



Australian Government
Australian Transport Safety Bureau

Descent below the minimum permitted altitude involving Boeing 737-838, VH-VXB

35 km SW of Canberra Airport, Australian Capital Territory | 17 October 2012



Investigation

ATSB Transport Safety Report
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Cover illustration: Map of airspace to the south-west of Canberra

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Addendum

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Safety summary

What happened

On 17 October 2012, a Boeing 737-838 aircraft, registered VH-VXB and operated by Qantas Airways Limited (Qantas), was conducting a flight from Adelaide, South Australia to Canberra, Australian Capital Territory. The flight crew received an approach clearance into Canberra via a standard arrival route (STAR) and then an Area Navigation (Required Navigation Performance) (RNAV (RNP)) instrument approach to runway 35 at Canberra Airport. Just prior to commencing descent, at about 2030 Eastern Daylight-saving Time, air traffic control (ATC) cancelled the STAR and cleared the aircraft to track direct to the initial approach fix, HONEY, via a high-speed descent. As the aircraft approached 8,000 ft, ATC provided a descent clearance to 7,000 ft and also cleared the aircraft for the approach. As the aircraft approached HONEY it descended below the 7,000 ft altitude clearance limit. After being alerted to this by ATC, the flight crew climbed the aircraft back to 7,000 ft and continued the approach to land.

What the ATSB found

The ATSB found that, as the aircraft approached 8,000 ft, the auto-flight system vertical mode changed from a flight management computer-derived and managed vertical navigation mode into the vertical speed mode. This was followed by a number of automated, but unnoticed, and crew-initiated changes in the aircraft's auto-flight system vertical mode. The combination of auto-flight system mode changes and the management of the airspeed during the descent resulted in a high workload environment where the 7,000 ft altitude clearance limit was overlooked by the flight crew.

The ATSB also found that, on receipt of the approach clearance, the Qantas RNAV (RNP) approach procedures allowed the flight crew to remove the current limiting altitude from the auto-flight system's Mode Control Panel (MCP) and set the decision altitude. Application of this procedure by the flight crew removed the last automated safety system available to them to prevent descent through the current altitude limitation, well before the aircraft was established on the approach.

What's been done as a result

Following this occurrence, Qantas changed their RNAV (RNP) approach procedures to only allow the altitude on the MCP to be changed from the current limiting altitude once the aircraft was within 2 NM (4 km) of commencing the approach.

Safety message

This occurrence highlights the importance of paying continuous attention to active and armed auto-flight modes and the need to continually monitor descent profiles and airspace limitations in relation to the aircraft's position, irrespective of the expectation that the descent is being managed by the auto-flight system. The adverse effect of workload and task focus on flight crew performance and the importance of robust procedures for high-precision approaches are also illustrated.

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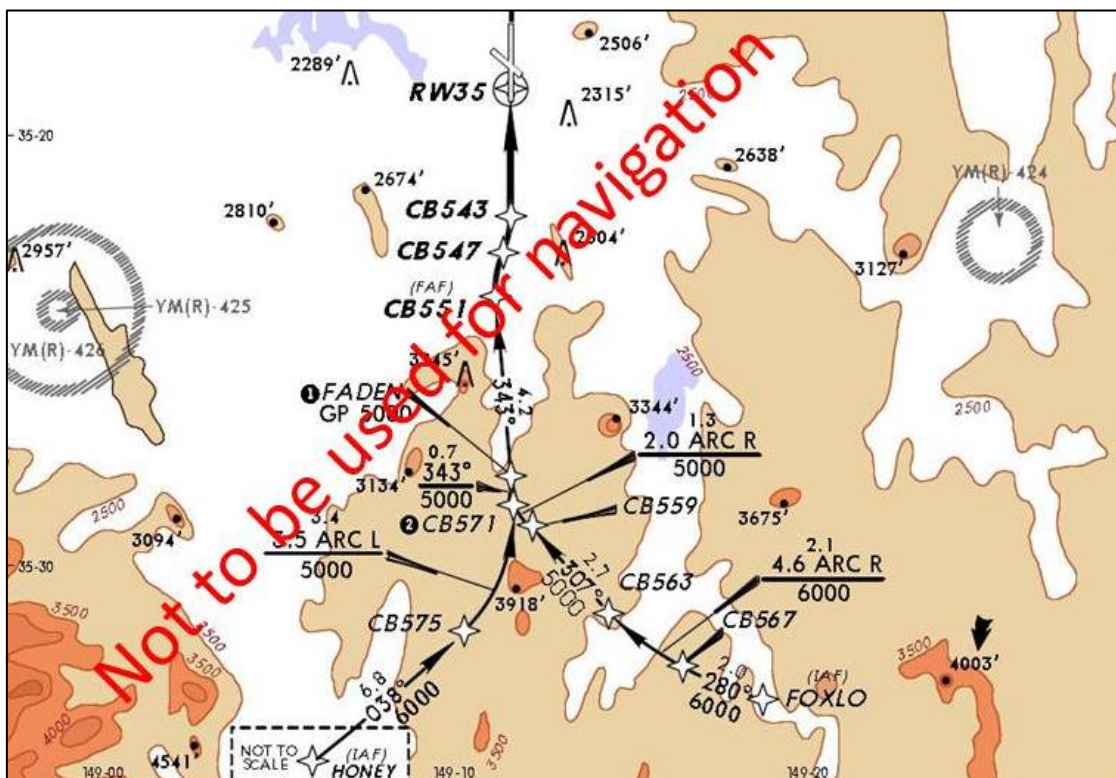
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The occurrence

On 17 October 2012, the flight crew of a Boeing 737-838 aircraft, registered VH-VXB and operated by Qantas Airways Limited (Qantas), was conducting a scheduled passenger service from Adelaide, South Australia to Canberra, Australian Capital Territory. The flight crew consisted of the captain, who was the pilot flying, and the first officer (FO), who was the pilot not flying.¹ At about 2030 Eastern Daylight-saving Time,² the descent into Canberra was commenced, during which the aircraft descended below an assigned air traffic control (ATC) altitude of 7,000 ft above mean sea level. At about the same time, ATC received a minimum safe altitude warning (MSAW) alert (see the section titled *Air traffic services—Minimum Safe Altitude Warning*).

Before commencing the descent, the flight crew prepared for arrival into Canberra via the POLLI 2U standard arrival route (STAR) for the Area Navigation (Required Navigation Performance) RNAV-U (RNP) RWY35 approach³ (RNAV-U) (Figure 1). This approach was subject to specifications defined under the RNP AR approach category, where the AR stood for 'authorisation required' (see the section titled *RNP AR approach procedures*). The vertical profile for the descent was calculated using the standard company descent profile of cruise Mach number/280 kt and the forecast descent winds that were entered into the vertical navigation page of the flight management computer (FMC).⁴

Figure 1: Extract of the Canberra RNAV-U (RNP) RWY 35 instrument approach chart (the complete chart, including vertical profile is at appendix B)

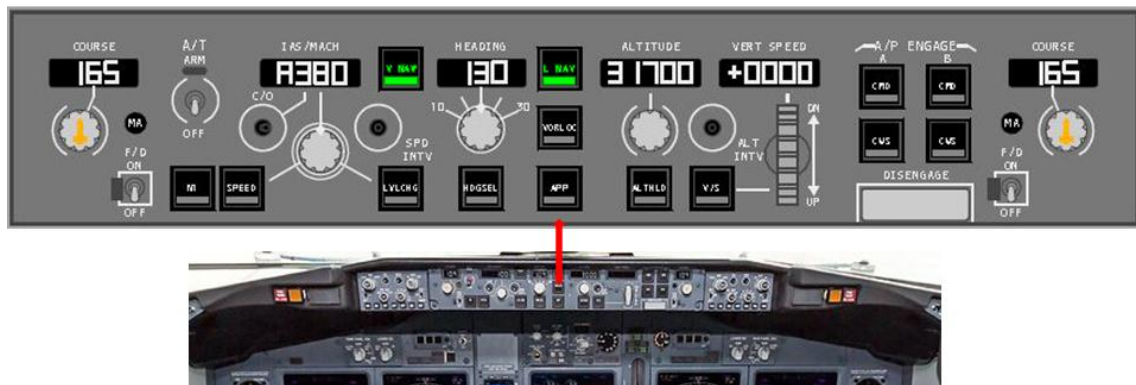


Source: Qantas

¹ The pilot flying does most of the flying, except in defined circumstances; such as planning for descent, approach and landing. The pilot not flying carries out support duties and monitors the pilot flying's actions and aircraft flight path.
² Eastern Daylight-saving Time (EDT) was Coordinated Universal Time (UTC) + 11 hours.
³ The RNAV-U approach was an approach procedure developed using Performance Based Navigation techniques (see *Appendix A – Performance based navigation*).
⁴ The FMC provides aircraft navigation, lateral and vertical guidance, and aircraft performance functions along a pre-planned route.

The flight crew stated that the briefing for the approach was normal and conducted before the commencement of the descent. Just prior to the descent, the flight crew accepted an ATC request to conduct a high-speed descent. This required a modification to the descent profile entered into the FMC, with the descent speed changed to 320 kt and the removal of the ATC speed reduction at 10,000 ft, but with the addition of an operator-required speed reduction to 250 kt at 5,000 ft above the height of the airport (equating to about 7,000 ft during approach to Canberra). However, the captain elected to conduct the high-speed descent at 310 kt to ensure a greater margin from the aircraft's maximum airspeed of 340 kt. The captain commenced the descent using the autopilot to control the aircraft's flight path by selecting vertical (V NAV) and lateral navigation (L NAV) modes on the Mode Control Panel (MCP)⁵ (Figure 2).

Figure 2: Glareshield with expanded MCP



Source: Qantas

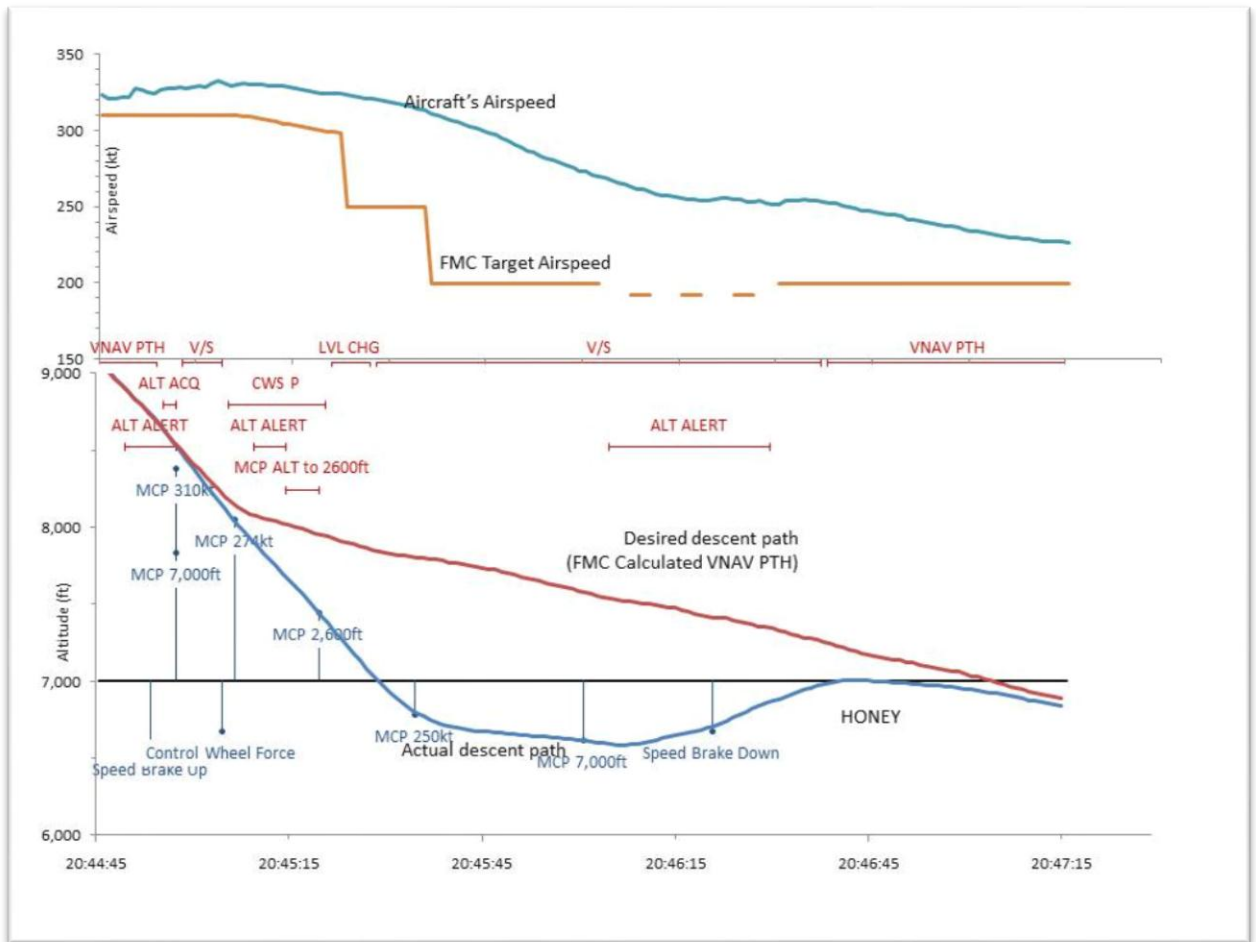
Shortly after commencing the descent, ATC instructed the flight crew to track directly to RNAV-U initial approach fix HONEY, which removed them from the STAR and resulted in some track shortening. At 2043, the FO contacted Canberra Approach and advised the controller that the aircraft was on descent to flight level (FL)⁶ 110. The controller responded with a clearance to continue the descent to 8,000 ft. This altitude was set in the MCP.

The aircraft's descent profile from about 9,000 ft until just after the aircraft passed HONEY is displayed graphically at Figure 3. At 2044:49, as the aircraft passed about 9,000 ft with a descent rate of about 2,700 feet per minute (fpm), the aircraft's altitude alert warning system (ALT ALERT) activated, indicating that the aircraft was approaching the 8,000 ft clearance limit set in the MCP. Four seconds later, the autopilot entered the altitude acquire mode (ALT ACQ) in order to level at 8,000 ft. At about the same time, ATC cleared the aircraft to continue descent to 7,000 ft and make the RNAV-U approach. The 7,000 ft altitude restriction ensured that the aircraft maintained at least 500 ft above the lower limit of controlled airspace until cleared further and provided in excess of 2,000 ft clearance above terrain.

⁵ The MCP enables the pilots to alter the altitude, speed, heading and other functions.

⁶ At altitudes above 10,000 ft in Australia, an aircraft's height above mean sea level is referred to as a flight level (FL). FL 110 equates to 11,000 ft.

Figure 3: Descent profile with auto-flight modes and MCP inputs annotated



Source: ATSB

As the FO responded to the ATC clearance at 2044:57, the captain changed the altitude in the MCP to 7,000 ft, which removed the 8,000 ft ALT ALERT warning. As a result of changing the MCP altitude while in the ALT ACQ mode, the autopilot changed its vertical control mode from the FMC-calculated vertical path (VNAV PTH) to vertical speed (V/S). On entering the V/S mode, the MCP airspeed and vertical speed windows (the IAS/MACH and VERT SPEED labelled windows at Figure 2) opened and displayed the current airspeed of 310 kt and rate of descent of 3,400 fpm.

The captain later reported that, at around this point of the descent, the aircraft encountered a significant windshear with reducing tailwind. This caused the airspeed to increase rapidly from the target of 310 kt to over 330 kt. In response, the captain selected full speed brake, but recalled that this had minimal effect in controlling the airspeed.

At 2045:05, 7 seconds after the aircraft entered the V/S mode and about the time the aircraft's speed reached 330 kt, the captain inadvertently applied sufficient force to the control column to cause the autopilot to enter the control wheel steering pitch mode (CWS P). The change of vertical mode from V/S to CWS P resulted in the VERT SPEED window closing while the IAS/MACH window remained open. A few seconds later the captain reduced the selected airspeed in the MCP to 274 kt. Both flight crew recalled that, at this time, their major focus was on reducing the aircraft's airspeed.

At 2045:09, with the aircraft passing through 8,000 ft at a speed of about 330 kt and a rate of descent of about 3,000 fpm, the ALT ALERT warning again activated indicating that the aircraft was approaching 7,000 ft. The captain reported that, as the aircraft had been cleared for the RNAV-U approach, the decision altitude (DA) of 2,600 ft for the approach was set in the MCP in

accordance with the Qantas RNP AR procedures. Replacing the 7,000 ft MCP altitude with the lower DA deactivated the altitude alert.

The aircraft continued to descend at about 3,000 fpm in the CWS P mode until at 2045:21, as the aircraft descended through about 7,400 ft, the captain selected the level change (LVL CHG) mode on the MCP (Figure 2). The captain reported expecting that the automation would have reduced the airspeed to 250 kt by 7,000 ft, as set up in the FMC before commencing the descent. However, as the aircraft passed about 7,200 ft, it became evident that the automation was not slowing the aircraft sufficiently, so the captain selected the V/S mode with the aim of levelling the aircraft and reducing the airspeed. The selection of the V/S mode caused the VERT SPEED window to open at the current rate of descent, which the captain then reduced to zero. At 2045:33, the captain reduced the MCP airspeed from 274 kt to 250 kt and observed that the aircraft had inadvertently descended below the VNAV PTH. The captain's intention was to correct this condition by reducing the airspeed to 250 kt in level flight and then re-intercept the VNAV PTH from below.

The flight crew did not recall the aircraft's pitch mode changing to CWS P, nor the change in vertical mode on the flight mode annunciator (FMA) (see the section titled *Automatic flight system*), until the captain manually selected the LVL CHG and V/S modes as the aircraft approached 7,000 ft. The captain reported checking the vertical mode in accordance with the RNP approach procedures before selecting the DA in the MCP, and both flight crew stated that they believed that the vertical mode was in the correct VNAV PTH mode. The aircraft flight data recording identified that the various mode changes were annunciated on the flight crew's primary flight displays. Both pilots reported that missing the mode changes probably occurred due to the high workload during that part of the descent, as well as their focus on containing the airspeed.

Just after the aircraft passed through 7,000 ft with a reducing rate of descent of about 2,000 fpm, ATC received a minimum safe altitude warning (MSAW) alert. In response to this alert, the controller queried the flight crew about maintaining the aircraft within controlled airspace, and then instructed them to climb the aircraft back to 7,000 ft until HONEY. The flight data indicated that the aircraft descended to about 6,600 ft before climbing back to 7,000 ft. After re-establishing the aircraft at 7,000 ft the captain selected the V NAV mode on the MCP. The aircraft passed HONEY and the flight crew continued the approach and landed on runway 35.

After landing, the captain reviewed the chart for the RNAV-U approach and the FMC data to check if there was an altitude restriction at HONEY. There was no altitude restriction at HONEY displayed on the RNAV-U approach chart or in the FMC database.

Context

Personnel information

The captain held an Air Transport Pilot (Aeroplane) Licence (ATP(A)L) and had accumulated about 8,000 hours of aeronautical experience. Of these, approximately 4,300 hours were in command and about 5,250 hours were on Boeing 737 aircraft. The first officer (FO) also held an ATP(A)L and had accumulated about 9,400 hours of aeronautical experience, including about 2,300 hours on the Boeing 737. Both pilots held current Class 1 Aviation Medical Certificates and were appropriately qualified to conduct the flight.

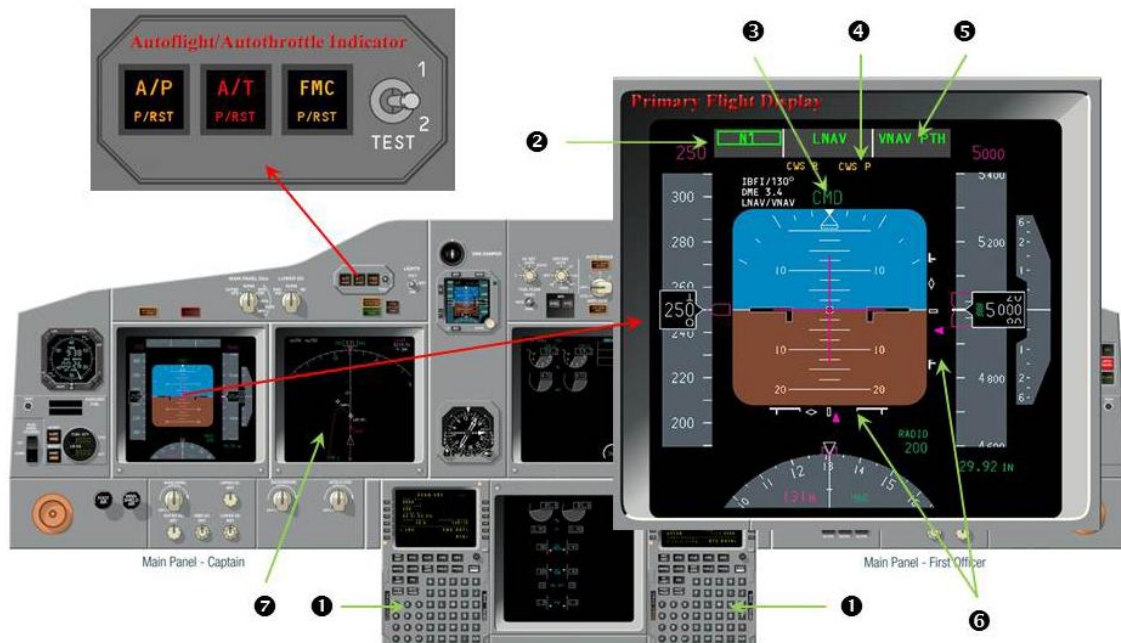
An assessment of the flight crew's rosters, sleep patterns and reported activities found no evidence that fatigue or other physiological issues affected their performance during the flight. The flight crew commenced duty in Adelaide at 1830 and both recalled that they were adequately rested before commencing duty.

Aircraft information

Automatic flight system

Flight crews normally control the climb, descent and approach in Boeing 737 aircraft using the aircraft's automatic flight system (AFS). The AFS consists of the autopilot/flight director system (AFDS) and the autothrottle (A/T). The AFDS is controlled through the Mode Control Panel (MCP) on the glareshield (Figure 2), as well as through inputs to the flight management computers (FMC) at each of the pilot stations (item ❶ on Figure 4).

Figure 4: Flight deck main panel with expanded auto-flight/autothrottle indicator and primary flight display



Source: Boeing

The AFDS flight mode annunciator (FMA) displays the engaged AFDS modes above the attitude indicator on the pilot's primary flight display (PFD) (item ❷ on Figure 4). The FMA is divided into three sections from left to right, being autothrottle, roll and pitch. The autothrottle and roll modes displayed on the PFD in Figure 4 are N1 and LNAV, while the pitch mode displayed is VNAV PTH (item ❸ on Figure 4). An AFDS mode change results in a highlighted symbol (rectangle) being

drawn around the relevant mode for 10 seconds after each engagement (see for example the boxed N1 displayed on the FMA in Figure 4). When the flight crew changes a flight mode, the change is initiated through switch selection on the MCP and then confirmed by ensuring that the appropriate mode is displayed on the FMA.

Immediately below the FMA are the AFDS status indicators. The status indications displayed in Figure 4 are:

- CMD, indicating that one or both autopilots are engaged (item ⑤)
- CWS P, indicating that the control wheel steering (CWS) pitch mode is engaged (item ④)
- CWS R, indicating that the CWS roll mode is engaged.

CWS P and/or CWS R are only displayed when the autopilot CWS mode is engaged.

As with changes in AFDS mode, changes in the AFDS status are also indicated by a highlighted symbol (rectangle) around the relevant status indicator for 10 seconds.

Control wheel steering

CWS may be engaged through the selection of the CWS switch on the MCP (Figure 2) or, when the autopilot is engaged, through either deselection of the current pitch or roll mode or by the application of force to the control column. When CWS is engaged, the autopilot manoeuvres the aircraft in response to the control pressures applied by either pilot to the control column. When control pressure is released, the autopilot maintains the current attitude. CWS disengages the respective AFDS mode; that is CWS R/CWS P disengages the respective AFDS roll/pitch modes, which in turn is reflected by the blanking of the FMA roll/pitch indication and display of the CWS P/CWS R annunciators. The CWS P mode may engage independently of CWS R due to control wheel pressure.

Both pilots also have an Autoflight/Autothrottle Indicator (Figure 4). When the CWS is engaged, the pushbutton light labelled A/P P/RST flashes yellow until either the alert is cleared through pressing that button, or a vertical and/or horizontal mode is selected on the MCP.

Among other recorded parameters, the aircraft's flight data recorder (FDR) records the forces applied to the control column. Data from the FDR identified that a force was applied to the control column coincident with the aircraft's auto-flight system vertical mode changing from V/S to CWS P. This force was substantially greater than the forces applied to the control column at any other time during the flight.

Vertical path guidance

The navigation performance scales (NPS) (item ⑥ on Figure 4) on the PFD display the aircraft's lateral and vertical displacement from the FMC-calculated horizontal and vertical path. A detailed discussion on performance-based navigation and the use of the NPS is at appendix A.

The navigation display (ND) (item ⑦ on Figure 4) is able to display a Vertical Situation Display (VSD) superimposed on the current display. Data presented in the VSD is extensive, including the MCP target altitude, the approach minima, waypoint altitude constraints, a graphic presentation of terrain, the vertical flight path vector, as well as a 3° descent path reference or the FMC approach glide path angle. The first officer's ND was reported to have had the VSD and terrain selected.

Operational information

RNP AR approach procedures

The *Supplementary Procedures* section of the Flight Crew Operating Manual (FCOM) contained the relevant procedures for the conduct of an RNAV (RNP AR) approach. These procedures included that the MCP was to be set to the decision altitude once cleared for the approach and the selection of VNAV PTH confirmed on the FMA. The flight crew was then required to monitor the vertical path performance to ensure that all waypoint crossing altitudes were met.

RNAV (RNP AR) approaches, coupled with a standard arrival route (STAR) and flown in the managed VNAV mode, ensured that the aircraft remained on the correct profile prior to commencing the approach, thereby preventing descent below assigned altitudes. Additionally, the use of a standard descent profile, rather than a high-speed descent, would have reduced crew workload in this occurrence. The company’s standard operating procedures permitted the use of high-speed descent at the discretion of the captain. However, following this occurrence, Qantas requested that Airservices Australia not combine the use of track shortening and high-speed descent when clearing company aircraft to conduct a precision approach into Canberra.

Standard operating procedures

The *Standard Operating Procedures* (SOPs) section of the Flight Administration Manual (FAM) stated that:

At all times, Flight Crew must retain positive control over automated systems. Timely reversion to basic modes of operation and/or disengagement of automatic systems should be accomplished if system performance becomes inaccurate, unclear or inappropriate.

The SOPs also emphasised the need to be aware of the status of aircraft systems as follows:

In order to improve awareness of system status, changes in the Flight Mode Annunciator (FMA) status or autopilot status are to be verbalised as follows:

...

After a pilot initiated mode change via the MCP or as a result of FMS generated changes, the PF will call changes to the annunciated mode(s) and the PNF will verify and call “checked”.

...

The actual words used to identify a mode change are not as important as the awareness of that change. For example, it is equally acceptable to call “LNAV” or “LNAV Capture” when that mode engages.

Finally, the SOPs stipulated the use of the altitude alerting system as follows:

The Altitude Alerting System shall be used to warn of approach to and deviation from cleared altitudes. It is not intended to be used as a reminder of transition altitudes or reporting altitudes. The Altitude Alerting System must always reflect the current altitude limit.

Prior to receiving an initial ATC clearance, the Altitude Alerting System may be set to an anticipated altitude/level. Following receipt of a clearance, the Altitude Alerting System shall be set to the first altitude clearance limit.

When clearance to an altitude is received, one of the pilots should set the numbers and it is mandatory for another pilot to crosscheck the setting.

Meteorological information

The flight crew reported that the approach was conducted in clear night-time conditions. They recalled that the forecast winds for the descent, which were entered into the FMC prior to top of descent, were accurate at altitude but not accurate below 10,000 ft.

Air traffic services

Minimum Safe Altitude Warning

The Australian Advanced Air Traffic System (TAAATS) is fitted with a Minimum Safe Altitude Warning (MSAW) system to assist in the prevention of controlled flight into terrain.

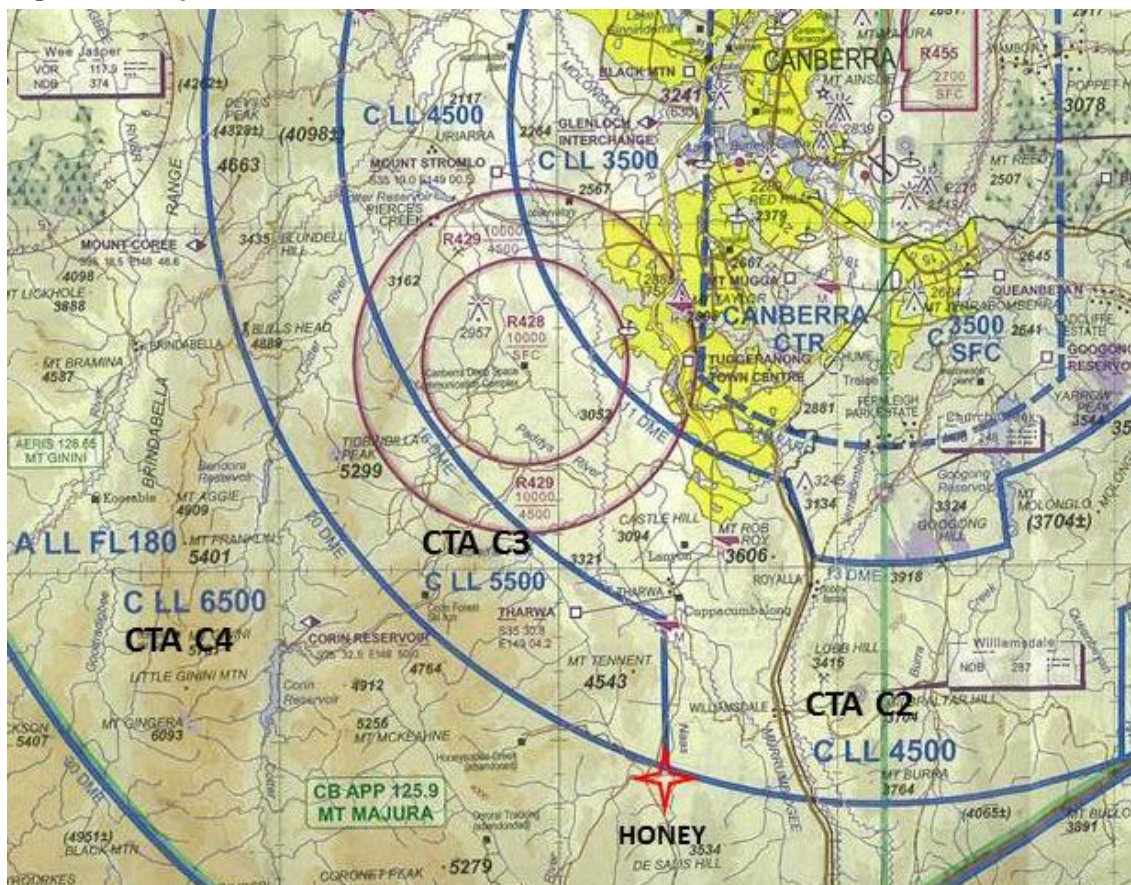
TAAATS uses a general terrain monitoring type of MSAW system that monitors the aircraft's reported altitude (Mode C)⁷ against a terrain map. The terrain map is based on a mosaic grid comprising areas of about 0.5 km square with each square set to an altitude represented by the highest terrain within that square, with obstacle data (such as towers or buildings) overlaid on that map. A predictive function calculates an aircraft's rate of descent from a number of Mode C returns and projects this rate of descent and the aircraft's track forward 60 seconds. If the projection predicts that the aircraft would impact the terrain map, a warning is provided to the controller.

The aircraft's recorded flight data showed that, as it approached 7,000 ft, its rate of descent decreased from about 3,000 fpm to about 1,500 fpm. During this period, the aircraft's radio altimeter recorded altitudes of about 3,000 ft above terrain. The relevant minimum vector altitude⁸ for the aircraft's position at the time of the MSAW alert was 6,500 ft.

Airspace information

Figure 5 depicts the airspace structure to the south of Canberra, focussing on the south-western approaches.

Figure 5: Airspace to the south-west of Canberra



Source: Airservices Australia, image modified by the ATSB.

The Designated Airspace Handbook (DAH) listed the particular airspace relevant to the descent towards RNAV-U initial approach fix (IAF) HONEY as a number of Class C controlled airspace segments. These segments were labelled CTA (controlled airspace) C2, C3 and C4, with lower

⁷ An aircraft transponder signal with barometric information from an encoding altimeter, encrypted so that it enables altitude presentation on air traffic control radar screens.

⁸ The minimum vector altitude was the lowest altitude that was able to be assigned to a pilot by ATC.

limits of 4,500 ft, 5,500 ft and 6,500 ft respectively. HONEY was about 200 m south-south-west of the common boundary between C2, C3 and C4, placing it just inside CTA C4. The lower limit of the Class C controlled airspace at HONEY was 6,500 ft.

The Aeronautical Information Publication Australia⁹ ENR 1.1 paragraph 3.12 stated that:

A pilot, desiring to retain control area protection during climb or descent in Class C or Class D airspace, should maintain at least 500FT above the lower limit of the CTA steps.

Approach aids procedure design

The International Civil Aviation Organization (ICAO) published a manual designed to aid instrument approach procedure designers in the construction of RNP AR instrument approaches—ICAO Document 9905 *Required Navigation Performance Authorization Required (RNP AR) Procedure Design Manual* (Doc 9905). Section 4.3.4 *Procedure altitudes/heights* of the manual stated:

All initial approach segments shall have procedure altitudes/heights established and published. Procedure altitudes/heights shall not be less than the OCA/H [obstacle clearance altitude/height] and shall be developed in coordination with air traffic control (ATC).

The Australian Manual of Standards Part 173—*Standards Applicable to Instrument Flight Procedure Design* included a chapter on design standards for instrument approach procedures. Paragraph 8.1.1.4 from that chapter stated:

Airspace Buffers. Procedures within controlled airspace must be designed so that:

...

(b) vertically:

- (i) A 500 ft buffer is provided between the nominal aircraft position and an airspace boundary set for VFR level;

The flight crew were using a Qantas-issued Jeppesen chart for the RNAV-U (RNP) RWY35 approach (see Figure 1). This chart had a segment altitude of 6,000 ft between HONEY and CB575, meaning aircraft could not descend below 6,000 ft in that segment. However, there was no altitude restriction displayed on the chart, or in the aircraft's FMC database for HONEY itself. Airservices Australia also published a chart relating to the approach, for the awareness of other operators. This chart included an altitude limitation of not below 6,000 ft at HONEY.

The position of HONEY within CTA C4 meant that the associated lower limit of controlled airspace in that position was 6,500 ft. Therefore, in accordance with ICAO Doc 9905 guidance, the requirements of AIP ENR 1.1 paragraph 3.12 and the Manual of Standards Part 173 paragraph 8.1.1.4, the RNAV-U (RNP) RWY35 approach required an altitude limitation of not below 7,000 ft overhead HONEY. During the course of this investigation the Australian Transport Safety Bureau (ATSB) raised this matter with the Civil Aviation Safety Authority and the relevant charts were amended accordingly.

Related occurrences

A review of the ATSB's occurrence database identified two recent similar occurrences on scheduled passenger transport flights that were investigated by the ATSB.¹⁰

ATSB investigation AO-2012-103

On 16 July 2012, at about 0830 New Zealand Standard Time, the flight crew of an Airbus A320-232 aircraft was conducting an RNAV (RNP) approach to runway 05 at Queenstown, New

⁹ A package of documents that provides the operational information necessary for the safe and efficient conduct of national (civil) and international air navigation throughout Australia and its Territories.

¹⁰ Available at www.atsb.gov.au

Zealand. During the approach the aircraft descended below two segment minimum safe altitudes. Upon recognising the descent profile error, the crew climbed the aircraft to intercept the correct profile and continued the approach to land.

The ATSB found that, contrary to their intentions, the crew continued descent with the auto-flight system in open descent mode, which did not provide protection against infringing the instrument approach procedure's segment minimum safe altitudes. The ATSB also found that the crew were not strictly adhering to the operator's sterile flight deck procedures, which probably allowed the crew to become distracted.

Finally, the ATSB found that the operator's procedures did not specifically draw the flight crew's attention to unchanged auto-flight system modes during descent or prompt flight crew reconsideration of the most suitable descent mode at any point during descent. Additionally, the operator's procedures allowed the flight crew to select the altitude to which they were cleared by ATC on the Flight Control Unit altitude selector, irrespective of intervening altitude constraints. This combination of procedures provided limited protection against descent through segment minimum safe altitudes.

ATSB investigation AO-2012-040

On 12 February 2012, the flight crew of a Boeing 737 aircraft was conducting a scheduled passenger service from Sydney, New South Wales to Canberra, Australian Capital Territory. Due to scheduled maintenance the instrument landing system at Canberra was not available and the flight crew prepared for a very high frequency omnidirectional radio range (VOR)¹¹ approach to runway 35. The flight was at night with rain showers and scattered cloud in the Canberra area.

Shortly after becoming established on the final approach course with the aircraft's automatic flight system engaged, the flight crew descended below the minimum safe altitude for that stage of the approach. The flight crew identified the deviation and levelled the aircraft until the correct descent profile was intercepted, then continued the approach and landed. No enhanced ground proximity warning system alerts were generated, as the alerting thresholds were not exceeded.

The ATSB found that, at the time of the occurrence, the automatic flight system was in level change (LVL CHG) mode rather than the VNAV mode specified by the operator for such approaches. In LVL CHG mode, the aircraft descended to the altitude selected by the flight crew on the MCP, ignoring FMC altitude constraints.

The crew had selected LVL CHG mode to account for the influence of an unexpected tailwind earlier during the arrival, believing that LVL CHG mode would be more effective in maintaining the optimum descent profile while decelerating to comply with a procedure speed restriction. The crew intended to reselect VNAV mode following compliance with the speed restriction, which would have ensured continued descent in compliance with segment minimum safe altitudes, but overlooked that re-selection. While in LVL CHG mode the flight crew had selected an altitude lower than the applicable segment minimum safe altitude, with the effect that the aircraft continued descent in LVL CHG mode through that altitude.

¹¹ A ground-based navigation aid that emits a signal that can be received by appropriately-equipped aircraft and represented as the aircraft's bearing (called a 'radial') to or from that aid.

Safety analysis

Introduction

During descent into Canberra, Australian Capital Territory on 17 October 2012, the Qantas Airways Limited (Qantas) Boeing 737 descended below the last altitude assigned by air traffic control (ATC) because the active autopilot flight management mode changed from the intended Flight Management Computer (FMC)-derived (or managed) vertical navigation (VNAV) mode to a number of non-managed descent modes while the crew were focused on controlling the aircraft's speed. The captain had anticipated that the aircraft would follow the pre-set FMC vertical path profile that fed into the Area Navigation (Required Navigation Performance) RNAV-U (RNP) approach to runway 35 (RNAV-U), which both pilots believed would ensure that all terrain and airspace requirements were met. While this understanding was essentially correct, it relied on the aircraft being in the managed VNAV mode. As the aircraft was not in VNAV, the profile was not being followed and the aircraft descended below the last assigned altitude of 7,000 ft above mean sea level. ATC subsequently alerted the flight crew and instructed them to climb back to 7,000 ft.

Although the descent was below the last assigned altitude, the altitude limit was intended to ensure that the aircraft remained in controlled airspace, the lowest level of which in that area was 6,500 ft. The aircraft levelled out at 6,600 ft, which was at least 2,000 ft above the surrounding terrain.

This analysis will examine the Qantas procedures for conducting the RNAV-U approach, as well as the flight crew's descent management and workload issues during the conduct of the RNAV-U approach.

RNP procedures

The procedures for conducting an RNP AR APCH (RNP AR)-type approach allowed the flight crew to set the approach decision altitude on the automatic flight system (AFS) Mode Control Panel (MCP) prior to commencing the approach. That is, they could enter a lower altitude in the MCP once cleared for the approach by ATC, but prior to reaching the approach commencement point (the initial approach fix (IAF)). This allowed the last cleared or assigned altitude issued by ATC, and as entered on the MCP and displayed on the pilot's Primary Flight Display, to be replaced with a lower altitude. By replacing the MCP altitude, the flight crew's awareness of the previously-issued altitude restriction was reduced and a defence against descending below this ATC-assigned level was removed.

Coupling an RNP AR approach with a standard arrival route (STAR) ensured that the aircraft was on the correct profile prior to commencing the approach. By being on the correct profile, and when in the managed VNAV mode, the aircraft would likely not descend below any assigned altitudes.

Following this occurrence, Qantas removed the procedure that permitted the flight crew to set the approach decision altitude on the MCP when cleared for the approach. There is now a requirement for the flight crew to retain the current altitude limit on the MCP until cleared for the approach and approximately 2 NM (4 km) from joining the approach, with the selection of VNAV PTH indicated on the FMA. The amended procedure meets the intent of the Altitude Alerting System standard operating procedure.

Descent management and workload

The flight crew's acceptance of a high-speed descent, coupled with a decreasing tailwind during the latter part of the descent, resulted in the aircraft's speed increasing towards the maximum permitted speed as the aircraft approached 8,000 ft. This led to the captain becoming focused on managing and reducing the aircraft's speed to the FMC-programmed 250 kt as the aircraft

approached the ATC descent clearance limit of 7,000 ft. That speed/height combination was a company requirement and, as such, further explained the captain's focus on speed reduction.

During this time, there were unintended mode changes in the AFS, which made speed control difficult and increased the flight crew's workload. When the AFS changed to the vertical speed (V/S) mode from VNAV as a result of changing the MCP altitude to 7,000 ft while capturing the previously-set 8,000 ft limit, the high rate of descent became the target descent rate for the AFS. The flight crew did not identify this mode change. At the same time, the crew were cleared for the approach by ATC and as such, they had a number of tasks to complete, including setting the MCP altitude to 2,600 ft.

At about the same time the captain inadvertently applied sufficient force to the control column to engage the control wheel steering in the pitch mode (CWS P). This mode change was also not detected by the flight crew, and resulted in any actions taken through the MCP to control airspeed having no effect. The combination of the required tasks, unintended modes and the flight crew's attention on the speed led to a high workload situation and a loss of awareness of the assigned altitude restriction of 7,000 ft. This in turn resulted in the aircraft breaching the descent clearance limit as it approached the HONEY waypoint.

The flight crew's lack of detection of a number of indicators that advised of the aircraft's undesired auto-flight system mode and vertical path was consistent with research showing that, in high workload situations, pilots will often not detect changes in auto-flight modes, even when they are looking at the changing screen (Sarter and others, 2007). While Qantas required the crew to check that the AFS was still in the VNAV/LNAV mode prior to commencing the RNP AR approach, and also prior to winding down the altitude on the MCP, research has shown that pilots don't always call out changes in the auto-flight mode, and sometimes they call out changes or mode settings without scanning the mode annunciator panel (Björklund and others, 2006). In addition, Goteman and Dekker (2006) found that mode call-outs were shed when pilots were under a higher task load.

The captain's report that the AFS mode was reviewed during the descent was in accordance with the Qantas procedures that required the crew to check that the mode remained as intended during the approach. However, it was likely that the short timeframe between the unintended, and undetected, vertical mode changes and the focus of the crew's attention on speed management, led to the crew missing the change from VNAV PTH.

The importance of mode awareness has been highlighted by aircraft manufacturers and was reflected in the Qantas checklists and training. However, research by Dismukes and Berman (2010) has shown that, although checklists and flight crew monitoring are important defences, and that in the vast majority of cases these actions are performed appropriately, these defences do not always catch flight crew errors and equipment malfunctions. Dismukes and Berman also noted that while increased automation has enhanced situation awareness in some ways, it has undercut it in other ways by moving pilots from direct, continuous control to a role of managing and monitoring, to which humans are poorly suited.

The RNAV-U approach chart issued by Qantas did not have a 'not below' altitude listed at waypoint HONEY. The equivalent Airservices Australia chart, which was for information to other operators only, did have a 'not below' altitude of 6,000 ft; however, this was 1,000 ft lower than the required crossing altitude of 7,000 ft. The captain noted that, had this crossing altitude been on the chart, the crew's awareness of the need to ensure they remained above 7,000 ft would have been higher. The absence of this prompt on the chart, coupled with the crew's high workload and focus on the airspeed, heightened the importance of the altitude alerting provided by setting the limiting altitude on the MCP, in this case 7,000 ft. The flight crew's selection of the approach decision altitude on the MCP removed the last cue for the crew to identify they had an airspace restriction to comply with, in addition to the company speed restriction.

Findings

From the evidence available, the following findings are made with respect to the descent below the minimum permitted altitude involving a Boeing 737, registered VH-VXB, during the approach into Canberra, Australian Capital Territory on 17 October 2012. These findings should not be read as apportioning blame or liability to any particular organisation or individual.

Safety issues, or system problems, are highlighted in bold to emphasise their importance.

A safety issue is an event or condition that increases safety risk and (a) can reasonably be regarded as having the potential to adversely affect the safety of future operations, and (b) is a characteristic of an organisation or a system, rather than a characteristic of a specific individual, or characteristic of an operating environment at a specific point in time.

Contributing factors

- The crew's focus on managing the increase in the aircraft's speed due to the high-speed descent and a reducing tailwind, combined with unintended mode changes in the aircraft's automatic flight system, resulted in a high workload environment.
- Due to the workload associated with managing the high airspeed, the flight crew did not identify that the flight management computer-derived VNAV PTH mode had disengaged, which permitted the aircraft to descend below the calculated profile.
- **The company's Required Navigation Performance approach procedure allowed the flight crew to set the approach minimum altitude in the auto-flight system prior to commencing the approach. This did not ensure the altitude alerting system reflected the assigned altitude limit of 7,000 ft and removed the defence of that alert when the flight crew did not identify the disengagement of the flight management computer-derived VNAV PTH mode. [Safety issue]**
- The high workload and removal of the assigned 7,000 ft limit from the altitude alerting system led to the flight crew's loss of awareness of the descent clearance limitation. This loss of awareness, when combined with the high rate of descent, resulted in the aircraft descending below the descent clearance limit.

Safety issues and actions

The safety issue identified during this investigation is listed in the Findings and Safety issues and actions sections of this report. The Australian Transport Safety Bureau (ATSB) expects that all safety issues identified by the investigation should be addressed by the relevant organisation(s). In addressing those issues, the ATSB prefers to encourage relevant organisation(s) to proactively initiate safety action, rather than to issue formal safety recommendations or safety advisory notices.

All of the directly involved parties were provided with a draft report and invited to provide submissions. As part of that process, each organisation was asked to communicate what safety actions, if any, they had carried out or were planning to carry out in relation to each safety issue relevant to their organisation.

Required navigation performance approach procedure

Number:	AO-2012-138-SI-01
Issue owner:	Qantas Airways Limited
Operation affected:	Aviation: Air transport
Who it affects:	Flight crew conducting RNP-AR operations

Safety issue description:

The company's Required Navigation Performance approach procedure allowed the flight crew to set the approach minimum altitude in the auto-flight system prior to commencing the approach. This did not ensure the altitude alerting system reflected the assigned altitude limit of 7,000 ft and removed the defence of that alert when the flight crew did not identify the disengagement of the flight management computer-derived VNAV PTH mode.

Proactive safety action taken by: Qantas Airways Limited

Qantas Airways Limited advised that the procedure that permitted the flight crew to set the approach minimum altitude on the Mode Control Panel (MCP) when cleared for the RNP-AR approach has been replaced. The new procedure requires that the flight crew retain the current altitude limit on the MCP until cleared for the approach and within approximately 2 NM (4 km) of the approach commencement, with the selection of the flight management computer-derived VNAV PTH indicated on the flight mode annunciator.

Action number: AO-2012-138-NSA-038

Current status of the safety issue:

Issue status: Adequately addressed

Justification: The procedure has been modified to ensure the last-assigned altitude remains in the auto-flight system as a defence against a descent below this level.

General details

Occurrence details

Date and time:	17 October 2012 – 2045 EDT
Occurrence category:	Incident
Primary occurrence type:	Descent below the minimum permitted altitude
Location:	35 km south-west of Canberra Airport, Australian Capital Territory

Aircraft details

Manufacturer and model:	Boeing 737-838
Registration:	VH-VXB
Operator:	Qantas Airways Limited
Serial number:	30101
Type of operation:	Air Transport – High Capacity
Damage:	Nil

Sources and submissions

Sources of information

The sources of information during the investigation included:

- the flight crew of VH-VXB
- Qantas Airways Limited (Qantas)
- Airservices Australia (Airservices)
- the Civil Aviation Safety Authority (CASA)
- the Bureau of Meteorology
- the Boeing Company.

References

Björklund, CM Alfredson, J & Dekker, SWA 2006, 'Mode monitoring and call-outs: An eye-tracking study of two-crew automated flight deck operations', *The International Journal of Aviation Psychology*, vol. 16, pp. 257-269.

Dismukes, RK & Berman, B 2010, *Checklists and monitoring in the cockpit: Why crucial defences sometimes fail*, National Aeronautics and Space Administration Technical Memorandum NASA/TM-2010-216396.

Goteman, O & Dekker, S 2006, Flight crew callouts and aircraft automation modes: An observational study of task shedding, *International Journal of Applied Aviation Studies*, vol. 6, pp. 235-248.

Sarter, NB Mumaw, RJ & Wickens, CD 2007, 'Pilots' monitoring strategies and performance on automated flight decks: An empirical study combining behavioural and eye-tracking data', *Human Factors*, vol. 49, pp. 347–357.

Submissions

Under Part 4, Division 2 (Investigation Reports), Section 26 of the *Transport Safety Investigation Act 2003* (the Act), the Australian Transport Safety Bureau (ATSB) may provide a draft report, on a confidential basis, to any person whom the ATSB considers appropriate. Section 26 (1) (a) of the Act allows a person receiving a draft report to make submissions to the ATSB about the draft report.

A draft of this report was provided to the flight crew of VH-VXB, Qantas, Airservices, and CASA.

Submissions were received from the flight crew, Qantas and CASA. The submissions were reviewed and where considered appropriate, the text of the report was amended accordingly.

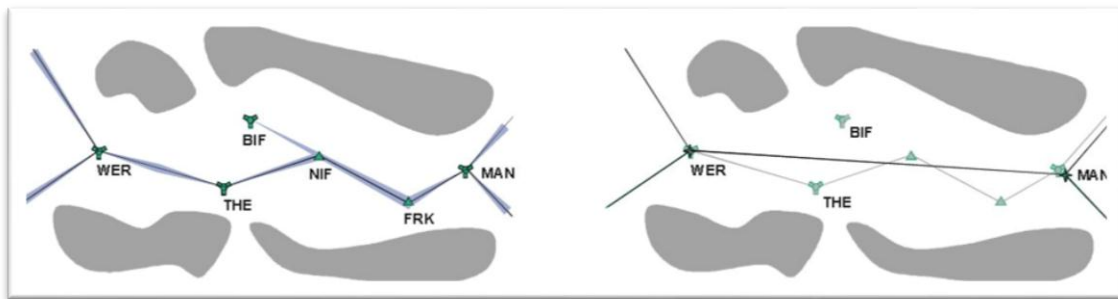
Appendices

Appendix A – Performance based navigation

Background

Until the 1980s, commercial aerial navigation was generally conducted along air routes that were defined by ground-based navigation aids (Figure A-1 left map). Ground-based navigation aids were also used for approach and landing guidance at an airfield. Certain airspace types required specific navigational accuracy, which was in turn linked with particular equipment types that could achieve that accuracy.

Figure A-1: Navigation by conventional navigation (left map) compared to area navigation (right map)



Source: International Civil Aviation Organization

The development of area navigation (RNAV) equipment and techniques enabled aircraft to track independently of ground-based navigation aids (Figure A-1 right map). Performance-based navigation (PBN) is a further development from RNAV and is founded on the principle of defining the navigation performance required for operations in a particular type of airspace. This performance is measured in terms of accuracy, integrity, continuity and functionality, but the practical effect is to require the aircraft to track within a defined set of navigational accuracy parameters. Further, the use of performance monitoring and alerting systems provides a level of assurance that the navigation system is achieving the required degree of accuracy. Performance monitoring and alerting systems also enable the use of PBN for closer route spacing, or precision approach paths with the option of flexible tracking in the terminal area through the use of curved paths. Reduced spacing and flexible tracking require more precise navigation, and this is reflected in the Required Navigation Performance (RNP) value associated with these types of operations. The aircraft's performance monitoring and alerting systems also enable the determination of the Actual Navigation Performance (ANP) of the aircraft.

Under the PBN system, the aircraft is navigated through the use of on-board computers coupled with global navigation satellite system equipment, inertial reference systems, and receivers that can use traditional ground-based navigation aids. Accurate navigation performance is ensured through the fitment of a performance monitoring and alerting system.

Qantas Airways Limited (Qantas) commenced developing PBN approach procedures in trials that started in 2005. These trials began by gaining experience using simpler non-precision approach-type procedures, designated as RNP APCH. In 2006, Qantas commenced developing and using RNP AR APCH procedures—more complex approach procedures that required prior

authorisation by the Civil Aviation Safety Authority (CASA) and enabled the use of lower minima and design features such as curved approach paths.¹²

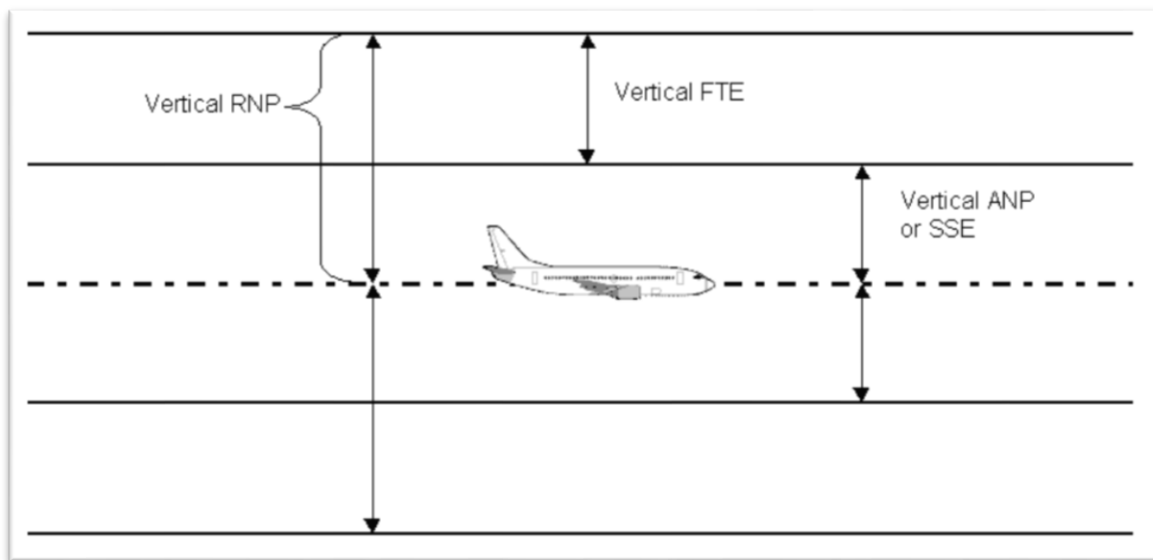
VH-VXB was fitted for and had the capacity to operate to a PBN accuracy of 0.1 NM (185 m) in the terminal area. Qantas was authorised by CASA to conduct approach and departure operations to the PBN standard RNAV (RNP-AR).¹³

Navigation performance scales

The relationships between the RNP, ANP and the actual displacement of the aircraft from the desired path are critical in determining the aircraft’s performance when using PBN systems in the terminal area (Figure A-2).

The accuracy of the vertical path measurement, and therefore the vertical ANP, is a function of known instrumentation errors associated with measuring altitude. The total value of these errors range from about 170 ft at flight level (FL) 410¹⁴ down to 50 ft at sea level. As the ANP value increases, the navigation performance becomes less accurate and the available Flight Technical Error (FTE) reduces. The Qantas procedures required the vertical RNP to be set to 125 ft prior to top of descent, a figure that was based on the known altimeter error at approach minima and the maximum vertical deviation allowable from the required flight path at approach minima (the vertical FTE). The net effect is for the available vertical FTE to increase as the aircraft descends and approaches the runway.

Figure A-2: The vertical RNP, ANP and FTE relationships



Source: Qantas

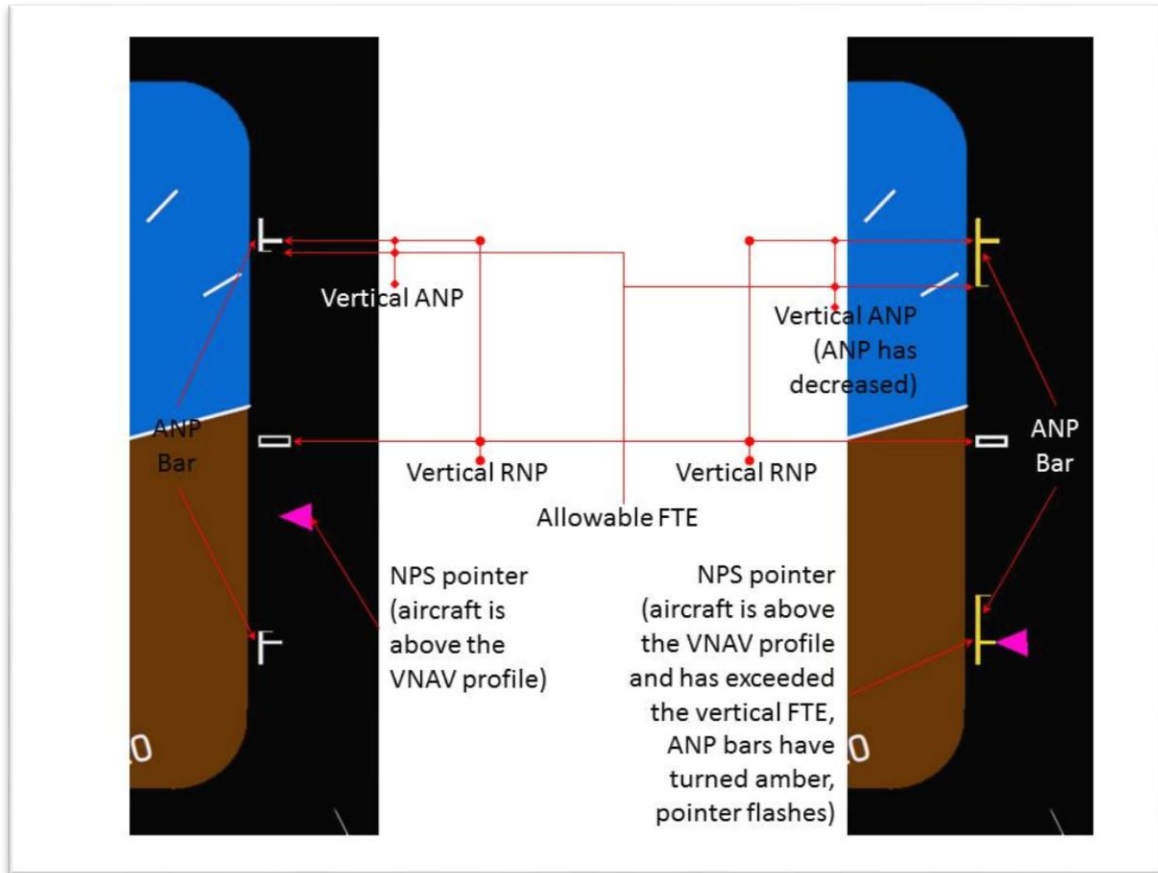
The navigation performance scales (NPS) on the primary flight display (PFD) displays the aircraft’s lateral and vertical displacement from the FMC-calculated horizontal and vertical path. The NPS also enables the flight crew to continuously monitor the relative values of the aircraft’s ANP with respect to the RNP, as well as the aircraft’s cross-track (or lateral FTE) error (see Figure A-3). The NPS is the primary navigation indicator used by the flight crew when conducting a PBN approach. The lateral ANP bars can be displayed in all phases of flight, while the vertical bars are only displayed when the aircraft has passed top of descent.

¹² See International Civil Aviation Organization Document 9613 *Performance-Based Navigation Manual* for further information on the standards and requirements for the various types of PBN procedures.

¹³ Instrument number CASA 12/12 dated 20 January 2012.

¹⁴ At altitudes above 10,000 ft in Australia, an aircraft’s height above mean sea level is referred to as a flight level (FL). FL 410 equates to 41,000 ft.

Figure A-3: The NPS display



The vertical NPS indicator provides vertical displacement information of the aircraft from the FMC-calculated descent path and the vertical ANP value is derived from a data table loaded into the FMC. The gap between the ANP bars is the available FTE—the maximum allowable vertical displacement from the FMC vertical path given the current vertical navigation accuracy. When the aircraft’s vertical track displacement from the FMC-calculated vertical path exceeds the FTE (that is the NPS pointer overlaps the ANP bars) for a period of 10 seconds or more, the NPS pointer will flash and the ANP bars will turn amber.

RNP AR approach procedures

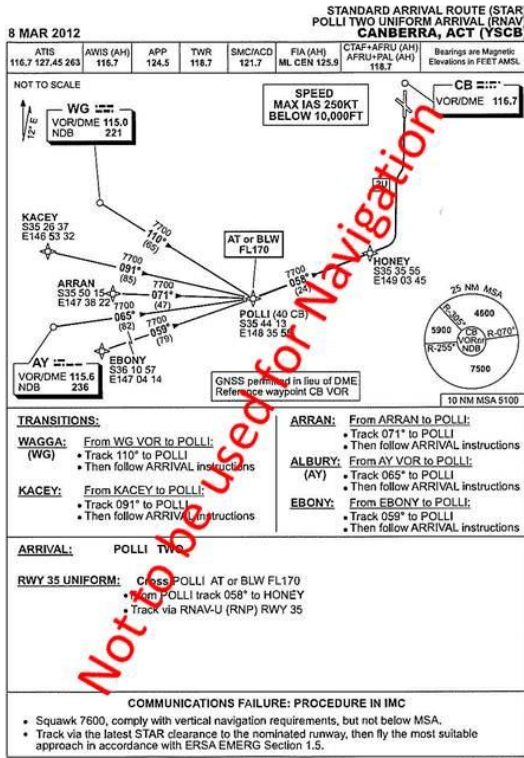
The *Supplementary Procedures* section of the Flight Crew Operating Manual (FCOM) contained the relevant procedures for the conduct of an RNAV (RNP AR) approach. These included that:

- The autopilot was to be engaged for all RNAV (RNP AR) approaches conducted at RNP values of less than 0.30 [NM (556 m)].
- The RNAV (RNP AR) approach was to be joined or re-joined no later than the Non-normal Decision Point (NNDP).
- The selected RNP value and associated Decision Altitude (DA) for the approach may be changed up until the airplane reaches the NNDP.
- Navigation Performance Scale (NPS) limits for both vertical and lateral tracking apply from the NNDP. Short-term above path excursions including reversion to VNAV SPD are acceptable, provided FAM [Flight Administration Manual] stable approach requirements are met.
- For RNAV (RNP AR) approaches, set the MCP to the DA once cleared for the approach with VNAV PTH annunciated. The flight crew must continue to monitor vertical path performance to ensure that all waypoint crossing altitudes are met.

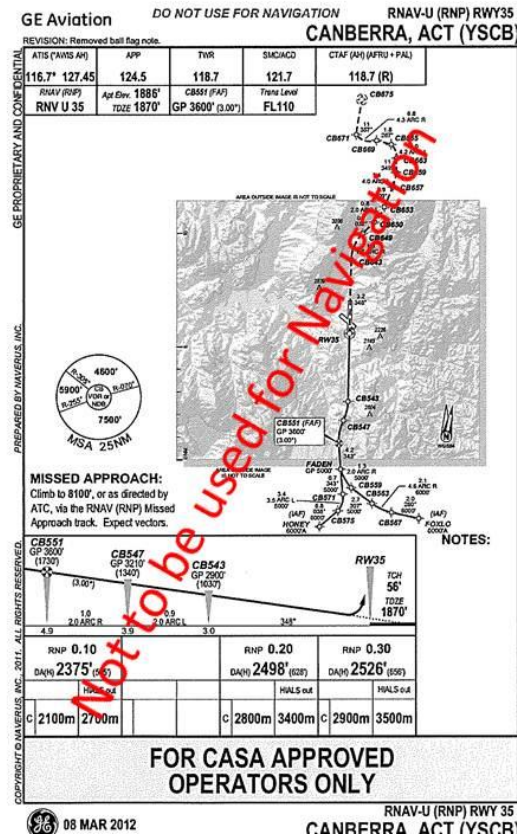
The Qantas procedures for the RNAV-U approach enabled the pilot to select a lateral RNP value of 0.3 (556 m), 0.2 (371 m) or 0.1 NM (185 m). The reducing lateral RNP value enabled the

approach to be flown to a lower decision altitude. The flight crew of VH-VXB selected a lateral RNP value of 0.3 NM (556 m). The company procedures also required the vertical RNP value to be set at 125 ft. The NNDP for the RNP-U approach was at FADEN (see Figure 1 in the section of this report titled *The occurrence*).

Appendix B – Relevant Canberra instrument approach charts



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Australian Transport Safety Bureau

The Australian Transport Safety Bureau (ATSB) is an independent Commonwealth Government statutory agency. The ATSB is governed by a Commission and is entirely separate from transport regulators, policy makers and service providers. The ATSB's function is to improve safety and public confidence in the aviation, marine and rail modes of transport through excellence in: independent investigation of transport accidents and other safety occurrences; safety data recording, analysis and research; fostering safety awareness, knowledge and action.

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.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and Regulations and, where applicable, relevant international agreements.

Purpose of safety investigations

The object of a safety investigation is to identify and reduce safety-related risk. ATSB investigations determine and communicate the factors related to the transport safety matter being investigated.

It is not a function of the ATSB to apportion blame or determine liability. At the same time, an investigation report must include factual material of sufficient weight to support the analysis and findings. 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.

Developing safety action

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. The ATSB prefers to encourage the relevant organisation(s) to initiate proactive safety action that addresses safety issues. Nevertheless, the ATSB may use its power to make a formal safety recommendation either during or at the end of an investigation, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation.

When safety recommendations are issued, they focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on a preferred method of corrective action. As with equivalent overseas organisations, the ATSB has no power to enforce the implementation of its recommendations. It is a matter for the body to which an ATSB recommendation is directed to assess the costs and benefits of any particular means of addressing a safety issue.

When the ATSB issues a safety recommendation to a person, organisation or agency, they must provide a written response within 90 days. That response must indicate whether they accept the recommendation, any reasons for not accepting part or all of the recommendation, and details of any proposed safety action to give effect to the recommendation.

The ATSB can also issue safety advisory notices suggesting that an organisation or an industry sector consider a safety issue and take action where it believes it appropriate. There is no requirement for a formal response to an advisory notice, although the ATSB will publish any response it receives.

Australian Transport Safety Bureau

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Investigation

ATSB Transport Safety Report Aviation Occurrence Investigation

Descent below the minimum permitted altitude involving Boeing
737-838, VH-VXB on 17 October 2012

AO-2012-138

Final – 29 October 2014