conflict scenario represents the operational consequence of one or more hazards.

4.6.1.2 The following conflict scenarios have been identified:

- The helicopter approaches the wrong installation (CS1).
- The helicopter comes into conflict with the sea (CS2).
- The helicopter comes into conflict with an obstacle (CS3).
- The helicopter comes into conflict with the destination installation (CS4).

4.6.1.3 Table 4.11 shows the links between each of the conflict scenarios and the hazards. Some hazards do not significantly contribute to any conflict scenarios.

Table 4.11 Relationship between hazards and conflict scenarios

Ref.	Description	CS1	CS2	CS3	CS4
ID1	Guidance system displays incorrect information		✓		✓
ID2	Aircraft database is incorrect	✓			✓
ID3	Weather radar provides incorrect information			✓	✓
ID4	Radio altimeter displays incorrect information		✓		
ID5	Wrong wind or other information from installation				
ID6	Miscommunication between flight crew or between flight crew and installation				
ID7	Flight crew error – misinterpretation of information		✓	✓	
ID8	Flight crew error – incorrect selection/operation of equipment	✓		✓	
ID9	Flight crew error – distraction/inattention/disorientation		✓	✓	

4.6.1.4 In this section, the importance of expert judgement should be noted. No quantitative data are available for some factors. The uncertainty in the probabilities calculated should be borne in mind when considering the tolerability of different events. Probabilities that have been used are derived as per the methods and assumptions presented earlier.

4.6.2 CS1: The helicopter approaches the wrong installation

4.6.2.1 Description

a) Within this conflict scenario, the helicopter approaches an installation that it had not intended to land on. Within the SOAP procedure this conflict may be caused either by flight crew error resulting from incorrect input of the destination, or by an error in the aircraft's database.

b) The following hazards have been identified that may contribute to this conflict scenario are:

- Flight crew input the incorrect destination waypoint (ID8).
- The aircraft database is incorrect (ID2).

4.6.2.2 Severity

a) Possible consequences of this conflict scenario include:

- The flight crew approach the wrong installation and come into conflict with another helicopter;
- The flight crew land on the wrong installation and it is in an unsafe condition.

b) The chain of consequences which could lead to these events is presented in Table 4.12.

Table 4.12 Chain of events causing Conflict Scenario 1

Event	Hazardous chain of events	Severity
A) The flight crew approach the wrong installation and come into conflict with another helicopter	Flight crew enter incorrect installation OR The aircraft database is incorrect AND Helicopter approaches the wrong installation AND Another helicopter in the vicinity AND Flight crew of both aircraft fail to see and avoid	CATASTROPHIC
B) The flight crew land on the wrong installation and it is in an unsafe condition	Flight crew enter incorrect installation OR The aircraft database is incorrect AND Helicopter approaches the wrong installation AND Flight crew fail to correctly identify installation AND Installation unsafe and flight crew not aware	CATASTROPHIC

4.6.2.3 Probability

a) Table 4.13 shows a probability for each of the events associated with CS1. The values used for the probabilities are based on analysis already undertaken in [Ref 1].

Table 4.13 Probability analysis for Conflict Scenario 1

Event	Hazardous chain of events	Probability	Source [Ref 1]
A) The flight crew approach the wrong installation and come into conflict with another helicopter	Flight crew enter incorrect installation OR The aircraft database is incorrect AND Flight crew fail to detect error AND Another helicopter in the vicinity AND Flight crew of both aircraft fail to see and avoid	1×10^{-5} 2×10^{-5} 1×10^{-3} 1×10^{-2} 1×10^{-4} Total: 3×10^{-14}	Part 3, sect. 4.3.3 Part 1, para. 4.3.3.1 Part 2, Table 4 Part 3, Table 4 Part 3, Table 4
B) The flight crew land on the wrong installation and it is in an unsafe condition	Flight crew enter incorrect installation OR The aircraft database is incorrect AND Flight crew fail to detect error AND Flight crew fail to correctly identify installation AND Installation unsafe and flight crew not aware	1×10^{-5} 2×10^{-5} 1×10^{-3} 1×10^{-2} 1×10^{-2} Total: 3×10^{-12}	Part 3, sect. 4.3.3 Part 1, para. 4.3.3.1 Part 2, Table 4 Part 2, Table 4 Part 3, Table 4

b) Note that the first event concerns the approach, and the second one concerns the landing. The hazard "flight crew fail to correctly identify installation" is only present in the latter event since the approach phase begins before the crew can visually identify the installation.

4.6.2.4 Risk tolerability

a) Table 4.14 shows a summary of CS1 based on the AMJ25–1309 risk acceptability criteria.

Table 4.14 Summary of Conflict Scenario 1

Conflict scenario 1: The helicopter approaches the wrong installation			
	Severity	**Probability**	**Result**
A) The flight crew approach the wrong installation and come into conflict with another helicopter	CATASTROPHIC	LESS THAN EXTREMELY IMPROBABLE	NEGLIGIBLE
B) The flight crew land on the wrong installation and it is in an unsafe condition	CATASTROPHIC	LESS THAN EXTREMELY IMPROBABLE	NEGLIGIBLE

4.6.3 CS2: The helicopter comes into conflict with the sea

4.6.3.1 Description

a) Within this conflict scenario, while approaching the correct installation the helicopter comes into conflict with the sea. This conflict scenario could be caused by flight crew error and/or equipment failure. Equipment failure could take the form of a guidance system failure combined with a failure of the radio altimeter. A cross-check for the guidance system is provided by the radio altimeter during the final approach and a low height alert is provided by AVAD (driven by the radio altimeter).

b) Within this conflict scenario the following hazards have been identified as potentially contributing to the conflict scenario:

- Incorrect information provided by the guidance system (ID1).
- Incorrect information provided by the radio altimeter (ID4).
- Flight crew loss of situational awareness e.g. inadvertently descending below the MDA (ID7 or ID9).

4.6.3.2 Severity

a) Within this conflict scenario, the helicopter comes into conflict with the sea. The conflict may arise as the result of a flight crew error or equipment failure.

b) The probable chain of events that may lead to this conflict scenario are presented in Table 4.15.

Table 4.15 Chain of events causing Conflict Scenario 2

Event	Hazardous chain of events	Severity
A) The helicopter comes into conflict with the sea due to flight crew error	Helicopter descends below MDA due to crew error AND Flight crew do not respond to the guidance system AND Flight crew do not respond to AVAD warning AND Flight crew fail to visually acquire the sea and rectify in time	CATASTROPHIC
B) The helicopter comes into conflict with the sea due to equipment failure	Unannunciated failure of the guidance system causes descent below MDA AND Unannunciated failure of the radio altimeter AND Flight crew fail to notice the discrepancy between the radio altimeter and rate of descent AND Flight crew fail to visually acquire the sea and rectify in time	CATASTROPHIC

4.6.3.3 Probability

a) Table 4.16 shows a summary of the probabilities associated with each of the events.

Table 4.16 Probability analysis for Conflict Scenario 2

Event	Hazardous chain of events	Probability	Source [Ref 1]
A) The helicopter comes into conflict with the sea due to flight crew error	Helicopter descends below MDA due to crew error AND	1 x 10^{-3}	Part 2, Table 4 (Note 1)
	Flight crew do not respond to guidance system AND	1 x 10^{-5}	Part 2, Table 4
	Flight crew do not respond to AVAD warning AND	1 x 10^{-5}	Part 2, Table 4
	Flight crew fail to visually acquire the sea and rectify in time	1 x 10^{-1} Total: 1 x 10^{-14}	Part 2, Table 4
B) The helicopter comes into conflict with the sea due to equipment failure	Unannunciated failure of the guidance system causes descent below MDA AND	1 x 10^{-5}	Part 2, sect. 4.2.2 (Note 2)
	Unannunciated failure of the radio altimeter AND	1 x 10^{-5}	Part 2, sect. 4.2.2
	Flight crew fail to notice the discrepancy between the radio altimeter and rate of descent AND	1 x 10^{-3}	Part 2, Table 4
	Flight crew fail to visually acquire the sea and rectify in time	1 x 10^{-1} Total: 1 x 10^{-14}	Part 2, sect. 4.2.2
Note 1. The probability used here is 10^{-3} which is the same as that for the ARA. However, it is noted that the vertical guidance provided by SOAP would be expected to reduce this probability. Note 2. A 'standard' equipment failure rate is assumed from [Ref. 1].			

4.6.3.4 Risk tolerability

a) Table 4.17 shows a summary of CS2 based on the AMJ25–1309 risk acceptability criteria. All risks are NEGLIGIBLE.

Table 4.17 Summary of Conflict Scenario 2

Conflict scenario 2: The helicopter comes into conflict with the sea			
	Severity	**Probability**	**Result**
A) The helicopter comes into conflict with the sea due to flight crew error	CATASTROPHIC	LESS THAN EXTREMELY IMPROBABLE	NEGLIGIBLE
B) The helicopter comes into conflict with the sea due to equipment failure	CATASTROPHIC	LESS THAN EXTREMELY IMPROBABLE	NEGLIGIBLE

4.6.4 CS3: The helicopter comes into conflict with an obstacle

4.6.4.1 Description

a) Within this scenario, the helicopter comes into conflict with an obstacle during approach to the correct installation. A total of four hazards are identified as contributing to this conflict scenario. These are:

- Weather radar provides incorrect information (ID3): This could mean, for example, that the weather radar fails to display obstacles that are in fact present or displays obstacles in the wrong place.
- Flight crew error through misinterpretation (ID7): This applies to the weather radar correctly displaying all the obstacles in the vicinity but the flight crew misinterpret these returns and assume that the area is clear of obstacles.
- Flight crew error through incorrect settings (ID8): This applies when the flight crew select the wrong range or tilt setting on the weather radar which could lead to incorrect interpretation or detection of obstacles.
- Flight crew error through distraction, disorientation or inattention (ID9): The flight crew may fail to detect obstacles correctly displayed by the weather radar.

b) It is a requirement of the procedure as defined in Section 2, that the flight crew check the area for the presence of obstacles prior to commencement of the final approach. The final approach and missed approach areas must be confirmed to be clear of obstacles. This conflict scenario can therefore only happen when the checks fail to show obstacles or the weather radar fails to display them.

4.6.4.2 Severity

a) This conflict scenario can occur in four ways:

- The helicopter comes into conflict with a charted obstacle in the vicinity of the installation due to flight crew error, e.g. the flight crew fail to notice an obstacle on the integrated navigation display due to display clutter, or distraction, disorientation or inattention.
- The helicopter comes into conflict with a charted obstacle in the vicinity of the installation due to the absence of the charted obstacle from the integrated navigation display through either a display failure or an aircraft database error.
- The helicopter comes into conflict with an uncharted obstacle in the vicinity of the installation due to the absence of the obstacle on the weather radar return on the integrated navigation display, e.g. due to unannunciated failure of the weather radar, or mis-setting of the weather radar controls.
- The helicopter comes into conflict with an uncharted obstacle in the vicinity of the installation due to crew error.

b) The chain of events that can result in any of these consequences is presented in Table 4.18.

Table 4.18 Chain of events causing Conflict Scenario 3

Event	Hazardous chain of events	Severity
A) The helicopter comes into conflict with a charted obstacle in the vicinity of the installation due to flight crew error	Obstacle present without vertical separation AND Flight crew fail to detect obstacle on display AND Flight crew fail to visually acquire obstacle and rectify in time	CATASTROPHIC
B) The helicopter comes into conflict with a charted obstacle in the vicinity of the installation due to the lack of display of the charted obstacle on the display	Obstacle present without vertical separation AND The aircraft database is incorrect OR The display system fails to plot the charted obstacle AND The obstacle is not shown on the weather radar display OR The crew miss-set the weather radar and the obstacle is not displayed AND Flight crew fail to visually acquire obstacle and rectify in time	CATASTROPHIC
C) The helicopter comes into conflict with an uncharted obstacle in the vicinity of the installation due to the absence of the obstacle on the weather radar display	Obstacle present without vertical separation AND The obstacle is not shown on the weather radar display OR The crew miss-set the weather radar and the obstacle is not displayed AND Flight crew fail to visually acquire obstacle and rectify in time	CATASTROPHIC
D) The helicopter comes into conflict with an uncharted obstacle in the vicinity of the installation due to crew error	Obstacle present without vertical separation AND Flight crew fail to detect obstacle on display AND Flight crew fail to visually acquire obstacle and rectify in time.	CATASTROPHIC

4.6.4.3 Probability

a) Table 4.19 shows a summary of the probabilities associated with each of the events.

Table 4.19 Probability analysis for Conflict Scenario 3

Event	Hazardous chain of events	Probability	Source [Ref 1]
A) The helicopter comes into conflict with a charted obstacle in the vicinity of the installation due to flight crew error	Obstacle present without vertical separation AND Flight crew fail to detect obstacle on display AND Flight crew fail to visually acquire obstacle and rectify in time	1×10^{-3} 1×10^{-6} (Note 1) 1×10^{-1} Total: 1×10^{-10}	Part 2, sect. 4.2.8 Part 2, Table 4 Part 2, Table 4
B) The helicopter comes into conflict with a charted obstacle in the vicinity of the installation due to the lack of display of the charted obstacle on the display	Obstacle present without vertical separation AND The aircraft database is incorrect OR The display system fails to plot the charted obstacle AND The obstacle is not shown on the weather radar OR The crew miss-set the weather radar and the obstacle is not displayed AND Flight crew fail to visually acquire obstacle and rectify in time	1×10^{-3} 2×10^{-5} 1×10^{-5} 1×10^{-5} 1×10^{-5} 1×10^{-1} Total: 6×10^{-14}	Part 2, sect. 4.2.8 Part 1, para. 4.3.3.1 Part 2, sect. 4.2.2 (Note 2) Part 2, sect. 4.2.2 (Note 2) Part 2, Table 4 Part 2, Table 4
C) The helicopter comes into conflict with an uncharted obstacle in the vicinity of the installation due to the absence of the obstacle on the weather radar	Obstacle present without vertical separation AND The obstacle is not shown on the weather radar dispaly OR The crew miss-set the weather radar and the obstacle is not displayed AND Flight crew fail to visually acquire obstacle and rectify in time.	1×10^{-3} 1×10^{-5} 1×10^{-5} 1×10^{-1} Total: 2×10^{-9}	Part 2, sect. 4.2.8 Part 2, sect. 4.2.2 (Note 2) Part 2, Table 4 Part 2, Table 4
D) The helicopter comes into conflict with an uncharted obstacle in the vicinity of the installation due to crew error	Obstacle present without vertical separation AND Flight crew fail to detect obstacle on display AND Flight crew fail to visually acquire obstacle and rectify in time.	1×10^{-3} 1×10^{-6} 1×10^{-1} Total: 1×10^{-10}	Part 2, sect. 4.2.8 Part 2, Table 4 Part 2, Table 4
Note 1: In other instances within this report a probability of 1×10^{-5} is used. However, in this instance it is felt that the different symbology that will be used on the display to distinguish charted obstacles decreases the probability that the flight crew will fail in this action. Note 2: A "standard" equipment failure rate is assumed from [Ref. 1].			

4.6.4.4 Risk tolerability

a) Table 4.20 shows a summary of CS3, based on the AMJ25–1309 risk acceptability criteria.

Table 4.20 Summary of Conflict Scenario 3

Conflict scenario 3: The helicopter comes into conflict with the sea			
	Severity	**Probability**	**Result**
A) The helicopter comes into conflict with a charted obstacle in the vicinity of the installation due to flight crew error	CATASTROPHIC	EXTREMELY IMPROBABLE	TOLERABLE
B) The helicopter comes into conflict with a charted obstacle in the vicinity of the installation due to the lack of display of the charted obstacle	CATASTROPHIC	LESS THAN EXTREMELY IMPROBABLE	NEGLIGIBLE
C) The helicopter comes into conflict with an uncharted obstacle in the vicinity of the installation due to the absence of the obstacle on the weather radar	CATASTROPHIC	EXTREMELY REMOTE	TOLERABLE (Note 1)
D) The helicopter comes into conflict with an uncharted obstacle in the vicinity of the installation due to crew error	CATASTROPHIC	EXTREMELY IMPROBABLE	TOLERABLE
Note 1. Although the probability of this CS (2×10^{-9}) implies an "UNACCEPTABLE" result, it is within the margin of error for "TOLERABLE" (1×10^{-9}) and has been assigned this value. This is because the risks combinations are not dissimilar to events A and D which are TOLERABLE, and it should be treated in a similar way.			

b) It is noted from Table 4.20 that three of the events in the conflict scenario are TOLERABLE. The inclusion of an additional mitigation(s) could result in these being acceptable.

c) Within the North Sea operations, uncharted obstacles will be large ocean going vessels such as cranes and tugs. The carriage of Automatic Identification Systems (AIS) is required for international vessels and is determined nationally on the basis of the regulatory authority. The AIS system comprises a transponder which broadcasts the ship's position, speed and intended direction. In the case of this procedure, the availability of AIS would enable uncharted obstacles to be detected and plotted on the aircraft's navigation display, and could also be used in an automatic collision warning system, such as TAWS A. The effect that this would have on the above event is illustrated in Table 4.21.

d) It is apparent that all of the CSs are reduced to 'NEGLIGIBLE' by the addition of the AIS display and collision warning function.

Table 4.21 Probability analysis of Conflict Scenario 3 – including AIS

Event	Hazardous chain of events	Probability	Source [Ref 1]
A) The helicopter comes into conflict with a charted obstacle in the vicinity of the installation due to flight crew error	Obstacle present without vertical separation AND Flight crew fail to detect obstacle on display AND Flight crew fail to respond to AIS–based collision avoidance warning system AND Flight crew fail to visually acquire obstacle and rectify in time.	1×10^{-3} 1×10^{-6} 1×10^{-5} 1×10^{-1} Total: 1×10^{-15}	Part 2, sect. 4.2.8 Part 2, Table 4 Part 2, Table 4 Part 2, Table 4
C) The helicopter comes into conflict with an uncharted obstacle in the vicinity of the installation due to the absence of the obstacle on the weather radar	Obstacle present without vertical separation AND The obstacle is not shown on the weather radar OR The crew mis-set the weather radar and the obstacle is not displayed AND Broadcasting AIS obstacle missing from the display AND Flight crew fail to visually acquire obstacle and rectify in time.	1×10^{-3} 1×10^{-5} 1×10^{-5} 1×10^{-5} 1×10^{-1} Total: 2×10^{-14}	Part 2, sect. 4.2.8 Part 2, sect. 4.2.2 (Note 1) Part 2, Table 4 Part 2, sect. 4.2. (Note 1) Part 2, Table 4
D) The helicopter comes into conflict with an uncharted obstacle in the vicinity of the installation due to crew error	Obstacle present without vertical separation AND Flight crew fail to detect obstacle on display AND Flight crew fail to respond to AIS–based collision avoidance warning system AND Flight crew fail to visually acquire obstacle and rectify in time.	1×10^{-3} 1×10^{-6} 1×10^{-5} 1×10^{-1} Total: 1×10^{-15}	Part 2, sect. 4.2.8 Part 2, Table 4 (Note 2) Part 2, Table 4 Part 2, Table 4

Note 1: A "standard" equipment failure rate is assumed from [Ref. 1].

Note 2: In other instances within this report a probability of 1×10^{-5} is used. However, in this instance the duplicate display of the obstacle (with AIS symbology and the weather radar returns) should reduce the probability that the flight crew will fail in this action.

4.6.5 CS4: The helicopter comes into conflict with the destination installation

4.6.5.1 Description

a) In this conflict scenario the helicopter comes into conflict with the destination installation during the approach or missed approach procedure. The conflict may be caused by equipment failure or by a database error. Crew error leading to this conflict scenario was considered infeasible, since it would involve a non-credible miss-reading of the navigation display.

b) The conflict scenario can occur where there is a discrepancy between the actual position of the installation relative to the helicopter and where the flight crew believe it to be located. This could result from an error in either the position of the helicopter (guidance system error), or from an error in the position of the installation (database error).

c) The hazards that have been identified as contributing to this conflict scenario are:

- The guidance system provides incorrect information unannunciated (ID1).
- The aircraft database is incorrect causing the destination to be incorrectly plotted on the navigation display (ID2);
- Weather radar provides incorrect information (ID3). For example, the weather radar could 'paint' the installation in the wrong place providing the flight crew with misleading information.

4.6.5.2 Severity

a) The chain of events that could lead to this conflict scenario is presented in Table 4.22. Note that the crew will be able to compare the guidance information and the weather radar, so should usually be able to identify that there is a hazard.

Table 4.22 Chain of events causing Conflict Scenario 4

Event	Hazardous chain of events	Severity
The helicopter comes into conflict with the destination installation through guidance system error or database error	The guidance system displays incorrect information OR The aircraft database is incorrect AND Crew unable to detect error using weather radar information AND Flight crew fail to see installation and avoid in time AND Some part of the installation is in the helicopter's path	CATASTROPHIC

4.6.5.3 Probability

a) Table 4.23 shows the summary of the probabilities associated with each of the events.

Table 4.23 Probability analysis of Conflict Scenario 4

Event	Hazardous chain of events	Probability	Source [Ref 1]
The helicopter comes into conflict with the destination installation through guidance system error or database error	The guidance system displays incorrect information	1×10^{-5}	Part 2, sect. 4.2.2 (Note 1)
	OR		
	The aircraft database is incorrect	2×10^{-5}	Part 1, para 4.3.3.1
	AND		
	Crew unable to detect error using weather radar information	1×10^{-2}	Part 2, Table 4 (Note 2)
	AND		
	Flight crew fail to see installation and avoid in time	1×10^{-1}	Part 2, Table 4
	AND		
	Some part of the installation is in the helicopter's path.	1×10^{-2}	Part 2, sect. 4.2.2
		Total: 3×10^{-10}	

Note 1: A "standard" equipment failure rate is assumed from [Ref. 1]. Some additional comment on this is given in b) below.
Note 2: The same probability as "Crosscheck against weather radar fails to show deviation" for CS1B, CS2, and CS3 is used.

b) Although GPS is more complex than some other equipment items, the same failure rate is assumed. Note that FAA AC20–130A [AC20–130A] states:

> *"Loss of navigation or flight management information is considered to be a major failure condition for the aircraft as defined in AC 25.1309–1A, AC 23.1309–1A, AC 27–1, or AC 29–2A, as applicable to the aircraft. Hazardously misleading information to the flight crew is also considered to be a major failure condition for the aircraft. Navigation data is considered to be hazardously misleading when unannunciated position errors exist that are greater than those specified by the multi-sensor equipment or individual sensor requirements… The applicant should conduct a system safety assessment to verify that design errors and failure modes that produce major failure conditions are improbable."*

c) A "major" failure implies an acceptable frequency of remote, i.e. at least 10^{-5}, which is consistent with the assumption here.

d) This is an undetected failure rate and is conservative compared to the ICAO assumption that undetected GPS errors occur at 10^{-7} probability (for a RAIM receiver).

4.6.5.4 Risk tolerability

a) Table 4.24 shows a summary of CS4, based on the AMJ25–1309 risk acceptability criteria.

Table 4.24 Summary of Conflict Scenario 4

Conflict scenario 4: The helicopter comes into conflict with the destination installation			
	Severity	Probability	Result
The helicopter comes into conflict with the destination installation through guidance system error or database error	CATASTROPHIC	EXTREMELY IMPROBABLE	TOLERABLE

b) In order to reduce the consequence of this CS to 'NEGLIGIBLE', the introduction of AIS is again considered. AIS could be installed on platforms (fixed or mobile) as well as vessels which would render them visible to aircraft equipped with an AIS receiver. The following table shows CS4 with AIS included as a means for the crew to detect the destination.

Table 4.25 Probability analysis of Conflict Scenario 4 – including AIS

Event	Hazardous chain of events	Probability	Source [Ref 1]
The helicopter comes into conflict with the destination installation through guidance system error or database error	The guidance system displays incorrect information	1×10^{-5}	Part 2, sect. 4.2.2 (Note 1)
	OR		
	The aircraft database is incorrect	2×10^{-5}	Part 1, para 4.3.3.1
	AND		
	Crew unable to detect error using weather radar information	1×10^{-2}	Part 2, Table 4. (Note 2)
	AND		
	AIS fails to display obstacle	1×10^{-5}	Part 2, sect. 4.2.2 (Note 1)
	OR		
	Flight crew fail to detect AIS obstacle on display	1×10^{-5}	Part 2, Table 4
	AND		
	Flight crew fail to see installation and avoid in time	1×10^{-1}	Part 2, Table 4
	AND	1×10^{-2}	Part 2, sect. 4.2.2
	Some part of the installation is in the helicopter's path		
		Total: 6×10^{-15}	

Note 1: A "standard" equipment failure rate is assumed from [Ref. 1].
Note 2: The same probability as "Crosscheck against weather radar fails to show deviation" for CS1b, CS2, and CS3 is used.

c) It is apparent that the inclusion of AIS reduces the risk of this CS to 'NEGLIGIBLE'.

4.7 Conclusions and recommendations

4.7.1 The success case noted that the lateral TSE is sufficiently small at the abeam point that separation from the installation is assured. It also noted that the vertical TSE consumes a significant portion of the minimum height required – a total of 125 ft – when at the alarm limit of operation. Under normal operations within the 2 sigma limit the FTE would be 76 ft, resulting in a minimum height of 124 ft.

4.7.2 The failure case analysis has shown that for most conflict scenarios presented the risk is 'NEGLIGIBLE' meaning that the risk is acceptable. However, in several cases the risk is 'TOLERABLE', meaning that further means of mitigation should be sought.

4.7.3 The failure case results are summarised in the following table.

Table 4.26 Summary of conflict scenarios

CS1: The helicopter approaches the wrong installation			
	Severity	**Probability**	**Result**
A) The helicopter approaches the wrong installation and comes into conflict with another helicopter	CATASTROPHIC	LESS THAN EXTREMELY IMPROBABLE	NEGLIGIBLE
B) The helicopter lands on the wrong installation and it is unsafe to do so	CATASTROPHIC	LESS THAN EXTREMELY IMPROBABLE	NEGLIGIBLE
CS2: The helicopter comes into conflict with the sea			
	Severity	**Probability**	**Result**
A) The helicopter comes into conflict with the sea due to flight crew error	CATASTROPHIC	LESS THAN EXTREMELY IMPROBABLE	NEGLIGIBLE
B) The helicopter comes into conflict with the sea due to EGNOS system failure	CATASTROPHIC	LESS THAN EXTREMELY IMPROBABLE	NEGLIGIBLE
CS3: The helicopter comes into conflict with an obstacle			
	Severity	**Probability**	**Result**
A) The helicopter comes into conflict with a charted obstacle in the vicinity of the installation due to flight crew error	CATASTROPHIC	EXTREMELY IMPROBABLE	TOLERABLE
B) The helicopter comes into conflict with a charted obstacle in the vicinity of the installation due to the lack of display of the charted obstacle	CATASTROPHIC	LESS THAN EXTREMELY IMPROBABLE	NEGLIGIBLE
C) The helicopter comes into conflict with an uncharted obstacle in the vicinity of the installation due to the absence of the obstacle on the weather radar	CATASTROPHIC	EXTREMELY IMPROBABLE	TOLERABLE
D) The helicopter comes into conflict with an uncharted obstacle in the vicinity of the installation due to crew error	CATASTROPHIC	EXTREMELY IMPROBABLE	TOLERABLE
CS4: The helicopter comes into conflict with the destination installation			
	Severity	**Probability**	**Result**
The helicopter comes into conflict with the destination installation through guidance system error or database error	CATASTROPHIC	EXTREMELY IMPROBABLE	TOLERABLE

4.7.4 As discussed, carriage of AIS would be a mitigation to enable crew to detect uncharted obstacles. The inclusion of AIS reporting equipment is already required on ships internationally and many vessels operating domestically have the system fitted. The AIS receiver on board the helicopter could provide the positions of uncharted obstacles for plotting on the aircraft's navigation display or possibly an alert to the flight crew in the event that the presence of a vessel is detected. The result of this mitigation is shown below, and it is recommended that AIS is further considered for this procedure both to allow AIS–equipped vessels to be displayed and to provide an automatic system to warn of collision with AIS–equipped obstacles.

Table 4.27 Comparison of impact of AIS for display and collision avoidance on TOLERABLE CS3 and CS4 probabilities

Event	Severity without AIS	Severity with AIS
CS3: The helicopter comes into conflict with an obstacle		
A) The helicopter comes into conflict with a charted obstacle in the vicinity of the installation due to flight crew error	TOLERABLE	NEGLIGIBLE
C) The helicopter comes into conflict with an uncharted obstacle in the vicinity of the installation due to the absence of the obstacle on the weather radar	TOLERABLE	NEGLIGIBLE
D) The helicopter comes into conflict with an uncharted obstacle in the vicinity of the installation due to crew error	TOLERABLE	NEGLIGIBLE
CS4: The helicopter comes into conflict with the destination installation		
The helicopter comes into conflict with the destination installation through guidance system error or database error	TOLERABLE	NEGLIGIBLE

4.7.5 It can be seen that the additional AIS functionality reduces these events to 'NEGLIGIBLE' and therefore this option should be further investigated.

5 EGNOS data collection and analysis

5.1 Overview

5.1.1 The visibility of the EGNOS Geostationary satellites at typical North Sea latitudes was identified as a possible constraint on the SOAP procedure during its conception, partly due to the relatively low elevation of the satellites at the higher latitudes involved and partly as a result of earlier research into the effects of helicopter rotors on GPS reception [Ref 7]. Activities were therefore planned to investigate this aspect both practically and through simulation as an element of the GIANT project. The simulation studies are reported in Section 6. This section summarises the flight trials performed to collect practical data on EGNOS reception for a particular aircraft installation for analysis.

5.1.2 The data collection task was split into two distinct activities. First, a static data collection activity was designed to allow the collection of SBAS GEO satellite measurements from the helicopter's antenna to examine the potential effects of rotor interference. Second, a flight test was planned to allow the collection of information on the performance of EGNOS during actual flight dynamics.

5.1.3 The purpose of the static data collection was to examine the effect of rotor movement upon the SBAS signals looking both for masking and interference that might affect reception.

5.1.4 The purpose of the flight test was to obtain metrics on the visibility of SBAS GEO satellites at high northerly latitudes at which the new EGNOS–enabled offshore approach procedure (SOAP) will be used. The flight test to collect the necessary data was performed at Aberdeen Airport on 12th September 2008 using a suitably equipped Eurocopter Super Puma AS332L aircraft. The objective of the flight test was to collect general signal reception data during simulated SOAP approaches and also under a range of manoeuvres designed to examine airframe masking across a range of heading and bank angles.

5.1.5 Figure 5.1 below shows the equipment configuration. This receiver has 6 channels dedicated to tracking SBAS satellites and is therefore more than capable of monitoring the entire visible EGNOS space segment. All observed SBAS data is logged on a flash memory card. The helicopter's flight data recording (FDR) equipment logs a range of aircraft parameters from which the aircraft's attitude and main rotor speed were extracted and used in the data analysis.

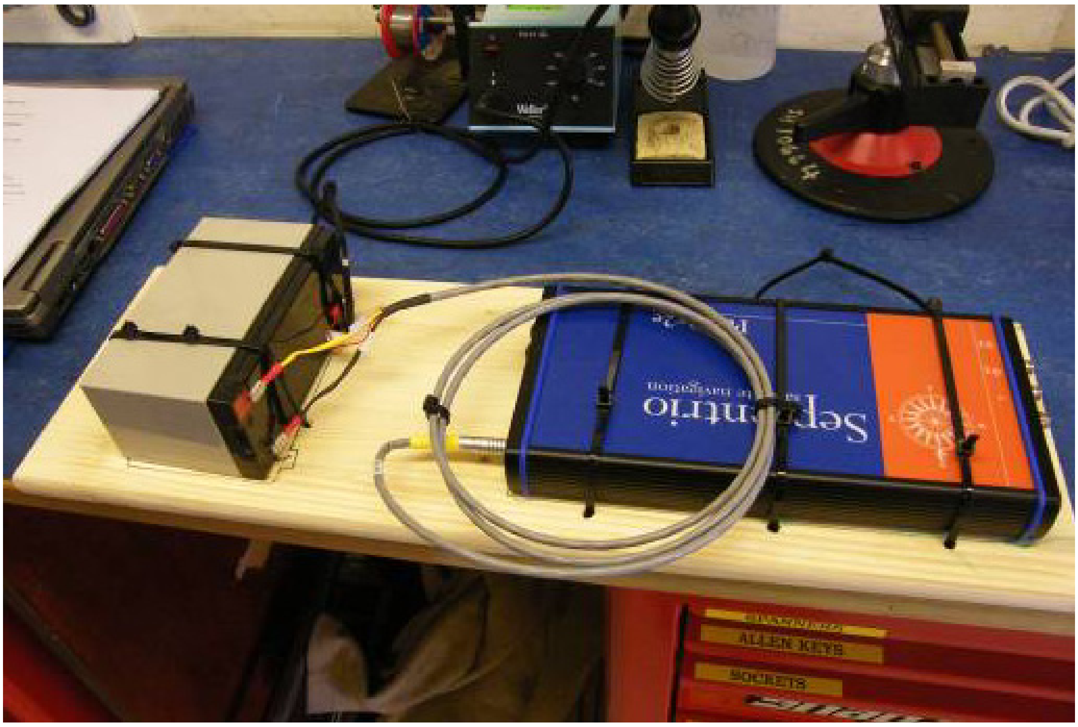

Figure 5.1 Trials equipment mounted on temporary plinth to facilitate carriage onto the aircraft as passenger luggage

5.1.6 On the aircraft the Septentrio receiver was connected to the aircraft's passive GPS antenna via an active splitter to provide appropriate gain for normal operation. The antenna cable was routed through the aircraft cabin to allow the observer to sit with a view of the cockpit (see Figure 5.2). For the static trial the receiver was configured to log all SBAS parameters at a rate of 10Hz. For the flight trial the receiver was configured to log all SBAS parameters at a rate of 1Hz and also to filter psuedoranges and generate protection levels in line with the requirements of the SBAS receiver MOPS DO–299D.

Figure 5.2 Airborne trials installation located in forward passenger seats with connection to aircraft GPS antenna

5.2 Description of the static trial

5.2.1 The static data collection took place during the morning of 12th September 2008 at Aberdeen Airport. The trials platform was an operational Eurocopter Super Puma (AS332L) helicopter registration G–PUME in operational service with CHC Scotia Helicopters (see Figures 5.3 and 5.4). The helicopter was turned to face due West in order to remove the potential effects of airframe masking and to ensure that the signals from all GEOs passed through the plane of the main rotor.

Figure 5.3 CHC Scotia Super Puma G–PUME

Figure 5.4 G–PUME on taxi out for departure

5.2.2 Data was initially collected from the SBAS GEOs with no rotor movement, serving both to create a baseline set of measurements for further comparison and to ensure full reception of signals prior to further tests. Subsequently, the main and tail rotors were run up from stationary to their normal operating speed and then back to stationary over a 5 to 10 minute period. This was repeated twice. On the first run down of the rotors the rotor brake was not applied, allowing the blades to slowly freewheel to idle enabling the collection of data with a very slow blade rotation rate.

5.2.3 Following the static trial the aircraft FDR data was downloaded to provide access to logged rotor rpm information.

5.3 Description of flight

5.3.1 The flight trial took place during the afternoon of 12th September 2008 and used the same trials platform as the static trial. The flight was conducted in Visual Meteorological Conditions (VMC) as a Visual Flight Rules (VFR) flight. The test flight was operated from Aberdeen Airport in the UK, with the test manoeuvres taking place in Class G airspace over Loch Skene.

5.3.2 Figure 5.5 shows the ground track of the flight. After positioning to the West of Aberdeen Airport three orbits were flown at 5, 10 and 15 degree bank angles. Subsequently four simulated SOAP approaches were flown, one to each compass point (North, South, East and West). The approaches consisted of a 700 feet per minute descent from 1,000ft to 300ft followed by a straight ahead climbing go-around manoeuvre. The aircraft returned to Aberdeen Airport on completion of the approaches.

5.3.3 Following the flight trial, the data was downloaded from both the Septentrio receiver and the aircraft's FDR system for subsequent processing and analysis.

Figure 5.5 Google Earth representation of flight track showing positioning to the West of the controlled airspace around Aberdeen Airport

5.4 Results of static data collection

5.4.1 The Carrier to Noise (CNo) measurements output by the receiver for each SBAS satellite were logged, both with and without rotors turning. As Figure 5.6 shows, with the rotors stationary the received CNo is highest for PRN124 Artemis, and lowest for PRN120 AOR–E.

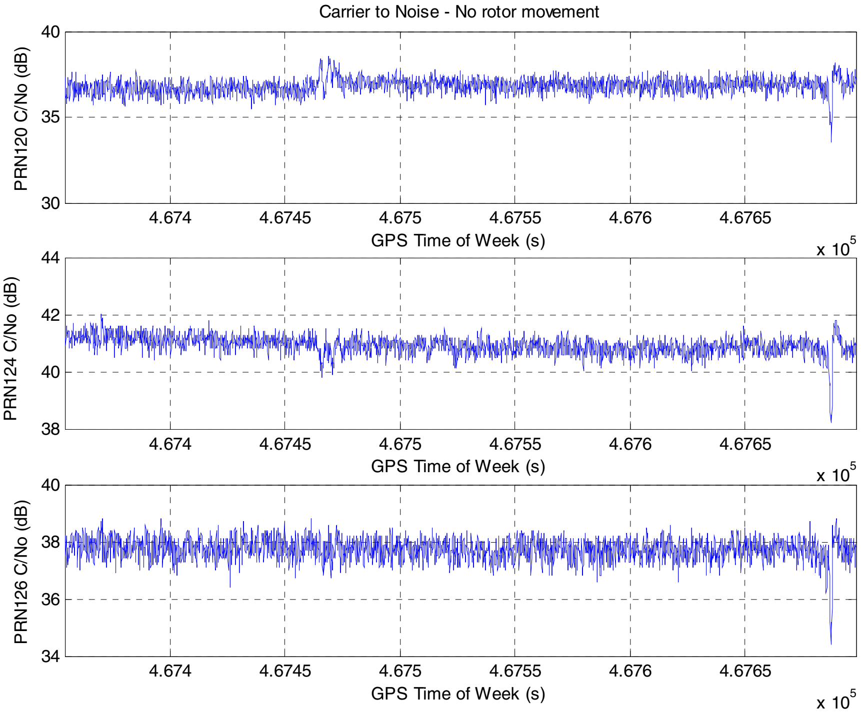

Figure 5.6 Carrier to Noise measurements with no rotor movement

5.4.2 The antenna installed on the aircraft only allows reception of GPS signals on the L1 frequency and the SBAS receiver used in the trial only provides observables in the form of psuedoranges, Doppler measurements and Accumulated Delta Ranges (ADR). Therefore, to be able to make an assessment of pseudorange accuracy and the potential impact of rotor movement, it is possible to develop a code-minus-carrier measurement. This measurement is developed by subtracting the ADR observable (ϕ) from the pseudorange (ρ):

$$\rho - \phi = 2I + (\eta_{code} - \eta_{carrier}) + (M_{code} - M_{carrier}) - N\lambda$$

5.4.3 The integer ambiguity ($N\lambda$) can be removed so long as there are no cycle slips as it represents a constant bias. Additionally carrier noise ($\eta_{carrier}$) and multipath ($M_{carrier}$) are also small in comparison to their code equivalents (η_{code}, M_{code}) so can be assumed to be negligible. Over short timescales (minutes) the ionospheric error (I) varies slowly and its effects can be modelled and removed. Hence, for the purposes of assessing accuracy:

$$\rho - \phi \approx \eta_{code} + M_{code}$$

5.4.4 Typically, for the trial receiver and antenna installation the code multipath errors are larger structures and can be removed by looking at the derivatives of the code-minus-carrier measurement. This allows observation of the receiver code tracking errors alone to see if there is any discernable impact of rotor movement.

5.4.5 Figure 5.7 shows the measured CNo for each SBAS satellite during the first 'rotors turning' test. It can be seen that there would appear to be significant constructive and destructive interference effects on all satellite measurements as the rotors are turning slowly. This is due to masking of the signals by the rotor blades and shows that, as expected, the satellite signals pass through the plane of the main rotor. This causes a short duration loss of lock on PRN126. Additionally, when the rotors have been at full power for a couple of minutes there are significant drops in CNo resulting in a loss of lock on both PRN120 and PRN126. Only the higher powered PRN124 was tracked through this occurrence. It is not clear what the cause of this event was.

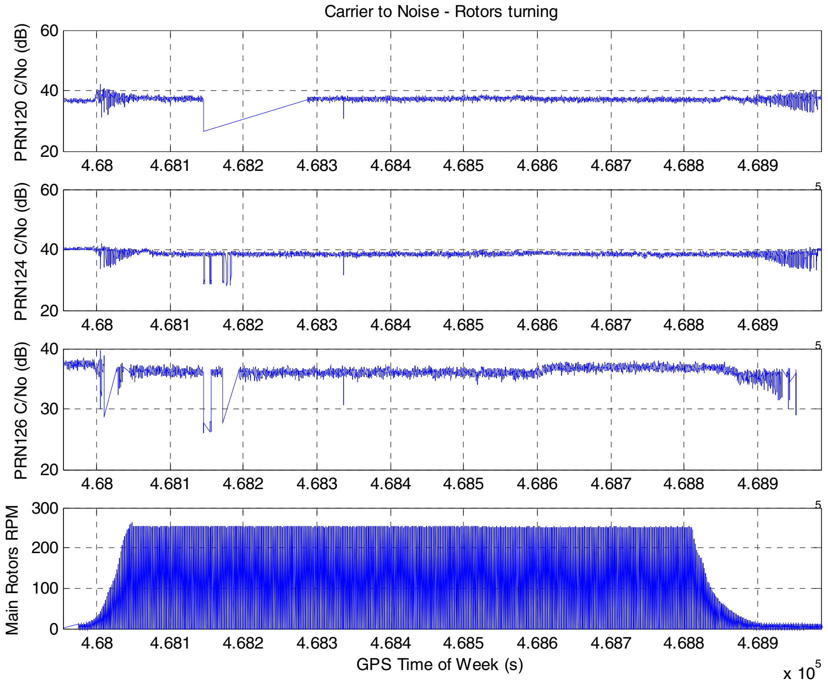

Figure 5.7 Measured CNo with rotors turning (trial 1)

5.4.6 Figure 5.8 through to Figure 5.10 show the calculated code-minus-carrier for each satellite together with its derivatives to allow any potential impact on code tracking noise (and thereby accuracy) to be observed. During this trial no discernable increase in code tracking noise can be seen.

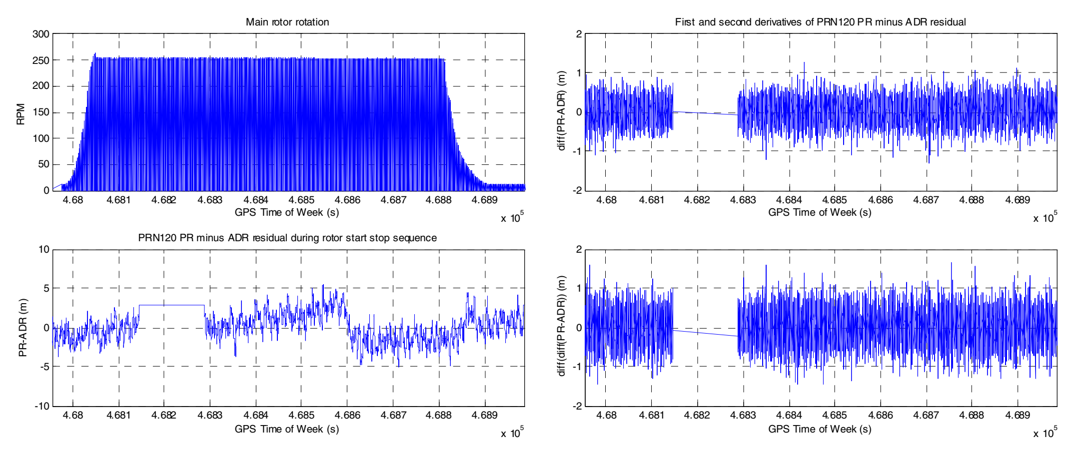

Figure 5.8 PRN 120 ADR residuals with rotors turning (trial 1)

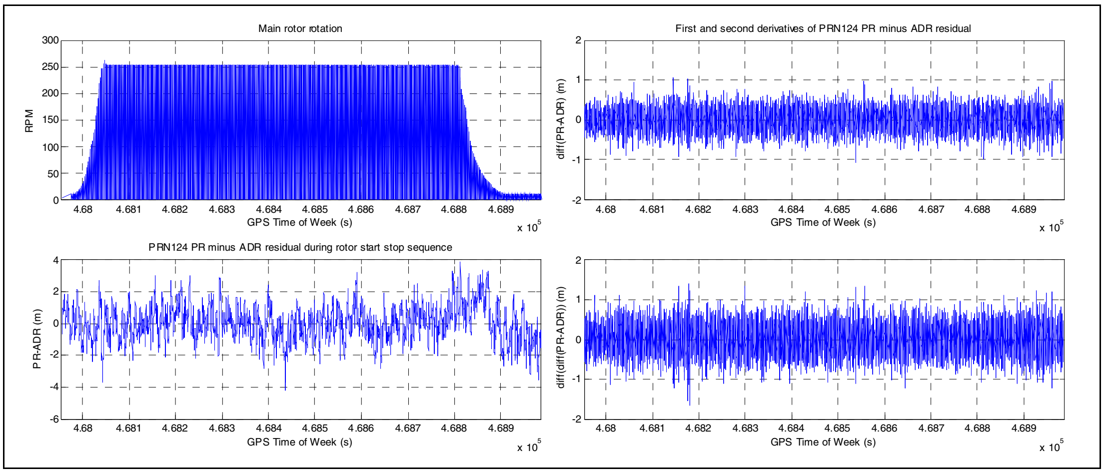

Figure 5.9 PRN 124 ADR residuals with rotors turning (trial 1)

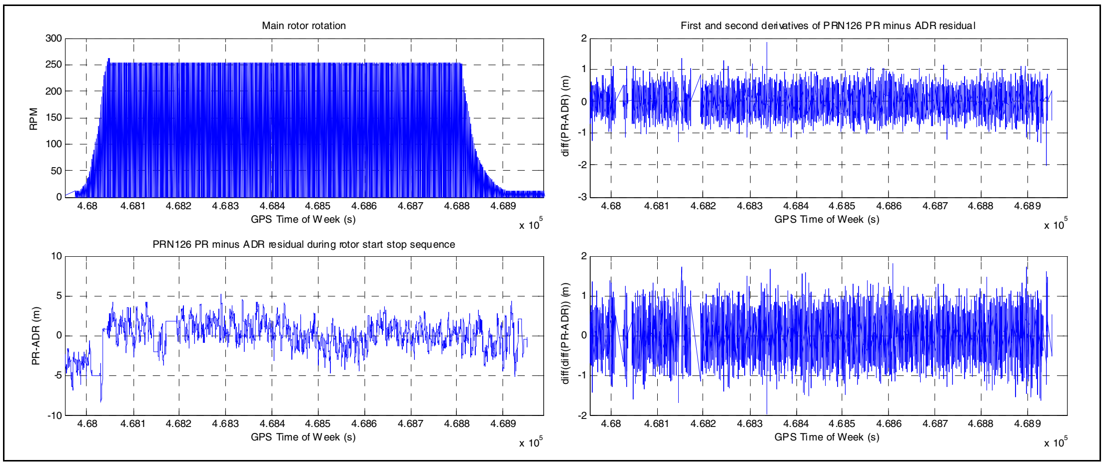

Figure 5.10 PRN 126 ADR residuals with rotors turning (trial 1)

5.4.7 Figure 5.11 shows the CNo measurements for the second 'rotors turning' trial. Again, there are notable interference effects when the blades are rotating at slow speed. During rotor run up the signal from PRN126 was lost and the receiver failed to reacquire it until the blades were stationary once again. The cause of this effect is unclear given that it did not manifest itself on the previous trial where successful reacquisition of PRN126 had occurred. Furthermore, the received CNo both prior to and after loss is well above the receiver reacquisition threshold. Another notable effect is the step change in CNo on PRN 124 once the rotors stop turning. This is likely to be due to masking from a stationary rotor blade.

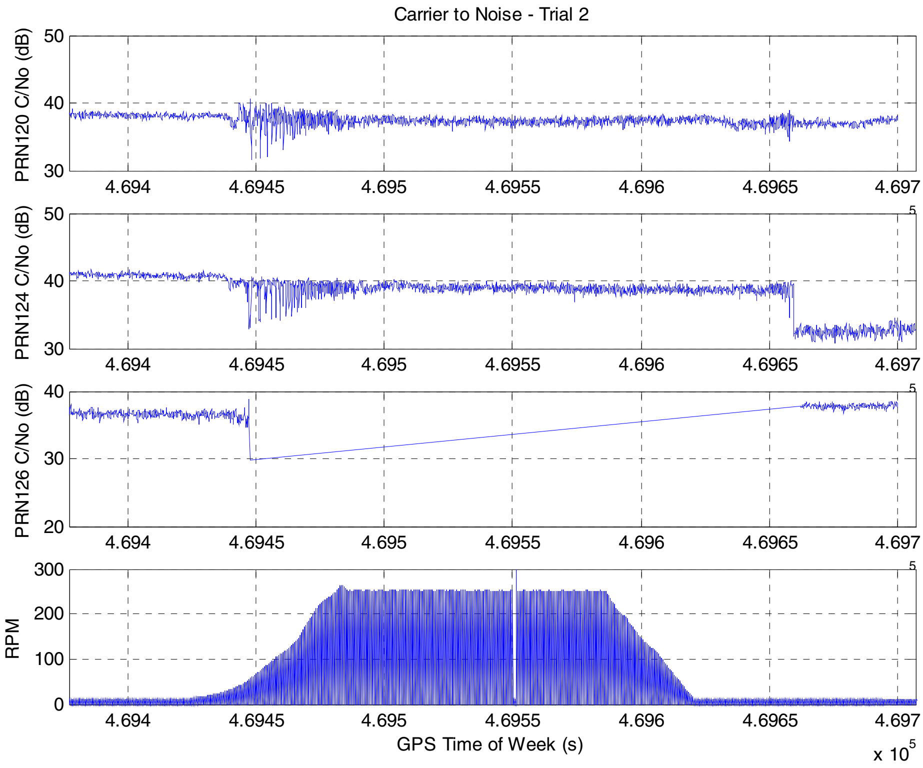

Figure 5.11 SBAS GEO measured CNo with rotors turning (trial 2)

5.4.8 Figure 5.12 and Figure 5.13 show the code-minus-carrier measurements for PRN120 and PRN 124 (PRN 126 was not tracked during the rotor run-up). Again, there is no discernable impact of the rotors turning on code tracking noise. For PRN 124, an increase in code tracking noise can be seen once the rotors have stopped turning. This corresponds to a reduction in CNo, most likely due to masking from a stationary rotor blade. With a lower power signal to track, the code tracking circuitry is likely to have to work harder to maintain tracking, resulting in a higher level of tracking noise.

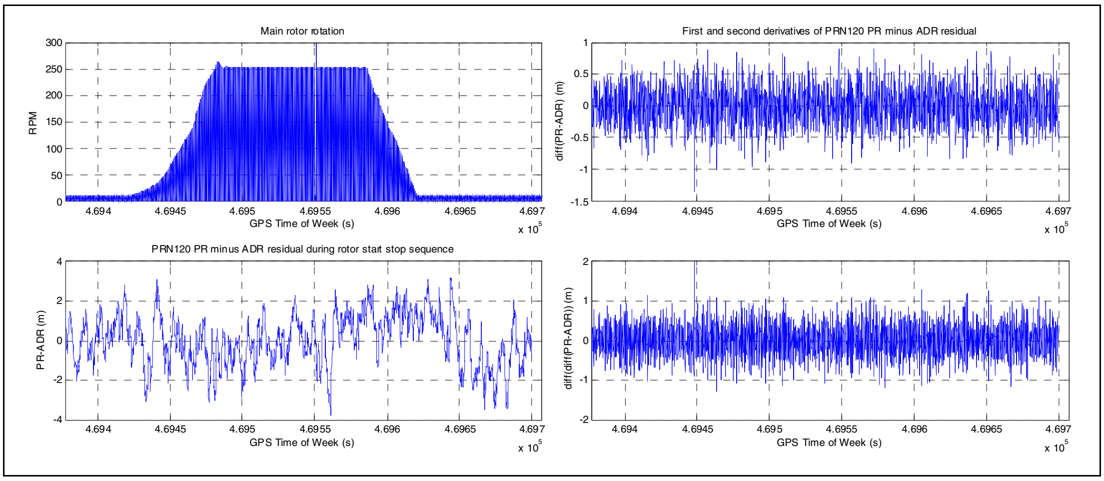

Figure 5.12 PRN 120 ADR residuals with rotors turning (trial 2)

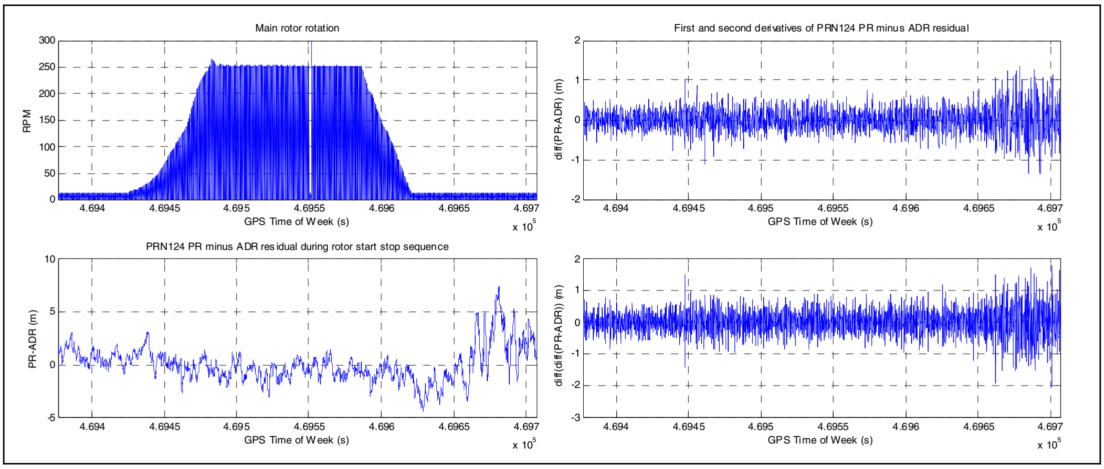

Figure 5.13 PRN 124 ADR residuals with rotors turning (trial 2)

5.5 Results of flight trial

5.5.1 The flight trial ground track is shown in Figure 5.14. The data points plotted in blue show the position as calculated taking full advantage of the SBAS differential corrections broadcast. The data points shown in red highlight where an SBAS position solution could not be generated and a standalone GPS position had to be used. It should also be noted that during the trial the SBAS receiver was capable of tracking and navigating with all three visible Geostationary satellites. In the operational EGNOS space segment only two satellites are expected to be supported. This should be taken into consideration when viewing the results.

5.5.2 The first instance of a loss of SBAS guidance was obtained on lift off from Aberdeen Airport at which point the helicopter nose initially pitches up as it leaves the ground, followed by a rapid pitch down as the helicopter gains velocity and then climbs out on the runway heading to the South-South-East. On this heading and at the pitch attitude measured the aircraft engine cowling successfully masks all GEO satellites. This situation continued until the aircraft rolled onto a South-West heading when reception was regained.

5.5.3 Further losses of SBAS positioning were noticed during orbits, during turns onto the SOAP approaches and also during the final landing manoeuvre as shown in Figure 5.14.

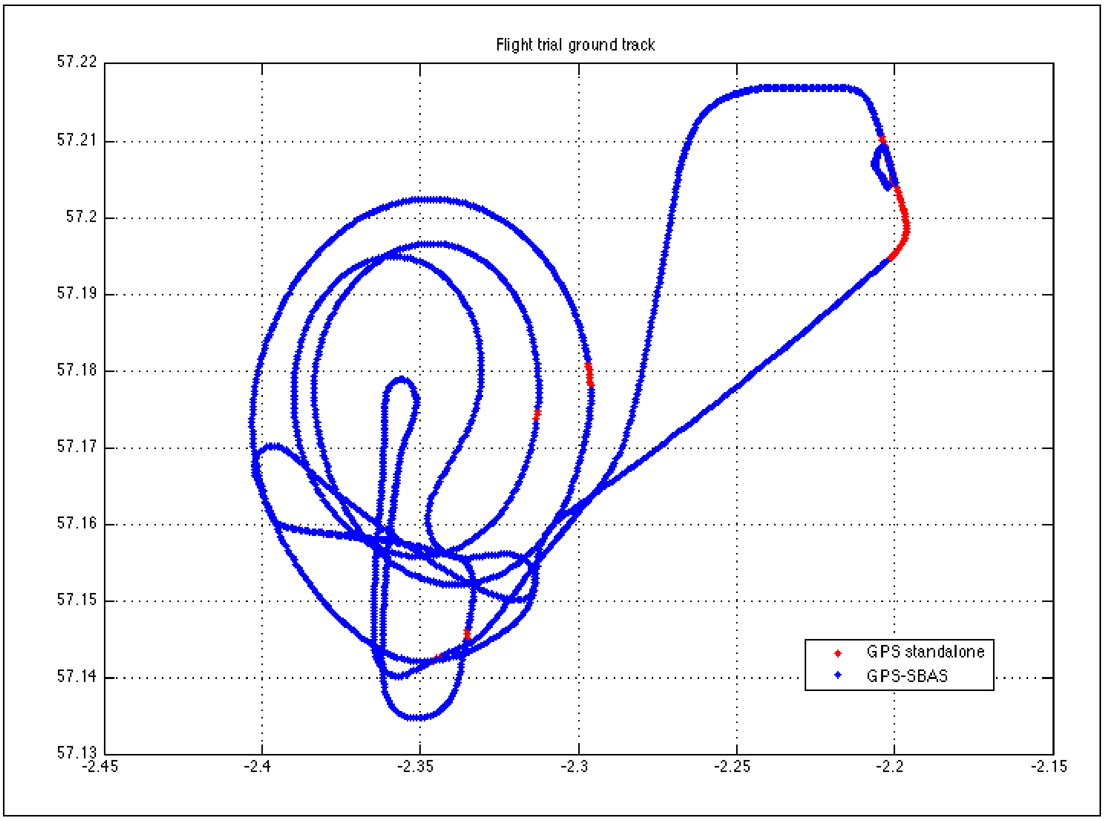

Figure 5.14 Flight trial ground track showing both SBAS and standalone GPS positions

5.5.4 During the test flight the visibility of GPS satellites was excellent and when combined with the SBAS signals meant that the receiver never tracked fewer than seven satellites, generally with a good DOP – more than enough for en-route navigation through to non-precision approach guidance. During engine run up and ground taxiing all three SBAS signals were acquired and tracked without problems. As shown in Figure 5.15, the number of satellites tracked and used during taxi and flight ranged from seven satellite signals up to as many as 14 during a number of epochs.

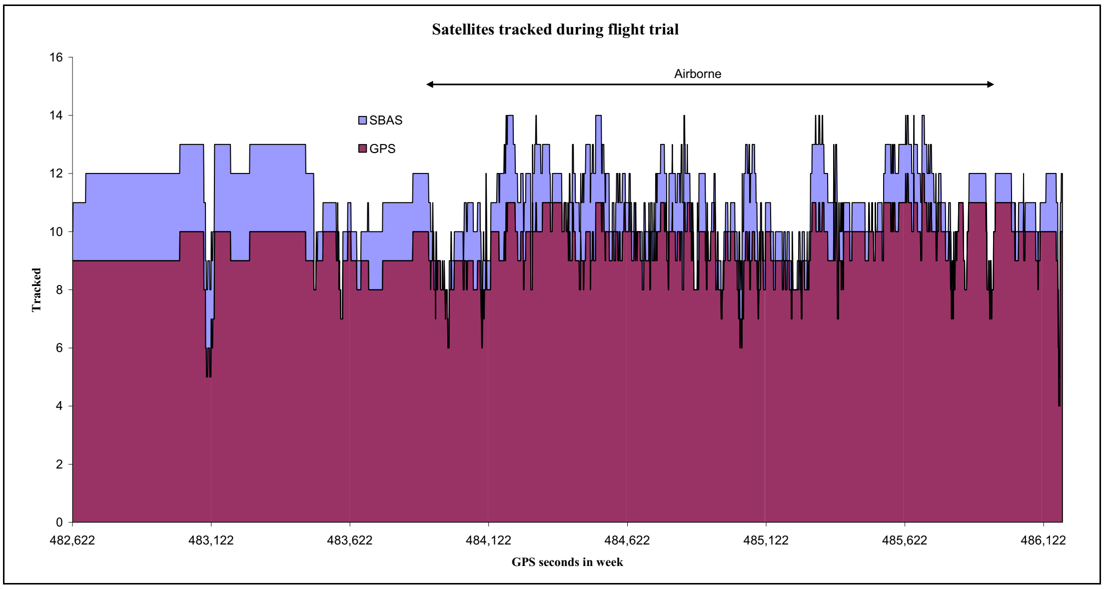

Figure 5.15 Number of GPS and SBAS satellites tracked by time

5.5.5 However, of concern in the visibility statistics is the actual visibility of GEO signals during the flight. Of the data points collected when the helicopter was airborne some 11% included no GEO signals, a further 42% saw only 1 GEO signal tracked with the remainder predominantly 2 GEOs (35%) with some 3 GEO tracking (11%). See Figure 5.16 below.

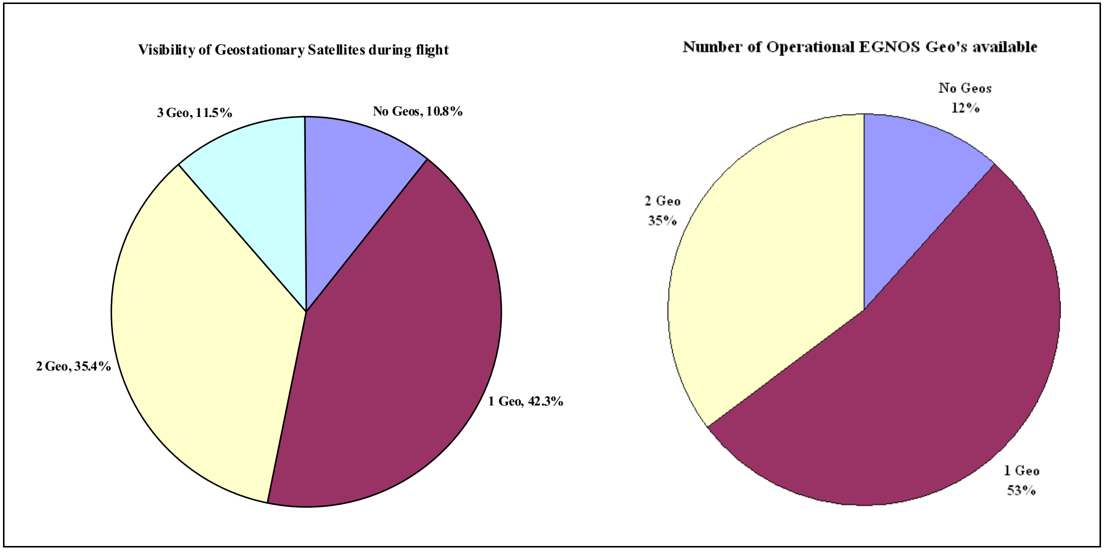

Figure 5.16 Number of satellites visible by proportion of airborne time

5.5.6 Given that the current EGNOS space segment comprises three satellites and that the operational service is to be composed of only two (ARTEMIS will not be included), Figure 5.16 also shows the proportion of time during which satellites from the operational constellation would be visible. This shows a marginally increased proportion of time during which no satellites are available together with a significant proportion of time during which only one is visible.

5.5.7 The impact of the high overall number of satellites tracked during the flight is to ensure that the measured Dilution of Precision (DOP) figures are low. This should, in turn, result in good overall performance in terms of accuracy. This is clearly illustrated in Figure 5.17, where the DOP values peak when the number of satellites momentarily dips due to aircraft manoeuvring.

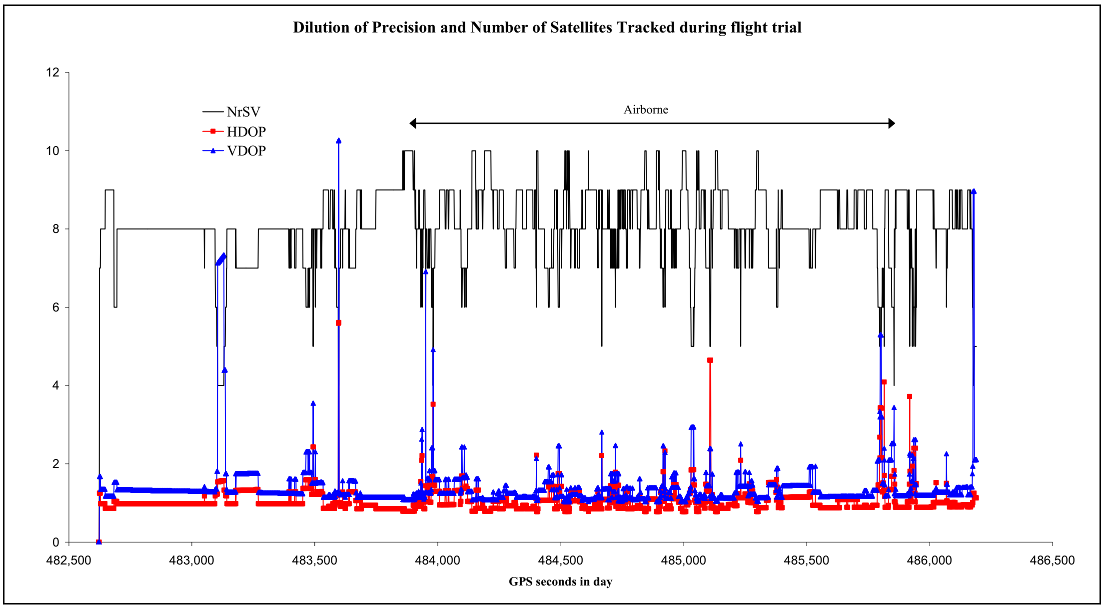

Figure 5.17 Dilution of Precision and number of GPS satellites tracked during flight

5.5.8 The measured horizontal and vertical protection levels (HPL/VPL) calculated by the Septentrio receiver were all comfortably within the requirements for APV approach operations when at least one SBAS GEO satellite was being tracked as shown in Figure 5.18. However, when no SBAS GEO satellites were available there were notable spikes in the protection levels that would result in alarm limits being exceeded for APV–II (20m VAL), LPV200 (35m VAL) and APV–I (50 m VAL) approach. During the SOAP approaches the protection levels were all comfortably within APV–II alert limits.

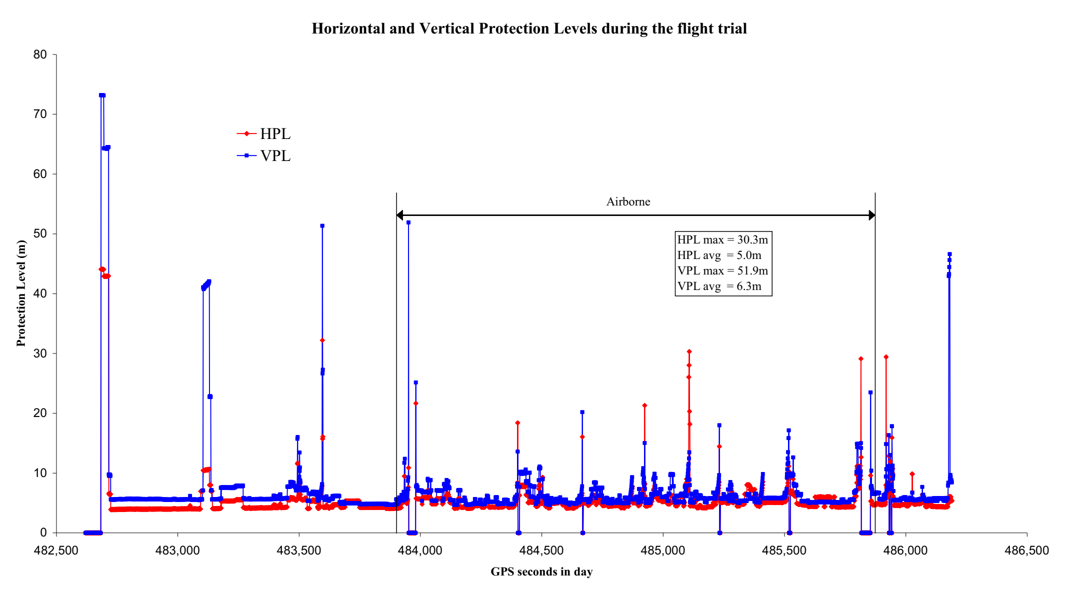

Figure 5.18 Horizontal and Vertical Protection Levels during flight

5.5.9 The Carrier-to-Noise (CNo) measurements for the Geostationary satellites were strong when the helicopter was stationary. The signals from PRN120 and 124 were higher than for PRN126 due to their higher elevation angles. The CNo measurements vary quite significantly during manoeuvring. This is to be expected, particularly as the passive helicopter antenna installed on the AS332L has a high gain roll-off at lower elevation angles that will accentuate variations in the received power levels. Figure 5.19 shows clear examples of deep fades in the CNo of the received signals. The figure also shows that the loss of tracking of the satellite signals occurs when the signals are formerly being received at high CNo, pointing to airframe masking as the root cause of the loss of lock. Note that the gaps in the traces are due to data loss and not loss of reception.

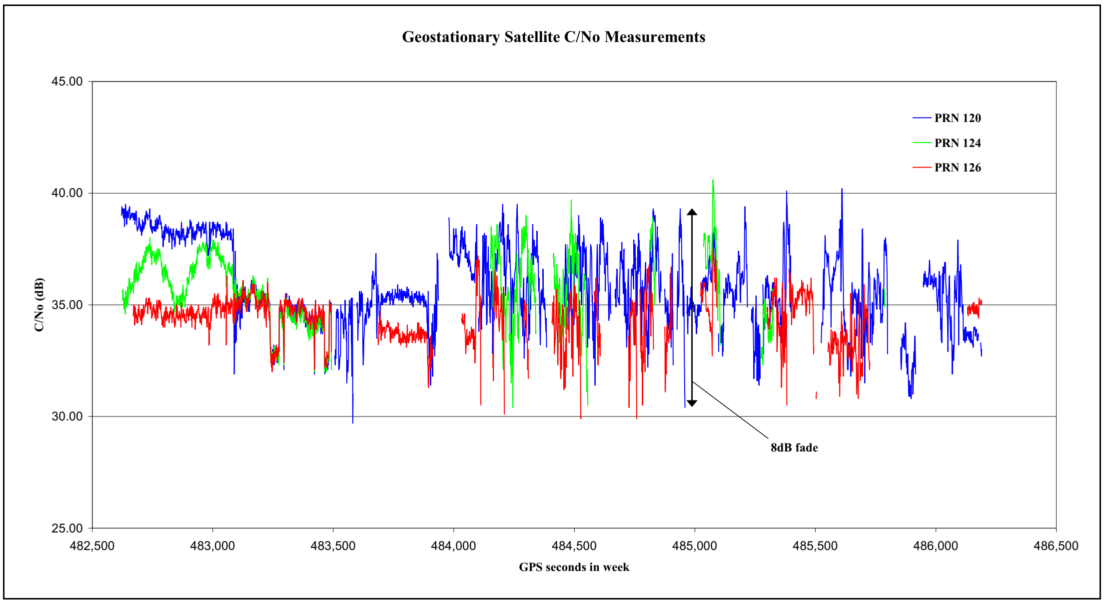

Figure 5.19 GEO Carrier-to-Noise measurements during flight

5.5.10 The receiver used for the flight test routinely searches for, acquires and tracks the visible SBAS satellite signals. Figure 5.20 shows that, initially, all three GEOs are being tracked by the receiver and, during the flight, the GEOs are then variously lost and re-acquired on different channels within the receiver.

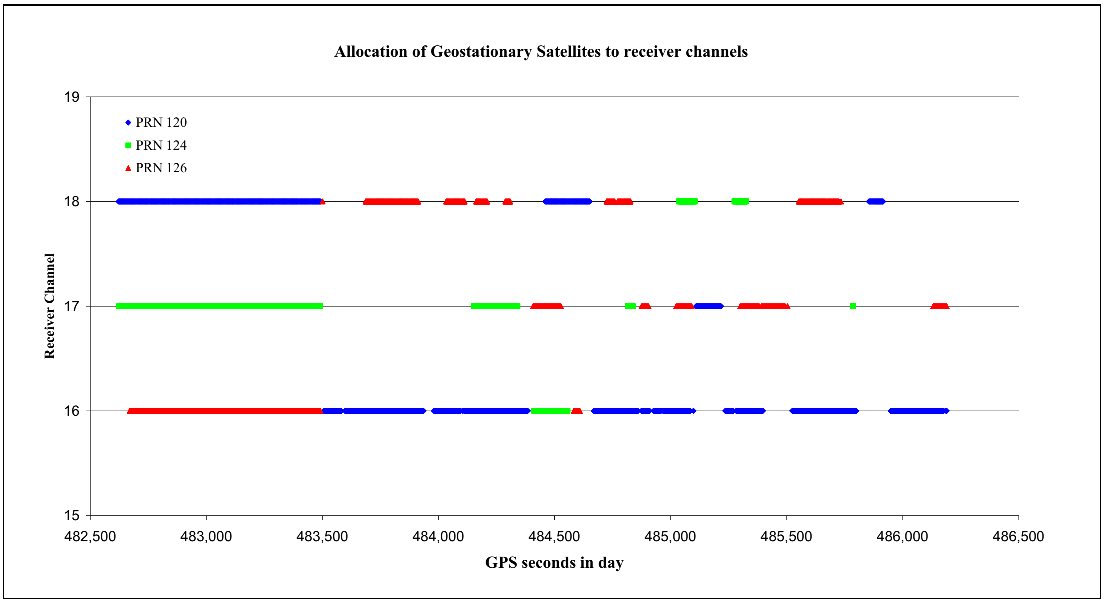

Figure 5.20 Allocation of SBAS satellites to receiver channels

5.5.11 The loss of lock of GEO satellite signals can be correlated to the attitude of the helicopter during the flight. Figure 5.21 shows that an initial loss of lock occurs when the helicopter is located on the southerly runway at Aberdeen and lifts off with a nose high attitude. In this situation the engine cowling is clearly masking all of the GEO satellites.

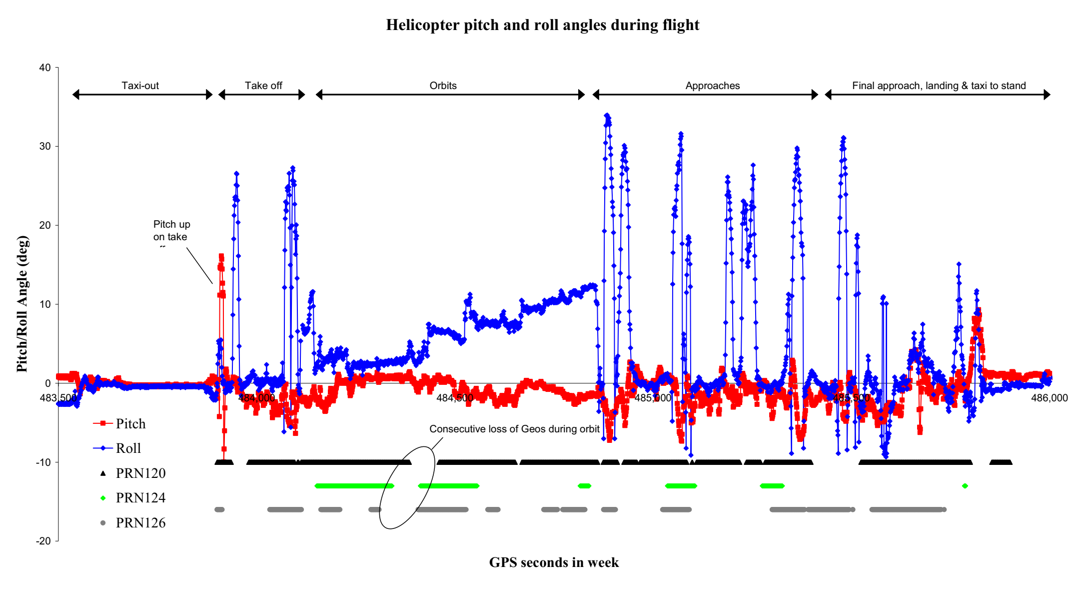

Figure 5.21 Helicopter pitch and roll during flight

5.5.12 During the orbits the GEOs are dropped in sequence as the helicopter fuselage obscures each signal in turn (IOR–W (PRN126) then ARTEMIS (PRN124) then AOR–E (PRN120) for a clockwise orbit – see Figure 5.22. Figure 5.23 shows a closer examination of the loss of SBAS signals that occurred during the initial 5 degree bank clockwise orbit as the helicopter heading passed through due South. In total, a 21 second loss of all SBAS signals occurred, but each individual satellite signal is being lost for approximately 100 seconds. Here the benefit of a multi-satellite space segment helps to reduce the impact of the outage. At higher bank angles masking was also observed, albeit of a shorter duration.

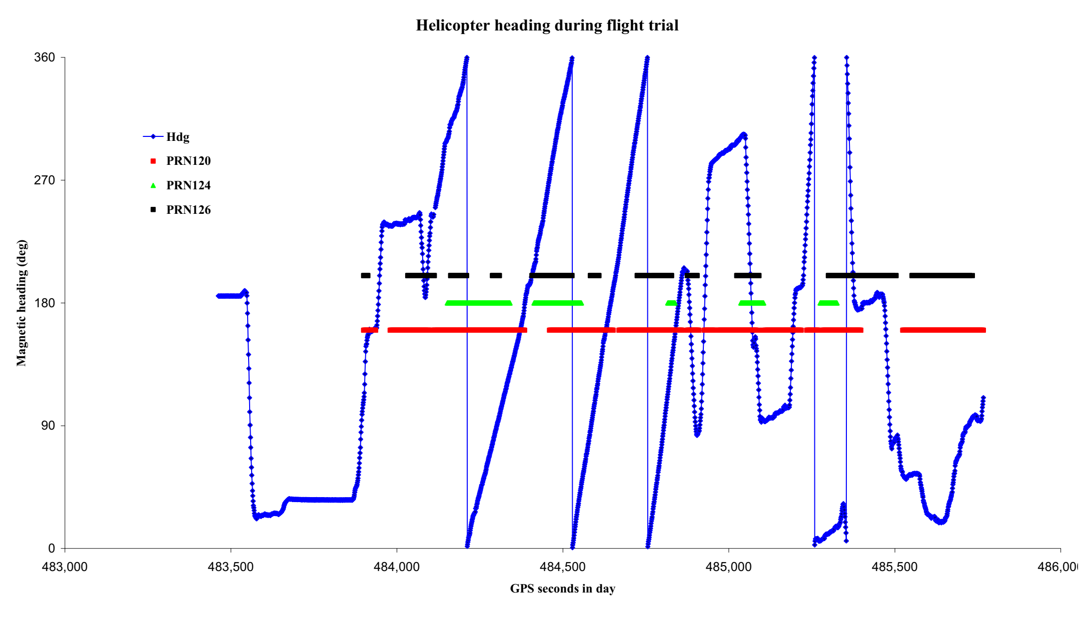

Figure 5.22 Helicopter heading during flight

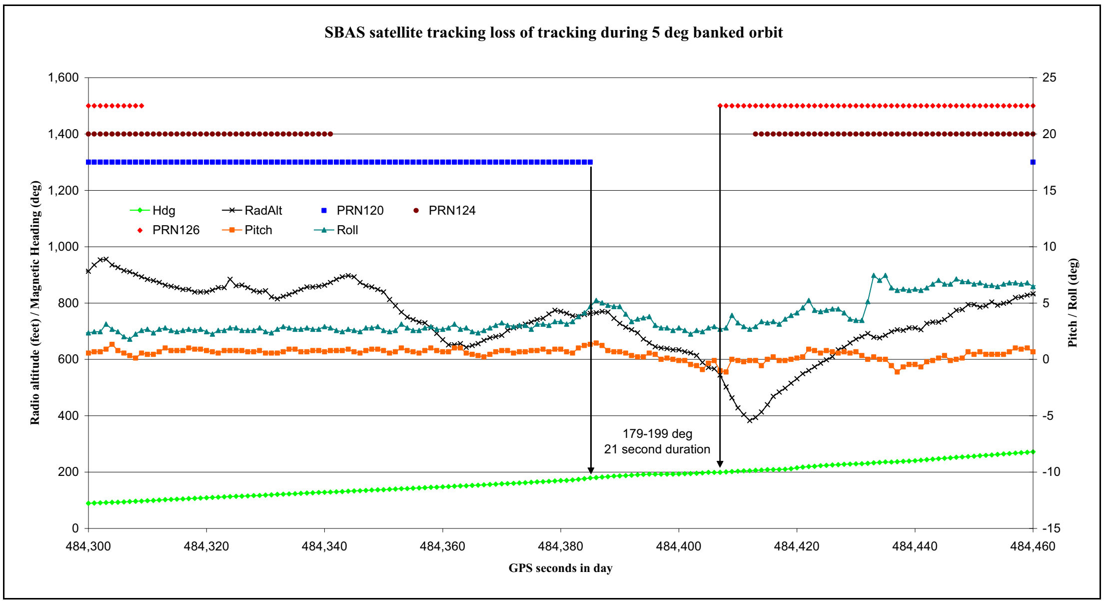

Figure 5.23 Loss of SBAS capability during orbit

5.5.13 The tracking of SBAS GEO signals also varied during the simulated SOAP procedures as shown in Figures 5.24 to 5.27. Although there were no total outages of SBAS tracking there were instances of loss of lock on individual GEOs. As would be expected, the visibility of GEOs was significantly constrained when the approach was being flown to the South. Similarly, all GEOs were tracked during the approach to the North. Perhaps the most surprising observation was that the approaches to the East and West were entirely dependent upon the AOR–E (PRN 120) satellite for their SBAS capability. This could be due to the low antenna gain characteristics at low elevation angles resulting in successful tracking of the highest elevation satellite only.

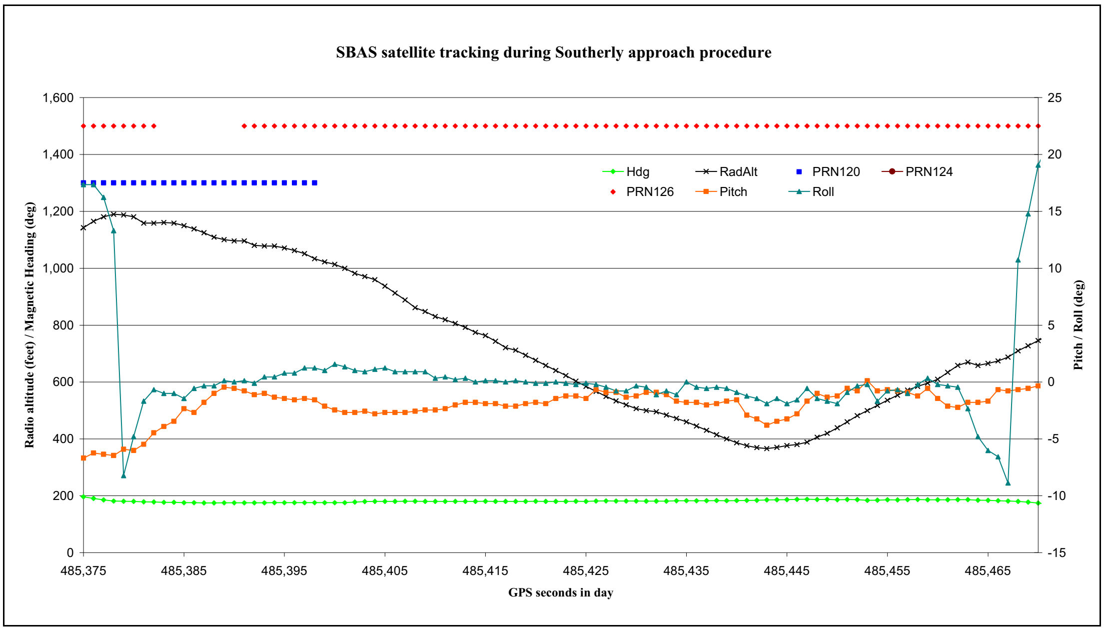

Figure 5.24 SOAP procedure flown to the South

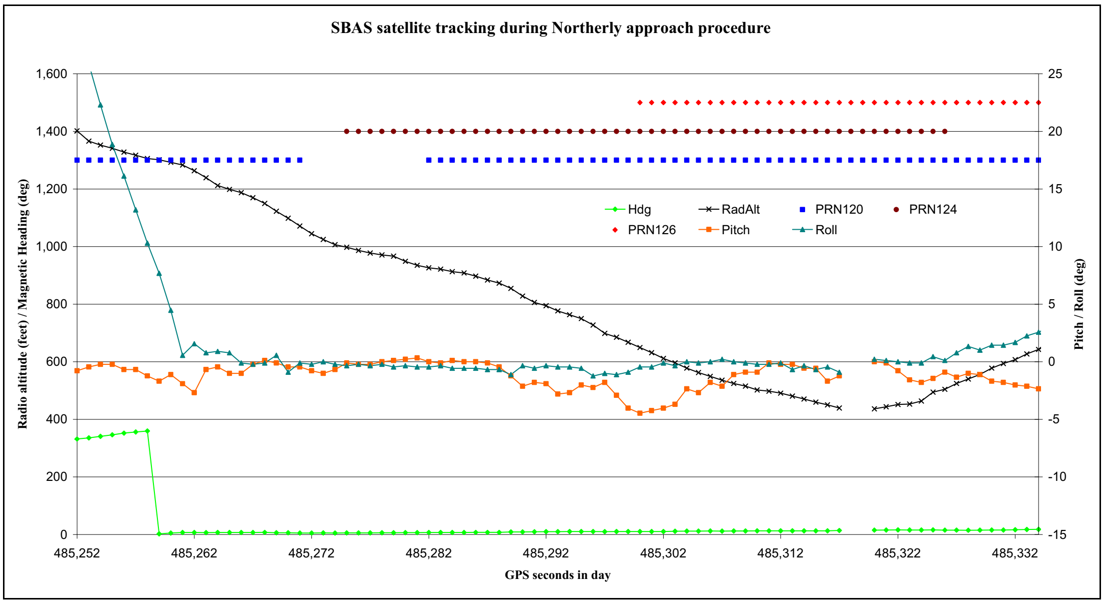

Figure 5.25 SOAP procedure flown to the North

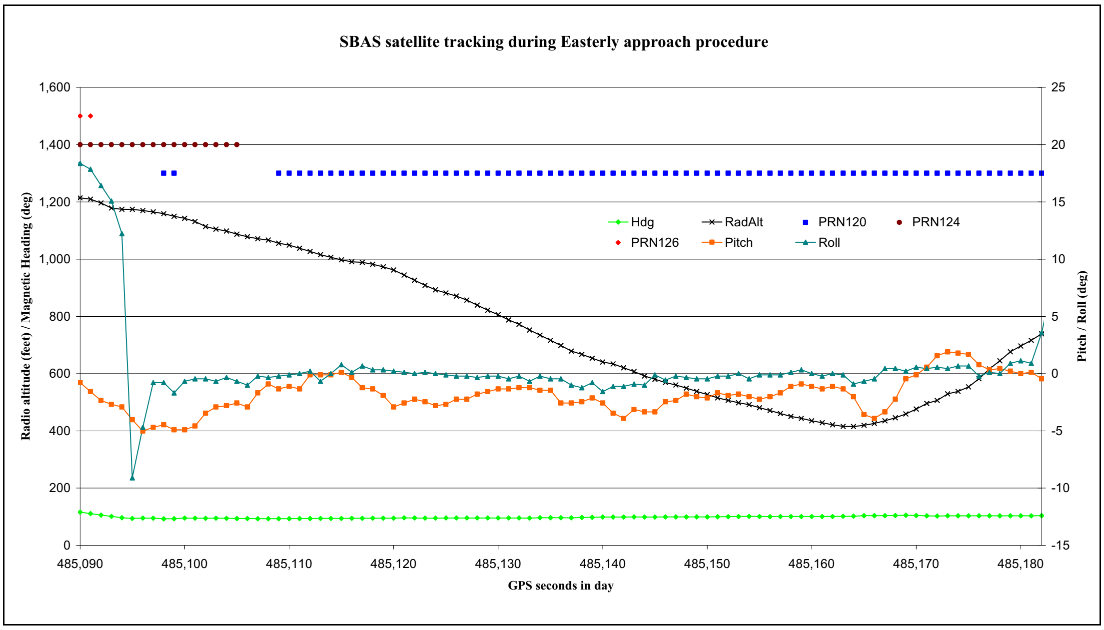

Figure 5.26 SOAP procedure flown to the East

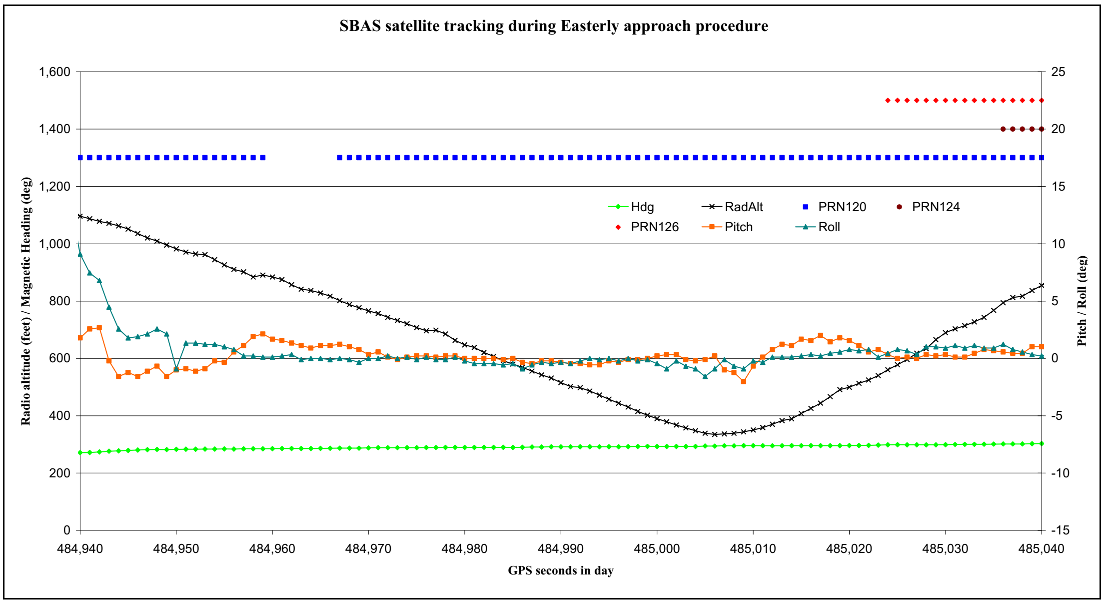

Figure 5.27 SOAP procedure flown to the West

5.5.14 Figure 5.28, Figure 5.29 and Figure 5.30 summarise the elevation and azimuth (from the centreline of the helicopter's fuselage) at which signals were lost from SBAS GEOs PRN120, PRN124 and PRN126 respectively during the flight trial, taking account of the relative attitude of the helicopter compared to the satellites. Superimposed upon the figures are the likely circumference of the cone formed by the main rotor (red) and the location of the fuselage (blue).

5.5.15 It is clear that, for the stronger signal from the PRN 120 satellite, a loss of signal tends to coincide with the location of the engine cowling ahead of the antenna. However, for the other two satellites the loss of signal tends to be largely independent of heading. This implies that loss of lock with lower power signals relates to more than just airframe masking, e.g. the effects of the main rotor – see CAA Paper 2003/7 [Ref 7].

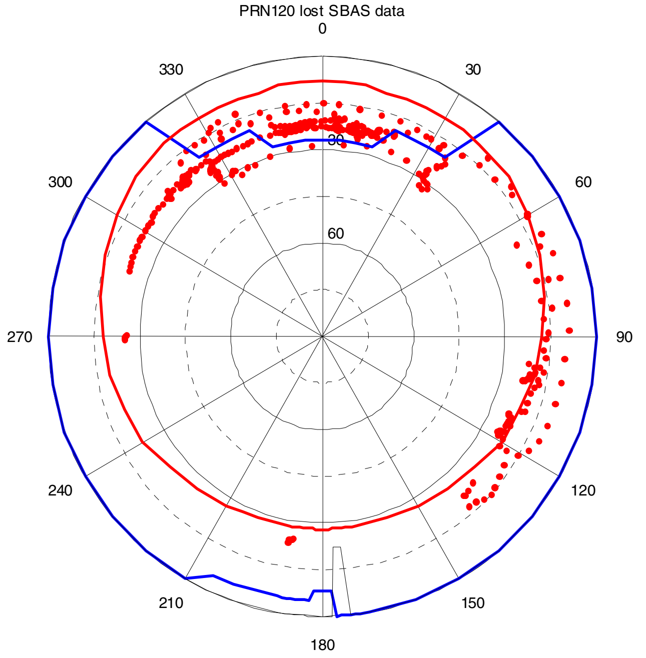

Figure 5.28 PRN120 lost signals by elevation and azimuth

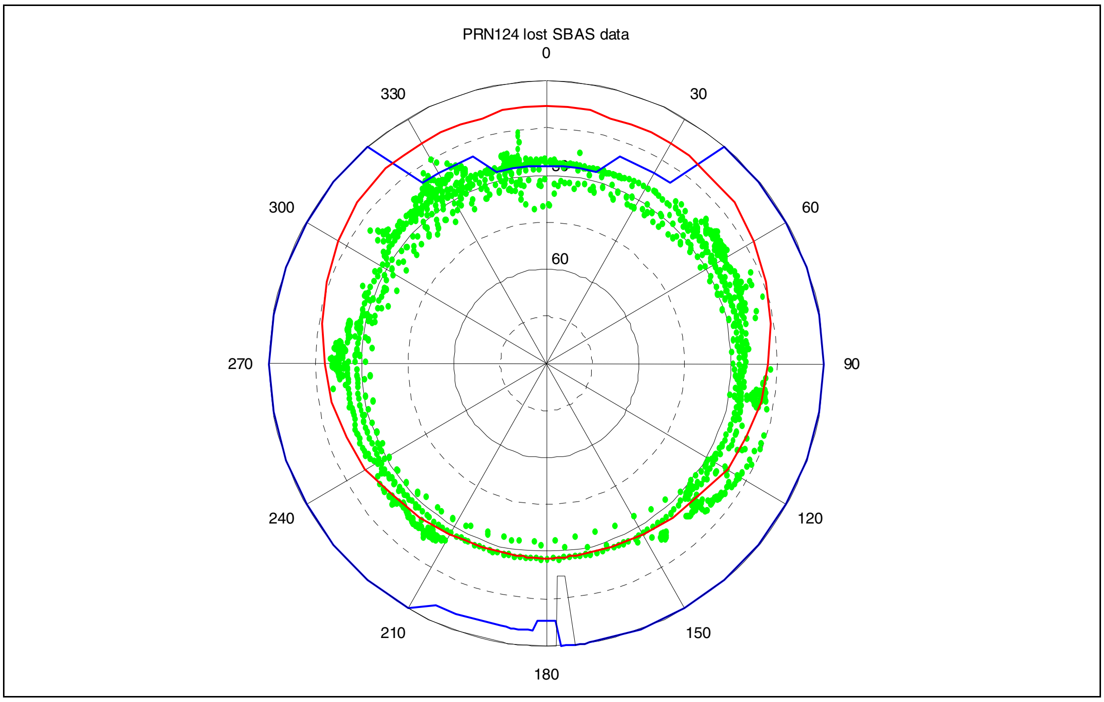

Figure 5.29 PRN124 lost signals by elevation and azimuth

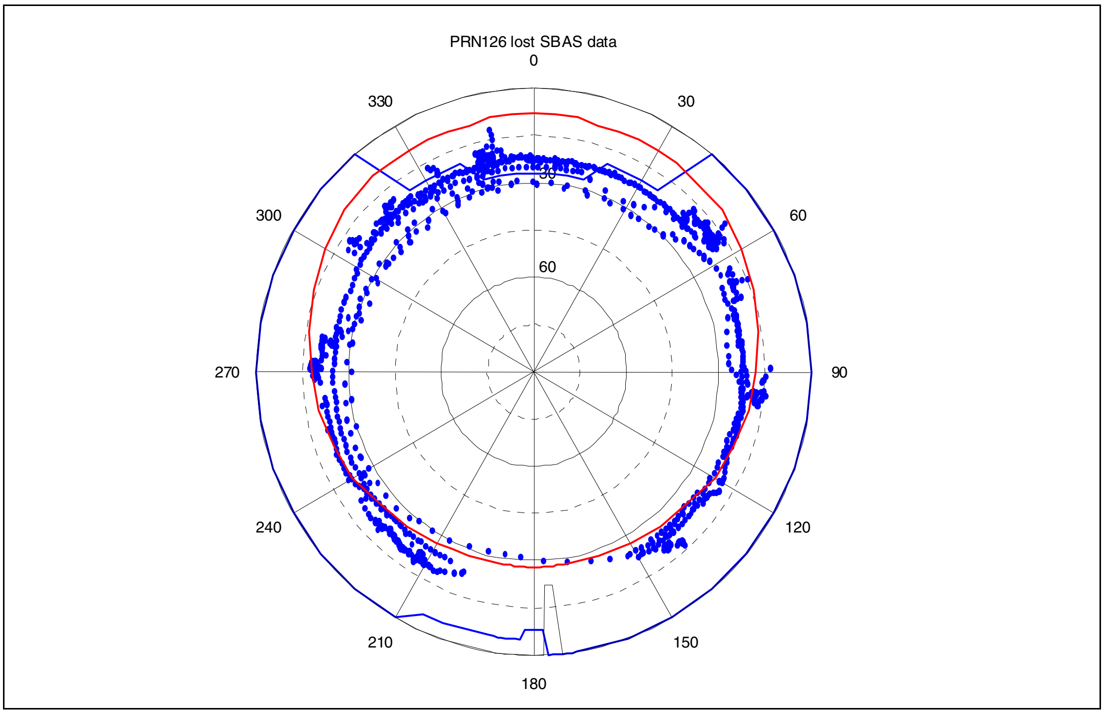

Figure 5.30 PRN126 lost signals by elevation and azimuth

6 EGNOS availability assessment

6.1 Overview

6.1.1 The visibility of the EGNOS Geostationary satellites at typical North Sea latitudes was identified as a possible constraint on the SOAP procedure during its conception. Hence, activities were planned to investigate this aspect both practically and through simulation as an element of the GIANT project. The practical investigations are reported in Section 5. This section summarises the simulation activities undertaken to establish the likely in-service SOAP availability for a particular aircraft installation.

6.2 Methodology

6.2.1 The meteorological conditions in the offshore environment dictate the approach tracks utilised by flight crew. For operational reasons the approach track will be selected to be predominantly into wind, particularly for operations in low visibility. For this exercise it has been assumed that EGNOS based SOAP approaches will either be configured to allow pilot selection of approach tracks, or will be oriented along the direction of the prevailing wind. On this basis, an analysis of prevailing winds in the North Sea area will establish typical approach headings.

6.2.2 The airframe masking experienced by a typical SBAS antenna installation constitutes the major element driving the availability of the SOAP. Expected masking effects have been established for the GNSS installation on board the Eurocopter AS323L Super Puma used for the GIANT flight trials. These masking effects have been broadly validated through the data collection activities and suggest that GEO masking is likely to occur in an arc ± 40 degrees either side of the aircraft heading due to the engines and main rotor gearbox being located ahead of the antenna.

6.2.3 To establish the likely heading of the aircraft for any given set of meteorological conditions the rules shown in Table 6.1 are applied. This results in an indicated heading against which to assess the impact of airframe masking.

Table 6.1 Aircraft heading for given wind speed

Wind Speed	Approach heading to be selected
< 10 knots	Preferred headings to be adopted. Flying due North optimises EGNOS availability
≥ 10 knots	Track selected such that no more than a 10 degree offset between heading and track due to wind is incurred. Seek to make the most Northerly approach possible.

6.2.4 When the aircraft preferred heading is combined with the results of the airframe masking effects, ascertained by visual inspection of the GNSS antenna location and subsequently validated during the flight trial, it is possible to produce averaged availability figures for SOAP operations in the North Sea.

6.2.5 Daily surface wind data is available for the North Sea from the JPL/NASA QuikSCAT satellite. This information has been used to provide an analysis of prevailing wind conditions in the North Sea environment. The met data is derived from the SeaWinds instrument on the QuikSCAT satellite.

6.2.6 All of the SeaWinds datasets from 1st January 2000 through to 31st December 2007 have been processed to arrive at daily wind speed and headings at a number of data points on a 0.25° x 0.25° grid across the entire UK sector of the North Sea. Example data is shown in Figure 6.1

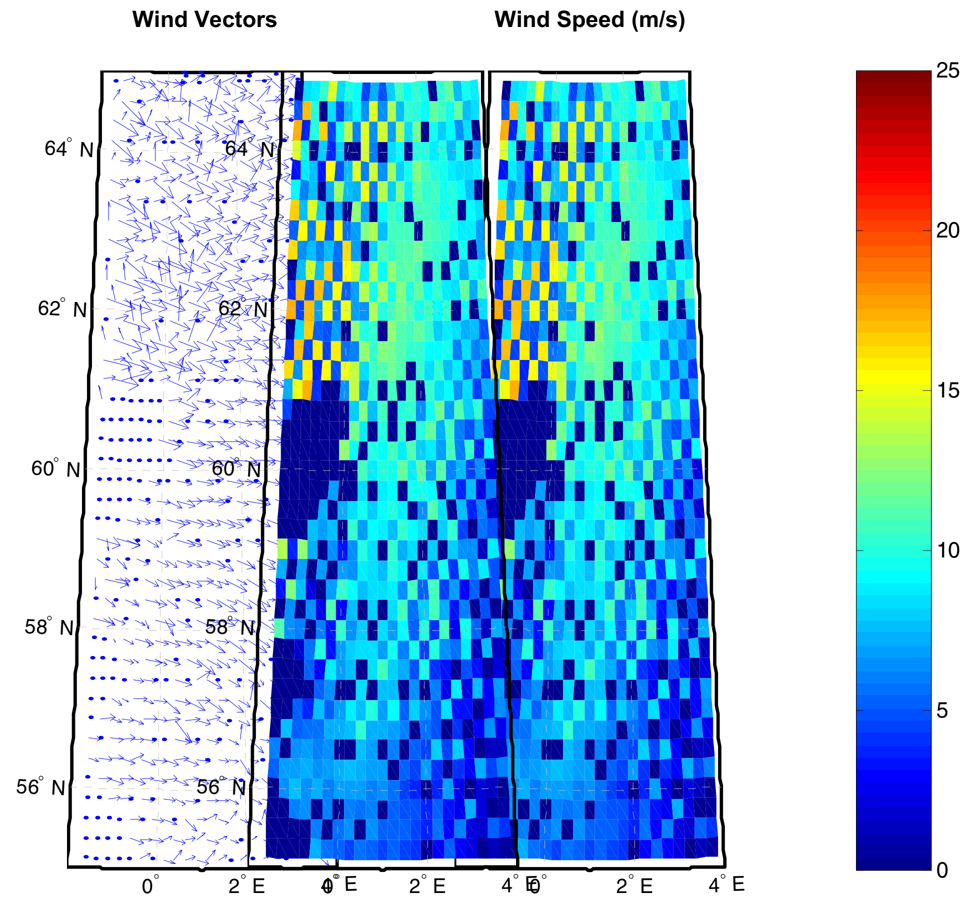

Figure 6.1 Example SeaWinds data for the North Sea

6.2.7 The weather conditions captured in the SeaWinds daily data have been assumed to be applicable over an entire 24 hour period. Furthermore, while the data is intended to be accurate at a height of 10m above the sea, it has been assumed to represent the met conditions at the approach heights of interest for SOAP (e.g. 200 ft – 1,500ft).

6.2.8 The simplistic airframe masking model specific to the Super Puma employed for the practical trails is shown in Figure 6.2. The blue line shows the headings and elevation angles at which masking of the GEO satellites could occur. Superimposed in green are the elevations of the EGNOS GEO satellites at Aberdeen, and in red the area in which the satellite signals could be expected to pass through the plane of the main rotor blades. As the aircraft moves further North and South of Aberdeen the elevation angle of the satellites could be expected to rise and fall. The analysis therefore takes account of the latitude of the grid points being simulated.

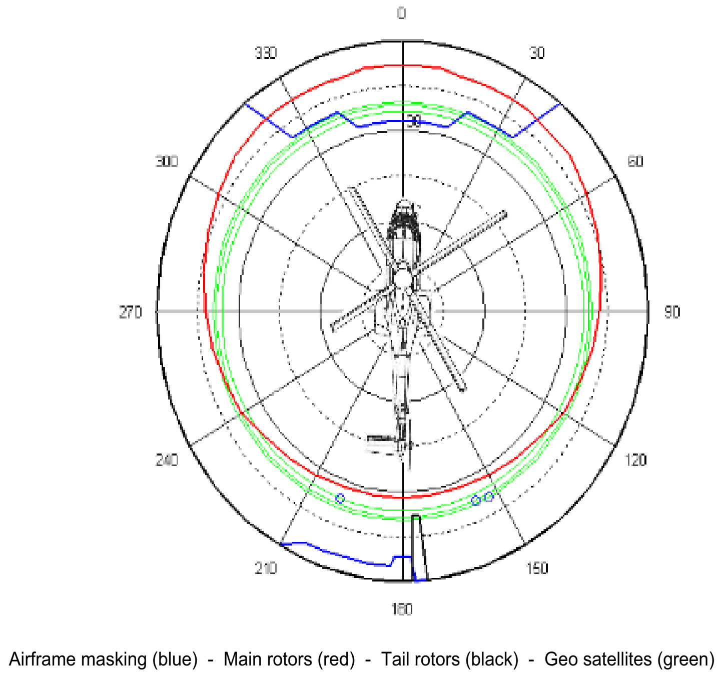

Figure 6.2 Airframe masking for SuperPuma aircraft

6.2.9 The simulation of EGNOS availability is calculated at a number of points on a 0.25° x 0.25° degree grid across the North Sea as illustrated in Figure 6.3. For each day during the period 2000 through to 2008 it calculates an estimate of the availability of EGNOS across the entire region as well as at each grid point.

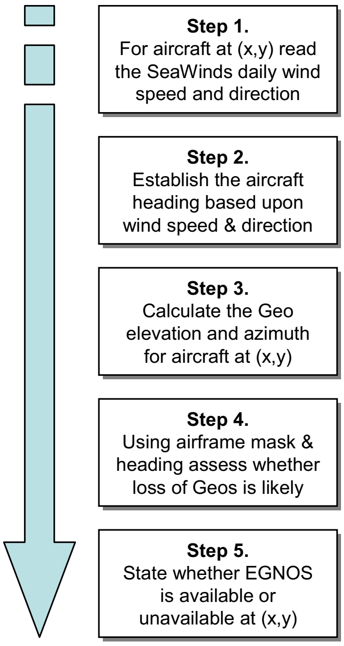

Figure 6.3 Overview of processing steps

6.2.10 The service is defined as being unavailable if either of the two EGNOS Geostationary satellites are likely to be masked at the selected aircraft heading. No consideration is given to the unavailability due to the EGNOS system itself (expected to be negligible, compared to that due to other causes), or due to limited numbers of GPS satellites in view (for example due to constellation or masking effects – see [Ref. 7]).

6.2.11 The resulting availability figures represent the proportion of the time that an EGNOS SOAP could have been used if required. It takes no account of the times at which the procedure would actually be needed due to poor visibility. Therefore, the actual availability of the approach on a 'per demand' basis has not been calculated.

6.3 Results

6.3.1 The results of the simulations are summarised in Figure 6.4. This illustrates the availability of the SOAP procedure measured across the UK sector of the North Sea on a grid point by grid point basis. The availability across the region as a whole is 93.2%. This compares with a minimum recommended (system level) availability for GNSS based flight operations of 99%. The minimum acceptable availability for this particular helicopter is an economic decision for the operator. It should be recalled that the overall availability obtained relates to the specific (tail boom) antenna installation on board the Eurocopter Super Puma used for the trials and is not necessarily more generally applicable.

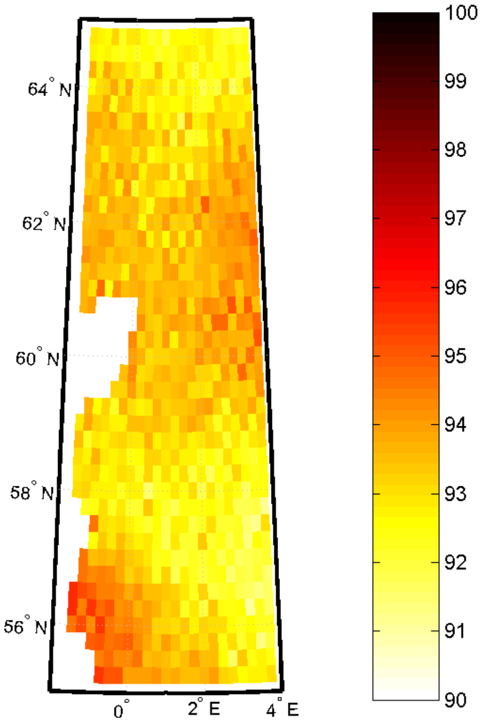

Figure 6.4 Average SOAP availability over period 2000 through to 2008

6.3.2 As would be expected, daily availabilities display much greater variability ranging from 100% to 40% depending upon the wind conditions measured by SeaWinds. The yearly availability figures are broadly consistent as shown in Figure 6.5, and vary in range by 3–4%.

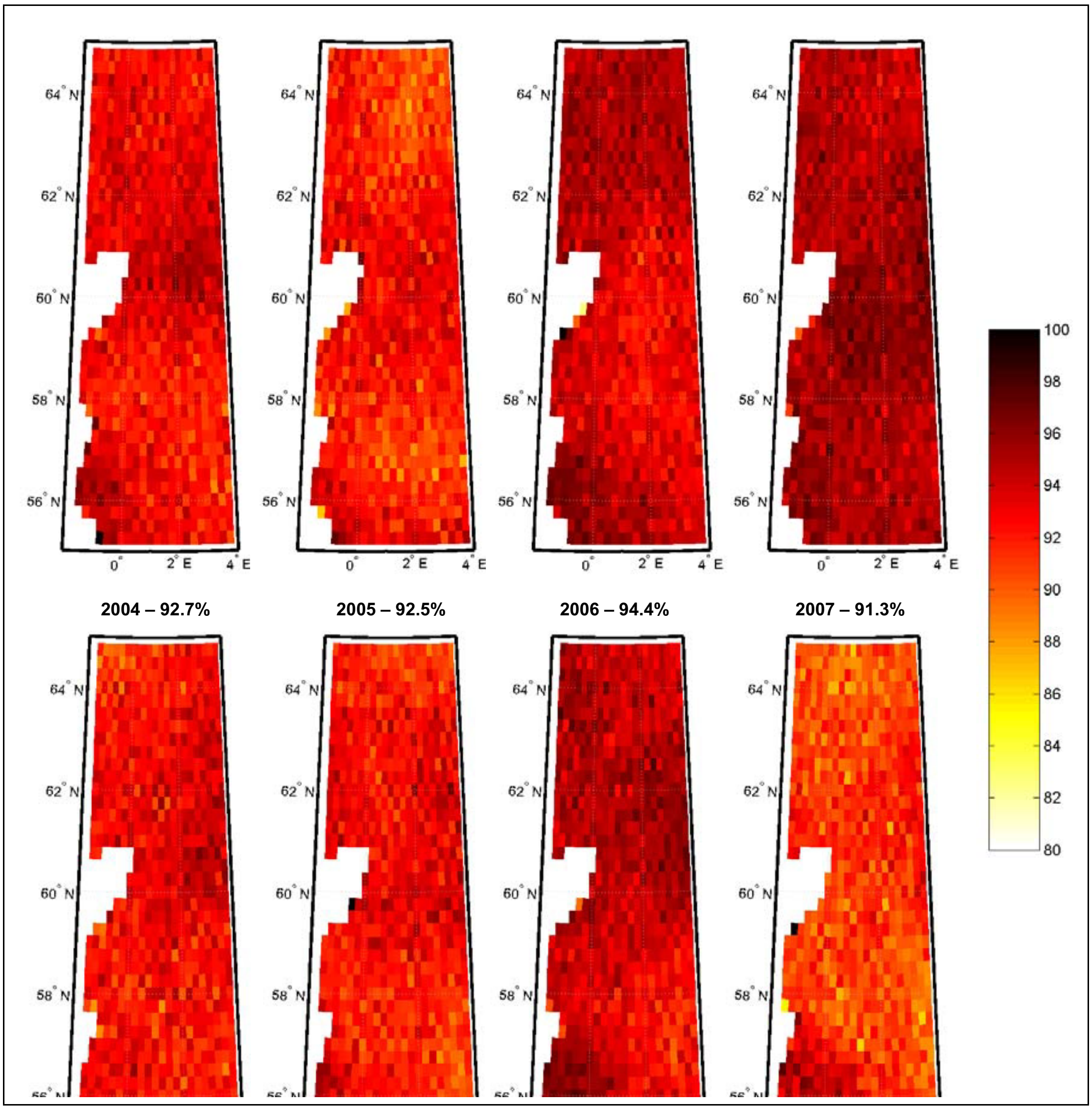

Figure 6.5 Annual SOAP availability figures for 2000 through 2008

6.4 Conclusions

6.4.1 An assessment of the likely availability of the SOAP procedure for a specific GNSS antenna installation on board a Eurocopter Super Puma has been undertaken. On the basis of the actual weather conditions experienced in the North Sea over the period 2000 through 2008 and certain assumptions regarding approach tracks, it is estimated that SOAP availability would be in the region of 93%. This level of availability suggests that, for the Super Puma at least, it would be worth expending the effort to improve the antenna installation prior to the commencement of SOAP operations. This could involve moving the existing antenna, changing the antenna characteristics and/or adding a second antenna (subject to resolution of a number of issues unique to SBAS).

7 Conclusions

7.1 General

7.1.1 This report has presented the results of work to investigate the feasibility of a new type of offshore approach procedure, SOAP, that will offer reduced workload and increased safety.

7.1.2 The procedure has been described, although some aspects of it still need to be confirmed:

- The manner of database coding to ensure the correct offset of the final approach track – it has been assumed here that a destination waypoint and obstacle radius are available to be used together with the offset distance to calculate the final approach track. The feasibility of this needs to be confirmed.
- The height of the final approach level segment – a fixed MDA of 200 ft has been assumed here. In practice the MDA will need to be linked to the helideck height which could conveniently be achieved by adding this information to the navigation database. The feasibility of this needs to be confirmed. In addition, a higher MDA could be applied if required, and the benefits and disadvantages of this need to be considered.

The conclusions are presented under each main area of activity.

7.2 Simulations

7.2.1 The simulations showed that the proposed SOAP procedure was easy to fly and provided positive feedback on the lateral and vertical guidance.

7.2.2 The simulations validated some of the proposed simulation parameters, including the descent slope, maximum offset angle, MDR, length of the level segment, minimum airspeed and maximum groundspeed (see Section 3.8 for details).

7.2.3 Overall, the ILS ‘look-alike’ guidance was preferred to the procedural guidance. This was confirmed in a meeting of interested parties following completion of the simulations.

7.3 Safety assessment

7.3.1 The safety assessment showed that the navigation performance of EGNOS–enhanced GPS would provide sufficient lateral and vertical accuracy under normal conditions. EGNOS performance limits of 40m horizontal and 27m vertical have been assumed. These should provide good service availability, but this needs to be confirmed in future work.

7.3.2 In most cases of system failure, the analysis found that the risk is 'negligible'. However in several cases the risk was found to be only 'tolerable', and it is recommended that mitigations should be investigated to reduce the probability of these events. One such mitigation could be the carriage of an AIS receiver on board helicopters to provide positive location and identification of all obstacles, and the possible interface with TAWS A to provide an automatic collision warning system. The analysis suggests that the use of AIS data for display and collision warning would be sufficient to make all the risks 'negligible'.

7.4 EGNOS data collection and analysis

7.4.1 The static tests highlighted that rotor interference is unlikely to degrade the accuracy of the SBAS satellite pseudorange measurements.

7.4.2 However, the flight test found clear evidence of both obscuration of satellites due to the airframe, as well as of an inability to track the low elevation satellites in the lower gain areas of the aircraft's GNSS antenna and some evidence of loss of lock potentially due to the helicopter's main rotor.

7.4.3 The antenna installation on the test helicopter (a Eurocopter Super Puma AS332L) appears well suited to its current purpose of providing an input into a GPS navigation receiver. However, the installation is sub-optimal for SOAP operations. Consideration should be give to re-siting the antenna and/or replacing it with a more suitable unit and/or adding a secondary antenna located forward of the engines and main rotor gearbox. These options need further investigation.

7.5 EGNOS availability assessment

7.5.1 An assessment was made of the likely availability of the SOAP procedure for a specific GNSS antenna installation on board the test helicopter. On the basis of the actual weather conditions experienced in the North Sea over the period 2000 through 2008, it is estimated that the overall SOAP availability would be in the region of 93%. This level of availability suggests that, for the Super Puma at least, it would be worth expending the effort to improve the antenna installation prior to the commencement of SOAP operations.

8 Recommendations

8.1 The following recommendations are made:

- The feasibility of including an obstacle radius and helideck height in the navigation database to permit automatic lateral offset and MDA selection should be investigated.
- The feasibility of displaying AIS information to the flight crew and of using the AIS information as part of a collision warning system should be investigated further.
- Consideration should be given to re-siting the antenna on the Super Puma AS332L or adding a secondary unit on this aircraft in particular. It is also recommended that EGNOS reception studies be conducted on other helicopter types to ensure adequate reception characteristics for SOAP, and that alternative antennas with higher gain at lower angles of elevation be considered.

9 References

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2 EGNOS – Mission Requirements Document, Galileo Joint Undertaking, Version 2.0, 08 May 2006.

3 Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment, RTCA, DO–229D, December 2006.

4 Aeronautical Telecommunications – Volume 1 (Radio Navigation Aids), ICAO Annex 10, Amendment 80, 24 November 2005

5 DGPS Guidance for Helicopter Approaches to Offshore Platforms, CAA Paper 2000/5, Civil Aviation Authority, London, November 2000.

6 DGPS Guidance for Helicopter Approaches to Offshore Platforms – Follow–On Studies, CAA Paper 2003/2, Civil Aviation Authority, London, June 2003.

7 Effect of Helicopter Rotors on GPS Reception, CAA Paper 2003/7, Civil Aviation Authority, London, December 2003.

8 JAA AMJ 25.1309–25.

Appendix A Abbreviations and acronyms

AFCS	Automatic Flight Control System
AIS	Automatic Identification System
APV	Approach with Vertical Guidance
ARA	Airborne Radar Approach
AVAD	Audio Voice Alerting Device
CAA	UK Civil Aviation Authority
CDI	Course Deviation Indicator
CDU	Control Display Unit
CNo	Carrier-to-Noise ratio
DGPS	Differential GPS
DOP	Dilution of Precision
EFIS	Electronic Flight Information System
EGNOS	European Geostationary Navigation Overlay System
EIRP	Effective Isotropic Radiated Power
ESA	European Space Agency
EUROCAE	European Organisation for Civil Aviation Equipment
FAA	Federal Aviation Administration
FAF	Final Approach Fix
FAS	Final Approach Segment
FD	Flight Director
FSD	Full Scale Deflectiont
FTE	Flight Technical Error
FAA	Federal Aviation Administration
FMS	Flight Management System
GEO	Geostationary Satellite
GIANT	GNSS in Aviation
GNSS	Global Navigation Satellite System

GPA	Glide Path Angle
GPS	Global Positioning System
GSA	GNSS Supervisory Authority
GSI	Glide Slope Deviation Indicator
HAL	Horizontal Alert Limit
HPL	Horizontal Protection Limit
HSI	Horizontal Situation Indicator
IAF	Initial Approach Fix
ICAO	International Civil Aviation Organisation
ILS	Instrument Landing System
LPV	Lateral Precision Performance with Vertical guidance
MAP	Missed Approach Point
MDA	Minimum Descent Altitude
MDR	Minimum Decision Range
MOPS	Minimum Operating Standards
MSA	Minimum Safe Altitude
ND	Navigation Display
Nm	Nautical mile
NSE	Navigation System Error
PFD	Primary Flight Display
RTCA	Radio Technical Commission for Aeronautics
SBAS	Satellite-Based Augmentation System
SOAP	SBAS Offshore Approach Procedure
SRG	Safety Regulation Group (of the CAA)
TAWS	Terrain Awareness Warning System
TSE	Total System Error
TSO	Technical Standards Order
VAL	Vertical Alert Limit
VPL	Vertical Protection Limit

Appendix B Flight simulation results

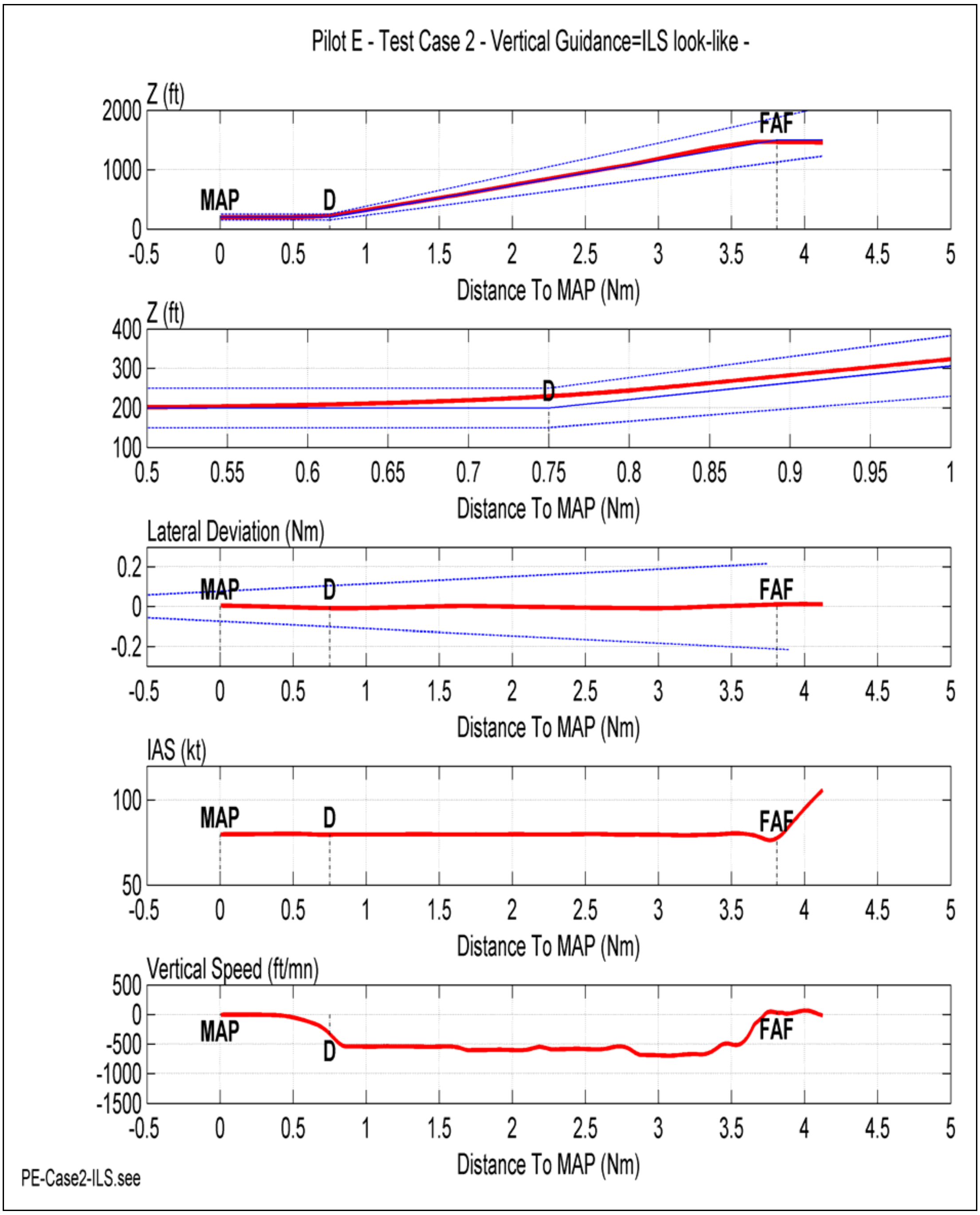

Figure B.1 Simulation results FAF to MAP – Test case 2

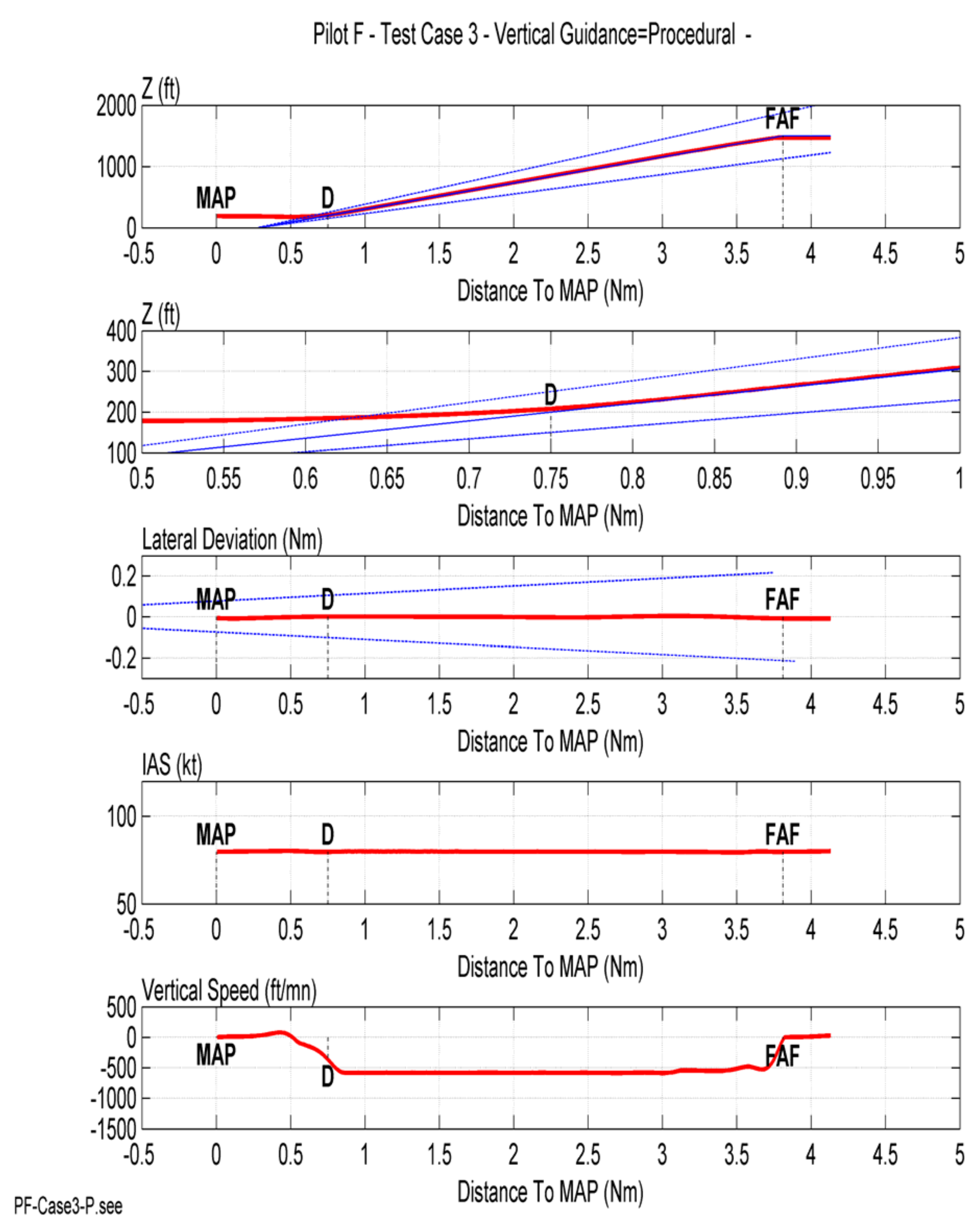

Figure B.2 Simulation results FAF to MAP – Test case 3

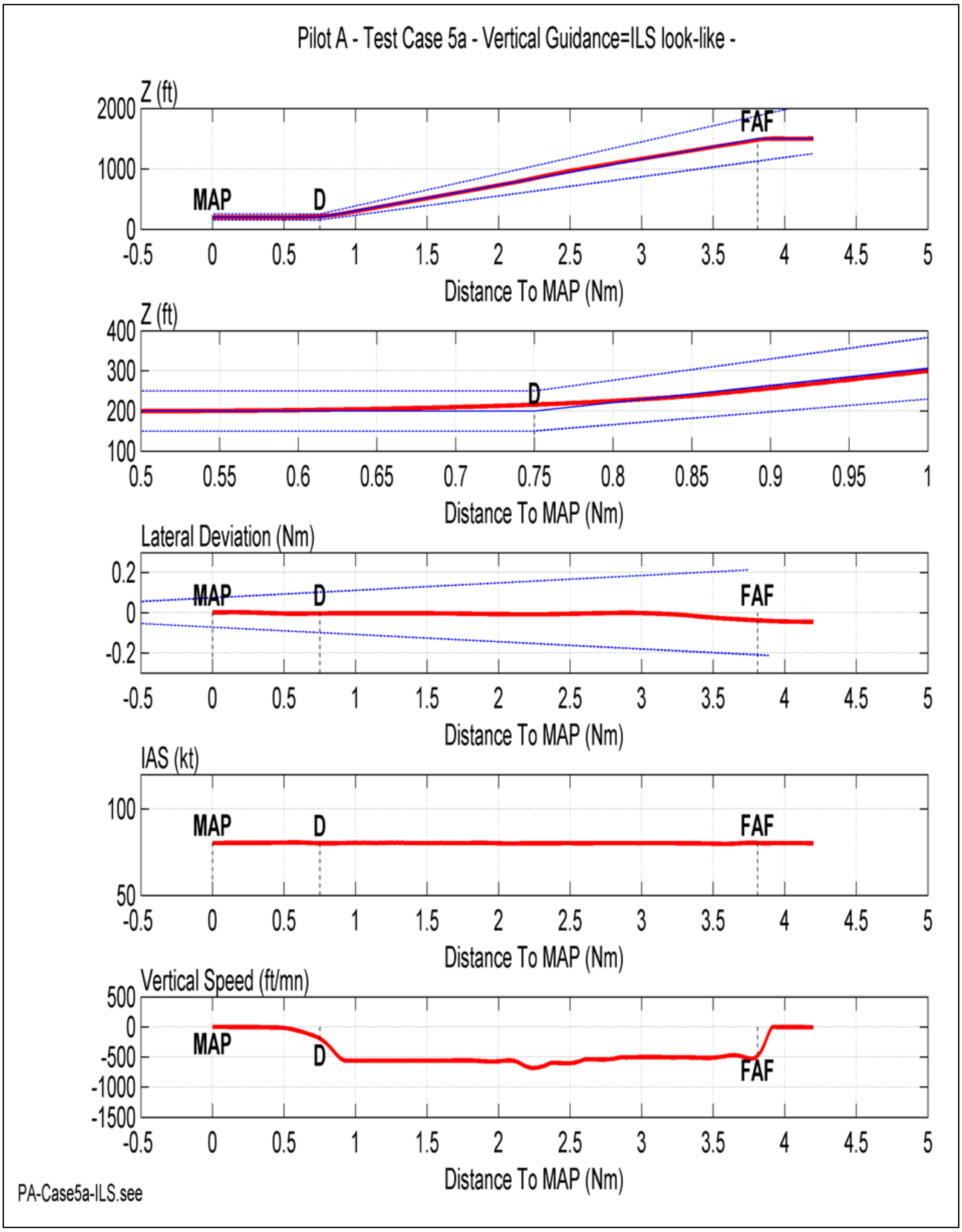

Figure B.3 Simulation results FAF to MAP – Test case 5a

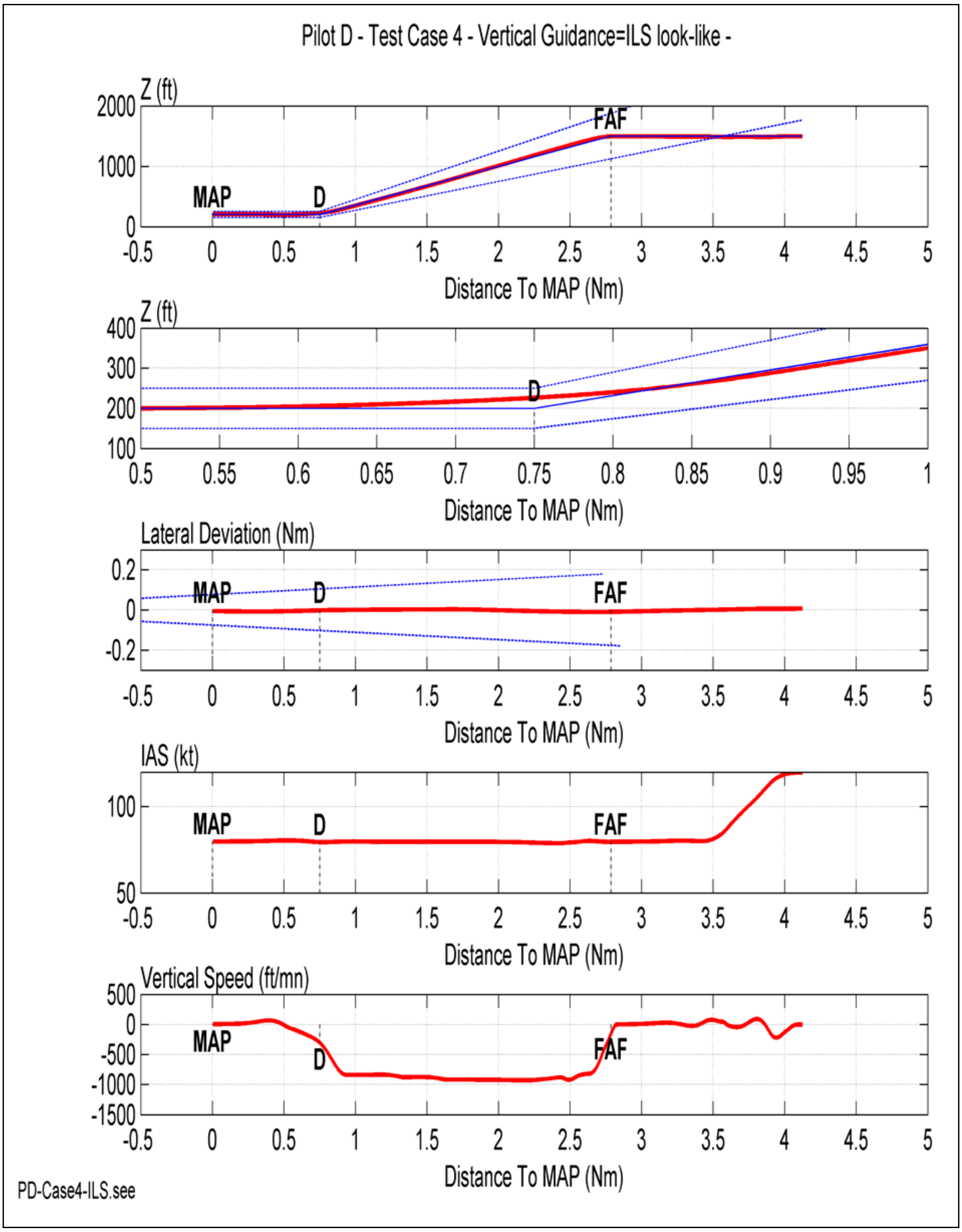

Figure B.4 Simulation results FAF to MAP – Test case 4

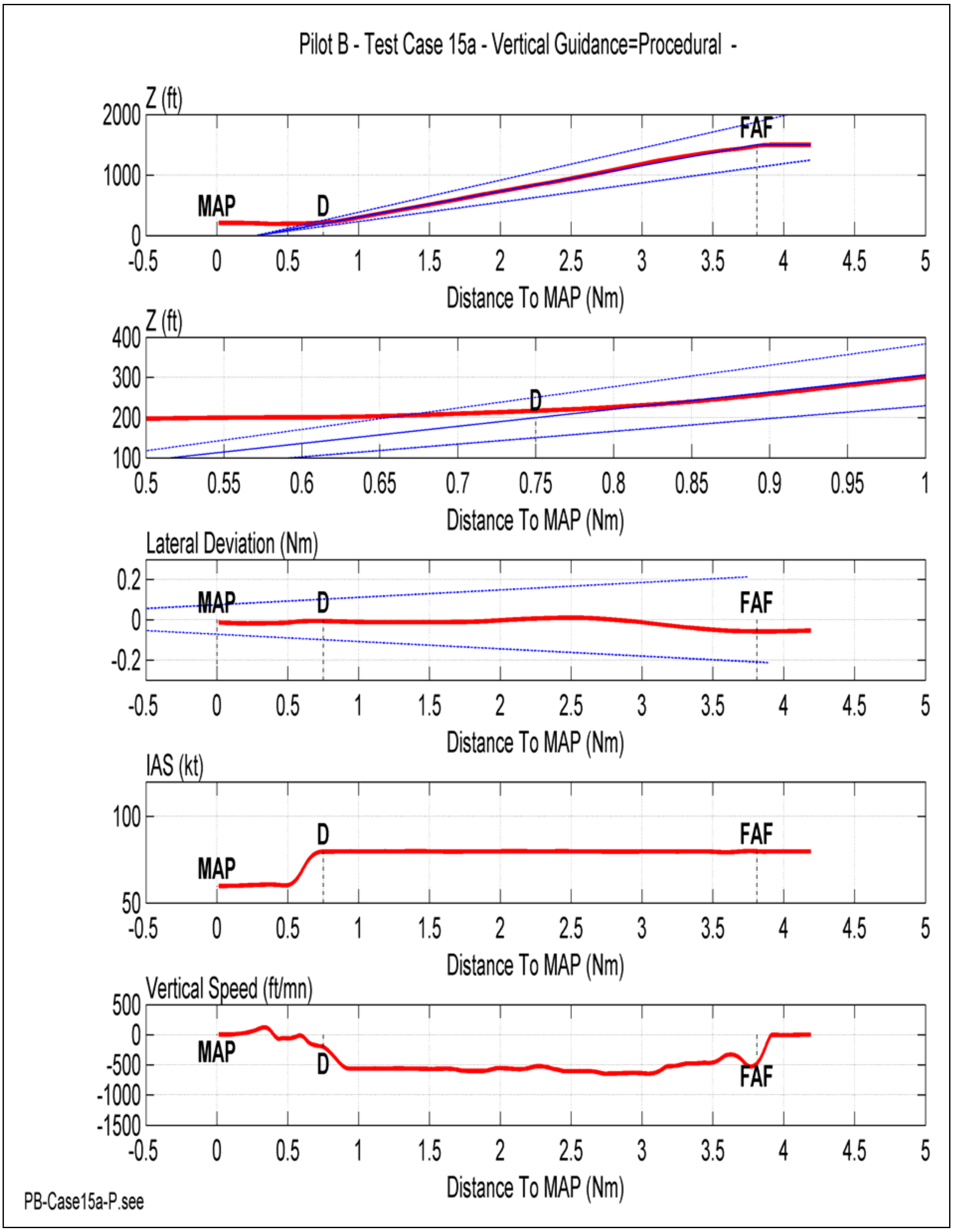

Figure B.5 Simulation results FAF to MAP – Test case 15a

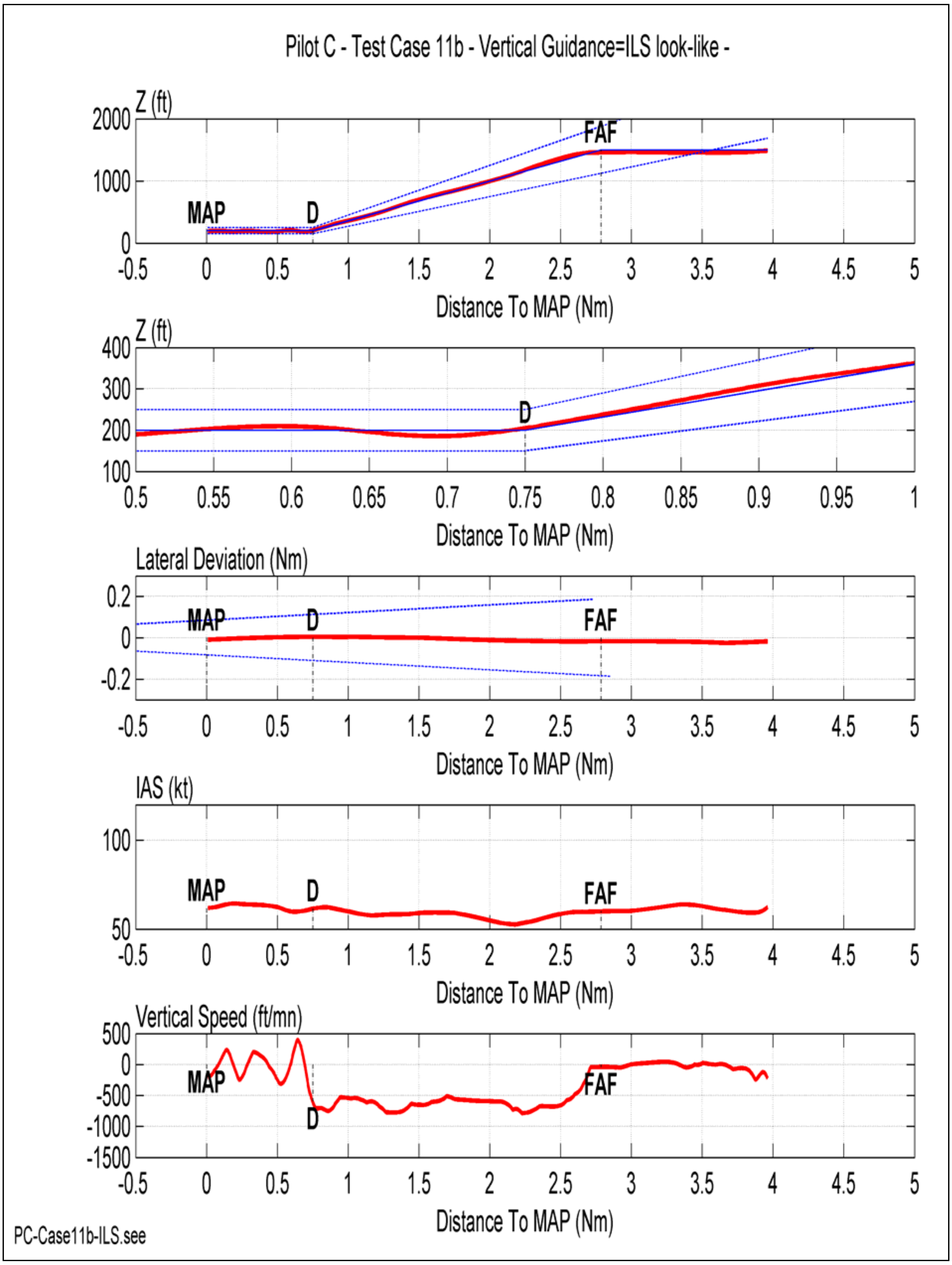

Figure B.6 Simulation results FAF to MAP – Test case 11b

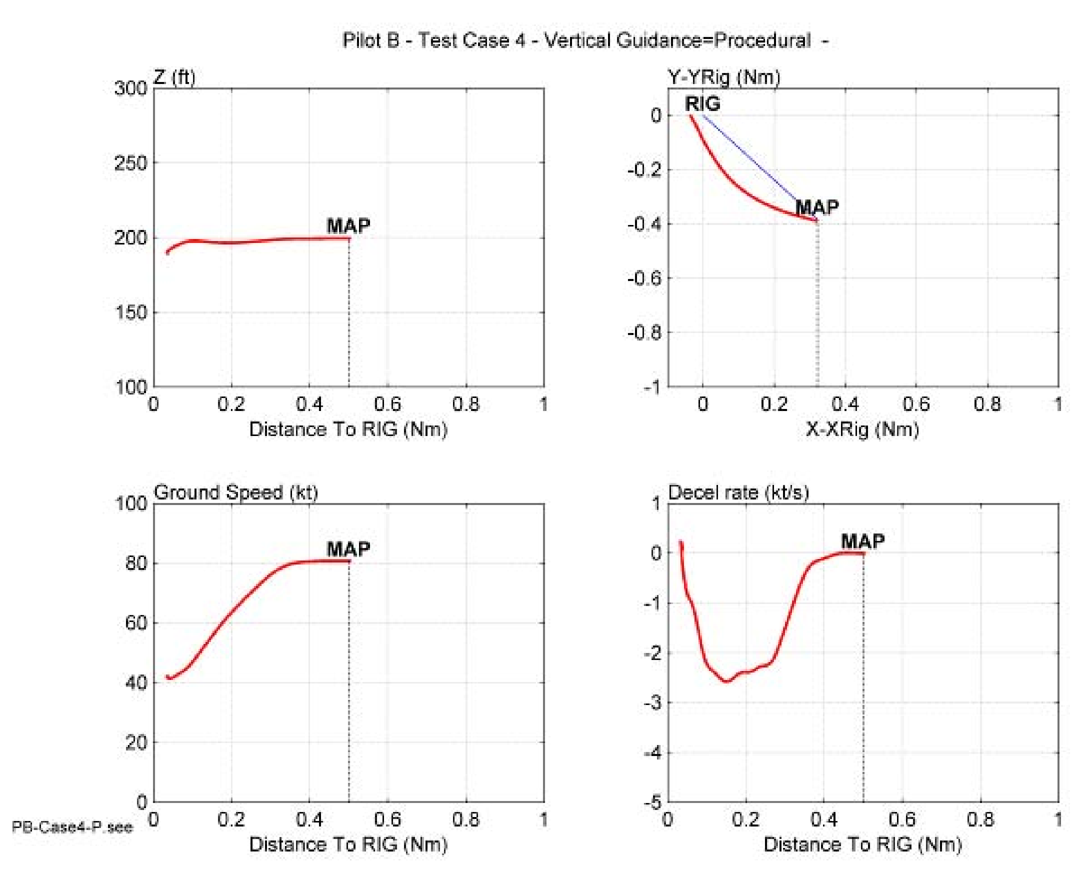

Figure B.7 Simulation results MAP to RIG – Test case 4

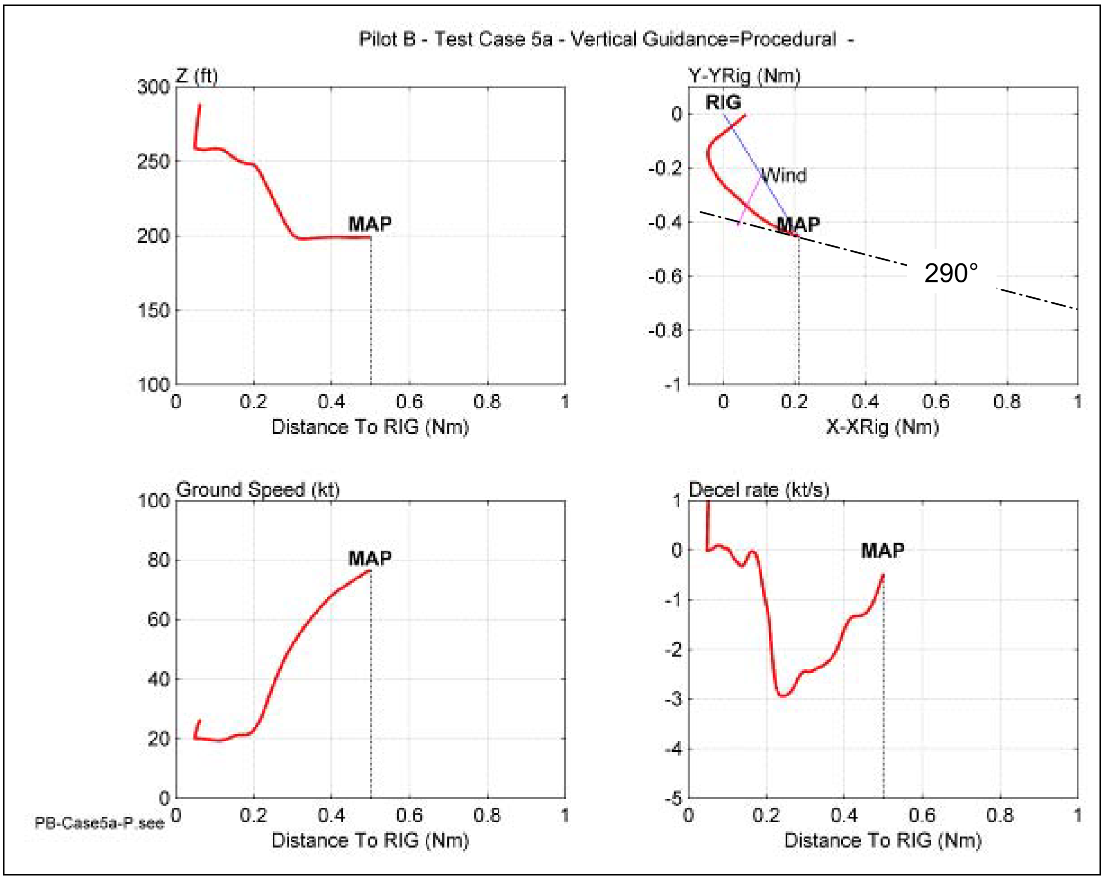

Figure B.8 Simulation results MAP to RIG – Test case 5a

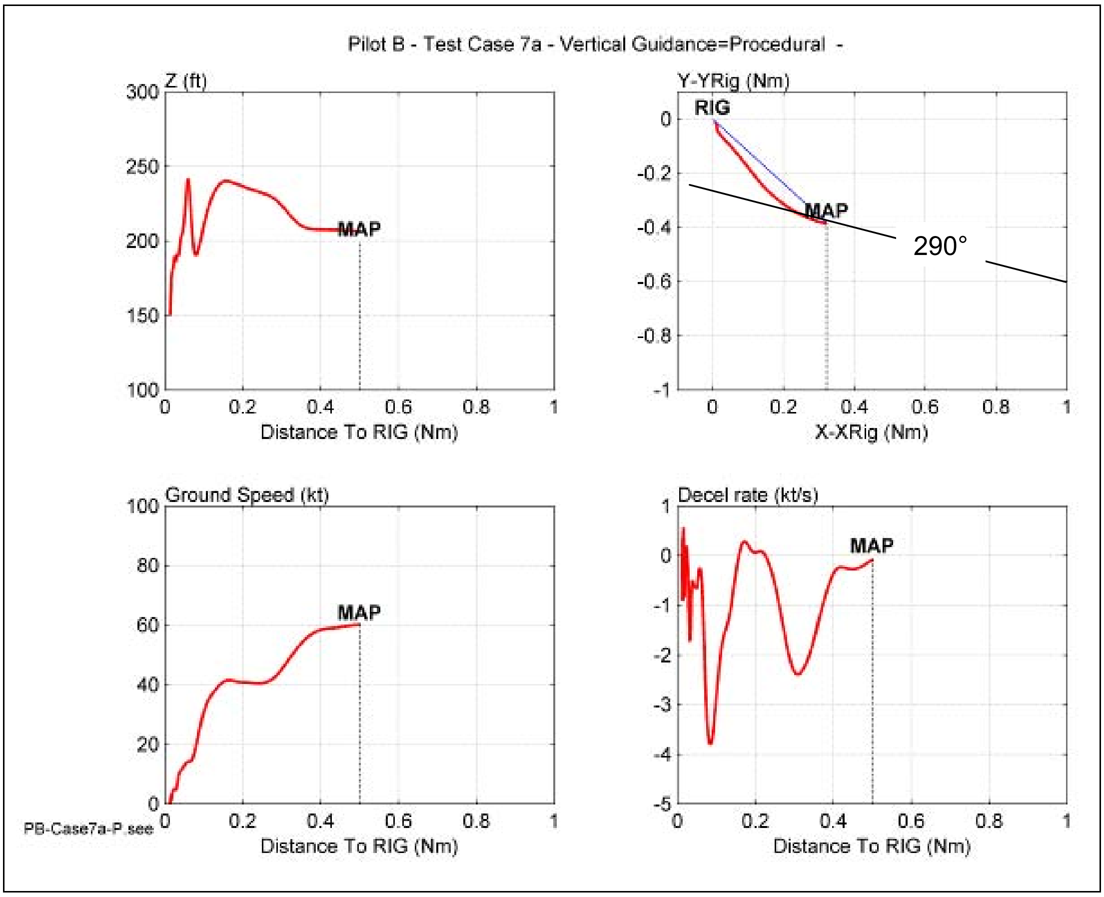

Figure B.9 Simulation results MAP to RIG – Test case 7a

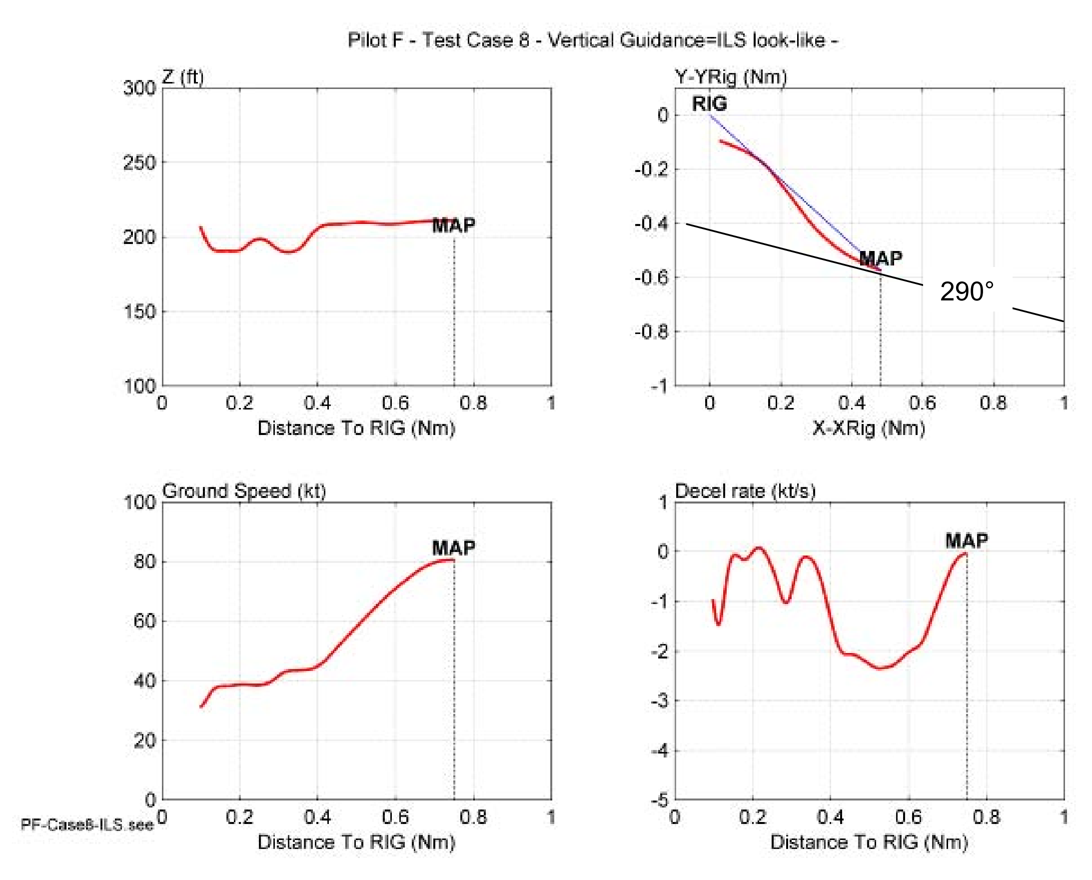

Figure B.10 Simulation results MAP to RIG – Test case 8