Safety Regulation Group

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RNAV (GNSS) Non-Precision Approach – Flight Trials Analysis Report

Based on a report prepared for the CAA by Dr. W Ochieng, C Milner and M Daly, Imperial College London and University of Leeds

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Executive Summary

1 Background

The Global Positioning System (GPS) is currently being used for en-route and oceanic phases of flight as a primary means navigation system and as a supplemental navigation aid for more demanding procedures. The development of GPS has allowed the creation of Area Navigation (RNAV) Global Navigation Satellite System (GNSS) approaches, a type of non-precision approach (NPA) procedure. At present, GPS is the only fully operational GNSS, therefore an RNAV (GNSS) approach can currently be considered as an RNAV (GPS) approach and was formally known as GPS/NPA. The arrival of this new technology, currently realised by GPS, brings with it the need for new techniques, both for the pilot and the air traffic controller. Pilots must make a safe transition from the techniques employed with traditional navigation aids to those required for the new techniques. This period of transition presents a significant risk in terms of human error and misunderstanding.

The aims of this project were to gain an understanding of pilot experience and interpretation of RNAV (GNSS) procedures within the UK through flight trials at six aerodromes. As well as the objective to understand the complexity of receiver programming and the spatial perception of pilots, other factors such as the interface with air traffic control (ATC), phraseology, traffic, pilot training and issues regarding missed approaches were also considered.

2 Methodology

In order to maximise involvement, the flight trials (hereafter referred to as the 'trials') were promoted on the CAA website, at aerodromes and within aviation magazines. Pilot perceptions were obtained through voluntary involvement and completion of an online trial questionnaire for each approach undertaken. Upon signing up to the trials, the pilots were required to provide basic information including their CAA registered pilot number, contact details and flight experience. The flight experience variables were designed to compare specific subgroups of pilots and to determine how pilot experience relates to performance.

The secure trials website was hosted at Leeds University and the data submitted by pilots were stored using a MySQL database. Pilots were required to have read the terms and conditions of the trials and various guides for GPS operation were accessible from this web interface.

Once registered, a pilot was authorized to fly an RNAV (GNSS) non-precision approach. Informing the relevant ATC unit of the proposed approach was necessary to corroborate the pilot questionnaire with an ATC log. The ATC log was also used to investigate the issues of sequencing, phraseology and traffic separation problems.

The questionnaire (Appendix A) was arranged in sections: characteristics, flight data, ease of receiver programming, flying the approach and conclusions. A number of open text box answers were possible for specific issues.

The data collected were analysed at Imperial College London following a data processing strategy specifically developed for this project. The first stage of this data processing strategy was data retrieval, to provide a means for acceptance, conversion, formatting and storage of the data. A method for converting the online questionnaires into a meaningful database to enable both qualitative and quantitative analysis was a key element of the retrieval stage. This constituted the design and coding of a script, which was run at regular intervals throughout the trials. The pre-processing of data was then performed to achieve data completeness and data reliability. This constituted a number of editing tasks such as cropping, copying, new variable computation, flagging of data and weighting.

The project aims were stated in a series of specific questions relating to each category and can be found in Appendix B. These were used to give a basis for interpretation and direction of the main data processing and analysis. The analysis methodology was defined following a study of how best to achieve these goals. Details of the individual analysis phases are given in Section 2 of the report.

3 Data Sample

The trials period was originally defined from May 2006 through to October 2006 and was subsequently extended through to December 2006. Registered pilots with UK licences were permitted to fly approaches at six UK aerodromes: Blackpool, Durham Tees Valley, Exeter, Gloucestershire, Inverness and Shoreham. There were a total of 171 trial questionnaires submitted to the website. These responses were generally from pilots using Category A aircraft (94.7%), with all but one of the responses from either Category A or B. All aircraft used for the trials had TSO-C129 (1996) (Class A1+) certified receivers of which 95% were panel mounted and 5% integrated with a Flight Management System (FMS). The most popular receiver used in the trials, the Garmin GNS 430, reflects general use within the non-commercial aviation world.

The frequency of the responses varied greatly between the six trial aerodromes (see Table 1 below). However, there was no evidence of any issues specific to an individual aerodrome, which meant that data could be pooled for subsequent analysis.

Table 1 Number of Trial Approaches Flown by Aerodrome

Aerodrome	Frequency	Percentage (%)
Blackpool	15	8·8
Durham Tees Valley	11	6·4
Exeter	22	12·9
Gloucestershire	85	49·7
Inverness	1	0·6
Shoreham	37	21·6
Total	**171**	**100·0**

4 Results

The main findings from the trials were as follows:

4.1 Data Reliability

4.1.1 94·7% of reports were accepted for analysis on the basis of ATC verification, latency of submission and a manual reasonability check.

4.2 **Pilot Checks**

4.2.1 The results showed that a large proportion of **pilots were confused by the installation status** of the receiver used for the trial. Approval of RNAV (GNSS) approaches should be accompanied by education of pilots on the issue of receiver approval status.

4.2.2 Some 88·4% of the trials and 85·8% of pilots had valid aeronautical databases in their receivers. There appeared to be no specific external causes for those pilots that used out-of-date databases.

4.2.3 The **majority** (92·0%) of reports submitted were from pilots who had made the necessary **RAIM availability check**, primarily using the on-board receiver, although RNAV experienced pilots also used online and simulator based functions.

4.2.4 Pilot behaviour could be improved by greater practicality and clarity of, and accessibility to the regulations and available guidance material with a practical checklist to help ensure pilots make the necessary checks.

4.3 **Flight Procedures**

4.3.1 The **most safety relevant issue** found in the trials was pilot confusion over range information displayed to the next waypoint and not the missed approach point or runway threshold.

4.3.2 The issue referred to in 4.3.1 was extenuated with the use of Garmin receivers, particularly the Garmin GNS 430/530 models, due to the coding of step-down fixes as waypoints within the receiver database.

4.3.3 Confusing range information complicates the calculation of the vertical descent profile and spatial perception suffers.

4.3.4 TSO-C145/6B receivers are capable of providing a 'distance-to-run' read-out to alleviate this problem.

4.3.5 There were **no traffic separation or sequencing issues** that were directly related to RNAV (GNSS), the only issue raised was the risk of mixing instrument and visual flight rules traffic.

4.3.6 Phraseology was deemed suitable both by ATC and pilots.

4.4 **Equipment**

4.4.1 There were a multitude of **difficulties learning to operate and programme** the equipment, the most serious of which was the loading and activation of the approach.

4.4.2 A small number of pilots encountered problems **resetting the approach following a missed approach**.

4.4.3 The most common problem pilots encountered with the equipment was setting of the course deviation indicator (CDI) due to incorrectly setting the auto-rescaling function.

4.5 **Approach Chart**

4.5.1 Generic problems with charting were not found, but specific chart errors, which are a **potential safety risk**, were observed and are given in detail in Section 4.5 of the report.

4.5.2 Approval of approaches should be dependent on a zero-error approach chart environment.

4.6 **Training**

4.6.1 Pilots found the **existing training** (79·0% of submitted reports) **to be adequate** for RNAV (GNSS) procedures. A level of improvement was observed as a result of learning during the trials.

4.6.2 There was little evidence to suggest a minimum level of flight experience is required for all pilots. However, for a pragmatic approach to safety, the trials suggested that **at least three approaches** needed to be flown for some pilots to uncover potential problems.

4.6.3 Current guidance was perceived to be too regulatory and **not practical enough**.

4.6.4 More than half of pilots who reported inadequate training (13·0% of all reports) advocated some form of **formal training course**.

4.7 **Pilot Perceived Performance**

4.7.1 It was concluded from the trials that pilots found **RNAV (GNSS) non-precision approaches simple, easy and accurate**.

4.7.2 A **fifth of all questionnaires were used to express special praise for GPS** and the RNAV (GNSS) approach procedures.

4.8 **Alarms and Warnings**

4.8.1 Only one Receiver Autonomous Integrity Monitoring (RAIM) alarm was reported during the trials, which was attributed to on-board interference caused by the high number of antennae and navigation and communications equipment on-board the specific aircraft.

4.9 **General Pilot Observations**

4.9.1 Pilots made comments referring to problems with equipment operation, the spatial perception problems stated in 4.3.1 - 4.3.3 and had special praise for RNAV (GNSS).

4.10 **GPS Signal-In-Space Performance**

4.10.1 **GPS Signal-In-Space (SIS) performance** was found to be **100%** following analysis of GPS performance monitoring parameters, recorded by Leeds University, and evidence from the trials.

4.11 **Future Application of GNSS**

4.11.1 Over 90% of pilots felt the extension to instrument meteorological conditions (IMC) to be entirely reasonable and all the reasons stated to the contrary were a matter of further practice being required.

Glossary

AFIS	Aerodrome Flight Information System
AGCS	Air/Ground Communications System
ATC	Air Traffic Control
ATSB	Australian Transport Safety Bureau
B-RNAV	Basic Area Navigation
CAA	Civil Aviation Authority
CDI	Course Deviation Indicator
DME	Distance Measuring Equipment
FAF	Final Approach Fix
FD	Fault Detection
FDE	Fault Detection and Exclusion
FMS	Flight Management System
FPL	Flight Plan
GA	General Aviation
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HSI	Horizontal Situation Indicator
IAF	Initial Approach Fix
ICAO	International Civil Aviation Organization
IF	Intermediate Fix
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
ISN	Institute of Satellite Navigation
MAPt	Missed Approach Point
MDA	Minimum Descent Altitude
NASA	National Aeronautics and Space Administration
NDB	Non-Directional Beacon
NM	Nautical Mile
NOTAM	Notice to Airmen
NPA	Non-Precision Approach
PDOP	Position Dilution of Precision
PERL	A dynamic scripting language
P-RNAV	Precision Area Navigation

RAIM	Receiver Autonomous Integrity Monitoring
RNAV	Area Navigation
RNAV (GNSS)	Area Navigation (Global Navigation Satellite System)
RWY	Runway
SA	Selective Availability
SBAS	Satellite Based Augmentation System
SDF	Step-Down Fix
SIS	Signal-In-Space
SPSS	Statistical Package for the Social Sciences
SRG	Safety Regulation Group
TAA	Terminal Arrival Altitude
TSO	Technical Standard Order
VFR	Visual Flight Rules
VOR	Very High Frequency Omni-directional Radio Range
WAAS	Wide Area Augmentation System
WP	Waypoint

RNAV (GNSS) Non-Precision Approach – Flight Trials Analysis Report

1 Background

Global Navigation Satellite Systems (GNSS) have and are continuing to revolutionise the world of aviation. The technology is able to give an accurate position, almost instantly and at relatively low cost to the user or operator. At present, the US Global Positioning System (GPS) is the only fully operational GNSS. However, with the resurgence of the Russian GLONASS and advent of Europe's GALILEO system the future of GNSS appears both exciting and secure.

GPS is currently being used for en-route and oceanic phases of flight as a primary means navigation system and as a supplemental navigation aid for more demanding procedures. The development of GPS has allowed the creation of Area Navigation Global Navigation Satellite System (RNAV (GNSS)) approaches, a type of non-precision approach (NPA) procedure formally known as GPS/NPA. The publication of RNAV (GNSS) procedures has recently been approved within the USA, Australia and other international states. At present, GPS is the only fully operational GNSS; therefore an RNAV (GNSS) approach can currently be considered as an RNAV (GPS) approach. The rapid introduction of GPS receivers for airborne navigation has outpaced the resolution of human factors issues concerning their safe use.

The arrival of this new technology brings with it the need for new techniques, both for the pilot and the air traffic controller. Pilots must make a natural and safe transition from the techniques employed with traditional navigation aids to those required for GNSS. This period of transition presents a significant risk to safety in terms of human error and misunderstanding. This is particularly true with the arrival of RNAV (GNSS). The ability of GPS to provide accurate coordinates as opposed to simple radials or distances gives the pilot superior navigation information but significantly alters the spatial perception mechanisms. It is these changes in spatial perception, coupled with the unfamiliarity of GNSS equipment, which could present the greatest threat to safety.

The goals of this project were to gain an understanding of pilots' experience and interpretation of RNAV (GNSS) procedures within the UK. As well as aiming to understand the complexity of programming and spatial perception, other factors such as the interface with ATC, phraseology, traffic, pilot training and issues regarding missed approaches were also considered.

The objectives of the research are presented in detail in the following section and a short review of previous studies is given. A detailed description of the methodology employed is presented in Section 2. Sections 3 and 4 deal with the main data analysis; Section 3 presents a description of the underlying variables or factors, which could govern variation within the data sample and Section 4 addresses the issues, which the project aimed to address. Section 5 discusses the results in a broader context, giving particular attention to issues raised in the High-Level Trials Approach Questions and future applications.

1.1 Research Objectives

The aim of the trials was to gain an understanding of the pilot experience and interpretation of flying RNAV (GNSS) approaches within the UK. Specific questions relating to each category can be found in Appendix B and are referenced below. The aim was to understand pilot perceptions with regard to the following areas:

- Training and Guidance (Appendix B Q1-Q4)
- Receiver Status (Appendix B Q5-Q8)
    - Approval Requirement
    - Database currency
- Receiver Programming (Appendix B Q10-Q11)
- Approach Procedure (Appendix B Q12-Q15)
    - Practical 'Fly-ability'
    - Approach Chart Use
    - Positioning
    - Traffic and ATC
- Performance Perception (Appendix B Q11-Q12)
    - Accuracy
    - Safety
    - Workload
    - Spatial Awareness
- Future Applications (Appendix B Q16-Q19)

A further objective was to quantify the signal-in-space performance during the trials.

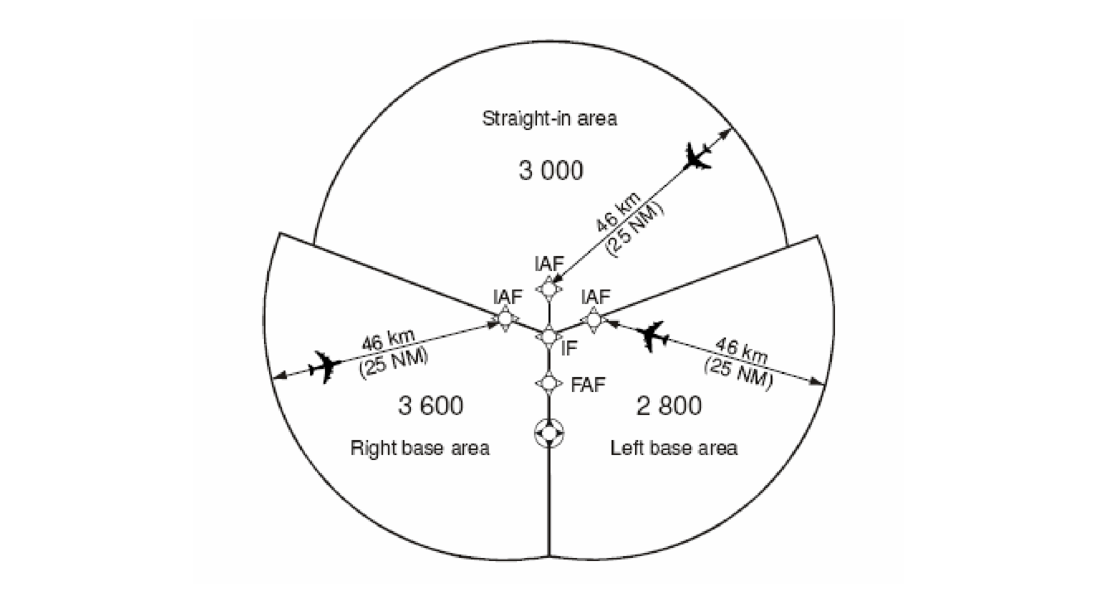
The objectives were achieved through the use of a pilot questionnaire. This questionnaire was mapped to the objectives listed above by the High-Level Trials Approach Questions. The High-Level Trials Approach Questions were designed to link the pilot questionnaire to the wider issues of RNAV procedure certification, changes to training procedures and future extensions of GNSS into IMC or non-ATC aerodromes.

1.2 RNAV (GNSS) Approaches

RNAV (GNSS) approaches are a sub-category of non-precision instrument approaches. They are designed to provide a pilot with area navigation information in the local horizontal plane. This navigation information is provided relative to a series of waypoints defined in geodetic co-ordinates: longitude and latitude. The waypoints are pre-programmed for each specific approach into the GPS receiver or flight management system (FMS).

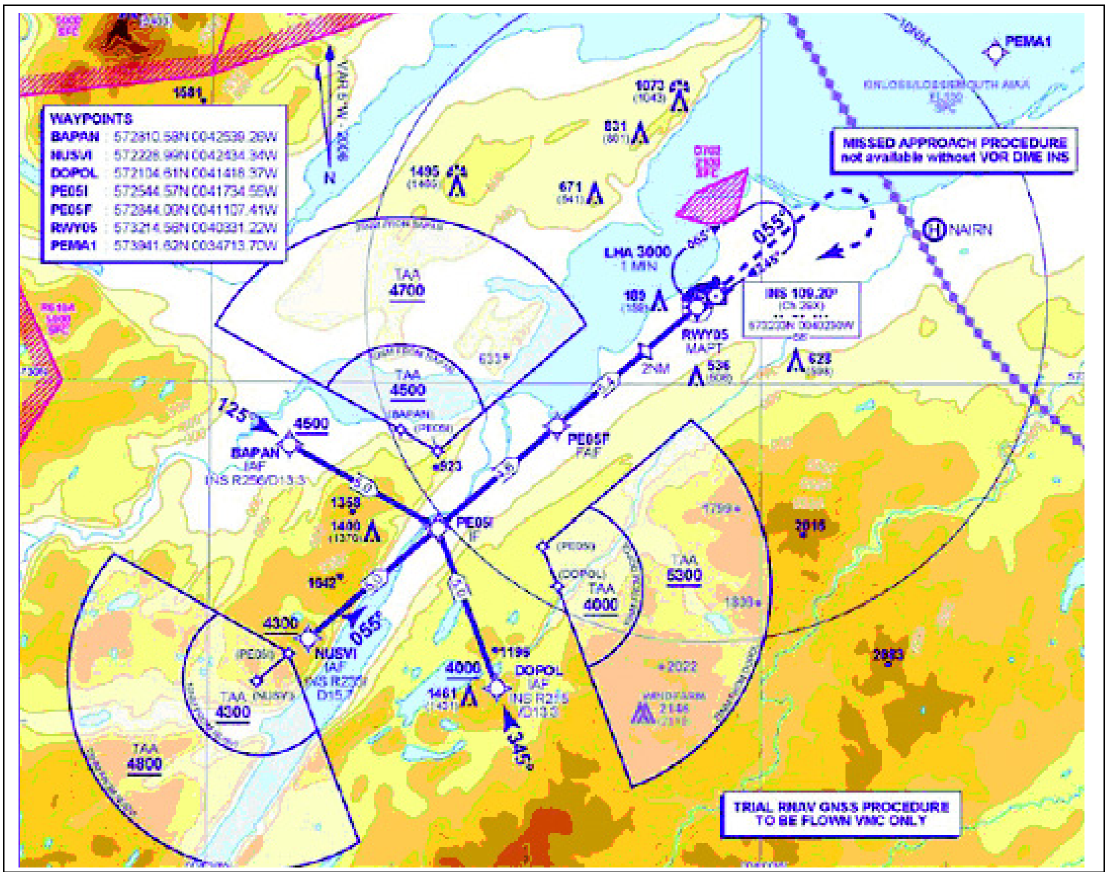
Approach procedures are designed with a standard five segments; arrival, initial, intermediate, final and missed approach. The initial approach fix (IAF), intermediate fix (IF) and final approach fix (FAF) lie at the beginning of their respective segments. There may in some procedures be more than one initial approach segment and corresponding IAFs. The angle of initial approach segment to the intermediate segment must not be greater than 120° (ICAO Pans-Ops 8168). This is in order to limit the steepness of the base turn; defined as the initial turn at the IF. The terminal arrival altitude (TAA) refers to a minimum altitude of arrival, defined with the aim of providing a link between the en-route and approach phases of flight. Figure 1.1 shows a typical arrangement of the arrival segments and corresponding TAAs.

Figure 1.1 Typical TAA Arrangement (source: ICAO Pans-Ops Document 8168)



Common approach types include 'T' and 'Y' approaches whose initial segments require a base turn of between 70° and 90°. Approach procedures are designed such that the final approach leg should lie within 30° of the runway radial (ICAO Pans-Ops 8168). The intermediate segment consists of two parts; an initial turn at the IF and a straight section once the turn is completed before arriving at the FAF. Figure 1.2 shows a typical 'Y' shaped approach. The optimal distance between waypoints is 5 NM, and the recommendation made by ICAO is between 2 NM and 10 NM.

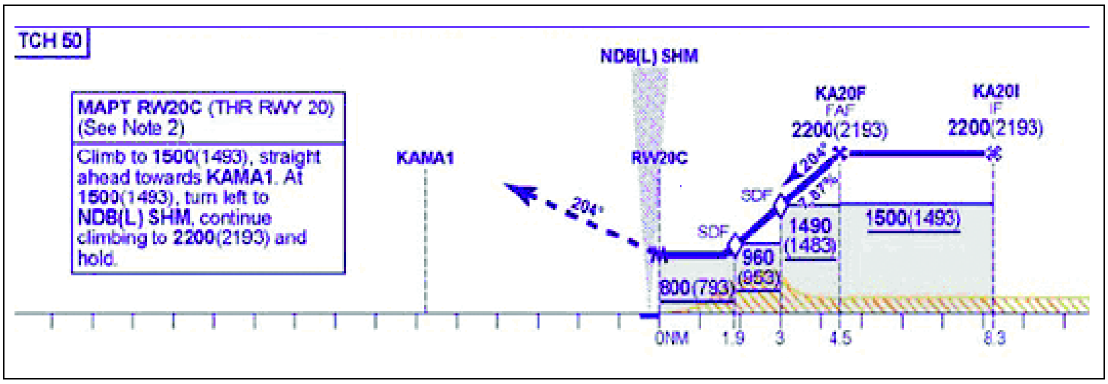
Figure 1.2 Example Procedure Design (not to be used for navigation)



Due to the lack of vertical guidance for RNAV (GNSS) procedures, pilots must use the distance to waypoint information output by the receiver and the vertical profile shown on the approach chart to maintain the desired altitude and appropriate glide path. Minimum altitudes are shown on the approach chart in grey and a number of additional step-down-fixes (SDF) may exist in order to achieve a minimum clearance of 300m over local obstacles or terrain. The approach to Shoreham, one of the aerodromes permitted for the trials, illustrates how local terrain can influence approach design and result in ICAO recommendations not being fully adhered to. ICAO Pans-Ops recommends a maximum descent gradient of 3 degrees (6·7%). However, Figure 1.3 showing the Shoreham vertical profile highlights the existence of additional SDFs and a gradient of 7·87%.

UK Waypoints are named with five alphanumeric characters. The intermediate fix and final approach fix are given the last two letters of the four letter aerodrome identifier, followed by the two digit runway number and a letter 'I' or 'F' to designate the waypoint type (e.g. Shoreham (EG<u>KA</u>) runway <u>20</u>: KA20I and KA20F). Missed approach waypoints are defined in a similar manner with the letters 'MA' used in place of the runway designator and a numeric digit to index each waypoint e.g. KAMA1.

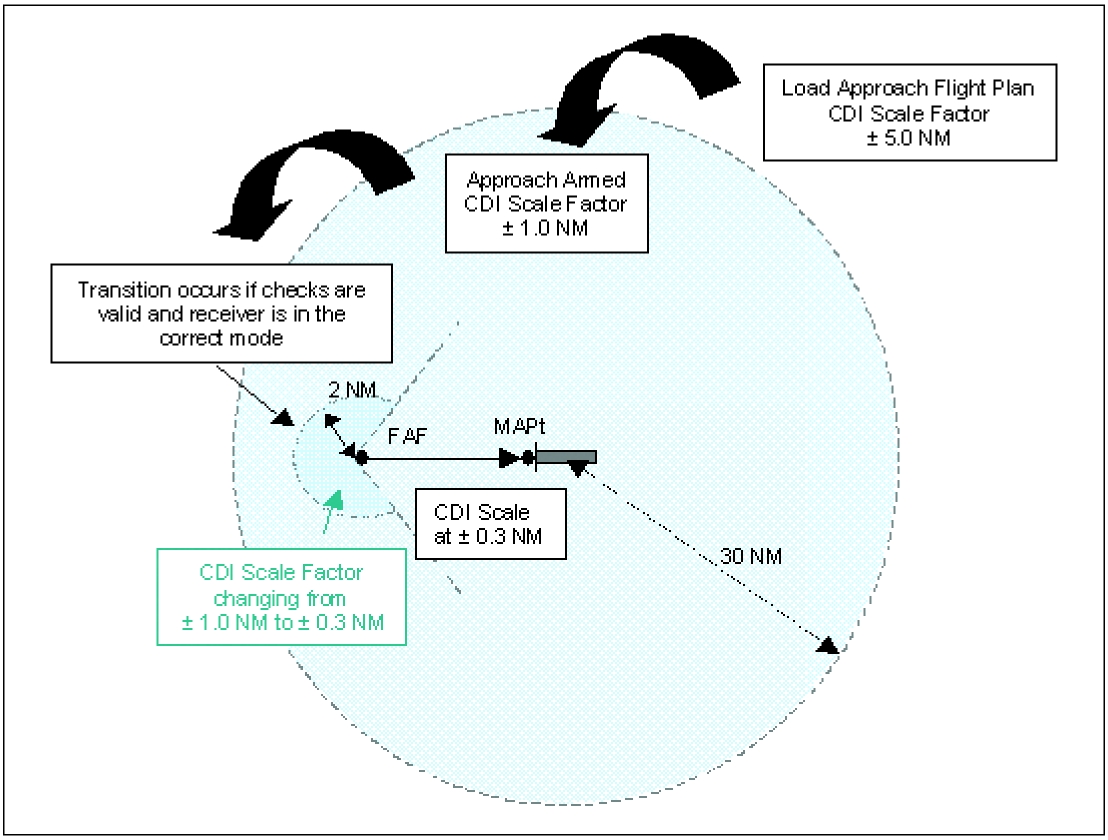
Figure 1.3 Shoreham Vertical Profile



In order to complete an RNAV (GNSS) procedure the pilot must first make the necessary checks regarding equipment installation, database validity and co-ordinate confirmation, RAIM availability, conventional navigation means equipment for use in case of missed approach and NOTAMS. User-defined waypoints are considered potentially hazardous and are not authorised for RNAV approaches.

A pilot must select a pre-programmed approach within the aircraft's GPS receiver or flight management system. These approaches are listed in reference to the choice of initial approach fix (IAF). A radius of 30 NM from the aerodrome is defined and TSO-C129 certified receivers are required to automatically arm the approach at this distance. This switches the course deviation indicator (CDI) scale from the En-Route setting of ±5·0 NM to ±1 NM. The CDI will then automatically rescale between ±1 NM and ±0·3 NM as the aircraft proceeds to the FAF, assuming the pilot has not disabled this function. During the final approach segment the CDI scale remains at ±0·3 NM. Figure 1.4 shows the receiver mode stages and the corresponding CDI scaling.

Figure 1.4 Approach Diagram (redrawn from Honeywell Bendix/King KLN 900 user manual)



1.3 Literature Review

There have been only a handful of studies on the effects of human factors within GNSS navigation. A brief review of the literature regarding human factors associated with the GPS receiver user interface is presented, followed by the human factors of relevance to RNAV (GNSS).

1.3.1 Equipment Use

A study by Winter & Jackson (1996) showed an increase in mental workload due to the lack of a 'distance to runway' read-out from GPS receivers. Pilots are required to calculate the distance before relaying the information to ATC. Joseph and Jahns (2000) conducted a survey of 1,880 US pilots and concluded that pilots had strong confidence in GPS and its simple use but more complex operations were found to be overwhelming. It was also found that a strong link existed between both previous experience and knowledge of GPS, and pilot confidence in the technology.

In 1995, Volpe published a checklist (Huntley *et al*, 1995) on behalf of the FAA in order to enhance standardisation in the usability of GPS standalone receivers. Williams (1998) interviewed a number of leading experts in human factors of relevance to GPS and extracted data from operational logs of the GPS Wide Area Augmentation System (WAAS) tests. The study concluded that the variability in receiver design meant that pilots familiar with one manufacturer might not have the necessary experience to operate with an alternative GPS receiver. A standardised receiver design in terms of usability beyond the current TSO-C129 specification was recommended. Modernisation of receiver design has to some extent improved usability without the requirement for such standardisation; however, confusing differences between receiver interfaces remain. The modern receiver standards TSO-C145/6B recommend a number of improvements over the required TSO-C129 certification, which should further improve usability.

Some evidence (Wreggit and March, 1998) has been found to suggest that the complexity of menu structures can increase the amount of 'head-down' time in comparison to conventional navigation aids. This paper also concluded that problems with pilot recovery from erroneous inputs, a lack of appropriate feedback and an inconsistent mapping of controls to functions could detriment pilot performance. This paper however, concentrated on the use of hand-held GPS receivers, contrary to the more common panel-mounted installations.

1.3.2 Human Factors and RNAV (GNSS)

Human factors research in the use of GPS for aviation operations has centred primarily on the ease of receiver use. Wider issues regarding procedural processes, interaction with ATC and pilot training have received less attention. Nendick (1994) suggested that pilots should undergo some type of formal training.

A recent survey-based study by the Australian Transport Safety Bureau (ATSB, 2006) looked at pilot workload, situational awareness and perceived safety. It was concluded that workload was perceived by pilots to be greater for RNAV (GNSS) than other approach types (visual (day/night), ILS, VOR/DME and DME arrival) except for non-directional beacon (NDB) approaches. It was also concluded that situational awareness was more difficult to maintain in comparison to other navigation aids, once again with the exception of NDBs. The considerable benefit in runway alignment was credited with providing improved safety over NDB approaches. Pilots of high capacity airliners perceived RNAV (GNSS) to be safer than other approaches with the exception of ILS and visual (day) approaches, whereas pilots of smaller aircraft perceived RNAV (GNSS) to only be safer than NDB approaches. The automation and vertical navigation functions available to airliner pilots contributed to their positive perception of RNAV (GNSS) safety. The most important concern raised by pilots within this survey was that the equipment did not display the distance to the missed approach point but to the next waypoint. This increased pilot workload, reduced spatial awareness and was detrimental to safety. The survey also concluded that pilots found interpretation of the approach charts more difficult for RNAV (GNSS) than alternative approaches. In regard to the quality of training, 86% endorsed the training as adequate and the most common problem suggested by the remaining 14% was a lack of approach practice. A study by Casner (2004) for NASA also found that more than five approaches were needed for pilots to be able to learn the various skills needed to perform IFR procedures with GPS.

The ATSB (2006) report will be the primary reference for comparison of the results found in this study. This is natural as the ATSB survey represents the only survey-based analysis to date of human factors related to RNAV (GNSS) procedures available in the public domain. A number of differences between this study and the ATSB survey should be highlighted. The ATSB survey was conducted post-certification; pilots were requested to express their views in lieu of their experience within the current RNAV (GNSS) operational environment. The trials described within this report, however, were conducted a priori as a test-bed to possible approval in the future. Questionnaires were completed to summarise pilot experience in the ATSB survey, whereas the study presented here attempted to capture the factors on a trial-by-trial basis. Finally, although similarities clearly exist between the operational environments of Australian and UK aviation, they do not represent the same test environment and therefore inconsistencies may arise.

2 Methodology

The desire for an independent safety analysis of RNAV (GNSS) approaches led to the CAA commissioning trial procedures at six selected UK aerodromes. In order to maximise involvement, the trials were promoted on the CAA website, at aerodromes and in aviation magazines. Pilot perceptions were obtained through voluntary involvement and completion of a trial report questionnaire for each approach flown.

The pilots were required to adhere to the terms and conditions of the trial and conform to the pilot declaration. This was necessary due to the non-operational status of RNAV (GNSS) non-precision approaches, which had still to be approved in the UK. Upon signing up to the trials the pilots were required to provide basic information including their CAA registered pilot number, contact details and flight experience. The flight experience variables were designed to compare specific subgroups and to assess how pilot experience was related to ease of use and situational awareness of flying an RNAV (GNSS) approach.

Once registered, a pilot was authorised to fly an RNAV (GNSS) non-precision approach within the terms of conditions of the trials. Informing the relevant ATC unit of the proposed approach was necessary to corroborate the pilot report questionnaire with an ATC log. The ATC log was also used to investigate the issues of sequencing, phraseology and traffic separation problems.

Each pilot was accompanied by an observer whose role was to record flight data for the purpose of completing the questionnaire report.

This section presents the methodology adopted for the trials starting with the design of the questionnaire, the design of the ATC log, data processing and analysis.

2.1 Questionnaire Design

The questionnaire was arranged in sections: characteristics, flight data, ease of receiver programming, flying the approach and conclusions. A number of open text slots were provided for specific issues.

The first section on characteristics requested the following information:

- Aircraft registration
- Aircraft type
- GPS receiver
- Installation approved for NPA
- Aeronautical/Navigation database expiry date
- Observer qualifications
- Aerodrome
- Date
- Approach start time
- Approach end time.

The fields relating to aircraft, receiver and aerodrome were selected to allow comparisons to establish any relationships between these variables and pilot response. The date and time information was used for cross-referencing with the ATC logs and to determine the time lag between the approach flight time and the submission of the questionnaire.

The next section titled 'Section 1 – Flight Data' was designed to assess if any undetected significant signal-in-space (SIS) errors were present in the GPS solution and to determine to some degree the accuracy of the approach. The CDI output was intended to determine to what degree pilots were able to follow the centreline throughout the approach. The section also recorded which other radio navigation aids the pilot may have used for crosschecking at the IAF and throughout the approach.

One of the primary goals of the trials was to assess the usability of GPS receivers and equipment. Section 2 was designed to capture the response with regard to receiver programming. The requirement for RAIM prediction was assessed as part of the study into whether pilots would make the correct necessary crosschecks under the guidelines and format of the trials, and within a future certified environment. Further questions on serious or common issues were also included. These were mainly concerned with the loading and setting of the approach, approach legs and displays.

The section headed 'Flying the Approach' had the goal of enabling the assessment of spatial awareness, accuracy and the ATC interface. Due to a potential high level of subjectivity with regard to the response to these questions, the section was constructed to allow a number of textual responses to be made. As with the other sections the text responses were subsequently coded to facilitate meaningful qualitative and quantitative analysis. The pilots were able to record any GPS or RAIM warning, which would require further analysis to identify causes.

The final section of the questionnaire was designed to provide feedback on chart design and operability, flight training procedures and to determine a measure of perceived performance in contrast to other navigation aids. Furthermore, pilot opinion on the expansion of RNAV (GNSS) to instrument meteorological conditions was to be canvassed. A final comments box was included at the end of the questionnaire for any further comments pilots wished to make.

2.2 ATC Log Design

The ATC log format was designed to be a simple and effective way of crosschecking the pilot questionnaire reports. A sample ATC log is given in Appendix C and contains the following fields:

- Date
- Time
- Callsign (Aircraft Registration Code)
- Pilot trial reference ID
- VFR/IFR
- Sequencing problems?
- Phraseology issues?
- Other Comments.

The first four fields were used to cross-reference the pilot reports and the remaining boxes were used to answer High-Level Trials Approach Questions relating to ATC service provision such as sequencing, separation and phraseology.

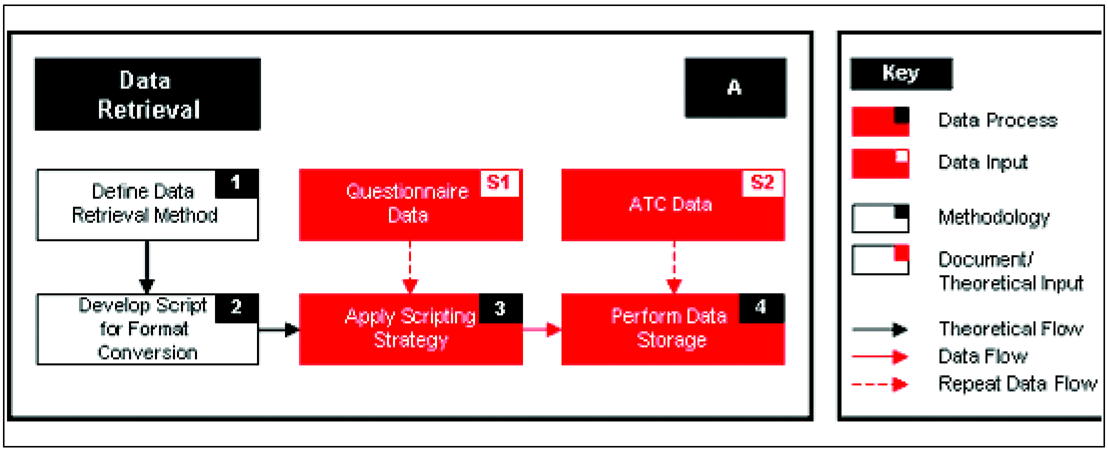
2.3 Data Processing

This section structures the processing tasks into four key areas: data retrieval, data pre-processing, data analysis and data reporting. Each of these processes contains a number of subtasks. In some cases the order of these tasks does not strictly follow the flow displayed in the relevant figure. However, in order to provide a simplistic linear view of the methodology applied, use of this flow of control enables straightforward interpretation.

2.3.1 Data Retrieval

The first stage of the data processing strategy was that of retrieval (Figure 2.1): to provide a means for acceptance, conversion, formatting and storage of the data. The primary data source of the project was the secure web-based questionnaire data form (S1). The web page stored the data as a continuous text file (Data Input S1) with one questionnaire field per line. A method of converting this text file into a meaningful database was the first phase of data processing. ATC report logs (S2) were also provided, and were intended for data verification. These log sheets were delivered either by post, e-mail or fax. Each task is described below relating to Figure 2.1.

Figure 2.1 Data Retrieval Method (Key applies to Figures 2.1-2.3)



A:1 Define Data Retrieval Method

The method for data format conversion of pilot data was dependent upon the intended software choice used for data analysis. Three options were considered: Microsoft Access, Microsoft Excel and SPSS. Microsoft Excel would have allowed the easiest data conversion process due to its inbuilt text importing function. However, the maximum string size of a variable entry was far below the necessary size determined by the pilot responses. The benefit of Microsoft Access was its ability to allow complex relations between data tables, such as an ATC report log table and pilot experience data table in the case of the trials. This added functionality was deemed unnecessary in comparison to the ease of use of SPSS and the efficient capabilities in terms of table, chart and statistical functionality. Hence the SPSS package was the recipient of the retrieved data.

Data import within SPSS could be achieved in a number of ways, the simplest method in this case being delimited text import. The formatted text file downloaded from the trials web page, initially required de-formatting and the addition of delimiters to allow SPSS to recognise both a new report and a new data field.

A:2 Develop Script for Format Conversion

The conversion of the raw text file into the format necessary for data import required a PERL text editing script to be developed. This script was to perform a number of formatting tasks. In fact, further steps could have been implemented to perform some of the additional data editing tasks, which formed part of the pre-processing strategy. A trade-off was sought, which minimised the time spent coding and the time spent performing low level editing. The script was left to perform tasks such as removing new line characters and replacing with semi-colons, which were recognised by SPSS. The data field names such as 'Aerodrome' and 'Q6a' were removed. A number of specialist functions were then applied to specific variables, particularly dates and times, to allow them to be read and displayed by SPSS. Finally, conversion of some data values from their text responses into coded numerical data was performed, for example 'yes' and 'no' were converted to '1' and '0' respectively. This allowed greater flexibility within SPSS for analysis. The PERL script is given in full in Appendix D.

A:3 Apply Scripting Strategy

The data conversion script was run intermittently as the number of filed pilot questionnaires increased.

A:4 Perform Data Storage

The data storage process was undertaken following the conversion of newly filed questionnaires. This was to allow for continual analysis of the data in case of any important feedback issues and the early capture of any significant errors. As well as the downloading of the current pilot questionnaire data file, both the pilot personal data file (recording each pilot’s unique identifier, experience and contact details) and the ATC report logs were also stored in their respective spreadsheets. ATC Report logs (Data input S2) were manually input from the e-mails and fax receipts.

2.3.2 Data Pre-Processing

The pre-processing of data was intended to achieve two goals; data completeness and data reliability. This methodology is displayed in Figure 2.2, with parts B1 and B2, illustrating the processes for ensuring data completeness and data reliability respectively.

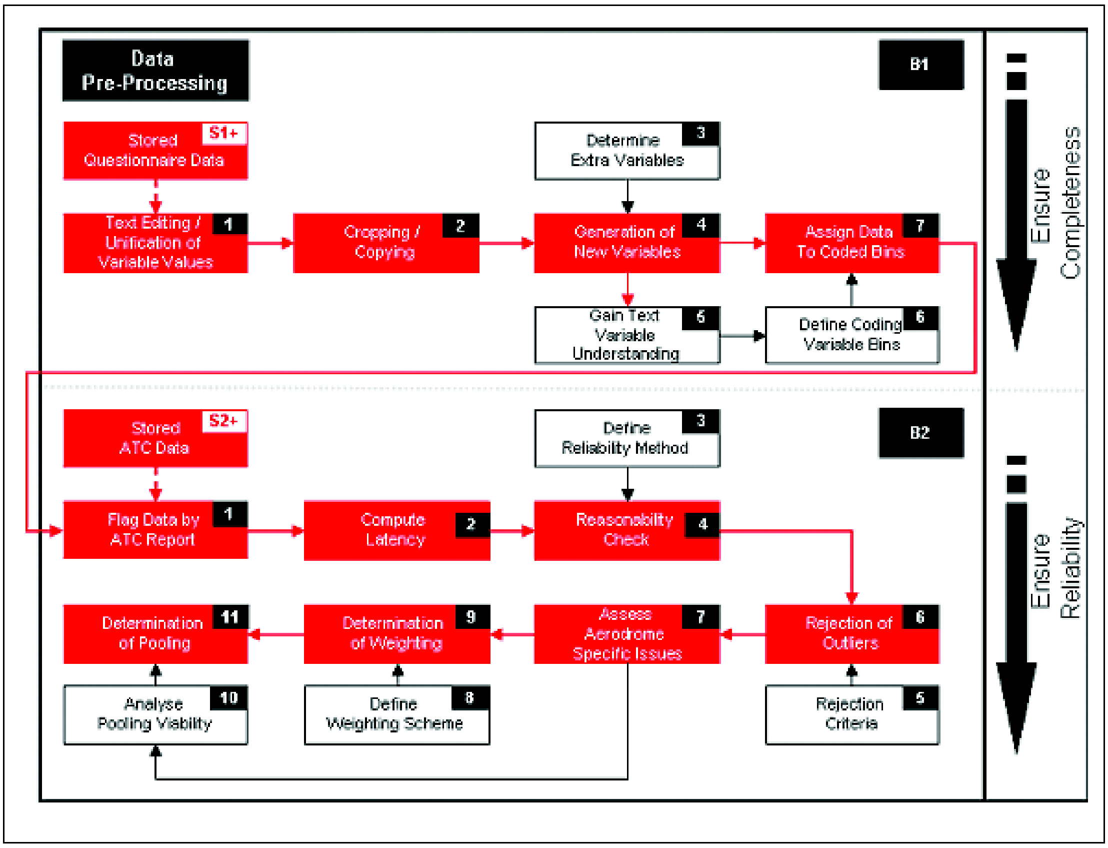
B1:1 Text Editing and Unification of Variable Values

Following the storage of data within the spreadsheet structure of SPSS, a number of import errors were present. These errors were inevitable, due to differentiation in pilot response. For example, the typographical error “19ty December 2006” would not be converted into the relevant date format and would require manual retrieval from the original file. Efficient utilisation of SPSS functions required that variable values were unified; responses such as ‘GNS 430’ and ‘Garmin GNS 430’ represented the same receiver type and must be treated as such within the database.

B1:2 Cropping and Copying

The nature of questionnaires and in particular open text response questions, inevitably resulted in missing data and/or apparent conflicting responses. Careful data pre-processing was thus required. A number of pilot responses cited “see below” in particular text response slots, thus, it was necessary to copy the specific phrases from elsewhere in the submitted report.

Figure 2.2 Data Pre-Processing Method



B1:3 Determination of New Variables

Discussions with the CAA at the start of the project identified the need for the definition of new variables that could be derived from the pilot responses to address particular issues. One such issue was the effect of pilot learning and its positive and negative impacts. This resulted in the need for a variable to capture the order of trials and the filing of pilot questionnaires and to flag first trial runs. It was expected that first trial runs from pilots lacking RNAV experience were most likely to encounter problems, particularly with equipment use and changes in spatial perception.

B1:4 Generation of New Variables

The complexity of each pilot report filed allowed the extension of the data stored into further variables. The simplest example of this was the generation of the 'latency' of report submission, calculated from the difference between the flight approach date and submission date.

B1:5 Gaining an Understanding of the Text Variables

A large proportion of questions within the trials survey were designed to allow text responses. This was due to the very nature of the project aim to study the relevant human factors. Furthermore, the lack of precedence to the project warranted the need for an 'open net' to capture relevant information.

The process of assigning indicators to each textual response to a survey question in order to group them with similar responses is known as coding. The coding of this data was necessary in order to quantify and characterise the key human factors issues. An in depth understanding of the data was required before the coding bins were defined to accept each of the textual responses.

B1:6 Define Coding Variable Bins

Once an understanding of the data was gained, a number of coding bins were defined. The number of bins was dependent upon the quantity of textual responses and the issues relevant to the specific question. A fine categorisation of the responses was necessary for the more important and safety relevant categories.

B1:7 Assign Data to Coded Bins

For each of the coded variables and each submitted questionnaire a value was assigned to a particular bin defined in B1:6. This coded value represented a new categorical variable in the data and was represented as such within the SPSS software package.

B2:1 Flag Data by ATC Report

In this process the data provided by each Aerodrome ATC unit was used to flag each questionnaire as to whether there was a corresponding ATC entry. Minor deviations in terms of time and number of approaches between the two data inputs were accepted as inevitable errors of the recording process and such reports were therefore flagged as verified.

B2:2 Compute Latency

The latency of the questionnaire report was defined as the difference between the time of the actual approach flown and the time of the submission of the corresponding report. The software employed for data processing was able to generate the latency variable on the basis of this formula.

B2:3 Define Reliability Method

Reliability here meant the trust the analyst could have, in that the surveyed data were true to the belief of the surveyed individual, and that the conditions of the survey process had been met. The conclusions of the trials would therefore carry more weight if the reliability of the data could be assured. The decision was taken to ensure reliability by determining outliers and assessing the feasibility of weighting and pooling of the data.

B2:4 Reasonability Check

The pre-processing elements B2:1 and B2:2 followed a strict logical structure. However, it was necessary that a manual check of data was undertaken to select any unreasonable reports not captured by B2:1 and B2:2. A number of checks were made; specifically the date of submission was checked not to be earlier than the date of the approach, aircraft and receiver types were checked and variables such as altitude were checked for their plausibility.

B2:5 Rejection Criteria

The criteria for rejection of outliers was initially planned to be governed by the ATC flags alone. However, any reports that failed the reasonability check or contained comments, which suggested the approaches were unofficial, were deemed unreliable. Furthermore, the need to avoid unnecessary rejection prompted a change in the rejection criteria with respect to ATC flagging. Reports in which the pilot had previously submitted a validated report were not rejected, unless they failed the reasonability check. The lack of a corresponding ATC log was therefore attributed to ATC or the pre-flight booking between the pilot and ATC.

B2:6 Rejection of Outliers

The rejection of outliers was performed on the basis of the criteria given in B2:5. Although the data analysis was performed using the remaining data, pilot opinion was scanned for possible issues within the rejected data, which could be relevant to the interpretation and discussion of results.

B2:7 Assess Aerodrome Specific Issues

The aim of multiple aerodromes was to allow a greater geographical coverage and thereby permit a higher number of pilots to take part in the trials. Furthermore, any variation in the performance of RNAV (GNSS) due to aerodrome specific problems should be visible. Such problems would likely be the product of unique procedural design or variations in traffic density. Other considerations such as local meteorological conditions, aerodrome size and aerodrome function could play a role in the results.

The results relating to traffic issues are presented in Section 4.3.2. No evidence was found that traffic significantly affected RNAV (GNSS) procedures in comparison to alternative NPA procedures. Comments relating to traffic volumes hinted at an increase in workload due to changes in approach, requests for holding, etc. Questionnaires expressing a high level of traffic were flagged to allow further analysis.

The existence of unique procedural elements, such as a particularly sharp turn, short leg or low attitude clearance would be the primary hurdle to combining the data from all aerodromes. A scan of pilot responses regarding such features found that there was no specific aerodrome or section of any procedure, which caused a prominent issue. In fact when assessing the procedures in detail, many of the steepest turns, shortest legs and highest terrain were not commented upon.

The small sample size and lack of meteorological data did not allow for a detailed assessment of aerodrome specific meteorological issues. Pilot responses, which included comments on the impact of high winds were flagged for further analysis.

B2:8 Define Weighting Scheme

The allowance of some pilot questionnaires not fully verified by ATC opened the question of whether to weight these questionnaires for some of the analysis. A check of the completeness of questionnaires in relation to latency found no obvious trends. Although a strong correlation was found between the latency and ATC flag, it was assumed that the correlation was likely due to unreasonable reports (unverifiable by ATC) being submitted late. The remaining ATC validated reports showed no evidence of integrity issues. The final weighting system was therefore a full weight of one to ATC verified reports and 0.5 to reports where validity was deduced through previous report submission. The reasonability analysis did not possess the necessary complexity of data to determine an accurate weighting system. Minor typographical or data input errors were expected and given the low sample size any weighting on a subjective basis would be unnecessary and counter-productive.

B2:9 Determination of Weighting

Weights were applied under the scheme described in B2:8. The analysis of variables was then performed following multiplication by the appropriate weights.

B2:10 Analyse Pooling Viability

The assessment of aerodrome specific issues was intended to be the primary consideration as whether to pool all the pilot questionnaires submitted into a single sample. The goal of pooling was to increase the sample size thereby generating greater statistical power, simplifying analysis and allowing less complex conclusions based upon the results. In order for pooling to be applied, the sample surveyed must have sufficient homogeneity.

The assessment of aerodrome specific issues found that there was no evidence of heterogeneity between aerodromes on the matter of procedure design. Due to the lack of data and high number of possible variable relationships, the decision was taken to check possible links to an aerodrome on a per question basis where it was felt that an aerodrome could be a factor.

This approach was taken for other possible factors. The ATSB (2006) study referred to in Section 1.3 chose not to pool pilots of varying aircraft category. The trials project described here captured primarily Category A aircraft, with a small number of Category B and a single Category C aircraft. In agreement with the ATSB assumption, no distinction was made between Category A and Category B and furthermore the Category C response was included after an initial check.

B2:11 Determination of Pooling

In effect, the determination of pooling was the act of not splitting the data. The motivation is described above in B2:10.

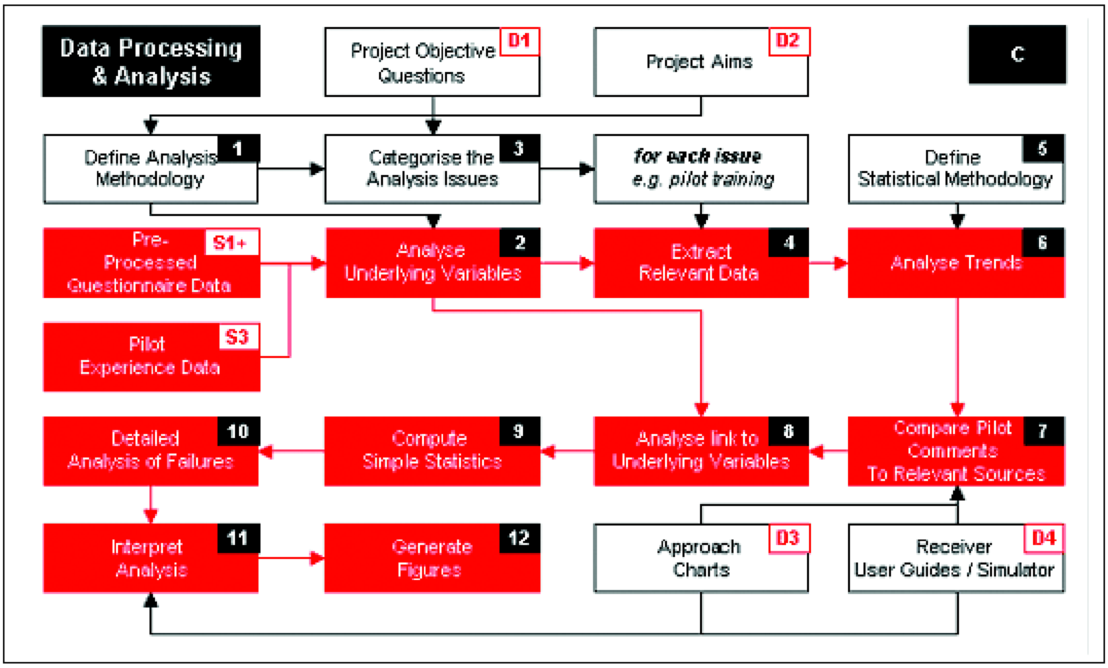
2.3.3 Data Analysis

The pre-processing stages defined in B1 and B2 ensured the completeness and reliability of the data. In this form the data were able to undergo analysis. A number of external references were used within the analysis; the High-Level Trials Approach Questions, project aims and objectives, approach charts of the trial aerodromes, receiver manuals and receiver simulators. Figure 2.3 shows the role of these documents and the process structure.

C:1 Define Analysis Methodology

The High-Level Trials Approach Questions were designed to provide a bridge between the project aims and the pilot questionnaire and was used to give a basis for interpretation and direction of the analysis. The analysis methodology was defined following a study of how best to achieve these goals. The conclusions of the literature review were also an element of the decision process. Throughout the trials process, a number of progress reports were delivered. These reports were formatted in a variety of ways to assess their respective simplicity in displaying the data analysis.

Figure 2.3 Data Analysis and Processing Structure



C:2 Analyse Underlying Variables

The strategy employed in the final analysis was to first gain an understanding of the underlying variables: aircraft type, receiver type, pilot experience and aerodrome. This was to ensure that when analysing the response data, a knowledge base for determining factors, influences and correlations was present. The analysis of these underlying variables is presented in Section 3.

C:3 Categorise the Analysis Issues

The project aims listed in Section 1.1 were used to define the relevant analysis issues. Each of these issues was analysed and the results are presented in Sections 4.2-4.7. Specific investigations and the general remarks box were treated separately.

C:4 Extract Relevant Data

For each of the categories described in C:3, the relevant data were selected. This involved selection of the relevant questions, as well as a decision whether to include only those trials that represented a completed approach.

C:5 Define Statistical Methodology

The statistical methodology was limited by the quantity of data received. For each trend observed within the data, the possible causes were formulated. These causes were then analysed in greater detail numerically and correlation coefficients calculated. T-tests were used to compare means when analysing the relationship between the data and pilot experience. In many cases, the number of responses to particular questions was insufficient to allow correlations to be calculated.

C:6 Analyse Trends

For each question, simple analytical techniques were applied to the data in order to understand any trends. Frequency tables of data were generated, followed by cross-tabulation with various factors to check any relationships.

C:7 Compare Pilot Comments to Relevant Sources

A number of pilot comments referred to a particular aspect of the operation or equipment. It was necessary to investigate in greater detail the functionality of the receiver type used by the pilot or interpret the approach chart used for navigation.

C:8 Analyse Link to Underlying Variables

This element of the analysis incorporated some of the trend analysis associated with C:6. Cross tabulation and charts were used to observe any relationships between data variables and factors. In the case of approach chart problems encountered by pilots it was necessary to factor by both chart publication and aerodrome.

C:9 Compute Simple Statistics

The differences in response from pilots with and without previous RNAV experience were analysed using the non-parametric chi-square analysis when relevant. T-tests were performed on the number of hours flown for particular questions to assess any influence of general flying experience.

C:10 Detailed Analysis of Failures

Any GPS or RAIM interruption was to be investigated in detail. There was one case of a RAIM alarm, the details of which can be found in Section 4.8.

C:11 Interpret Analysis

The results generated required careful consideration and interpretation to determine which issues were relevant to safety. Furthermore, it was important to extract which issues raised were specific to RNAV (GNSS) approaches and not to alternative NPA procedures or topics, which pilots continually raised through other channels. This task was achieved through careful consideration of the approach charts, equipment user manuals and of the techniques required for VOR, DME and NDB navigation.

C:12 Generate Figures

It was necessary to generate the tables and figures, which displayed the relevant results and conclusions obtained in the analysis for presentation within this report.

2.4 Summary of Methodology

Section 2 presented the project methodology and in detail the specific data processing and analysis tasks. As described in Section 2.3.3, the data analysis was performed in two stages; firstly the data sample was characterised by analysing the underlying factors, followed by the detailed analysis of the question data. Section 3 presents the data sample characteristics obtained from analysis task C:2.

3 Data Sample Characteristics

A total of 172 registered pilots signed up for the trials of which 77 completed an approach. A total of 171 trial approaches were flown, of which data from 162 was used in the subsequent analysis. Pilots submitted details regarding their experience on initial registration and within each submitted questionnaire recorded the aircraft flown, receiver model used and the aerodrome at which the trial approach was performed. This type of data was used to characterise the data sample obtained from the survey process in order to facilitate simple interpretation and ensure survey integrity. The analysis of aircraft type is given in Section 3.1, followed by receiver model in Section 3.2, pilot experience in Section 3.3 and aerodrome in Section 3.4.

3.1 Aircraft Type

A total of 32 aircraft models from 13 manufacturers were used in the trials. Table 3.1 shows the distribution by aircraft model. As expected, due to the focus of the trials being on general aviation, the majority of aircraft used were Category A (94.7%). This was beneficial to the trials as Category A are the slowest, smallest and possibly most unstable category of aircraft, and most likely to be flown by a single pilot.

Table 3.1 Aircraft Category and Type

Aircraft Category and Type		Frequency	Percentage (%)
A	BE76 Duchess	9	5·3
	Cessna 172	20	11·7
	Cessna 177	7	4·1
	Cessna 182	1	0·6
	Cessna 303	4	2·3
	Diamond DA 40	4	2·3
	Diamond DA 42	3	1·8
	Grumman AA5	4	2·3
	Maule M7	1	0·6
	Mooney M20J	3	1·8
	Pilatus PC-12	2	1·2
	Piper PA-23	1	0·6
	Piper PA-24	1	0·6
	Piper PA-27	5	2·9
	Piper PA-28	55	32·2
	Piper PA-30	2	1·2
	Piper PA-32	1	0·6
	Piper PA-34	5	2·9
	Piper PA-39	1	0·6
	Robin 2112	12	7·0
	Robin DR253	4	2·3
	Robin DR400	2	1·2
	Ruschmeyer R90	1	0·6
	SA Bulldog	2	1·2
	Socata TB10	1	0·6
	Socata TB20	9	5·3
	Socata TB21	2	1·2
	Category A Total	**162**	**94·7**
B	Beech BE20	3	1·8
	Cessna 340	1	0·6
	Cessna 414	3	1·8
	Piper PA-31	1	0·6
	Category B Total	**8**	**4·7**
C	BAE 146	1	0·6
	Category C Total	**1**	**0·6**
	Overall Total	**171**	**100·0**

3.2 Receiver Type

Data on the receiver type were collected to analyse problems associated with equipment use in greater detail. The receiver model recorded was further processed to give the extra variable of receiver manufacturer to detect manufacturer specific concerns. Table 3.2 shows each of the receiver types used in the trials, the corresponding frequency and the type of mounting adopted.

Table 3.2 GPS Receiver Type

GPS Receiver Type	Frequency	Percentage (%)	Mounting
Bendix/King KLN89	8	4·7	Panel Mounted
Bendix/King KLN90	3	1·8	
Bendix/King KLN94	16	9·4	
Garmin 155	8	4·7	
Garmin 400	2	1·2	
Garmin 420	1	0·6	
Garmin G1000	5	2·9	Integrated FMS
Garmin GNS 430	108	63·2	Panel Mounted
Garmin GNS 530	15	8·8	
Trimble 2000 Approach Plus	4	2·3	Integrated FMS
Universal UNS-1L	1	0·6	Panel Mounted
Total	**171**	**100·0**	

Table 3.2 shows that none of the participants used a hand-held GPS unit, which in any case were not allowed by the terms of the trial. The majority of pilots used panel mounted units and only about five percent had a fully integrated flight management system in operation. The most popular manufacturer was Garmin and the GNS 430 was by far the most common unit used in the trials reflecting its widespread popularity.

All receivers used in the trials were TSO-C129 certified to class A1 and above. The panel-mounted receivers were further certified to TSO-C129 class B. The more recent TSO-C145/6B recommends improved performance in a number of areas; selective availability (SA) is turned off, fault detection and exclusion (FDE) functionality, satellite based augmentation system (SBAS) capable functionality, necessary training aids and reduced impact of interference. None of the receivers used in the trials were TSO-C146 certified, however, some of the new functionalities beyond the scope of TSO-C129 were included in the more modern receivers used.

3.3 Pilot Experience

The experience of the pilot at the time of registration for the trials was recorded. This capability was added during the trials period and therefore a number of pilots were required to input their flight experience data after their initial trials run. Although these pilots were briefed to input these variables as they were at registration, possible biases towards greater experience gained during the trial may be present. Data on the type of pilot licence held, total hours flown, P1 hours flown and previous RNAV experience were also recorded.

3.3.1 Instrument Rating

The licence information requested referred to whether the pilot possessed an instrument rating. This additional aspect of a UK pilot licence could be in two forms, an IR rating which is the most stringent and an IMC rating which is only applicable to the UK and certain airspace classes and conditions. The intention behind the collection of this information was to assess if the higher level IR qualification provided pilots with superior training that significantly improved their proficiency in flying RNAV (GNSS) approaches. Details of the breakdown of instrument ratings are given in Table 3.3.

Table 3.3 Pilot Instrument Rating (per-pilot who flew a trial approach)

Pilot Instrument Rating	Frequency	Percentage (%)
IMC	28	36·4
IR	42	54·5
Incorrect Pilot Reference ID	1	1·3
None	1	1·3
Data Not Collected	5	6·5
Total	**77**	**100·0**

A number of pilots did not provide experience data due to the late addition of the web page to allow this information to be recorded. Furthermore, due to pilots making an unequal number of trial approaches, the licence rating totals in terms of the number of approaches flown could differ in nature to those based on the number of pilots (as shown in Table 3.3). Table 3.4 therefore, shows the instrument rating totals on a per-approach basis.

The high numbers in the IMC and IR categories should ensure that any differences between the two groups should be visible through the data analysis. Any such disparity will be presented in Section 4.

Table 3.4 Pilot Instrument Rating (per-approach flown)

Pilot Instrument Rating	Frequency	Percentage (%)
IMC	60	35·1
IR	99	57·9
Incorrect Pilot Reference ID	2	1·2
None	3	1·8
Data Not Collected	7	4·1
Total	**171**	**100·0**

3.3.2 Total Hours Flown

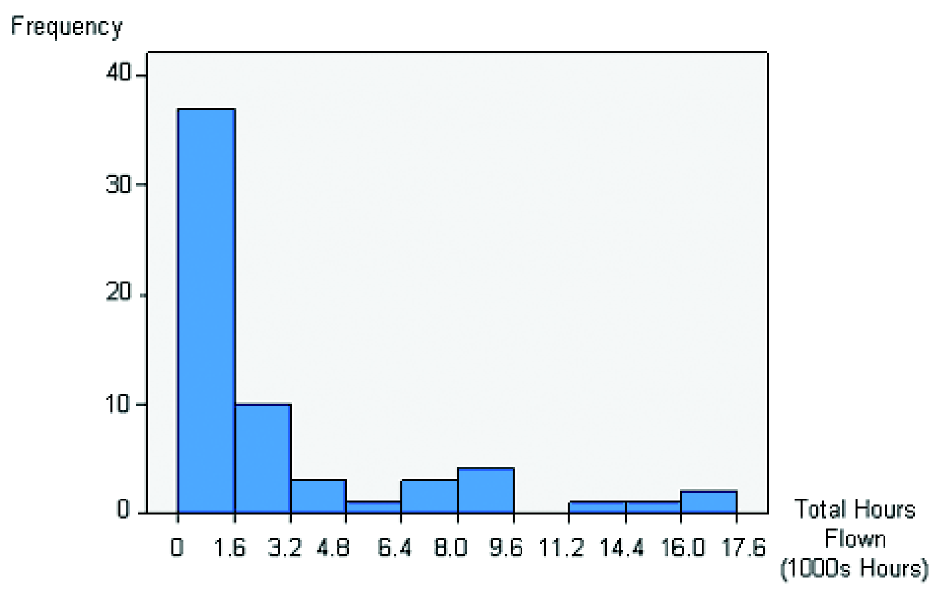
The total number of hours flown was a variable recorded by the pilot to indicate the time in which they had been a member of the flight crew. This included the number of P1 hours, which represented those in primary command of the aircraft. Table 3.5 shows the simple statistics describing the distribution of total hours flown by the participating pilots.

Table 3.5 Pilot Total Hours Flown

Statistic	Value (Hours)
Mean	2,743·3
Standard Deviation	3,771·2
Minimum	176·0
Maximum	16,000·0
Interquartile Range	2,583·0

There was a large variation in the data, ranging from a high number of cases below 1,000 hours to those exceeding 15,000. A histogram of the data is shown in Figure 3.1. The form of this histogram is simply interpreted. The majority of pilots participating in the trials were private pilots, which was observed through the type of aircraft used and comments received. These pilots had much less flight experience than professional pilots and were accounted for by the first two bars shown in Figure 3.1. The professional pilots, pilot trainers and retired professional pilots constituted an evenly distributed tail as seen in Figure 3.1.

Figure 3.1 Histogram of Total Hours Flown



3.3.3 P1 Hours Flown

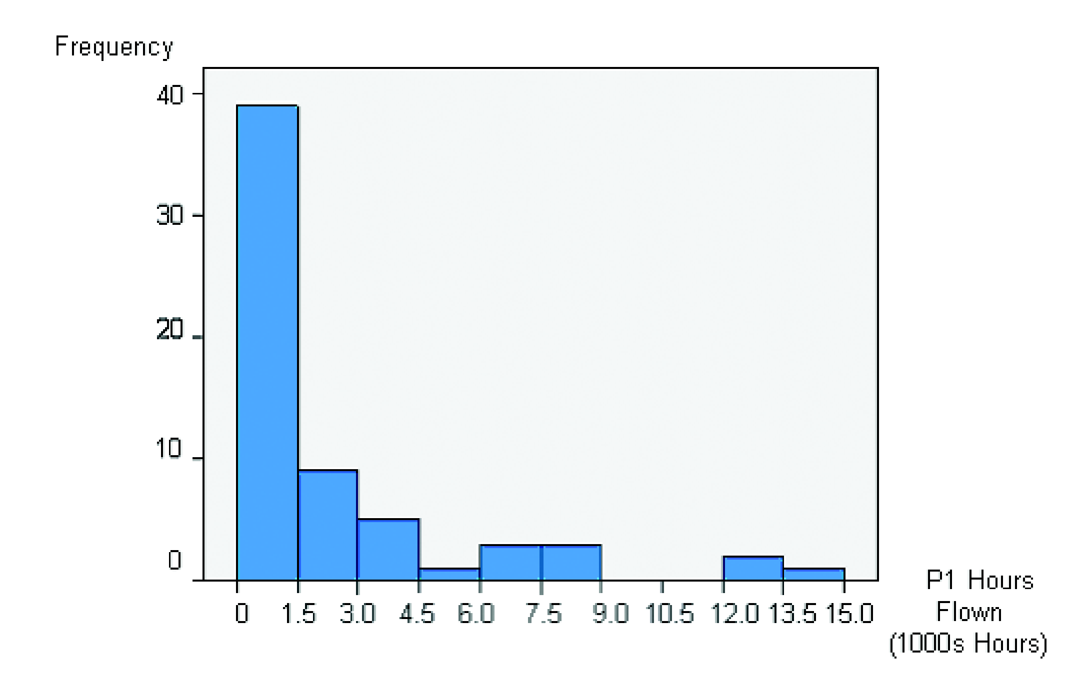
The number of P1 hours flown by a pilot was a record of the flight time the pilot had been in primary command of an aircraft. Table 3.6 shows the statistics for P1 hours flown.

Table 3.6 Pilot P1 Hours Flown

Statistic	Value (Hours)
Mean	2,264·4
Standard Deviation	3,248·7
Minimum	85·0
Maximum	14,900·0
Interquartile Range	2,410·0

Figure 3.2 shows a histogram of the P1 hours flown.

Figure 3.2 Histogram of P1 Hours Flown



The distribution of P1 hours flown followed a similar pattern to that of total hours flown, as would be expected. The histogram and statistics both displayed comparable values to those of Section 3.3.2, with the natural reduction due to the removal of the extra flight crew positions.

3.3.4 Relationship between Hours Flown and Instrument Rating

As alluded to in Section 3.3.1, it may be necessary to investigate the variation in response to questions between pilots possessing an IR and those possessing an IMC rating. Any variable that was found to be statistically dependent upon the type of instrument rating may be due to other external factors, which were related to both the said variable and the type of instrument rating. To show that the two sample populations of IMC and IR pilots may possess different characteristics, a statistical test was performed on the difference in means of their respective hours flown. This was undertaken for both total hours and P1 hours flown.

Table 3.7 Instrument Rating Group Statistics

	Rating	No.	Mean	Std Deviation
Total Hours	IMC	28	720·3	518·4
	IR	42	4,343·6	4,352·8
P1 Hours	IMC	28	588·6	507·5
	IR	42	3,636·3	3,697·6

Table 3.7 shows a considerable difference in the means of the IMC and IR samples both for total and P1 hours flown. Furthermore, there was much greater variation in the IR samples; this was to be expected due to the requirement of professional pilots to have an IR rating. To substantiate this observation a t-test was performed on the sample means for both total hours and P1 hours, the results are presented in Table 3.8.

Table 3.8 T-test of IMC and IR Sample Means

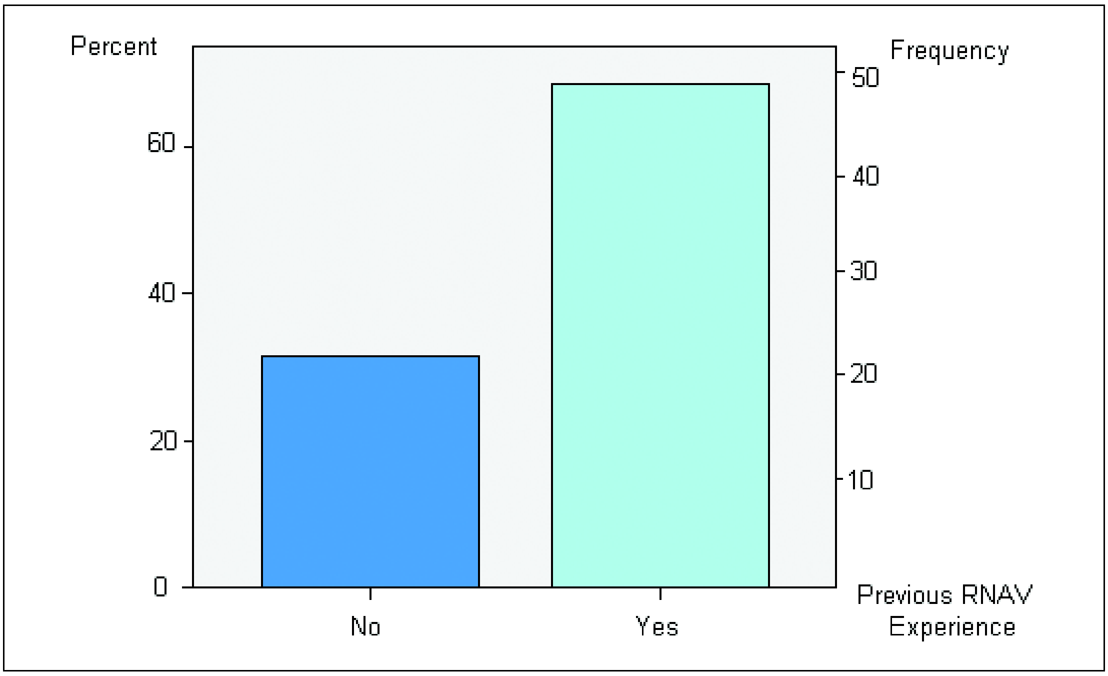
		Levene's Test		t-test for Equality of Means		
		F	**Sig.**	**t**	**Sig. (2-tailed)**	**Mean Difference**
Total Hours	Equal variances assumed	45·4	< 0·0005	-4·03	< 0·0005	-3,493.5
	Equal variances not assumed			-4·73	< 0·0005	-3,493·5
P1 Hours	Equal variances assumed	31·3	< 0·0005	-3·92	< 0·0005	-2,960·4
	Equal variances not assumed			-4·60	< 0·0005	-2,960·4

A Levene's test was used to test the equality of variance and showed that at the 99·9% level the variances were unequal (i.e. significance of the variances being equal was < 0·0005). The t-test showed that with 99·9% significance there was a difference in the mean hours flown between IMC and IR rated pilots. To conclude, the considerable difference in hours flown between IMC and IR rated pilots provided a possible useful pointer to pilot experience, namely instrument rating. However, although this relationship showed that flight experience and instrument rating were related, it was detrimental in that it was not possible to conclude on the influence of IR pilots' superiority of training in RNAV (GNSS). It may be the case that any improvement observed in the IR pilots was simply due to flight experience.

3.3.5 Previous RNAV Experience

Pilots were requested to record previous experience of RNAV approaches. Figure 3.3 shows the proportion of pilots with previous RNAV experience.

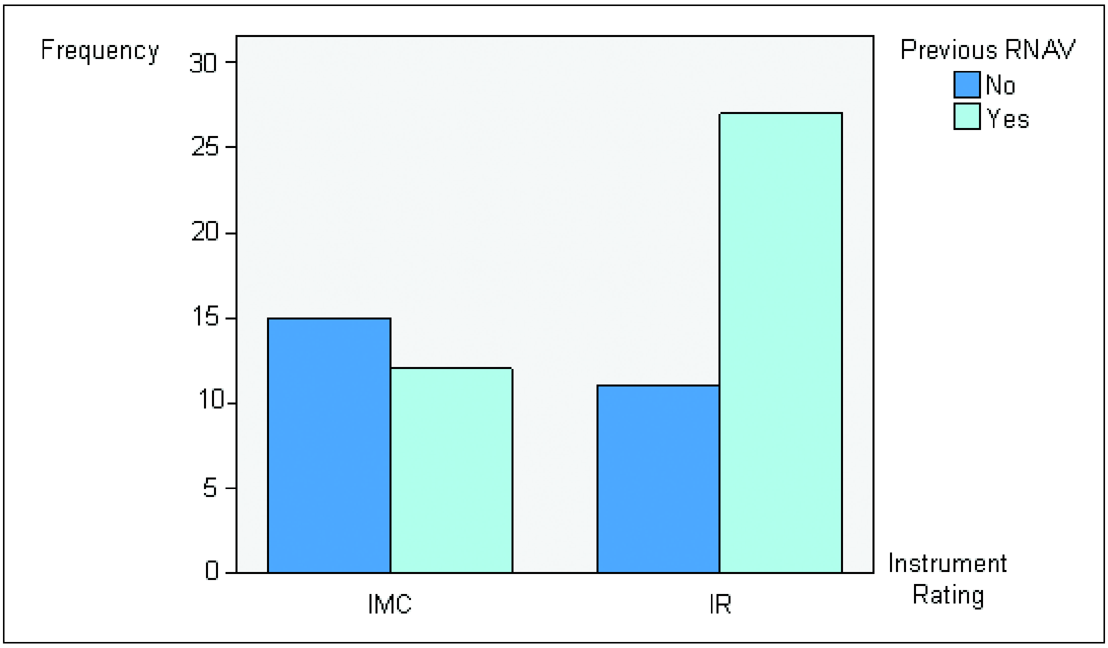
Figure 3.3 Previous RNAV Experience (per-pilot who flew a trial approach)



In order to check any sampling errors a chi-square correlation test was executed between the binary variable of previous RNAV experience and the binary variable, which flagged pilots as to whether they had submitted a report. The result was not statistically significant and no conclusion was possible. This was of course a crude test and certainly did not protect against the possible sampling of pro-RNAV (GNSS) pilots from the entire population.

A relationship between instrument rating and RNAV experience, however, was found to be statistically significant (at the 99% level). Figure 3.4 shows this relationship.

Figure 3.4 Previous RNAV Experience by Instrument Rating



This relationship warrants the use of either the 'instrument rating' or 'previous RNAV' variables as pointers to superior pilot experience and capabilities, particularly with regard to RNAV (GNSS) approaches. However, due to the inter-relationships between experience pointers, conclusions regarding one aspect of experience must be taken with caution. The inter-relationships shown here allowed the generic term 'experience' to be used throughout the report. Where there is a natural link to a particular experience variable and strong statistical evidence, a more precise relationship is described.

3.3.6 Observer Qualification

The request for observer qualification was intended to identify the less experienced pilots that did not possess the safety net of an experienced observer. Table 3.9 shows the breakdown of observer qualification. The most notable observation from Table 3.9 is that trials in which the observer was a professional IFR pilot were almost entirely with an experienced IR pilot. The responses of most interest were IMC rated pilots with non-IFR private pilots in the observer role. There were a total of 18 responses in this case. This group of pilots were considered as worthy of particular attention within the analysis.

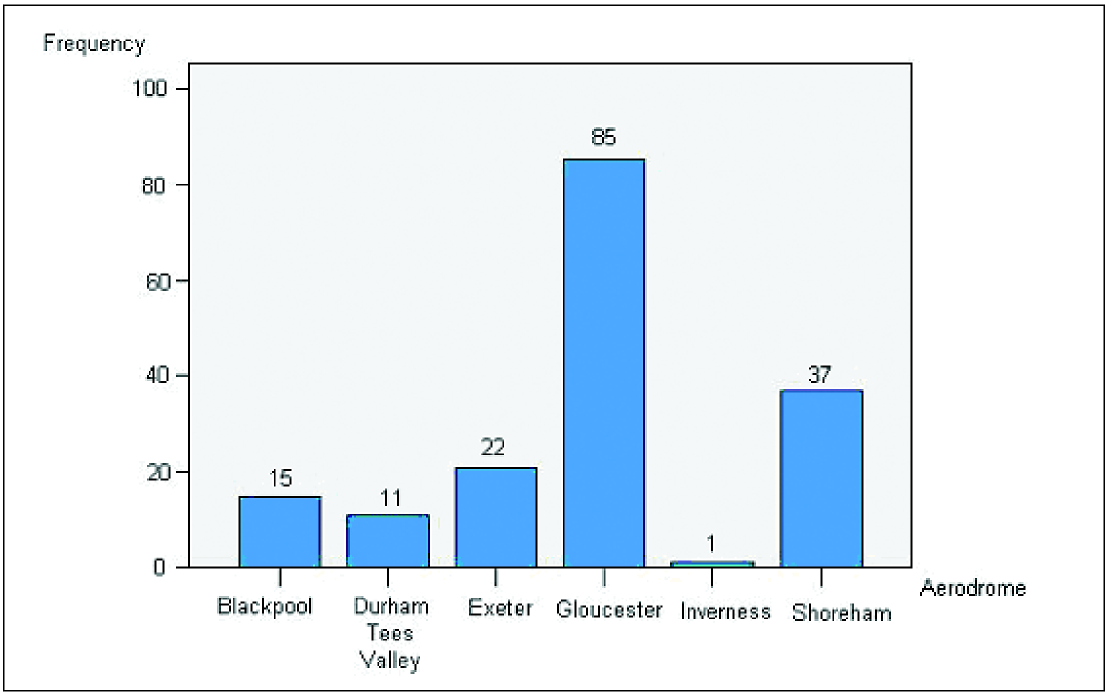
Table 3.9 Pilot and Observer Qualification (Verified Reports c.f. Section 4.1)

Observer Qualification	Pilot Instrument Rating					
	IMC	**IR**	**None**	**Incorrect ID**	**Not collected**	**Total**
IFR Private Pilot	32	30	0	0	5	67
IFR Professional Pilot	5	40	0	2	2	49
Non IFR Private Pilot	18	16	3	0	0	37
Other	1	8	0	0	0	9
Total	**56**	**94**	**3**	**2**	**7**	**162**

3.4 **Aerodrome**

A total of 171 questionnaire reports were filed for trial approaches to the six aerodromes. Figure 3.5 presents the breakdown of these reports by aerodrome.

Figure 3.5 Frequency of Submitted Reports by Aerodrome



It was hoped that the survey process would result in more than 30 filed questionnaires per aerodrome. In order to assess the correlation of results to the aerodrome, a chi-square test was performed for the measures of performance collected in section 4 of the questionnaire. However, the results were not conclusive, due to the conditions of minimal bin numbers not being met for any of the tests. It was therefore necessary to make purely qualitative statements regarding the independence from aerodrome. This is discussed further in Sections 4 and 5.

In order to assess the feasibility of pooling data from each aerodrome, an analysis of pilot comments, which referred to aerodrome specific issues, was undertaken. There were two major factors, which were governed by the choice of aerodrome; namely traffic volume and approach design. The first issue with approach design was the sharpness and anticipation of turns at the IF. Two pilots specifically requested turn angles to be reduced, one such comment is given below.

"It would be much easier if the IAF could be placed at a reduced angle…"

Each of the comments referred to a 90º angle, which was the most common design of the trial approaches. The approach base turn angles varied from 70º to 115º. The similarity between aerodromes on this matter ensured that pooling was acceptable.

The Shoreham approach was observed to have an unusually high descent gradient of 7·87%. This was the most obvious choice for a possible procedural element, which could cause a problem. Although a small number of pilots commented on this steep approach (3/77), there were no comments referring to the steep descent and RNAV (GNSS) approaches in particular. It was felt that the comments did not warrant separate analysis of the Shoreham data.

Differences with regard to traffic volumes were expected due to the variation in size of the aerodromes. The number of comments referring to traffic did not allow for any kind of statistical analysis. All bar one of the comments referring to traffic issues were not RNAV specific. This is discussed in greater detail in Section 4.3.2 but no aerodrome specific issues were found.

No further trends were observed within the data to suggest other aerodrome specific issues existed, therefore the decision was taken that pooling the data from individual aerodromes was acceptable. This was taken with the minor caveat that some issues such as approach chart design would still require the consideration of the aerodrome as a factor.

4 Results

The pilot submissions were subjected to the data reliability process described in Section 2.3.2 to ascertain the integrity of each filed report. The results of this process are given in Section 4.1. The data analysis results are then presented in a structure, which reflects the relevant issues as per the description in 2.3.3. This also reflects the structure of the pilot questionnaire. A number of sections have been merged or extracted from this structure in order to facilitate a better understanding of the issues raised.

4.1 Data Reliability

The data reliability of a survey is the measure of believability or 'truth' of the responses and is important in determining if the conditions of a survey process have been met. There were three methods applied to ensuring the reliability of the pilot response data as described in Section 2.3.2. These were the rejection of outliers unverified by ATC report logs, down weighting of partially verified reports and an assessment of the viability of data pooling. The motivation behind the requirement of ATC to record data on each approach was two fold; to gain knowledge of RNAV (GNSS) issues specifically related to ATC and to ensure that registered pilots did not submit unreasonable reports.

The initial approach was to exclude those records that did not have a corresponding ATC log entry. However, to enhance the reliability check process it was decided to extend this simple exclusion/inclusion approach to include the latency and manual reasonability check. The accuracy of memory-based data entry is known to reduce as the time period between the event and when it is recorded increases. However, the requirement of a flight observer to record information was intended to minimise this fact. The following two sections describe the results of outlier rejection and the weighting scheme. The decision making process with regard to pooling is described in Section 3.4.

4.1.1 Outlier Rejection

The extension of the trial period by three months was intended to boost the number of responses. The ATC logs provided a valuable check against unreasonable reports. However, the use of ATC cross checking was a contentious issue as it had the potential to reduce the sample size. Initially it appeared that many of the reports had not been validated, but a change in the communication of ATC logs rectified this setback. All of the reports matched by ATC were deemed reasonable by the manual checking process. The final result showed that a large proportion of the trials were matched (89·5%), after minor editing of small errors. Table 4.1 shows these results. A further nine (5·3%) of the reports came from pilots who had previously submitted a verified approach and these nine reports were flagged as partially verified.

Table 4.1 ATC Report Verification

Pilot Report Verified by ATC Log?	Frequency	Percentage (%)
Yes	153	89·5
Partial	9	5·3
No	9	5·3
Total	**171**	**100·0**

The reports accepted were both verified by ATC and deemed reasonable by the manual check. In this context the process adopted to reject outliers could be considered to be conservative as both systematic and manual procedures were applied. The latency of submission for the unverified reports was generally greater than for the verified reports. Therefore, it can be concluded that the rejection of the reports not verified by ATC is substantiated to some degree.

4.1.2 Weighting

Weighting of reports can be used to reduce the influence of some reports, which are included for analysis even though they do not possess the same reliability as the other reports. The intention was to avoid reducing the sample size whilst still retaining high reliability of the data. Discussion with the CAA identified a potential link between reliability and latency. This effect was assessed by looking for trends in the reasonability and errors of the reports and their relation to latency. No trend was observed. The decision was taken to simply halve the weight of the partially verified reports as discussed in Section 4.1.1.

4.2 Pre-Flight Checks

A number of pre-flight checks were required for the purpose of the trials as would apply to fully approved RNAV (GNSS) approaches. Pilots had to ensure that the receiver was installed and approved, that the database was valid and that RAIM would be available for the period of the approach. The results with regard to these checks are presented in the following Sections 4.2.1 – 4.2.3.

4.2.1 Receiver Installation

The weighted average of the receiver installation variable resulted in 61·1% of the pilots believing that their equipment installation had been correctly approved for NPA operations. This was a confusing issue for pilots, particularly as a special condition of the trials permitted the use of appropriately installed equipment without the need for its certification for NPA operations to be entered in the Aircraft Flight Manual (AFM). The lack of approved GNSS approaches in the UK prior to the trials meant that there had previously been no need to obtain installation approval for approach operations.

Pilots commented on the confusion between TSO certification, B-RNAV approval and NPA approval, which coupled with the special condition of the trials, meant that the results of this variable might be misleading. It was felt that very few, if any, aircraft had an approved receiver installation for NPA operations.

A total of nine multiple use aircraft were recorded of which six had pilots who gave different answers with regard to the approval status of the aircraft's receiver installation. This accounted for approximately a third of the unapproved cases. It was clear, therefore, that different pilots had drawn different conclusions given the same information.

In conclusion, certification of RNAV (GNSS) approaches should be accompanied with a policy to educate pilots on the complexity of equipment approval.

4.2.2 **Database Validity**

The aeronautical information database loaded within the receiver had to be valid for the time of any flight using the trial RNAV (GNSS) procedures. Approximately 11% of the approaches and 14% of the pilots did not possess the required current database. The data were inspected in more detail to search for any key groups, which represented these unacceptable cases. As pilots were required to check the status of the database, neither previous pilot experience nor learning during the trial process appeared to have contributed to a change in behaviour.

Figure 4.1 Out of Date Navigation Databases

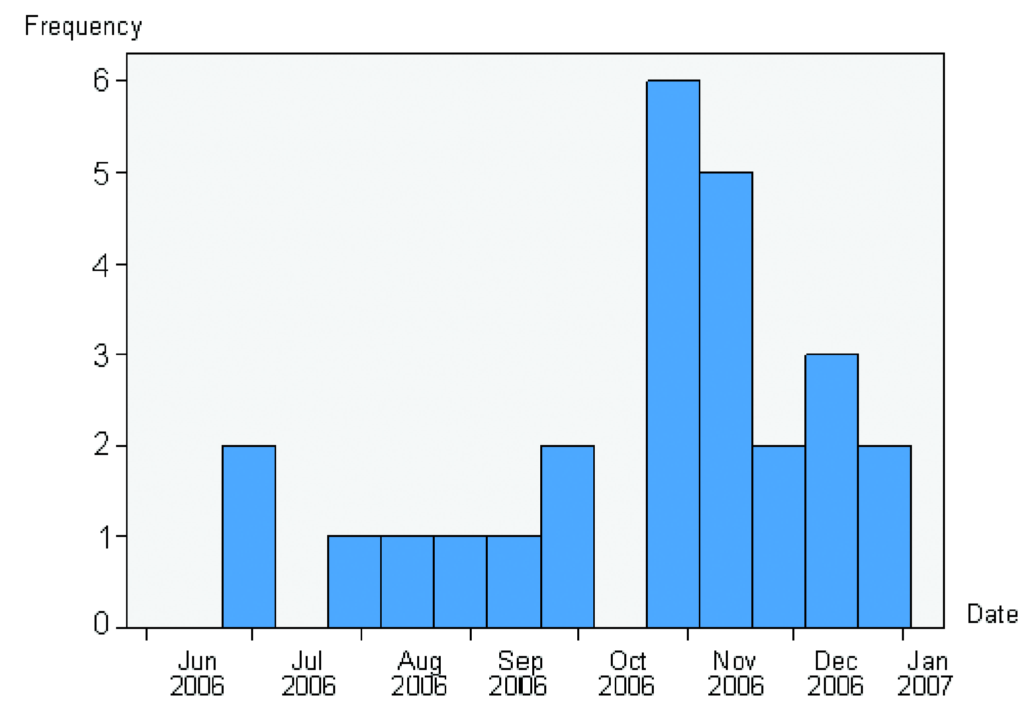
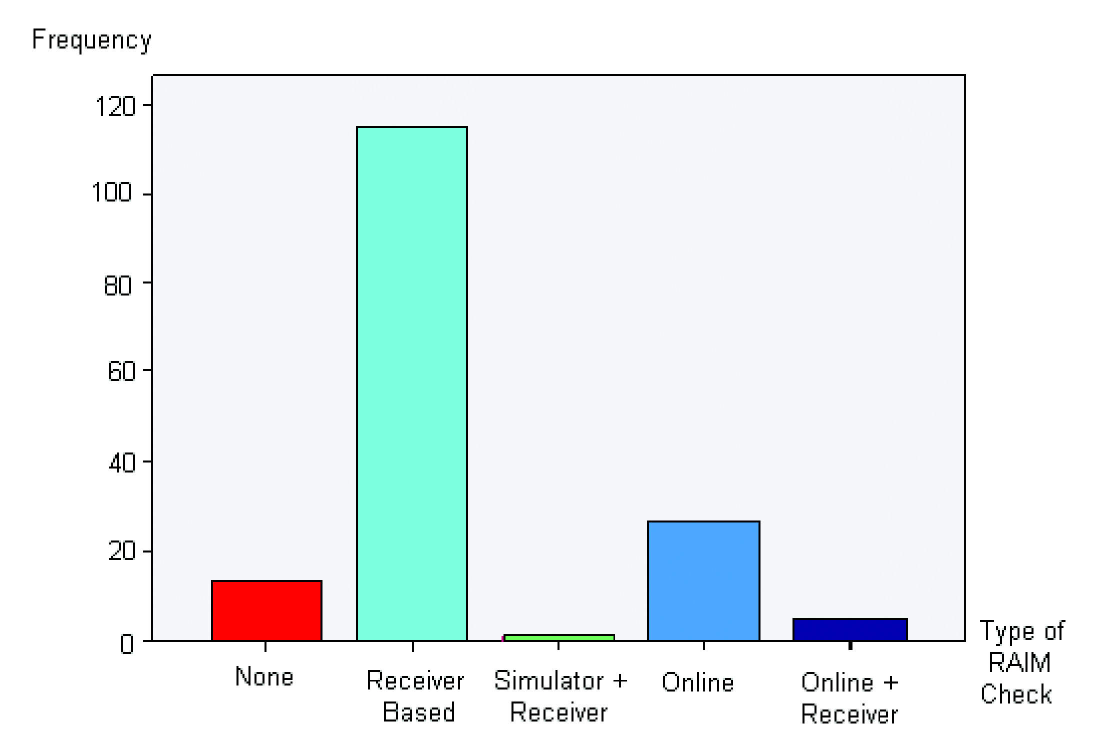


Figure 4.1 shows an increase in out-dated databases in November, which corresponded to an increase in approaches flown in this period. There appeared to be no specific external causes for pilots using out-of-date databases. It is only reasonable to assume that the knowledge and conscientiousness of the pilot were factors.

4.2.3 RAIM Check

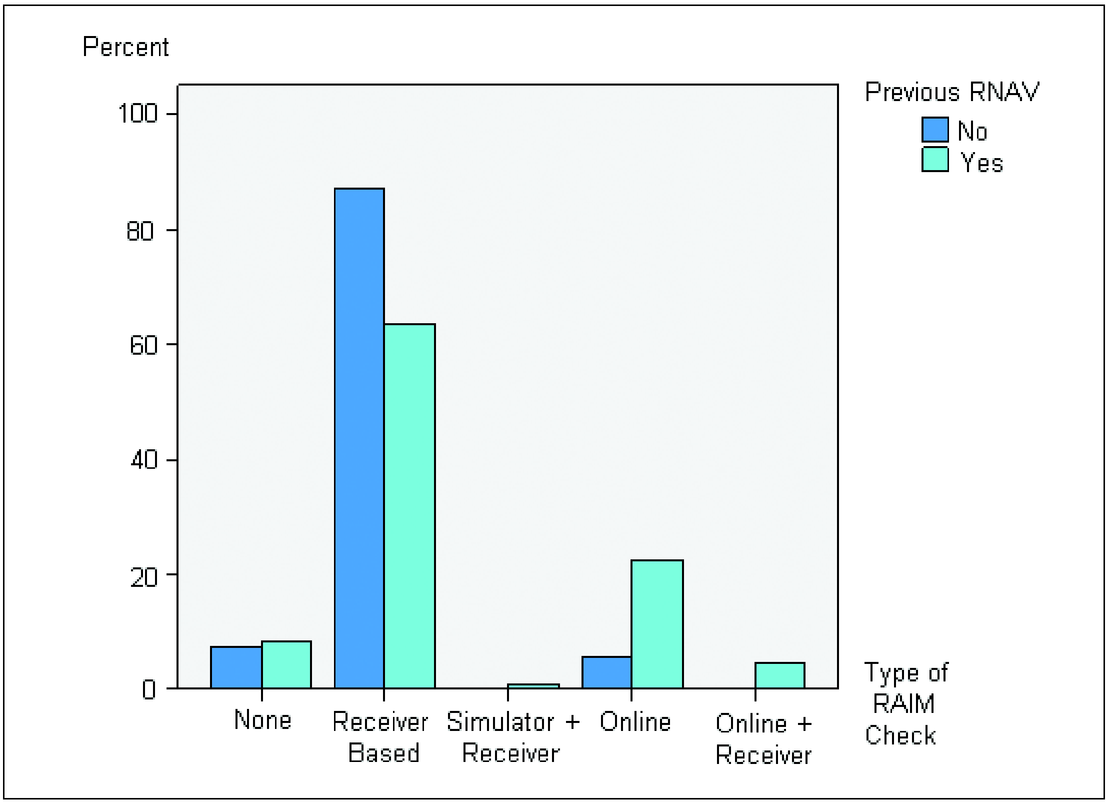
The survey of RAIM checks made by pilots revealed that a large number (92·0%) of approaches were checked for GPS-RAIM availability. The results are displayed in Figure 4.2 and show that receiver based checking was the most popular method. This was likely to be due to the convenience by which an on-board check could be made. Less than 10% of approaches were flown without the pilot having made this required check.

Figure 4.2 Type of RAIM Check



There was no observable difference between the behaviour of IMC and IR pilots regarding pilot RAIM availability checks. However, Figure 4.3 shows a clear difference between those pilots with and without previous RNAV experience in relation to web checking. Caution should be exercised here due to the interaction of experience variables described in 3.3.5.

Figure 4.3 RAIM Check by Previous RNAV Experience



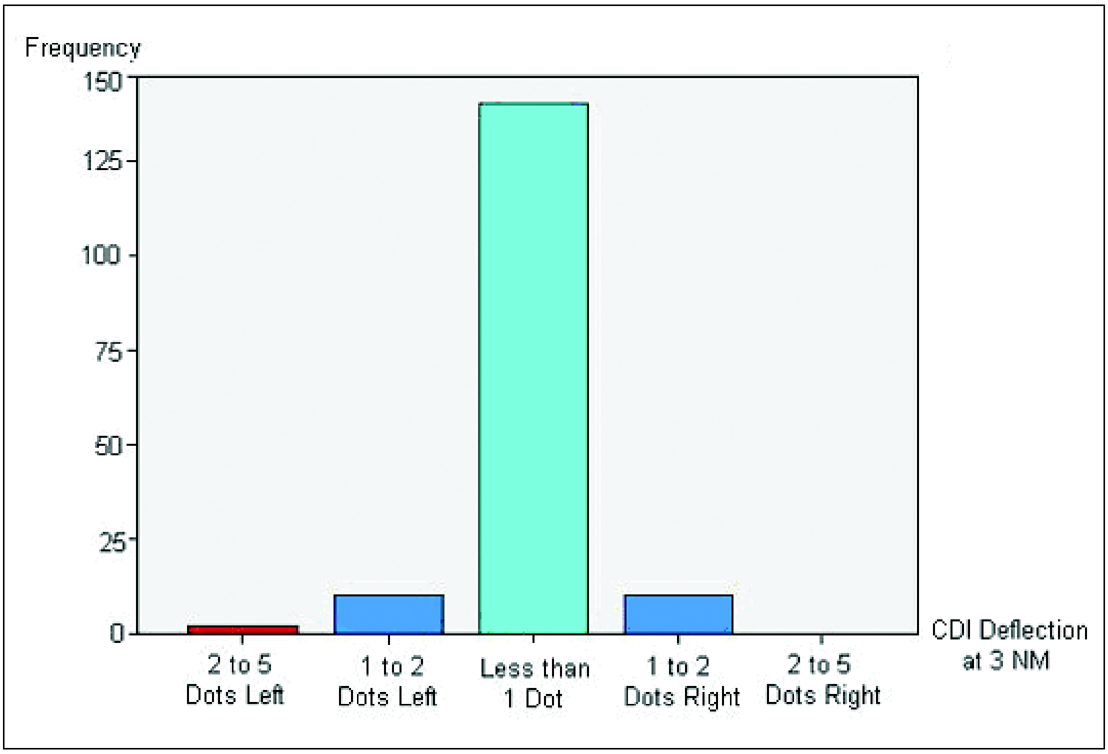
4.3 Flying the Approach

A variety of information was recorded throughout the flights. The intention of a secondary flight crewmember, the "observer", was to improve the quality of this information, specifically to avoid errors due to pilot memory lapses. A number of fields were requested to quantify the ability of GPS to provide accurate course information and maintain the aircraft on the correct radial. Furthermore, any difficulties with ATC, traffic, equipment usage and spatial orientation were to be recorded. The following subsections present the results with regard to these responses. Of the 162 approaches not rejected as outliers, 146 were completed to the missed approach point without breaking off.

4.3.1 Flight Data

Course Deviation Indicator (CDI) readings were recorded at 3 NM, the minimum descent altitude (MDA) and the missed approach point (MAPt). The course deviation is output in terms of 'number of dots'; the magnitude of a dot varies automatically as the approach progresses as described in Section 1.2. The CDI data are presented below.

Figure 4.4 Course Deviations at 3 NM



It can be seen from Figure 4.4 that the majority of trials followed the centreline accurately to within a single dot with only small deviations present. The two cases shown in red in Figure 4.4 were due to vectoring from ATC instead of following the RNAV (GNSS) approach. One of these two significant reports also recorded that the aircraft receiver did not activate the correct display mode before reaching the Final Approach Fix (FAF).

Figure 4.5 Course Deviations at MDA

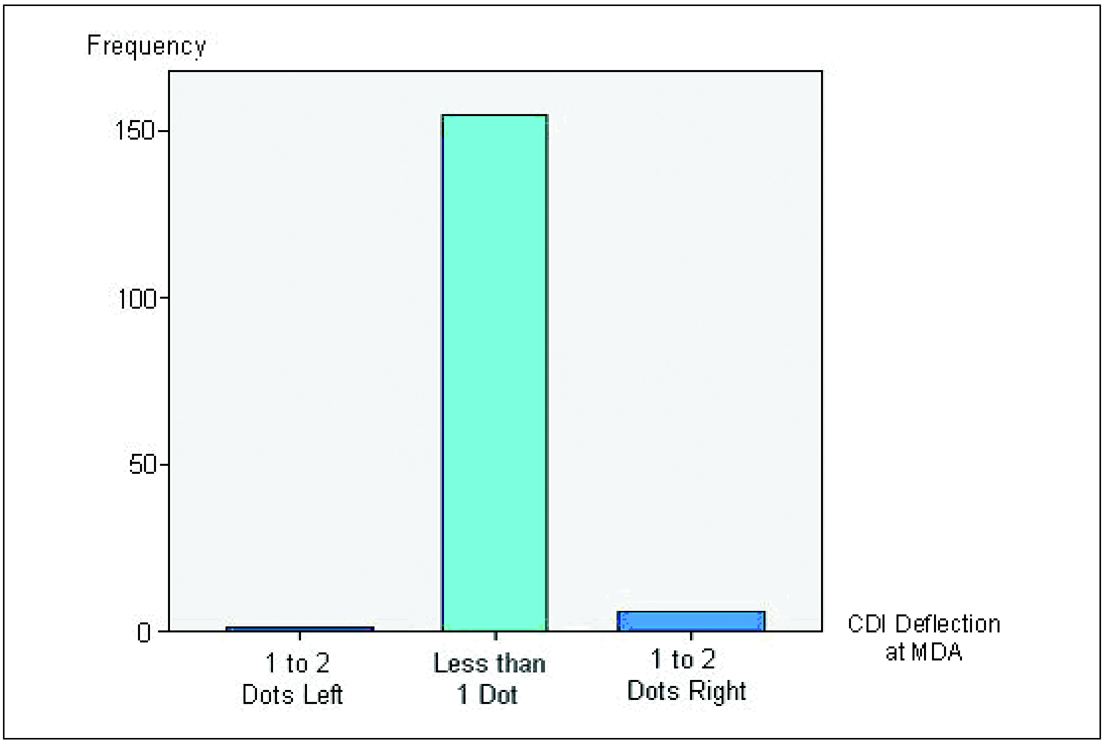


Figure 4.6 Course Deviations at MDA by Pilot Licence

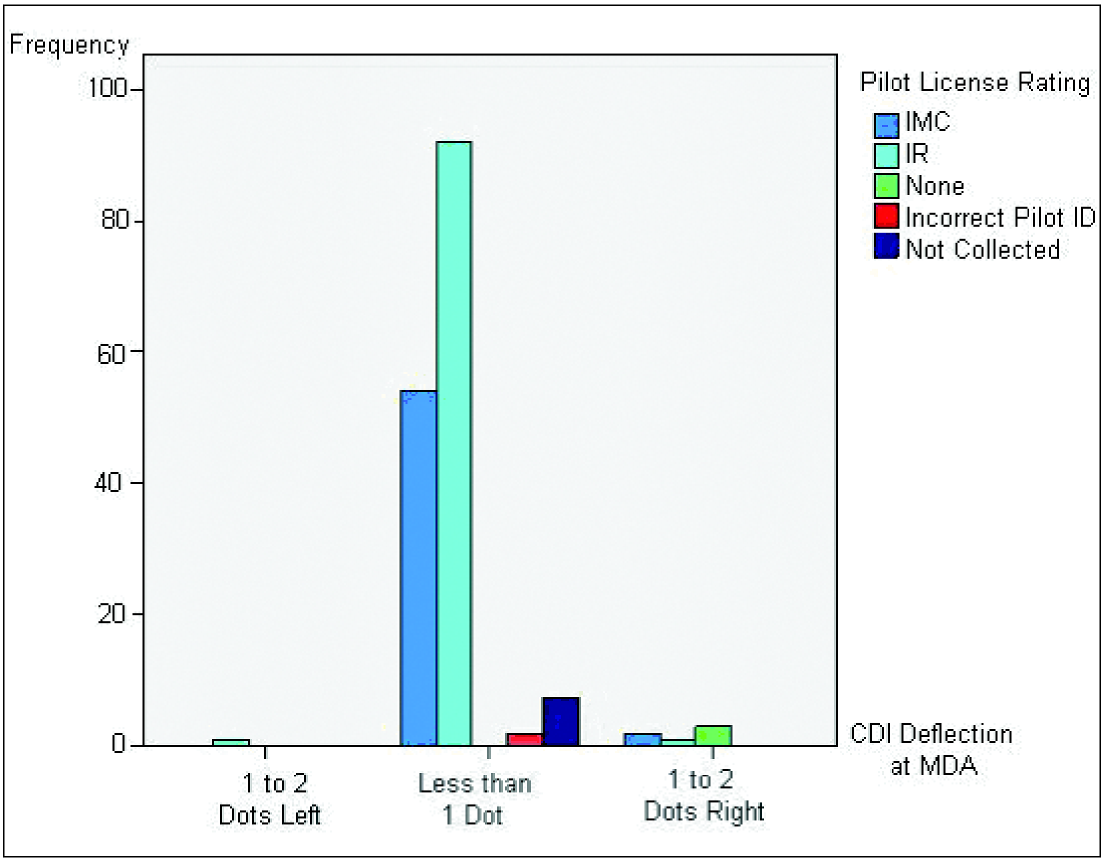


Figure 4.5 shows an analogous chart to Figure 4.4 for deviations at the minimum descent altitude. The results for this position also show a good conformance within a single dot of the centreline in the majority of cases. No statistical relationship was found to explain the minor deviations of one to two dots. However, Figure 4.6 on the type of pilot licence held shows that the majority of the deviations to the right were from a pilot without an instrument rating and undergoing training. The other minor deviations could have been caused by winds or nominal flight errors.

Course deviations at the missed approach point are shown in Figure 4.7. Once again the general performance and ability of the system to position the aircraft upon the correct path was excellent, with less than 5% of approaches deviating by greater than a single dot. All the trial approaches corresponding to the greatest deviation of more than 2·5 dots were found to be through breaking off the approach (c.f. Appendix A, Q17). A typical ATC instruction was the most common reason given for breaking off the approach. Figure 4.8 shows a breakdown of course deviation against whether the approach was completed.

Figure 4.7 Course Deviations at MAPt

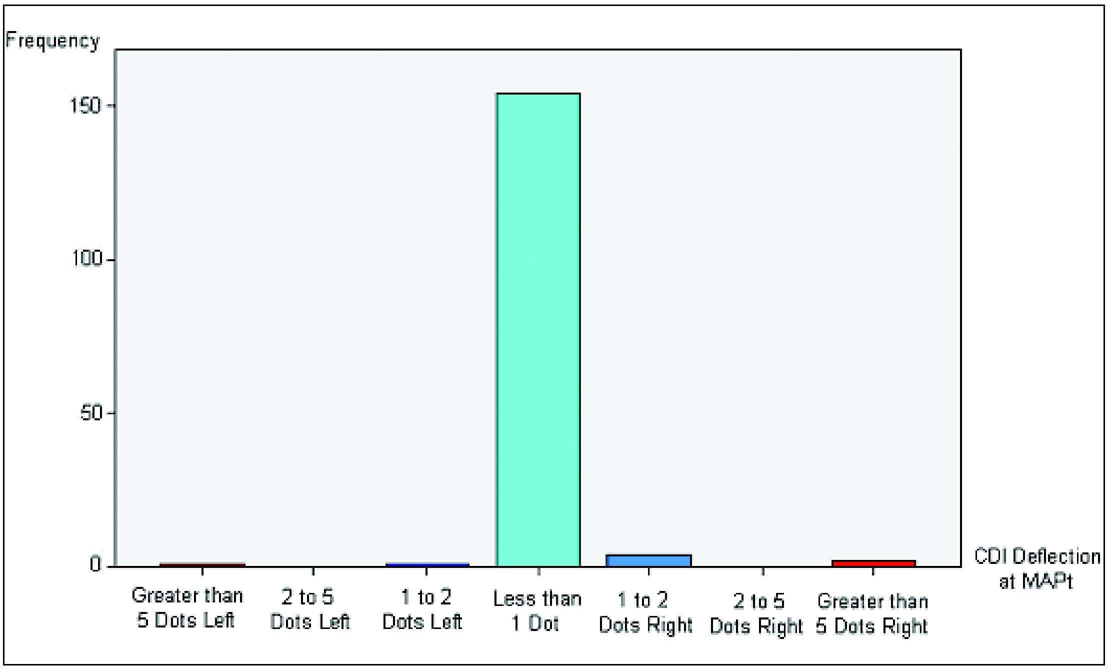
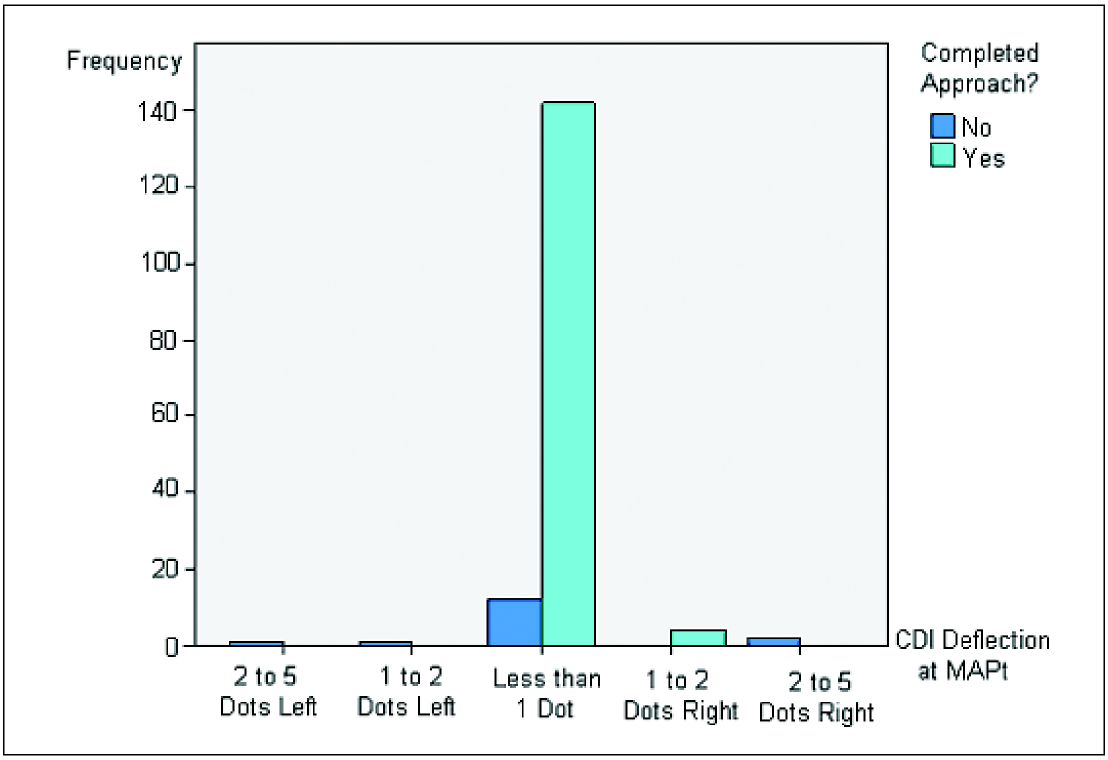


Figure 4.8 Course Deviations at MAPt by Approach Completion



Concluding on this section, it had been found that no significant issues existed in the performance of RNAV (GNSS) approaches to position the aircraft upon the correct flight path. Any significant deviations from the flight path were explained either through pilots breaking off the approach or due to training status. The remaining minor deviations were extremely small in number and could be considered to be due to nominal flight error.

4.3.2 Air Traffic

This section presents the pilot responses regarding their interaction with ATC throughout the trial approaches and the effects of other traffic. The ATC report logs were also analysed to highlight any issues raised.

Pilots were asked (Appendix A, Q10) if they encountered any difficulties or interruptions from ATC. Figure 4.9 shows the ratio of responses. The majority of reasons given for the interruptions were standard ATC requests concerning high traffic levels. Familiarity with the RNAV (GNSS) approach procedure appeared to be an issue in a few cases. One pilot commented that:

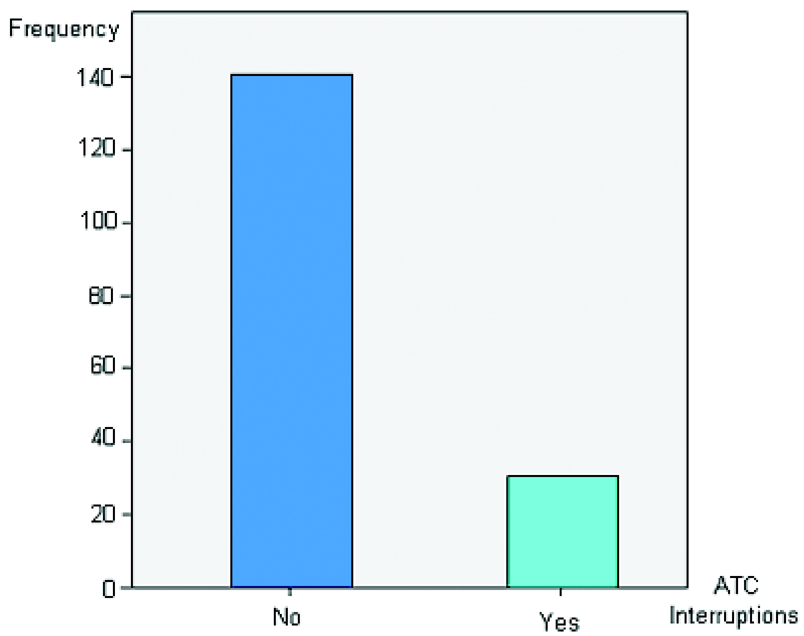
> "ATC asked for DME range (when I had about 7·5 NM to run) I didn't have the DME tuned and the Frequency is not on the RNAV chart, nor is the DME part of the procedure."

Similarly, confusion over minimum altitudes of the RNAV (GNSS) approach appeared, seemingly in relation to alternative approach procedure requirements. For example:

> "Some confusion on handover to the Aerodrome about the RNAV approach. Aerodrome Radar cleared us to 2600, when procedure calls for not below 2800 at LETSI."

Both of the examples given above were isolated incidents and appeared to have been caused by ATC familiarity with other instrument approach procedures.

Figure 4.9 ATC Difficulties or Interruptions



The pilot questionnaire and the ATC log both contained a similar question referring to phraseology and whether RNAV (GNSS) approaches hindered the communication interface between the pilot and ATC. Only six of the 162 (3·7%) validated pilot responses logged any such confusion. The majority of these were related to the previous question on ATC interruptions and none of the responses presented a safety concern. Similarly, the ATC reports made just four minor comments, and these were neither a threat to safety nor general operation.

A total of 33 from 162 (20·4%) reports from pilots stated that traffic had a general influence on their approach. However, only one RNAV specific comment was made, with the remaining comments remarking on nominal operational issues. An example is given below:

"Lots of VFR traffic using other runways. These approaches are positively dangerous in VMC would be much safer in IMC."

This was certainly not the general perception of the pilots participating but it did highlight that some pilots may feel that high VFR traffic levels in conjunction with instrument approach traffic could be a safety issue. This did not specifically reflect on RNAV (GNSS).

The ATC report logs contained a few comments on traffic issues and all were minor operational remarks.

This section has shown that although minor issues worthy of comment from pilots and ATC existed, it was the general view that RNAV (GNSS) did not impinge upon the use of air communication nor influence the sequencing of traffic in a detrimental fashion.

4.3.3 Orientation and Positioning

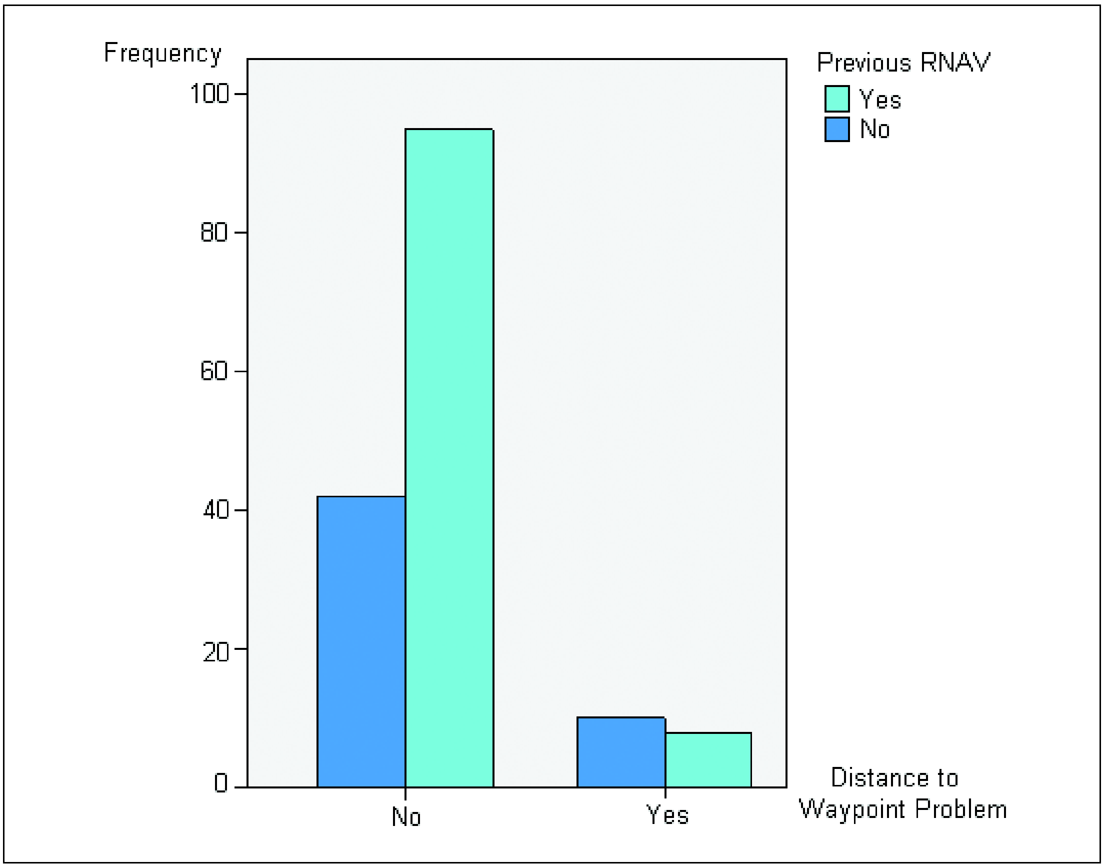
The spatial orientation aspects and perception of the positioning success of GPS was assessed through a variety of questions on the pilot report. The most straightforward mapping was to question 13 (Appendix A, Q13), which was designed to capture any difficulty pilots may have had with spatial orientation. Pilots who flew with ease but foresaw a possible problem or hazard commented on spatial orientation within the final comments box (Appendix A, Q26) and other open text questions. Approximately 21·0% (34/162) of reports stated that pilots had experienced spatial orientation difficulties. There were four primary reasons for this: distance to next waypoint confusion, vertical profile issues, positioning in high winds and chart deficiency or misunderstanding.

The most common spatial awareness problem (>50%) perceived by pilots was regarding the distance to next waypoint read-out of the GPS unit. A total of 20 (12·3%) questionnaire reports commented on the issue of a distance to waypoint read-out as opposed to distance to runway threshold. There was disagreement on whether this difficulty in spatial awareness was due to familiarity with previous instrument procedures. One such response captured the essence of this issue:

"There is potential for confusion where the GPS gives it's own range to the next waypoint in the procedure, which is not to be confused with the range to threshold distance, which is what one normally expects to see on most instrument procedures. In IMC under pressure the range to next waypoint read-out could be easily mistaken as threshold distance….However, the visual presentation used correctly with proper training makes for a very simple and accurate process with little brain input required to carry out a simple and accurate approach……the visual presentation makes for excellent constant position and spatial awareness….The process worked brilliantly."

The small quantity of data made it impossible to infer any statistically valid relationships between the reports marking the distance to waypoint as an issue and an independent variable. However, Figure 4.10 shows that those pilots with previous RNAV experience reported fewer problems with the distance to waypoint read-out.

Figure 4.10 Distance to Waypoint Comment by Previous RNAV Experience



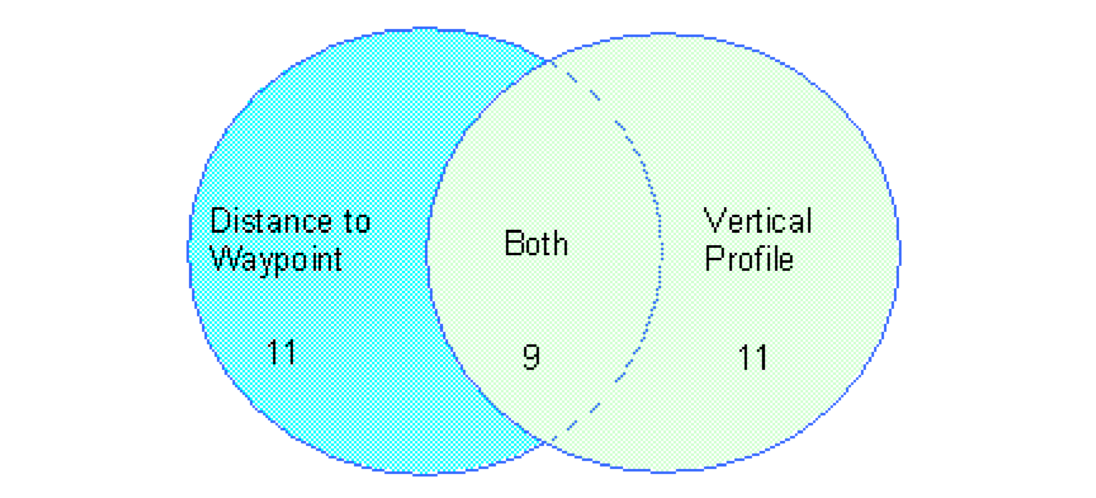
The issue of vertical guidance and accurate following of the vertical profile were closely associated to the distance to waypoint confusion described above. A similar number of respondents (20 or 12·3%) flagged that they experienced difficulty in descending. Table 4.2 presents a cross-tabulation between the two issues.

Table 4.2 Cross Tabulation of Most Common Spatial Orientation Issues

		Distance to Waypoint		Total
		No	Yes	
Vertical Profile	No	131	11	**142**
	Yes	11	9	**20**
Total		**142**	**20**	**162**

The table shows that a total of 31 questionnaires cited a lack of distance to runway or trouble following the vertical descent gradient as an issue. This is further illustrated in Figure 4.11.

Figure 4.11 Distance to Waypoint or Vertical Profile Problems



The 20 pilots that had a problem with the distance to waypoint were found to be highly dependent upon the manufacturer of their receiver as shown in Table 4.3.

Table 4.3 Waypoint Problem vs Receiver Manufacturer

	Garmin	**Bendix/ King**	**Trimble**	**Universal**
Total Number of Receivers	131	26	4	1
Distance to Waypoint	17	0	3	0
Vertical Profile	20	0	0	0

The Garmin GNS 430/530 receivers presented the greatest problem to pilots. These receivers accounted for 80·0% of the distance to waypoint problems and all of the vertical profile problems encountered by pilots. Pilot comments suggested that these problems arose from the way step-down fixes were treated in the receivers. The coding of step-down fixes as waypoints in the receiver database was found to cause confusion with regard to spatial orientation and the mental workload required of pilots. The three Trimble problems were encountered by a single pilot who had difficulty setting the receiver within a newly installed FMS.

Due to the relatively low number of responses, it was difficult to gauge whether the correlation of high winds and RNAV (GNSS) usage would be perceived as problematic by a high proportion of pilots. However, one pilot argued vehemently concerning this problem:

> "This approach was attempted with a strong (35kt) northerly wind. The effect was that on commencing the turn from LETSI at TE21F the aircraft was blown some 5 miles south of the centreline….At that stage the Approach has not armed and so the deflection on the CDI implied that the aircraft was only just off track….."

This trial had been completed using a Garmin 155, which should arm the approach within 30 NM of the runway. The position referred to was approximately 7 NM out and so it was assumed that the auto-arming feature of the Garmin 155 had been disabled. In this case the particular problem could be attributed to equipment familiarity. The issue of turn anticipation in high winds, which has been touched upon here should be accounted for within the receivers' functionality as it uses the aircraft groundspeed to calculate the necessary annunciation time.

The issue of chart deficiency is dealt with in Section 4.5.

To conclude, spatial orientation presented one of the major new challenges to pilots. Previous experience may have been a minor aid but it was clear that a lack of distance to runway read-out caused difficulty in making a smooth descent. A lack of data made it impossible to assess the severity of the effects of high winds on turn anticipation features of receivers.

4.4 Equipment – Ease of Use

One objective of the trials was to assess the role of equipment in RNAV (GNSS) procedures. It was important to discover how quickly pilots learnt the necessary functions to load, activate and implement an approach and to ascertain if any specific equipment related issues existed, be it across the board or within a particular receiver type. Questions 5, 6 and 7 (Appendix A, Q5, Q6 & Q7) were designed to assess the ease of receiver programming performed pre-flight. Questions were then asked of the pilot on how their interaction with the equipment followed during the approach (Appendix A, Q14, Q16 & Q19). Finally, pilot perception performance metrics in comparison to other NPA approaches also have relevance to the issue of operability of the GNSS equipment. This will be discussed in Section 4.7.

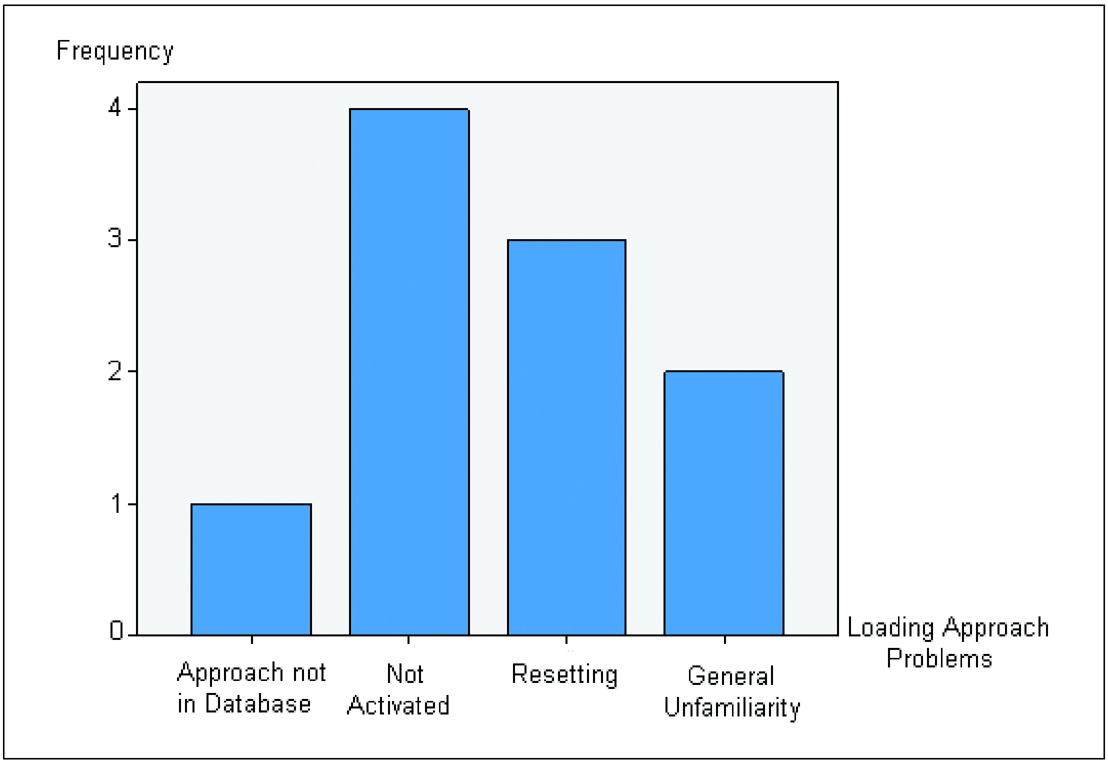
4.4.1 Receiver Programming

A small number of reports from pilots (10/162 or 6·2%) described problems with the selection, loading and activation of the approach from the receiver database. These responses fell into a number of categories as shown in Figure 4.12. The two most common issues were failure to activate the approach before the necessary position and trouble resetting the approach. Resetting the approach was required following a missed approach or after being vectored off course by ATC. Unfamiliarity of the equipment led to a mistake being made by two pilots on the Garmin GNS 430. Confusion over whether selection of the aerodrome was required prior to selection of the approach led to this mistake.

> "…Because for this approach we pressed the "Enter" key after selecting EGBJ and before selecting the approach, the GPS tried to route us from the IAF to the airfield and back to the IAF before beginning the procedure. We cannot think of any circumstance where that would be the desired routing…"

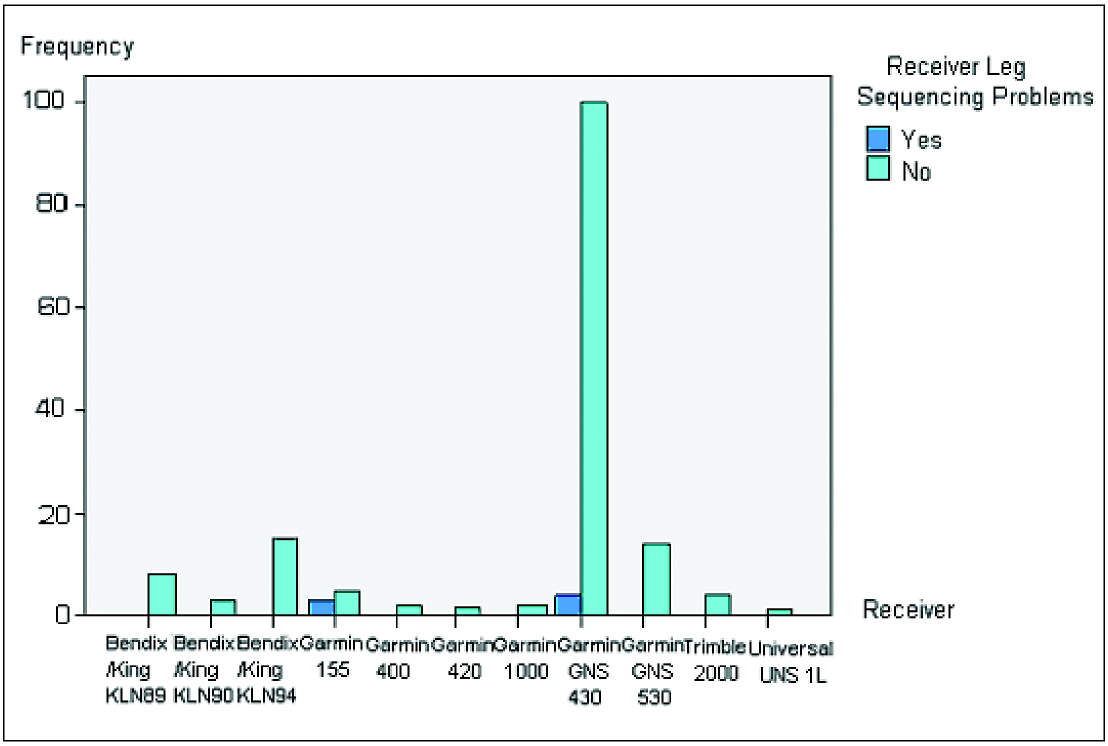
This view conforms to that echoed in the literature (Section 1.3) in that GPS equipment does not deal with mistakes nor provide the necessary internal checking.

Figure 4.12 Approach Loading and Activation Problems



Less than 5% of responses reported incorrect sequencing of legs by the receiver and no statistically significant causes for this were found. The Garmin 155, which was the cheapest of the Garmin receivers featured in the trials, appeared to perform poorly in this test as shown in Figure 4.13. However, this receiver was only used by a single pilot in a single aircraft and, as such, generalisation on its ease of use was not possible.

Figure 4.13 Leg Sequencing Problems



The final receiver programming function to be investigated was the setting of the instrument display – horizontal situation indicator/course deviation indicator (HSI/CDI). A total of 24 pilots encountered difficulty with the HSI or CDI, either in pre-programming or during the procedure itself. Many of the problems encountered were unique, and the majority were minor events common to the experience of using new equipment irrespective of the field of use. One issue worthy of mention involved a pilot that perceived the course deviation being referenced to the wrong track.

"The GPS gave a wrong "track required" indication at IAF - heading direct to the runway, not to the IF or FAF. The FPL was input as LAPKU to EGBJ GNSS27 but presented at the IAF as LAPKU direct to EGBJ to LAPKU and then the procedure."

Another pilot also encountered a similar problem to the pilot quoted above. It was possible that the pilots inadvertently used the direct-to key unnecessarily.

The findings on equipment programming showed that a large number of pilots encountered problems operating the GPS receivers. These problems were varied, but the most prominent issue seemed to be in understanding the mechanisms behind how an approach was loaded and activated.

4.4.2 Receiver Use in Flight

Pilots were requested to observe annunciations from the GPS equipment during the approach. The vast majority of trial runs either recorded no messages or standard track messages referring to waypoints and turns. A breakdown of the message types is given in Table 4.4. There was a single RAIM alarm, an unexpected occurrence for such a small number of trials. The details of the analysis into this event are given in Section 4.8. The other warning of note was that of a terrain warning system, an additional unit supplementary to the GPS functions. The remaining messages recorded by pilots were standard track messages, barometric setting and receiver setting messages. These messages were present in normal operations and thus no other safety issues were found.

Table 4.4 Receiver Messages

	Frequency	**Percentage (%)**
Track Messages	46	28·4
Receiver Setting	3	1·9
Barometric Aid Setting	3	1·9
RAIM Alarm	1	0·6
None	109	67·3
Total	**162**	**100·0**

4.5 Approach Chart

The quality of an approach chart was dependent upon successful procedure design and the chart's clarity. The goal of canvassing pilot opinion with regard to the approach charts was to assess any issues with the approach procedure design as well as any possible design discrepancies at individual aerodromes or display issues with a particular publication. Table 4.5 presents the breakdown of pilot questionnaires by chart publication.

Table 4.5 Chart Publications

	Frequency	Percentage (%)
AERAD	27	16·7
Jeppesen	33	20·4
UK AIP	98	60·5
Other	4	2·5
Total	**162**	**100·0**

The discrepancies, which were noted by pilots were coded through performing the data pre-processing strategy. The most common issues were those of reading difficulty, missing information, a lack of altitude data and confusion over altitudes and vertical profiling. The two major variables, which could contribute towards a skew of the data were the aerodrome and the chart publication type. Table 4.6 presents the frequencies of the coded data with respect to these two variables

Table 4.6 Chart Publication Issues

	Aerodrome															
	Black-pool		Durham			Exeter			Gloucester-shire				Inver-ness	Shoreham			
	AERAD	Jeppesen	AERAD	Jeppesen	UK AIP	AERAD	Jeppesen	UK AIP	AERAD	Jeppesen	Other	UK AIP	UK AIP	AERAD	Jeppesen	Other	UK AIP
2 MA Gradients	0	0	0	0	0	0	0	0	0	0	0	5[a]	0	0	0	0	0
Altitude Confusion	0	0	0	0	0	0	1	2	1[i]	1	0	4	0	1	0	0	0
Distance to Next WP	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
Missing Information	0	2	0	0	0	0	2[b]	0	0	0	0	5[c]	0	1	1[e]	1[f]	1[e]
Plausible Error Note	0	0	0	0	0	0	0	0	0	0	0	2[g]	0	3[d]	0	0	0
Reading Difficulty	1	0	0	0	1[h]	1	1	3[h]	0	2	0	5	0	1	0	0	3
None	1	8	2	5	2	8	1	3	7	5	2	40	1	0	3	1	20

Definitions

2 MA Gradients	Confusion over the two missed approach gradients.
Altitude Confusion	The information presented with reference to the altitudes of step-down-fixes, waypoints, vertical profiles, etc. was confusing.
Distance to Next WP	The chart presented altitudes at distances to runway as opposed to the next waypoint, which was the case for the GPS unit.
Missing Information	Pilots perceived the need for extra information or additions to the approach procedure.
Plausible Error	A chart error, which required further investigation.

Reading Difficulty	An issue primarily with the clarity or format of the chart.
None	No deficiencies present in the chart.

The specific comments of interest indexed in Table 4.6 are described below (sample RNAV (GNSS) charts for the six trial aerodromes are shown in Appendix E).

a) Runway 09 at Gloucestershire possessed two missed approach gradients. A total of five pilots found the lack of an explanation on the approach chart confusing.

b) An important comment regarding the clarity of navigation aid information. Two pilots considered that the arrow giving radial and distance information, on the Jeppesen plate for Exeter, did not clearly identify the particular navigation aid. There was no evidence to suggest this problem existed at other aerodromes, but it was clear the issue could be replicated in further approach chart publications.

c) One pilot commented that there were no holding patterns defined prior to commencing the approach procedure. This was true for all approaches.

d) One pilot commented that the radial from MID to SUSAX, on the Shoreham chart, was incorrect (should be 136 degrees), whereas another response suggested that the radial from MID should refer to BITLI and not SUSAX as was the case for the distance.

e) Two pilots responded regarding the lack of navigation aid (DME) frequency on the Shoreham chart.

f) A single response advised the inclusion, on the Shoreham chart, of the terminal airspace indicator (Gatwick) to the north.

g) The heights of obstacles were inconsistent between the RWY 09 and RWY 27 charts at Gloucestershire. The approach charts appeared to verify this.

h) The large size of the approach chart was considered troublesome for a small light aircraft.

i) Confusion due to the minimum altitude at the Gloucestershire IF being greater than the minimum altitude at the IAF (SOSAB → BJ09I). Hence a need to climb between the IAF and IF.

It is worth noting that a number of further comments were made with regard to formatting of charts, such as 'too much detail' or 'too little information', but many of these were contradictory and appeared to be simple statements of individual pilot preferences. These comments referred to general approach chart design and were not relevant to the goals and scope of this report.

In summary, the issues highlighted above were mostly specific to a particular publication at a particular aerodrome and did not reflect negatively on the technology. However, they did present a significant safety risk and approval of RNAV (GNSS) should be made on the basis of error free charts. The issues appeared to be caused by the relative novelty of the approach procedure design. The difference in response between aerodromes appeared to be the product of these design issues and no significant differences in performance between aerodromes were found.

4.6 RNAV (GNSS) Training

The issue of specific pilot training on the use of RNAV (GNSS) procedures was considered to be important. In many walks of life, good preparation, experience and knowledge can reduce the safety risk. The role of the CAA on this issue is to ensure that pilots have the necessary experience and ability to safely use RNAV (GNSS) whilst minimising the regulatory burden.

The expectations of pilots were canvassed in this regard. Only seven (4·3%) responses found the approach more difficult than expected and this reduced to just three (1·9%) for the questionnaires submitted after each pilot's first trial approach.

A total of 128 (79%) reports stated that the current provisions for RNAV (GNSS) training were sufficient. An interesting link to training was identified through the effect of learning on repeated trials. A breakdown of these is given in Table 4.7.

Table 4.7 Training Adequacy by First Trial Approach

		Is Training Adequate?		Total
		Yes	No	
First Trial Approach?	Yes	49	20	69
	No	79	14	93
Total		**128**	**34**	**162**

The table shows a clear correlation between the effect of learning from the initial trial approach and opinion to the adequacy of training. A chi-square test confirmed this observation at the 95% level. Hence, at the very least, it could be concluded that flying a single approach had the positive effect of improving the confidence and skill required to execute further approaches.

The assessment of learning over more than a single trial approach was performed using a more qualitative method. The reports submitted by pilots who completed at least three approaches were analysed in sequence. Whereas in some cases these pilots had a single problem on the first run as suggested above, a number of pilots also encountered problems on their following approaches, typically their third or fourth. This suggested that a small number of approaches were needed to uncover the majority of potential problems that might arise.

A correlation analysis between the training question variable and pilot experience showed mixed results. There appeared to be no difference in response between pilots with previous RNAV experience and those without. However, the distributions of total pilot hours flown and P1 hours flown between the two groups defined in terms of their response to this question showed a considerable difference.

Table 4.8 Training Views against P1 Hours Flown

Is Training Adequate?	No.	Mean Pilot P1 Hours	Standard Deviation
No	34	1,110·8	1,544·0
Yes	128	3,493·1	4,560·0

Table 4.9 Training Views against Total Hours Flown

Is Training Adequate?	No.	Mean Total Hours	Standard Deviation
No	34	1,339·3	2,019·0
Yes	128	4,180·3	5,393·5

Tables 4.8 and 4.9 show quite clearly that the more experienced pilots assessed the training to be adequate more often than inexperienced pilots. No statistically significant relationship was found for pilots holding an IR or IMC rating. The most inexperienced group identified in Section 3.3.6 did show slightly more 'no' responses to the training adequacy question. However, no gross effect was found and no significant relationship was observed to suggest that this inexperienced group faired any worse.

The 34 (21·0%) reports that answered that training was inadequate included comment on how training could be improved. The results were coded into the following categories:

Single Trial	A single RNAV (GNSS) approach flown with an instructor.
Formal Training	A formal training course provided either by the CAA or receiver manufacturers.
Guidance Material	Improved guidance material, a clearer pilots guide, checklists and terminology definitions specific to RNAV (GNSS).

Table 4.10 Training Improvement Recommendations

Training Improvement	Frequency	Percentage (%)
Single Trial	4	11·8
Formal Training	18	52·9
Guidance Material	10	29·4
None	2	5·9
Total	**34**	**100·0**

Formal training was the most popular choice amongst pilots. In fact 11 (16·0%) of the 69 pilots who submitted verified reports suggested some form of formal training would be useful. Five of the 18 responses that recommended formal training specifically referred to receiver and equipment training.

Pilot responses placed within the guidance material section suggested a variety of informative documents, which could aid the learning process. Comments referring to difficulty in learning to use the equipment were given as were requests for appropriate checklists, terminology and a formal set of instructors' notes.

No relationships were found between the type of response and pilot experience or learning.

In summary, the majority of pilots felt training was adequate. However, a considerable proportion of pilots found this not to be the case and although not conclusive, pilots with less flight experience were more susceptible to feeling a lack of confidence in the training they had received. The variety of training improvements suggested were widespread ranging from simple document improvements to comprehensive training. The problems which some pilots encountered on their third trials and beyond suggested that approximately three to five practice approaches were needed to ensure pilots had the necessary familiarity and skills required for safe operation.

4.7 Pilot Perceived Performance

The conclusions section of the pilot questionnaire provided an opportunity for pilots to give simple indicators to their views on RNAV (GNSS). These indicators were designed to assess the pilot perception of ease of operation, accuracy and cockpit workload in comparison to conventional NPA procedures.

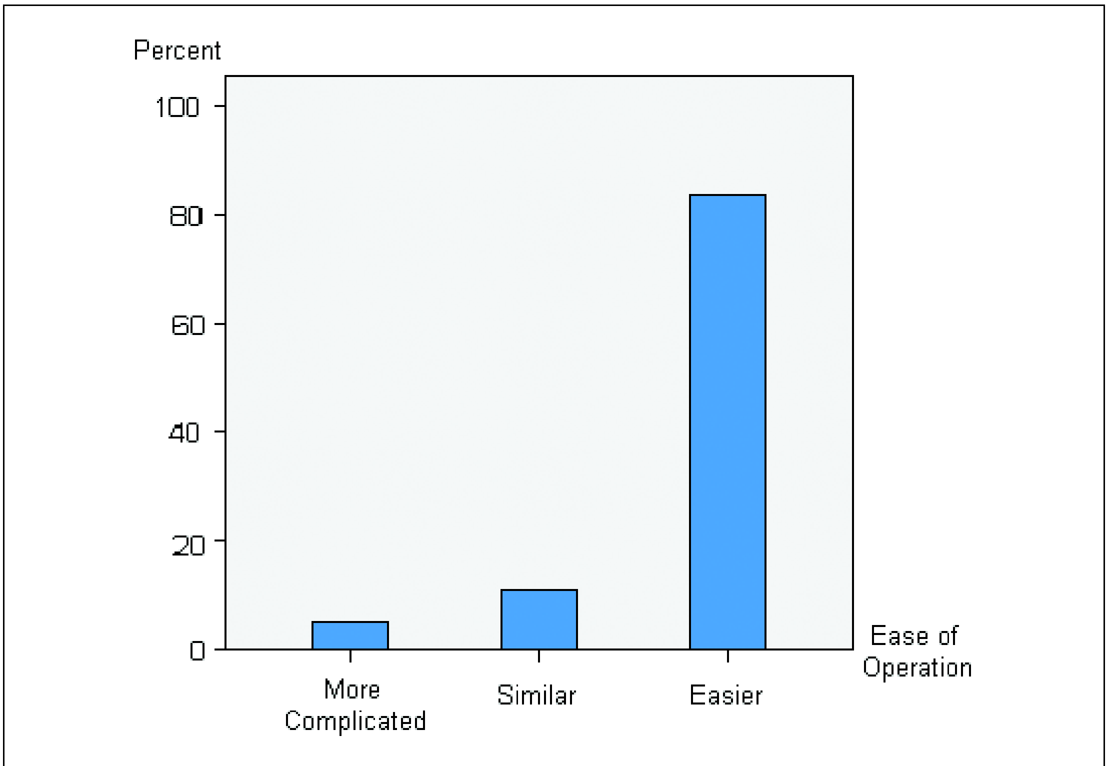
The comparison of general pilot experience of flying the trial approaches against their expectations was also assessed. Table 4.11 shows that the vast majority of pilots found RNAV (GNSS) approaches to be either as expected or easier than their expectations.

Table 4.11 Pilot Experience vs Expectation

	Frequency	Percentage (%)
More Difficult	7	4·3
As Expected	84	51·9
Easier	71	43·8
Total	**162**	**100·0**

The assessment of ease of operation referred to the general ease of performing the procedure, which included ease of equipment use, ease of communications with ATC and ease of maintaining spatial awareness, positioning and guidance. Figure 4.14 shows the pilot response. Assigning the values -1, 0 and 1 to the three variable values 'more complicated', 'similar' and 'easier', respectively, allowed the calculation of the weighted average of 0·72. A value of one would correspond to a 100% 'easier' bar. However, Figures 4.14 to 4.16 do not take account of weighting.

Figure 4.14 Ease of Operation



These results show pilots clearly favoured RNAV (GNSS) over conventional NPA navigation aids such as VORs and NDBs. Opinions with respect to pilot perceived accuracy were more emphatic, as can be seen in Figure 4.15. The weighted average, defined analogously to the ease of operation value, was 0·83 for pilot perceived accuracy.

Figure 4.15 Perceived Accuracy

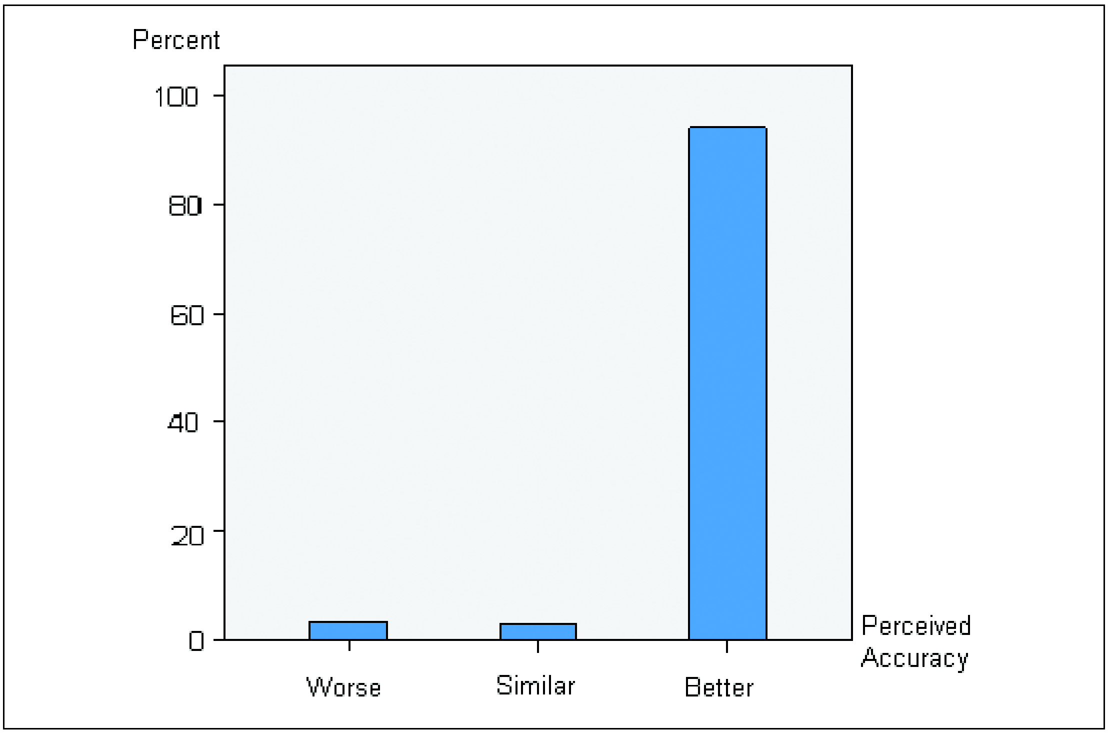
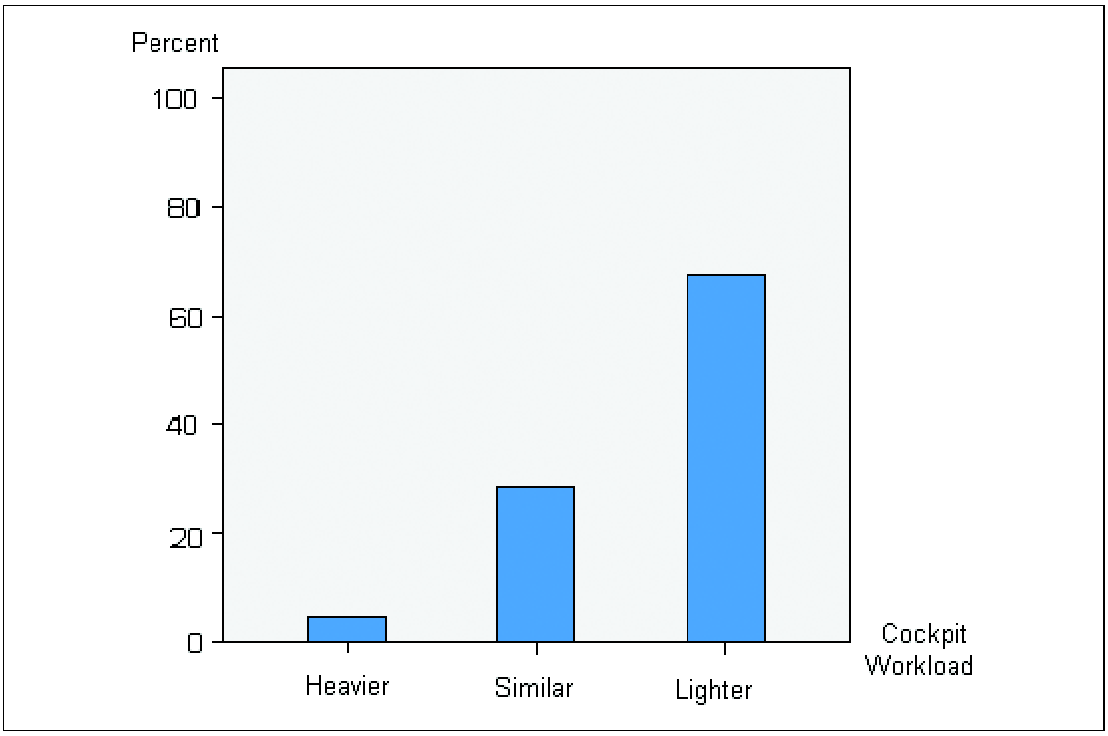


Figure 4.16 Cockpit Workload



The result for perception of cockpit workload, although less positive than the other measures, was still conclusively in favour of RNAV (GNSS). The proportion of pilot opinions are shown in Figure 4.15 with a computed weighted average of 0·57.

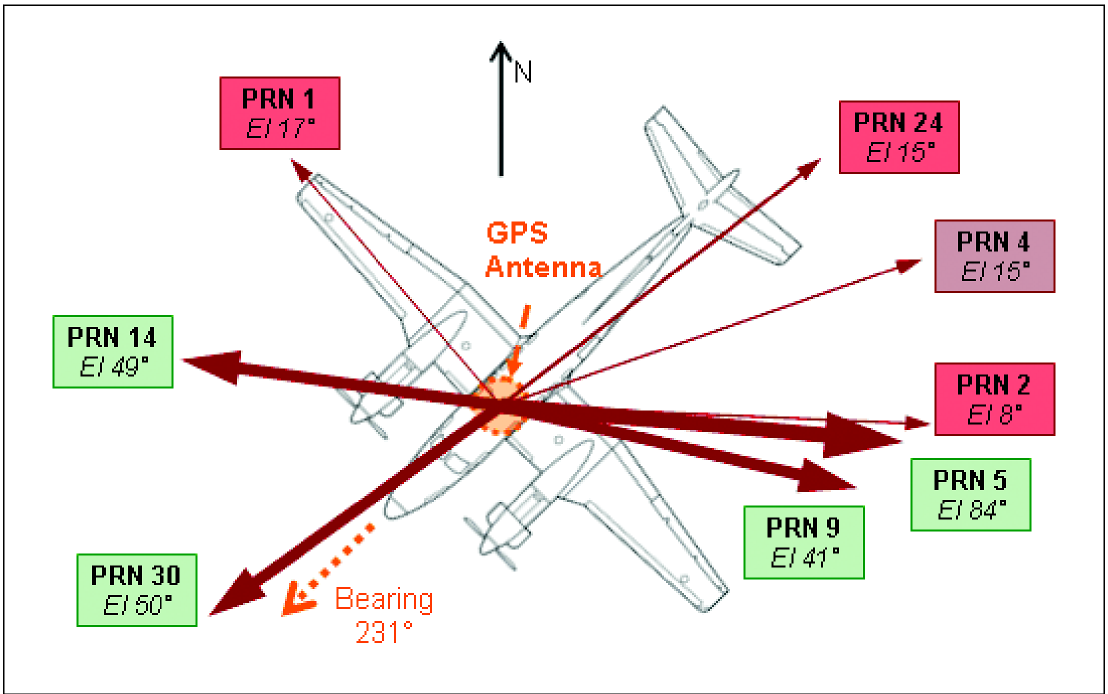
No statistically significant correlations were found to suggest that any particular factor was the cause of the negative responses. In summary, pilot opinion of RNAV (GNSS) procedures was positive. Pilots found such approaches easier to fly, more accurate and less demanding than other NPA procedures such as VOR or NDB.

4.8 RAIM Alarm

The occurrence of a RAIM alarm recorded during the trials warranted further investigation. The monitoring of GPS signals at Leeds University allowed a check of space segment performance at the time of the alarm. A total of eight satellites were visible during the period of interest. No unscheduled outages were recorded. Furthermore, residuals over the period were typical and no abnormal behaviour was found.

Due to the nominal performance found in the residuals analysis, a study of the visible satellite geometry was undertaken. Using the approach chart and approach flight times, a simulation run was able to generate the satellite positions, relative geometry and relevant geometry parameters. Figure 4.17 shows the approximate geometry over the period under investigation.

Figure 4.17 Satellite Geometry during RAIM Alarm



Although eight satellites were present, the geometry had a number of weaknesses in that half of the satellites were at particularly low elevations. A combination of minor aircraft manoeuvres could have caused changes to pitch and bank angles, which could then have left satellite 1, 2, 4 or 24 at a very low elevation. Although the four satellites were above the standard 7·5 degree mask angle, the low relative elevations could have affected antenna gain considerably, which could have increased the effects of nominal range errors.

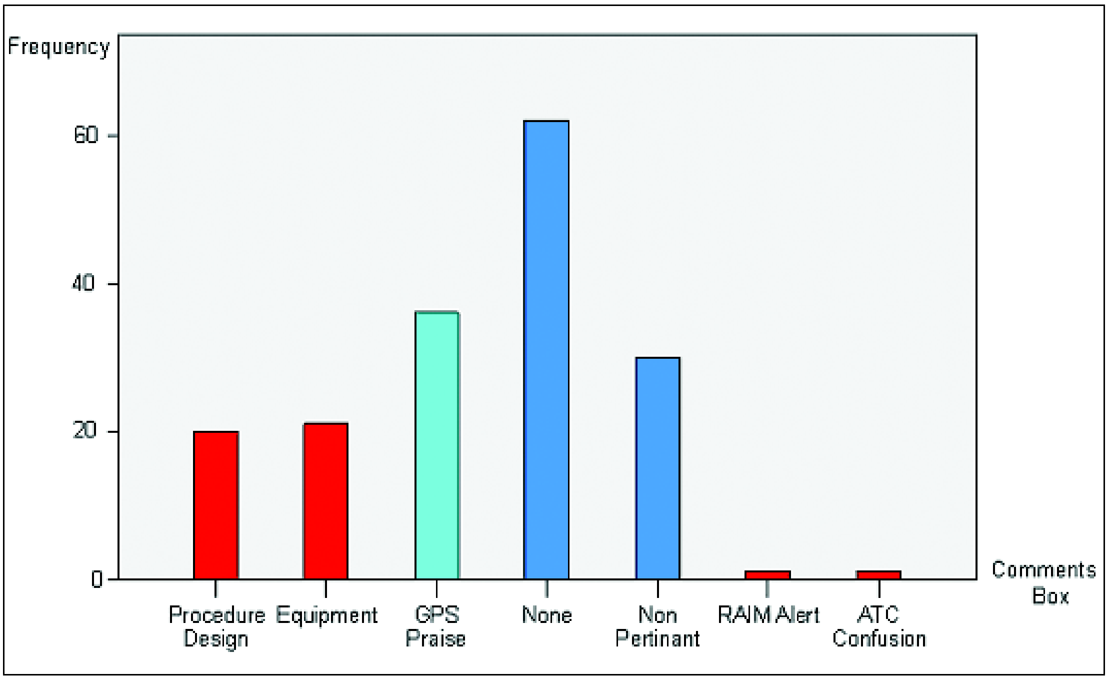
The issue of on-board aircraft interference had been highlighted by the experience of Australian GPS air operations. This knowledge, coupled with the fact that the aircraft in which the RAIM warning took place was laden with a large variety of navigation and testing equipment, including a series of antennae, led to the conclusion that on-board aircraft interference was the most likely cause for this RAIM outage.

4.9 General Pilot Observations

The unpredictable nature of human factors required a generic comments box to allow pilots to express views and issues not covered elsewhere. Consideration of these comments was undertaken over all submitted reports including those previously rejected for the more specific, quantifiable analysis.

Coding of the text variables generated a wide range of responses. The results are displayed in Figure 4.18. The comments referring to ATC confusion and the RAIM alarm have been considered in previous sections (see 4.3.2 and 4.8 respectively).

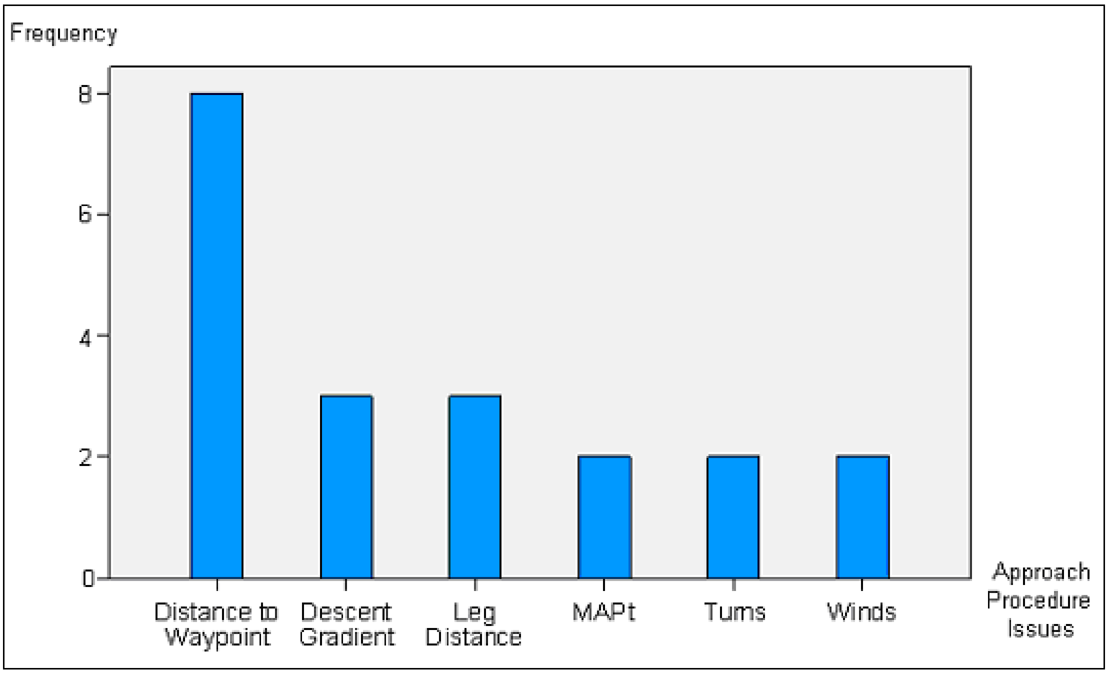
Figure 4.18 General Comments Box Responses



The vast majority of comments were either unimportant and flagged as non-pertinent or had special praise for the accuracy, safety or ease of use of RNAV (GNSS) approaches. These comments are clearly shown in blue within Figure 4.18. Other issues included approach procedure design and familiarisation with equipment and these are depicted in red.

An assessment of approach procedure design issues was a key goal of the trials. It was necessary to analyse in greater detail the confusion pilots experienced regarding descent gradients and distance to waypoints, particularly following the conclusions of the ATSB report (2006). The comments referring to approach procedure design issues were further coded into more specific groups, which are depicted in Figure 4.19. Confusion regarding the distance to next waypoint read-out on GPS units was by far the most prominent response. Furthermore, although not intrinsically stated, trouble with descent gradients was the major symptom of distance to waypoint difficulties and there was certainly an argument to suggest that these two issues were strongly related.

Figure 4.19 Comments referring to Approach Procedure Design



The pilots who made reference to the distance to waypoint issue in the final text box could be considered to have felt most strongly about the issue. However, this issue could have influenced a number of other questions, mostly within the 'fly the approach' section of the questionnaire. Two flag variables were created to collate the comments referring to distance read-out as well as one for vertical profile and descent gradient problems. These variables collated responses to any question regarding these two prominent issues. The results are presented in Section 4.3.3.

The three comments referring to leg distance suggested changes to specific approach leg lengths.

In conclusion, responses from "the comments box question" confirmed the two most significant issues raised in the previous analysis sections, namely equipment familiarity and distance to waypoint/descent gradient confusion. The consequences of these issues and other results are discussed in the context of the goals of the project in Section 5.

4.10 GPS Signal-in-Space (SIS) Performance

A total of 162 validated reports were filed by pilots, of which 146 related to completed approaches. The 16 remaining approaches were broken off due to standard requests from ATC as a result of high traffic levels at the time and did not reflect a lack of GPS system continuity. The one RAIM alarm was found to have been a local problem, most likely due to on-board interference caused by a multitude of navigation and communications equipment specific to the test aircraft. No monitoring stations at the time detected any SIS errors.

The monitoring of the GPS standard positioning service (SPS), carried out by Leeds University, could be used to estimate signal performance. Although the monitoring outputs were not able to directly measure the SIS performance experienced by aircraft that flew trial approaches, a number of the parameters could be used to estimate SIS performance. The SPS availability is a measure of the operational status of the constellation, defined in terms of coverage, which requires at least four satellites to be visible, each with a Position Dilution of Precision (PDOP) less than six. This parameter remained at 100% for the length of the trials.

Predictable horizontal accuracy values, which are approximations of the true accuracy, remained less than 12·0m for the length of the trials. Although this accuracy was with respect to the local receiver environments at Leeds and Herstmonceux, many of the errors, which may detriment performance, are correlated over UK airspace. The SPS requirements for both horizontal (<300m) and vertical (<500m) predictable accuracy were easily met. Although care must be taken in translating the predictable accuracy determined by the monitoring to the SIS accuracy for an individual aircraft or even an average across the trials, it was possible to state that the SPS performance suggested that no significant degradation in accuracy should have occurred. The remaining SIS parameters of integrity, continuity and availability relate more closely to flight operations and it was therefore not possible to make conclusions regarding them from the monitoring outputs. It could be concluded, however, that no evidence was present in the monitoring data to suggest SIS performance was degraded.

The evidence from the trials, external monitoring stations and the Leeds University monitoring output suggested the SIS performance to have been 100%.

5 Conclusions

5.1 Training

Determination of the success of current training procedures was a key goal of the project. Pilots in general found the **training** (79·0% of reports) **to be adequate** for RNAV (GNSS) procedures. This was in agreement with the findings of the ATSB report (2006) where 86·0% of pilots found training to be adequate.

An improvement was observed between the initial reports filed by pilots and further reports with regard to their views of training. This observation complemented the suggested improvement to training made by pilots of flying a single RNAV trial approach. There were in fact a number of comments across the board in reference to flight procedures and equipment use that suggested any confusion or problems pilots had were simply a 'first usage' issue. Although there was little evidence to suggest a minimum level of flying experience was applicable to all pilots, the problems encountered by pilots completing multiple trials suggested a **small number of approaches (three to five)** would be sufficient to uncover the majority of problems. This recommendation agreed with previous studies (Casner, 2004).

There were a variety of suggestions regarding improvements to the guidance material provided by the CAA. The general consensus was that current guidance was too regulatory and **not practical enough**. One pilot commented that he was unaware of any guidance material available, which may question whether he followed the trial procedures correctly, but it did highlight the issue of accessibility of such documents. A pilot checklist was specifically proposed to help ensure pilots make the necessary pre-flight preparations. Confusion over terminology was cited as a problem and a guide to terminology would be beneficial to some pilots. The most common suggestion to address the problem of overly regulatory documents was to produce a much more **practical version of the pilots guide**. The complication here lies in the non-standardised design of the receiver-user interface for GPS equipment, as was highlighted in the Williams (1998) report. It may be the case that pilots do not have access to receiver manuals or that with use of a new aircraft and hence new equipment, the menu structure can cause confusion.

More than half of pilots who reported inadequate training (13·0% of all reports) advocated some kind of **formal training course**. This was suggested as a course run by the CAA, external training organisations or receiver manufacturers. The materials currently provided by manufacturers are extensive and it is once again possibly a lack of accessibility or indeed over-confidence, which means pilots are left confused with equipment during a procedure.

5.2 Approach Preparation

The results presented in Section 4.2.1 showed that a large proportion of **pilots were confused by the installation status** of the receivers used for the trials. It was likely, in the case of flying club aircraft, that pilots felt the approval of the receiver installation was not their responsibility, or they did not fully study the pilot guide provided or were confused by the varying certification levels.

Some 88·4% of the trials and 85·8% of pilots had valid aeronautical databases in their receivers. There appeared to be no specific external causes for those pilots that used out-of-date databases.

Pilots made the necessary **RAIM availability checks** prior to flight in the **majority** (92·0%) of the trial approaches. Of the approaches undertaken, 74·7% used the receiver based functions. The alternative methods for checking RAIM availability such as web-based software or receiver simulators were primarily employed by pilots with previous RNAV experience.

Improvement in pilot behaviour for approach preparation is an educational issue and could be improved by greater accessibility, practicality and clarity of the regulations and guidance material available. Confusion regarding equipment installation approval status should be addressed and provision of a practical checklist would help to ensure pilots make the necessary checks.

5.3 Approach Procedure

Some pilots had significant difficulties **operating and programming their equipment**. The most serious issue was loading and activation of the approach. A small number of pilots encountered problems **resetting the approach following a missed approach**. Although not categorically quoted by pilots in the UK trials, it was stated in the ATSB report (2006) that this significantly increases 'head down' time at a critical stage. This increase in cockpit workload represents a safety issue. The most common problem pilots encountered with the equipment was setting of the CDI. The inactivation of auto-rescaling was experienced by pilots due to incorrectly loaded approaches, manual deactivation or failure to set the CDI to the GPS unit. Regulation with regard to receiver design is a difficult issue. As alluded to in Section 1.3, a lack of standardisation and complex functionality can contribute to pilot confusion. Improvements have been made since this problem was first identified. Modern receivers certified to TSO-C145/6B standards provide much improved functionality and greater ease of use. The receivers currently installed in UK GA aircraft are in general not TSO-C145/6B compliant but still possess some of the usability improvements, for example, full colour displays.

The most safety relevant issue was found to be confusion over range to the runway or missed approach point. Traditional navigation aids provide this information and therefore using the altitude allows a simple calculation in order to follow the correct descent profile. The GPS receiver read-out differs in that it **provides distance information to the next waypoint**. This complicates the calculation with reference to the vertical descent profile. This issue was also one of the major findings of the ATSB report (2006). This problem is amplified in Garmin receivers by the programming of step-down fixes as waypoints within the database, further exacerbating the complex calculations pilots must perform in order to position the aircraft on the correct glide path. This issue increases pilot workload as well as reducing spatial awareness. Although no relationship was observed between this issue and aerodrome, it was clear that the steeper descent gradients such as was the case at Shoreham would exacerbate the safety risk from aircraft incorrectly positioned on the glide path.

Section 4.5 analysed the issues raised in charting of the RNAV (GNSS) approaches. **No generic problems with charting were found**. Each publication type appeared to have its advantages and disadvantages and thus supporters and opponents. The specific issues, which are given in detail in Section 4.5, present individual **safety risks**. Error free approach charts should be a prerequisite for approval of RNAV (GNSS) approaches.

There were **no traffic separation or sequencing issues** that were directly related to RNAV (GNSS). However, mixing of IFR and VFR traffic was deemed to be a significant safety issue by one pilot. Phraseology was considered suitable both by ATC and pilots.

The main conclusion of the trials was that pilots found **RNAV (GNSS) approaches simple, easy and accurate**. Pilot opinion expressed RNAV (GNSS) procedures to be **considerably more accurate** than alternative NPA procedures. Pilot experience with regard to receiver ease of use and cockpit workload were less emphatic but still greatly in favour of GNSS over traditional navigation aids. Course deviations presented in Section 4.3.1 were minor and the majority were explained through breaking off the approach and training approaches. Deviations above or below the glide path were far more common than lateral positioning errors. This was in agreement with the conclusions of Section 4.3.3 and Section 4.9. The final comments box at the end of the questionnaire provided an opportunity for pilots to express their experience and opinions. A **fifth of all questionnaires had special praise for GPS** and the RNAV (GNSS) approach procedures. **GPS SIS performance** was found to be **100%**. This follows the conclusion that the single RAIM alarm encountered in the trials was most probably due to a local effect on the aircraft, with the most likely cause being on-board interference. Furthermore, monitoring of SPS performance by Leeds University found predictable accuracy to be well within the performance standards, presenting no evidence to the contrary.

5.4 Future Applications

The most obvious extension to RNAV (GNSS) approaches from the trials would be to flight in IMC. Pilots were questioned on whether they would feel comfortable with performing an RNAV (GNSS) procedure in IMC. Over 90% felt the extension to IMC to be entirely reasonable. Almost all the reasons to the contrary were simply a matter of further practice being required.

A further option for the extension of RNAV (GNSS) approaches could be to aerodromes without an instrument runway or aerodromes without a full ATC service. The issue raised in Section 4.3.2, which relayed one pilot’s concern of the interaction between IFR and VFR traffic would be relevant here. The trials presented little evidence to suggest the use of RNAV (GNSS) at aerodromes without a full ATC service would be unsafe. However, the large number of uncompleted approaches due to ATC requests for holding suggested that the combination of IFR and VFR traffic would require ATC assistance when traffic was high. The trials did not present enough evidence to provide a simple answer to this question and it must be taken into consideration with a number of other factors.

6 References

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Appendix A Pilot Questionnaire

GPS FLIGHT TRIALS QUESTIONNAIRE

Please print out this questionnaire prior to your flight. As there are 26 questions it is a good idea to have these at hand so you will remember what observations are required.

SURNAME	INITIALS *May not be required*	PILOT'S TRIAL REF NUMBER	AIRCRAFT REG.	
AIRCRAFT TYPE	GPS RECEIVER MAKE & TYPE		INSTALLATION APPROVED FOR NPA IN FLIGHT MANUAL / POH Y / N	
AERONAUTICAL / NAVIGATION DATABASE EXPIRY DATE	OBSERVER'S QUALIFICATIONS: IFR PROFESSIONAL PILOT; IFR PRIVATE PILOT; NON IFR PRIVATE PILOT; OTHER			
AERODROME	DATE		APPROACH START TIME	APPROACH END TIME

SECTION 1 – FLIGHT DATA

1 **As you pass the IAF as indicated on the GPS, record the range and bearing information from any other radio navigation aid you used for position crosscheck.** (Or answer Nil)

Radio Aid Name or Identifier ____________________

Range __________nm Bearing __________ °

2 **Please complete the following table from the data collected during the flight.** (include N/A box)

At 3 nm distance indication on GPS:

State Aircraft Altitude or Height – specify QNH / QFE

Eg 1200' QFE

Tick the box that most closely resembles CDI / HSI Indication at 3 miles:

> 2.5 dots L	2.5 dots L	1-2 dots L	< 1 dot L/R	1-2 dots R	2.5 dots R	>2.5 dots R

On reaching MDA:

Distance indication on GPS

Eg 1.4 nm

Tick the box that most closely resembles CDI / HSI Indication at MDA(H):

> 2.5 dots L	2.5 dots L	1-2 dots L	< 1 dot L/R	1-2 dots R	2.5 dots R	>2.5 dots R

At the Missed Approach Point (MAPt):

Tick the box that most closely resembles CDI / HSI Indication at MAPt:

> 2.5 dots L	2.5 dots L	1-2 dots L	< 1 dot L/R	1-2 dots R	2.5 dots R	>2.5 dots R

Record any messages or warnings received from the GPS during the approach. *This box need only appear on the printed version. The printed version of this PAGE can then be used to record things that may be forgotten between flight and reporting.*

SECTION 2 – EASE OF RECEIVER PROGRAMMING

3 **Did you check on a RAIM prediction for your expected approach time (EAT)?** (Y/N)

Yes: Receiver based.
Yes: Web based.
Yes: Other
If 'OTHER': Please explain how you confirmed RAIM availability.

3a **Approximately how many hours before takeoff did you check on the RAIM prediction?**
("NoRAIM Prediction" or two figures text box (eg 24 hours))

4 **Did you add the approach to a pre-programmed route as part of a GPS flight plan?**
(Y/N)

5 **Did you encounter any difficulty in selecting, loading and activating the approach from your receiver database?** (Y/N / N/A)
If Yes: Please describe any difficulties you had.

6 **Did the receiver activate the approach and sequence the legs correctly throughout the procedure?** (Y/N / N/A)

7 **Did you encounter any difficulty in setting the instrument display (HSI/CDI) correctly for the approach?** (Y/N / N/A)
If Yes: Please describe any difficulties you had.

SECTION 3 – FLYING THE APPROACH

8 *Answer only if you were vectored onto final approach by ATC instead of following the Initial Approach by GPS:* **Were you fully established on the final approach track before reaching the Final Approach Fix?** (Y/N)

9 *Answer only if you answered Q8:* **Once established on the final approach track, did your receiver activate the correct display mode (correct active leg and HSI scaling to +/- 0.3nm) before reaching the Final Approach Fix?** (Y/N/Don't Know)

10 **Did you encounter any difficulties with or interruptions from ATC?** (Y/N)
If Yes: Please explain the difficulties you had.

11 **Were ATC instructions and phraseology for the approach itself, clear and concise?** (Y/N/NA)
If No: Please explain the confusion.

12 **Did other traffic, in the area at the time, have any significant effect on your approach?** (Y/N/NA)
If Yes: Please explain the effects from other traffic.

13 **Whilst flying the approach, did you experience any difficulty with spatial orientation, particularly when transitioning from one leg of the procedure to the next?** (Y/N/NA)
If Yes: Please describe any difficulties you had.

14 **Did you encounter any difficulty in setting or following the instrument indications in the cockpit, (for example during turns or HSI/CDI scale changes)?**
(Y/N/NA)
If Yes: Please describe any difficulties you had.

15 **Did you have any difficulty in decelerating and descending to follow the vertical profile of the approach?** (Y/N/NA)

If Yes: Please describe any difficulties you had – with any reasons you think may be relevant.

16 **Did you observe any messages or warnings from your equipment during the approach?** (Y/N/NA)
If Yes: Using any notes you made, please detail the warnings and or messages, together with any consequent actions you took.

17 **Did you complete the approach to minima by reference to GPS and without breaking off the approach or resorting to other means of navigation?** (Y/N)
If No: Please explain why you had to discontinue the GPS approach.

18 **Did the approach system guide the aircraft accurately to a position from which a safe landing was possible?** (Y/N)
No: Aircraft too far off the runway centreline
No: Aircraft above / below a safe glidepath
No: both A & B
None of the above – Please explain why it was unsafe to continue to land.

19 **Did you encounter** any **difficulty in flying the MAP itself or in re-programming the GPS system?** (Y / N / Did not fly GPS MAP)
If Yes: Please describe any difficulty you had.

SECTION 4 – CONCLCUSIONS

20 **Which chart publication did you use?**
UK AIP
JEPPESEN
AERAD
OTHER *(mark 1 only)*

21 **In your opinion are there any deficiencies in the chart presentation?** (Y/N)
If Yes: How might the chart be improved?

22 **In your opinion, is the information available for training in the flying of GPS approaches adequate?** (Y/N)
If No: Please highlight the areas where you think the available information could be improved.

23 **How did your experience of flying the approach compare with your expectations?** (NA)
Flying the approach was:
A – Easier than expected
B – As expected
C – More difficult than expected.
If More Difficult: Please explain the difficulties you met.

24 **In terms of ease of operation, accuracy and workload, how would you compare flying this approach with that of flying other Non Precision Approaches such as VOR and NDB?** (NA)

Please Tick one box in each column

Ease of operation		Accuracy		Cockpit Workload	
Easier		Better		Lighter	
Similar		Similar		Similar	
More complicated		Worse		Heavier	

Please try to give reasons for your answers to this question (in a text box)

25 **Would you feel confident in flying this approach all the way to minima and throughout the Missed Approach Procedure <u>in IMC</u>?** (Y/N/NA)
If No: Please explain your reservations.

26 **Finally, please add any comments you think may be useful in the analysis of this trial. If you were unable to commence or complete your intended approach, please add any other reasons or comments here.** (big/expanding Textbox – say max 150 words.)

Submit Report button

Thank you for taking the time to complete this report.

Please continue to fly approaches for the trial – the aerodromes where trial approaches are available are Blackpool, Durham Tees Valley, Exeter, Gloucester, Inverness and Shoreham. However, before visiting any new aerodrome where you intend to fly the approach, please remember to re-visit the Trial Website (add web-link here) for the Approach Briefing at that aerodrome.

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Appendix B High-Level Trial Approach Questions

The following high-level mapping was designed to ensure that the trials' pilot questionnaire captures the required criteria for satisfactory analysis of the trials. This questionnaire also provided a foundation for the analysis and formulation of this report.

1. Are pilots satisfied with the level of information available for training in GPS approaches?
2. Could the guidance material from the CAA, on flying GPS approaches, be improved?
3. Is it satisfactory to continue without any mandatory training or qualification requirements to fly GPS approaches?
4. Do the results and comments indicate a minimum level of flying experience required?
5. Are pilots and operators aware of the approval requirements of their equipment installation?
6. Are pilots using non-approved GPS equipment?
7. Are pilots using the correct / up-to-date software and current AIP Data?
8. Are pilots making the necessary preparations and crosschecks before flying GPS approaches?
9. Has the trial identified any deficiencies in the GPS signal-in-space for NPA?
10. Are pilots reporting difficulty in learning to operate and programme the equipment for NPA? If so, what are these difficulties?
11. Are there any safety issues associated with the difficulties revealed by Q10?
12. What are the safety issues (if any) with the fly-ability of the approaches?
13. Has the trial identified any deficiencies in the charting of RNAV (GNSS) approaches?
14. Are there any traffic sequencing or separation issues?
15. Is the RTF phraseology suitable?
16. Should the system minima of 350 ft be reconsidered?
17. Is it safe to permit these approaches at aerodromes without an instrument runway?
18. Is it safe to permit these approaches at aerodromes with AGCS or AFIS only?
19. Is it safe to transition to approval of these approaches in IMC?

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Appendix C ATC Log

UNIT	AERODROME ID						
Date	Time	Callsign	Pilot's Trial Ref No:	VFR/IFR	Sequencing Problems? **Y / N**: if Yes please state	Phraseology Appropriate? **Y / N**: if No please state	Other Comments / Observations
21/11	1015	G****	????	V	N	Y	-
23/11	1115	G****	????	I	N	Y	-
26/11	1437	G****	????	I	N	Y	-

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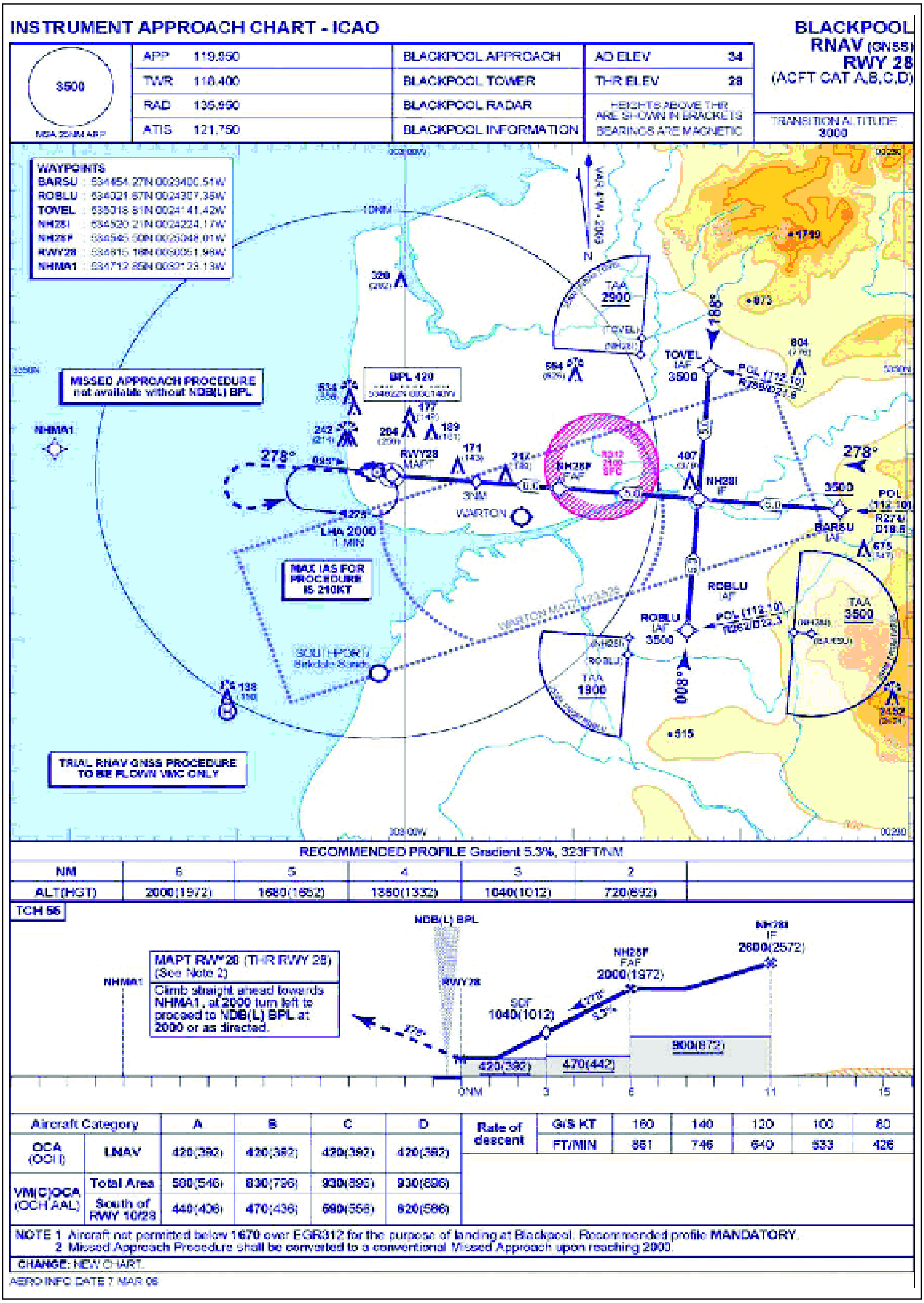
Appendix D PERL Data Formatting Script

```
print "Questionnaire Converter\n\n";
$infile = "this.txt";
open(F, $infile) || die "Can't open - $!\n";
@lines = <F>;
print "input filename:  ";
print $infile;
print "\n";
#print "\ncontent is: ";
#print "@lines\n";
close(F);

#my $search=";";   my $replace=",";

$outfile = "out171.txt";
print "output filename: ";
print $outfile;
print "\n";

open(OUTPUT1, ">$outfile");

@f[1] = ": yes";     @r[1] = ": 1";
@f[2] = ": no";     @r[2] = ": 0";
@f[3] = ": na";     @r[3] = ": -1";
@f[4] = ": 1_dot";  @r[4] = ": 0";
@f[5] = ": 12R_dots";  @r[5] = ": 1.5";
@f[6] = ": 12L_dots";  @r[6] = ": -1.5";
@f[7] = ": 25R_dots";  @r[7] = ": 3.5";
@f[8] = ": 25L_dots";  @r[8] = ": -3.5";
@f[9] = ": G25R_dots";  @r[9] = ": 5.5";
@f[10] = ": G25L_dots";  @r[10] = ": -5.5";
@f[11] = ": easier";  @r[11] = ": +10";
@f[12] = ": as_expected";  @r[12] = ": 0";
@f[13] = ": more_difficult";  @r[13] = ": -10";
@f[14] = ": harder";  @r[14] = ": -10";
@f[15] = ": similar";  @r[15] = ": 0";
@f[16] = ": better";  @r[16] = ": +10";
@f[17] = ": worse";  @r[17] = ": -10";
@f[18] = ": lighter";  @r[18] = ": +10";
@f[19] = ": lighter";  @r[19] = ": -10";
@f[20] = ";";  @r[20] = ",";
@f[21] = "^aerodrome";  @r[21] = ";aerodrome";
@f[22] = "\n";  @r[22] = ";";
@f[23] = "##############################################;";  @r[23] = "\n";
@f[24] = ";\n";  @r[24] = "\n";
@f[25]="^[A-Za-z0-9_]+:"; @r[25]="";
@f[26] = "aerodrome: ";  @r[26] = "";
@f[27] = "^ ";  @r[27] = "";

$length = @f;
$j = 0;
foreach $currentLine (@lines)
{
    if ($currentLine =~ /creation_date:/)
    {
```

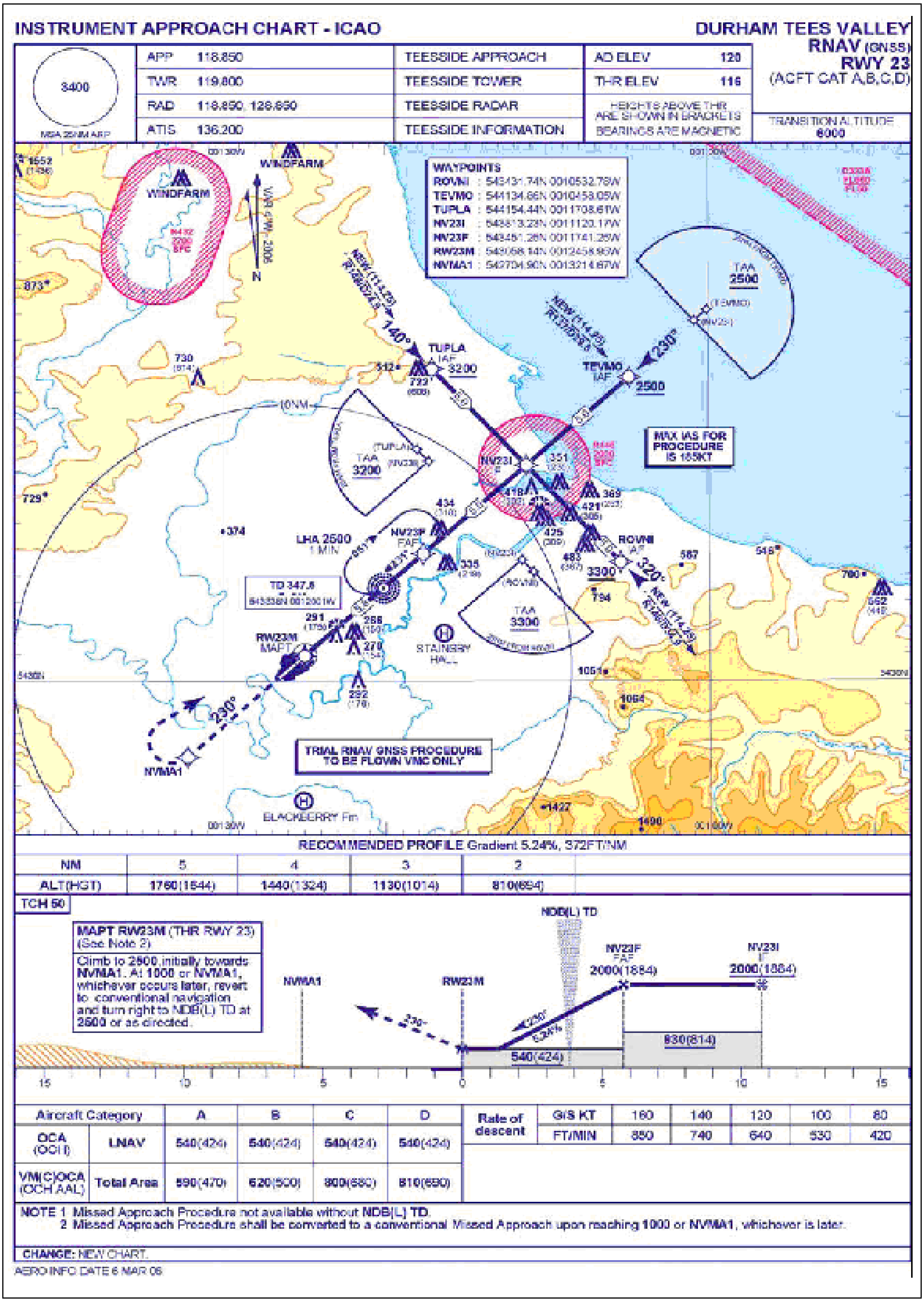
```
        @inputTime = split(" ", $currentLine);
        $currentLine = " ".@inputTime[1]."\n".@inputTime[2]."\n";
        #print $currentLine."\n";
    }
    for (my $i=0; $i < $length; $i++)
    {
        $currentLine =~ s/@f[$i]/@r[$i]/g;
    }

    if ($j ne 0) {print OUTPUT1 $currentLine;}
    $j++;
}

close(OUTPUT1);
print "conversion done, please see ",$outfile;
```

Appendix E Sample RNAV (GNSS) Approach Charts

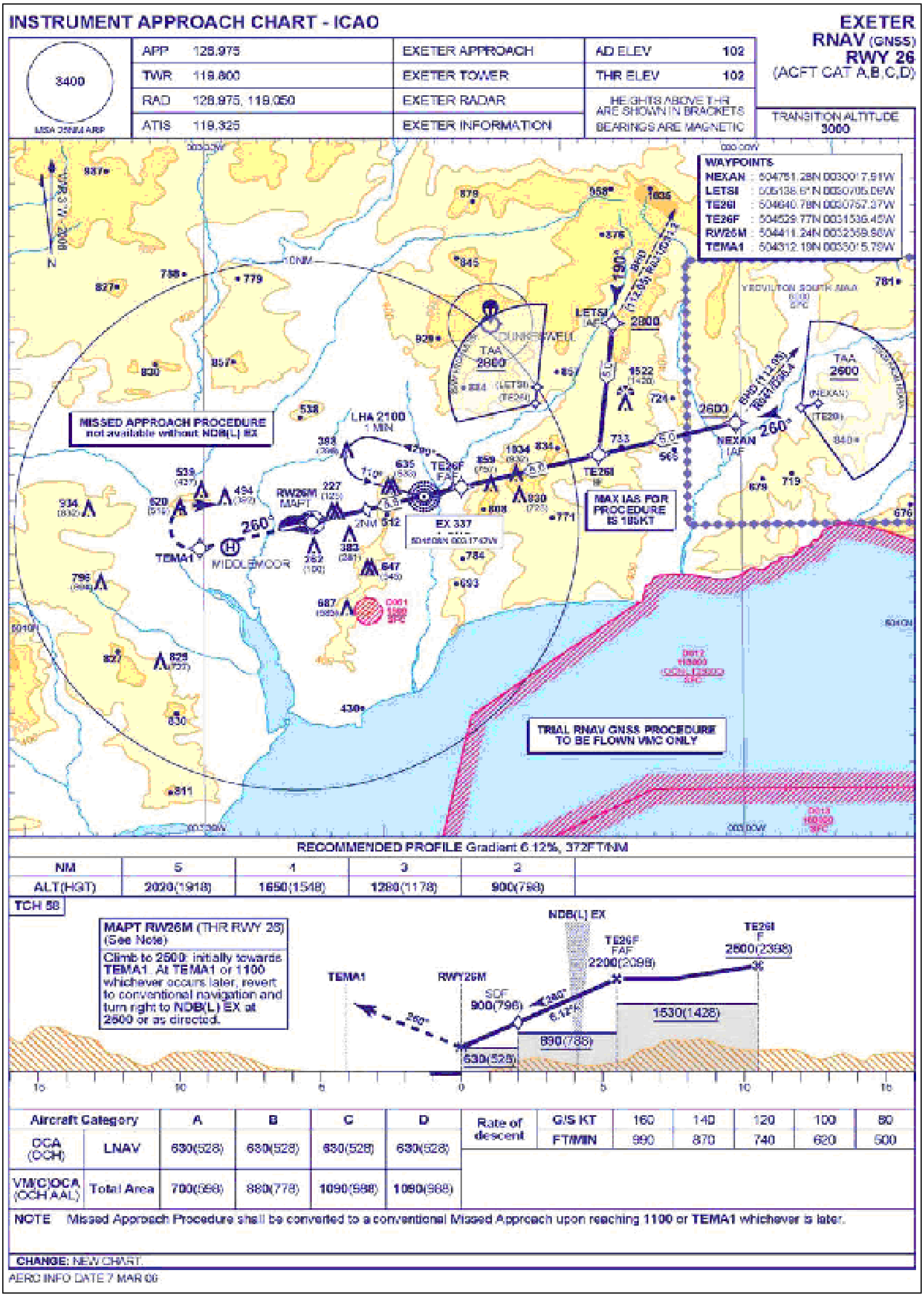
Blackpool



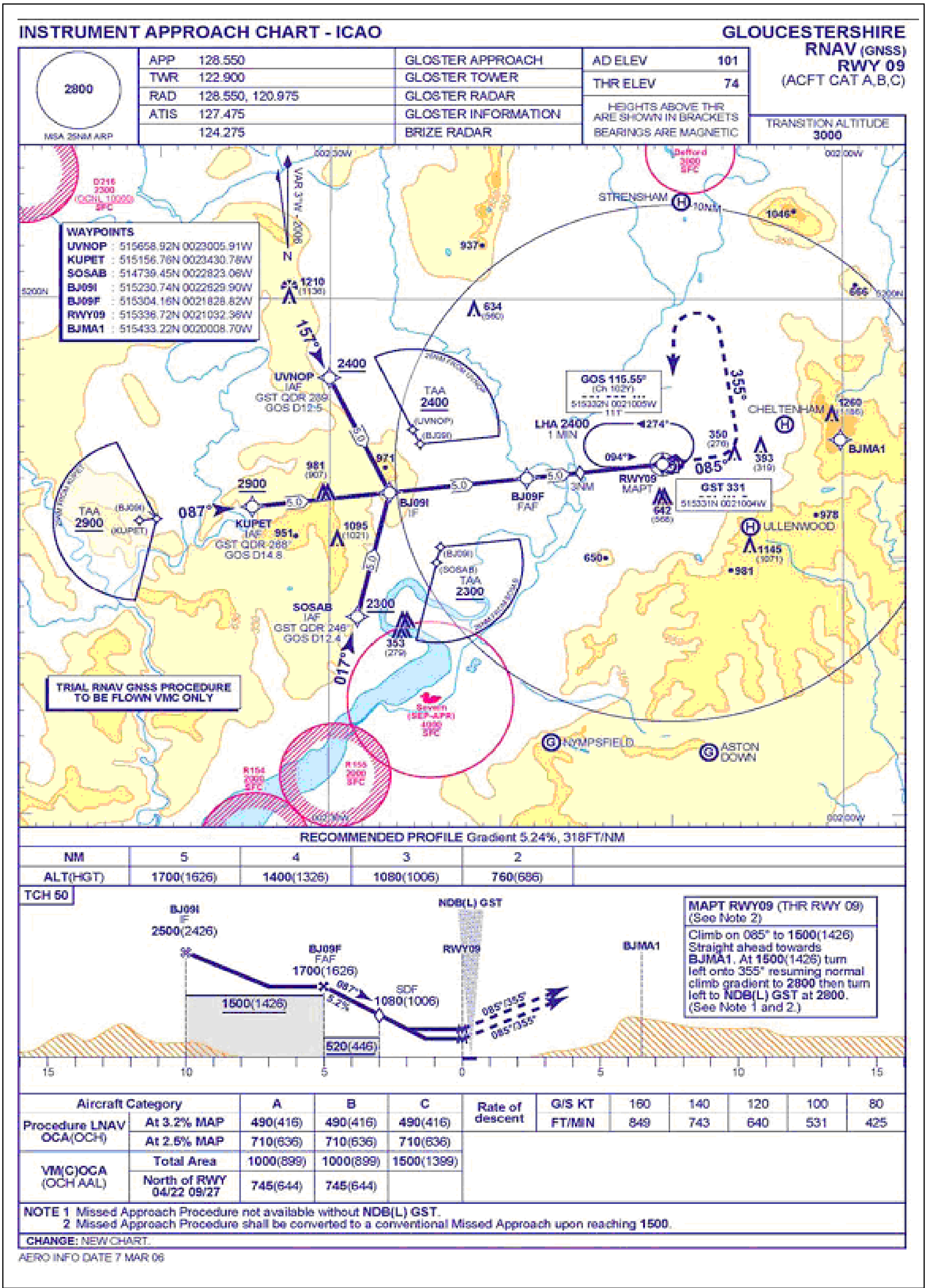
Durham Tees Valley



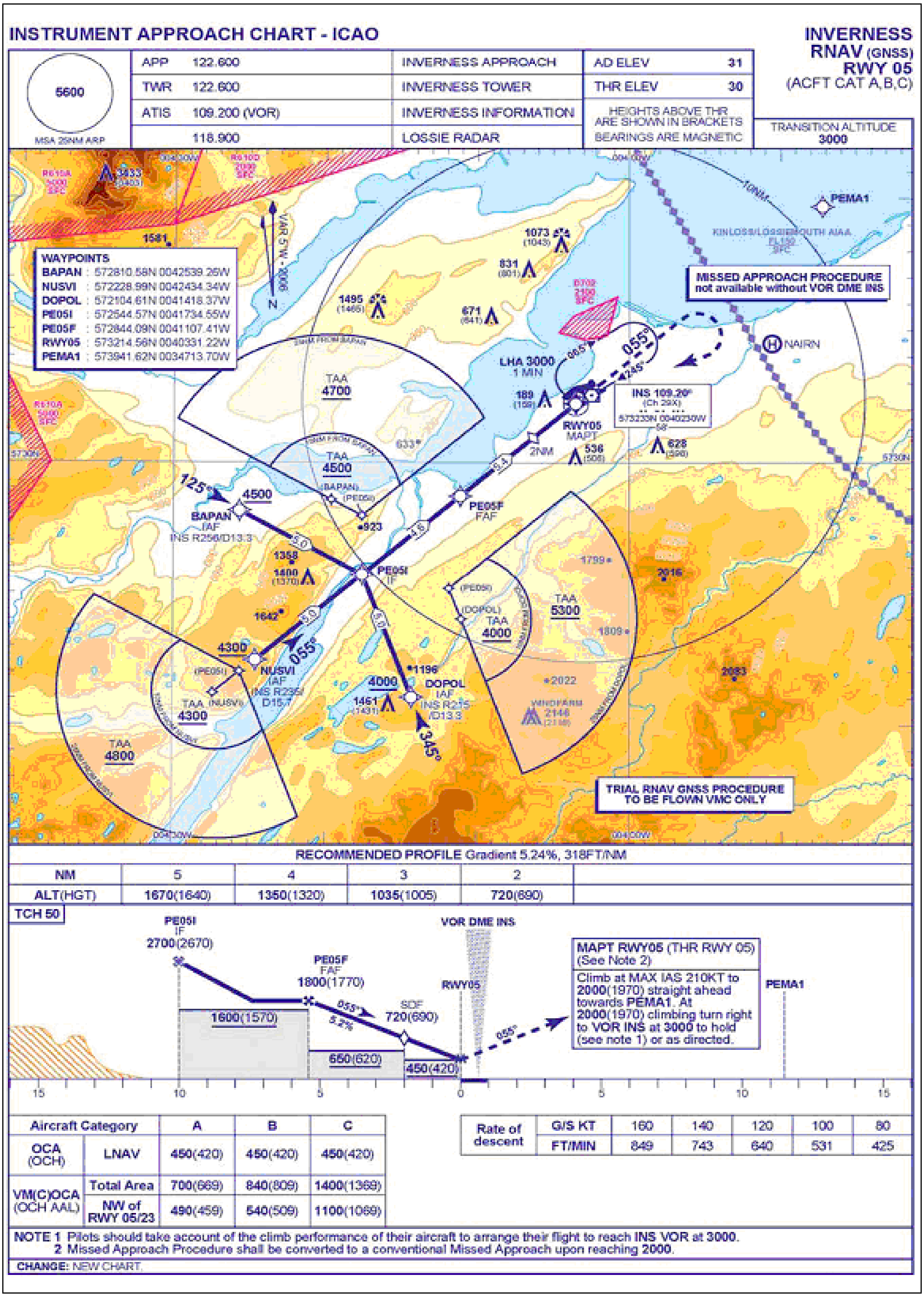
Exeter


INSTRUMENT APPROACH CHART - ICAO
EXETER
RNAV (GNSS)
RWY 26
(ACFT CAT A,B,C,D)
APP 128.975 EXETER APPROACH
TWR 119.800 EXETER TOWER
RAD 128.975, 119.050 EXETER RADAR
ATIS 119.325 EXETER INFORMATION
AD ELEV 102
THR ELEV 102
HEIGHTS ABOVE THR ARE SHOWN IN BRACKETS
BEARINGS ARE MAGNETIC
TRANSITION ALTITUDE 3000
3400
MISSED APPROACH PROCEDURE not available without NDB(L) EX
MAX IAS FOR PROCEDURE IS 185KT
TRIAL RNAV GNSS PROCEDURE TO BE FLOWN VMC ONLY
RECOMMENDED PROFILE Gradient 6.12%, 372FT/NM
NM 5 4 3 2
ALT(HGT) 2020(1918) 1650(1548) 1280(1178) 900(798)
TCH 58
MAPT RW26M (THR RWY 26) (See Note)
Climb to 2500: initially towards TEMA1. At TEMA1 or 1100 whichever occurs later, revert to conventional navigation and turn right to NDB(L) EX at 2500 or as directed.
Aircraft Category A B C D
OCA (OCH) LNAV 630(528) 630(528) 630(528) 630(528)
VM(C)OCA (OCH AAL) Total Area 700(598) 880(778) 1090(988) 1090(988)
Rate of descent G/S KT 160 140 120 100 80
FT/MIN 990 870 740 620 500
NOTE Missed Approach Procedure shall be converted to a conventional Missed Approach upon reaching 1100 or TEMA1 whichever is later.
CHANGE: NEW CHART.
AERO INFO DATE 7 MAR 06

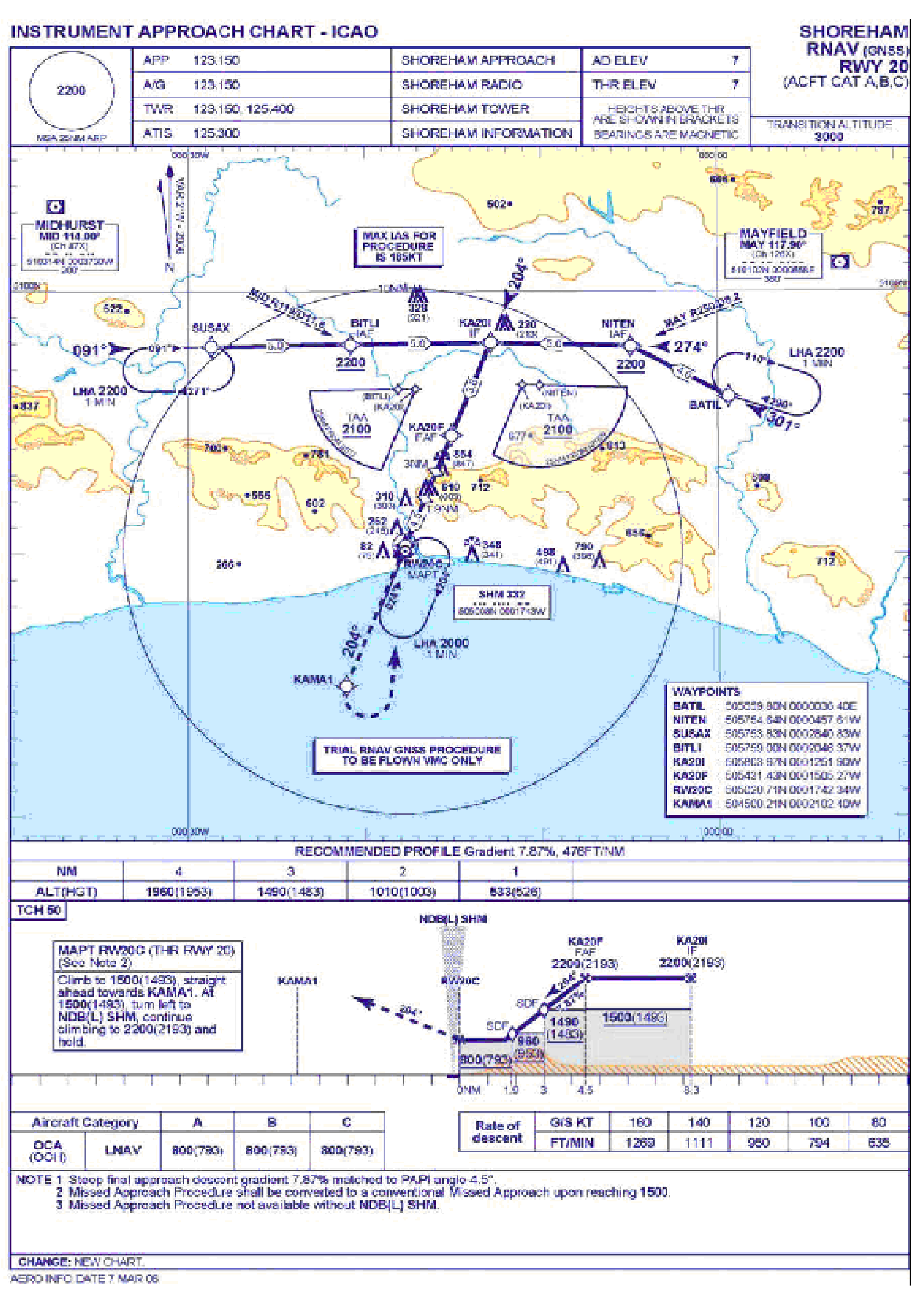
Gloucestershire



Inverness


INSTRUMENT APPROACH CHART - ICAO
INVERNESS
RNAV (GNSS)
RWY 05
(ACFT CAT A,B,C)
5600
MSA 25NM ARP
APP 122.600 INVERNESS APPROACH
TWR 122.600 INVERNESS TOWER
ATIS 109.200 (VOR) INVERNESS INFORMATION
118.900 LOSSIE RADAR
AD ELEV 31
THR ELEV 30
HEIGHTS ABOVE THR ARE SHOWN IN BRACKETS
BEARINGS ARE MAGNETIC
TRANSITION ALTITUDE 3000
WAYPOINTS
BAPAN : 572810.58N 0042539.26W
NUSVI : 572228.99N 0042434.34W
DOPOL : 572104.61N 0041418.37W
PE05I : 572544.57N 0041734.55W
PE05F : 572844.09N 0041107.41W
RWY05 : 573214.56N 0040331.22W
PEMA1 : 573941.62N 0034713.70W
MISSED APPROACH PROCEDURE not available without VOR DME INS
TRIAL RNAV GNSS PROCEDURE TO BE FLOWN VMC ONLY
RECOMMENDED PROFILE Gradient 5.24%, 318FT/NM
NM | 5 | 4 | 3 | 2
ALT(HGT) | 1670(1640) | 1350(1320) | 1035(1005) | 720(690)
TCH 50
PE05I IF 2700(2670)
PE05F FAF 1800(1770)
1600(1570)
SDF 720(690)
650(620)
450(420)
VOR DME INS
RWY05
PEMA1
MAPT RWY05 (THR RWY 05) (See Note 2)
Climb at MAX IAS 210KT to 2000(1970) straight ahead towards PEMA1. At 2000(1970) climbing turn right to VOR INS at 3000 to hold (see note 1) or as directed.
Aircraft Category | A | B | C
OCA (OCH) LNAV | 450(420) | 450(420) | 450(420)
VM(C)OCA (OCH AAL) Total Area | 700(669) | 840(809) | 1400(1369)
NW of RWY 05/23 | 490(459) | 540(509) | 1100(1069)
Rate of descent G/S KT | 160 | 140 | 120 | 100 | 80
FT/MIN | 849 | 743 | 640 | 531 | 425
NOTE 1 Pilots should take account of the climb performance of their aircraft to arrange their flight to reach INS VOR at 3000.
2 Missed Approach Procedure shall be converted to a conventional Missed Approach upon reaching 2000.
CHANGE: NEW CHART.

Shoreham


INSTRUMENT APPROACH CHART - ICAO
SHOREHAM RNAV (GNSS) RWY 20 (ACFT CAT A,B,C)
2200
MSA 25NM ARP
APP 123.150 SHOREHAM APPROACH
A/G 123.150 SHOREHAM RADIO
TWR 123.150, 125.400 SHOREHAM TOWER
ATIS 125.300 SHOREHAM INFORMATION
AD ELEV 7
THR ELEV 7
HEIGHTS ABOVE THR ARE SHOWN IN BRACKETS
BEARINGS ARE MAGNETIC
TRANSITION ALTITUDE 3000
MIDHURST MID 114.00
MAYFIELD MAY 117.90
MAX IAS FOR PROCEDURE IS 185KT
SUSAX
BITLI IAF
KA20I IF
NITEN IAF
BATIL
KA20F FAF
KAMA1
LHA 2200 1 MIN
LHA 2000 1 MIN
TAA 2100
SHM 332
TRIAL RNAV GNSS PROCEDURE TO BE FLOWN VMC ONLY
WAYPOINTS
BATIL 505559.90N 0000030.40E
NITEN 505754.84N 0000457.61W
SUSAX 505753.83N 0002840.83W
BITLI 505759.00N 0002046.37W
KA20I 505803.97N 0001251.90W
KA20F 505421.43N 0001505.27W
RW20C 505020.71N 0001742.34W
KAMA1 504500.21N 0002102.40W
RECOMMENDED PROFILE Gradient 7.87%, 476FT/NM
NM 4 3 2 1
ALT(HGT) 1960(1953) 1490(1483) 1010(1003) 533(526)
TCH 50
MAPT RW20C (THR RWY 20) (See Note 2)
Climb to 1500(1493), straight ahead towards KAMA1. At 1500(1493), turn left to NDB(L) SHM, continue climbing to 2200(2193) and hold.
NDB(L) SHM
Aircraft Category A B C
OCA (OCH) LNAV 800(793) 800(793) 800(793)
Rate of descent G/S KT 160 140 120 100 80
FT/MIN 1269 1111 950 794 635
NOTE 1 Steep final approach descent gradient 7.87% matched to PAPI angle 4.5°.
2 Missed Approach Procedure shall be converted to a conventional Missed Approach upon reaching 1500.
3 Missed Approach Procedure not available without NDB(L) SHM.
CHANGE: NEW CHART.
AERO INFO DATE 7 MAR 06