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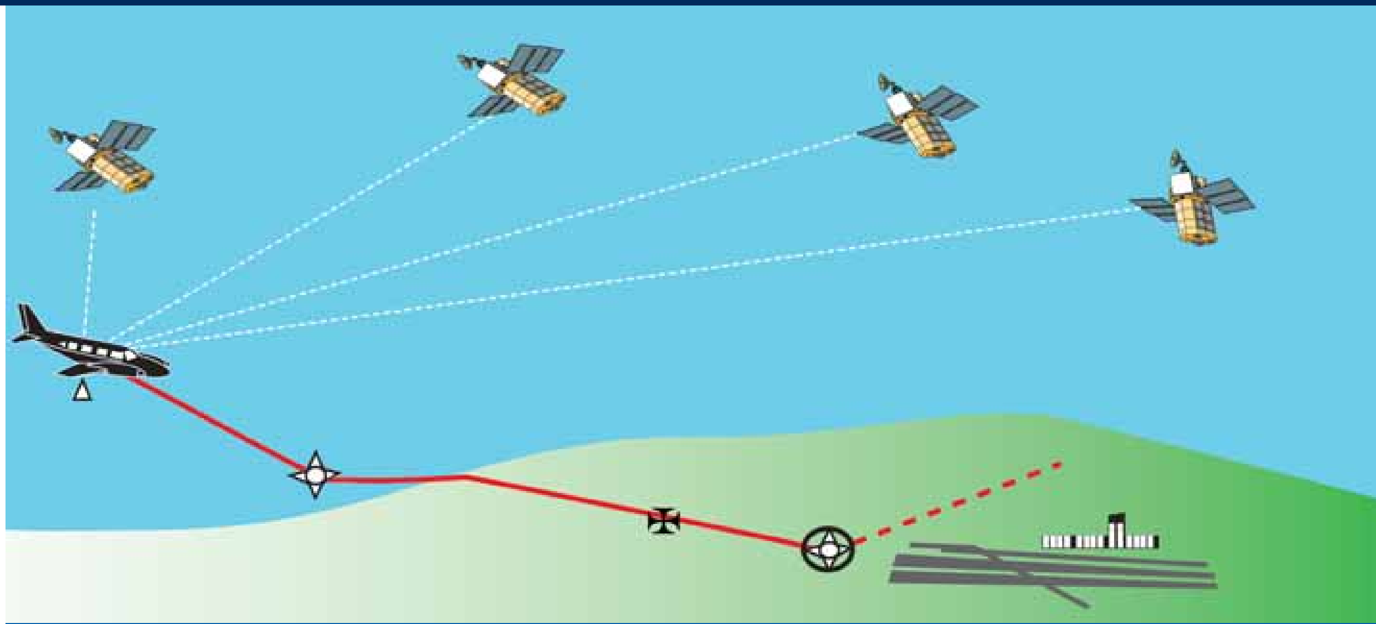

ATSB TRANSPORT SAFETY INVESTIGATION REPORT
Aviation Safety Research and Analysis Report 20050342
Final

Perceived Pilot Workload and Perceived Safety of RNAV (GNSS) Approaches

Australian Government

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Perceived Pilot Workload and Safety of RNAV (GNSS) Approaches

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Abstract

Area navigation global navigation satellite system (RNAV (GNSS)) approaches have been used in Australia since 1998 and have now become a common non-precision approach. Since their inception, however, there has been minimal research of pilot performance during normal operations outside of the high capacity airline environment. Three thousand five hundred Australian pilots with an RNAV (GNSS) endorsement were mailed a questionnaire asking them to rate their perceived workload, situational awareness, chart interpretability, and safety on a number of different approach types. Further questions asked pilots to outline the specific aspects of the RNAV (GNSS) approach that affected these assessments. Responses were received from 748 pilots, and answers were analysed based on the aircraft performance category[1]. For pilots operating Category A and Category B aircraft (predominantly single and twin-engine propeller aircraft), the RNAV (GNSS) approach resulted in the highest perceived pilot workload (mental and perceptual workload, physical workload, and time pressure), more common losses of situational awareness, and the lowest perceived safety compared with all other approaches evaluated, apart from the NDB approach. For pilots operating Category C aircraft (predominantly high capacity jet airliners), the RNAV (GNSS) approach only presented higher perceived pilot workload and less perceived safety than the precision ILS approach and visual day approach but lower workload and higher safety than the other approaches evaluated. The different aircraft category responses were likely to have been due to high capacity aircraft having advanced automation capabilities and operating mostly in controlled airspace. The concern most respondents had regarding the design of RNAV (GNSS) approaches was that they did not use references for distance to the missed approach point on the approach chart and cockpit displays. Other problems raised were short and irregular segment distances and multiple minimum segment altitude steps, that the RNAV (GNSS) approach chart was the most difficult chart to interpret, and that five letter long waypoint names differing only by the last letter can easily be misread.

1 Aircraft performance approach categories are determined by multiplying the aircraft's stall speed in the approach configuration by a factor of 1.3. See Section 3.1.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

The Australian Transport Safety Bureau (ATSB) is an operationally independent multi-modal Bureau within the Australian Government Department of Transport and Regional Services. ATSB investigations are independent of regulatory, operator or other external bodies.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to fare-paying passenger operations. Accordingly, the ATSB also conducts investigations and studies of the transport system to identify underlying factors and trends that have the potential to adversely affect safety.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and, where applicable, relevant international agreements. The object of a safety investigation is to determine the circumstances in order to prevent other similar events. The results of these determinations form the basis for safety action, including recommendations where necessary. As with equivalent overseas organisations, the ATSB has no power to implement its recommendations.

It is not the object of an investigation to determine blame or liability. However, it should be recognised that an investigation report must include factual material of sufficient weight to support the analysis and findings. That material will at times contain information reflecting on the performance of individuals and organisations, and how their actions may have contributed to the outcomes of the matter under investigation. At all times the ATSB endeavours to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why, in a fair and unbiased manner.

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. While the Bureau issues recommendations to regulatory authorities, industry, or other agencies in order to address safety issues, its preference is for organisations to make safety enhancements during the course of an investigation. The Bureau prefers to report positive safety action in its final reports rather than making formal recommendations. Recommendations may be issued in conjunction with ATSB reports or independently. A safety issue may lead to a number of similar recommendations, each issued to a different agency.

The ATSB does not have the resources to carry out a full cost-benefit analysis of each safety recommendation. The cost of a recommendation must be balanced against its benefits to safety, and transport safety involves the whole community. Such analysis is a matter for the body to which the recommendation is addressed (for example, the relevant regulatory authority in aviation, marine or rail in consultation with the industry).

CONSULTATION PROCESS

On 31 August 2006 the ATSB released this report in the form of a discussion paper, and invited interested members of the industry, public and stakeholder organisations to consider and comment on the information and findings presented.

The consultation period was 28 days. Comments were received from individuals, associations representing their constituents, and from the Civil Aviation Safety Authority (CASA) and Airservices Australia.

As a consequence of the views received, the ATSB has been able to provide some further detail on developments that promise to deliver more accurate and safer approaches through vertical guidance displays in the cockpit. Small changes have also been made throughout the paper in an effort to clarify information, or provide the most up-to-date information.

The ATSB is grateful to all those individuals and organisations that provided feedback through the consultation process. This final report supersedes the earlier discussion paper.

EXECUTIVE SUMMARY

Background

Area navigation global navigation satellite system (RNAV (GNSS)) approaches are a type of non-precision instrument approach procedure. Formally known as global satellite system non-precision approaches (GPS/NPA), RNAV (GNSS) approaches are relatively new, both in Australia and internationally, with the first approaches designed in 1996-97. By 2006, over 400 RNAV (GNSS) approaches had been published for aerodromes across the country and their use had become common among instrument-rated pilots.

Due to the relatively recent introduction of RNAV (GNSS) approaches, very little accident and incident data is available concerning them. However, the Australian Transport Safety Bureau (ATSB) has recently investigated two high profile accidents where the pilots were conducting an RNAV (GNSS) approach. These were:

- A Piper PA-31T Cheyenne aircraft, registered VH-TNP, which collided with terrain while undertaking an RNAV (GNSS) approach to Benalla Aerodrome, Victoria, on 28 July 2004. The pilot and all five passengers were fatally injured (ATSB aviation safety investigation BO/200402797 – investigation concluded).
- A Fairchild Industries SA227-DC (Metro 23) aircraft, registered VH-TFU, which collided with terrain while undertaking an RNAV (GNSS) approach to Lockhart River, Queensland, on 07 May 2005. The two pilots and 13 passengers were fatally injured (ATSB aviation safety investigation BO/200501977 – under investigation at the time this report was published).

Objectives

The objective of this research project was to gain an understanding of the experiences and perceptions of RNAV (GNSS) approaches in Australia from pilots who are currently using these approaches. Specific objectives were to understand pilot perceptions of:

- pilot workload during an RNAV (GNSS) approach;
- ability to maintain situational awareness during an RNAV (GNSS) approach;
- ease of approach chart use during an RNAV (GNSS) approach;
- how safe RNAV (GNSS) approaches are; and
- which aspects of RNAV (GNSS) approach and chart designs contribute to these perceptions.

Methodology

A survey was mailed to all Australian pilots holding a civilian licence and a command instrument rating endorsed for RNAV (GNSS) approaches. The first part of the survey asked respondents to provide an assessment of their experience of a range of approach types, including visual (day), visual (night), ILS[2], LOC/DME, VOR/DME, GPS Arrival, DME Arrival, NDB, and RNAV (GNSS) approaches. This was done so perceptions about the RNAV (GNSS) approach could be contrasted with other approaches. Assessments were made for: preparation time and effort; mental workload; physical workload; time pressure; approach chart interpretability; situational awareness; and safety.

Part 2 of the survey involved open-ended answers to questions specifically dealing with the RNAV (GNSS) approach. Respondents were asked to describe which aspects of the RNAV (GNSS) approach contributed to mental workload, physical workload, time pressure, approach chart interpretability, and safety. Separately, they were asked to indicate if any aspects of the RNAV (GNSS) approach could be improved, what were the circumstances in which they were the most difficult, and if there were any particular locations where they were difficult. Part 2 also queried respondents about training and equipment, and asked them to indicate the details of any incident they had been involved in during an RNAV (GNSS) approach.

Part 3 of the survey involved pilot experience, both in general and for each approach type specifically. It also asked respondents to indicate their main method of flying each approach, either using autopilot or by hand-flying, and whether they conducted each approach mainly inside or outside of controlled airspace.

Demographic data

There were 748 surveys completed and returned to the ATSB, a response rate of 22%. Survey responses were received from individuals representing a broad range of pilot licence holders (private to airline), covering a variety of aircraft types. Respondents were placed in groups based on the main aircraft they operated using aircraft performance categories[3], (see table below). The relatively small number of responses from helicopter pilots did not allow for reliable statistical analysis of responses within this group.

Approach Performance Category	**Target threshold Speed (V_{at})**	**Typical aircraft**	**Number of Respondents**
Category A	Up to 90 kt	Beechcraft 36, 76, Pilatus PC-12, Cessna 182, 210, Piper PA-30	145
Category B	91 to 120 kt	Fairchild SA227 Metro, de Havilland Dash 8, King Air, SAAB 340	271
Category C	121 to 140 kt	Boeing 737, other high capacity jet airliners	231
Category H	Helicopters	Bell 412, Kawasaki BK 117	42
Aircraft type not stated			58

Note: see Appendix D for the full lists of aircraft

2 See the glossary section following for definitions and explanations of these approaches.

3 Aircraft performance approach categories are determined by multiplying the aircraft's stall speed in the approach configuration by a factor of 1.3. See Section 3.1.

Findings

- Pilot workload was perceived as being higher, and reported losses of situational awareness were more common, for the area navigation global navigation satellite system (RNAV (GNSS)) approach than all other approaches except the non-directional beacon (NDB) approach, which involved similar workload and situational awareness levels.

  This was especially a concern for pilots operating Category A and Category B aircraft. Further research into pilot workload and losses of situational awareness associated with RNAV (GNSS) approaches is warranted.

  However, respondents from Category C aircraft (predominantly high capacity jet airline aircraft) differed from these general results. These respondents considered the RNAV (GNSS) approach to be only more difficult than day visual approaches and the precision instrument landing system (ILS) approach, but involving less workload than the other approaches assessed in this survey. Similarly, high capacity airliner pilots indicated that they had lost situational awareness less often or at similar frequencies on the RNAV (GNSS) approach to most other approaches, and only lost situational awareness more often on RNAV (GNSS) approaches than on ILS and day visual approaches.

- Respondents indicated that they perceived the RNAV (GNSS) approach as safer than an NDB approach, equivalent to a visual approach at night, but perceived it as less safe than all other approaches included in the survey. However, the high capacity airliner pilots differed and assessed the RNAV (GNSS) approach safer than most approaches, with the exception of the ILS and visual (day) approaches. High capacity airliner pilots indicated that automation, and vertical navigation functions in particular, increased safety.

- The runway alignment of RNAV (GNSS) approaches was reported as increasing safety by 30% of respondents.

- The differences between the responses from pilots from Category C (predominantly from high capacity airlines) and those from the slower Category A and Category B aircraft (predominantly single engine and small twin-engine aircraft, and larger twin-engine propeller aircraft respectively), were likely to have been due to two main reasons. Firstly, the Category C aircraft pilots mostly conducted RNAV (GNSS) approaches using autopilots and have more sophisticated autopilot systems and vertical navigation (VNAV) capabilities not available to the slower and less complex aircraft. Secondly, high capacity airline pilots mostly conducted RNAV (GNSS) approaches inside controlled airspace while the Category A and B aircraft mostly operated RNAV (GNSS) approaches outside controlled airspace where the latter increased workload levels during an approach. More detailed approach briefings and company approach procedures in high capacity airlines probably also contribute to the differences found.

- The concern that most respondents had about the design of RNAV (GNSS) approaches was that they did not use a reference for distance to the missed approach point throughout the approach on the global positioning system (GPS) or flight management system (FMS) display and limited distance references on the approach charts were inadequate. This response was common from respondents in all types of aircraft categories, and was listed as affecting all areas of this survey. It was one of the most common issues influencing mental workload, approach chart interpretability, and perceived safety, influenced physical workload and time pressure assessments, and the most common aspect of the approach that trainees took the longest to learn. The inclusion of distance to the missed approach point throughout the approach on the cockpit display and approach chart was also the most common improvement suggested by respondents.

- The 21.5% of Australian RNAV (GNSS) approaches with short and irregular segment distances, and/or multiple minimum segment altitude steps (necessary for approaches in the vicinity of high terrain) were also identified as a major concern for many pilots. They were listed as the most common reason pilots experience time pressures and were one of the most commonly mentioned contributors to mental workload, physical workload, lack of approach chart interpretability, and perceived lack of safety. These sub-optimal characteristics were common in the list of aerodromes considered to have the most difficult RNAV (GNSS) approaches.
- Approach chart interpretability was assessed as more difficult for the RNAV (GNSS) approach than all other approaches by respondents from all aircraft performance categories. Unlike the non-directional beacon (NDB) and ILS approach charts, ease of interpretation did not increase with the number of approaches conducted per year.
- The naming convention of using five capital letters for waypoint names, with only the final letter differing to identify each segment of the approach, was reported to cause clutter on the charts and GPS and FMS displays, and also increase the chance of a pilot misinterpreting a waypoint.
- The amount of time and effort required to prepare for an RNAV (GNSS) approach was reported as higher than for all other approaches.
- Late notice of clearance by air traffic control to conduct an RNAV (GNSS) approach was identified as the most common difficult external condition to operate an RNAV (GNSS) approach, especially from high capacity airliner pilots.
- Most (86%) respondents considered their RNAV (GNSS) endorsement training to have been adequate. Of the 14% who considered it not to have been adequate, the most common reason was that not enough approach practice had been given.
- Flight instructors who answered the survey indicated that the most common problem trainees had with learning the RNAV (GNSS) approach was maintaining situational awareness, often related to becoming confused about which segment they were in and how far away they were from the runway threshold.
- There were 49 respondents (1 in 15) who reported that they had been involved in an incident involving RNAV (GNSS) approaches. The most common incident (15 respondents) was commencing the descent too early due to a misinterpretation of their position, and a further three respondents indicated that they misinterpreted their position, but that this was discovered before they started to descend too early. Another five incidents were reported as involving other losses of situational awareness. A further four respondents indicated that they had descended below the constant angle approach path and/or minimum segment steps.

Safety Actions

As a result of the findings of this study, and from feedback received during the consultation process, the ATSB has made a number of recommendations to enhance the safety of RNAV (GNSS) approaches.

Recommendations to Airservices Australia include:

- A study to determine whether the presentation of information, including distance information, on RNAV (GNSS) approach charts is presented in the most effective way;
- A review of the 21.5% of approaches with segment lengths different from the 5 NM optimum and/or multiple steps to determine whether some further improvements could be achieved;
- A review of waypoint naming conventions for the purpose of improving readability and contributing to situational awareness; and
- A review of training for air traffic control officers for the purpose of ensuring clearances for RNAV (GNSS) approaches are granted in a timely manner.

Recommendations to CASA include:

- Further research to better understand factors affecting pilot workload and situational awareness during the RNAV (GNSS) approach; and
- A review of training for pilots for the purpose of ensuring clearances for RNAV (GNSS) approaches are granted in a timely manner.

GLOSSARY

Navigation & approach aids

Aircraft are able to receive information from ground base aids that can be interpreted by aircraft instruments. These allow the aircraft's systems to use this information to provide navigation information enroute, or may be used to guide an aircraft during the approach and landing phases of a flight.

Over the last decade, civil aircraft have been able to use a system of satellites for very accurate navigation. A constellation of 24 geostationary satellites makes up the global positioning system or GPS. Receivers on aircraft can interpret the signals transmitted by these satellites to provide exceptionally accurate latitude and longitude information. This technology has also been adopted to provide a new form of instrument approach for aircraft, avoiding the need for ground-based transmitters.

Definitions of approaches

A number of different techniques can be used to approach a runway for the intention of landing. In good visibility, pilots may choose to fly an approach to land either visually, or by using navigational instruments. However, in poor visibility, pilots must rely on instruments to make an approach. Several types of instrument approach exist and several are described below.

Instrument approaches can be classified into two categories: precision and non-precision approaches. Precision approaches provide the pilot with both lateral and vertical guidance, while non-precision approaches only provide the pilot with lateral and/or longitudinal guidance.

Visual approaches

To conduct a visual approach, the pilot must be able to see the runway during the entire approach.

Visual (day)

During a visual approach in daylight, the pilot estimates the correct descent angle and lateral approach by visual reference to the runway and aerodrome, and may use visual landing aids (lights) such as VASIS (visual approach slope indicator) or PAPI (precision approach path indicator), if they are available.

Visual (night)

During a visual approach at night, the pilot relies on visual runway lighting, and aerodrome based visual landing aids (such as VASIS and PAPI when available) as cues to position the aircraft on the correct descent angle for landing.

Precision approaches

ILS (or ILS/LOC)

An Instrument Landing System (ILS) approach is a precision approach conducted by intercepting electronic localiser (LOC) and glidepath signals. The signals provide both lateral and vertical guidance to a minimum altitude aligned with the runway. The signals are displayed to the pilot pictorially in terms of aircraft navigation error.

Deflection of the glideslope needle indicates the position of the aircraft with respect to the glidepath. When the aircraft is above the glidepath the needle is deflected downward. When the aircraft is below the glidepath, the needle is deflected upwards. When the aircraft is on the glidepath, the needle is horizontal, overlying the reference dots. The glidepath needle provides an indication of glideslope between 1.4 degrees above and below the ideal approach glideslope. The glidepath indication is more accurate than the localiser course, making the needle very sensitive to displacement of the aircraft from on-path alignment. The localiser course provides lateral guidance. Full scale deflection shows when the aircraft is 2.5 degrees either side of centreline, permitting accurate tracking to the runway. Flags on the instrument show the pilot when an unstable signal or receiver malfunction occurs.

Non-precision approaches

DME Arrival

A Distance Measuring Equipment (DME) arrival is flown as a series of steps. On passing a DME distance, descent to the next lower altitude may be commenced to the published minimum altitude. A DME approach might not align the aircraft with the runway, requiring further visual manoeuvring before landing.

The approach is an approach usually from a greater distance away from the runway than other approaches (apart from the GPS arrival). Distances displayed are the distance to the DME transmitter, often on or near the airfield.

GPS Arrival

A global positioning system (GPS) arrival is similar to the DME arrival mentioned above, however the distances referred to during the approach are provided by the space-based GPS system, and not through ground-based transmitters used for DME approaches.

VOR/DME

A Very-High-Frequency Omni-directional radio range (VOR) is a VHF facility that generates directional information and transmits it by ground equipment to the aircraft, providing 360 magnetic courses TO and FROM the VOR station. The courses are called radials and radiate FROM the station.

The course deviation indicator (CDI) located on the aircraft instrument panel, is composed of a dial and a needle hinged to move laterally across the dial. The needle centres when the aircraft is on the selected radial or its reciprocal. Full needle deflection from centre to either side of the dial indicates the aircraft is ten degrees or more off course. The TO/FROM indicator called an ambiguity indicator shows whether the selected course will take the aircraft TO or FROM the station. (It does not indicate whether the aircraft is heading TO or FROM the station.) The approach is conducted by using a VOR radial for lateral guidance, while the DME provides distance information. The approach chart references altitude information to distance, allowing the pilot to descend to a minimum safe altitude during the approach.

LOC/DME

This approach utilising a localiser (LOC) for lateral guidance (as described for an ILS approach), and distance measuring equipment for longitudinal guidance (as described for the DME arrival). The DME distance steps verses altitudes are used to provide vertical guidance, but as a non-precision approach, provides a higher minimum altitude than the ILS. Like the ILS, this approach is aligned with the runway.

NDB

The low-frequency non-directional radio beacon (NDB) facility was one of the earliest electronic navigation aids adopted. A typical beacon facility incorporates a low-frequency transmitter and an associated antenna system that provides a non-directional radiation pattern. The automatic direction finder (ADF) equipment in the aircraft is a radio receiver that determines the aircraft's bearing from the aircraft to the NDB transmitting station.

The NDB approach begins when the aircraft is positioned over the NDB station. It follows a prescribed outbound track with the pilot making a time (or distance) reference, and descent is commenced once established outbound if published. On reaching the outbound time or distance limit, a turn inbound may be commenced to intercept a prescribed inbound track. When established on the inbound track further descent is allowed, down to a minimum altitude whereby the minimum altitude is maintained until visual or crossing overhead the NDB. The effect of wind is compensated by the pilot making heading corrections for the drift, and the timing can be adjusted to compensate for any tailwind or headwind component. On establishing visual contact with the runway, manoeuvring may be required to visually align the aircraft with the runway for landing. If the pilot is not visual when passing the NDB, a missed approach is carried out.

RNAV (GNSS)

Formally known as a global satellite system non-precision approach (GPS/NPA), an area navigation global navigation satellite system (RNAV (GNSS)) approach provides pilots with lateral guidance only based on waypoints. These waypoints are published latitude and longitude positions (given a five letter name) in space that are pre-programmed into a GPS receiver or a flight management system (FMS). The GPS antenna receives transmissions from at least four satellites to establish the aircraft's location. There are generally five waypoints in Australian RNAV (GNSS) approaches (see Figure 4 on page 6). During the approach, the GPS/FMS displays to the pilot(s) each leg as a track and distance to the next waypoint in the approach sequence. From that information, the pilot must determine what altitude to descend to, based on altitudes published in the approach chart. Like other non-precision approaches, there is no altitude guidance.

Aircraft systems

FMS	Flight management system. This is a computerised avionics system whose primary function is to assist pilots in navigating and managing the aircraft, incorporating the functions of a GPS receiver.
GPS	Global positioning system. A system that provides navigational information based on satellite information that can be used for both enroute navigation and during instrument approaches. The receiver displays to the pilots the location of the aircraft in terms of latitude and longitude and pre-determined waypoints.

Abbreviations (aviation)

ATC	Air traffic control
ATPL	Air transport pilot licence
CPL	Commercial pilot licence
CTAF	Common traffic advisory frequency area
FAF	Final Approach Fix
IAF	Initial Approach Fix
IF	Intermediate Fix
IMC	Instrument meteorological conditions
Kts	Knots
LNAV	Lateral navigation aircraft flight system
MAPt	Missed approach point
MDA	Minimum descent altitude
NM	Nautical miles (1 NM = 1.85 kilometres)
PIC	Pilot in Command
PPL	Private pilot licence
RPT	Regular public transport
VHF	Very High Frequency
VNAV	Vertical navigation aircraft flight system in Boeing aircraft, known as ‘managed descent’ on Airbus aircraft.

Abbreviations (statistical)

ANOVA	Analysis of variance.
α	Type 1 error rate
p	Probability that two groups that are statistically different and are not different by chance alone. A probability of 1% or less ($p \leq .01$) is considered by this report to be statistically significant.
r	Rho, refers to correlation. The proportion of the variance accounted for by the correlation is equal to the square of r.
SEM	Standard error of the mean[4]
SD	Standard deviation[5]

4 The SEM is equal to the standard deviation divided by the square root of the sample size. When the means of two groups differ by an amount more than their standard errors, the difference between the means is likely to be statistically significant.

5 SD is a measure of dispersion around a mean. For a representative sample of a normal distribution, about two-thirds of the observations lie within one standard deviation either side of the mean.

1 BACKGROUND

A landing approach to a runway can be conducted visually in visual meteorological conditions (VMC) and/or by using navigational instruments. However, in weather conditions below that determined for VMC (termed instrument meteorological conditions or IMC), pilots must conduct an instrument approach. During an instrument approach, pilots follow navigational instruments to position the aircraft (longitudinally, laterally and vertically) near the runway at the minimum safe altitude, a position known as the missed approach point (MAPt). At the MAPt, the pilot must be able to make visual reference with the runway to continue the approach and land the aircraft.

A number of different instrument approaches can be used, which can be broadly classified into two categories: precision approaches and non-precision approaches. Precision approaches provide the pilot with both lateral and vertical guidance down to the minima. The only precision approach operating in Australia currently is the instrument landing system (ILS). In contrast, non-precision approaches, including all other instrument approaches referenced in this report, only provide the pilot with lateral and/or longitudinal guidance. This is a major disadvantage compared with precision approaches as altitudes and the descent path need to be calculated by the pilot based on charts and lateral positions obtained or calculated based on instrument approach aids. This is reflected in the analysis for the Flight Safety Foundation of 287 fatal approach-and-landing accidents involving jet or turboprop aircraft above 5,700 kg between 1980 and 1996 worldwide by Ashford (1998). He found that three quarters of these accidents occurred in instances where a precision approach aid was not available or not used. A third type of approach recently introduced by International Civil Aviation Organization (ICAO) is known as an 'approach procedure with vertical guidance' (APV). APVs are instrument procedures that utilise lateral and vertical guidance, but do no meet the requirements for a precision approach. APVs had not been implemented in Australia when this report was published (see Section 1.2.3).

Area navigation global navigation satellite system (RNAV (GNSS)) approaches are a type of non-precision instrument approach procedure. Previously known as global satellite system non-precision approaches (GPS/NPA), RNAV (GNSS) approaches are relatively new, both in Australia and internationally. The procedures for air navigation services for aircraft operations (PANS-OPS) standard was published by the ICAO, and the first approaches designed in 1996-97. In Australia, the first RNAV (GNSS) instrument ratings were issued to pilots in 1998, and were first used by an airline in 1999. By 2006, over 400 RNAV (GNSS) approaches had been published for aerodromes across the country and their use had become common among instrument-rated pilots flying aircraft ranging from single engine piston aircraft up to high capacity jet airliners.

Due to the relatively recent introduction of RNAV (GNSS) approaches, very little accident and incident data is available concerning them. However, the Australian Transport Safety Bureau (ATSB) has recently investigated two high profile accidents where the pilots were conducting an RNAV (GNSS) approach. These were:

- A Piper PA-31T Cheyenne aircraft, registered VH-TNP, which collided with terrain while undertaking an RNAV (GNSS) approach to Benalla Aerodrome on 28 July 2004. The pilot and all five passengers were fatally injured (ATSB aviation safety investigation BO/200402797).

- A Fairchild Industries SA227-DC (Metro 23) aircraft, registered VH-TFU, which collided with terrain while undertaking an RNAV (GNSS) approach to Lockhart River, Queensland, on 07 May 2005. The two pilots and 13 passengers were fatally injured (ATSB aviation safety investigation BO/200501977).

1.1 Research objectives

The objective of this research project was to gain an understanding of the experiences and perceptions of RNAV (GNSS) approaches in Australia from pilots who are currently using these approaches. Specific objectives were to understand pilot perceptions of:

- pilot workload during an RNAV (GNSS) approach;
- ability to maintain situational awareness during an RNAV (GNSS) approach;
- ease of approach chart use during an RNAV (GNSS) approach; and
- how safe RNAV (GNSS) approaches are.

These objectives were achieved through a pilot survey which aimed to understand pilot views of these issues relative to other approach types. It was also designed to determine which aspects of RNAV (GNSS) approach and chart designs contribute to these perceptions.

1.2 RNAV (GNSS) approaches

RNAV (GNSS) approaches are a type of non-precision instrument approach. They are used by pilots to position an aircraft and make an approach to a runway with the intention to land.

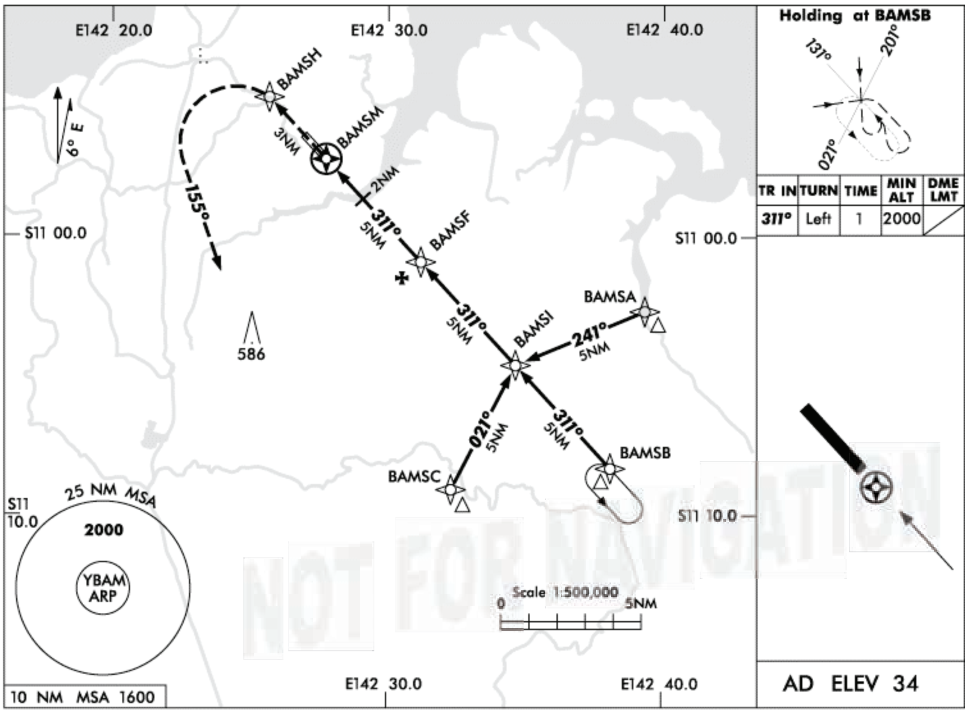
RNAV (GNSS) approaches provide pilots with lateral and longitudinal guidance based on a series of waypoints. These waypoints are published latitude and longitude positions in space with no associated ground navigational aid. They are pre-programmed into a global positioning satellite (GPS) receiver or flight management system (FMS), which display the aircraft's position relative to these waypoints during the approach.

1.2.1 RNAV (GNSS) approach design

There are generally five waypoints in Australian RNAV (GNSS) approaches. These waypoints generally have five alphanumeric characters and in Australia, always consist of five letters. The first four letters of each waypoint remains the same within an approach, and represent the three letter aerodrome identifier (e.g. BAM for Bamaga), and the direction from which the aircraft has travelled during the final approach (e.g. E for east). Only the fifth letter in the waypoint name varies to identify which waypoint the aircraft is approaching.

The final four waypoints have the standard fifth letter of I (for intermediate fix), F (for final approach fix), M (for missed approach point) and H (for holding point beyond the runway for when a missed approach is conducted). (On a few approaches, another waypoint, ending in T, occurs after the runway but before the holding point to specify a turning point to track to the holding point.) The missed approach point is generally 500 metres before the runway threshold. There is generally more than one choice for the first waypoint (the initial approach fix), giving pilots a choice of direction to enter the approach (for example, from the south, east, or north, for a final runway approach from the east). As such, there are up to three waypoints published for the initial approach fix. The fifth and only unique letter of the initial approach fix is, for example, either A, B or C (Figure 1).

Figure 1: Plan view of the East RNAV (GNSS) approach to Bamaga, Qld.



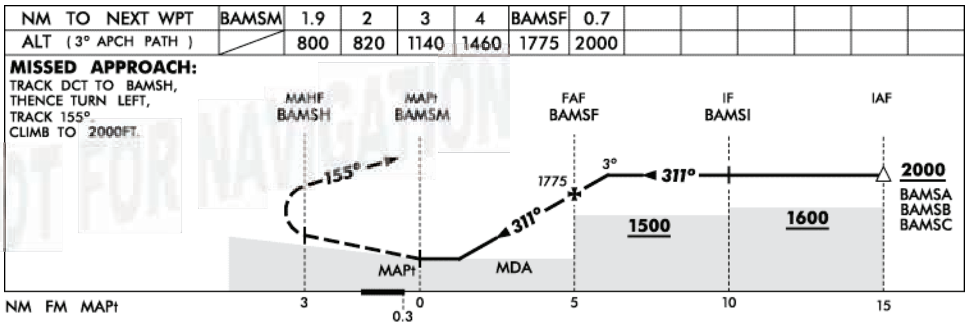
During the approach, the GPS or FMS in the cockpit displays to the pilot how far the aircraft is away from the next waypoint in the approach sequence. From that information, pilots must determine what altitude they should be at based on published altitudes given in the approach chart. There is no vertical guidance.

The international standards for an RNAV (GNSS) instrument approach were specified in the ICAO document *Procedures for Air Navigation Services – Aircraft Operations* document 8168 volume 2 (PANS-OPS). PANS-OPS specified that the standards were:

- initial approach segment - the ‘optimum length is 9.3 km (5.0 NM)’ (with a minimum distance determined by being able to accommodate the aircraft speeds of 210 kts);
- intermediate segment - ‘not to be less than 3.7 km (2.0 NM) allowing the aircraft to be stabilised prior to the FAF’; and
- final approach segment – ‘optimum length … is 9.3 km (5.0 NM)’.

The international standards for lengths between each waypoint in an RNAV (GNSS) approach, as described in the ICAO PANS-OPS document 8168, were: for the initial approach segment, the ‘optimum length is 5 NM’ (with a minimum distance determined by being able to accommodate the aircraft speeds of 210 kts); for the intermediate segment, it was ‘not to be less than 2 NM, allowing the aircraft to be stabilised before overflying the FAF’; and for the final approach segment, was to be ‘normally 5 NM’. In accordance with a decision made by CASA in 1996 and agreed to by industry[6], Airservices Australia[7] aimed to make all waypoint distances 5 NM when possible. The PANS-OPS also required the profile descent path to have an angle of no greater than 3.5 degrees (6.1%) for Category C aircraft, and 3.77 degrees (6.5%) for Category A and B aircraft[8], with an optimum slope of 3 degrees. An example of an approach with a 3 degree slope with 5 NM distances between the waypoints is presented in Figure 2 below. A further PANS-OPS requirement for RNAV (GNSS) approaches was for the final approach path to be aligned within 15 degrees of the runway centreline for Category C and D aircraft, or within 20 degrees for Category A and B aircraft. This criterion eliminates the need to conduct a circling approach.

Figure 2: RNAV (GNSS) approach to Bamaga, Qld, from the East. Approach uses the optimum segment length and slope design



Minimum segment altitudes are displayed between each pair of waypoints (shown as the grey shaded area and underlined number in Figure 2 above). These altitudes indicate that it is not safe to fly lower than these levels, and some pilots set the aircraft’s altitude alerting system (if available) as a defence against descending below these levels.

Complications can arise when designing to PANS-OPS optimum standards due to obstacle clearance requirements. For example, high terrain can lead to a variation of the optimum approach seen in Figure 2 above. As a result, distances between the waypoints can vary from 5 NM, the slope can be steeper than 3 degrees, and multiple minimum segment altitudes between each pair of waypoints can be needed to maintain appropriate obstacle clearance. An example is provided in Figure 3 below. Of the 414 Australian RNAV (GNSS) approaches published in late 2006, only 89 (21.5%) varied from the optimum 5 NM configuration.

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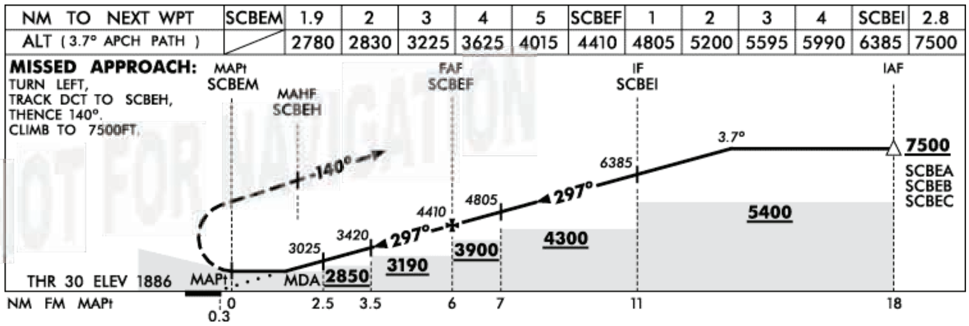
6 Undertaken through the GNSS Implementation Team (GIT).

7 Airservices Australia is approved to design RNAV (GNSS) approaches and have designed most current Australian RNAV (GNSS) approaches.

8 Aircraft categories are based on approach speeds. See Section 3.1 on page 15 for more detail.

Figure 3: RNAV (GNSS) approach to Canberra, ACT, to runway 30 Approach departs from the optimum design

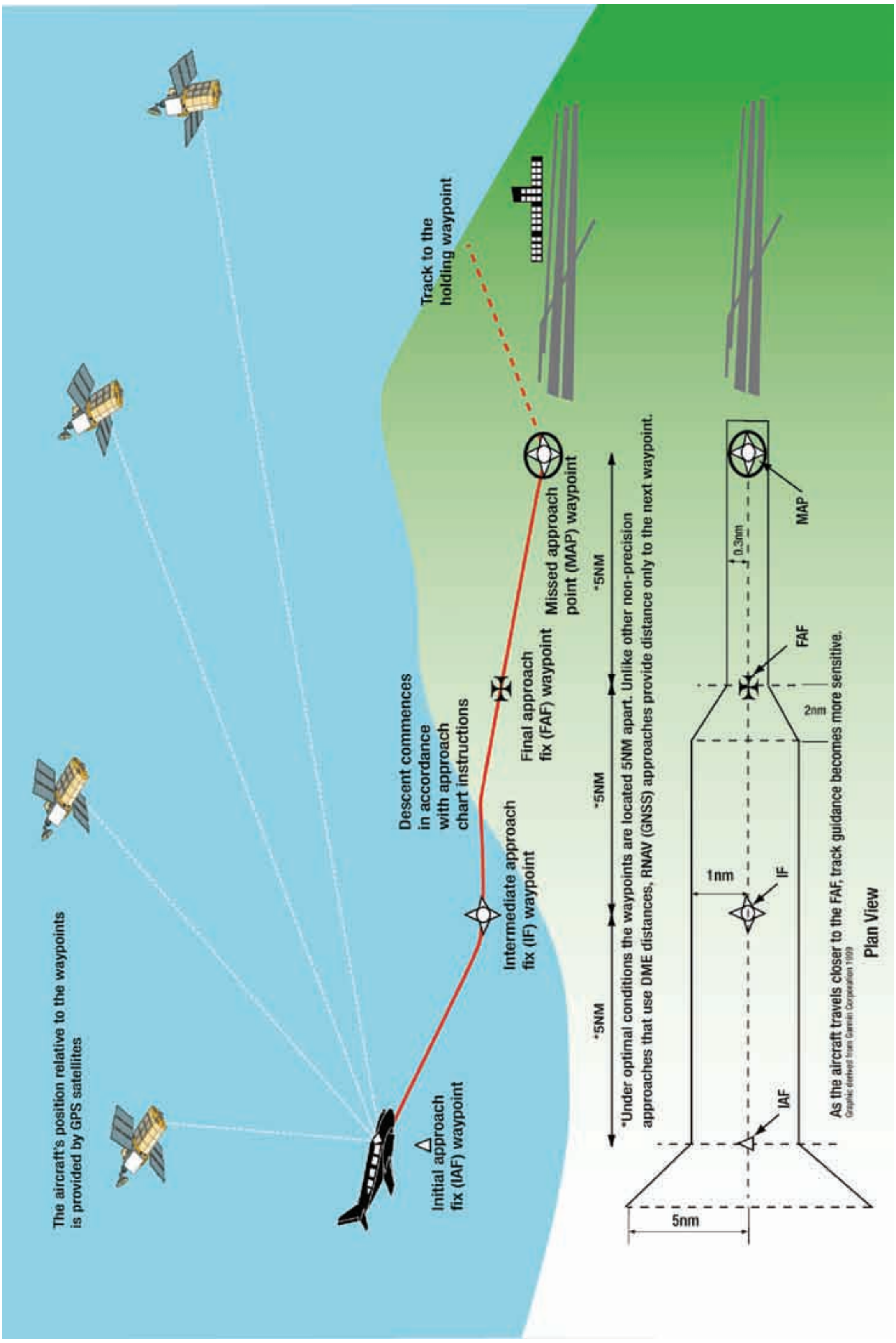


1.2.2 Conducting an RNAV (GNSS) approach

To operate an RNAV (GNSS) approach, a pilot must first select a pre-programmed approach in the aircraft's GPS or FMS, selecting one of generally two or three initial approach fixes (IAF) (see examples of charts in the appendix in section 8.1). The GPS/FMS stores the sequence of waypoints that make up the approach.

Once the approach is selected, the GPS/FMS will provide navigation guidance to the IAF (Figure 4). Most GPS receivers will automatically arm the approach within 30 NM from the aerodrome. A course deviation indicator (CDI) on the GPS unit and/or cockpit instrument panel displays navigation error to the pilots. Approaching the IAF, the CDI will become more sensitive, making a steady transition from the 5.0 NM to the 1.0 NM scale either side of the desired track (see insert in Figure 4).

Figure 4: Generic RNAV (GNSS) approach



Once the aircraft has passed the IAF, the GPS will display the estimated distance and, on some models at least, estimated time to travel to the intermediate fix (IF). The desired track between initial and intermediate fixes is shown on the GPS display, matching the heading shown on the approach chart. The approach chart also shows the desired altitude between these waypoints.

Once past the intermediate fix, the waypoint indicator displayed on the GPS changes to the final approach fix (FAF). The estimated distance and time to the FAF is shown on the GPS display. From 2 NM from the FAF, the CDI scale will gradually change from 1.0 NM either side of the track to 0.3 NM by the time the FAF is reached so the pilot can more accurately track to the runway.

As the aircraft approaches the FAF, the same process occurs as for approaching the IF, except the pilot must start the descent. (However, some approaches start the descent before the IF.) To maintain the appropriate constant angle approach path, the pilots can use the altitude profile in the altitude/distance table on the approach chart for guidance (see examples in the appendix in section 8.1).

Passing the FAF, the GPS display changes again, and now the displayed distance is in referenced to the missed approach point (MAPt). Again, reference altitudes from the approach chart need to be compared with the distance display on the GPS unit.

1.2.3 Autopilot and vertical guidance

If an aircraft has a suitably capable autopilot, pilots can choose to use the autopilot to automatically track the aircraft to each waypoint in an RNAV (GNSS) approach rather than hand-flying and using the CDI display as guidance.

Traditionally, GPS units have not provided pilots with vertical guidance from the satellite signals. The pilot must cross-reference altitude/distance information published on an approach chart with aircraft altimeter and GPS distance to waypoint display. However, if an aircraft has a vertical navigation capability, such as VNAV[9], pilots can program the aircraft's flight director via the FMS to generate a glideslope down to the MAPt. VNAV can only be used as an advisory on an RNAV (GNSS) approach, and not as a primary means of vertical guidance. VNAV displays vertical path error information to the pilot on a vertical deviation indicator in a similar way as an ILS (but with less accuracy), which can be followed to maintain a correct and constant angle of descent down to the MAPt.

In Australia, Boeing and Airbus aircraft are the main users of VNAV technology. Although some de Havilland Dash 8 aircraft are VNAV equipped, this function had generally not been used at the time of this survey. Only the very recent and 'top-end' models of smaller aircraft (such as business jets) had vertical navigation through the FMS. In addition, some of the next generation GPS receivers now also have advisory vertical guidance capabilities similar to FMS VNAV. However, such units were only just entering the GPS market at the time this survey was conducted. Hence, most aircraft in general and regional aviation sectors lacked the advisory vertical guidance capability.

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9 VNAV refers to Vertical Navigation capability in Boeing aircraft. It is referred to as 'managed descent' in Airbus aircraft.

RNAV (GNSS) approaches have the potential to be operated as an APV[10] rather than a non-precision approach. This can be achieved by fitting specific equipment into aircraft that provides 'required navigation performance' (RNP), developing specific RNAV (GNSS) approach procedure designs, and additional pilot training, along with vertical guidance provided by barometric-VNAV (baro-VNAV) or appropriate satellite-based or ground-based augmentation (see page 56). The result is that pilots have true vertical guidance similar to, but without the guaranteed accuracy level of, a precision approach. If using RNP baro-VNAV with the autopilot engaged, automatic positioning of the aircraft (vertically) along the glideslope occurs.

At the time of this survey, no APVs had been implemented in Australia. However, one Australian operator has been approved to operate Boeing 737 NG aircraft using RNP baro-VNAV RNAV (GNSS) approaches into Queenstown in New Zealand since 2004. Pilots operating this RNP approach were required to have an additional approval. RNP capability is currently restricted to later model high capacity jet aircraft.

1.3 Literature review

There has been very little research conducted on pilot workload and situational awareness levels for RNAV (GNSS) instrument approaches. However, both pilot workload and situational awareness have important implications for flight safety and excessive workload and loss of situational awareness are commonly cited as contributing to aviation accidents.

1.3.1 Pilot workload

Pilot workload refers to the number of mental and physical tasks a pilot needs to do, the time period in which these tasks must be completed, as well as the complexity of these tasks. Relative increases in pilot workload generally result in a subsequent reduction in pilot performance, especially at the cognitive level (Laudeman & Palmer, 1995).

Generally, more complex tasks will increase workload more than less complex or less difficult tasks, unless the complex tasks are well rehearsed and have become automated. Workload levels cannot increase indefinitely without leading to task performance decrements. This level will depend on a number of things, including pilot arousal levels, which are influenced by fatigue and motivation (higher pilot arousal, to an extent, allows higher workload levels before performance decrements start, e.g. Kahneman, 1973), and the commonality of multiple tasks (the more common concurrent tasks are, the more likely task decrements will occur, e.g. Wickens, 1984).

One study looking at pilot workload was a project commissioned by the Bureau of Air Safety Investigation[11] by Wiggins, Wilks and Nendick (1996). They found that instrument flight rules rated pilots flying various non-precision approaches assessed subjective workload as being higher for the NDB approach than for a VOR/DME

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10 Approach procedure with vertical guidance (see page 1 above).

11 The Bureau of Air Safety Investigation was integrated into the new multi-modal Australian Transport Safety Bureau from 1 July 1999.

approach. RNAV (GNSS) approaches were not yet in use so were not part of this study.

In a GPS receiver orientated study, Winter and Jackson (1996; cited in Joseph & Jahns, 1999) reported instances where GPS receivers affected pilot performance during the intermediate approach segments because they did not allow easy access to distance to the runway information. In particular, they noted increased pilot workload and increased response time for responding to ATC requests asking for their distance from the aerodrome. This was because pilots were required to either mentally calculate the distance information or access this information on the GPS by exiting the current function page, entering a new page, and then returning to the original page, requiring at least four key strokes, or up to nine if done incorrectly.

To date, only one research study (Goteman & Dekker, 2003) has been reported measuring crew workload during RNAV (GNSS) approaches. Goteman and Dekker (2003) investigated navigation accuracy and pilot workload for RNAV (GNSS) and ILS approaches using airline pilots operating Boeing 737 NG aircraft equipped with LNAV[12] and vertical guidance through barometric-VNAV with the autopilot on. The study found good tracking accuracy and low pilot workload based on subjective workload assessments completed at the end of the flight. Compared with other non-precision approaches, the low workload assessments and higher pilot acceptance of RNAV (GNSS) approaches were reported as being due to the change from a cognitive task (calculating vertical position) to a perceptual task (matching the constant angle approach path with the aircraft's position).

Oman, Kendra, Hayashi, Stearns, and Bürki-Cohen (2001) investigated the effect of VNAV on pilot workload, preference, and navigational accuracy during RNAV (GNSS) approaches. Using an aircraft simulator, they compared flights with LNAV alone or LNAV with one of three types of VNAV displays. Results showed that all types of VNAV reduced vertical flight error by up to a factor of two without increasing pilot workload. That is, pilots maintained high workload levels with VNAV resulting in improved navigation performance rather than having the same navigation performance with lower workload levels compared with the non-VNAV condition.

Therefore, when using the most sophisticated available automation with LNAV and VNAV capabilities, RNAV (GNSS) approaches appear to be acceptable to pilots and generate an acceptable pilot workload. However, outside of the automated and VNAV capable high performance aircraft types, there have been no studies published evaluating pilot workload resulting from RNAV (GNSS) approaches. As mentioned above, VNAV capability is generally limited to high capacity jet airliners in Australia.

1.3.2 Situational awareness

Situational awareness refers to the pilot having an accurate mental representation of the material state of the world they are operating in at the present time (Dekker & Lützhöft, 2004). Endsley (1995) defines it as the perception of the elements in the

12 LNAV refers to Lateral NAVigation directing the autopilot to the waypoints in the non-precision approach.

environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future. It involves three stages:

- perception (observing the environment);
- comprehension (how does the state of the perceived world affect me now); and
- projection (how will it affect me in the future) (Endsley, 1995).

A loss of situational awareness occurs when there is a failure at any one of these stages resulting in the pilot not having an accurate mental representation of the physical and temporal situation.

No published studies could be located that have investigated potential or actual losses of situational awareness during RNAV (GNSS) approaches.

1.3.3 Safety

In its March 2006 newsletter *Avlinks*, the QBE (Aviation) insurance company noted that with the RNAV approaches becoming more common in Australia, it was receiving a number of insurance claims associated with fatal accidents where the pilot had reported that an RNAV (GNSS) approach was being conducted. It noted that early opinion by experts were that these approaches were relatively easy to conduct compared with the older style approaches such as NDB approaches. However, it also noted concern coming from within the flight training industry. The industry flagged a number of concerns to QBE, including:

- Pilots are used to flying to distances referenced to the missed approach point (MAPt), where as RNAV (GNSS) approaches display only the distance to the next waypoint and never to the MAPt until the final approach fix (FAF) waypoint has been passed. This was noted to make these approaches more difficult than they first seem, and to make maintaining situational awareness difficult.
- When the aircraft has reached the MAPt and cannot establish visual contact with the runway, a missed approach is conducted. However, at this time, when the pilot has other significant workload demands, a considerable amount of GPS manipulation is required to initiate a missed approach.
- Most approaches do not have holding patterns on all initial approach fixes, so these have to be improvised on the spot by the pilot.
- Differences between Airservices and Jeppesen charts, including that Jeppesen charts do not display the first leg of the approach on the profile (see Appendix A for examples).
- The vast differences between the designs of GPS receivers from different manufacturers.

2 METHODOLOGY

Given the minimal amount of research into pilot workload, situational awareness and safety of RNAV (GNSS) approaches as outlined above, the Australian Transport Safety Bureau (ATSB) conducted a survey of pilots to gain an understanding of pilot perceptions of these approaches.

The aim of this survey was to target all pilots holding an Australian civil licence with a current command instrument rating endorsed for RNAV (GNSS) approaches. For reasons of privacy, the ATSB did not receive the names of pilots. Instead, CASA provided names and contact details to an independent mailing house, who distributed the survey on behalf of the ATSB.

The first part of the survey asked respondents to provide an assessment of their experience on a range of approach types, including RNAV (GNSS) approaches. This was done so perceptions about the RNAV (GNSS) approach could be contrasted with other approaches.

Throughout the survey, such questions always included the RNAV (GNSS) approach as the last approach on the list. Questions specifically targeting the RNAV (GNSS) approach were not used until the second part of the survey. Furthermore, the survey title, 'Pilot Experiences on Instrument Approaches', did not mention RNAV (GNSS) approaches. These two strategies were used to obscure the fact that the main topic of interest of the survey was RNAV (GNSS) approaches. This was done to maximise the chance that the sample of pilots who chose to complete and return the survey was a representative sample of the pilot group using these approaches. That is, to minimise the chance that respondents were biased either in favour or against RNAV (GNSS) approaches.

2.1 Survey design

The full survey appears in Appendix B: Survey questions. Part 1 of the survey asked pilots to rate the following approaches on a number of dimensions and in the following order:

- Visual (Day)
- Visual (Night)
- Instrument landing system approach (ILS)
- Localiser and distance measuring equipment approach (LOC/DME)
- Very-High-Frequency Omni-directional radio range and DME (VOR/DME)
- Global positioning system arrival (GPS Arrival)
- DME Arrival
- non-directional radio beacon approach (NDB)
- RNAV (GNSS).

The approaches were assessed on seven scales related to the planning and execution of an approach to obtain an understanding of perceived pilot workload, situational awareness, and safety. The assessments for each dimension were completed for all approaches together so that the respondent could record relative values. The seven assessment scales used were:

- preparation time and effort
- mental workload
- physical workload
- time pressure
- approach chart interpretability
- situational awareness
- safety.

The dimensions above regarding mental workload, physical workload, and time pressure, were taken from Hart and Staveland's (1988) NASA-TLX subjective workload index. The explanatory description of the assessments scales given to respondents were as follows.

> *Preparation time and effort* – How much time and effort is involved in preparing for each approach? (Preparing for the approach includes programming flight instruments, self/crew briefing, etc.; Does preparation take a very short time and little effort (1) or a long time and a lot of effort (7)?);
>
> *Mental workload* – How much mental and perceptual workload is involved during each approach? (Mental and perceptual activities may include mental calculations, visual scanning of instruments, decision making, task management etc.; Is the approach easy, simple (1) or demanding, complex, challenging (7)?);
>
> *Physical workload* – How much physical workload is involved during each approach? (Physical activities may include control manipulation, configuration changes, discussing options, reading checklists, etc.; Is the approach relaxed, physically undemanding (1) or demanding, strenuous, laborious (7)?);
>
> *Time pressure* – How much time pressure do you experience during each approach due to the pace of the activities involved in the approach? (Is the pace of the approach slow, leisurely (1) or rapid, frantic (7)?);
>
> *Approach chart interpretability* – How easy is it to interpret the relevant approach chart during each approach? (i.e. is the approach chart unambiguous, immediately understandable, clear (1) or easily misinterpreted, difficult or laborious to follow (7)?);
>
> *Situational awareness* – Have you ever had trouble maintaining situational awareness during any of the following approaches?
>
> *Safety* – How safe do you think each approach is? (Is the approach safe, secure (1) or dangerous, hazardous (7)?).

The assessments were completed using seven-point Likert scales for all dimensions above, except dimension 6 (situational awareness), which used a 4-point scale of 1 (never), 2 (once), 3 (sometimes), and 4 (often).

For respondents operating single pilot aircraft, each assessment was completed only once for each approach. For respondents from multi-pilot aircraft, the assessments were completed twice, once as the pilot flying, and once as the support pilot[13].

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13 Support pilot is also known as the pilot not flying or the monitoring pilot.

Part 2 of the survey involved open-ended answers to questions specifically dealing with the RNAV (GNSS) approach. Respondents were asked to write which aspects of the RNAV (GNSS) approach contributed to five of the dimensions assessed in Part 1. These were mental workload, physical workload, time pressure, approach chart interpretability, and safety. Separately, they were asked to indicate if any aspects of the RNAV (GNSS) approach could be improved, what were the circumstances in which they were the most difficult, and were there any particular locations where they were difficult. Part 2 also queried respondents about training and equipment, and asked them to indicate the details of any incident they had been involved in during an RNAV (GNSS) approach.

Part 3 of the survey involved pilot experience, both in general and for each approach type specifically. It also asked respondents to indicate their main method of flying each approach, either using autopilot or by hand-flying, and whether they conducted each approach mainly inside or outside of controlled airspace.

2.2 Data analysis

Responses to the approach assessments from Part 1 of the survey and the pilot opinions of RNAV (GNSS) approaches from Part 2 were only included in the data analyses if the respondent indicated that he or she held a current instrument rating on that approach in Part 3 (question 1a).

The approach assessments from Part 1 of the survey were analysed using the inferential statistical technique of analysis of variance (ANOVA), (see Appendix C: Data analysis for the full details). Assessments for the RNAV (GNSS) approach were compared with the assessments for each other approach type, and interactions between groups of respondents and the approach types were tested for:

- aircraft performance category (based on the main aircraft type the respondent indicated they operated);
- number of crew involved in the respondent's main flying activity (single pilot or multi-crew operations); and
- GPS type (panel mounted GPS or FMS integrated system).

Responses based on the number of pilots whose main aircraft contained an autopilot could not be meaningfully examined as 94% of respondents indicated their main aircraft had an autopilot.

Inferential statistics could not be used to analyse assessments based on whether pilots normally operated each type of approach using autopilot or by hand-flying (question 2a of part 3), or inside or outside of controlled airspace (question 2b of part 3), because these variables did not consistently vary across approaches for individual pilots (see Appendix C: Data analysis for a full explanation). The differences in the number of respondents indicating autopilot use and airspace for each approach were analysed using the non-parametric chi-square analysis.

Bivariate correlations were conducted between the assessments given for each approach and the following: total hours; total hours in the last 90 days; total instrument hours; total instrument hours in the last 90 days; number of approaches (of that type) conducted per year; and number of years the approach endorsement had been held.

A common convention for statistics in the behavioural sciences is to use a type 1 error rate of 5%. However, the data analysis for this survey used a more conservative type 1 error rate of 1% ($\alpha \leq .01$) as a compensatory method for the number of statistical tests conducted. Statistical results are reported below using probability levels only.

3 DEMOGRAPHIC DATA

The survey was mailed to every pilot with a command instrument rating and a GNSS endorsement on their Civil Aviation Safety Authority's (CASA) pilot's licence[14]. In total, 3514 surveys mailed and 748 were returned by the addressed pilot. A further 43 were returned unopened as the addressee was no longer at that address. Therefore, there was a 22% response rate.

As can be seen in demographic data below and based on the types of aircraft flown by the respondents (seen in the appendix, Section 8.4 on page 98), survey responses were received from pilots across a broad spectrum of the aviation industry. This included private and commercial pilots, pilots flying piston, turbo-propeller and jet aircraft, and pilots operating privately, in the flight training industry, in regional aviation and both low and high capacity regular public transport operations.

As with all surveys using a sample of a total population, the results below represent an estimate of the population of RNAV (GNSS) endorsed pilots, rather than exact measure of that population. Statistical tests used to determine whether differences exist take into account the number of respondents within each group as well as the variation between respondents within each group.

3.1 Aircraft performance category

The respondents were split into groups based on the main aircraft type they reported that they operated. The aircraft were placed into aircraft performance categories based on landing speed categories published in the Aeronautical Information Publication[15]. These categories, based on indicated airspeed at the threshold[16] (V_{at}), which determine the landing minima for the aircraft, are reproduced in Table 1.

Table 1: AIP aircraft performance categories

Aircraft Performance Category	Speed Range at V_{at}
Cat A	Up to 90 kts
Cat B	91 to 120 kts
Cat C	121 to 140 kts
Cat D	141 to 165 kts
Cat E	166 to 210 kts
Cat H	Helicopters

14 Pilot details were not provided to the ATSB. An independent mailing house distributed the surveys to pilots from details provided directly to them by CASA. Licence holders with a Private IFR rating were not targeted in this survey.

15 AIP En Route, Section EN ROUTE 1.5, Part 1.2 (16 MAR 2006).

16 V_{at} is the indicated airspeed at the threshold which is equal to the stalling speed with landing gear extended and flaps in the landing position (V_{so}) multiplied by 1.3 or the stalling speed with flaps and landing gear retracted (V_{s1g}) multiplied by 1.23.

In Table 2 below, the main aircraft types within each aircraft performance category are listed. It can be seen that there was a wide range of aircraft included in Category A, which were comprised predominantly of single-engine aircraft and small twin-engine aircraft. Category B also had respondents operating a range of aircraft which can the described as mostly larger twin-engine propeller aircraft, both piston and turbine. Of these aircraft, the most common were de Havilland Dash 8 aircraft representing 23% of respondents, King Air aircraft (17%), and SAAB 340 aircraft (16%). In contrast, Category C and Category D aircraft were predominantly high capacity regular public transport jet aircraft. The Category C aircraft respondents were dominated by Boeing 737 aircraft pilots (79%). Other aircraft in this category included the Airbus 320, British Aerospace 146, and Boeing 717, and some small business jets.

Table 2: Main aircraft types by aircraft performance category (Full list appears in the appendix in Table 5)

Aircraft Category	Aircraft common names	Number	% of category
Cat A	Bonanza, Beechcraft 36	15	10%
	Pilatus PC-12	13	9%
	Cessna 182 Skylane	10	7%
	Cessna 210 Centurion	10	7%
	Piper PA-44 Seminole	9	6%
	Piper PA-30 Twin Comanche	9	6%
	Beechcraft 76	8	6%
	Piper PA-34 Seneca	7	5%
	Piper PA-28 Cherokee, Archer	7	5%
Cat B	Bombardier de Havilland Dash 8-100/200/300	62	23%
	Beechcraft 200 Super KingAir	46	17%
	SAAB 340	43	16%
	Piper PA-31 Navajo, Mojave, Chieftain	21	8%
	Fairchild SA227 Metro	19	7%
	Beechcraft, BE55, B55, BE58	15	6%
Cat C	Boeing 737 (classic &/or NG)	184	79%
	British Aerospace 146	14	6%
	Airbus 320	8	3%
Cat H	Eurocopter/Kawasaki BK 117, EC 145	8	19%
	Sikorsky S-76	6	14%
	Eurocopter AS 365N, EC 155	5	12%
	Agusta Westland A 109	4	10%

The survey analyses used the four groupings seen in Table 3 below. Category D aircraft were grouped with Category C aircraft due to the minimal number of respondents from Category D aircraft (13 in total), the fact that most of the Category D respondents' experience with RNAV (GNSS) approaches was likely to have been in Category C aircraft (as pilots in Category D airline aircraft have minimal exposure to RNAV (GNSS) approaches), and due to the similarity of aircraft characteristics between these two categories. The numbers of respondents in each aircraft category are shown in Table 3.

Table 3: Number of respondents by main aircraft performance category

AIP Category	Number of Respondents
Category A	145
Category B	271
Category C	231
Category H	42
Aircraft type not stated	59

3.2 Pilot licence ratings

Pilot responses were only included in data analyses where the respondent held the appropriate pilot instrument rating for the approach being assessed. The number of respondents rated on each approach can be seen in Table 4.

Table 4: Number of respondents with pilot licence ratings on each approach

Rating	Rating held	Rating not held	Not answered
Night VFR	723	9	16
ILS	720	22	6
LOC/DME	721	20	7
VOR/DME	735	5	8
GPS Arrival	718	18	12
DME Arrival	719	18	11
NDB	741	-	7
RNAV (GNSS)	**706**	**32**	**10**

Pilot licence ratings within each aircraft performance category can be seen in Table 5.

Table 5: Number of respondents with current pilot licence ratings on each approach by aircraft approach category

	Category A	Category B	Category C	Category H
VFR	143	262	228	41
Night VFR	141	262	227	41
ILS	127	268	231	40
LOC/DME	131	266	231	40
VOR/DME	140	266	231	42
GPS Arrival	140	266	217	41
DME Arrival	129	266	228	42
NDB	144	269	230	42
RNAV (GNSS)	**136**	**257**	**221**	**39**

3.3 Number of pilots

The number of operating crew that usually operated in the main aircraft flown by the respondent are listed in Table 6. Category A respondents were mostly (97%) from single pilot operations, while Category C respondents (predominantly from high capacity airlines) were entirely from multi-crew operations. Category B aircraft and helicopter pilots were more evenly spread, with but more multi-crew operations (62%) for Category B, and more single pilot (67%) operations from helicopters.

Table 6: Number of respondents by main aircraft performance type and number of crew

Aircraft Performance Category	Single Pilot	Multi-crew
Category A	140 (96.6%)	5 (3.4%)
Category B	101 (37.3%)	168 (62%)
Category C	-	228 (100%)
Category H	28 (66.7%)	14 (33.3%)
Aircraft not stated	26	30
Total	*293*	*447*

3.4 Pilot licence type

It can be seen in Table 7 that all respondents from Category C aircraft and the majority (79%) of respondents from Category B aircraft and helicopters had an air transport pilot licence (ATPL), which is the highest level of pilot licence. Only Category A (single engine and smaller twin-engine) aircraft were flown by pilots with a range of licence types.

Table 7: Number of respondents for each pilot licence type by main aircraft performance type

Aircraft Performance Category	Air transport (ATPL)	Commercial (CPL)	Private (PPL)
Category A	37 (27.4%)	47 (34.8%)	51 (37.8%)
Category B	214 (79.9%)	46 (17.2%)	8 (3%)
Category C	226 (100%)	-	-
Category H	32 (78%)	9 (22%)	-
Not stated	37 (27.4%)	47 (34.8%)	51 (37.8%)
Total	*543 (75.1%)*	*113 (15.6%)*	*67 (9.3%)*

3.5 Crew position

The number of respondents in each crew position is shown in Table 8. Category A results reflects the dominance of single pilot operations in this aircraft category. There were more respondents in the position of pilot in command (PIC) for the other categories than there were responses from the copilot.

Table 8: Number of respondents in each crew operating position by main aircraft performance type

Aircraft Cat	Pilot in Command	Copilot/First Officer	Second Officer
Category A	101 (96.2%)	4 (3.8%)	-
Category B	186 (72.1%)	71 (27.5%)	1 (0.4%)
Category C	123 (53.9%)	100 (43.9%)	5 (2.2%)
Category H	36 (92.3%)	3 (7.7%)	-
Not answered	44 (84.6%)	8 (15.4%)	-

3.6 GPS receiver

It can be seen in Table 9 that none of the respondents used hand-held GPS receivers to conduct an RNAV (GNSS) approach. Hand-held receivers are not allowed to be used for RNAV (GNSS) approaches in Australia. Category A respondents mostly used panel mounted GPS units, while Category C respondents mostly had flight management system (FMS) integrated receivers. There was a more even split between the two types of displays for Category B and H aircraft.

Table 9: Number of respondents using a panel mounted GPS or FMS by main aircraft performance type

Aircraft Category	Hand held GPS	Panel Mounted GPS	FMS Integrated	Did not answer
Category A	-	125 (86.2%)	12 (8.3%)	8 (5.5%)
Category B	-	122 (45%)	135 (49.8%)	14 (5.2%)
Category C	-	8 (3.5%)	207 (89.6%)	16 (6.9%)
Category H	-	20 (47.6%)	20 (47.6%)	2 (4.8%)
Not answered	-	21	31	7
Total	*0*	*296*	*405*	*47*

GPS receivers and FMS units normally offer the pilot more than one way to display an RNAV (GNSS) approach. The navigation page displays only digital information such as estimated distance (and sometimes estimated time) to the next waypoint, the last and next waypoint, next track heading required, current heading and required heading, ground speed, and a course deviation indicator (CDI) display. In contrast, the moving map display is a pictorial representation of the waypoints showing the current aircraft position in addition to some or all of the above information.

Of those respondents with an FMS integrated receiver, most indicated that they displayed the moving map during the approach, or both the moving map and navigation page (using two displays). However, for those using a panel mounted GPS, about half used moving map and half used the navigation page.

Table 10: Number of respondents by GPS receiver type and page displayed

	GNSS Page Displayed During RNAV (GNSS) approach				
Receiver Type	**Moving Map**	**Navigation / CDI**	**Both Map & NAV**	**Other**	**Not stated**
Panel Mounted	101 (43%)	105 (45%)	12 (5.1%)	16 (6.8%)	58
FMS Integrated	189 (63%)	59 (19.7%)	30 (10%)	22 (7.3%)	102
Not stated	1	1	2	-	8
Total	*291 (54%)*	*165 (31%)*	*44 (8%)*	*38 (7%)*	*168*

4 RESULTS

Only those results where statistical differences were found are presented in this report due to the large number of potential comparisons that could be reported. The type 1 error rate was controlled at 1% to compensate for the number of comparisons. When the sample size of a group was small (below 40), that group was not included in the statistical analyses. For example, the number of responses from appropriately qualified helicopter pilots was too low for inferential statistics. However, many graphs and tables presented in this report do represent the helicopter respondents' answers to enable the interested reader to make non-statistical comparisons.

The pilot not flying (support pilot) assessments followed the same pattern of results as did the pilot flying assessments, only at slightly lower absolute assessment levels for each approach type. Therefore, the pilot not flying assessments are not presented here, but the reader can assume the same pattern of results as what is reported for the pilot flying.

In addition, it was found that the two arrival-type approaches (DME arrival and GPS arrival) generally received the same subjective assessments. Likewise, the two non-precision approaches involving a DME (VOR/DME and LOC/DME) also generally received the same assessments. Therefore, to reduce the number of items presented to ease interpretability, only one of each of these approach pairs is presented when describing approach type assessments, namely, the DME arrival and the VOR/DME. However, all approach types are included in the 'Pilot experience' results in Section 4.1 below.

4.1 Pilot experience

There were significant differences between total flying hours for each fixed-wing aircraft category. Post-hoc tests (Tukey HSD) indicated that Category C aircraft pilots, predominantly from high capacity jet airliners, had more experience (total hours) than both Category A and Category B aircraft pilots ($p<.001$). Category B aircraft pilots, predominantly from larger twin-engine propeller aircraft, had more total experience than pilots from the slower and less complex single engine and smaller twin-engine Category A aircraft ($p<.001$), (Table 11). Hours flown in the last 90 days did not differ between the aircraft categories.

Average instrument hours, both in total and in the last 90 days, were statistically higher for Category C aircraft pilots than both Category A and Category B aircraft pilots ($p<.001$). However there were no statistical differences between Category A and Category B aircraft pilots in terms of instrument hours.

Table 11: Mean hours (& SD[17]) experience by aircraft performance type

	Category A	Category B	Category C	Category H	*All Responses*
Total hours	4659 (5384)	8390 (5720)	10931 (5583)	5905 (3565)	**8408 (5989)**
Hours last 90 days	172 (1233)	117 (68)	256 (995)	67 (38)	**168 (777)**
Total instrument hours	664 (1224)	863 (914)	1555 (2141)	431 (291)	**1059 (1619)**
Instrument hours last 90 days	10 (11)	15 (14)	26 (32)	10 (9)	**19 (44)**

The experience levels for each approach type are shown in the following two tables. Table 12 shows the length of time respondents had been endorsed on each approach while Table 13 on page 23 shows the average number of approaches conducted each year.

Table 12: Years pilot licence rating held by number of respondents

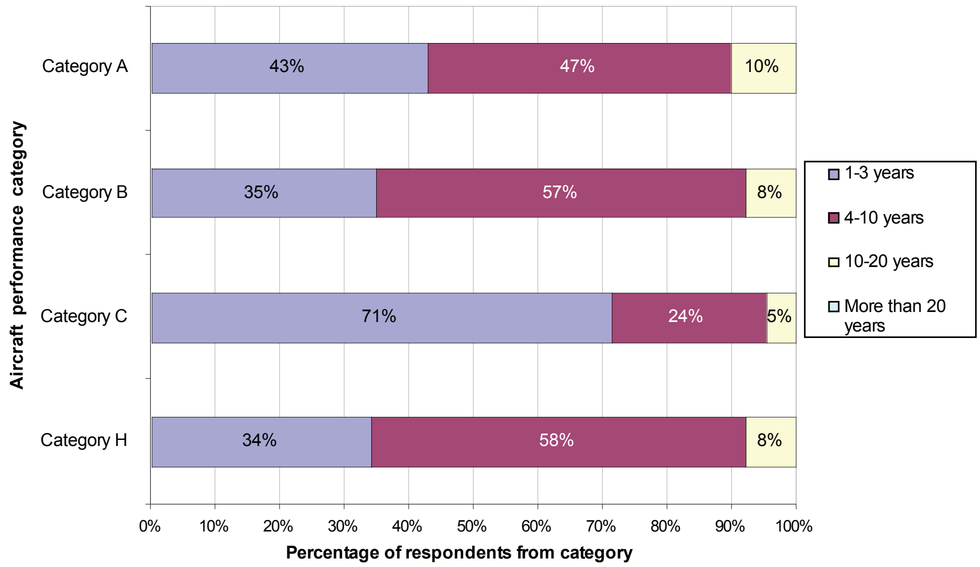
Rating	1-3 years	4-10 years	10-20 years	More than 20 years
VFR	36 (5%)	124 (17%)	231 (32%)	324 (45%)
Night VFR	38 (5%)	139 (20%)	241 (34%)	289 (41%)
ILS	43 (6%)	173 (25%)	275 (39%)	215 (30%)
LOC/DME	43 (6%)	173 (25%)	270 (38%)	216 (31%)
VOR/DME	45 (6%)	177 (25%)	272 (38%)	219 (31%)
GPS Arrival	164 (24%)	340 (49%)	142 (20%)	-
DME Arrival	51 (7%)	174 (25%)	258 (37%)	213 (31%)
NDB	52 (7%)	167 (23%)	261 (37%)	231 (32%)
RNAV (GNSS)	**329 (48%)**	**296 (43%)**	**49 (7%)**	**-**

Table 12 above shows that while most respondents had held ratings on all approaches other than those involving GPS for more than 10 years, the RNAV (GNSS) approach ratings have nearly exclusively been held for less than 10 years as they have only been available for about a decade.

For the RNAV (GNSS) instrument rating, most (71%) Category C respondents, mostly from high capacity airlines, had held the rating for less than 3 years. In contrast, Category A and Category B aircraft pilots had more commonly (47% and 57%, respectively) held the RNAV (GNSS) endorsement for between 4 and 10 years (Figure 5).

17 SD refers to the standard deviation which is shown in brackets.

Figure 5: Number of years RNAV (GNSS) instrument rating held by aircraft performance category



For respondents holding a rating for an approach type, Table 13 shows that LOC/DME, VOR/DME and NDB were the least frequently used approaches. RNAV (GNSS) approaches were used to a similar extent to GPS arrivals and DME arrivals, but less than ILS and visual approaches.

Table 13: Average number of approaches completed each year

Rating	Mean (& SD)*
Visual (Day)	223 (338)
Visual (Night)	66 (93)
ILS	65 (88)
LOC/DME	10 (44)
VOR/DME	15 (45)
GPS Arrival	29 (62)
DME Arrival	21 (51)
NDB	15 (48)
RNAV (GNSS)	**26 (51)**

* Includes only respondents holding a rating.

The average number of approaches completed each year for the aircraft performance categories is presented in Table 14. It can be seen that for all aircraft categories, while all instrument approaches were conducted less often than visual approaches, respondents conducted RNAV (GNSS) approaches at least as often as other non-precision approaches and more often than the NDB (except Category A aircraft) and LOC/DME approaches. Category B and Category C respondents conducted, on average, fewer RNAV (GNSS) approaches each year than precision (ILS) approaches. Category A aircraft pilots conducted fewer ILS approaches, on average than the faster fixed wing aircraft categories, and the faster aircraft categories conducted fewer NDB approaches than the slower aircraft categories.

Statistical comparisons between the aircraft groups were conducted for the number of RNAV (GNSS) approaches conducted each year. Pilots from Category B aircraft (typically larger twin-engine propeller aircraft) indicated that, on average, they completed twice as many RNAV (GNSS) approaches compared with both Category C and Category A aircraft pilots. Based on post-hoc (Tukey HSD) comparisons, these differences were statistically significant ($p<.001$). However, RNAV (GNSS) approaches per year did not differ statistically between respondents from Category A and Category C aircraft.

Table 14: Average number of approaches (& SD) completed each year by aircraft category.

	Category A	Category B	Category C	Category H
Visual (day)	150 (243)	267 (256)	168 (148)	322 (426)
Visual (night)	26 (44)	77 (102)	69 (74)	106 (115)
ILS	19 (33)	50 (71)	111 (87)	17 (10)
LOC/DME	6 (15)	7 (11)	8 (18)	4 (4)
VOR/DME	13 (39)	12 (18)	16 (21)	9 (11)
GPS Arrival	14 (18)	46 (66)	13 (20)	17 (34)
DME Arrival	11 (19)	29 (43)	13 (18)	15 (35)
NDB	21 (44)	15 (31)	6 (18)	12 (9)
RNAV (GNSS)	**19 (38)**	**36 (41)**	**15 (13)**	**19 (13)**

4.2 Pilot workload

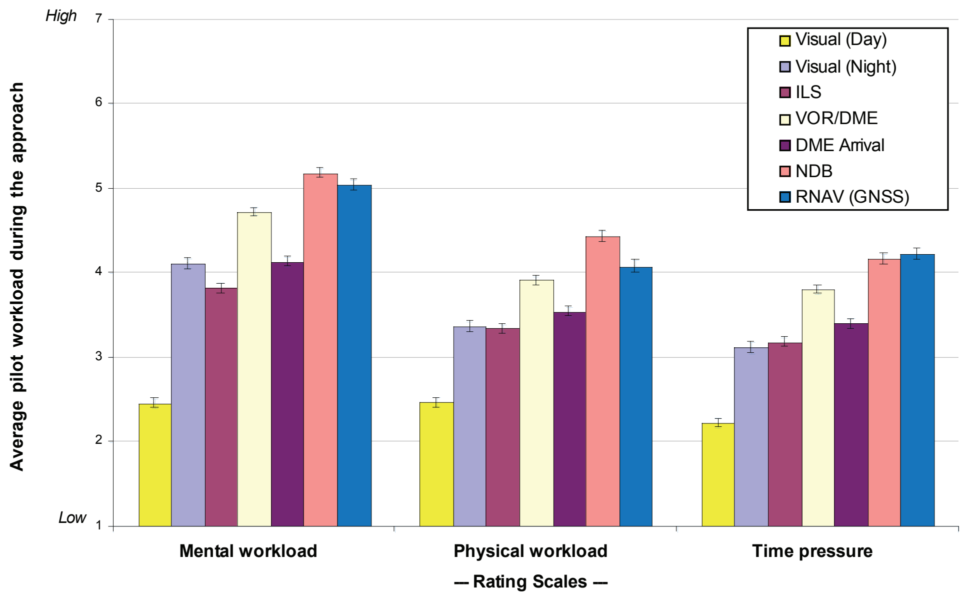
Pilot workload was measured by a combination of three scales from the NASA-TLX subjective workload questionnaire: mental workload, physical workload, and time pressure. Mental workload was defined on the survey as including mental calculations, visual scanning of instruments, decision making, and task management during the approach. Physical workload was defined as including control manipulation, configuration changes, discussing options, and reading checklists, during the approach. Finally, time pressure was defined in the survey as the pace of the activities involved in the approach.

4.2.1 Type of approach

The RNAV (GNSS) approach (dark blue bars in Figure 6) was assessed as requiring more pilot workload on each scale (mental workload, physical workload, and time pressure), than each of the other approaches ($p<.001$) except for the NDB approach (Figure 6). There were no statistically differences between the NDB and RNAV (GNSS) assessments for mental workload and time pressure. However, for the physical workload scale, the RNAV (GNSS) approach was assessed as having less physical workload than the NDB approach ($p<.001$).

It can also be seen in Figure 6 that, averaged across all approach types, mental workload assessments (left group) were significantly higher than the other workload assessments (p<.001), and that physical workload assessments (middle group) were slightly, but still statistically, higher than time pressure assessments (right group) across the approaches (p<.001).

Figure 6: Mean (±1 SEM)[18] pilot workload assessments



The interactions presented below between the approach types and approach performance categories, crew number, and GPS type, were the same for the three workload constructs: mental workload, physical workload, and time pressure. As such, the data below are presented below as 'pilot workload' and use an average of these three assessments.

4.2.2 Aircraft performance categories

Averaged across all of the approaches types, assessments from Category C aircraft pilots, predominantly from high capacity jet airliners, were higher than those from pilots from the slower Category A and Category B aircraft (p<.001). This can be seen by the generally higher maroon bars in the Figure 7 below to compared with the blue bars.

Averaged across the approach types, there was no statistical difference between responses from Category A aircraft pilots and Category B aircraft pilots for any of the pilot workload scales.

The pilot workload assessments from Category A and Category B aircraft indicated the RNAV (GNSS) approach was more difficult than the other approaches, except the NDB (blue bars in Figure 7). However, pilots from the faster Category C aircraft (maroon bars in Figure 7) assessed the other approaches (with the exception of visual (day) and ILS) as involving higher workload levels than the RNAV (GNSS) approach. This led to significant interactions between the RNAV (GNSS) approach and all other approaches (p<.001) except with the ILS. The RNAV (GNSS) approach was similarly more difficult than the ILS by both groups of respondents.

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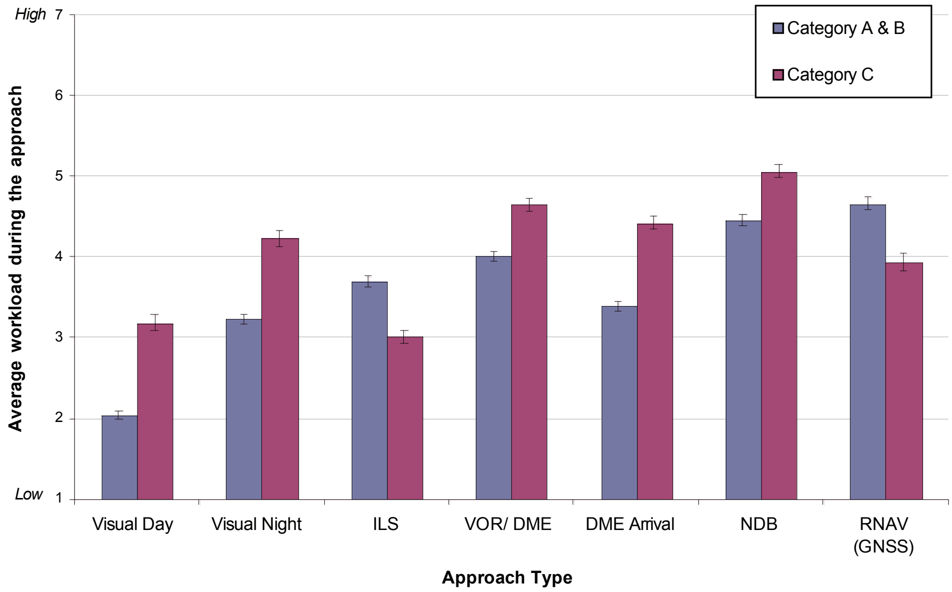
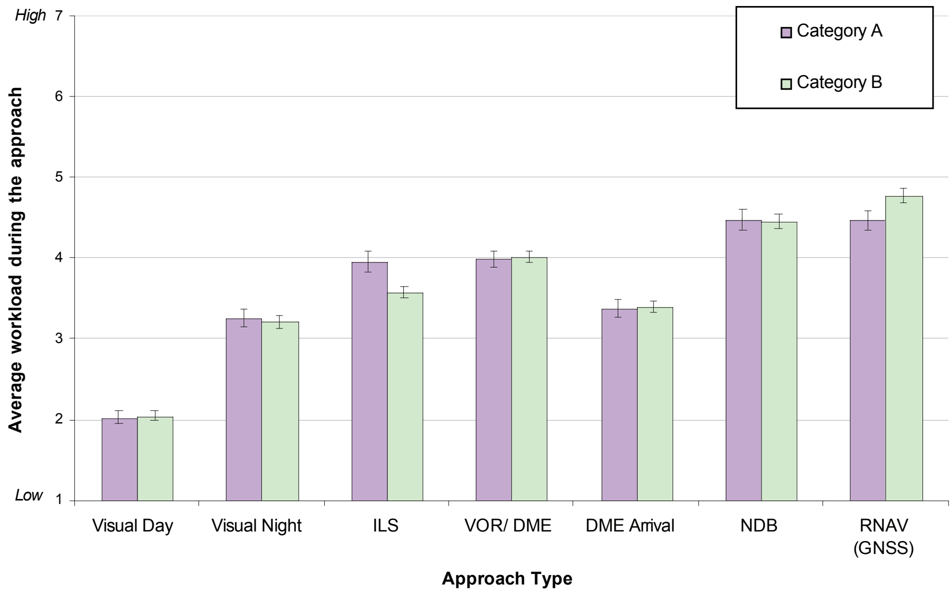
18 Standard error of the mean is shown by the error bars.

Figure 7: Mean (±1 SEM) pilot workload assessments for aircraft performance categories (Cat A and Cat B combined)



The only two approach types which received different assessments from pilots from Category A aircraft and Category B aircraft were the ILS and RNAV (GNSS) approach. Category B (larger twin-engine propeller) aircraft pilots (green bars in Figure 8) assessed the RNAV (GNSS) approach as more difficult than pilots from the slower Category A (single engine and smaller twin-engine) aircraft (purple bars in Figure 8), but the ILS approach as less difficult, leading to a significant interaction ($p<.001$).

Figure 8: Mean (±1 SEM) pilot workload assessments for aircraft performance categories (Cat A and Cat B only)

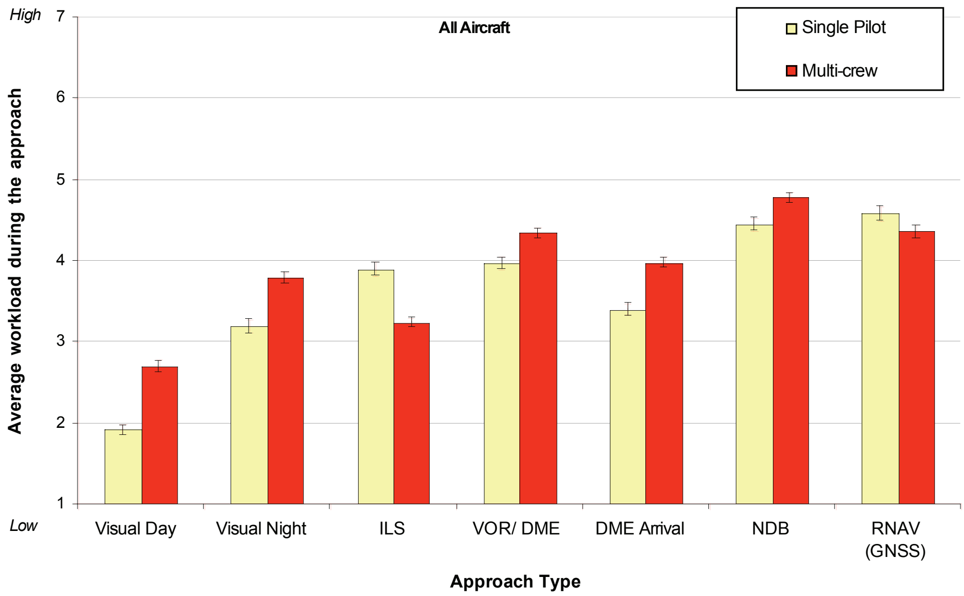


4.2.3 Number of crew

Averaged across all the approach types, pilots from multi-crew aircraft gave higher mental workload, physical workload, and time pressure assessments than did pilots from single pilot aircraft ($p<.01$).

It can be seen in Figure 9 that pilot workload assessments were very similar for the RNAV (GNSS) approach between single pilot and multi-crew pilots. However, the ILS approach assessments, which were lower than the RNAV (GNSS) approach assessments, were even lower for multi-crew pilots resulting in a significant interaction ($p<.001$) with the RNAV (GNSS) approach. In contrast, the lower pilot workload assessments for other approaches (except NDB) were lower for the single pilots than they were for multi-crew pilots, leading to significant interactions ($p<.01$). The differences between the RNAV (GNSS) approach and NDB also followed this trend, but were not significant to the 1% level for the mental workload assessments.

Figure 9: Mean mental workload (±1 SEM) for single pilot and multi-crew

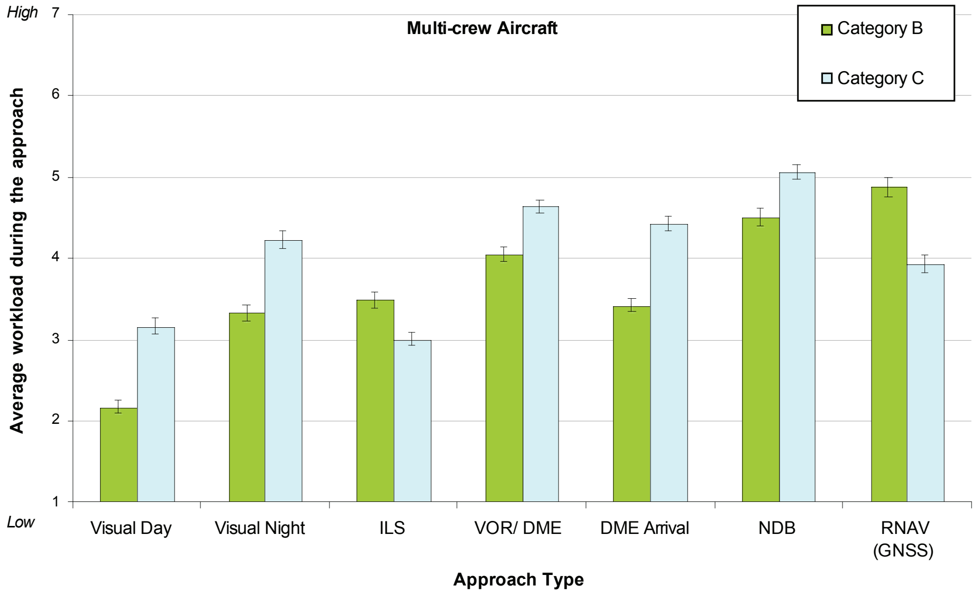


Multi-crew assessments

All of the Category C aircraft pilots and 62 percent of the Category B aircraft pilots were from multi-crew operations (see Table 6 on page 18). In contrast, nearly all of the Category A aircraft pilots were from single pilot operations. The results described in Figure 9 above partially reflect these aircraft performance categories.

Figure 10 displays the differences between the two categories of multi-crew pilots for the average of all workload constructs combined. The Category B larger twin-engine propeller aircraft pilots operating with a multi-crew indicated the RNAV (GNSS) approach involved more pilot workload than all other approaches. In contrast, this was only true for the Category C high capacity airliner pilots for the visual (day) and ILS approaches, and to a lesser extent. As a result, there was a significant interaction between the RNAV (GNSS) approach and each other approach types between the two multi-crew aircraft approach categories ($p<.001$).

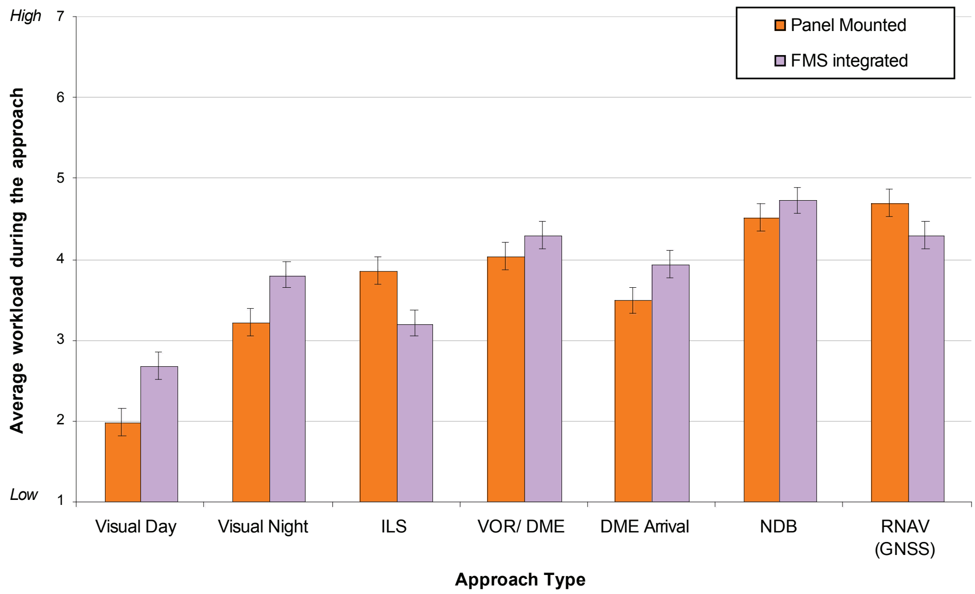
Figure 10: Mean pilot workload (±1 SEM) for multi-crew by aircraft category



4.2.4 GPS/FMS

Respondents with panel mounted GPS units indicated the RNAV (GNSS) approach involved more pilot workload than the other approaches. However, pilots from FMS equipped aircraft indicated this to a smaller extent (and not at all for the NDB), leading to significant interactions ($p<.001$) with the exception of the ILS approach. The higher RNAV (GNSS) approach workload assessments compared with the ILS assessments were similar for both panel mounted GPS and FMS aircraft pilots.

Figure 11: Mean pilot workload (±1 SEM) for panel mounted and FMS integrated GPS receivers

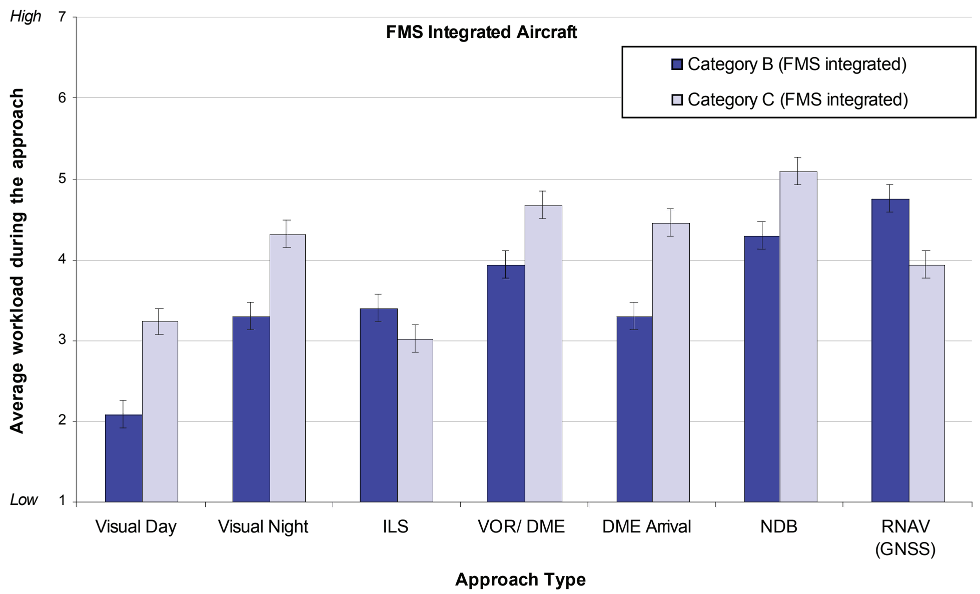


FMS assessments

It can be seen in Table 9 (page20) that nearly all Category C aircraft pilots (predominantly from high capacity jet airlines) used FMS equipped aircraft, and nearly all Category A aircraft pilots (from single engine and small twin-engine aircraft) used panel mounted GPS units. Category B aircraft pilots (from larger twin-engine propeller aircraft) were about evenly split between the two. The results shown in Figure 11 above partially reflect these considerations.

Figure 12 displays the differences between the two categories of pilots operating FMS equipped aircraft for the average of all workload constructs. The Category B aircraft pilots operating FMS equipped aircraft indicated the RNAV (GNSS) approach assessed pilot workload as higher than all other approaches. In contrast, this was only true for the Category C airliner pilots for the visual (day) and ILS approaches, and to a lesser extent. As a result, there was a significant interaction between the RNAV (GNSS) approach and each other approach between the two FMS equipped aircraft approach categories ($p<.001$) except the ILS approach.

Figure 12: Mean pilot workload (±1 SEM) for FMS integrated GPS receivers by aircraft performance category



4.2.5 Correlations between workload assessments and experience and recency levels

A summary of the correlation results can be seen in Table 15. The number of years since respondents' RNAV (GNSS) rating were gained was significantly and positively correlated with the time pressure experienced during an RNAV (GNSS) approach ($p<.01$). That is, the longer a respondent had held an RNAV (GNSS) rating, the more likely it was that their time pressure estimates for the RNAV (GNSS) approach were higher. This was the only statistically significant correlation for the RNAV (GNSS) workload assessments.

In contrast, the mental workload, physical workload, and time pressure assessments on the ILS approach were negatively correlated with total hours experience, total instrument hours experience, the number of ILS approaches per year, and years the pilot had held an ILS rating ($p<.001$). That is, the more experience a pilot had with ILS approaches, the lower their pilot workload assessments were.

Mental workload, physical workload, and time pressure assessments for the NDB approach were negatively correlated with the number of years the pilot held an NDB rating ($p<.01$), and mental workload was also negatively correlated with total flying experience ($p<.01$).

The time pressure assessments on the DME arrival were negatively correlated with the number of DME arrivals completed each year.

General recency measures (total hours in the past 90 days and total instrument hours in the past 90 days) were not correlated with any of the workload assessments, so are not included in Table 15.

Table 15: Summary of workload correlations*

	Total hours	Total instrument hours	Years rating held	Approaches conducted per year
Visual (Day)				
Visual (Night)				
ILS	- MW,PW,TP	- MW,PW,TP	- MW,PW,TP	- MW,PW,TP
VOR/DME				
DME Arrival				- TP
NDB	- MW		- MW,PW,TP	
RNAV (GNSS)			**+ TP**	

* Positive correlations are shown as +, negative correlations as -. Workload scales are abbreviated as MW (mental workload), PW (physical workload), and TP (time pressure).

4.2.6 Aspects of an RNAV approach that contribute to pilot workload

Respondents were asked to state which aspects of the RNAV (GNSS) approach contributed to each pilot workload scale with open responses. That is, they were free to write what they liked and were not restricted by predetermined choices.

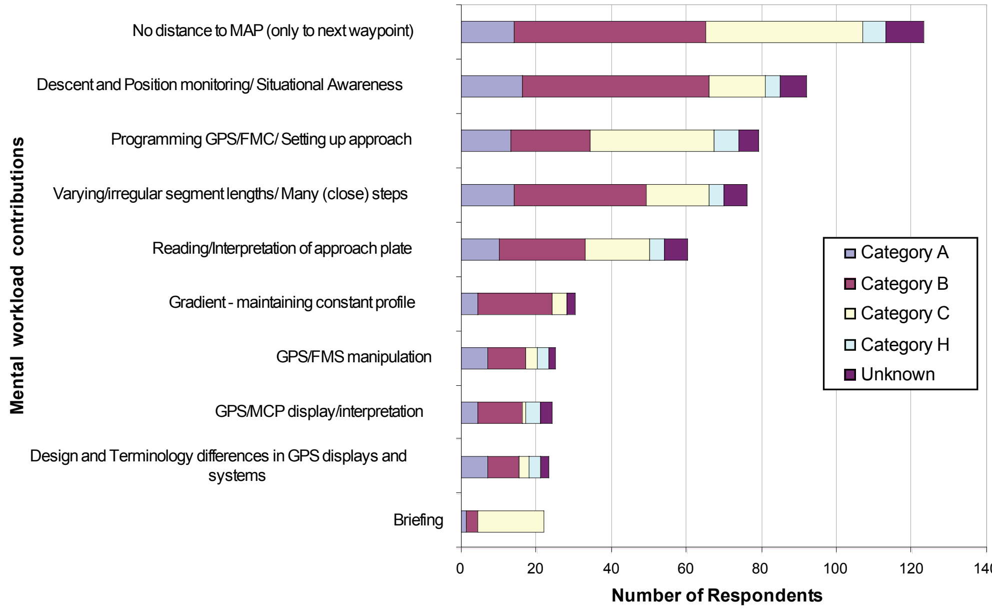
Mental workload

Figure 13 shows the most common responses to which aspects of the RNAV (GNSS) approach contributed to mental workload. The full list of responses appears in the appendix in Section 8.5, Table 24 on page 101.

When asked to state which aspects of the RNAV (GNSS) approach contributed to mental workload, 123 respondents (20.8% of those answering this question) included the fact that the GPS receiver or FMS and/or approach chart do not reference distances to the missed approach point throughout the approach. A further 92 respondents noted the mental workload was related to maintaining an awareness of the aircraft's position and altitude throughout the approach.

Another common response (13%) included the amount of programming needed for the FMS or GPS before an approach. The most common approach design related response (13%) involved irregular segment lengths and/or many close steps which increased workload, or conversely, an optimum design with 5 NM segments which reduced workload. Reading and interpreting the approach chart was also mentioned by 10% of respondents.

Figure 13: Number of respondents noting aspects of an RNAV (GNSS) approach that contributes to the degree of *Mental Workload*



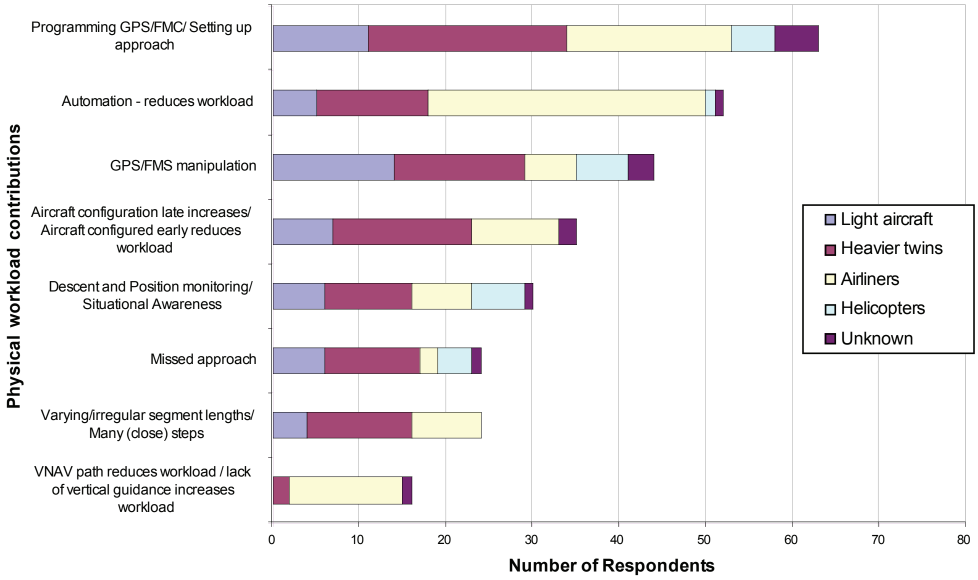
Physical workload

The most common aspects of an RNAV (GNSS) approach contributing to physical workload can be seen in Figure 14. The full list appears in Table 25 on page 104.

The most common contributions to physical workload were setting up the approach on the FMS or GPS (16%), and manipulation of the FMS or GPS (11%). Configuring the aircraft (setting flaps and landing gear to the appropriate positions) late in the approach increased physical workload and conversely, configuring the aircraft for landing early in the approach was listed as helping reduce physical workload (9%).

The main issue seen in Figure 14 that reduced physical workload was the use of automation (13%). This was most commonly listed by Category C aircraft pilots (28%). An additional 11% of Category C aircraft pilots listed VNAV as reducing workload. Category C aircraft respondents to this survey were mostly from high capacity jet airliners.

Figure 14: Number of respondents noting aspects of an RNAV (GNSS) approach that contributes to the degree of *Physical Workload*



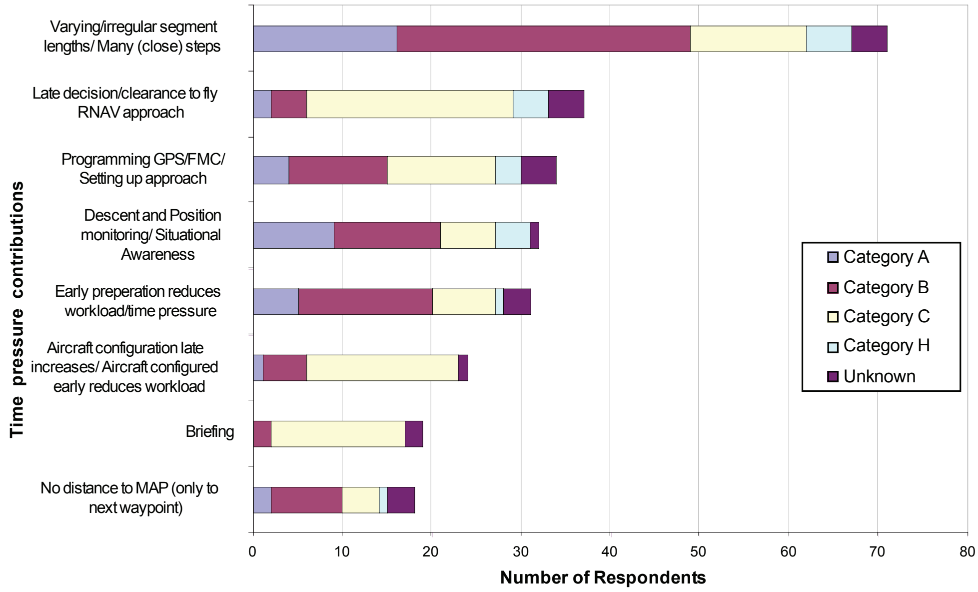
Time pressure

The most common aspects contributing towards time pressures can be seen in Figure 14, with the full list appearing in the appendix in Table 26 on page 106.

The most common aspect listed as increasing time pressure during an approach was irregular segment lengths and/or many altitude limiting steps (19% of all respondents), especially for Category A (24%) and Category B (25%) pilots from single and twin-engine propeller aircraft.

For the predominantly high capacity airline Category C pilots, receiving a late clearance from air traffic control (ATC) to fly an approach was the most common aspect leading to time pressure (20%), followed by late configuration of the aircraft (15%), briefing requirements (13%), and FMS programming requirements (10%). Briefing requirements were not listed as increasing time pressure at all for Category A aircraft pilots and by very few Category B aircraft pilots.

Figure 15: Number of respondents noting aspects of an RNAV (GNSS) approach that contributes to the degree of *Time Pressure*

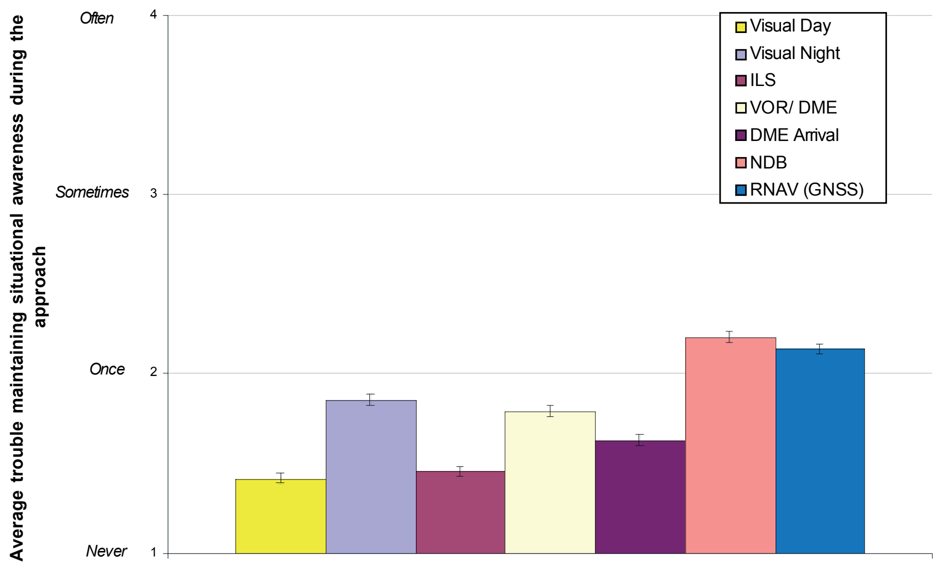


4.3 Pilot situational awareness & preparation issues

4.3.1 Situational awareness assessments

Respondents indicated they have had trouble maintaining situational awareness more often on the RNAV (GNSS) approach (dark blue bar in Figure 16) than each of the other approaches (p<.001) except for the NDB approach. The assessments for the NDB and RNAV (GNSS) approaches were not statistically different.

Figure 16: Mean (±1 SEM) assessment of trouble maintaining situational awareness

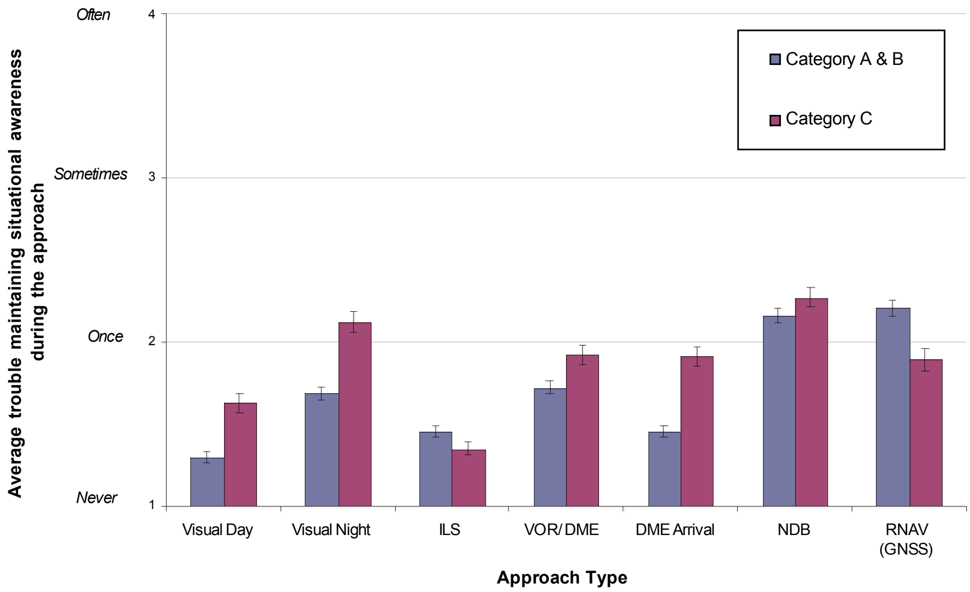


Aircraft performance category

Respondents from Category C indicated more instances of losing situational awareness averaged across all approach types than did respondents from Category A and Category B aircraft ($p<.001$). There was no statistical difference between Category A and Category B aircraft respondents averaged across the approaches.

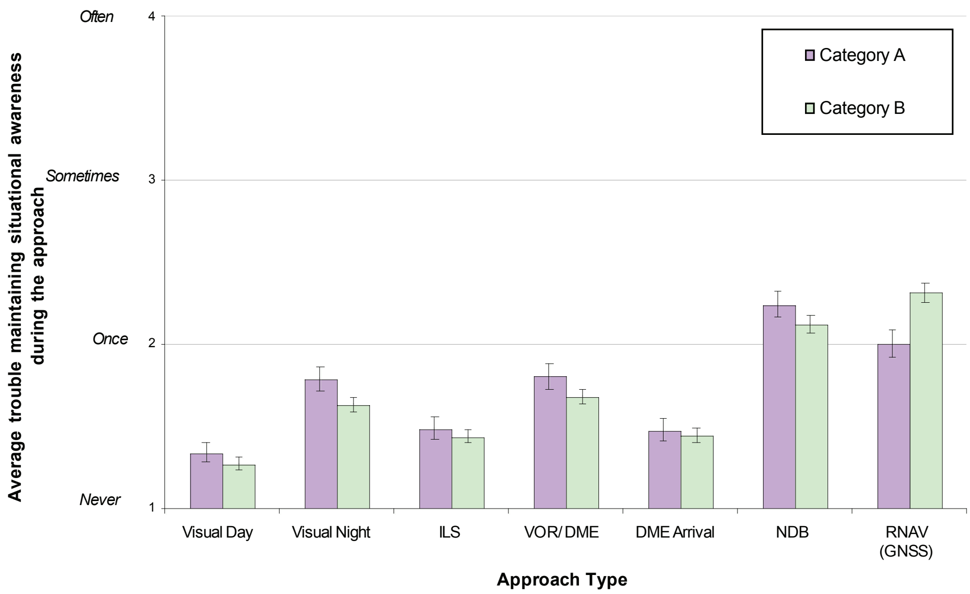
For Category A and Category B aircraft pilots (typically from single and twin-engine propeller aircraft), the average number of loss of situational awareness experiences on the RNAV (GNSS) approach was higher than on all other approach types except the NDB. In contrast, loss of situational awareness experiences for Category C aircraft pilots (predominantly from high capacity airlines) was more similar on other approach types (other than the ILS) to the RNAV (GNSS) approach (Figure 17). This led to significant interactions between the RNAV (GNSS) approach and the other approaches ($p<.001$) except the ILS.

Figure 17: Mean (±1 SEM) situational awareness loss assessments by aircraft performance categories (Cat A and Cat B combined)



The Category B aircraft pilots indicated they had lost situational awareness on the RNAV (GNSS) approach more often than the other approaches to a greater extent than pilots from the slower Category A aircraft. However, this difference was only statistically significant compared with the visual (night) approach ($p<.01$), (Figure 18).

Figure 18: Mean (±1 SEM) loss of situational awareness assessments by aircraft performance categories (Cat A and Cat B only)



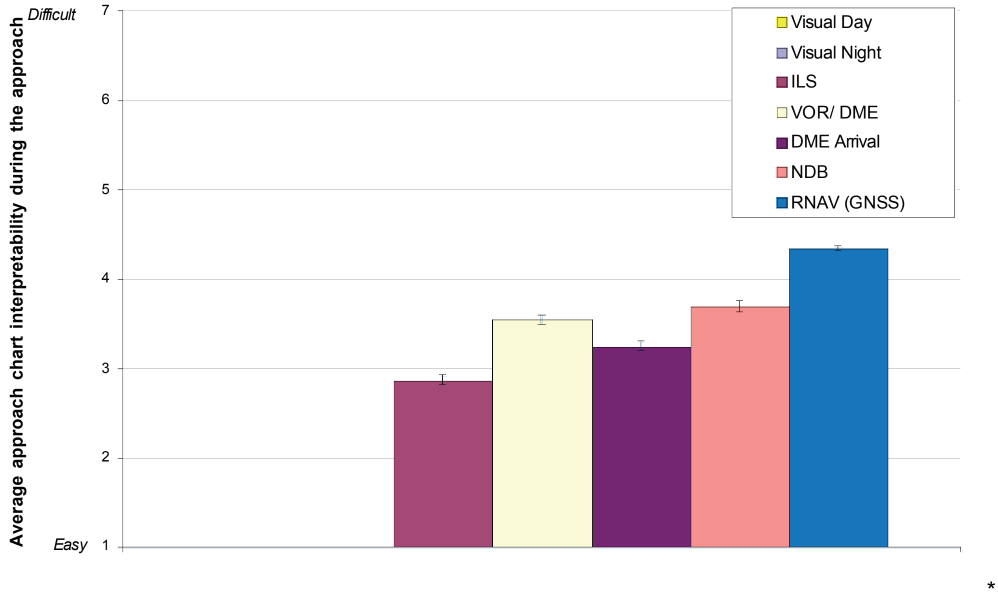
Other results

There were no differences between the number of loss of situational awareness experiences between pilots from multi-crew and single pilot operations for the RNAV (GNSS) approach and as interactions with the other approaches. There were also no differences based on whether the pilot mostly operated using a panel mounted GPS unit or an FMS integrated unit.

4.3.2 Approach chart interpretability

Respondents assessed the RNAV (GNSS) approach charts as being more difficult to read and more easily misinterpreted during the approach than the approach chart for each of the other approaches ($p<.001$), (Figure 19).

Figure 19: Mean (±1 SEM) approach chart interpretability*



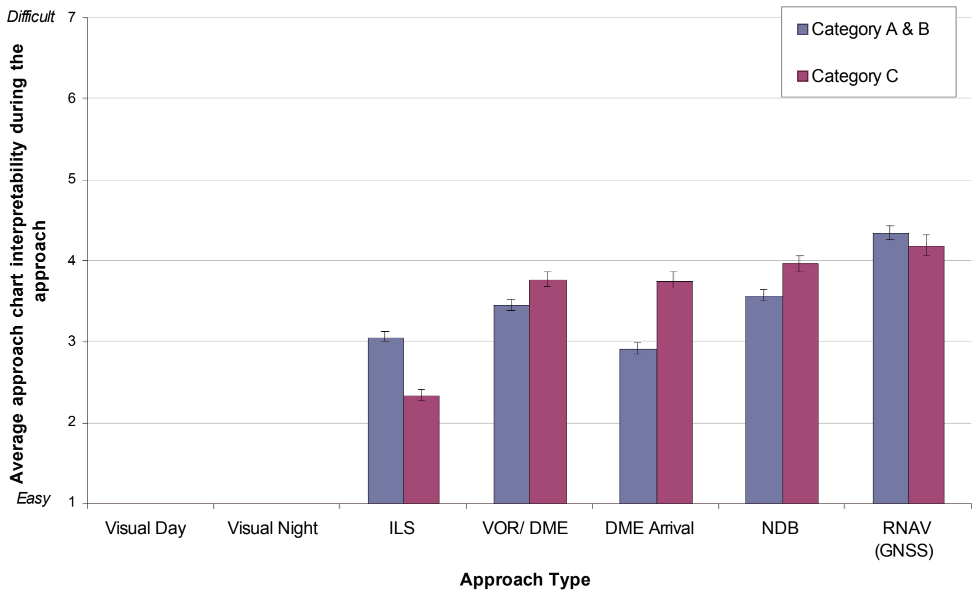
Note: Visual approaches do not have approach charts.

Aircraft performance category

Averaged across all approach types, approach chart interpretability was assessed as being more difficult by Category C aircraft pilots than it was by pilots from Category A and Category B aircraft ($p<.01$). There were no differences between Category A and Category B aircraft pilots averaged across the approaches.

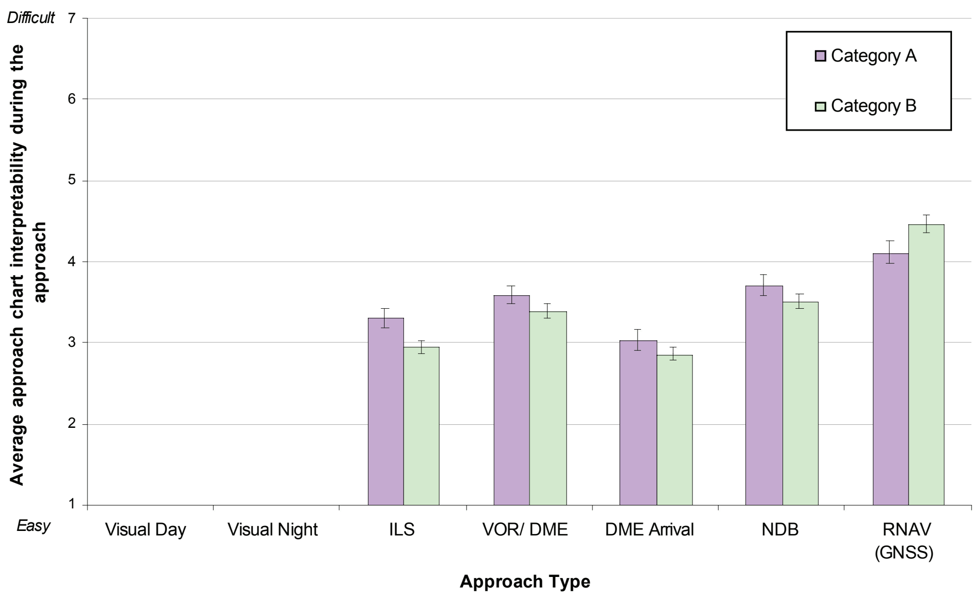
Although the RNAV (GNSS) approach chart interpretability was more difficult than the other approach types for all aircraft categories, this difference was smaller for Category C respondents compared with respondents from Category A and Category B aircraft for the DME arrival ($p<.001$), while it was larger for the Category C aircraft pilots for the ILS approach ($p<.01$), (Figure 20).

Figure 20: Mean (±1 SEM) approach chart interpretability assessments by aircraft performance categories (Cat A and Cat B combined)



The approach chart interpretability for the RNAV (GNSS) approach was assessed as being more difficult than the other approach charts by both the Category B aircraft pilots than the Category A aircraft pilots. However, this difference was greater for the Category B aircraft pilots than by the pilots from the slower Category A aircraft (Figure 21). This resulted in significant interactions with the ILS approach ($p<.001$) and the VOR/DME approach ($p<.01$).

Figure 21: Mean (±1 SEM) approach chart interpretability assessments by aircraft performance categories (Cat A and Cat B only)



Other results

There were no differences between RNAV (GNSS) approach chart interpretability between single pilot and multi-crew respondents, except compared with the ILS approach chart. That is, the more difficult assessments of the RNAV (GNSS) approach chart interpretability compared with the ILS approach chart was larger for the multi-crew pilots than the single pilot respondents due to differences in ILS chart assessments between the two groups ($p<.001$).

There were no significant correlations between the RNAV (GNSS) approach assessments and experience or recency levels. However, both the NDB and ILS approach chart interpretability assessments were negatively correlated with the number of these approaches conducted each year ($p<.001$). That is, the more NDB or ILS approaches completed each year, the less difficulty the pilot had interpreting the NDB or ILS approach chart, respectively.

Contributing aspects to approach chart interpretability

The most common contributions listed by respondents to approach chart interpretability are shown in Table 16. A full list, broken into aircraft performance categories, appears in the appendix in Table 27 on page 108.

Not having distance references to the MAPt throughout the approach and having distances referenced to the next waypoint was the most common reason (25% of respondents) the RNAV (GNSS) approach charts were reported as being difficult to interpret. A further 6% of respondents commented that the distance/altitude table could be improved.

Six percent of respondents, particularly from Category A and Category B aircraft (single and twin-engine propeller aircraft), indicated the waypoint names were too confusing (as they were all five letters long and differed only by the final letter). A further 5% indicated that the chart was generally too cluttered.

Despite the poorer interpretability assessments, 25% of respondents indicated that they considered the RNAV (GNSS) approach charts to be either acceptable or good.

Table 16: Number (and percentage[19]) of respondents noting aspects that contribute to the degree of *approach chart interpretability*

Aspects contributing to approach chart interpretability	Total
Distance to go needs analysis	**117 (25.3%)**
Good/No problems with approach chart	**117 (25.3%)**
Complex/poor interpretability	**33 (7.1%)**
Descent profile (distance/alt table) difficult to interpret	**28 (6%)**
Confusing waypoint names (Long names differing by one letter only)	**28 (6%)**
Cluttered/crowded	**23 (5%)**

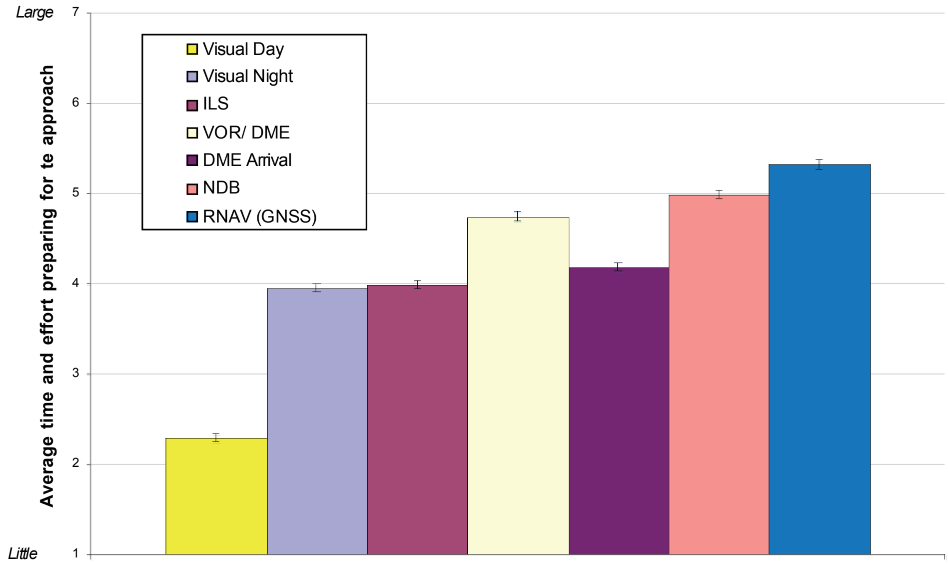
4.3.3 Time and effort preparing for the approach

Time and effort preparing for the approach was defined on the survey as including programming flight instruments and briefings. On average, respondents assessed the RNAV (GNSS) approach as requiring statistically ($p<.001$) more time and effort

19 Percentage of respondents answering this question.

preparing for the approach than each of the other approaches (dark blue bar in Figure 22).

Figure 22: Mean (±1 SEM) of time and effort preparing for the approach

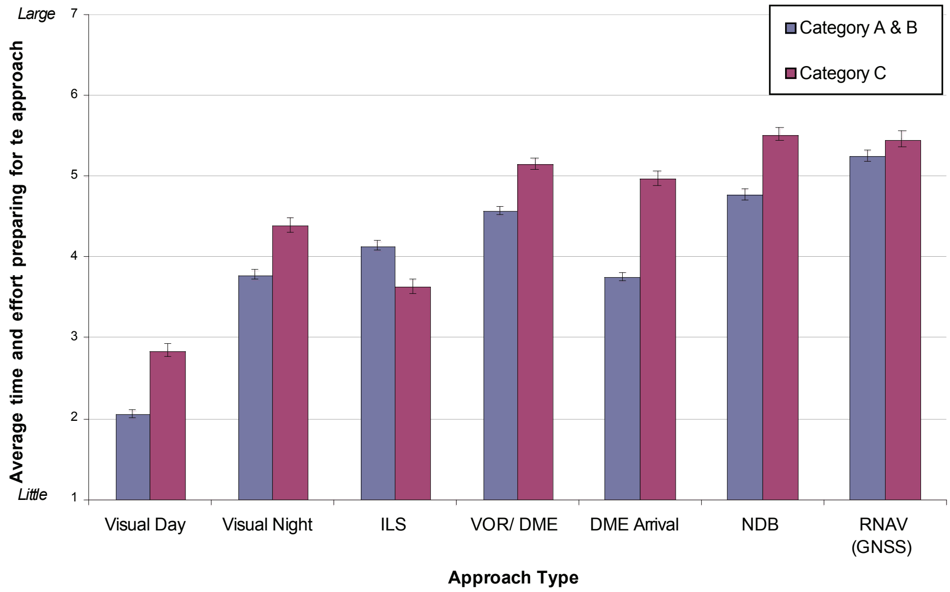


Aircraft performance category

Averaged across of the approach types, the Category C aircraft pilots indicated more time and effort was involved preparing for an approach than did pilots from Category A and Category B aircraft ($p<.001$). There were no statistical differences between respondents from Category A aircraft compared with those from Category B aircraft.

The longer time and effort preparing for an RNAV (GNSS) approach compared with the other approaches was more pronounced for the Category A and Category B aircraft respondents than for the Category C respondents ($p<.001$). Furthermore, it can be seen in Figure 23 that unlike the pilots from the slower Category A and Category B aircraft, the time and effort preparing was similar between all of the non-precision approaches for the predominantly high capacity airline Category C pilots.

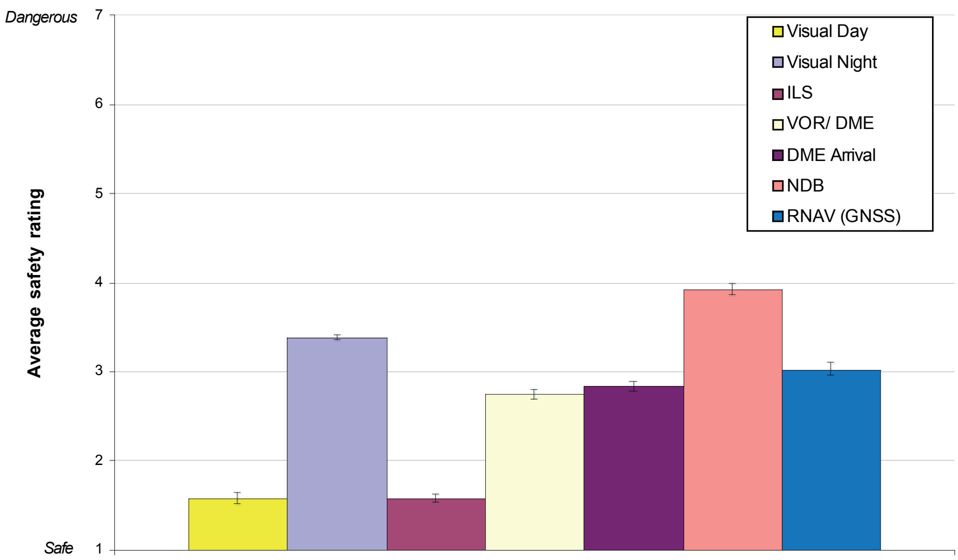
Figure 23: Mean (±1 SEM) time and effort preparing for the approach by aircraft performance categories (Cat A and Cat B combined)



4.4 Perceived safety

The average safety assessments indicated the RNAV (GNSS) approach (dark blue bar in Figure 24) was perceived as being more dangerous than each of the other approaches (p<.001) except the visual (night) and NDB approaches. There were no differences in the safety assessments between the RNAV (GNSS) approach and the visual (night) approach (light blue bar in Figure 24). However, the NDB approach (salmon coloured bar in Figure 24) was assessed as significantly more dangerous than the RNAV (GNSS) approach (p<.001).

Figure 24: Mean (±1 SEM) perceived safety during the approach

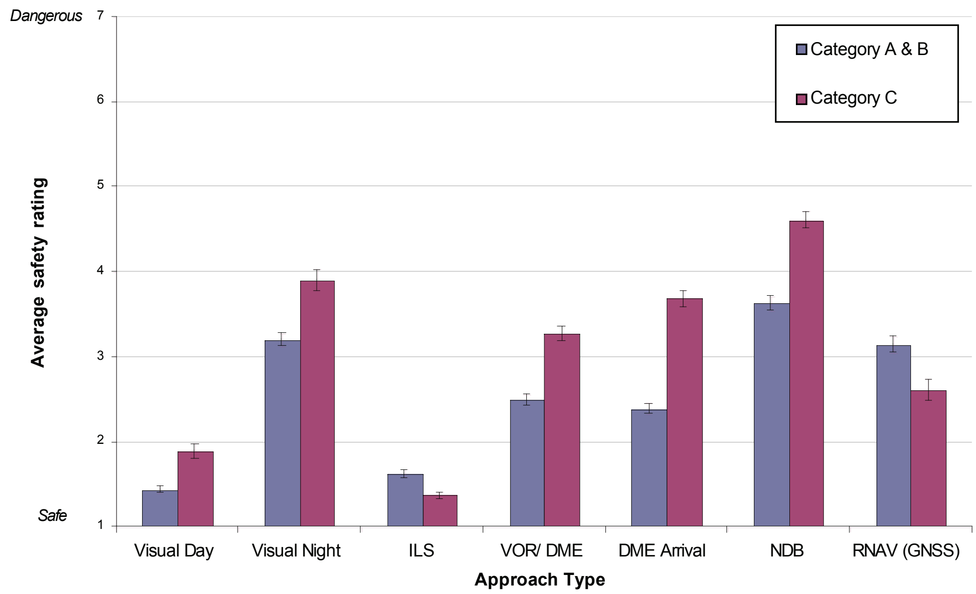


Aircraft performance category

Averaged across all of the approach types, the respondents from Category C gave higher assessments of perceived risk than did pilots from Category A and Category B aircraft ($p<.001$).

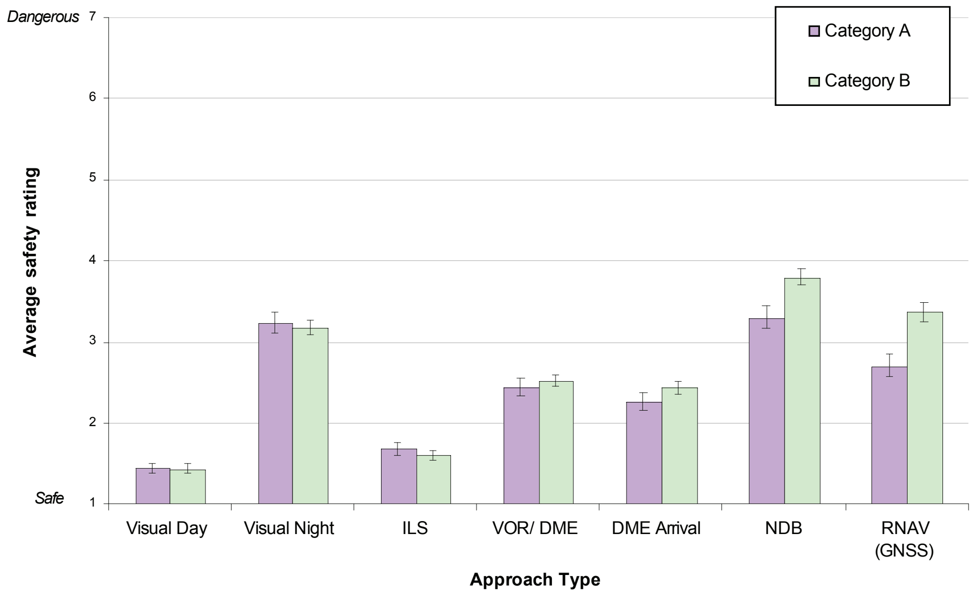
As can be seen in Figure 25, the RNAV (GNSS) approach was assessed as less safe than the visual (day) approach by the Category C aircraft pilots, but to a lesser extent than from pilots from the slower Category A and Category B aircraft ($p<.001$). In addition, the RNAV (GNSS) approach was assessed as safer than the remaining approaches (except ILS) by Category C aircraft pilots (predominantly from high capacity airlines), but only the NDB approach was assessed as less safe than the RNAV (GNSS) approach by the pilots of the slower aircraft categories ($p<.001$). There was also a significant interaction with the NDB approach due to more extreme NDB assessments (is terms of being less safe) over the RNAV (GNSS) approach for the Category C aircraft pilots than from Category A and Category B aircraft pilots.

Figure 25: Mean (±1 SEM) perceived safety for the approach by aircraft performance categories (Cat A and Cat B combined)



There were no significant differences averaged across the approach types between Category A and Category B aircraft respondents. However, as can be seen in Figure 26, the Category B (larger twin-engine propeller) aircraft respondents assessed the RNAV (GNSS) approach as more dangerous than both the visual (day) and ILS approaches to a greater extent than did the pilots from the slower Category A (single engine and smaller twin-engine) aircraft ($p<.01$).

Figure 26: Mean (±1 SEM) perceived safety by aircraft performance categories (Cat A and Cat B only)



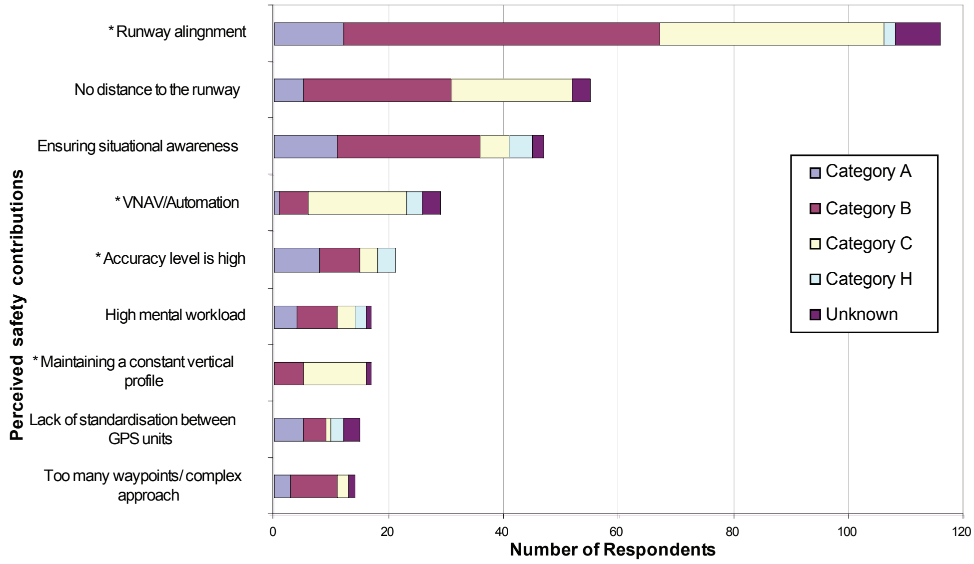
Contributing aspects to perceived safety

A list of the most common contributions to RNAV (GNSS) approach perceived safety appear in Figure 27. A full list appears in the appendices in Table 28 on page 110.

The most common reason that influenced respondents perceptions of lower RNAV (GNSS) approach safety were the lack of distance to the MAPt information throughout the approach (14%) and not being able to ensure situational awareness (12%).

In contrast, the runway alignment of RNAV (GNSS) approaches was seen as a positive contribution towards safety by 30% of respondents. Category C aircraft pilots (from predominantly high capacity jet airliners) also indicated that automation and VNAV in particular improved the safety of RNAV (GNSS) approaches (14%). Pilots from this category also commented that maintaining a constant profile down to the MAPt also improved safety (9%).

Figure 27: Number of respondents noting aspects that affect *perceived safety* of the approach

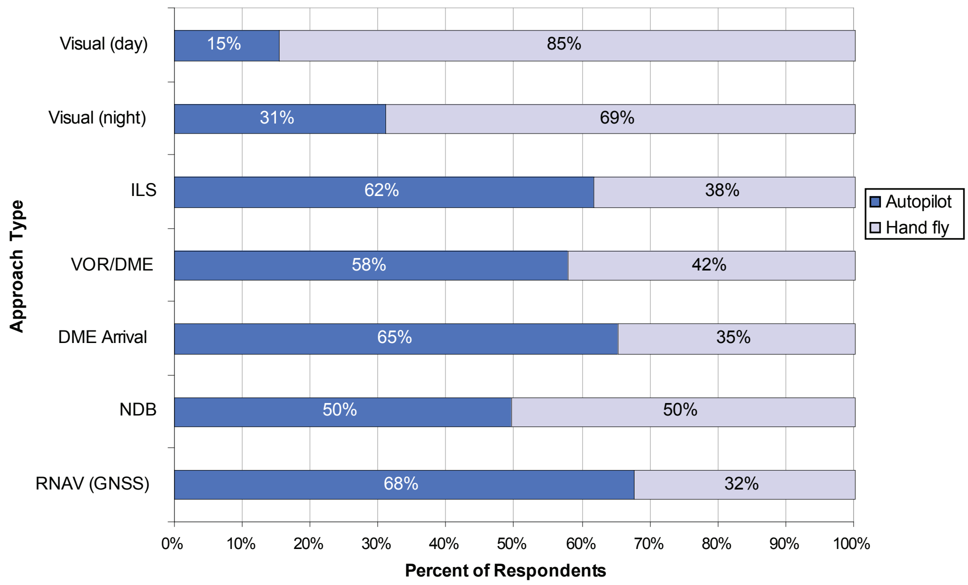


** Indicated contribution improves safety.*

4.5 Autopilot

All instrument approaches except for the NDB had a higher proportion of respondents using an autopilot than hand-flying ($p<.001$). The NDB approach had a similar proportion using the autopilot as hand-flying. In contrast, the two visual approaches had a significantly higher proportion of respondents hand-flying the approach than using an autopilot ($p<.001$).

Figure 28: Autopilot use flying approach

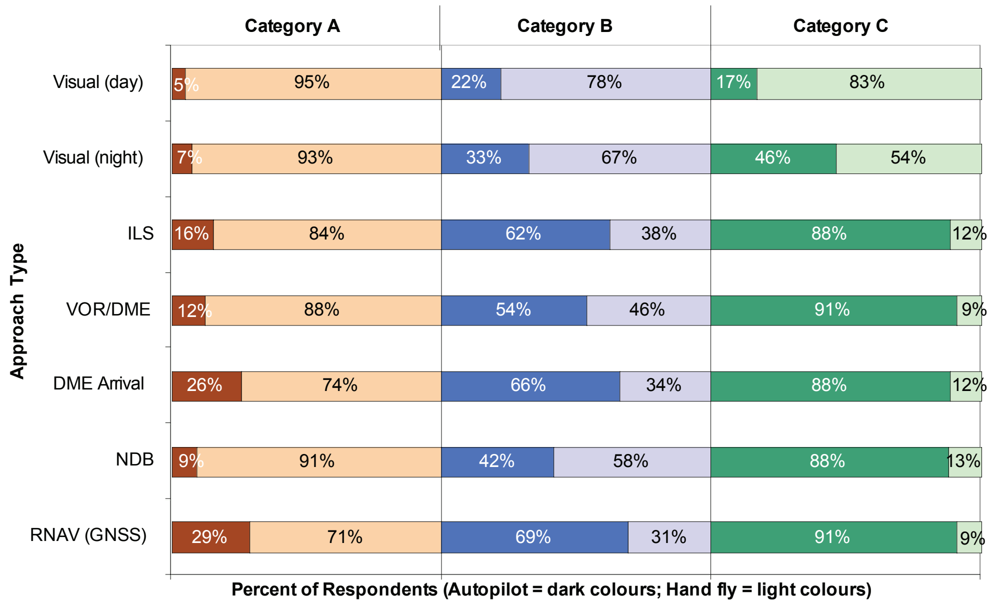


It can be seen in Figure 29 that the majority respondents from Category A (typically small single and twin-engine aircraft) operated every approach by hand-flying ($p<.001$).

In contrast, the only approaches with more respondents hand-flying for Category B aircraft (generally larger twin-engine propeller aircraft) were the visual (day) approach (p<.001) and NDB (p<.01). The VOR/DME had the same proportion of Category B aircraft pilots' hand-flying and using autopilot, while all other approaches, including the RNAV (GNSS) approach, had slightly more pilots using an autopilot (ranging from 62 to 69%).

Category C aircraft pilots (predominantly from high capacity jet airliners) had over 87% of all pilots using an autopilot on each instrument approach (p<.001), but had 83% of pilots hand-flying visual (day) approaches (p<.001). The visual (night) approaches had about equal proportion of Category C aircraft pilots using an autopilot and hand-flying.

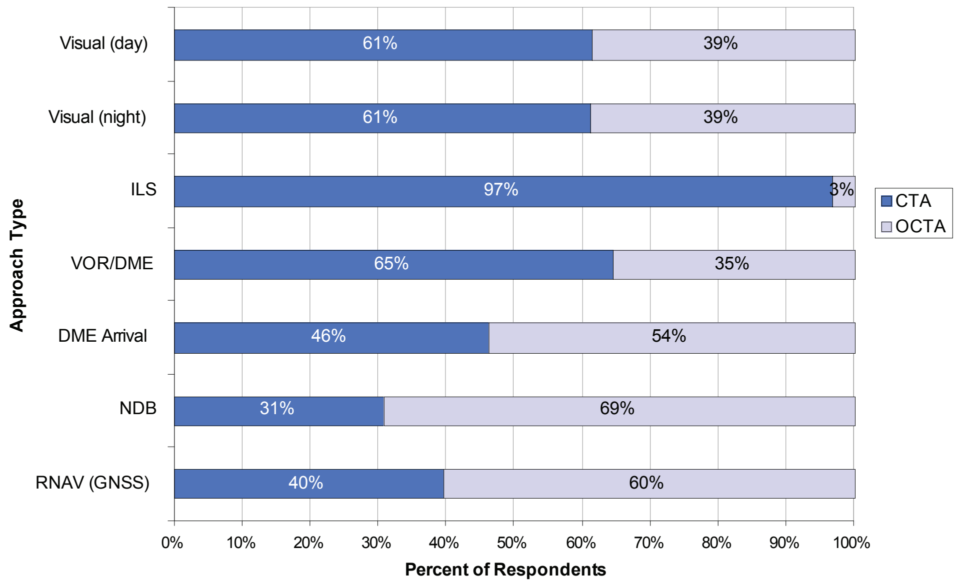
Figure 29: Autopilot use by aircraft performance category



4.6 Airspace

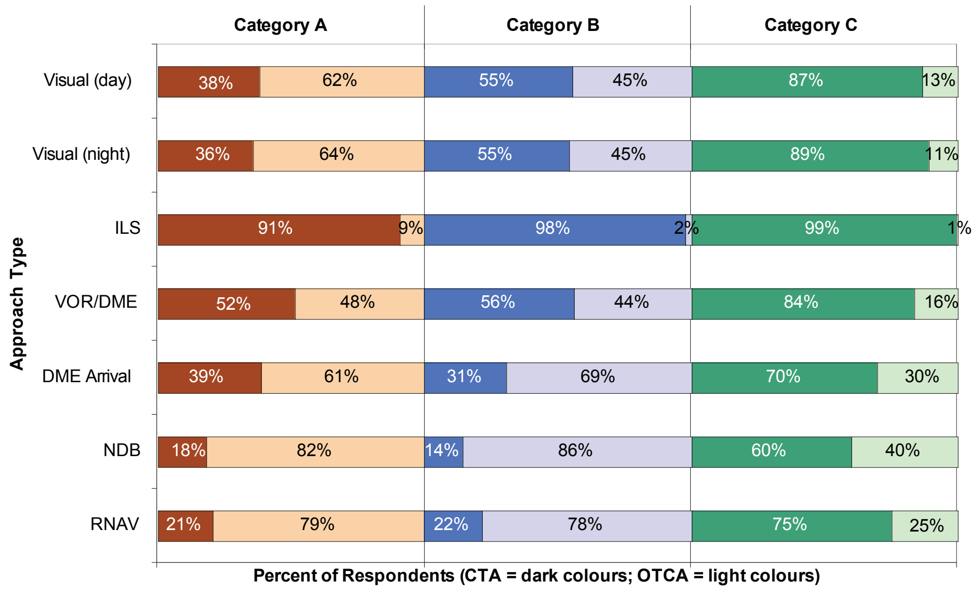
It can be seen in Figure 30 that the majority of respondents operated RNAV (GNSS) approaches (60%) and NDB approaches (69%) outside controlled airspace (OTCA), while visual approaches (61%), ILS (97%) and VOR/DME (65%) approaches were conducted in controlled airspace (CTA) by most respondents.

Figure 30: Airspace mainly used for each approach type



The majority of RNAV (GNSS) approaches were conducted outside controlled airspace by the Category A and Category B aircraft (79 and 78% respectively), (p<.001). However, in contrast to these generally slower propeller aircraft, most (75%) respondents from the high capacity jet dominated Category C conducted RNAV (GNSS) approaches mostly in controlled airspace (p<.001).

Figure 31: Airspace mainly used for by aircraft performance category



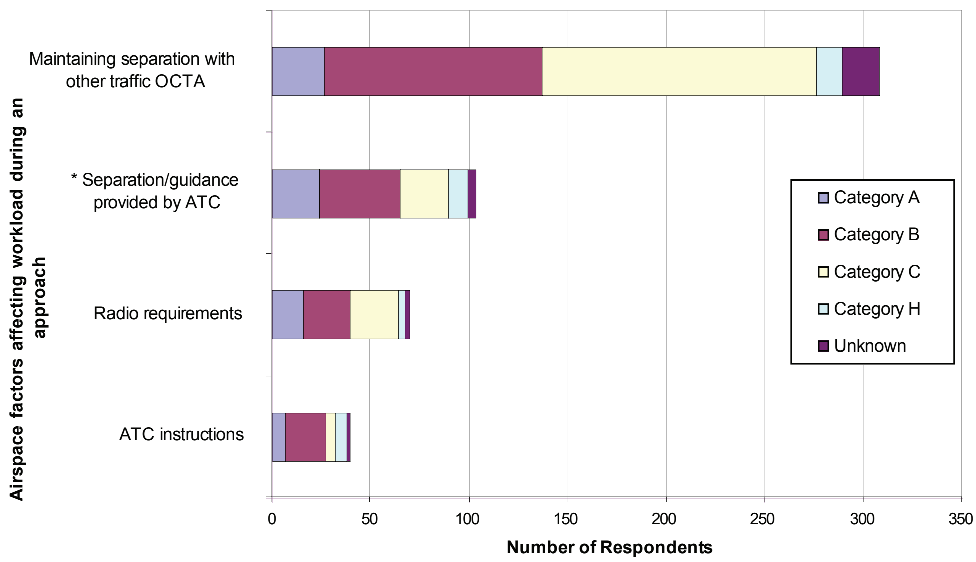
The majority of respondents indicated that the type of airspace influenced pilot workload during an approach (p<.001), (Table 17). However, for Category A aircraft pilots (from single engine and smaller twin-engine aircraft), there was no statistical difference between the proportion of respondents who agreed and disagreed.

Table 17: Number of respondents indicating that type of airspace impacts on their workload during an approach

Airspace impacts workload	Cat A	Cat B	Cat C/D	Cat H	Not specified	Total
Yes	79 (57.2%)	194 (72.1%)	211 (91.7%)	31 (75.6%)	40 (74.1%)	**555 (75.8%)**
No	59 (42.8%)	75 (27.9%)	19 (8.3%)	10 (24.4%)	14 (25.9%)	**177 (24.2%)**

The most common reasons airspace affected workload during an approach are presented in Figure 32, with the full list appearing in the appendix in Table 31 on page 118. The majority (61%) of respondents that indicated that airspace did influence workload reported that this was due to the monitoring and maintenance of traffic separation outside controlled airspace (Figure 32). Traffic separation and guidance by ATC in controlled airspace influenced workload for 20% of respondents, and Category A aircraft pilots (34%) in particular. Fourteen percent indicated radio requirements, including the completion of radio calls, radio distractions, radio clutter and poor radio communications. Instructions from ATC, other than traffic separation, were indicated by 7.7% of respondents. These included ATC instructions which resulted in too little time to prepare the aircraft for the approach; distractions by ATC; continually talking with ATC; responding/monitoring ATC instructions; no flexibility on the approach due ATC instructions; and ATC instructions that failed to take into consideration an aircraft performance category.

Figure 32: Number of respondents noting aspects of airspace that influence approach workload



** Indicated aspects reduces workload.*

4.7 Aerodromes

Participants were asked to list the most difficult RNAV (GNSS) approaches that they have experienced. As not all participants specified individual approaches to runways, the list in Table 18 is grouped only by aerodrome names.

Table 18: Most difficult RNAV (GNSS) approaches

Aerodrome	Number of Responses	Percentage of Respondents
Canberra	56	23.1%
Gladstone	26	10.7%
Lockhart River	14	5.8%
Gold Coast	13	5.4%
Albury	11	4.5%
Camden	10	4.1%
Wollongong	10	4.1%
Cooma	9	3.7%
Tumut	9	3.7%
Lismore	9	3.7%
Cairns	9	3.7%
Mount Hotham	9	3.7%
Bankstown	9	3.7%
Adelaide	9	3.7%
Lilydale	8	3.3%
Townsville	8	3.3%
Ballina/Byron Gateway	8	3.3%

The frequency of the aerodromes being listed by respondents would have been influenced by how many of the respondents have had exposure to each of these aerodromes. As such, a rate per 1,000 movements into each aerodrome was calculated and is presented in Table 19 below. These calculations were done using domestic and regional air services movements provided by the Bureau of Transport and Regional Economics as these were the only data available for most of the range of aerodromes listed by respondents. As such, private flight movements to these aerodromes are not represented in these movement statistics, and so responses given by pilots with a private pilot licence were excluded from this analysis. Only aerodromes with more than 100 movements per year were included in this analysis.

Table 19: Most difficult RNAV (GNSS) approaches per 1,000 movements into the aerodrome*

Aerodrome	Number of commercial movements inbound during 2004-05 financial year	Number of responses per 1,000 commercial sectors*
Mount Hotham	116	60.34
Lockhart River	377	34.48
Gladstone	2659	9.4
Lismore	1380	6.52
Merimbula	1378	5.08
Bathurst	1089	4.59
Ballina/Byron Gateway	2462	3.25
Canberra	18431	2.98
Albury	4149	2.65
Mount Isa	1778	2.25

* Responses from private pilots not included and aircraft movements for private flights not included.

4.8 Difficult circumstances

The most difficult circumstances to conduct an RNAV (GNSS) approach are shown in Table 20. The full list of responses and details from each aircraft performance category can be seen in the appendix in Table 30 on page 115.

The most common responses involved conditions that can apply to all approaches and included poor weather conditions, turbulence, and night. Traffic considerations also rated highly. The most common operational circumstances included single pilot operations, fast approaches, and hand-flying the aircraft.

Factors specific to RNAV (GNSS) approaches included multiple and/or short steps within an approach, followed by steep approaches and the missed approach. Another factor was late clearances given by air traffic control (ATC) that result in a rushed preparation and briefing for the approach. This was a particularly common response from the generally high capacity Category C pilots (33% of respondents). Radio communications, especially CTAF requirements, was also reported to make RNAV (GNSS) approaches more difficult, as did older styles of GPS equipment. These responses were more common for Category B (larger twin-engine propeller) aircraft pilots.

Table 20: Most difficult circumstances for an RNAV (GNSS) approach

Most difficult circumstances	Number (& %) of responses
Conditions	
Weather conditions poor	69 (13.9%)
Turbulent conditions	58 (11.7%)
Night	58 (11.7%)
Instrument meteorological conditions (IMC)	46 (9.3%)
Operations	
Single pilot operations	34 (6.9%)
Speed too fast (rushed or tailwind)	22 (4.4%)
Hand flying	19 (3.8%)
Approach	
Multiple (short) limiting steps/ complex approach design	46 (9.3%)
Steep approaches	20 (4%)
Missed approach	17 (3.4%)
Other circumstances	
Short notice from ATC or limited preparation time	85 (17.1%)
Traffic	78 (15.7%)
Outside controlled airspace	36 (7.3%)
CTAF requirement/radio communications	22 (4.4%)
Older GPS equipment being used/ no moving map display	20 (4%)
Not recently used (or unfamiliar) GPS equipment	15 (3%)

4.9 Improvements

The majority (82%) of respondents indicated that they thought aspects of the RNAV (GNSS) approach could be improved. This proportion was similar across aircraft performance categories.

A summary of the most common improvements suggested is provided in Table 21. For all responses and details from each aircraft performance category, see the appendix Table 29 on page 112.

The most common improvement response (40% of respondents) involved making reference to the distance to run to the MAPt (for the entire approach) on both the approach charts and the GPS/FMS, rather than only including distance to the next waypoint. Similarly, another 7% indicated the FAF could be removed as a distance-referenced waypoint, essentially giving distance to run to the MAPt from the intermediate fix.

Several respondents also indicated the naming convention of waypoints should be changed to minimise the chance of misreading a waypoint and subsequently loosing situational awareness. The main issue arising involved the Australian design of five letter waypoints with only the final letter differing for each waypoint within an approach.

Using the PANS-OPS optimum design criteria for all RNAV (GNSS) approaches and removing short and intermediate altitude restriction steps was also a common improvement suggestion. The most common approach design improvement was for lower minimas, while the main air traffic control improvement (mostly from Category C aircraft pilots) was to connect standard terminal arrival routes (STARs) with the commencement of RNAV (GNSS) approaches.

The most common aircraft capability improvement listed was some sort of vertical navigation guidance (such as VNAV). This response was the most frequent for Category B aircraft pilots (9.2%).

Table 21: Common suggested improvements to the RNAV (GNSS) approach

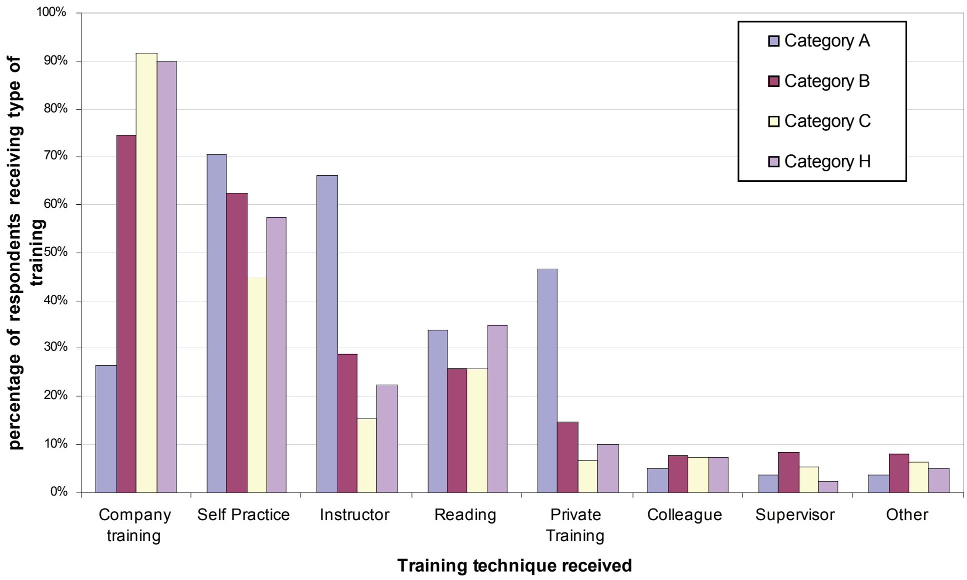
Suggested Improvements	Number (& %) of responses
RNAV Concepts	
Single distance to MAPt used for chart and GPS references	194 (40%)
FAF (and steps after FAF) removed from design (10 NM last segment)	34 (7%)
Naming convention of waypoints (more than 1 letter difference is needed for long waypoint names)	29 (6%)
Reduction in number of waypoints/steps /Removal of short steps	22 (4.5%)
Standard distances between all waypoints/ standard MAPt position	16 (3.3%)
Other improvements	
Chart improvements	99 (20.4%)
Vertical navigation capability	35 (7.2%)
Standard GPS design across manufacturers	32 (6.6%)
Lower minima	26 (5.4%)
Connect STARs with RNAV approaches	19 (3.9%)
GPS/FMS units made 'user friendly'/Reduced GPS/FMS inputs	17 (3.5%)

4.10 Training

Respondents were asked to indicate whether their RNAV (GNSS) approach training was adequate. Of the 700 respondents who answered, 86% indicated that it was, and 14% indicated that it was not. These proportions were similar across aircraft performance categories. The most common reasons given for training not being adequate were: not enough approach practice given (either in flight training or in a simulator) before the test and approval, or that the training was too rushed, or not given in a variety of conditions; and, the instructor did not have enough knowledge about the approach or equipment.

It can be seen in Figure 33 that most RNAV (GNSS) approach training was from company training and self practice for Category C (generally high capacity airline pilots) and Category B (typically larger twin-engine aircraft pilots). In contrast, pilots from Category A aircraft (generally small single and twin-engine aircraft) received their RNAV (GNSS) approach training mostly through instructors, self practice, and private training.

Figure 33: Type of RNAV (GNSS) approach training received by aircraft performance category*



* Note: Respondents could indicate more than one type of training.

Respondents who were flight instructors were asked to comment on which aspects of the RNAV (GNSS) approach were the most difficult for trainees to learn. Of the 166 responses, it can be seen in Table 22 that the most frequent responses were operation of the GPS, approach position awareness, and preparation for the approach.

Table 22: Aspects of RNAV (GNSS) approaches that are the most difficult for trainees to learn

Difficult to learn	Number (& %) of responses
Operation of GPS receiver	46 (27.7%)
Position in approach awareness/situational awareness	41 (24.7%)
Approach preparation	41 (24.7%)
Missed approach	25 (15.1%)
Maintenance of descent profile	25 (15.1%)
Aircraft handling	19 (11.4%)
Interpretation of distances (to waypoints not MAPt)	18 (10.8%)
Waypoint issues	15 (9%)
Completing operational requirements	14 (8.4%)
Holding patterns	7 (4.2%)
GPS mode awareness	5 (3%)
Chart interpretation	5 (3%)

4.11 Incidents

There were 49 respondents (7% or 1 in 15) who reported that they had been involved in an incident involving RNAV (GNSS) approaches. Fifteen respondents indicated that they had commenced the descent before the descent point due to a misinterpretation of their position, and a further three respondents indicated that they misinterpreted their position, but that this was discovered before they started to descend too early (Table 23). Five respondents discussed incidents involving a loss of situational awareness during the approach, generally for reasons other than misinterpreting the waypoint. (The 15 incidents involving descending before the descent point also represent loss of situational awareness.) A further four respondents indicated that they had descended below the profile and/or minimum segment steps.

Where information was available, most of these incidents occurred during line flying (39%) rather than during approach training (8%). However, as this question was not specifically asked, the time of the incident relative to their training was not obvious in most (53%) cases.

Table 23: Incidents during RNAV (GNSS) approaches

Incident Reason	Total
Descent commenced before the descent point	15
Other traffic considerations	9
Loss of situational awareness	5
Descended below approach profile	4
Aircraft systems failure	4
Waypoint misinterpretation	3
Completing other operational requirements	3
Operation of GPS receiver	2
Terrain considerations	1
Incorrect QNH selected	1
Other	2
Total	***49***

5 DISCUSSION

5.1 Pilot workload

Subjective pilot workload was estimated in this survey by three of the scales from the NASA-TLX subjective workload scale: mental workload; physical workload; and time pressure.

Averaged across all types of aircraft and operations, this survey clearly indicated that pilots perceived RNAV (GNSS) approaches to involve more mental workload, physical workload, and time pressure, than all other approaches except the NDB approach. The NDB approach received similar assessments to the RNAV (GNSS) approach.

The general trend described above was also found for pilots flying Category A (small single and twin-engine) aircraft and Category B (larger twin-engine propeller) aircraft. That is, that RNAV (GNSS) approaches were assessed as requiring more workload during the approach than each of the other approach types apart from the NDB approach. In contrast, pilots from the faster but generally more sophisticated Category C (jets and mostly high capacity airline type) aircraft with autopilot and VNAV capabilities considered the RNAV approach only to be more difficult than the ILS and visual (day) approaches, and have lower workload than the other approaches. The instrument landing system (ILS) was the only precision approach assessed in the survey.

An interesting finding across this survey was that respondents operating Category C aircraft generally gave higher assessments on the workload and other scales than did the respondents from the slower and generally less sophisticated aircraft categories. Similarly, respondents from multi-crew operations generally gave higher assessments than those from single pilot operations. These results are not particularly relevant for this discussion as subjective assessments were not (and should not be) directly compared across different groups of participants. Instead, only the relative differences within groups were compared across groups. However, it may be interesting to some readers that respondents from high capacity jet airline type aircraft and multi-crew operations generally gave higher assessments. Possible explanations of these results are that it could be due to more rigorous and frequent focus on matters related to safety within high capacity airline training and line operations, and/or a result of the faster, but more complex aircraft, and the more complex multi-crew environment.

Given that mental workload, physical workload, and time pressure, were all found to be higher for RNAV (GNSS) approaches and NDB approaches for the slower and less sophisticated Category A and B aircraft, but not for the faster and more sophisticated Category C aircraft, the sections below describe the reasons given by respondents why this was the case. Each section involves the contributions to only one of the specific workload scales. Before the differences affecting workload are outlined, however, it is worth noting some of the differences between aircraft performance categories that did *not* influence assessments.

RNAV (GNSS) approach workload assessments were *not* influenced by experience or recency levels (general or instrument), nor the number of RNAV (GNSS) approaches conducted per year. In contrast, ILS workload assessments were lower for respondents with longer experience levels and more ILS approaches conducted each year, and these differences were reflected in relatively higher ILS subjective workload assessments for slower aircraft categories. In addition, Category C (typically higher capacity airline) pilots operated with multi-crew and FMS equipped aircraft and the higher workload assessments from pilots from both multi-crew operations and FMS equipped aircraft for the RNAV (GNSS) approach (relative to other non-NDB approach types) were not as high as those from pilots from single pilot operations and aircraft with panel mounted GPS units. However, these trends were mostly a result of the Category C multi-crew pilots and FMS assessments, respectively, and not from the Category B multi-crew pilots or FMS assessments.

5.1.1 Mental and perceptual workload

The most common aspect of the RNAV (GNSS) approach offered by respondents as affecting mental workload was the fact that the GPS or FMS, and/or approach chart, do not reference distances to the missed approach point (MAPt) throughout the approach. That is, they display distances to the next waypoint, increasing mental workload in that the pilot requires more thinking time to undertake mental calculations to keep situational awareness during the approach. The RNAV (GNSS) approach is unique in that distances are referenced to waypoints rather than the runway or the missed approach point. This response was received from one quarter of the Category C aircraft pilots and 22% of the Category B aircraft pilots. Examples of responses included:

> Have to work out how your profile is going, then the only info on the GPS is related to the next fix means that the pilot has to focus more mental effort into interpreting the RNAV (GNSS) approach.
>
> Continual need to change navigation reference point - changing waypoints distance counts down to 0, then back to 5 on 3 occasions.

Another common response from the larger twin-engine Category B aircraft pilots (and, but to a lesser extent, pilots from the slower Category A aircraft), involved monitoring the descent and position during an approach and keeping situational awareness, along with maintaining a constant vertical gradient. This was related to ensuring the aircraft was at the correct waypoint and at the correct height and speed. However, this was a less common response for other pilots. This was probably due to the predominant use of autopilots and VNAV capability in Category C aircraft (predominantly high capacity jets) reducing the pilot workload involved in monitoring the descent.

RNAV (GNSS) approach designs that included varying waypoint and segment lengths, and/or designs with many limiting steps close together typically after the final approach fix, were a mentioned by 13% of respondents. This response was similar across aircraft performance categories. Reading and/or interpreting the approach chart was reported as contributing to mental workload by 10% of respondents across all aircraft categories. Ten percent of Category C (high capacity jet airline) aircraft pilots also mentioned that company briefing requirements for RNAV (GNSS) approaches increased workload.

5.1.2 Physical workload

Much of the physical workload contributions were reported as being from programming the FMS or GPS, and GPS/FMS manipulation in general. Differences between Category C aircraft pilots and those from Category A and Category B aircraft involved automation and the missed approach. That is, 28% of Category C aircraft pilots (predominantly from high capacity airlines) mentioned that automation (with a further 11% indicating VNAV specifically) reduced the amount of physical workload, but only 7% and 8% of pilots from the slower and less sophisticated Category A and Category B aircraft (respectively) reported the same. This probably reflects the generally greater levels of automation sophistication, as well as VNAV capabilities, on more complex and faster aircraft that are usually not present in most Category A and B aircraft.

In contrast, 8% and 7% of Category A and B (respectively) aircraft pilots reported the missed approach during an RNAV (GNSS) approach contributed towards physical workload, but only 2% of Category C reported the same. Missed approaches were generally reported as a significant contributor to physical workload due to amount of GPS manipulation (button pushing) involved to initiate a missed approach, with this 'head-down' time occurring at a safety critical moment in the approach. It is possible that autopilots and FMS equipment in Category C present a lower workload burden in the missed approach.

A further contribution to physical workload across all aircraft categories was configuring the aircraft during the approach (9% of responses). Many respondents indicated that early configuration was needed to ensure that physical workload did not get too high. Appropriate company procedures for commercial pilots can be used to ensure this is achieved, and high capacity RPT operators' procedures designed to ensure this probably also reduced the Category C aircraft pilots' assessments of physical workload.

5.1.3 Time pressure

The most common (20% of respondents) contribution to time pressure was RNAV (GNSS) approach designs that involved irregular segment lengths (other than 5 NM) and/or those with additional steps occurring close together. The PANS-OPS criteria sets the waypoint distance limits to be between 2 and 10 NM, with an optimum length of 5 NM. Airservices Australia designs RNAV (GNSS) approaches in accordance to this criteria and have reported that nearly 78.5% of RNAV (GNSS) approaches in Australia have 5 NM waypoint distances. Some of these, however, may have additional limiting steps (up to three) within each segment, especially the segment from the FAF to the MAPt where the profile comes closest with terrain.

About a quarter of all Category A and Category B aircraft pilots reported that these irregular and multiple steps increased time pressure compared with only 11% of Category C respondents. Examples of how multiple and short steps affect time pressure include:

> If an approach is complex (many height restrictions), time is reduced for other tasks like checklists and traffic management.

> Some RNAV approaches eg Gladstone have so many descent steps there is difficulty for non-flying pilot to complete all duties i.e. radio calls, cockpit calls and checklists.

The issue of multiple and short steps affecting time pressure was possibly more common for the slower aircraft due to the airspace and aerodromes that respondents from the different aircraft categories operated in. Category C respondents generally operated their high capacity jets in controlled airspace (CTA) and to the larger city aerodromes. Apart from Canberra, no other major city aerodrome was listed as having a difficult RNAV (GNSS) approach. Furthermore, operating outside controlled airspace was found to increase pilot workload, giving additional time pressure to Category A and Category B aircraft pilots as this was where they primarily operated RNAV (GNSS) approaches.

Late clearance to fly an RNAV (GNSS) approach was listed by 20% of the high capacity airline respondents but only 3% of Category A and Category B aircraft pilots. This reflects the dominance of CTA in Category C generally high capacity airline operations and possibly more FMS/GPS setting-up time and briefing requirements (as 10% and 13% of Category C respondents indicated FMS setting up and briefing respectively, affected time pressure). The minimal mention of briefing by pilots from the two slower aircraft categories also suggests the possibility that less approach briefing for RNAV (GNSS) approaches may occur in Category A and Category B operations. Respondents from all aircraft categories indicated that early preparation reduces time pressure (8.4% of all respondents).

Correlation results showed that as a pilot's experience using RNAV (GNSS) approaches increased, the higher the time pressure assessments were. It could be expected that pilots who have been using these approaches longer or more often would perceive less time pressure, as was found for ILS, NDB, and DME arrival approaches, suggesting experience gives pilots an appreciation of what is involved during an approach that may not be apparent to a pilot less experienced with RNAV (GNSS) approaches. Several respondents also indicated that inexperienced pilots mistakenly look upon RNAV (GNSS) approaches as easy.

5.1.4 Subjective workload summary

It is clear that pilots outside of high capacity regular public transport airline operations that generally operate slower but less sophisticated aircraft find the RNAV (GNSS) approach to be as difficult as the NDB approach and more difficult than other approaches. That is, for pilots operating Category A and B aircraft (typically single and twin-engine propeller aircraft), perceived workload (mental workload, physical workload, and time pressure) was higher during an RNAV (GNSS) approach compared with any other approach apart from the NDB. The NDB approach, which received similar mental workload and time pressure assessments and higher physical workload assessments compared with the RNAV (GNSS) approach, is a complicated procedure based on old technology and Airservices Australia has stated that they will be phased out in Australia by 2012 to be replaced by RNAV (GNSS) approaches.

The differences between the perceived pilot workload from pilots from Category C and those from Category A and B aircraft was likely have been a result of aircraft automation, possibly the type of airspace used, and possibly greater briefing requirements and better training. The majority of Category C aircraft pilots (predominantly from high capacity jet airlines) indicated they conducted instrument approaches using an autopilot, while only just over half of Category B (larger twin-engine propeller) aircraft pilots and a minority of Category A (single and smaller twin-engine) aircraft pilots indicated this. Further, Category C aircraft generally have more sophisticated autopilot systems, and furthermore, generally have vertical navigation systems like the VNAV function. As such, the predominant use of autopilot within this aircraft performance category may have reduced workload assessments for the RNAV (GNSS) approach. For the open-end questions, 7% of pilots from Category C indicated that automation did reduce workload.

Pilots from Category C also primarily (75%) used RNAV (GNSS) approaches in controlled airspace, while Category A and Category B aircraft pilots mostly experienced them outside controlled airspace (21%). Although the Category A and B aircraft pilots also operate outside controlled airspace (OCTA) to about the same extent for many of the other approaches (with the most notable exception being ILS approaches), if pilot mental workload is already towards the upper limits of the pilot's attentional capacity when not using an autopilot and/or VNAV, the addition of traffic monitoring and separations and radio broadcasts OCTA will increase the chance that pilot workload limits are reached during the RNAV (GNSS) approach for Category A and Category B aircraft pilots.

5.2 Situational awareness issues

5.2.1 Experiences of losses of situational awareness

Overall, respondents indicated they have had trouble maintaining situational awareness more often on the RNAV (GNSS) approach than each of the other approaches except for the NDB approach.

In line with the above finding, pilots from Category A (single and smaller twin-engine) aircraft and especially pilots of Category B (larger twin-engine propeller) aircraft, indicated they had lost situational awareness during an RNAV (GNSS) approach more often then any other approach except the NDB approach. In contrast, Category C (typically high capacity jet airline) aircraft pilots experienced losses of situational awareness on RNAV (GNSS) approaches less often or at a similar frequency to most approaches, and only lost situational awareness more often on RNAV (GNSS) approaches than on ILS and visual (day) approaches. Again, this may have reflected the level of automation within these aircraft as well as high capacity RPT airline procedures and training.

5.2.2 Approach chart interpretability

Approach chart interpretability was assessed as more difficult for the RNAV (GNSS) approach than all other approaches, and by all aircraft performance categories. Unlike the NDB and ILS approach chart, interpretability did not increase with the number of approaches conducted per year.

The most common issue respondents had with the approach chart design was that it referenced distances to each waypoint and did not include continuous distance references to the missed approach point (MAPt) unlike other charts such as the DME. At the bottom of the profile diagram on the charts, there are limited displays of distances to the MAPt (see Section 8.1 on page 84 for examples), but the respondents did not consider that they were adequate for pilot needs, especially as they do not appear in the distance/altitude table. This issue was reported to lead to confusion, loss of situational awareness, and increased workload and time pressure. In total, 25% of all respondents indicated that distance to run should be included in the charts, while this was the most common for Category C aircraft pilots (37% of respondents). A further 6% of all respondents (and 8% of Category C aircraft pilots) indicated that the altitude/distance table in particular was difficult to interpret, again mostly due to the changing distance reference points.

Five percent of respondents indicated that the charts were difficult to interpret due to the waypoint naming convention. That is, each waypoint had been given a five letter designator, with the first four letters being the same for every waypoint in an approach (three letter aerodrome designator plus a one letter cardinal indicator). Pilots reported that they had difficulty distinguishing between the segments as all waypoints looked so similar (as only the fifth letter in the waypoint name was different) when quick glances were made to the approach chart during an approach, or in poor light conditions at night, or in turbulence. Becoming confused about the current position in an approach can easily result from such an error. An example of these responses was:

> Waypoints can only be differentiated by last letter for example BBNWA - BBNWI -BBNWF - BBNWM – BBNWN. At a quick glace (scan) and I find it difficult to keep track of which segment I am in.

Despite the more difficult assessments averaged across pilots, 25% of pilots indicated that they had no difficulties reading the RNAV (GNSS) approach chart, or that they considered the charts to be good.

5.2.3 Approach preparation

The amount of time and effort required to prepare for an RNAV (GNSS) approach was reported to be higher than for all other approaches for all aircraft categories, although this was only marginally more for Category C aircraft pilots compared with the other non-precision approaches.

5.3 Perceived safety

Overall, respondents indicated that they perceived the RNAV (GNSS) approach as safer than an NDB approach, equivalent to a visual approach at night, but less safe than all other approaches included in the survey.

Category A and Category B aircraft (typically single and twin-engine propeller aircraft) respondents assessed the NDB approach as the least safe of all approaches listed. They also assessed the RNAV (GNSS) approach and the visual (night) approach, although more safe than the NDB, as less safe than the other approaches. In contrast, pilots from the faster and more sophisticated Category C jet aircraft assessed the RNAV (GNSS) approach as less safe than the ILS and visual (day) approaches, but safer than other approaches. Pilots from Category C aircraft, mostly from high capacity airlines, indicated that automation, and the VNAV function in particular, increased safety. The general lack of availability of automation with vertical profile display in Category A and Category B aircraft was probably a significant contribution to the differences in perceived safety assessments between the aircraft categories.

The most common aspects listed as reducing perceived safety of the RNAV (GNSS) approach were the lack of a single distance information to the missed approach point (or runway) throughout the approach, requiring the calculation of distance information during the approach (17% Category C and 16% of Category B respondents). Similarly, trouble maintaining situational awareness was stated as reducing safety levels of the RNAV (GNSS) approach by Category A and Category B aircraft pilots (19% and 15% of respondents, respectively), but less so for Category C aircraft pilots (4%). This corresponds with the situational awareness assessments. The complexity of the RNAV (GNSS) approaches in terms of the number of segments was reported by Category A and Category B aircraft pilots (5%), but not Category C aircraft pilots. Additionally for Category A single engine and smaller twin-engine aircraft pilots, the lack of standardisation between GPS receivers (9%) and the need to be familiar with each RNAV (GNSS) approach (7%) also contributed to reduced safety assessments.

After reaching the minima, the RNAV (GNSS) approach differs from the other non-precision approaches in that the PANS-OPS design criteria specifies a maximum of 15 degrees offset between the final approach heading and the runway (or up to 20 degrees in the case of Category A and B aircraft), eliminating the need for a circling approach for all RNAV (GNSS) approaches. This runway alignment of RNAV (GNSS) approaches was reported as increasing safety by 30% of respondents.

Respondents were asked to rate approach types from the initial approach fix down to the minima. RNAV (GNSS) approaches were perceived as less safe than other non-precision approaches apart from the NDB, but circling approaches were perceived by 30% of respondents to be more dangerous. As such, it is unclear to what extent perceived safety assessments were influenced by the runway alignments of RNAV (GNSS) approaches.

5.4 Conditions and locations

5.4.1 Difficult circumstances

The most common difficult circumstance, mostly identified by Category C aircraft pilots, was late clearance to conduct an RNAV (GNSS) approach by air traffic control (ATC). This was a result of the extensive briefing and FMS preparation requirements in high capacity RPT operations for the RNAV (GNSS) approach. These requirements are to ensure that crews are adequately prepared for the approach and to ensure that the aircraft flight systems have been set correctly and cross checked. The latter requires adequate time, without rushing, to minimise the potential for crew error. Late ATC clearance can reduce the effectiveness of these defences. Assessments for the amount of time and effort taken to prepare for an RNAV (GNSS) approach also indicated that pilots take longer to prepare for them than for the other approaches. Short sectors also limit preparation time and were mentioned by 17 respondents. A typical example concerning late ATC clearance was:

> [RNAV (GNSS) approaches] take longer to set up than conventional approaches - due to FMS workload, checking and etc, therefore require longer briefing time. Yet in current practice, even if you ask for RNAV (GNSS) approach, ATC are unable to give clearance until approaching TOP descent - especially critical approaching Adelaide. Where clearance given w/in 80nm of Top descent.

Single pilot operations were mentioned by 7% of respondents who indicated that RNAV (GNSS) approaches can be extremely difficult to conduct without a support pilot, or if the support pilot is occupied by other duties. Fast approaches, mentioned by 4% of respondents, result in more time pressure and increased workload as each step of the approach occurs more quickly. Hand-flying the aircraft (mentioned by 4% of respondents) was also noted as increasing workload for the pilot flying as an autopilot turns the pilot's role into one of monitoring the aircraft's position rather than monitoring and controlling its position.

The main factor specific to the design of RNAV (GNSS) approaches was multiple and/or short steps. These designs were the result of high terrain close to the runway. They also featured in the aerodromes that respondents indicated were the most difficult (see below). Multiple and/or short steps make flying the approach difficult because of two reasons. Firstly, as most (78.5%) RNAV (GNSS) approaches in Australia follow a 5 NM segment design, approaches outside of this design are less commonly experienced by the pilot population. Secondly, the short segments and intermediate steps require additional pilot actions. An aircraft's altitude alerting system (if available) is generally set for each altitude limit (step), the pilot must undertake additional profile checks and adjustments to ensure altitude limits are not broken, and additional mental calculations are needed. More steps also make the chance of reduced situational awareness about which segment the aircraft is currently in more likely.

Radio communications, especially common traffic advisory frequency (CTAF) requirements, were reported to make RNAV (GNSS) approaches more difficult. This was because they occupy the pilot, either the pilot flying for solo operations or the support pilot in multi-crew operations, leaving less attentional capacity to concentrate on the approach. This is also the case when traffic is heavy in the airspace requiring monitoring and when outside controlled airspace where self managed traffic separation is an additional task that pilots must undertake. Additional requirements such as these can effectively turn a two-crew operation into a single pilot approach, increasing the workload for the pilot flying and increasing the chance the support pilot will lose situational awareness of their position on the approach.

Category B (larger twin-engine propeller) aircraft pilots also mentioned that older styles of GPS equipment increased the difficulty of conducting RNAV (GNSS) approaches. These units generally had small screens and were inappropriate to display a moving map during the approach. The latter was considered by several respondents to be the main weakness of these older units as they considered the moving map display helps the crew maintain situational awareness.

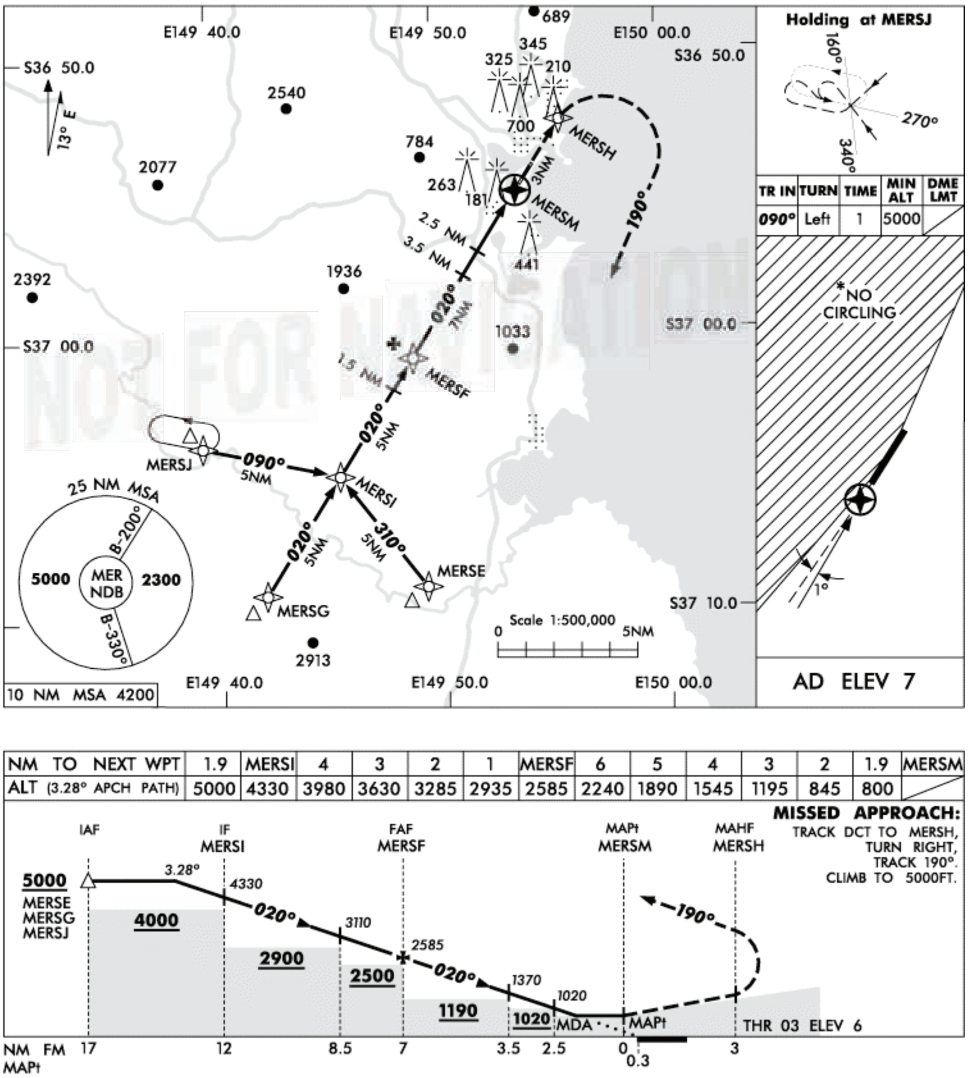
5.4.2 Aerodromes

The aerodromes assessed in this survey as having the most difficult RNAV (GNSS) approaches (corrected for aerodrome activity) fall into one of three categories. Firstly, many of these approaches had multiple minimum segment altitudes (steps) within the final segment from the FAF to the MAPt, and segment lengths not complying with the 5 NM PANS-OPS optimum. An example of such a profile is shown for Merimbula runway 03 in Figure 34. Approaches listed as difficult that fall into this category include Lockhart River 12; Gladstone 10; Merimbula 03; Canberra 30; Albury 25.

Multiple, short, and irregularly spaced steps, was the most common difficult circumstance associated with RNAV (GNSS) approach design listed by respondents. This was also listed as the most common reason why pilots experience time pressure.

Furthermore, it was one of the most common contributions to mental workload, physical workload, lack of approach chart interpretability, and lack of perceived safety.

Figure 34: Merimbula runway 03 RNAV (GNSS) approach showing multiple minimum segment altitudes per segment with waypoints other than the 5 NM optimum.

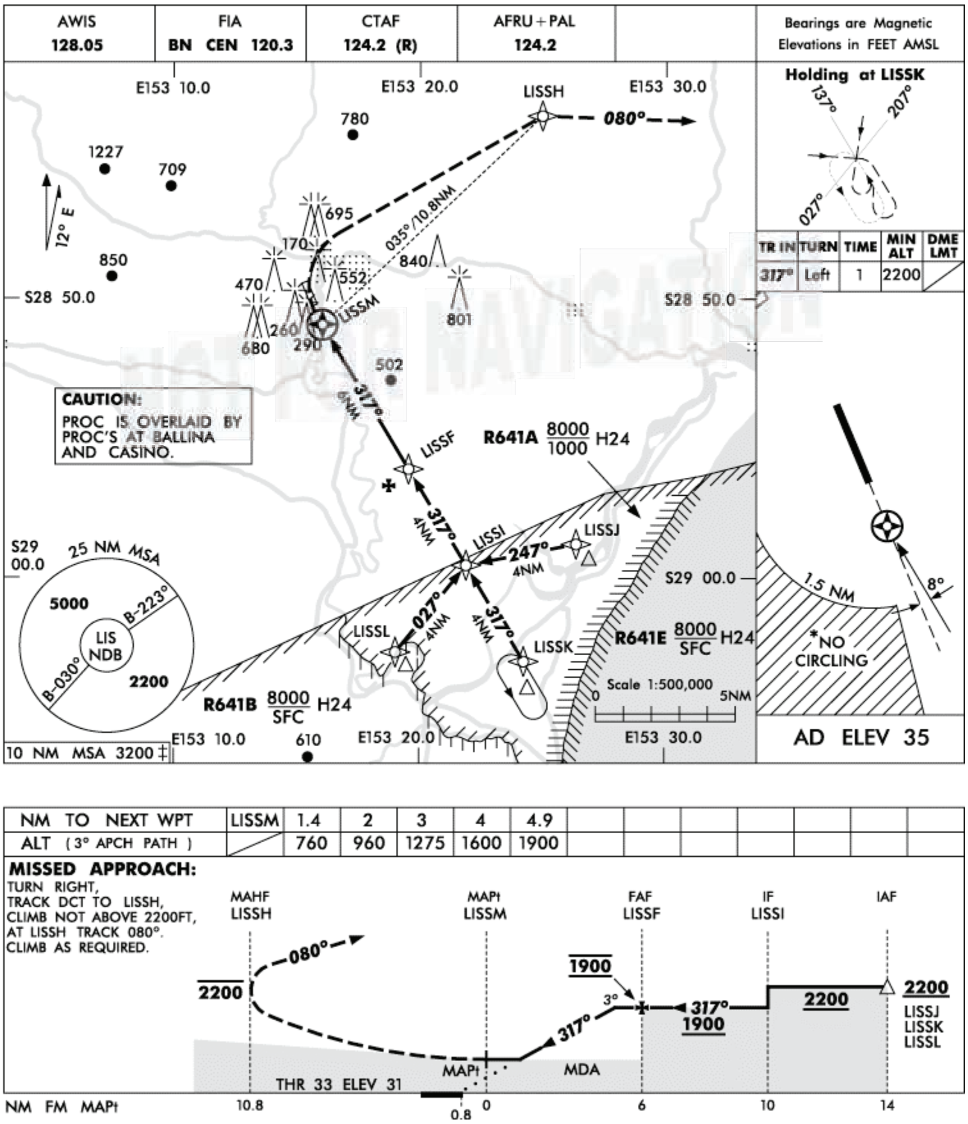


NM TO NEXT WPT	1.9	MERSI	4	3	2	1	MERSF	6	5	4	3	2	1.9	MERSM
ALT (3.28° APCH PATH)	5000	4330	3980	3630	3285	2935	2585	2240	1890	1545	1195	845	800	

Secondly, other difficult approaches listed by respondents had the recommended constant angle approach path for the first and sometimes second segments equal to the minimum segment altitude. An example of this can be seen in Figure 35 for Lismore runway 33 RNAV approach. Difficult approaches of this type include Mt Hotham 29; Lismore 33; Mount Isa 16 & 34. Such approach designs make an approach more difficult for two reasons.

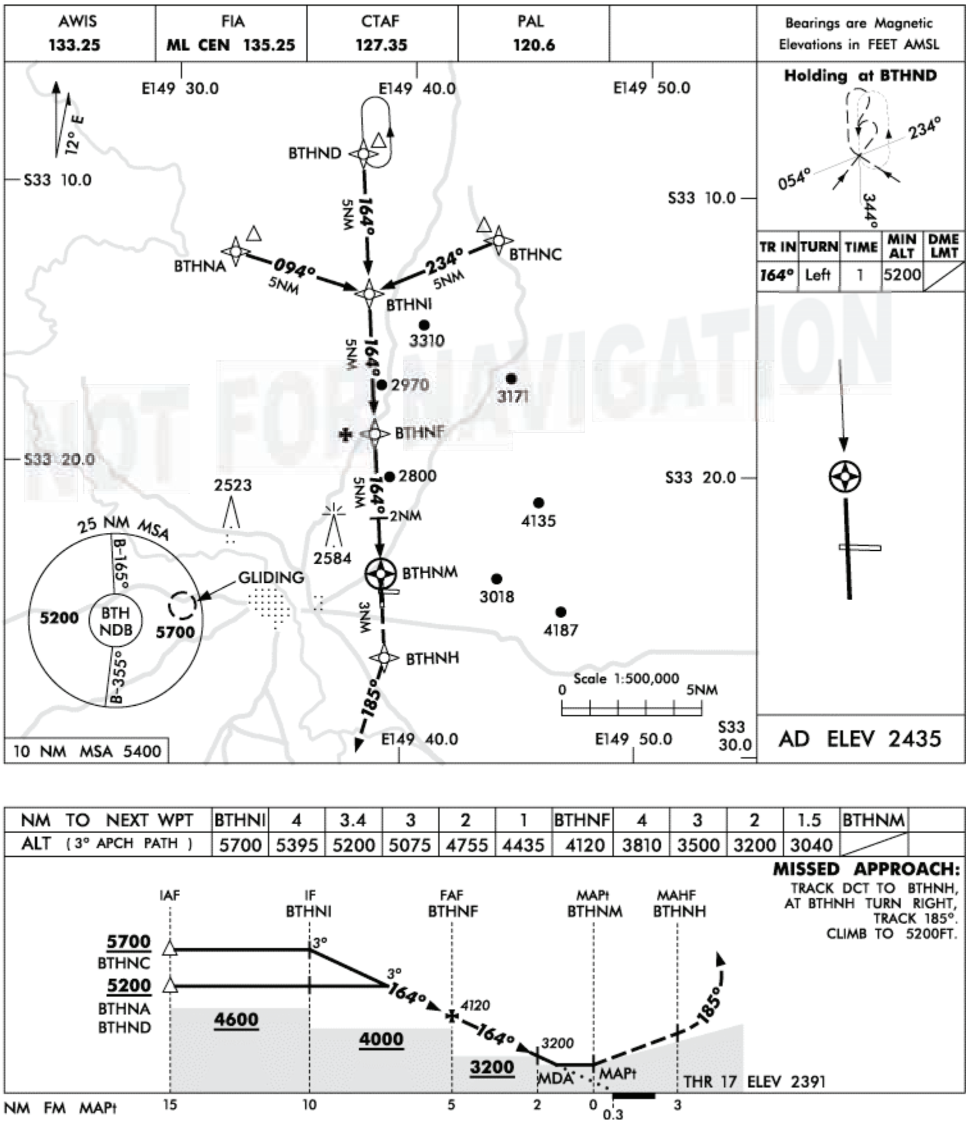
An aircraft using automation will ‘altitude capture’ the minimum segment altitude unless the aircraft is deliberately flown above the profile, resulting in resetting of the minimum steps altitudes during the approach. This was mentioned by several respondents as a factor increasing pilot workload. Also, pilots must be even more vigilant of maintaining the correct altitude on the profile when dropping below the profile also means dropping below the minimum safe segment altitude. Mount Hotham also has weather related difficulties due to snow in the winter months.

Figure 35: Lismore runway 33 RNAV (GNSS) approach showing minimum segment altitudes at the same height as the recommended glide path.



The third type of approach listed as being among the most difficult were approaches with multiple entry track altitudes, as seen in Figure 36 for Bathurst runway 17. Approaches listed by respondents of this type of design included Bathurst 17 and Ballina 06.

Figure 36: Bathurst runway 17 RNAV (GNSS) approach showing multiple initial segment altitudes for recommended glide path.



5.5 Training

Most respondents considered their RNAV (GNSS) endorsement training to have been adequate. Of the 14% who considered it not to have been adequate, the most common reason given was that not enough approach practice had being given.

Flight instructors who answered the survey indicated that the most common problems trainees have with learning the RNAV (GNSS) approach were maintaining position awareness. This was often related to becoming confused about which segment they were currently in and how far away they were from the runway threshold. Examples of responses included:

> Loss of situational awareness during the approach under high work load and going to MDA one waypoint early.
>
> Keeping orientated i.e. thinking they are tracking to a different fix on the approach, then getting disorientated and/or behind time line.
>
> Trainees have the most trouble with setup, on a few occasions they have lost situational awareness and wanted to start the approach descent 1 waypoint early.

5.6 Incidents involving RNAV (GNSS) approaches

There were 49 respondents (1 in 15) who reported that they had been involved in an incident involving RNAV (GNSS) approaches. Most of these, where it could be determined, occurred during line flying rather than during training.

The most common incident type (15 respondents) was commencing the descent too early due to a misinterpretation of their position For example, one respondent wrote:

> Misidentified stage of approach and descended below minimum altitude for the stage at night at an unfamiliar location.

A further three respondents indicated that they misinterpreted their position, but that this was discovered before they started to descend too early. Similarly, a further four respondents indicated that they had descended below the profile and/or minimum segment steps. These incidents were possibly due to descending too early, but the not enough information was provided to make this conclusion.

Another five respondents discussed incidents involving other reasons causing a loss of situational awareness. For example:

> Momentary loss of situational awareness when distracted by checklist or traffic and thinking I had passed a waypoint when I hadn't. This was due to distance to next waypoint readout.

5.7 Possible improvements to RNAV (GNSS) approaches

Most respondents in all aircraft performance categories considered improvements could be made to RNAV (GNSS) approaches. The most common improvements mentioned included:

- Distance to MAPt used for chart and GPS references
- Naming convention of waypoints
- Chart improvements
- Reduction in number of waypoints and/or steps
- Vertical guidance capability

Lack of distance to missed approach point information

The most common improvement, across all aircraft category groups, involved including a single distance reference to the missed approach point (MAPt) or removing the final approach fix (FAF) to give distance to run to the MAPt from the intermediate fix (IF), (228 respondents). An example of these responses was:

> I believe distance should be measured to the ‘MAP’, not the next fix. At Wollongong, for instance, the top of descent is 2NM from the "FAF". I have seen three different pilots … commence descent from 3600 when 2 miles from WOLNI instead of WOLNF - very dangerous. This would not occur if all distances were to the MAP - therefore top of descent at WOL would be 8 miles from ‘MAP’. The change necessary would be (a) to the distance shown on the GPS and (b) to the scale showing dist/alt on the chart.

In several places in this survey, the theme of a single distance to the MAPt throughout the approach has emerged. It was the leading, or one of the leading, responses for the contributions toward mental workload, (lack of) perceived safety, and approach chart interpretability. It was also a common response for contributions towards physical workload and time pressure. Reasons given why the lack of distance references to the MAPt impacts on these areas have included increased mental calculations, difficulty working out distance from the field, loosing situational awareness, descending too early, and difficulty in establishing another aircraft’s position when they are reporting their distance from the field. At least 259 or 39%[20] of respondents mentioned for at least one open-answer question they had an issue with a continuous distance to the MAPt not currently being included in RNAV (GNSS) approach designs.

The reason distance to the MAPt had not been included for RNAV (GNSS) approaches was due to the limited display area available on the first generation of GPS units, resulting in GPS manufacturers, and agreed to by the United States’ Federal Aviation Administration, that distances to the waypoints only would be used to keep RNAV (GNSS) approaches consistent with enroute navigation based on GPS. This resulted in the technical standing order TSO-129 in 1992. However, the most recent GPS standard (TSO-146) and FMS standard (TSO-145) published in 2006 still did not include a distance to the MAPt, despite the fact that new displays that meet these standards do have enough space to display such information. However, some of the recent GPS models give pilots the option of displaying the distance to the runway and the distance to the next waypoint simultaneously.

Naming convention of waypoints

Another common suggested improvement involved waypoint naming conventions. That is, respondents indicated that waypoint names should be different from each other by more than one letter. The Australian system was designed to increase situational awareness by using standard letters across all approaches. However, there are several disadvantages with this system. All waypoint names on an approach chart and GPS display look the same except for the final letter. When people read, however, they naturally look at the whole word starting with the beginning of the word. For waypoints, the pilot must ignore the whole word and focus on the final letter only. This makes the first four letters redundant during an approach, with the only purpose they serve being an awareness of which approach has been selected. However, as pilots must ignore the first four letters anyway, the chance that this design will produce this awareness is low.

As all waypoints look very similar, the pilot must look carefully to ensure the correct waypoint is read. Several respondents noted that quick glances at an approach chart,

20 Percentage based on the 667 respondents who answered at least one open-answer question.

or viewing the chart in turbulence or at night, can result in the misreading of a waypoint resulting in initiating the descent too early.

Respondents also indicated that five letters is too many, causing clutter on the approach chart and display. It is also particularly difficult to read the final letter when all waypoint characters are capital letters. Some respondents suggested using numbers in the waypoint names to count down to the MAPt, while others have suggested anything else besides the current system so that they can be easily and quickly identifiable and less likely to the misread. Examples of waypoint improvement comments included:

> The danger with GNSS approaches is the five NM [nautical mile] leg with the waypoints named with abstract name, eg, EA, EF, EI etc. It is very easy to lose situational awareness of where you are and it is very easy in the heat of the moment to select the wrong next step.
>
> Waypoint should have different name so on the GPS screen it would be easier to read, or the words themselves come up on screen. i.e. Initial - Intermediate - Final - Missed.
>
> The only difference between waypoints is one letter. If next waypoint is mistaken for the waypoint beyond then the aircraft will be 1500 ft too low.

Segment lengths

Using an optimum 5 NM design for all segments without intermediate steps was also a common improvement suggested. This coincides with the most commonly listed difficult design aspect and reasons contributing to workload and lack of perceived safety. Reasons given for this type of improvement were mostly due to workload considerations, for example:

> Consideration of pilot workload in considering the number of steps. Steps closer than 3NM impose high work load.

Vertical navigation

Respondents from Category B aircraft (generally larger twin-engine propeller aircraft) also indicated that aircraft equipment that provided some sort of vertical guidance advice during an RNAV (GNSS) approach would be an improvement. This type of technology is available in high capacity airline type aircraft through VNAV in Boeing aircraft and 'managed descent' in Airbus aircraft, which can be used as vertical navigation guidance on all RNAV (GNSS) approaches, and is generally also available in non-airline Category C aircraft (generally business jets). Such equipment was generally not installed or not in use on Category B aircraft at the time this survey was completed, and was only present in high capacity airline aircraft.

True vertical guidance is currently available with barometric-VNAV on the latest model high capacity jet aircraft (including Boeing 737 NG). Barometric-VNAV can upgrade an RNAV (GNSS) approach from a non-precision approach to an 'approach procedure with vertical guidance' (APV). At the time of publication, this was only available in Queenstown, New Zealand, and was being selectively introduced in Australia.

Following the outcome of studies of Controlled Flight into Terrain (CFIT) accidents, the International Civil Aviation Organization (ICAO) made the recommendation[21] in 2003 that the minimum level of approach available should be that provided by the approach procedure with vertical guidance (APV). This recommendation was endorsed subsequently by the Asia Pacific regional implementation group. In 2006, a paper was presented to the Aviation Policy Group[22] to seek an Australian policy on this initiative. They endorsed a proposal for CASA to undertake a cost benefit analysis to help determine the most suitable methods for providing an APV capability in Australia.

Aircraft based augmentation (ABAS), such as barometric-VNAV is capable of providing APV approaches to FMS-equipped airliners. However, other augmentation solutions may be needed if vertical navigation is going to accessible by regional airlines and general aviation aircraft. Various augmentation systems could provide the necessary technical solution, and include satellite-based augmentation systems (SBAS), including barometric-VNAV, or ground-based augmentation systems (GBAS). The Australian Strategic Air Traffic Management Group (ASTRA) is also examining options for an augmentation solution to meet Australia's needs.

An important challenge will be to provide low capacity RPT and general aviation aircraft with access to APV's, as the provision of glidepath information will enhance safety measurably. It would also mean that lower minimas will provide a more efficient transport service, especially to the many regional airports where ILS cannot be provided economically. A further benefit is the possibility that older and less safe non-precision approach aids (such as the NDB) will be made redundant, and the ability to decommission these aids will deliver ongoing savings. However, this will only be feasible if the cost of equipping aircraft with the necessary GPS units is affordable, and some incentives may be appropriate to ensure a quick uptake of this technology by aircraft owners.

5.8 Summary of discussion

For pilots operating Category A and B aircraft (generally single and twin-engine propeller aircraft), the RNAV (GNSS) approach resulted in the highest perceived pilot workload (mental workload, physical workload, and time pressure), more common losses of situational awareness, and the lowest perceived safety compared with all approaches evaluated apart from the NDB approach.

For pilots operating Category C aircraft, mostly Boeing 737 and other high capacity regular public transport aircraft, the RNAV (GNSS) approach only presented higher pilot workload and lower perceived safety than the precision ILS approach.

The differences between the responses from pilots from Category C aircraft and those from the slower Category A and B aircraft were likely to have been due to aircraft and airspace differences, and possibly crew and training and procedures approach briefings. Category C aircraft were generally operated on RNAV (GNSS) approaches using an autopilot with VNAV. This significantly reduces the pilot's

21 Eleventh Air Navigation Conference in 2003.

22 The Aviation Policy Group comprises representatives of the Department of Transport and Regional Services, the Department of Defence, CASA and Airservices Australia.

cognitive requirements for calculating the descent profile and changes the flying task to a perceptual task of reducing descent angle error, significantly reducing pilot workload while maintaining or increasing vertical and lateral navigation accuracy. Category C aircraft pilots indicated that aircraft automation did reduce pilot physical workload during an approach and increased safety. Furthermore, 91% of respondents from this category indicated they normally conduct RNAV (GNSS) approaches using automation. The second difference is that RNAV (GNSS) approaches were mostly conducted in controlled airspace for Category C, but OCTA for Category A and Category B aircraft. Further, OCTA was found to increase workload levels (for Category B aircraft and Category C aircraft pilots), placing additional pressures on pilots during an already difficult approach. More detailed approach briefings and company approach procedures in high capacity airlines probably also contribute to the differences found.

The concern that most respondents had about the design of RNAV (GNSS) approaches was that they do not use references for distance to the missed approach point (MAPt) throughout the approach on the approach chart and GPS/FMS display. This response was common from respondents in all types of aircraft categories, and was listed as affecting all areas of this survey, including all aspects of pilot workload, approach chart interpretability, and perceived safety. It was also the most common improvement suggestion made by respondents, and the most common aspect of the approach that trainees took the longest to learn. The RNAV (GNSS) approach is the only instrument approach that does gives changing distance references as the aircraft approaches the runway. The data is technically available to display distance to the MAPt information, but electronic displays must be changed to allow this. Some of the very recent models of GPS currently reaching the market do allow this information to be displayed in addition to distances to each waypoint. Approach chart altitude distance tables could also be modified easily, while still accommodating the current GPS distance displays by including an addition row showing distances to the MAPt. Until these changes are made, the potential for pilots to be overloaded and/or lose situational awareness during an RNAV (GNSS) approach, resulting in a controlled flight into terrain, remains high.

Short and irregular segment distances, and multiple minimum segment altitude steps, were also clearly a major concern for many pilots using RNAV (GNSS) approaches. They were listed as the most common reason why pilots experienced time pressure and were one of the most commonly mentioned contributions to mental workload, physical workload, lack of approach chart interpretability, and lack of safety. Furthermore, they were the most commonly listed difficult aspect associated with the design of RNAV (GNSS) approaches. Such irregular designs also featured prominently in aerodrome approaches listed as being the most difficult RNAV (GNSS) approaches. These types of approaches represent the minority (21.5%) of approaches in Australia, as RNAV (GNSS) approaches are designed with three 5 NM segments without intermediate minimum altitude steps wherever possible. When terrain does not permit such a design, irregular designs are put in place. Although these approaches do still meet the ICAO PANS-OPS requirements, the results of this survey suggest that consideration of pilot workload and potential to lose situational awareness also needs to be considered before publishing such approaches. When they are published, pilots need to include in their approach briefings the potential for such designs to increase workload.

The RNAV (GNSS) approach was the most difficult chart to interpret for respondents in all aircraft performance categories. This was mostly a result of the way distances were represented in the chart diagrams and in the distance/altitude tables. Secondarily, this was due to the amount of clutter on the chart and the long waypoint names mostly containing redundant information. The naming convention of using five capital letters for waypoint names with only the final letter differing within an approach, was reported to not only cause clutter on the charts and GPS and FMS displays, it was also reported as increasing the chance of a pilot misinterpreting a waypoint, especially in high workload situations and adverse weather conditions.

6 FINDINGS

1. Pilot workload was perceived as being higher, and reported losses of situational awareness were more common, for the area navigation global navigation satellite system (RNAV (GNSS)) approach than all other approaches except the non-directional beacon (NDB) approach, which involved similar workload and situational awareness levels.

   This was especially a concern for pilots operating Category A and Category B aircraft. Further research into pilot workload and losses of situational awareness associated with RNAV (GNSS) approaches is warranted.

   However, respondents from Category C aircraft (predominantly high capacity jet airline aircraft) differed from these general results. These respondents considered the RNAV (GNSS) approach to be only more difficult than day visual approaches and the precision instrument landing system (ILS) approach, but involving less workload than the other approaches assessed in this survey. Similarly, high capacity airliner pilots indicated that they had lost situational awareness less often or at similar frequencies on the RNAV (GNSS) approach to most other approaches, and only lost situational awareness more often on RNAV (GNSS) approaches than on ILS and day visual approaches.

2. Respondents indicated that they perceived the RNAV (GNSS) approach as safer than an NDB approach, equivalent to a visual approach at night, but perceived it as less safe than all other approaches included in the survey. However, the high capacity airliner pilots differed and assessed the RNAV (GNSS) approach safer than most approaches, with the exception of the ILS and visual (day) approaches. High capacity airliner pilots indicated that automation, and vertical navigation functions in particular, increased safety.

3. The runway alignment of RNAV (GNSS) approaches was reported as increasing safety by 30% of respondents.

4. The differences between the responses from pilots from Category C and those from the slower Category A and B aircraft (predominantly single engine and small twin-engine aircraft, and larger twin-engine propeller aircraft respectively), were likely to have been due to two main reasons. Firstly, the Category C aircraft pilots mostly conducted RNAV (GNSS) approaches using autopilots and have more sophisticated autopilot systems and vertical navigation (VNAV) capabilities not available to the slower and less complex aircraft. Secondly, high capacity airline pilots mostly conducted RNAV (GNSS) approaches inside controlled airspace while the Category A and B aircraft mostly operated RNAV (GNSS) approaches outside controlled airspace where the latter increased workload levels during an approach. It is possible that more detailed approach briefings and company approach procedures in high capacity airlines may have also contributed to the differences found.

5. The concern that most respondents had concerning the design of RNAV (GNSS) approaches was that they did not use references for distance to the missed approach point throughout the approach on the global positioning system (GPS) or flight management system (FMS) display and the consequential limited references on the approach charts were inadequate. This response was common from respondents in all types of aircraft categories, and was listed as affecting all areas of this survey. It was one of the most common

issues influencing mental workload, approach chart interpretability, and perceived safety, influenced physical workload and time pressure assessments, and the most common aspect of the approach that trainees took the longest to learn. The inclusion of distance to the missed approach point throughout the approach on the cockpit display and approach chart was also the most common improvement suggested by respondents.

6. The 21.5% of Australian RNAV (GNSS) approaches with short and irregular segment distances, and/or multiple minimum segment altitude steps (necessary for approaches in the vicinity of high terrain) were also identified as a major concern for many pilots. They were listed as the most common reason pilots experience time pressures and were one of the most commonly mentioned contributors to mental workload, physical workload, lack of approach chart interpretability, and perceived lack of safety. These sub-optimal characteristics were common in the list of aerodromes considered to have the most difficult RNAV (GNSS) approaches.

7. Approach chart interpretability was assessed as more difficult for the RNAV (GNSS) approach than all other approaches by respondents from all aircraft performance categories. Unlike the non-directional beacon (NDB) and ILS approach charts, ease of interpretation did not increase with the number of approaches conducted per year.

8. The naming convention of using five capital letters for waypoint names, with only the final letter differing to identify each segment of the approach, was reported to cause clutter on the charts and GPS and FMS displays, and also increase the chance of a pilot misinterpreting a waypoint.

9. The amount of time and effort required to prepare for an RNAV (GNSS) approach was reported as higher than for all other approaches.

10. Late notice of clearance by air traffic control to conduct an RNAV (GNSS) approach was identified as the most common difficult external condition to operate an RNAV (GNSS) approach, especially from high capacity airliner pilots.

11. Most (86%) respondents considered their RNAV (GNSS) endorsement training to have been adequate. Of the 14% who considered it not to have been adequate, the most common reason was that not enough approach practice had been given.

12. Flight instructors who answered the survey indicated that the most common problem trainees had with learning the RNAV (GNSS) approach was maintaining situational awareness, often related to becoming confused about which segment they were in and how far away they were from the runway threshold.

13. There were 49 respondents (1 in 15) who reported that they had been involved in an incident involving RNAV (GNSS) approaches. The most common incident (15 respondents) was commencing the descent too early due to a misinterpretation of their position, and a further three respondents indicated that they misinterpreted their position, but that this was discovered before they started to descend too early. Another five incidents were reported as involving other losses of situational awareness. A further four respondents indicated that they had descended below the constant angle approach path and/or minimum segment steps.

7 SAFETY ACTIONS

7.1 Airservices Australia

Aviation safety will be enhanced considerably if regional airlines, charter operators and general aviation users can be provided with vertical guidance during area navigation global navigation satellite system (RNAV (GNSS)) approaches, complementing the accurate track information and straight-in approaches already available from GNSS. The Australian Transport Safety Bureau (ATSB) has been advised that the board of directors of Airservices Australia has endorsed the ground based regional augmentation system (GRAS) for Australia, with the intention that it becomes operational from 2009, subject to certification by the Civil Aviation Safety Authority.

The ATSB regards the introduction of a vertical navigation capability for area navigation global navigation satellite system (RNAV (GNSS)) approaches as a high priority, particularly as it is likely to offer the highest safety benefit for the widest number of users. The ATSB will monitor the progress of approach with vertical guidance (APV) implementation.

7.2 Civil Aviation Safety Authority

The ATSB notes the Civil Aviation Safety Authority's (CASA) intention to have the findings of this report considered by the Australian Strategic Air Traffic Management Group (ASTRA) for the purpose of identifying opportunities to improve current practices. The ATSB will monitor the outcomes of this group's advice.

The ATSB notes CASA's intention to review the findings of this report and consult with regulators overseas and review research findings from other studies. The ATSB will monitor the outcomes of this process.

7.3 Australian Strategic Air Traffic Management Group

The ATSB notes the role of the Australian Strategic Air Traffic Management Group (ASTRA) in air traffic management planning, and in particular, its role examining augmentation solutions for Australia's needs. The ATSB supports ASTRA's consideration of the introduction of appropriate augmentation solutions that will provide an approach procedure with vertical guidance (APV) capability as soon as practicable.

7.4 Recommendations

Recommendation R20060019

Safety issue: RNAV (GNSS) approach pilot workload and situational awareness

Pilot workload was perceived as being higher, and reported losses of situational awareness were reported as more common, for the area navigation global navigation satellite system (RNAV (GNSS)) approach than all other approaches except the non-directional beacon (NDB) approach, which involved similar workload and situational awareness levels.

This was especially a concern for pilots operating Category A and Category B aircraft. Further research into pilot workload and losses of situational awareness associated with RNAV (GNSS) approaches is warranted.

The Australian Transport Safety Bureau recommends that the Civil Aviation Safety Authority address this safety issue.

Recommendation R20060020

Safety issue: RNAV (GNSS) approach chart design and interpretability

The most common concern identified by respondents about the design of RNAV (GNSS) approaches was that the charts did not use references for distance to the missed approach point throughout the approach on the global positioning system (GPS) or flight management system (FMS) displays, and distance references on the approach charts were inadequate. Approach chart interpretability was assessed as more difficult for the RNAV (GNSS) approach than all other approaches by respondents from all aircraft performance categories. Respondents considered that the information presented on RNAV (GNSS) approach charts, including distance information, may not be presented in the most usable way, and consequently may lead to loss of situational awareness.

The Australian Transport Safety Bureau recommends that Airservices Australia address this safety issue.

Recommendation R20060021

Safety issue: Sub-optimal RNAV (GNSS) approach design

The 21.5% of Australian area navigation global navigation satellite system (RNAV (GNSS)) approaches deviates from the optimum design parameters (short and irregular segments less than 5 NM and/or multiple steps within segments, and/or multiple minimum segment altitude steps) particularly approaches in the vicinity of high terrain. This was identified as a major concern by many pilots. A review to determine whether designs closer to the optimum approach profile could be developed, within the ICAO Pans-Ops limitations, was considered appropriate.

The Australian Transport Safety Bureau recommends that Airservices Australia address this safety issue.

Recommendation R20060022

Safety issue: RNAV (GNSS) approach chart waypoint naming convention

The naming convention of using five capital letters for waypoint names, with only the final letter differing to identify each segment of the approach, was reported to cause clutter on the charts and GPS and FMS displays, and also increase the chance of a pilot misinterpreting a waypoint. This can lead to a loss of situational awareness.

With the growing body of international experience using RNAV (GNSS) approaches, it may be timely to review the naming convention.

The Australian Transport Safety Bureau recommends that Airservices Australia address this safety issue.

Recommendation R20060023

Safety issue: RNAV (GNSS) approach late notice of air traffic control clearance

Late notice of clearance by air traffic control to conduct an RNAV (GNSS) approach was identified as the most common difficult external condition affecting an RNAV (GNSS) approach, particularly for high capacity airline pilots. An examination of opportunities to improve training and/or procedures for air traffic controllers to help ensure timely approach clearances is warranted.

The Australian Transport Safety Bureau recommends that Airservices Australia, in conjunction with the Civil Aviation Safety Authority, address this safety issue.

Recommendation R20060024

Safety issue: RNAV (GNSS) approach late notice of air traffic control clearance

Late notice of clearance by air traffic control to conduct an RNAV (GNSS) approach was identified as the most common difficult external condition affecting an RNAV (GNSS) approach, particularly for high capacity airline pilots. An examination of opportunities to improve training and/or procedures for pilots to help ensure timely approach clearances is warranted.

The Australian Transport Safety Bureau recommends that the Civil Aviation Safety Authority, in conjunction with Airservices Australia, address this safety issue.

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Safety recommendation R20060003

Date issued: 20 January 2006

The Australian Transport Safety Bureau recommends that the Civil Aviation Safety Authority review the adequacy of current legislation and regulations:

- to assess the safety benefit that could be achieved from the fitment of a serviceable autopilot to all aircraft currently on the Australian civil aircraft register, engaged on scheduled air transport operations
- with a view to ensuring that all aircraft placed on the Australian civil aircraft register after a specified date and intended to be engaged on scheduled air transport operations are equipped with a serviceable autopilot.

Response from Civil Aviation Safety Authority

Date Received: 16 August 2006

CASA has conducted a preliminary review of Civil Aviation Order (CAO) 20.18 and examined the history of changes as they relate to fitment of autopilot equipment. The relevant current provisions in CAO 20.18 have existed since about 1960 and are consistent with current provisions of the US Federal Aviation Administration (FAA) and the European Joint Aviation Authorities (JAA).

A review of CASA data to identify the 'population' of RPT Operators and aircraft that are affected revealed a total of 52 aircraft, 80% of which are the Metro SA227. Some feedback indicates that the standard autopilot approved for this aircraft type is widely known within the aviation industry to be unreliable old technology and expensive. This may account for the fact that few Metro SA227 aircraft are fitted with autopilots. All Australian aircraft operating in high capacity regular public transport operations have approved autopilots fitted.

CASA will consult industry through the Standards Consultative Committee (SCC) before deriving a conclusion on the matter.

Furthermore, CASA has extracted relevant Crew Resource Management/training and Human Factors material out of draft Civil Aviation Safety Regulation Part 121A and is developing a Civil Aviation Advisory Publication. This material is currently with CASA senior managers for comment.

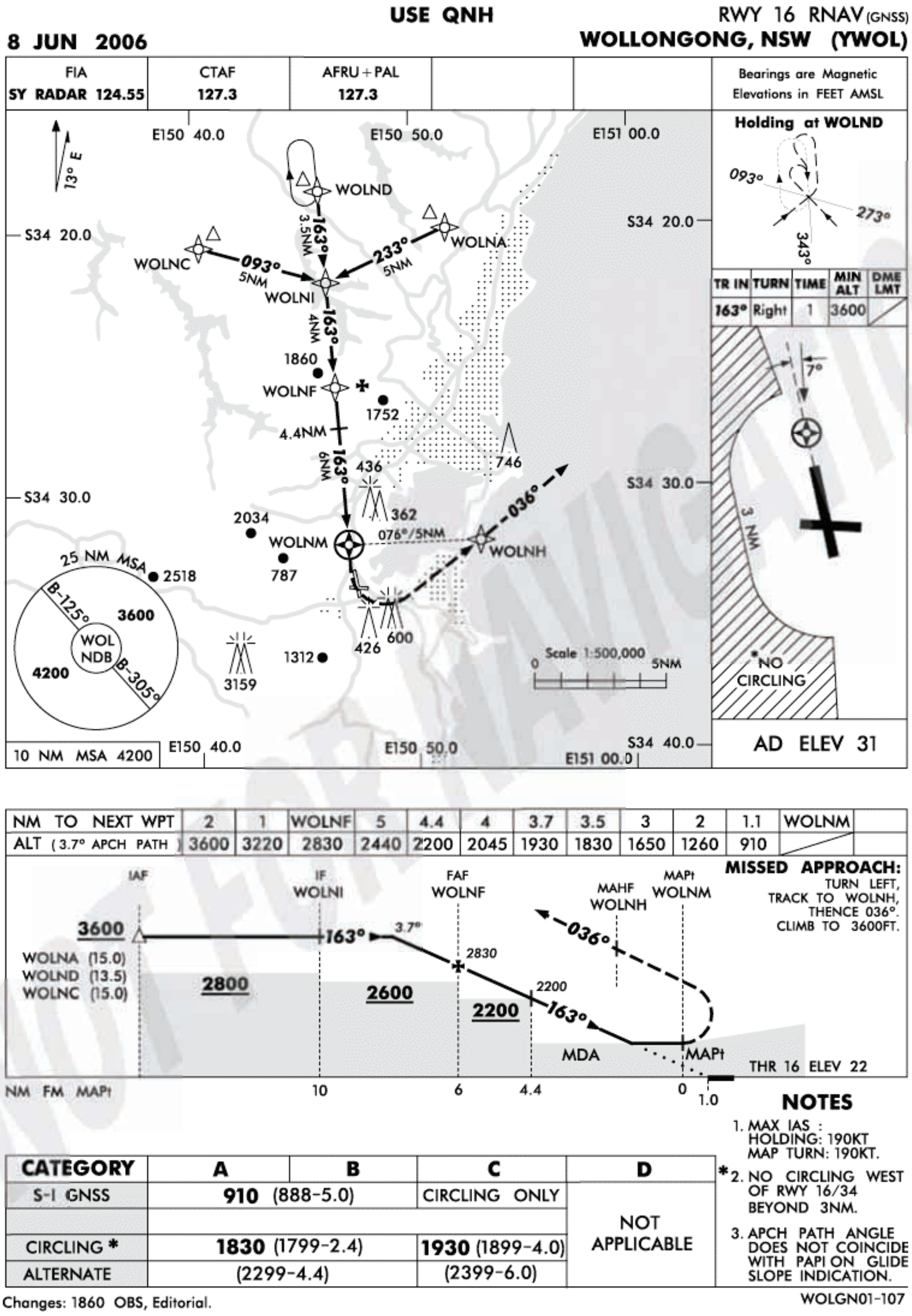
Response Status: Monitor

APPENDICES

Appendix contents

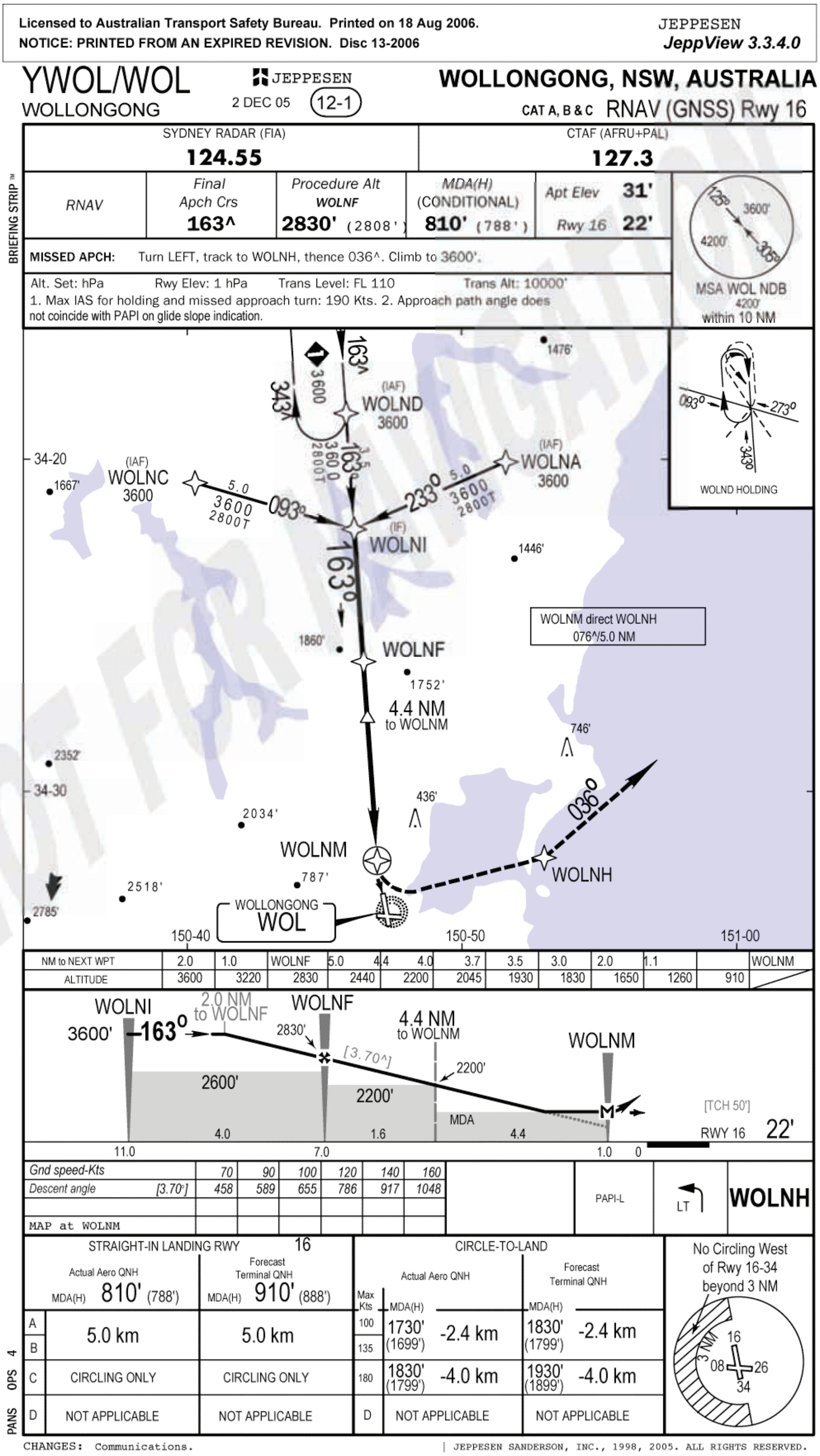
8.1 Appendix A: RNAV (GNSS) approach charts

RNAV (GNSS) approach chart from Airservices Australia



AIRSERVICES AUSTRALIA

RNAV (GNSS) approach chart from Jeppesen



8.2 Appendix B: Survey questions

Australian Government

Australian Transport Safety Bureau

SURVEY

PILOT EXPERIENCES ON INSTRUMENT APPROACHES

Survey Anonymity & Confidentiality Arrangements

- This research is being conducted under the *Transport Safety Investigation Act 2003 (TSI Act)*.
- Individual responses gathered in this survey will remain with the ATSB and be classified as Restricted Information under the *TSI Act*.
- All responses will be entered into a database and analysed as a whole.

This survey will take about 25 minutes to complete.

Please return the survey using the enclosed pre-paid envelope to the ATSB by 22 December 2005.

Instructions

Some of the questions in this survey use a rating scale. These ratings represent a continuous scale from low to high. Please circle a number on the scale to record your opinion.

Ratings in Part 1 of the survey have been separated into *Pilot flying* (sole pilot operations and manipulating pilot for two-crew operations) and *Pilot not-flying* (supporting pilot for two-crew operations). If you do not have experience with two-crew operations, please ignore the *pilot not-flying* ratings.

Rate only approach types that you have experience flying. Circle N/A (not applicable) for approaches for which you do not have experience.

Answer each question based on the main type of aircraft you now fly.

For example: Workload ratings

Approach 1 has a moderately high workload.
Approach 2 has a very low workload.
The pilot is not experienced with Approach 3.
Approach 4 has a medium level of workload required.

	low			*medium*			high	
Approach 1	1	2	3	4	5	6	7	N/A
Approach 2	1	2	3	4	5	6	7	N/A
Approach 3	1	2	3	4	5	6	7	N/A
Approach 4	1	2	3	4	5	6	7	N/A

3. How much **physical workload** is involved ***during*** each approach?
   - Physical activities may include control manipulation, configuration changes, discussing options, reading checklists, etc.
   - Is the approach relaxed, physically undemanding (1) or demanding, strenuous, laborious (7)?

	Pilot Flying/Single Pilot Ops								Pilot Not-Flying/Support Pilot							
	low physical workload		*medium physical workload*			*high physical workload*			*low physical workload*		*medium physical workload*			*high physical workload*		
Visual Approach (day)	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
Visual Approach (night)	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
ILS	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
LOC/DME	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
VOR/DME	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
GPS Arrival	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
DME Arrival	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
NDB	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
RNAV (GNSS)	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A

4. How much **time pressure** do you experience ***during*** each approach due to the pace of the activities involved in the approach?
   - Is the pace of the approach slow, leisurely (1) or rapid, frantic (7)?

	Pilot Flying/Single Pilot Ops								Pilot Not-Flying/Support Pilot							
	low time pressure		*medium time pressure*			*high time pressure*			*low time pressure*		*medium time pressure*			*high time pressure*		
Visual Approach (day)	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
Visual Approach (night)	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
ILS	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
LOC/DME	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
VOR/DME	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
GPS Arrival	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
DME Arrival	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
NDB	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
RNAV (GNSS)	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A

5. How **easy is it to interpret the relevant approach plate** *during* each approach?
   - I.e. is the approach plate unambiguous, immediately understandable, clear (1) or easily misinterpreted, difficult or laborious to follow (7)?
   - Circle N/A for any approach type for which you do not use a plate.

	Pilot Flying/Single Pilot Ops								Pilot Not-Flying/Support Pilot							
	easy		*medium*			*difficult*			*easy*		*medium*			*difficult*		
Visual Approach (day)	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
Visual Approach (night)	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
ILS	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
LOC/DME	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
VOR/DME	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
GPS Arrival	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
DME Arrival	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
NDB	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
RNAV (GNSS)	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A

6. Have you ever **had trouble maintaining situational awareness** *during* any of the following approaches?

	Pilot Flying/Single Pilot Ops					Pilot Not-Flying/Support Pilot				
	never	*once only*	*sometimes*	*often*		*never*	*once only*	*sometimes*	*often*	
Visual Approach (day)	1	2	3	4	N/A	1	2	3	4	N/A
Visual Approach (night)	1	2	3	4	N/A	1	2	3	4	N/A
ILS	1	2	3	4	N/A	1	2	3	4	N/A
LOC/DME	1	2	3	4	N/A	1	2	3	4	N/A
VOR/DME	1	2	3	4	N/A	1	2	3	4	N/A
GPS Arrival	1	2	3	4	N/A	1	2	3	4	N/A
DME Arrival	1	2	3	4	N/A	1	2	3	4	N/A
NDB	1	2	3	4	N/A	1	2	3	4	N/A
RNAV (GNSS)	1	2	3	4	N/A	1	2	3	4	N/A

7. How **safe** do you think each approach is?
- Is the approach safe, secure (1) or dangerous, hazardous (7)?

	Pilot Flying/Single Pilot Ops								Pilot Not-Flying/Support Pilot							
	safe			*medium*			*dangerous*		*safe*			*medium*			*dangerous*	
Visual Approach (day)	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
Visual Approach (night)	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
ILS	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
LOC/DME	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
VOR/DME	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
GPS Arrival	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
DME Arrival	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
NDB	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A
RNAV (GNSS)	1	2	3	4	5	6	7	N/A	1	2	3	4	5	6	7	N/A

PART 2 – RNAV (GNSS) APPROACHES

RNAV (GNSS) approaches, previously known as GPS/NPA's, were introduced into Australia relatively recently when compared with other instrument approaches. Although this type of approach is becoming more prevalent, little data are available regarding pilots' perception of RNAV (GNSS) approaches. This section attempts to address that data shortage and focuses on your perceptions of RNAV (GNSS) approaches from the IAF to the minima.

1. What aspects of an RNAV (GNSS) approach contribute to the degree of:

   a. mental and perceptual workload: ....

   ....

   ....

   b. physical workload: ....

   ....

   ....

   c. time pressure: ....

   ....

   ....

   d. approach plate interpretability: ....

   ....

   ....

   e. safety: ....

   ....

   ....

2. Are there any aspects of RNAV (GNSS) approaches that could be improved?

   Yes ☐ No ☐ *If yes, please explain:*

   ....

   ....

   ....

   ....

   ....

   ....

   ....

   ....

   ....

3. Under what circumstances are RNAV (GNSS) approaches the most difficult?

   ....

   ....

   ....

   ....

   ....

   ....

   ....

4. In your experience, which locations (airports and runways) have the most and least difficult RNAV (GNSS) approaches?

Most difficult	*Least difficult*
....	....
....	....
....	....
....	....
....	....

5. How did you develop expertise on RNAV (GNSS) approaches?:
(tick more than one box if necessary)

Private training	☐	Instructor	☐	Reading	☐	Colleague	☐
Company training	☐	Supervisor	☐	Self practice	☐		

Other ☐ ....

6. Was your training on RNAV (GNSS) approaches adequate? Yes ☐ No ☐

If no, why not?: ....

7. What GPS receiver type do you most commonly use for RNAV (GNSS) approaches?:
Hand held ☐ Panel mounted ☐ FMS integrated unit ☐

8. What GPS receiver model do you most commonly use? ....
Unknown ☐

9. Does the receiver you most commonly used give you the option to select different pages to view RNAV (GPS/NPA) approaches:
Yes ☐ No ☐

If yes, what is your preferred page? Navigation/CDI ☐ Moving Map ☐

Other ☐ ....

10. Have you been involved in any serious incidents on RNAV (GNSS) approaches? Yes ☐ No ☐
If yes, please provide detail:

....
....
....
....
....
....
....

11. If you are an instructor and provide instruction to trainees on RNAV (GNSS) approaches, which aspects of the approach are the most difficult for trainees to learn?

....
....
....
....
....
....

6

PART 3: PREFERENCES & EXPERIENCE

1. *Please indicate in the table below:*
   a. Which approaches you are rated on.
   b. How long you have been rated on each approach.
   c. How often you are exposed to each approach (including simulator time).

	a. Rating held	b. Years since rating	c. Approaches each year
Visual Approach (day)	Yes ☐ No ☐	1-3☐ 4-10☐ 10-20☐ >20☐	☐
Visual Approach (night)	Yes ☐ No ☐	1-3☐ 4-10☐ 10-20☐ >20☐	☐
ILS	Yes ☐ No ☐	1-3☐ 4-10☐ 10-20☐ >20☐	☐
LOC/DME	Yes ☐ No ☐	1-3☐ 4-10☐ 10-20☐ >20☐	☐
VOR/DME	Yes ☐ No ☐	1-3☐ 4-10☐ 10-20☐ >20☐	☐
GPS Arrival	Yes ☐ No ☐	1-3☐ 4-10☐ 10-20☐ >20☐	☐
DME Arrival	Yes ☐ No ☐	1-3☐ 4-10☐ 10-20☐ >20☐	☐
NDB	Yes ☐ No ☐	1-3☐ 4-10☐ 10-20☐ >20☐	☐
RNAV (GNSS)	Yes ☐ No ☐	1-3☐ 4-10☐ 10-20☐ >20☐	☐

2. *Please indicate in the table below:*
   a. Whether you normally conduct each approach type (from the IAF) on autopilot or while hand flying.
   b. The airspace type in which you normally fly each approach (tick more than one box if appropriate).

	a. Autopilot or hand	b. Main Airspace approach flown in
Visual Approach (day)	Autopilot ☐ Hand fly ☐	CTA ☐ OCTA ☐
Visual Approach (night)	Autopilot ☐ Hand fly ☐	CTA ☐ OCTA ☐
ILS	Autopilot ☐ Hand fly ☐	CTA ☐ OCTA ☐
LOC/DME	Autopilot ☐ Hand fly ☐	CTA ☐ OCTA ☐
VOR/DME	Autopilot ☐ Hand fly ☐	CTA ☐ OCTA ☐
GPS Arrival	Autopilot ☐ Hand fly ☐	CTA ☐ OCTA ☐
DME Arrival	Autopilot ☐ Hand fly ☐	CTA ☐ OCTA ☐
NDB	Autopilot ☐ Hand fly ☐	CTA ☐ OCTA ☐
RNAV (GNSS)	Autopilot ☐ Hand fly ☐	CTA ☐ OCTA ☐

3. Do you think the class of airspace impacts on your workload during an approach?

Yes ☐ No ☐ If yes, why? ....

....

....

4. Main aircraft type currently operating: ....

Is there an autopilot on this aircraft? Yes ☐ No ☐

5. Other aircraft regularly flown: ....

Is there an autopilot on any of these aircraft? Yes ☐ No ☐

6a. Main crew-configuration you operate as:	Single pilot	☐	Two-pilot	☐	Three/four-pilot	☐
b. Main position operating as:	Captain	☐	First Officer	☐	Second Officer	☐
c. Highest pilot licence held:	PPL	☐	CPL	☐	ATPL	☐

7a. Total hours: .... Last 90 days: ....

b. Total Instrument hours: .... Last 90 days: ....

OPTIONAL

You are not required to provide your name and contact details, but if you do, the information you provide will become restricted information under Section 3 of the Transport Safety Investigation Act 2003.

Providing your contact details will allow the ATSB to follow-up on any concerns you have raised in this survey if necessary.

Name: ....

Day time telephone: ....

Email: ....

Would you like to be notified when the results of this survey are published? Yes ☐ No ☐
(If yes, an email address is required above).

Thank you for completing this survey

8

Additional Comments

Please place the completed survey in the envelope supplied (no stamp required) and post it to the ATSB.

Australian Government

Australian Transport Safety Bureau

Australian Transport Safety Bureau
PO Box 967, Civic Square ACT 2608 Australia
1800 621 372
www.atsb.gov.au

ABN 86 267 354 017

8.3 Appendix C: Data analysis

Responses to the approach assessments from Part 1 of the survey and the pilot opinions of RNAV (GNSS) approaches from Part 2, were only included in the data analyses if the respondent indicated that he or she held a current rating on that approach in Part 3 (question 1a).

Where possible, comparisons were made between the approach assessments from Part 1 of the survey using the inferential statistical technique of analysis of variance (ANOVA) using a mixed model (both between-subjects independent variables and a repeated measures factor). The repeated measures factor was always the approach type. Simple repeated measures contrasts were used to compare the assessments for each approach with the RNAV (GNSS) approach. Several between-subjects variables were analysed in separate ANOVAs. These included: aircraft performance category (as determined by the ATSB based on the main aircraft type the respondent indicated they flew); number of crew involved in the respondent's main flying activity (single pilot or multi-crew operations); and GPS type (panel mounted GPS or FMS integrated system). All between-subjects variables were analysed using planned orthogonal (i.e. independent) contrasts. That is, contrasts that were planned on the basis of theoretical considerations rather than based on the resulting data (known as post-hoc comparisons). For example, aircraft performance categories were compared by contrasting respondents Category C (treated as one group) with the average of respondents from both Category A and Category B aircraft for the first contrast, with the second contrast (orthogonal to the first) comparing Category A and Category B aircraft respondents with each other.

Although respondents were asked whether they usually operated each type of approach using autopilot or by hand-flying (question 2a of part 3), these data could not be analysed using inferential statistics because as the between-subjects variable (autopilot/hand-flying) did not consistently vary across approaches, it was not possible to make a comparison between the approaches across this variable (using an ANOVA). Comparisons within the RNAV (GNSS) approach (or any other approach) between those who primary used autopilot with those who primarily hand-flew that approach also could not be made due to the nature of subjective assessments. That is, only repeated measures comparisons can be made due to the possibility of different baselines between groups. For the same reasons, inferential statistics could not be conducted to analyse response differences between pilots who indicated an individual approach was usually flown in controlled airspace (CTA) compared with those who usually experienced an approach outside controlled airspace (OCTA) (question 2b of part 3).

The differences in the number of respondents indicating autopilot use and airspace for each approach were analysed using a chi-square analysis. This evaluated the proportion of respondents within each aircraft performance category using an autopilot (rather than hand-flying) and operating in CTA (rather than OCTA) for each approach. A chi-squared analysis was also used for other yes/no questions.

Bivariate correlations (Pearson's coefficient using two-tailed test for significance) were conducted between the assessments given for the each approach and the following: total hours; total hours in the last 90 days; total instrument hours; total instrument hours in the last 90 days; number of approaches (of that type) conducted per year; and number of years the endorsement for that approach had been held.

8.4 Appendix D: Aircraft performance categories used

Category A aircraft					
Main Aircraft Flown	**Number of Crew**		**GPS Type**		**Total**
	Single	***Multi-crew***	***Panel***	***FMS***	
Bonanza, Beechcraft 36	15	-	14	1	**15**
Pilatus PC-12	13	-	9	4	**13**
Cessna 182 Skylane	10	-	9	-	**10**
Cessna 210 Centurion	9	1	7	1	**10**
Beechcraft 76	8	1	7	-	**9**
Piper PA-30 Twin Comanche	8	1	8	1	**9**
Piper PA-44 Seminole	9	-	8	1	**9**
Piper PA-28 Cherokee, Archer	7	-	7	-	**7**
Piper PA-34 Seneca	6	1	7	-	**7**
Piper PA-32 Cherokee Six, Lance, Saratoga	6	-	5	1	**6**
Cessna 310, 320	5	-	5	-	**5**
Cirrus SR20	5	-	5	-	**5**
Pacific Aerospace CT-4 Airtrainer	5	-	5	-	**5**
Cessna 208, Caravan	4	-	3	-	**4**
Cessna 172 Skyhawk	3	-	3	-	**3**
Cessna 337, 336, Skymaster	3	-	2	1	**3**
Cirrus SR22	3	-	2	-	**3**
Piper PA-23 Apache, Aztec	3	-	3	-	**3**
Vulcan Air (Partenavia) P.68	3	-	3	-	**3**
Cessna 177 Cardinal	2	-	-	2	**2**
Cessna 185 Skywagon	1	-	1	-	**1**
Cessna 303 Crusader	1	-	1	-	**1**
Commonwealth Aircraft CA-14 Boomerang	-	1	-	-	**1**
Grob G115	1	-	1	-	**1**
Piper PA-24 Comanche	1	-	1	-	**1**
Piper PA-46 Malibu	1	-	1	-	**1**
Other (aircraft not specified)	6	2	8	-	**8**

Category B aircraft					
Main Aircraft Flown	**Number of Crew**		**GPS Type**		**Total**
	Single	***Multi-crew***	***Panel***	***FMS***	
Bombardier/de Havilland Dash 8 100/200/300	-	60	18	43	**62**
Beechcraft 200 Super King Air	34	12	24	22	**46**
SAAB 340	-	43	2	41	**43**
Piper PA-31 Navajo, Mojave, Chieftain	19	2	16	3	**21**
Fairchild SA227 Metro	1	18	17	1	**19**
Beechcraft, BE55, B55, BE58	15	-	13	1	**15**
Beechcraft 350, 300 KingAir	3	6	-	9	**9**
Cessna 525, 550, 560	1	8	2	7	**9**
AeroCommander 500, 560, 680	3	2	4	-	**5**
Beechcraft 1900	-	5	4	-	**5**
Cessna 441, Conquest	5	-	5	-	**5**
Cessna 401, 402, 411	4	-	4	-	**4**
Embraer EMB-120 Brasilia	1	3	2	2	**4**
Fokker F27 MK 50/100/500/600	-	4	-	1	**4**
Pilatus PC-9	4	-	4	-	**4**
Raytheon Hawker 800	-	4	-	4	**4**
Cessna 340, 335	2	-	1	-	**2**
Cessna 414, 421	2	-	1	1	**2**
Beechcraft 65-B80, Queen Air	1	-	1	-	**1**
Cessna 404 Titan	1	-	1	-	**1**
Rockwell Turbo Commander	1	-	1	-	**1**
Other (aircraft not specified)	4	1	2	-	**5**

Category C & D aircraft (predominantly high capacity airliners					
Main Aircraft Flown	**Number of Crew**		**GPS Type**		**Total**
	Single	***Multi-crew***	***Panel***	***FMS***	
Boeing 737 3/4/7/8/900 or NG	-	181	4	173	**184**
British Aerospace 146	-	14	3	11	**14**
Airbus 320	-	8	1	5	**8**
Boeing 744, 744-3/400	-	5	-	2	**5**
Boeing 717, DC9	-	4	-	3	**4**
Bombardier Global Express	-	4	-	4	**4**
Airbus 330	-	2	-	1	**2**
Boeing 727	-	2	-	1	**2**
Cessna 650*	-	2	-	2	**2**
McDonnell Douglas MD-11	-	1	-	-	**1**
Bombardier/Gates Learjet 35*	-	1	-	1	**1**
Dassault Falcon 900*	-	1	-	1	**1**
Gulfstream Aerospace / IV*	-	1	-	1	**1**
Other (aircraft not specified)	-	2	-	2	**2**

* Business jet aircraft usually equipped to airline standard avionics and navigation instruments

Category H (Helicopters)					
Main Aircraft Flown	**Number of Crew**		**GPS Type**		**Total**
	Single	***Multi-crew***	***Panel***	***FMS***	
Bell 412	11	1	4	8	**12**
Eurocopter/Kawasaki BK 117, EC 145	7	1	7	1	**8**
Sikorsky S-76	1	5	-	5	**6**
Eurocopter AS 365N, EC 155	4	1	2	3	**5**
Agusta Westland A 109	3	1	3	2	**4**
Eurocopter AS 332, EC 225 Sup Puma	-	2	2	-	**2**
Bell 206 Kiowa, JetRanger	-	1	1	-	**1**
Bell222	-	1	1	-	**1**
Other (aircraft not specified)	2	1	1	1	**3**

8.5 Appendix F: Open-answer questions (Part 2) – Full list of responses

Table 24: Number (and percentage[23]) of respondents noting aspects of an RNAV (GNSS) approach that contribute to *Mental and Perceptual Workload*

Aspects of an RNAV (GNSS) approach contributing to the degree of Mental and Perceptual Workload contributions	Cat A	Cat B	Cat C/D	Cat H	Not specified	Total
No distance to MAPt (only to next waypoint)	14 (12.7%)	51 (22.2%)	42 (25%)	6 (17.1%)	10 (22.2%)	**123 (20.8%)**
Descent and Position monitoring/Situational Awareness	16 (14.6%)	50 (21.7%)	15 (8.9%)	4 (11.4%)	7 (15.6%)	**92 (15.6%)**
Programming GPS/FMC/Setting up approach	13 (11.8%)	21 (9.1%)	33 (19.6%)	7 (20%)	5 (11.1%)	**79 (13.4%)**
Irregular segment lengths/Many (close) steps (Optimum profile reduces workload)	14 (12.7%)	35 (15.2%)	17 (10.1%)	4 (11.4%)	6 (13.3%)	**76 (12.9%)**
Reading/Interpretation of approach chart	10 (9.1%)	23 (10%)	17 (10.1%)	4 (11.4%)	6 (13.3%)	**60 (10.2%)**
Gradient - maintaining constant profile	4 (3.6%)	20 (8.7%)	4 (2.4%)	-	2 (4.4%)	**30 (5.1%)**
GPS/FMS manipulation	7 (6.4%)	10 (4.4%)	3 (1.8%)	3 (8.6%)	2 (4.4%)	**25 (4.2%)**
GPS/MCP display/interpretation	4 (3.6%)	12 (5.2%)	1 (0.6%)	4 (11.4%)	3 (6.7%)	**24 (4.1%)**
Design and terminology differences in GPS displays and systems	7 (6.4%)	8 (3.5%)	3 (1.8%)	3 (8.6%)	2 (4.4%)	**23 (3.9%)**
Briefing	1 (0.9%)	3 (1.3%)	18 (10.7%)	-	-	**22 (3.7%)**
Checking RAIM and other data	4 (3.6%)	8 (3.5%)	2 (1.2%)	3 (8.6%)	1 (2.2%)	**18 (3.1%)**
Experience/Familiarity with approach and/or instrument	6 (5.5%)	5 (2.2%)	2 (1.2%)	1 (2.9%)	3 (6.7%)	**17 (2.9%)**
Waypoint Names too similar	3 (2.7%)	4 (1.7%)	6 (3.6%)	1 (2.9%)	2 (4.4%)	**16 (2.7%)**
Calculating profile	4 (3.6%)	9 (3.9%)	2 (1.2%)	-	-	**15 (2.5%)**
Multiple tracks/initial waypoints and Orientation inbound to IAF	7 (6.4%)	3 (1.3%)	3 (1.8%)	2 (5.7%)	-	**15 (2.5%)**
Checklists	-	-	12 (7.1%)	2 (5.7%)	-	**14 (2.4%)**

23 Percentages given are percentage of respondents answering that question

Aspects of an RNAV (GNSS) approach contributing to the degree of Mental and Perceptual Workload contributions	**Cat A**	**Cat B**	**Cat C/D**	**Cat H**	**Not specified**	**Total**
Coupling data/direction from GPS/FMS with approach chart	3 (2.7%)	4 (1.7%)	4 (2.4%)	2 (5.7%)	1 (2.2%)	**14 (2.4%)**
Runway alignment/straight in approach - reduces workload	1 (0.9%)	4 (1.7%)	8 (4.8%)	-	1 (2.2%)	**14 (2.4%)**
Moving map showing location (reduces workload) / Lack of moving map	3 (2.7%)	5 (2.2%)	2 (1.2%)	-	1 (2.2%)	**11 (1.9%)**
Position of GPS/FMS in panel	3 (2.7%)	3 (1.3%)	2 (1.2%)	3 (8.6%)	-	**11 (1.9%)**
Traffic management	2 (1.8%)	5 (2.2%)	4 (2.4%)	-	-	**11 (1.9%)**
VNAV path (reduces workload) / lack of vertical guidance increases workload	1 (0.9%)	7 (3%)	1 (0.6%)	-	1 (2.2%)	**10 (1.7%)**
Missed approach	4 (3.6%)	3 (1.3%)	-	2 (5.7%)	1 (2.2%)	**10 (1.7%)**
Automation - reduces workload	-	2 (0.9%)	7 (4.2%)	-	-	**9 (1.5%)**
Altitude capture/conflict with approach and autopilot	1 (0.9%)	4 (1.7%)	1 (0.6%)	2 (5.7%)	1 (2.2%)	**9 (1.5%)**
Early preparation reduces workload/time pressure	3 (2.7%)	1 (0.4%)	4 (2.4%)	-	-	**8 (1.4%)**
Setting altitude constraints	-	1 (0.4%)	5 (3%)	-	2 (4.4%)	**8 (1.4%)**
Cross-referencing GPS and other flight instrument	2 (1.8%)	2 (0.9%)	1 (0.6%)	-	-	**5 (0.8%)**
Holding/approach suspension	3 (2.7%)	-	-	2 (5.7%)	-	**5 (0.8%)**
Profile on approach chart - reduces workload	1 (0.9%)	2 (0.9%)	1 (0.6%)	1 (2.9%)	-	**5 (0.8%)**
Glideslope intercept point	1 (0.9%)	3 (1.3%)	-	-	-	**4 (0.7%)**
Lack of glideslope information/Crossing heights (early approach sections)	-	4 (1.7%)	-	-	-	**4 (0.7%)**
Late decision/clearance to fly RNAV approach	-	1 (0.4%)	2 (1.2%)	-	1 (2.2%)	**4 (0.7%)**
Lower Safe Altitude	-	2 (0.9%)	2 (1.2%)	-	-	**4 (0.7%)**
Naming convention reduces workload	1 (0.9%)	2 (0.9%)	1 (0.6%)	-	-	**4 (0.7%)**
Single pilot is difficult (adequate support from NFP improves workload)	1 (0.9%)	2 (0.9%)	-	1 (2.9%)	-	**4 (0.7%)**
Speed management	-	2 (0.9%)	2 (1.2%)	-	-	**4 (0.7%)**
Monitoring scale changes on GPS	2 (1.8%)	1 (0.4%)	-	-	-	**3 (0.5%)**
Procedural calls/checks	-	2 (0.9%)	1 (0.6%)	-	-	**3 (0.5%)**

Aspects of an RNAV (GNSS) approach contributing to the degree of Mental and Perceptual Workload contributions	Cat A	Cat B	Cat C/D	Cat H	Not specified	Total
Not aligned with STAR/CTA interference with approach	-	-	2 (1.2%)	-	-	**2 (0.3%)**
Training	-	2 (0.9%)	-	-	-	**2 (0.3%)**
Waypoints in space (not on the ground)	1 (0.9%)	1 (0.4%)	-	-	-	**2 (0.3%)**

Table 25: Number (and percentage) of respondents noting aspects of an RNAV (GNSS) approach that contribute to *Physical Workload*

Aspects of an RNAV (GNSS) approach contributing to the degree of Physical Workload	Cat A	Cat B	Cat C/D	Cat H	Not specified	Total
Programming GPS/FMC/Setting up approach	11 (14.7%)	23 (14.9%)	19 (16.4%)	5 (17.2%)	5 (20%)	**63 (15.7%)**
Automation - reduces workload	5 (6.7%)	13 (8.4%)	32 (27.6%)	1 (3.5%)	1 (4%)	**52 (13%)**
GPS/FMS manipulation	14 (18.7%)	15 (9.7%)	6 (5.2%)	6 (20.7%)	3 (12%)	**44 (11%)**
Aircraft configuration Late increases/Aircraft configured early reduces workload/time pressure	7 (9.3%)	16 (10.4%)	10 (8.6%)	-	2 (8%)	**35 (8.7%)**
Descent and Position monitoring/Situational Awareness	6 (8%)	10 (6.5%)	7 (6%)	6 (20.7%)	1 (4%)	**30 (7.5%)**
Missed approach	6 (8%)	11 (7.1%)	2 (1.7%)	4 (13.8%)	1 (4%)	**24 (6%)**
Irregular segment lengths/Many close steps	4 (5.3%)	12 (7.8%)	8 (6.9%)	-	-	**24 (6%)**
Early preparation reduces workload/time pressure	3 (4%)	8 (5.2%)	4 (3.5%)	-	1 (4%)	**16 (4%)**
No distance to MAPt (only to next waypoint)	3 (4%)	8 (5.2%)	4 (3.5%)	-	1 (4%)	**16 (4%)**
Checking RAIM and other data	2 (2.7%)	8 (5.2%)	-	4 (13.8%)	1 (4%)	**15 (3.7%)**
Position of GPS/FMS in panel	1 (1.3%)	6 (3.9%)	2 (1.7%)	2 (6.9%)	1 (4%)	**12 (3%)**
Procedural calls/checks	1 (1.3%)	5 (3.3%)	2 (1.7%)	1 (3.5%)	3 (12%)	**12 (3%)**
Setting altitude constraints	-	5 (3.3%)	6 (5.2%)	-	1 (4%)	**12 (3%)**
Checklists	1 (1.3%)	1 (0.7%)	6 (5.2%)	3 (10.3%)	-	**11 (2.7%)**
Reading/Interpretation of approach chart	2 (2.7%)	5 (3.3%)	-	3 (10.3%)	1 (4%)	**11 (2.7%)**
Adjusting tracking/profile/power	3 (4%)	4 (2.6%)	-	1 (3.5%)	2 (8%)	**10 (2.5%)**
Briefing	-	2 (1.3%)	6 (5.2%)	1 (3.5%)	1 (4%)	**10 (2.5%)**
Coupling data/direction from GPS/FMS with approach chart	6 (8%)	3 (2%)	-	1 (3.5%)	-	**10 (2.5%)**
Runway alignment/straight in approach - reduces workload	-	6 (3.9%)	4 (3.5%)	-	-	**10 (2.5%)**
Traffic management	3 (4%)	4 (2.6%)	1 (0.9%)	2 (6.9%)	-	**10 (2.5%)**

Aspects of an RNAV (GNSS) approach contributing to the degree of Physical Workload	**Cat A**	**Cat B**	**Cat C/D**	**Cat H**	**Not specified**	**Total**
Experience/Familiarity with approach and/or instrument	3 (4%)	3 (2%)	2 (1.7%)	-	1 (4%)	**9 (2.2%)**
Gradient - maintaining constant profile	1 (1.3%)	6 (3.9%)	-	1 (3.5%)	-	**8 (2%)**
VNAV path (reduces workload) / lack of vertical guidance increases workload	-	2 (1.3%)	13 (11%)	-	1 (4%)	**16 (4%)**
GPS/MCP display/interpretation	2 (2.7%)	1 (0.7%)	2 (1.7%)	2 (6.9%)	-	**7 (1.7%)**
Late decision/clearance to fly RNAV approach	-	1 (0.7%)	4 (3.5%)	1 (3.5%)	1 (4%)	**7 (1.7%)**
Altitude capture/conflict with approach and autopilot	-	3 (1.9%)	4 (3.4%)	-	-	**7 (1.7%)**
Design and Terminology differences in GPS displays and systems	2 (2.7%)	3 (2%)	1 (0.9%)	-	-	**6 (1.5%)**
Monitoring scale changes on GPS	-	2 (1.3%)	1 (0.9%)	3 (10.3%)	-	**6 (1.5%)**
Profile on approach chart - reduces workload	1 (1.3%)	2 (1.3%)	2 (1.7%)	-	-	**5 (1.2%)**
From FAF to MAPt	1 (1.3%)	2 (1.3%)	-	-	-	**3 (0.7%)**
Single pilot is difficult (adequate support from NFP improves workload)	-	2 (1.3%)	1 (0.9%)	-	-	**3 (0.7%)**
Speed management	1 (1.3%)	1 (0.7%)	1 (0.9%)	-	-	**3 (0.7%)**
Steep approaches	2 (2.7%)	-	1 (0.9%)	-	-	**3 (0.7%)**
Accuracy of GPS	1 (1.3%)	1 (0.7%)	-	-	-	**2 (0.5%)**
Holding/approach suspension	1 (1.3%)	1 (0.7%)	-	-	-	**2 (0.5%)**

Table 26: Number (and percentage) of respondents noting aspects of an RNAV (GNSS) approach that contribute to *Time Pressure*

Aspects of an RNAV (GNSS) approach contributing to the degree of Time Pressure	Cat A	Cat B	Cat C/D	Cat H	Not specified	Total
Irregular segment lengths/Many close steps	16 (24.2%)	33 (25.2%)	13 (11.1%)	5 (19.2%)	4 (14.8%)	**71 (19.1%)**
Late decision/clearance to fly RNAV approach	2 (3%)	4 (3.1%)	23 (19.7%)	4 (15.4%)	4 (14.8%)	**37 (10%)**
Programming GPS/FMC/Setting up approach	4 (6.1%)	11 (8.4%)	12 (10.3%)	3 (11.5%)	4 (14.8%)	**34 (9.2%)**
Descent and Position monitoring/Situational Awareness	9 (13.6%)	12 (9.2%)	6 (5.1%)	4 (15.4%)	1 (3.7%)	**32 (8.6%)**
Early preparation reduces time pressure	5 (7.6%)	15 (11.5%)	7 (6%)	1 (3.9%)	3 (11.1%)	**31 (8.4%)**
Aircraft configuration Late increases/Aircraft configured early reduces workload/time pressure	1 (1.5%)	5 (3.8%)	17 (14.5%)	-	1 (3.7%)	**24 (6.5%)**
Briefing	-	2 (1.5%)	15 (12.8%)	-	2 (7.4%)	**19 (5.1%)**
No distance to MAPt (only to next waypoint)	2 (3%)	8 (6.1%)	4 (3.4%)	1 (3.9%)	3 (11.1%)	**18 (4.9%)**
Missed approach	3 (4.6%)	10 (7.6%)	3 (2.6%)	1 (3.9%)	-	**17 (4.6%)**
High performance aircraft - fast approach	3 (4.6%)	6 (4.6%)	2 (1.7%)	2 (7.7%)	-	**13 (3.5%)**
Procedural calls/checks	2 (3%)	9 (6.9%)	1 (0.9%)	1 (3.9%)	-	**13 (3.5%)**
Traffic management	3 (4.6%)	5 (3.8%)	4 (3.4%)	-	-	**12 (3.2%)**
Checklists	-	1 (0.8%)	7 (6%)	1 (3.9%)	1 (3.7%)	**10 (2.7%)**
Experience/Familiarity with approach and/or instrument	3 (4.6%)	4 (3.1%)	1 (0.9%)	-	2 (7.4%)	**10 (2.7%)**
GPS/FMS manipulation	3 (4.6%)	1 (0.8%)	4 (3.4%)	1 (3.9%)	-	**9 (2.4%)**
Steep approaches	5 (7.6%)	2 (1.5%)	-	2 (7.7%)	-	**9 (2.4%)**
Checking RAIM and other data	-	5 (3.8%)	2 (1.7%)	1 (3.9%)	-	**8 (2.2%)**
Runway alignment/straight in approach - reduces time pressure	1 (1.5%)	3 (2.3%)	3 (2.6%)	1 (3.9%)	-	**8 (2.2%)**
Setting altitude constraints	1 (1.5%)	4 (3.1%)	2 (1.7%)	-	-	**7 (1.9%)**
Adjusting tracking/profile/power	3 (4.6%)	2 (1.5%)	-	1 (3.9%)	-	**6 (1.6%)**

Aspects of an RNAV (GNSS) approach contributing to the degree of Time Pressure	**Cat A**	**Cat B**	**Cat C/D**	**Cat H**	**Not specified**	**Total**
Automation reduces time pressure	1 (1.5%)	1 (0.8%)	4 (3.4%)	-	-	**6 (1.6%)**
From FAF to MAPt	3 (4.6%)	1 (0.8%)	-	-	1 (3.7%)	**5 (1.3%)**
Altitude capture/conflict with approach and autopilot	-	4 (3%)	1 (0.9%)	-	-	**5 (1.3%)**
GPS/MCP display/interpretation	1 (1.5%)	1 (0.8%)	1 (0.9%)	1 (3.9%)	-	**4 (1.1%)**
Reading/Interpretation of approach chart	-	2 (1.5%)	-	1 (3.9%)	1 (3.7%)	**4 (1.1%)**
Coupling data/direction from GPS/FMS with approach chart	1 (1.5%)	2 (1.5%)	-	-	-	**3 (0.8%)**
Design and Terminology differences in GPS displays and systems	1 (1.5%)	1 (0.8%)	1 (0.9%)	-	-	**3 (0.8%)**
Monitoring scale changes on GPS	1 (1.5%)	-	2 (1.7%)	-	-	**3 (0.8%)**
Not aligned with STAR/CTA interference with approach	-	-	2 (1.7%)	-	1 (3.7%)	**3 (0.8%)**
VNAV path (reduces time pressure) / lack of vertical guidance increases time pressure	-	2 (1.5%)	1 (0.9%)	-	-	**3 (0.8%)**
Calculating profile	-	1 (0.8%)	-	-	1 (3.7%)	**2 (0.5%)**
Holding/approach suspension	1 (1.5%)	-	-	1 (3.9%)	-	**2 (0.5%)**

Table 27: Number (and percentage) of respondents noting aspects of an RNAV (GNSS) approach that contribute to *Approach Chart Interpretability*

Aspects of an RNAV (GNSS) approach contributing to the degree of Approach Chart Interpretability	Cat A	Cat B	Cat C/D	Cat H	Not specified	Total
Distance to go needs analysis	13 (14.9%)	36 (20.2%)	51 (36.7%)	7 (29.2%)	10 (28.6%)	**117 (25.3%)**
Good/No problems with approach chart	27 (31%)	31 (17.4%)	39 (28.1%)	7 (29.2%)	13 (37.1%)	**117 (25.3%)**
Complex/poor interpretability	7 (8.1%)	14 (7.9%)	7 (5%)	1 (4.2%)	4 (11.4%)	**33 (7.1%)**
Descent profile (distance/alt table) difficult to interpret	5 (5.8%)	11 (6.2%)	11 (7.9%)	-	1 (2.9%)	**28 (6%)**
Confusing waypoint names (Long names differing by one letter only)	5 (5.8%)	12 (6.7%)	6 (4.3%)	2 (8.3%)	3 (8.6%)	**28 (6%)**
Cluttered/crowded	6 (6.9%)	14 (7.9%)	2 (1.4%)	-	1 (2.9%)	**23 (5%)**
Too many segments (intermediate additional segments)	3 (3.5%)	13 (7.3%)	2 (1.4%)	2 (8.3%)	2 (5.7%)	**22 (4.8%)**
Familiarity with approach needed	3 (3.5%)	8 (4.5%)	6 (4.3%)	1 (4.2%)	-	**18 (3.9%)**
Vertical profile assists interpretability	2 (2.3%)	10 (5.6%)	4 (2.9%)	-	-	**16 (3.5%)**
Early segments not presented on descent profile (Jeppesen charts)	3 (3.5%)	10 (5.6%)	1 (0.7%)	-	-	**14 (3%)**
Irregular segment distances	1 (1.2%)	8 (4.5%)	4 (2.9%)	1 (4.2%)	-	**14 (3%)**
size of print too small	-	8 (4.5%)	2 (1.4%)	1 (4.2%)	1 (2.9%)	**12 (2.6%)**
Distance/Altitude table	1 (1.2%)	4 (2.3%)	4 (2.9%)	2 (8.3%)	-	**11 (2.4%)**
Standardisation of charts and approach	4 (4.6%)	1 (0.6%)	1 (0.7%)	2 (8.3%)	2 (5.7%)	**10 (2.2%)**
Table for distance/altitude and profile reads left-right is confusing	4 (4.6%)	4 (2.3%)	-	1 (4.2%)	-	**9 (1.9%)**
Missed approach procedures unclear	1 (1.2%)	2 (1.1%)	4 (2.9%)	-	1 (2.9%)	**8 (1.7%)**
Preparation time needed	1 (1.2%)	2 (1.1%)	2 (1.4%)	-	2 (5.7%)	**7 (1.5%)**
Shaded MSA enhances awareness	-	3 (1.7%)	-	1 (4.2%)	-	**4 (0.9%)**
Lateral and profile diagrams not aligning	-	2 (1.1%)	1 (0.7%)	-	1 (2.9%)	**4 (0.9%)**
Not matching with FMC database	-	-	4 (2.9%)	-	-	**4 (0.9%)**
Multiple entry waypoints	1 (1.2%)	2 (1.1%)	-	-	-	**3 (0.6%)**

Aspects of an RNAV (GNSS) approach contributing to the degree of Approach Chart Interpretability	Cat A	Cat B	Cat C/D	Cat H	Not specified	Total
Waypoint naming convention enhances interpretability	-	2 (1.1%)	-	-	-	**2 (0.4%)**
Holding pattern not marked on chart	-	1 (0.6%)	-	1 (4.2%)	-	**2 (0.4%)**

Table 28: Number (and percentage) of respondents noting aspects of an RNAV (GNSS) approach that contribute to *Perceived Safety*

Aspects of an RNAV (GNSS) approach contributing to the degree of Safety	**Cat A**	**Cat B**	**Cat C/D**	**Cat H**	**Not specified**	**Total**
Runway alignment/Straight in approaches - improves safety	12 (20.3%)	55 (33.5%)	39 (32%)	2 (10%)	8 (34.8%)	**116 (29.9%)**
Distance to go needs careful analysis/ No distance to the runway	5 (8.5%)	26 (15.9%)	21 (17.2%)	-	3 (13%)	**55 (14.2%)**
Ensuring situational awareness	11 (18.6%)	25 (15.2%)	5 (4.1%)	4 (20%)	2 (8.7%)	**47 (12.1%)**
VNAV/Automation improves safety	1 (1.7%)	5 (3%)	17 (14%)	3 (15%)	3 (13%)	**29 (7.5%)**
Accuracy level is high	8 (13.6%)	7 (4.3%)	3 (2.5%)	3 (15%)	-	**21 (5.4%)**
High mental workload	4 (6.8%)	7 (4.3%)	3 (2.5%)	2 (10%)	1 (4.4%)	**17 (4.4%)**
Maintaining a constant vertical profile improves safety	-	5 (3%)	11 (9.1%)	-	1 (4.3%)	**17 (4.4%)**
Lack of standardisation between GPS units (keeping current on different units)	5 (8.5%)	4 (2.4%)	1 (0.8%)	2 (10%)	3 (13%)	**15 (3.9%)**
Too many waypoints/ complex approach	3 (5.1%)	8 (4.9%)	2 (1.6%)	-	1 (4.4%)	**14 (3.6%)**
Preparation is needed	-	7 (4.3%)	6 (4.9%)	1 (5%)	-	**14 (3.6%)**
Familiarity with approach is needed	4 (6.8%)	5 (3.1%)	3 (2.5%)	-	-	**12 (3.1%)**
Single pilot unsafe/difficult (Two-pilots increases safety)	2 (3.4%)	6 (3.7%)	2 (1.6%)	1 (5%)	-	**11 (2.8%)**
QNH set incorrectly is not identifiable throughout the approach	-	-	10 (8.2%)	1 (5%)	-	**11 (2.8%)**
Some GPS units (especially older units) are less safe	2 (3.4%)	3 (1.8%)	1 (0.8%)	2 (10%)	1 (4.4%)	**9 (2.3%)**
Varying segment lengths/Different approach designs to optimum	2 (3.4%)	3 (1.8%)	2 (1.6%)	-	-	**7 (1.8%)**
Missed approach requires re-keying box	2 (3.4%)	4 (2.4%)	1 (0.8%)	-	-	**7 (1.8%)**
Confusing waypoint names (differ by one letter only)	1 (1.7%)	5 (3.1%)	1 (0.8%)	-	-	**7 (1.8%)**
Standardisation between approaches improves safety	1 (1.7%)	5 (3.1%)	1 (0.8%)	-	-	**7 (1.8%)**
Moving map display improves safety	3 (5.1%)	1 (0.6%)	-	1 (5%)	1 (4.4%)	**6 (1.5%)**
RAIM reliability	-	4 (2.4%)	-	1 (5%)	1 (4.4%)	**6 (1.5%)**
GPS position in cockpit	-	1 (0.6%)	2 (1.6%)	1 (5%)	1 (4.4%)	**5 (1.3%)**

Aspects of an RNAV (GNSS) approach contributing to the degree of Safety	Cat A	Cat B	Cat C/D	Cat H	Not specified	Total
RNAV now available where no ground based aids ever were	1 (1.7%)	1 (0.6%)	2 (1.6%)	-	-	**4 (1%)**
Minima could be lower to improve safety	-	2 (1.2%)	2 (1.6%)	-	-	**4 (1%)**
Setting minima on each sector	-	1 (0.6%)	1 (0.8%)	-	1 (4.4%)	**3 (0.8%)**
Steep approach/Higher than visual approach aids/ILS	-	1 (0.6%)	2 (1.6%)	-	-	**3 (0.8%)**
Scaling automatic changes	-	2 (1.2%)	-	-	-	**2 (0.5%)**
Untrained pilots think they are easy	-	2 (1.2%)	-	-	-	**2 (0.5%)**
Lower MDA than other approaches improves safety	-	-	1 (0.8%)	1 (5%)	-	**2 (0.5%)**
No back up to FMS	-	-	2 (1.6%)	-	-	**2 (0.5%)**

Table 29: Number (and percentage) of respondents noting aspects of an RNAV (GNSS) approach that could be improved

Suggested Improvements	Cat A	Cat B	Cat C/D	Cat H	Not specified	Total
RNAV Concept	***47 (59.5%)***	***129 (66.2%)***	***84 (55.3%)***	***18 (72%)***	***22 (64.7%)***	***300 (61.9%)***
Distance to MAPt used for chart and GPS references	31 (39.2%)	78 (40%)	58 (38.2%)	10 (40%)	17 (50%)	**194 (40%)**
FAF (and steps after FAF) removed from design (10 NM last segment)	4 (5.1%)	16 (8.2%)	7 (4.6%)	3 (12%)	4 (11.8%)	**34 (7%)**
Naming convention of waypoints (> 1 letter difference needed for long names)	3 (3.8%)	13 (6.7%)	10 (6.6%)	3 (12%)	-	**29 (6%)**
Reduction in number of waypoints/steps or Removal of short steps	3 (3.8%)	14 (7.2%)	4 (2.6%)	1 (4%)	-	**22 (4.5%)**
Standard distances between all waypoints/ standard MAPt position	5 (6.3%)	5 (2.6%)	4 (2.6%)	1 (4%)	1 (2.9%)	**16 (3.3%)**
Descent points to correspond with waypoints not in between them	-	3 (1.5%)	1 (0.7%)	-	-	**4 (0.8%)**
Alternative approaches made available when approach is over difficult terrain	1 (1.3%)	-	-	-	-	**1 (0.2%)**
Chart	***16 (20.3%)***	***47 (24.1%)***	***24 (15.8%)***	***5 (20%)***	***7 (20.6%)***	***99 (20.4%)***
Charts need improvement - other	9 (11.4%)	16 (8.2%)	12 (7.9%)	1 (4%)	3 (8.8%)	**41 (8.5%)**
Extend profile heights to IAF	-	15 (7.7%)	-	1 (4%)	-	**16 (3.3%)**
Distance/Altitude table needs improving	1 (1.3%)	5 (2.6%)	5 (3.3%)	1 (4%)	1 (2.9%)	**13 (2.7%)**
Match chart profile and plan diagrams	2 (2.5%)	5 (2.6%)	1 (0.7%)	-	2 (5.9%)	**10 (2.1%)**
Chart profile heights for every mile to run	-	2 (1%)	2 (1.3%)	-	1 (2.9%)	**5 (1%)**
MAPt crossing altitude needs to be clearer	1 (1.3%)	1 (0.5%)	2 (1.3%)	-	-	**4 (0.8%)**
Holding patterns published on each IAF waypoint	1 (1.3%)	1 (0.5%)	-	2 (8%)	-	**4 (0.8%)**
Left to Right table layout only	2 (2.5%)	1 (0.5%)	1 (0.7%)	-	-	**4 (0.8%)**
Publish waypoint capture regions	-	1 (0.5%)	1 (0.7%)	-	-	**2 (0.4%)**
Equipment	***17 (21.5%)***	***37 (19%)***	***20 (13.2%)***	***13 (52%)***	***7 (20.6%)***	***94 (19.4%)***
Standard GPS design across manufacturers	7 (8.9%)	20 (10.3%)	1 (0.7%)	3 (12%)	1 (2.9%)	**32 (6.6%)**

GPS/FMS units made 'user friendly'/Reduced GPS/FMS inputs	3 (3.8%)	4 (2.1%)	5 (3.3%)	2 (8%)	3 (8.8%)	**17 (3.5%)**
QNH automation	-	1 (0.5%)	9 (5.9%)	1 (4%)	-	**11 (2.3%)**
Missed approach auto sequenced in GPS system	1 (1.3%)	4 (2.1%)	3 (2%)	1 (4%)	-	**9 (1.9%)**
EFIS/FMS waypoint names should match chart (not numbers)	-	3 (1.5%)	2 (1.3%)	1 (4%)	-	**6 (1.2%)**
Auditory alert when passing over waypoints	3 (3.8%)	2 (1%)	-	-	-	**5 (1%)**
Moving map display should be required	-	1 (0.5%)	-	3 (12%)	1 (2.9%)	**5 (1%)**
Panel instruments close together (GPS/HSI)	1 (1.3%)	2 (1%)	-	1 (4%)	1 (2.9%)	**5 (1%)**
Holding patterns in the GPS system	1 (1.3%)	-	-	1 (4%)	1 (2.9%)	**3 (0.6%)**
Minimum segment heights displayed on GPS unit	1 (1.3%)	-	-	-	-	**1 (0.2%)**
Approach design	***6 (7.6%)***	***26 (13.3%)***	***41 (27%)***	***1 (4%)***	***2 (5.9%)***	***76 (15.7%)***
Lower minima	1 (1.3%)	3 (1.5%)	21 (13.8%)	-	1 (2.9%)	**26 (5.4%)**
3 degree slope only	1 (1.3%)	9 (4.6%)	4 (2.6%)	-	1 (2.9%)	**15 (3.1%)**
Runway alignment on all approaches	2 (2.5%)	2 (1%)	7 (4.6%)	-	-	**11 (2.3%)**
Overlayed approaches/waypoints matching ground based aids	-	1 (0.5%)	5 (3.3%)	1 (4%)	-	**7 (1.4%)**
MAPt should be further away from runway &/or higher	2 (2.5%)	3 (1.5%)	-	-	-	**5 (1%)**
Remove non-straight in IAF / reduce number of IAFs	-	5 (2.6%)	-	-	-	**5 (1%)**
Waypoint crossing height should be higher than minimum segment altitude	-	-	2 (1.3%)	-	-	**2 (0.4%)**
Position approach over lower terrain when available	-	2 (1%)	-	-	-	**2 (0.4%)**
Additional IAF needed at some approaches	-	-	2 (1.3%)	-	-	**2 (0.4%)**
No level segments	-	1 (0.5%)	-	-	-	**1 (0.2%)**
Capability	***10 (12.7%)***	***19 (9.7%)***	***3 (2%)***	***1 (4%)***	***3 (8.8%)***	***36 (7.4%)***
Vertical guidance	10 (12.7%)	18 (9.2%)	3 (2%)	1 (4%)	3 (8.8%)	**35 (7.2%)**
RAIM outage predictions	-	1 (0.5%)	-	-	-	**1 (0.2%)**
Air Traffic Control	***3 (0%)***	***1 (0%)***	***19 (0%)***	***-***	***-***	***23 (4.7%)***

Connect STARs with RNAV approaches	2 (2.5%)	-	17 (11.2%)	-	-	**19 (3.9%)**
ADS-B radar so ATC can see if off-track or off-profile	1 (1.3%)	1 (0.5%)	1 (0.7%)	-	-	**3 (0.6%)**
More flexible speed control	-	-	1 (0.7%)	-	-	**1 (0.2%)**
Procedures	***-***	***-***	***3 (2%)***	***-***	***1 (2.9%)***	***4 (0.8%)***
Not setting altitude limits (to reduce workload)	-	-	3 (2%)	-	1 (2.9%)	**4 (0.8%)**
Regulations	***3 (3.8%)***	***6 (3.1%)***	***2 (1.3%)***	***-***	***-***	***11 (2.3%)***
Training	3 (3.8%)	4 (2.1%)	2 (1.3%)	-	-	**9 (1.9%)**
Shorter currency period than 90 days	-	2 (1%)	-	-	-	**2 (0.4%)**

Table 30: Number (and percentage) of respondents noting circumstances of an RNAV (GNSS) approach that are the most difficult

Circumstances of an RNAV (GNSS) approach that are the most difficult	Cat A	Cat B	Cat C/D	Cat H	Not specified	Total
Conditions	***39 (47%)***	***74 (37%)***	***37 (26.2%)***	***19 (57.6%)***	***16 (41%)***	***264 (53.2%)***
Weather conditions poor	13 (15.7%)	25 (12.5%)	15 (10.6%)	9 (27.3%)	7 (17.9%)	**69 (13.9%)**
Turbulent conditions	16 (19.3%)	27 (13.5%)	8 (5.7%)	2 (6.1%)	5 (12.8%)	**58 (11.7%)**
Night	10 (12%)	22 (11%)	14 (9.9%)	8 (24.2%)	4 (10.3%)	**58 (11.7%)**
IMC	10 (12%)	22 (11%)	10 (7.1%)	2 (6.1%)	2 (5.1%)	**46 (9.3%)**
Terrain is significant	5 (6%)	3 (1.5%)	3 (2.1%)	-	-	**11 (2.2%)**
Cross-wind	4 (4.8%)	2 (1%)	-	-	2 (5.1%)	**8 (1.6%)**
RAIM loss during approach	1 (1.2%)	2 (1%)	-	1 (3%)	1 (2.6%)	**5 (1%)**
Temperature (high temperatures produce vertical offset)	-	-	2 (1.4%)	-	2 (5.1%)	**4 (0.8%)**
Marginal VMC	-	1 (0.5%)	2 (1.4%)	-	-	**3 (0.6%)**
Windshear	-	-	2 (1.4%)	-	-	**2 (0.4%)**
Operations	***13 (15.7%)***	***32 (16%)***	***14 (9.9%)***	***14 (42.4%)***	***2 (5.1%)***	***143 (28.8%)***
Single pilot operations	5 (6%)	14 (7%)	6 (4.3%)	8 (24.2%)	1 (2.6%)	**34 (6.9%)**
Speed too fast (rushed or tailwind)	5 (6%)	8 (4%)	3 (2.1%)	5 (15.2%)	1 (2.6%)	**22 (4.4%)**
Hand flying	3 (3.6%)	10 (5%)	5 (3.5%)	1 (3%)	-	**19 (3.8%)**
Short sectors (limited preparation time)	-	9 (4.5%)	6 (4.3%)	2 (6.1%)	-	**17 (3.4%)**
Unfamiliar approach	4 (4.8%)	6 (3%)	4 (2.8%)	2 (6.1%)	1 (2.6%)	**17 (3.4%)**
Reprogramming/positioning for a second approach	1 (1.2%)	5 (2.5%)	2 (1.4%)	2 (6.1%)	1 (2.6%)	**11 (2.2%)**
Aircraft malfunction/Engine out	-	1 (0.5%)	3 (2.1%)	2 (6.1%)	1 (2.6%)	**7 (1.4%)**
Fatigued	1 (1.2%)	1 (0.5%)	1 (0.7%)	2 (6.1%)	1 (2.6%)	**6 (1.2%)**
Inadequate support from PNF	-	4 (2%)	2 (1.4%)	-	-	**6 (1.2%)**

Circumstances of an RNAV (GNSS) approach that are the most difficult	Cat A	Cat B	Cat C/D	Cat H	Not specified	Total
High on approach	1 (1.2%)	2 (1%)	1 (0.7%)	-	-	**4 (0.8%)**
Approach	***14 (16.9%)***	***48 (24%)***	***7 (5%)***	***7 (21.2%)***	***7 (17.9%)***	***113 (22.8%)***
Multiple (short) limiting steps/ complex approach design	3 (3.6%)	29 (14.5%)	4 (2.8%)	5 (15.2%)	5 (12.8%)	**46 (9.3%)**
Steep approaches	6 (7.2%)	10 (5%)	2 (1.4%)	1 (3%)	1 (2.6%)	**20 (4%)**
Missed approach	5 (6%)	9 (4.5%)	1 (0.7%)	1 (3%)	1 (2.6%)	**17 (3.4%)**
Approach not runway aligned	-	3 (1.5%)	6 (4.3%)	1 (3%)	2 (5.1%)	**12 (2.4%)**
Significant heading changes	1 (1.2%)	6 (3%)	1 (0.7%)	-	1 (2.6%)	**9 (1.8%)**
Holding patterns (flown manually; maintaining orientation)	1 (1.2%)	1 (0.5%)	1 (0.7%)	1 (3%)	-	**4 (0.8%)**
Reaching limiting steps on autopilot	-	1 (0.5%)	2 (1.4%)	-	1 (2.6%)	**4 (0.8%)**
Straight approaches (no turn at IF)	1 (1.2%)	-	-	-	-	**1 (0.2%)**
ATC	***10 (12%)***	***31 (15.5%)***	***60 (42.6%)***	***2 (6.1%)***	***5 (12.8%)***	***108 (21.8%)***
Short notice from ATC or limited preparation time	9 (10.8%)	24 (12%)	46 (32.6%)	2 (6.1%)	4 (10.3%)	**85 (17.1%)**
Vectors don't join approach or join approach too close to initial/intermediate waypoint	1 (1.2%)	3 (1.5%)	12 (8.5%)	-	-	**16 (3.2%)**
ATC required limits (height/speed limits)	-	4 (2%)	2 (1.4%)	-	1 (2.6%)	**7 (1.4%)**
Traffic	***14 (16.9%)***	***53 (26.5%)***	***22 (15.6%)***	***5 (15.2%)***	***7 (17.9%)***	*101 (20.4%)*
Traffic	9 (10.8%)	42 (21%)	15 (10.6%)	5 (15.2%)	7 (17.9%)	78 (15.7%)
VFR Traffic	4 (4.8%)	6 (3%)	4 (2.8%)	-	-	14 (2.8%)
Traffic conducting non-RNAV approach	1 (1.2%)	5 (2.5%)	3 (2.1%)	-	-	9 (1.8%)
Airspace	***7 (8.4%)***	***23 (11.5%)***	***27 (19.1%)***	***1 (3%)***	***1 (2.6%)***	*59 (11.9%)*
Outside controlled airspace	4 (4.8%)	10 (5%)	21 (14.9%)	1 (3%)	-	36 (7.3%)
CTAF requirement/radio communications	3 (3.6%)	12 (6%)	6 (4.3%)	-	1 (2.6%)	22 (4.4%)
Restricted airspace	-	1 (0.5%)	-	-	-	1 (0.2%)

Circumstances of an RNAV (GNSS) approach that are the most difficult	Cat A	Cat B	Cat C/D	Cat H	Not specified	Total
Equipment	***9 (10.8%)***	***20 (10%)***	***6 (4.3%)***	***5 (15.2%)***	***4 (10.3%)***	*46 (9.3%)*
Older GPS equipment being used/ no moving map display	3 (3.6%)	11 (5.5%)	2 (1.4%)	1 (3%)	3 (7.7%)	20 (4%)
Not recently used (or unfamiliar) GPS equipment	5 (6%)	5 (2.5%)	1 (0.7%)	4 (12.1%)	-	15 (3%)
Variety of GPS receivers used regularly	1 (1.2%)	4 (2%)	3 (2.1%)	-	1 (2.6%)	9 (1.8%)
Coupling GPS information to HSI	1 (1.2%)	1 (0.5%)	-	-	-	2 (0.4%)

Table 31: Number (and percentage) of respondents indicating reasons why the class of airspace has an impact on workload during an approach

Airspace factors impacting on workload during an approach	Cat A	Cat B	Cat C/D	Cat H	Not specified	Total
Maintaining and monitoring self separation with other traffic OCTA	26 (36.6%)	111 (61%)	139 (74.3%)	13 (41.9%)	19 (55.9%)	**308 (61%)**
The provision of traffic separation, radar vectoring and weather information by ATC	24 (33.8%)	41 (22.5%)	24 (12.8%)	10 (32.3%)	4 (11.8%)	**103 (20.4%)**
Radio requirements	16 (22.5%)	23 (12.6%)	25 (13.4%)	3 (9.7%)	3 (8.8%)	**70 (13.9%)**
ATC instructions	7 (9.9%)	20 (11%)	5 (2.7%)	6 (19.4%)	1 (2.9%)	**39 (7.7%)**
OCTA increases workload/CTA reduces workload	10 (14.1%)	5 (2.7%)	11 (5.9%)	-	2 (5.9%)	**28 (5.5%)**
Increased SA required in OCTA	1 (1.4%)	2 (1.1%)	5 (2.7%)	3 (9.7%)	1 (2.9%)	**12 (2.4%)**
CTA step requirements	-	1 (0.5%)	10 (5.3%)	-	1 (2.9%)	**12 (2.4%)**
Increased workload at high density aerodromes	-	8 (4.4%)	1 (0.5%)	1 (3.2%)	1 (2.9%)	**11 (2.2%)**
OCTA operational requirements (excluding radio and traffic separation)	1 (1.4%)	4 (2.2%)	4 (2.1%)	-	2 (5.9%)	**11 (2.2%)**
CTA/OCTA transition requirements	2 (2.8%)	2 (1.1%)	2 (1.1%)	3 (9.7%)	-	**9 (1.8%)**
Airspace procedural changes	1 (1.4%)	5 (2.7%)	3 (1.6%)	-	-	**9 (1.8%)**
Weather considerations (including no weather information provided OCTA)	1 (1.4%)	5 (2.7%)	2 (1.1%)	-	-	**8 (1.6%)**
CTA increases workload	1 (1.4%)	1 (0.5%)	2 (1.1%)	1 (3.2%)	-	**5 (1%)**
Approach flexibility in OCTA	1 (1.4%)	1 (0.5%)	1 (0.5%)	1 (3.2%)	-	**4 (0.8%)**
Terrain considerations	-	1 (0.5%)	2 (1.1%)	-	1 (2.9%)	**4 (0.8%)**
Reduced SA required in CTA	-	2 (1.1%)	-	-	1 (2.9%)	**3 (0.6%)**
VFR traffic in Class E is unpredictable; not assured of the location of VFR traffic	-	1 (0.5%)	-	-	2 (5.9%)	**3 (0.6%)**
Workload is increased in procedural CTA compared with radar CTA	1 (1.4%)	1 (0.5%)	1 (0.5%)	-	-	**3 (0.6%)**
Situational awareness (other)	-	-	1 (0.5%)	-	-	**1 (0.2%)**