Australian Government

Australian Transport Safety Bureau

Unforecast weather and flight below minimum altitude involving Fokker Aircraft F100, VH-NHV

Paraburdoo Airport, Western Australia, on 22 November 2021

ATSB Transport Safety Report

Aviation Occurrence Investigation (Systemic)

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Addendum

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Executive summary

What happened

On the morning of 22 November 2021, a Network Aviation Fokker Aircraft F100, registered VH-NHV, operating from Perth Airport to Paraburdoo Airport, Western Australia, encountered unforecast weather on arrival at Paraburdoo. Low cloud had developed below the landing minima, which resulted in 3 missed approaches. On the fourth approach, the aircraft fuel state was near the minimum fixed reserve, so the flight crew continued the approach below landing minima without visual reference and landed without further incident.

What the ATSB found

The ATSB found that, after having completed 2 missed approaches at Paraburdoo, the flight crew had lost confidence in their flight plan weather forecasts and were reluctant to attempt a diversion to an alternate airport without current weather information. After the third missed approach, the aircraft did not have sufficient fuel to reach a suitable alternate and the flight crew were committed to landing at Paraburdoo.

The flight crew's flight plan for Paraburdoo indicated the lowest cloud would be above their landing minima, with deteriorations in the weather lasting for up to 60 minutes. However, the actual conditions encountered were below their landing minima and continued to deteriorate. This was difficult to forecast by the Bureau of Meteorology as detection of low cloud was obscured by higher level cloud. The development of low cloud at Paraburdoo contrasted with the expectation that surface heating would lift the existing cloud base.

After the second missed approach at Paraburdoo, the flight crew attempted to obtain an updated forecast for Newman Airport from air traffic control, but they did not express any urgency with this request. This, in combination with air traffic control workload at the time, resulted in a delay of 15 minutes before an update was offered. By that time, it was no longer required as they had insufficient fuel remaining to divert to Newman. Further, the aircraft was not fitted with an operational aircraft communications addressing and reporting system (ACARS), and they were beyond the range of the nearest automatic en route information service (AERIS). Therefore, the flight crew had no other means for obtaining updated weather forecasts for potential alternate aerodromes.

Paraburdoo Airport had an automatic weather station, which could measure the relative humidity at the surface. However, there were no means for measuring atmospheric data above the surface, which is one of the elements used to forecast cloud bases. In addition, the nearest weather balloon stations were more than 160 NM (300 km) from Paraburdoo, and therefore, the Bureau of Meteorology relied on cloud observations at nearby aerodromes to verify the expected conditions for Paraburdoo. Also, as the Newman automatic weather station was not recording the cloud or weather data groups, it was unknown if a SPECI report should have been issued for Newman for low cloud conditions, as it was for Paraburdoo.

Other than a procedure that limited the number of missed approaches to 2, Network Aviation did not provide flight crew with diversion decision-making procedural guidance when encountering unforecast weather at a destination.

In addition, Network Aviation had not included the threat of weather below the landing minima in their risk assessments for controlled flight into terrain. Consequently, these risk assessments did not include risk controls to address this threat. Without the identification of this threat and associated controls, their safety assurance team would not have had oversight of how effectively this was managed.

What has been done as a result

Following this incident, Network Aviation have implemented several proactive safety actions, which included:

- An amendment to their flight plans to include diversion calculations for 2 alternate aerodromes. This was provided pre-incident for flights that required an alternate and amended post-incident to provide it for all flights.
- Their arrival briefing procedure was amended to require flight crew to brief the minimum fuel required to divert to an alternate for all flights.
- Introduced a Fokker Aircraft F100 company procedures manual with pre-populated diversion information for each of their F100 destinations.
- Re-issued an updated internal safety advisory notice for their flight crew about the limitations of automatic weather information services.
- Updated their Paraburdoo Airport risk assessment to capture this incident as a risk and their safety action as controls.
- Updated their risk assessments for controlled flight into terrain to include adverse weather as an environmental threat.
- Amended their company fuel policy to mandate additional alternate fuel requirements for nominated airports (operator approved variations). Airport classification is assessed based on alternate availability, instrument approach availability, aerodrome forecast reporting and historical accuracy, local mesoscale weather phenomena, and topography/terrain.
- Established access for flight crew to obtain expanded briefings on ports (with operator fuel policy approved variations) from internal company meteorologists.
- Updated the company's *Aerodrome and Route Data Manual* to provide a new section on weather planning tools and resources, and a new section explaining the limitations of ceilometers and visibility meters installed in automatic weather information stations throughout the company network.
- Enhanced the company's training reference library for flight crew to support pilot knowledge and decision making. Additional content in the library is focused on company learnings from QF1616, which includes:
  - fuel management
  - threat management and contingency planning
  - time management in areas of vulnerability
  - pilot in command responsibilities.
- Updated their take-off and landing data cards to provide a dedicated section for recording the alternate aerodrome, estimated time interval, fuel burn and fuel on arrival.

Safety message

Adverse weather conditions may not be experienced in the Australian environment to the same extent as they are in other countries. However, these events have been identified as contributing factors to incidents and accidents throughout aviation history and have been a driver for numerous safety initiatives. Therefore, it is important for all operators to consider how unforecast weather will be managed and ensure it is reflected in their risk management so that safety assurance activities can review how effectively it is managed and provide feedback for management review.

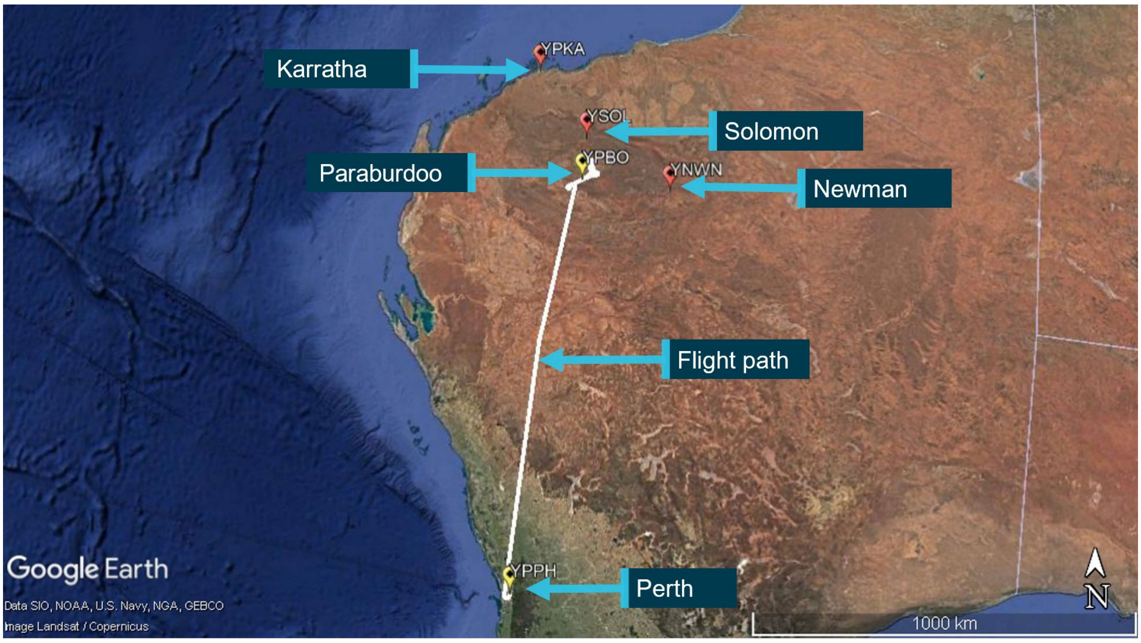
Contents

The occurrence

Overview

On 22 November 2021, at about 0746 Western Standard Time,[1] a Network Aviation Fokker Aircraft F100, registered VH-NHV, operating flight QF1616 from Perth Airport to Paraburdoo Airport (YPBO), Western Australia, encountered unforecast low cloud on arrival at Paraburdoo. Three missed approaches were conducted during which time the flight crew considered diversion options to Karratha Airport (YPKA), Newman Airport (YNWN), and Solomon Airport (YSOL) (Figure 1). On the fourth approach, the aircraft fuel state was near the minimum fixed reserve, so the flight crew continued the approach below the minimum descent altitude (MDA)[2] without visual reference to the runway. The aircraft landed without further incident.

Figure 1: Incident flight path from Perth to Paraburdoo



Source: Google Earth, annotated by the ATSB

Pre-flight and departure

On the morning of 22 November 2021, the captain and first officer (FO) for flight QF1616 arrived at the airport and proceeded directly to their aircraft for a planned 0600 departure. Their flight was the first of 3 Network Aviation F100 flights from Perth to Paraburdoo, with the second and third flights scheduled to depart at 0630 (QF1618) and 0700 (QF1840). The flight time to Paraburdoo was scheduled to be 1 hour 29 minutes.

Once on board the aircraft, the flight crew downloaded and reviewed their flight plan on their electronic flight bags. The flight plan indicated a direct flight to Paraburdoo with the minimum required fuel, which included a 10% flight fuel variable reserve, 60 minutes of holding fuel for

[1] Western Standard Time (WST): Coordinated Universal Time (UTC) + 8 hours.

[2] Minimum descent altitude (MDA) is the minimum altitude for a non-precision approach to obtain visual reference and decision altitude (DA) is the altitude at which a missed approach must be commenced from a precision approach if visual reference is not obtained.

arrival at Paraburdoo, and 30 minutes of fixed fuel reserve. The additional 10-minute company fuel reserve was recorded on the flight plan as removed due to the forecast payload.

The mean weather conditions for arrival at Paraburdoo from the aerodrome forecast[3] included scattered[4] cloud at 1,000 ft and broken cloud at 3,000 ft with visibility greater than 10 km.[5] There was also a TEMPO[6] period for broken cloud at 1,000 ft and visibility reduced to 4,000 m, valid for their arrival time, which required 60 minutes holding fuel. The TEMPO conditions were forecast to be above their landing minima,[7] so while they departed with minimum fuel, the flight crew expected visual conditions at Paraburdoo before reaching the MDA. The captain recalled that the other inland airports in the Pilbara region had similar forecasts with TEMPO or INTER[8] periods, and that Karratha 'was bad, but forecast to improve'.

At about 0553, the flight crew received a last-minute change on their flight plan, which reduced the planned take-off and landing weights by 847 kg. At this time, the fuel truck had departed, and the captain elected not to delay the flight by recalling the refueller to load additional fuel.

The flight data recorder indicated the aircraft departed at 0619:32 and reached its cruise altitude of flight level (FL)[9] 350 at 0646:05. The FO was designated as the pilot flying (PF) and the captain was the pilot monitoring (PM) at the start of the flight.[10] The PF had loaded Paraburdoo into the flight management computer (FMC) as route 1 and YPKA as route 2. Therefore, the FMC was calculating the fuel required for both destinations.

Arrival at Paraburdoo

The cockpit voice recorder indicated that at about 1 hour after take-off, at 0719 and FL 350, the flight crew listened to the Paraburdoo automated weather information service (AWIS).[11] The AWIS indicated the wind was from 050° at 6 kt, the cloud was scattered at 2,100 ft, broken at 4,800 ft, overcast at 6,700 ft, QNH[12] 1012, temperature and dewpoint[13] were 20 °C and 19 °C respectively, and relative humidity 94%. The flight crew discussed the weather and noted there was no rainfall reported and that the wind favoured runway 06. As the operator had a requirement for an

[3] Aerodrome forecast (TAF): a statement of meteorological conditions expected for a specific period of time in the airspace within a radius of 5 NM (9 km) of the aerodrome reference point.

[4] Cloud cover is reported using words that denote the extent of the cover – 'few' indicates that up to a quarter of the sky is covered, 'scattered' indicates that cloud is covering between a quarter and a half of the sky, 'broken' indicates that more than half to almost all the sky is covered, and 'overcast' indicates that all the sky is covered.

[5] Cloud data is height above aerodrome elevation.

[6] TEMPO: a temporary deterioration in the forecast weather conditions, during which significant variation in prevailing conditions are expected to last for periods of between 30 and 60 minutes.

[7] Landing minima: specified meteorological conditions of cloud ceiling and visibility. For an aircraft to land at an aerodrome, the actual weather conditions need to be at or above the landing minima.

[8] INTER: an intermittent deterioration in the forecast weather conditions, during which a significant variation in prevailing conditions is expected to last for periods of less than 30 minutes duration.

[9] Flight level: 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 350 equates to 35,000 ft.

[10] Pilot Flying (PF) and Pilot Monitoring (PM): procedurally assigned roles with specifically assigned duties at specific stages of a flight. The PF does most of the flying, except in defined circumstances; such as planning for descent, approach and landing. The PM carries out support duties and monitors the PF's actions and the aircraft's flight path.

[11] Automated weather information service (AWIS): actual weather conditions, provided via telephone or radio broadcast, from Bureau of Meteorology (BoM) automatic weather stations, or weather stations approved for that purpose by the BoM.

[12] QNH: the altimeter barometric pressure subscale setting used to indicate the height above mean seal level.

[13] Dewpoint: the temperature at which water vapour in the air starts to condense as the air cools. It is used, among other things, to monitor the risk of aircraft carburettor icing or the likelihood of fog.

instrument approach to be flown for arrivals at Paraburdoo, they commenced preparations for the area navigation (RNAV) approach to runway 06, which included their arrival briefing.

At about 0724, the PM contacted their ground station at Paraburdoo to advise them of their 0745 estimated time of arrival and their ground handling requirements. At 0725:41, the descent was commenced, and the PM advised Melbourne Centre air traffic control (ATC) of their estimated time of arrival at Paraburdoo. At about 0730, while on descent through FL 240, the flight crew listened to the Paraburdoo AWIS a second time.[14] The PM then verbalised '1013'[15] to the PF, who acknowledged the change in QNH, and they noted that the reported rainfall was less than moderate.

At interview, the captain (PM) recalled only noting the change in QNH and expected the visual conditions for landing to remain the same after listening to the AWIS.[16] The FO (PF) did not recall this second instance of listening to the AWIS.

First approach (runway 06)

At about 0731, the flight crew selected the Paraburdoo common traffic advisory frequency (CTAF) and turned on the pilot activated lighting (PAL),[17] which provided precision approach path indicators (PAPI)[18] for each runway and low intensity runway edge lighting. At about 0736, the flight crew completed their approach checklist for the runway 06 RNAV approach and noted their estimated time of arrival was 0744. As the aircraft descended through 5,500 ft, the flight crew observed extensive cloud. At 0741:43, just after passing the initial approach fix, the PF decided to configure the aircraft early due to a tailwind on the approach. At 0743:28, the flight crew changed the autopilot vertical mode from altitude hold to vertical speed and commenced their final descent to runway 06.[19]

At about 0744, the PF called for the before landing checklist, which the PM reported as completed as the aircraft descended through 3,000 ft towards the MDA of 1,960 ft. During the approach, the PM verbalised the aircraft's vertical position relative to a 3° descent path and each subsequent distance-altitude step in the procedure as required. At 0746:01, the PM reported they were 100 ft above the minima, which was acknowledged by the PF. Shortly after, the PM announced 'minima', followed by 'no contact'. The PF then announced that they were going around, and the PM commented that they were too high. The flight crew reported at interview that they sighted the runway with the PAPI indicating 4 white lights and were therefore too high to safely land from the first approach.

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[14] On the cockpit voice recorder, most of the broadcast was inaudible due to traffic on the ATC frequency, except for the wind 040° at 4 kt and QNH 1013.

[15] A QNH obtained from an approved source within 15 minutes of conducting an instrument approach may be used to lower the MDA by 100 ft if the procedure is in a grey shaded box. Network Aviation standard operating procedures require their flight crew to fly a continuous descent profile for non-precision approaches and add 50 ft to the MDA.

[16] Due to the Melbourne Centre flight information area frequency volume, some of the flight crew discussions and automated weather information service broadcasts during the flight were inaudible due to concurrent radio traffic on the Melbourne Centre frequency.

[17] Pilot activated runway and taxiway lighting (PAL): PAL is activated by a series of timed transmissions using the aircraft's very high frequency radio on a designated frequency.

[18] Precision Approach Path Indicator (PAPI): a ground-based system that uses a system of coloured lights used by pilots to identify the correct glide path to the runway when conducting a visual approach.

[19] In accordance with the Network Aviation Flight Administration Manual standard operating procedure 8.50: *Automatic flight shall be used when possible for all instrument approaches when Instrument Meteorological Conditions (IMC) exist*. Vertical speed mode (vertical navigation) and NAV mode (lateral navigation) were used for all approaches as per company recommendation for an RNAV approach.

The aircraft was climbed to 5,200 ft in the missed approach, and while on climb, the flight crew briefly discussed the first missed approach. They concluded that they were too high on the approach due to a tailwind and decided to conduct an approach to runway 24. At 0747, the PM notified ATC of the missed approach and that they would make an approach to runway 24 and requested an operations normal[20] time of 0815.

Second approach (runway 24)

At 0752:46, while setting up for an approach to runway 24, the PM commented that the weather at all the surrounding airports was unsuitable, and then listened to the AWIS. The AWIS broadcast indicated the cloud was broken at 800 ft, overcast at 1,500 ft, and visibility had reduced to 5,000 m. Between 0753:20 and 0756, the flight crew had several conversations about the weather. This included that they could see 'holes' in the cloud where they were holding, that they were too steep when they became visual on the first approach, and that they expected to have a headwind on the approach to runway 24.

At about 0757, the flight crew activated the PAL, and the PM made a CTAF call to announce their intention to conduct an approach to runway 24. At about the same time, the flight crew of QF1618 contacted ATC for their clearance to leave controlled airspace on descent to Paraburdoo. At about 0758, the PM of QF1616 reported to QF1618 that they had commenced the runway 24 RNAV approach. This was followed 1 minute later by a broadcast from the flight crew of another aircraft (QF1802) to ATC that they had landed at Newman.

At 0802:43, the PM announced that they were 100 ft above the minima (of 2,040 ft) on the runway 24 RNAV approach, followed by 'minima'. At 0802:53, the PF announced they were going around. At interview, the flight crew explained that they became visual with the ground on the approach to runway 24, but low cloud in front of them obscured the runway, which required a missed approach.

At 0805, while holding at 4,100 ft, the flight crew again discussed the weather and the PF commented that an aircraft had landed at Newman. They were uncertain of the actual weather conditions at that location and the PM noted they only had about 40 minutes of holding fuel remaining. At interview, the flight crew reported that, following the second missed approach, they noted that the FMC indicated they were at minimum fuel to divert direct to Karratha from their present position. However, the PM was cognisant of the fact that the FMC calculation did not account for the actual wind conditions they might experience en route or allow for an instrument approach on arrival. As Newman was closer than YPKA, they considered potentially diverting there with a fuel reserve on arrival for an approach.

At 0806, the PM contacted ATC to notify them of their second missed approach due to low cloud and requested the latest weather for Newman. Melbourne Centre acknowledged the request. However, there was no urgency conveyed by the PM nor was the aircraft's fuel status relayed with this request. The flight crew and ATC then diverted their attention to their other tasks, which included traffic inbound to Paraburdoo.

Third approach (runway 06)

Between 0807 and 0809, the flight crew discussed their options, which included a preference to remain at Paraburdoo and that they had enough fuel for 2 more approaches. The PM then broadcast their intentions to QF1618. The flight crew of QF1618 reported that they had sufficient

[20] The operations normal call time provided the next expected transmission time from this aircraft to indicate operations were normal.

fuel for 35-40 minutes holding and then a diversion to Karratha.[21] At 0810:32, the PM contacted the Paraburdoo safety car officer and asked if the cloud overhead the airport was 'sitting still or moving through'. The officer reported that it was coming from the north-west and was 'moving through'. The flight crew briefly discussed this observation and then elected to make another approach to runway 06. The PF commented that the weather felt like it was persistent and that they did not have any options.

At about 0813, the PM provided ATC with a new operations normal time of 0830 and they commenced their third approach. At 0816:33, the PM announced 'minima' and 5 seconds later the PF announced that they were going around. During the missed approach, the PF reported that the runway 24 approach was better, and the PM noted that the wind was getting worse.

Fourth approach and landing (runway 24)

The aircraft climbed to 5,200 ft after the third missed approach and entered a holding pattern for the runway 24 RNAV approach. At about 0819, the flight crew noted they had 1.8 tonne of fuel on board and decided to hold while QF1618 conducted an approach to runway 24. The PM then advised QF1618 of their intention to hold until minimum fuel and offered them an approach while they were holding.

At about 0821, ATC contacted QF1616, and the PM notified them that they were manoeuvring to allow QF1618 to make an approach and provided a new operations normal time of 0840. This was acknowledged by ATC with the additional query as to whether the flight crew still required the weather forecast for Newman. The PM responded that it was no longer required (due to their fuel state).

At about 0822, the PF commented that Solomon was directly ahead (55 NM to the north), and the flight crew then discussed Solomon as a divert option and the need to obtain updated weather while they were holding. However, the PF then noted the lowest MDA at Solomon was about 800 ft above the aerodrome elevation (2,800 ft MDA), which was about 200 ft higher than at Paraburdoo. There were no further discussions of Solomon given the lower probability of establishing visual reference from an approach with a higher MDA.

At about 0825, the flight crew listened to the Paraburdoo AWIS, which reported the cloud was broken at 400 ft and 800 ft, visibility was 4,200 m, wind from 270° at 6 kt, QNH 1013 and relative humidity was 93%. At about 0826, QF1618 notified QF1616 they were going to start their approach and queried how long QF1616 would hold before diverting. The PM replied that they could not divert and would hold until they were ready to make a final approach. At about 0827, QF1840 broadcast that they were inbound to Paraburdoo and ATC notified them that QF1616 and QF1618 were traffic for them. At about 0828, the PM remarked that they had 12 minutes fuel remaining before landing with a 1.1 tonne fuel reserve.

At 0828:49, the captain and FO exchanged roles, the captain became the PF, and the FO became the PM for the final approach. The flight crew then discussed their options, which were to either comply with the missed approach criteria and declare a MAYDAY[22] fuel situation if not visual at the missed approach point or continue below MDA for a landing if they were not visual at the minima. They agreed to continue below the MDA for a landing.

At about 0834, ATC broadcast a SPECI alert for Paraburdoo, which was followed by a CTAF call from QF1618 to report their missed approach from runway 24, and then another ATC broadcast

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[21] QF1618 flight plan fuel load had 1,694 kg more than QF1616.

[22] MAYDAY: an internationally recognised radio call announcing a distress condition where an aircraft or its occupants are being threatened by serious and/or imminent danger and the flight crew require immediate assistance.

for a SPECI alert for Solomon. At 0834:48, the PM of QF1616 made a CTAF call that they were commencing the runway 24 RNAV approach. The PF then emphasised to the PM that they both needed to be prepared to call a go-around if either of them sensed the approach was becoming unsafe. At about 0837, ATC contacted QF1616 for an update and the PM reported that they had commenced the approach.

At 0841:51, the ground proximity warning system[23] announced '1,000 ft', which was followed shortly after by the PM stating they were at 3 NM and 'on profile'. Ten seconds later, at 844 ft above ground level and 273 ft above the MDA, the PM remarked the cloud was starting to break up. The PM called 'minima' at 0842:25. The ground proximity warning system then announced '500 ft', '400 ft', and '300 ft'. At 0842:50, the autopilot was disconnected, and the PM announced that they had sighted the runway and were on profile, at which stage they were 293 ft above ground level and 291 ft below the MDA. The flight crew reported they were slightly left of centreline, but on glideslope with the PAPI when they became visual with the runway. This was consistent with the flight data recorder information, which indicated a steady descent profile on the approach and a maximum of 5° heading change between the autopilot disconnect and landing.

At 0843:23, the aircraft landed without further incident. During the landing roll, the captain recalled noting that their fuel on board indicated 0.96 tonne.[24] Following the landing, the PM made a CTAF broadcast that there were some very low patches of cloud at 250-300 ft above ground level. Figure 2 depicts the weather during the landing roll.

Figure 2: Weather at Paraburdoo during the landing roll of flight QF1616

Source: Aerodrome Management Services, annotated by the ATSB

[23] The ground proximity warning system is intended to alert the flight crew to a situation that could lead to ground contact and to warn of impending ground contact. During the incident flight, the system provided callouts to the flight crew on each approach, commencing from 2,500 ft above ground level.

[24] The aircraft's flight data recorder did not record either fuel flow or fuel load parameters. Therefore, the flight data could not be used to analyse this information, which was the critical parameter for the flight crew in this incident.

Context

Personnel information

Captain

The captain held a valid Air Transport Pilot Licence (Aeroplane) with a multi-engine aeroplane instrument rating, type ratings for the Fokker FK70/100 (F100) and De Havilland Canada DHC-8 aircraft, and a Class 1 Aviation Medical Certificate. They had accrued 6,698 hours total flying experience with 2,641 hours on the F100. The captain reported being awake for about 5 hours at the time of the incident, having slept 7 hours the previous night, and recorded a mental fatigue score of 3 ('Okay, somewhat fresh') for the time of the occurrence.

First officer

The first officer (FO) held a valid Air Transport Pilot Licence (Aeroplane) with a multi-engine aeroplane instrument rating, type ratings for the Airbus A320, Fokker FK70/100, Embraer EMB 120 and Dornier DO328-100 aircraft, and a Class 1 Aviation Medical Certificate. They had accrued 6,735 hours total flying experience with 1,556 hours on the F100. The FO reported being awake for 5 hours at the time of the incident, having slept 8 hours the previous night and recorded a mental fatigue score of 2 ('Very lively. Responsive, but not at peak') for the time of the occurrence.

Aircraft information

Fuel requirements and weight limits

In accordance with the forecast conditions, the QF1616 flight plan fuel for take-off from Perth comprised of 89 minutes flight fuel (3,614 kg), 11 minutes variable reserve (361 kg), 60 minutes holding fuel (1,733 kg) and 30 minutes fixed reserve (962 kg). This resulted in a minimum take-off fuel load of 6,670 kg. In addition, the aircraft was loaded with 36 kg of tanker fuel[25] and 100 kg of taxi fuel, resulting in a flight plan fuel load at engine start of 6,806 kg.

The operator's fuel requirements included the option for an additional 10 minutes holding fuel (equating to about 290 kg), payload permitting. The flight plan indicated that this was removed due to the forecast payload. To allow for last minute, minor payload variations without exceeding maximum landing weight, flight dispatch was required to plan a tanker fuel limit that ensured a 300 kg buffer on maximum landing weight. Consistent with these requirements, the flight plan landing weight at Paraburdoo was 39,615 kg and the maximum landing weight was 39,915 kg.

At about 0553 (7 minutes prior to the scheduled departure), there was a last-minute change to the passenger and freight loads. This resulted in a reduced planned landing weight of 38,768 kg, which would have permitted the captain to take an additional 1,147 kg of tanker fuel. However, the aircraft had already been refuelled and the refueller had departed when the flight crew received their last-minute change.

Navigation system information

The aircraft was equipped with a flight management system (FMS), with an associated flight management computer (FMC). The FMS navigation source was the global navigation satellite

25 Tanker fuel is extra fuel uplifted from airports with a lower fuel price, such as capital city airports.

system (GNSS). In GNSS mode, the FMS was certified for RNP[26] 2, RNP 1 and RNP 0.3 operations but the vertical navigation (VNAV) function was not certified. Therefore, Network Aviation could conduct RNAV approaches to the LNAV landing minima but did not have approval to conduct them to the LNAV/VNAV minima.

Aircraft communications addressing and reporting system

The incident aircraft was fitted with a non-operational aircraft communications addressing and reporting system (ACARS). The ACARS is a digital datalink system used for transmitting messages between the aircraft and ground stations via very high frequency (VHF) radio or satellite. This system provides another mechanism for flight crews to obtain weather information.

The Network Aviation Group-A F100 aircraft, which included the incident aircraft, were not fitted with satellite communications. Without satellite communications, the ACARS was limited to VHF line of sight with the ground stations.

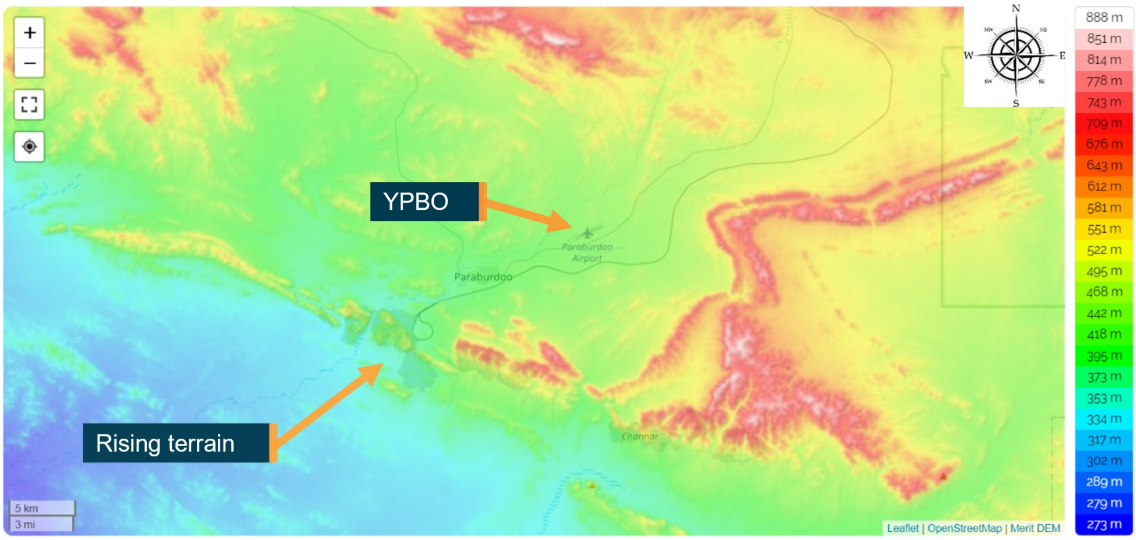
According to the operator, the F100 fleet had a mixture of ACARS hardware units, and they were originally acquired without ground station connectivity and had no service provider. In 2016, 2 aircraft were selected for a feasibility study to test the technical viability and likely cost for activating the ACARS, which was then projected out to the remainder of the fleet. A business case, which included the activation of ACARS across the F100 fleet, was submitted in 2016 and the decision was made not to proceed with implementation at that point in time. This decision was based on a consideration of the range of projects underway across Network Aviation and a benefits analysis of implementing the solution. They had not considered including satellite communications in their ACARS business case and believed that most of their operational requirements could be met with VHF ground station connectivity. Network Aviation continues to operate the F100 aircraft and are not currently planning to implement ACARs on the fleet, however, they have not ruled out implementation of ACARs in the future.

Airport information

Paraburdoo Airport was an uncontrolled aerodrome with an elevation of 1,406 ft. The town of Paraburdoo is located about 5 NM west of the airport and lower terrain is located to the west of the town along a north-west to south-east divide (Figure 3). The airport had one runway, runway 06/24 (2,132 m long and 45 m wide), which had low intensity runway lighting installed and precision approach path indicator lighting set at a 3.0° slope for a threshold height of 50 ft, which were serviceable. The instrument approaches available included RNAV using GNSS for runways 06 and 24.

[26] Required navigation performance (RNP) levels refer to the performance required from the navigation system. RNP 0.3 means the aircraft navigation system must be able to calculate its position to within a circle with a radius 0.3 NM.

Figure 3: Paraburdoo (YPBO) terrain map



Source: Topographic-map.com, annotated by the ATSB

The LNAV landing minima for the RNAV approach was the minimum descent altitude (MDA) of 2,010 ft for runway 06 (604 ft above aerodrome level (AAL)) and 2,090 ft (684 ft AAL) for runway 24. The MDA could be reduced by 100 ft if an accurate QNH was obtained within 15 minutes of arrival, which reduced it to 504 ft AAL for runway 06 and 584 ft for runway 24. For the flight crew of QF1616, when flying a constant descent profile, they were required to add 50 ft to the MDA for the missed approach commencement altitude. Therefore, the flight crew operated to a minima of 1,960 ft (554 ft AAL) for runway 06 and 2,040 ft (634 ft AAL) for runway 24.

The aerodrome was equipped with an automatic weather station (AWS), which provided an automatic weather information service (AWIS) to flight crew, and meteorological METAR and SPECI reports to the Bureau of Meteorology (BoM) and Airservices Australia (air traffic services provider). Local radio traffic was conducted on a common traffic advisory frequency and air traffic services were provided by a Melbourne Centre flight information area (FIA) frequency.

Automatic weather station

A basic AWS has sensors for the temperature, dewpoint,[27] wind, QNH and rainfall data groups. At aerodromes, these basic AWS sensors are supplemented with a ceilometer and visibility meter. The ceilometer estimates cloud height by sending a laser light pulse near vertically through the atmosphere and using the back scatter[28] to measure cloud height. The AWS algorithm processes the raw sensor data every minute. While the current ceilometer data is used by the AWIS, the METAR and SPECI reports use the 30-minute average of data, but with the last 10 minutes given a double weighting to improve the response time to changing conditions. The BoM provided the following explanation for the difference between a ceilometer and human observer:

> The ceilometer is an estimate based on the continuous sampling of a single point over a period of time (30 minutes for the ceilometer); whereas a human observer produces an estimate based on a view of the whole airfield and the whole sky over a short time prior to the observation.

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27 The temperature to which air must be cooled, at constant pressure and water vapour content, in order for saturation to occur. If the air is cooled further, some of the water vapour will condense to liquid.

28 The light pulse is scattered by aerosols including water droplets (clouds), and the component of light scattered back towards the ceilometer is measured.

According to the BoM, the AWS will trigger a SPECI report if the 10-minute average for the cloud base is below the highest alternate minimum[29] (1,664 ft at Paraburdoo) or 1,500 ft. A SPECI is also triggered if the 10-minute average for the visibility is below the highest alternate minimum (7,000 m at Paraburdoo) or 5,000 m.

If a data group is not available when a METAR or SPECI report is produced by the AWS, then this is indicated by solidi; '////' for visibility, '//' for weather and '//////' for cloud. This is broadcast by the AWIS as '[data group] not available'.

Meteorological information

The flight plan for QF1616 provided the flight crew with the aerodrome forecasts (TAFs) for their departure, destination, and company approved alternate aerodromes. The FO programmed Karratha Airport as route 2 in the FMS and the flight crew discussed Karratha, Newman Airport and Solomon Airport as divert options after the second and third missed approaches at Paraburdoo. Therefore, the investigation of meteorological information focussed on the forecast and actual conditions for these aerodromes.

Flight plan forecast conditions

Paraburdoo

At the scheduled departure time from Perth of 0600, the forecast mean conditions for Paraburdoo were light rain with scattered cloud at 1,000 ft AAL, broken cloud at 3,000 ft, and visibility greater than 10 km with a TEMPO period until 1100 for broken cloud at 1,000 ft and visibility reduced to 4,000 m with moderate rain showers. The Paraburdoo METAR conditions, issued at 0430, reported rain, scattered cloud at 4,500 ft, 5,700 ft and 6,700 ft, wind from 060° at 8 kt, and the temperature and dewpoint were 20 °C and 19 °C respectively.

Newman

The forecast cloud and visibility conditions for Newman were the same as Paraburdoo with the exception that the TEMPO period extended until 1400. The Newman METAR conditions, also issued at 0430, reported cloud overcast at 11,000 ft and the weather data group was not available.

Karratha

The forecast mean conditions for Karratha were light showers of rain with scattered cloud at 2,000 ft, broken cloud at 5,000 ft, and visibility greater than 10 km. The conditions were forecast to improve at 0900 to no significant weather with scattered cloud at 5,000 ft. There was an intermittent period of variation from the prevailing conditions on the forecast that ended at 0400 for broken cloud at 1,500 ft and visibility reduced to 3,000 m in showers of rain. The METAR conditions, also issued at 0430, reported scattered cloud at 7,900 ft, overcast cloud at 11,000 ft, greater than 10 km visibility and the weather data group was not available. The flight plan did not include a forecast for Solomon.

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[29] When operating instrument flight rules, the instrument approach chart will show the ceiling (cloud base height) and visibility minima to be compared with the meteorological forecasts and reports to determine both the need to provide for an alternate aerodrome and the suitability of that aerodrome as an alternate (ENR 1.5 section. 6: Alternate weather minima).

Aerodrome weather reports

Paraburdoo

The Paraburdoo AWS issued the following observation reports on the morning of the incident (Table 1). For each of the times provided below, the QNH was 1013 and there were light rain showers, except for 0930 when the weather data group was not available.

Table 1: Aerodrome weather reports for Paraburdoo

Time	Type	Wind	Visibility	Cloud (above ground level)	Temp. (°C)	Dewpoint (°C)
0730	METAR	040° at 4 kt	>10 km	scattered at 500 ft broken at 1,500 ft and 2,400 ft	21	20
0731	SPECI	040° at 4 kt	>10 km	scattered at 600 ft broken at 1,500 ft and 2,400 ft	21	20
0751	SPECI	340° at 3 kt	reduced to 6,000 m	broken at 800 ft overcast at 1,500 ft	21	19
0800	SPECI	330° at 4 kt, varying from 290° to 350°	reduced to 3,000 m	broken at 800 ft overcast at 1,000 ft	21	20
0830	SPECI	260° at 7 kt	7,000 m	broken at 400 ft, 1,000 ft, and 1,300 ft	21	20
0839	SPECI	250º at 7 kt	7,000 m	broken at 500 ft and overcast at 1,600 ft	21	20
0845	SPECI	240º at 8 kt	6,000 m	broken at 400 ft, 700 ft and overcast at 1,700 ft	21	20
0900	SPECI	240° at 7 kt	>10 km	broken at 400 ft overcast at 900 ft and 1,700 ft	21	20
0930	SPECI	250° at 5 kt	>10 km	scattered at 600 ft overcast at 1,100 ft and 1,500 ft	22	19
1056	SPECI	300° at 4 kt	>10 km	scattered at 1,300 ft broken at 1,800 ft overcast at 3,200 ft	24	20
1100	The aerodrome exited SPECI conditions.					

The period in which the cloud base was broken below 1,000 ft extended from 0751 until 0930. Scattered cloud at 500–600 ft buffered this period. The actual conditions recorded by the AWS indicated a cloud base lower than the forecast conditions, which extended beyond the 30-60-minute duration for TEMPO conditions. According to the BoM's analysis of the meteorological conditions at the time of the incident, the TAF for Paraburdoo was amended to alternate conditions in low cloud at 0834, which was 4 minutes after the TEMPO holding period of 60 minutes was no longer satisfying the observed conditions. Overall, the observed weather reports included a cloud base below the highest alternate minima of 1,664 ft for 3 hours 26 minutes, from 0730 to 1056.

Newman

The reports for Newman indicated the AWS weather and cloud data groups were not available for the period 0600-1000. In this period, 11 reports were issued, 9 METAR and 2 SPECI reports. The SPECI reports were for a reduction and subsequent improvement in the visibility at 0934 and 0944 respectively. As the cloud data group was not available, it could not be determined if Newman was suitable at the time the captain requested the latest weather from air traffic control for this location.

Karratha

The reports for Karratha indicated the cloud base was above 10,000 ft from 0730–1000, and the visibility was greater than 10 km for the period 0600-1000. Therefore, the weather reports for Karratha indicated it was a suitable diversion option during the period of the incident.

Solomon

From 0600-1000, 16 reports were issued for Solomon, which consisted of 12 SPECI and 4 METAR reports. At 0804, the lowest cloud was broken at 600 ft, which was below the lowest landing minima, and therefore it was unsuitable at the time the flight crew were considering it. At 0841, the cloud was scattered at 500 ft and 1,400 ft, and broken at 2,100 ft with 5,000 m visibility. The weather data group was not available for this period.

Development of low cloud base at Paraburdoo

The BoM noted that Paraburdoo was outside the optimal range[30] for the nearest weather radar stations, located at Learmonth (210 NM) and Dampier (162 NM). At these distances, any echoes appearing on the weather radar displays would be from clouds higher up in the atmosphere and thus not representative of conditions closer to the surface. So, while Paraburdoo appeared clear of rain on the weather radars at the time of the incident, light showers of rain reported on the METARs indicated that this was not the case. Nearby weather stations all recorded rainfall and it was likely that the light rain or drizzle was widespread due to a rainband over the area. The BoM further stated that the period of low visibility leading up to the incident further supported the presence of precipitation.[31] It was likely that the rainfall provided extra moisture through evaporative processes as it fell into unsaturated air, which is known as the wet bulb effect.

The BoM also reported that the wind direction was likely a contributing factor for the low cloud base, which backed from the north-east at 0730 to the north-west at 0751 and around to the west at 0830. When the wind blows from the west, the local terrain surrounding Paraburdoo forces the air to rise. Rising air cools, while the amount of moisture remains constant, thus reducing the dewpoint depression[32] and promoting the development of low cloud as the air becomes saturated. This process is known as orographic uplift and results in upslope stratus[33] cloud. Therefore, the BoM concluded that the mechanisms that produced the low cloud at Paraburdoo were a combination of the wet bulb effect due to moistening of the airmass from rainfall and the orographic uplift provided by the terrain.

On their first approach at Paraburdoo, the flight crew noted they had a tailwind component to runway 06, despite the AWIS indicating the surface wind was north-easterly. The BoM reported that the winds described by the flight crew indicated the layer of wind above the surface layer would have been ascending as it flowed over the terrain. If this layer was close to saturation, then this could have promoted the formation of low cloud. The BoM indicated that ‘meteorological theory supports this conclusion if all factors were to line up, but it can’t be stated for certain.’

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30 The optimal range is generally within 110 NM of the weather radar station, terrain dependent, to capture rainfall echoes from clouds about 10,000 ft above mean sea level.

31 Precipitation: Any product of the condensation of atmospheric water vapour that falls under gravity.

32 Dewpoint depression: The difference between the temperature and dewpoint temperature at certain height in the atmosphere.

33 A principal cloud type, forming in the low levels of the troposphere (the lowest layer of the atmosphere) and normally existing as a flat layer that does not exhibit individual elements.

Forecasting for Paraburdoo

The Paraburdoo TAF used by the flight crew during pre-flight planning was issued at 0208 with a validity period from 0200 to 2000. The BoM reported that, at 0200, there had been observations of scattered cloud at 1,000 ft at nearby airports, which supported the TEMPO forecast for broken cloud at 1,000 ft at Paraburdoo. Early in the morning, broken cloud at about 1,000 ft was observed at various locations, mostly for periods of less than 1 hour at a time. Meteorological model guidance was forecasting the low cloud would lift at around 0800. However, from the duty forecaster's experience, low cloud would persist in the Paraburdoo area longer than what the modelling generally indicated. As a result, a conservative approach was taken regarding the timing of the TEMPO and the Paraburdoo TAF issued at 0208 retained the TEMPO for broken cloud at 1,000 ft until 1100.

The BoM's model traces had indicated saturated levels through to near to the surface. However, modelling in northern Australia was subject to false alarms for widespread low cloud. Therefore, some form of surface verification and/or satellite observations were required for them to have confidence in the modelling. They noted that the lifting trend in the modelling did not occur, and cloud bases dropped further below the highest alternate minima after 0700 and persisted for longer than the 1-hour TEMPO periods. They reported that, this event was difficult to forecast accurately, given modelling false alarms and the lack of observed lower cloud and satellite imagery available prior to the onset of very low cloud at Paraburdoo. The cloud that lowered significantly after 0700 contrasted with what they would normally expect, where the surface heating would lift the cloud base rather than for it to lower further.

The 0208 TAF forecast the temperature to rise throughout the morning. However, the AWS recordings indicated a slower temperature rise than what was forecast and a small dewpoint depression. The following table presents the TAF forecast temperatures and the recorded AWS temperatures and dewpoints on the morning of the incident.

Table 2: Aerodrome forecast (TAF) and automatic weather station (AWS) temperatures and dewpoints

Time	0200	0500	0800	1100
TAF temperature (°C)	20	22	23	25
AWS temperature (°C)	20	20	21	24
AWS dewpoint (°C)	19	19	20	21

Sources of atmospheric moisture

The BoM reported that the depth of moisture through the atmosphere is important in determining the potential for low cloud development. There are not many observation sources that indicate the depth of moisture in an airmass, except for balloon soundings and aircraft meteorological data relay (AMDAR). There were no weather balloons or AMDAR profiles available at Paraburdoo to provide atmospheric data, including the depth of moisture in an airmass and there is currently no plan to install a weather balloon station, or a weather radar, at Paraburdoo.

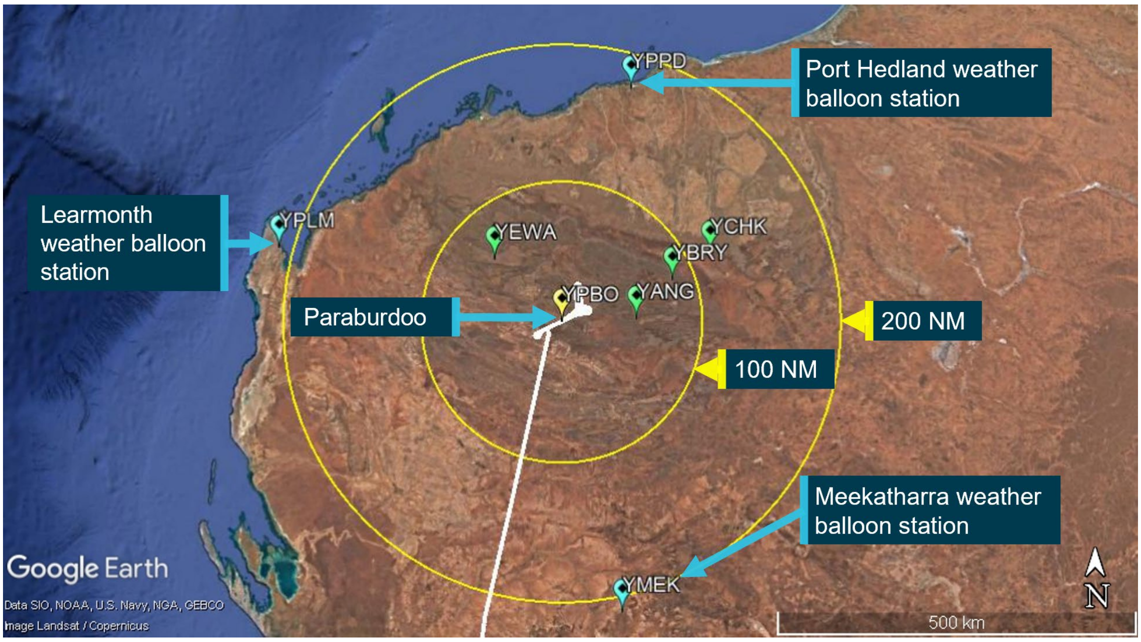
Weather balloons and radar

Balloon-based weather observations provide precise measurements of temperature, pressure, humidity, wind speed and direction. The BoM released about 56 balloons each day from 38 locations. The main items attached to the balloon are a foil-coated cardboard target used to slow the descent of the balloon and track it with radar, and a small white plastic box known as a radiosonde, which has the sensors used to measure meteorological variables.

During the radiosonde's flight it is constantly transmitting the meteorological data to ground equipment, which processes and converts the data into weather messages and is displayed as an aerological diagram for use by forecasters. The aerological diagram allows forecasters to obtain a snapshot of the atmosphere above a specific location to determine the atmosphere's stability and forecast the lower and upper levels of clouds and their types.

The nearest weather balloon stations were Port Hedland, Learmonth, and Meekatharra. These locations were 175-210 NM from Paraburdoo and not guaranteed to be representative of the conditions at Paraburdoo. Figure 4 depicts the nearest weather balloon stations to Paraburdoo (blue) and the nearby airports (West Angelas (YANG), Barimunya (YBRY), Eliwana (YEWA) and Christmas Creek (YCHK), in green) where the 0200 observation of scattered cloud at 1,000 ft was used to support the incident TAF conditions.

Figure 4: Weather balloon stations relative to Paraburdoo



Source: Google Earth, annotated by the ATSB

According to the BoM, the spatial distribution of the upper air network is designed to meet the requirements of national and regional numerical weather prediction models. The spatial density was reviewed in 2022 and found to meet the requirements set by the World Meteorological Organization for numerical weather prediction. The weather radars are targeted to areas where significant or hazardous weather intersect with areas of highest community need. While this covers 98% of the population, much of inland Australia, such as Paraburdoo, are not covered. Consequently, no precipitation was detected at Paraburdoo by the nearest weather radar stations at Learmonth and Dampier at the time of the incident.

Aircraft meteorological data relay

The World Meteorological Organization, in cooperation with some international airlines, has established the aircraft meteorological data relay program (AMDAR). The AMDAR system predominantly utilises existing aircraft onboard sensors, computers, AMDAR software and communications systems to collect and transmit meteorological data to ground stations via satellite or radio links using ACARS. This data is then relayed to national meteorological and hydrological services. These observations supplement the data gathered by other meteorological instruments and help to improve the accuracy of forecasts.

Vertical profiles of the atmosphere are taken when the aircraft climbs or descends during the departure or arrival phase of flight. According to the World Meteorological Organization guide to aircraft-based observations (ABO):

> Vertical profiles derived from ABO should be considered as being very similar in character and application to those derived from meteorological radiosondes. AMDAR and other ABO generally provide an improvement in forecasting ability through a reduction in NWP [numerical weather prediction] forecast error of 10%–20% over the first 24 hours of the forecast period.

The AMDAR profiles coverage for Western Australia throughout the month of November 2021 is shown in Table 3 (fractional profiles are the result of averaging over multiple weeks). Paraburdoo was not part of the AMDAR network.

Table 3: AMDAR profiles Western Australia in November 2021

Airport name	Profiles taken (per week)
Broome International	1.69
Christmas Creek Station	6.52
Fortescue Dave Forrest	2.90
Ginbata	9.41
Newman	4.10
Karratha	13.03
Kalgoorlie Boulder	5.55
Port Hedland International	14.48
Perth International	125.52

Sources of in-flight weather updates

Air traffic control

According to the Airservices Australia *Aeronautical Information Publication* (AIP) section GEN 3.3.4, air traffic control provides pilots with pertinent information that will affect flight within one hour's flight time. At the time the information is identified, it will be directed to pilots maintaining continuous communications and broadcast on appropriate air traffic services frequencies.

In November 2018, a new filtering system for SPECI reports was launched by Airservices Australia. The new system assessed SPECI reports for all locations and provided more specific filtering to identify significant SPECIs. Air traffic control then directed these SPECI reports to affected pilots within one hour's flight time. However, SPECIs were only disseminated if they differed from the associated TAF.

For example, the Paraburdoo SPECI issued at 0731 was for the cloud base below the highest alternate minima, which was expected with the TEMPO forecast on the TAF. Therefore, there was no requirement to disseminate this SPECI. However, the 0830 SPECI with broken cloud at 400 ft differed significantly from the TAF conditions and was therefore broadcast by ATC at 0834.

Automatic en route information service

The automatic en route information service (AERIS) continuously broadcasts METAR, SPECI and TAF information from a network of VHF transmitters installed around Australia. However, there are many gaps in the coverage provided across Australia. The nearest AERIS station to Paraburdoo was Meekatharra. This station broadcasted information for several airports, which included Paraburdoo and Karratha. However, as Paraburdoo was located about 210 NM north of Meekatharra and, disregarding any local terrain shielding effects, an aircraft would have to be at an altitude of about 36,500 ft overhead Paraburdoo for AERIS reception. Therefore, while holding and conducting missed approaches at Paraburdoo, the aircraft was too low to receive Meekatharra AERIS broadcasts.

The flight from Perth to Paraburdoo passed through the Meekatharra AERIS coverage and could have been used to update the actual weather conditions for Karratha, which was route 2 in the FMC. However, the flight crew were operating with holding fuel for Paraburdoo and no expectation that they would need to consider Karratha.

Aircraft communication addressing and reporting system

The ATSB discussed the potential use of ACARS for weather updates in-flight with the flight crew. The captain reported no previous experience with ACARS, but provided the following comments about its potential benefit in this incident:

> Had we been able to utilise the ACARS for weather information it may have further allowed us to also get weather for other aerodromes and perhaps with that information have gone somewhere else.

The FO, who had previous experience using ACARS, provided the following comments about its potential benefit:

> The Fokker have ACARS in them, but they're not connected, whereas with other aircraft we could just dial it into the computer and request the ATIS or the TAF on any airport and get an automatic update – we don't have to rely on anyone. It was busy that day, you could tell the controllers were working hard, when I said we waited for the weather for 15 minutes, he was busy, it wasn't like he was ignoring us.

According to the Société International de Télécommunications Aeronautiques, who are the ACARS ground station gateway service provider in the Australian region, the nearest VHF datalink ground station to Paraburdoo was located at Newman, which was about 115 NM to the east. Disregarding any local terrain shielding effects, without a satellite connection the aircraft would have required an altitude of about 11,000 ft overhead Paraburdoo to receive weather information via the ACARS.

Diversion options

The captain reported that their nearest preferred diversion airports were Karratha and Newman. The Karratha AWS was reporting a cloud base above 10,000 ft, whereas Newman had the same TEMPO forecast as Paraburdoo, and the cloud base was unknown. While they considered Solomon after their third missed approach, a SPECI was subsequently issued with cloud below the landing minima.

The ATSB used the fuel figures reported by the flight crew at interview and on the cockpit voice recorder to estimate the fuel on board (excluding fixed reserve) and potential diversion range of the aircraft after each missed approach, with reference to the airports of Karratha, Newman and Solomon.

The Network Aviation *F100 aircraft performance manual* indicated FL 160 was the optimum level for a diversion of 150 NM (Karratha was 157 NM) and FL 110 for 100 NM (Newman was 115 NM). The FL 150 performance table figures were the closest to FL 160 and indicated the range from the first missed approach was about 242 NM,[34] and about 155 NM from the second missed approach. The A100 (10,000 ft) table figures were the closest to FL 110 and indicated the range from the third missed approach was about 84 NM (Solomon was 55 NM).

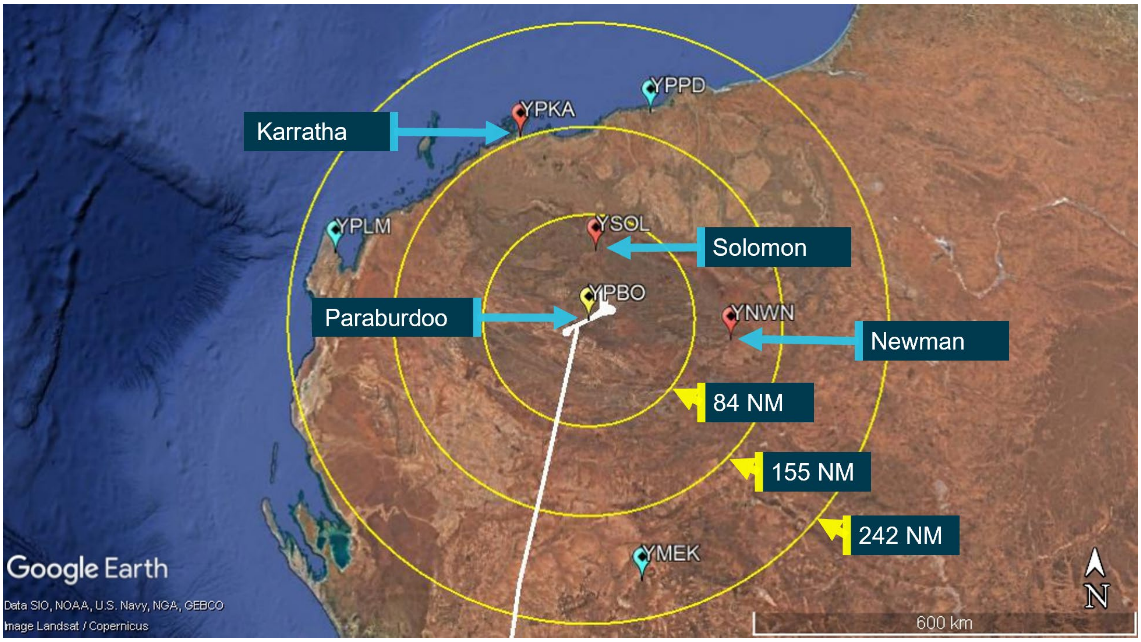
[34] Calculations are based on nil wind from the start of the take-off roll with anti-icing on.

The captain recalled that they did not consider diverting after the first missed approach and that the FMC indicated they were at the minimum fuel for a diversion to Karratha after the second missed approach. The FO had set route 2 in the FMC to Karratha, and it was calculating the fuel direct to Karratha from their present position. However, the captain recalled that the FMC calculation did not consider the actual winds that would be experienced en route, or the additional fuel for an instrument approach if it was required at the destination.

The captain and FO reported that they decided minimum fuel was insufficient to divert to Karratha after the second missed approach without current weather, noting they would be committed to a landing on arrival. The captain recalled that they had looked at the forecast but were not aware of the actual weather conditions at Karratha. Consequently, they considered Karratha to be a 'worse choice than staying at Paraburdoo where we did have the fuel to hold'. The FO also recalled that they had a discussion after the second and third missed approaches but concluded that they did not have enough fuel to divert anywhere safely without an updated weather forecast.

The flight crew subsequently decided to request a weather update for Newman as they heard QF1802 reporting to ATC at 0759 that they had landed at Newman, which occurred between their first and second missed approach. However, the captain reported that a diversion to Newman would have only been considered if ATC had reported significantly better weather as it also had TEMPO holding on the forecast and they had insufficient fuel to comply with that requirement. The use of Solomon was considered after the third missed approach, but then dismissed as the landing minima there was higher than the minima at Paraburdoo. Figure 5 depicts the estimated nil wind diversion range from each missed approach (242 NM, 155 NM, and 84 NM) and the airports that were under consideration by the flight crew.

Figure 5: Approximate nil wind diversion range from each missed approach



Source: Google Earth, annotated by the ATSB

Organisational and management information

Diversion decision-making guidance

According to the Network Aviation *Aerodrome and Route Data Manual*, the preferred alternates for Paraburdoo were Karratha or Port Hedland. The flight crew had Karratha loaded in the FMC as route 2, but they did not obtain a weather update for Karratha before arriving at Paraburdoo. Their flight plan weather forecast and AWIS at top of descent indicated they would be visual before reaching the MDA. The operator noted that the weather forecast for Karratha was well above landing minima with no expectation of deterioration, and that ATC would broadcast if a SPECI was issued. Consequently, there was no company expectation or requirement for the flight crew to obtain updated weather for Karratha while en route to Paraburdoo.

According to the International Civil Aviation Organization (ICAO) Doc 8168 (2018), *Aircraft Operations (Vol 3) – Aircraft operating procedures*, standard operating procedures 'provide guidance to flight operations personnel to ensure safe, efficient, logical and predictable means of carrying out flight operations'. Therefore, the ATSB asked the operator if they had considered a diversion decision-making procedure.[35,36] They did not consider a prescriptive procedure necessary but had published a standard operating procedure to limit the number of missed approaches. The Network Aviation *Flight Administration Manual* provided the following information:

> **8.59.2 Multiple Missed Approaches**
>
> Multiple Missed Approaches are not only distressing to passengers, but can also increase the risk of incident or accident. Therefore, during normal operations, Flight Crew should limit the number of weather-related Missed Approaches to two. A third approach in these circumstances should not be immediately attempted unless the Pilot In Command believes there is a high probability of a successful approach and landing, or greater emergency or operational requirement exists.

With respect to procedure 8.59.2, the captain reported that it was not weather-related or considerate of a fuel-critical state and the FO indicated there was insufficient fuel to divert after 2 missed approaches. The captain further stated that their interpretation of the procedure was that it was intended for the benefit of the passengers and to only continue if confident a landing would be made from the third approach. The chief pilot noted that, while it was worded from the perspective of passenger comfort, it did have a secondary intent of not continuing to conduct approaches in unsuitable conditions, and the 2 missed approaches were a limit unless there was an expectation that a landing would be made from the third approach.

The operator did not consider a prescriptive diversion decision-making procedure necessary. However, after the incident, they noted flight crew could benefit with better tools to assist their diversion decision-making process. For example, company flight plans included a summary on the possible diversion locations only when the flight legally required an alternate.

The operator also noted that they did not have a requirement for their flight crews to brief their minimum divert fuel at the top of descent. They had not provided a procedural expectation that this would be briefed, although it was a common practice for one of their management pilots in their previous employment. The operator considered that, if the flight crew had briefed their minimum divert fuel for Karratha as part of their arrival briefing for Paraburdoo, it might have influenced their decision-making.

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35 A diversion decision-making procedure is a requirement for extended diversion time operations, but this was not applicable to the operator's F100 fleet. Refer Civil Aviation Advisory Publication 82-1(1): Extended Diversion Time Operations (EDTO); '6.6.1 The operator's operations manual must establish procedures for flight crew outlining the criteria that indicate when a diversion or change of routing is recommended whilst conducting an EDTO'.

36 On 2 December 2021, 10 days after the incident, the new Civil Aviation Safety Regulations flight operations regulations commenced. This required all Part 121 operations to plan at least one destination alternate aerodrome when the relevant forecast weather was: less than 1,000 ft above the landing minima determined by the operator under regulation 121.185, or when the forecast visibility was less than the greater of 5km, or the landing visibility determined by the operator under regulation 121.185 plus 2 km.

The operator's observations were consistent with ICAO Doc 8168 (2018), which stated that 'Crew briefings communicate duties, standardize activities, ensure that a plan of action is shared by crew members and enhance crew situational awareness'. The objectives for flight crew briefings for safety-critical actions included:

> a) refreshing prior knowledge to make it more readily accessible in real-time during flight;
>
> b) constructing a shared mental picture of the situation to support situational awareness;
>
> c) building a plan of action and transmitting it to crew members to promote effective error detection and management; and
>
> d) preparing crew members for responses to foreseeable hazards to enable prompt and effective reaction.

The section for arrival briefings in ICAO Doc 8168 (2018) also provided the following information:

> 3.5.4 Flight crew arrival briefings should prioritize all relevant conditions that exist for the descent, approach and landing. They should include, but not be limited to:
>
> …
>
> h) alternate aerodromes and fuel considerations;

While this incident involved unforecast low cloud, and alternate aerodromes were not required for the flight plan, the operator noted, that even on a clear weather day, a preceding aircraft could have an accident at the destination airport, which could require a diversion.

Risk management

Bowtie risk assessments

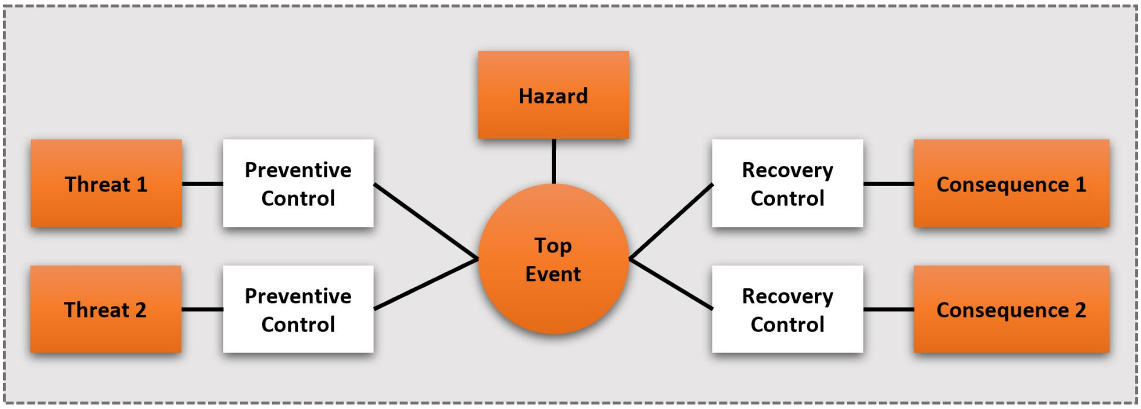
Network Aviation, a subsidiary of Qantas, used the Qantas Group safety management system *Risk assessment procedure and risk assessment guide* for their risk management processes. Among their various tools was a bowtie risk assessment software. According to the software user manual (2019):

> Risk in bowtie methodology is elaborated by the relationship between hazards, top events, threats and consequences. Barriers [*also known as controls or defences*] are used to display what measures an organization has in place to control the risk.

The top event represents the loss of control of the hazard (undesired aircraft state), and damage or injury is represented by the consequence(s). A threat is a factor that 'itself should have the ability to cause the top event' (Figure 6). While aviation traditionally distinguishes between threat and error, the software program used threat as the descriptor for both.

When the risk assessment is constructed with multiple threats on the left side and consequences on the right side of the top event, a bowtie like structure appears. Between the threats and the top event are the preventive controls, to reduce the likelihood of the top event occurring. Between the top event and the consequences are the recovery controls, to reduce the likelihood and/or severity of the consequences.

Figure 6: Example bowtie structure



Source: ATSB

United Kingdom Civil Aviation Authority bowties

The United Kingdom (UK) Civil Aviation Authority (CAA) initiated a 'Significant Seven' task force in 2009. From this they then developed a series of bowtie risk assessments, known as the 'Significant Seven', with 3 bowties for each of the 7 risks. They were published on their website in their software file format so that they could be downloaded and customised by industry. According to the CAA website the scope of the Significant Seven project was focussed on the risks that contribute to UK commercial air transport fixed-wing operations. The operating environment and equipment were generic but UK oriented, therefore they recommended the following:

> Aircraft operators can be expected to encounter operating environments outside the scope of the bowtie templates during international operations and these conditions are an example of issues that should be addressed when customising the bowties.

Their Significant Seven included controlled flight into terrain (CFIT) with the 3 bowties CFIT 3.1, CFIT 3.2 and CFIT 3.3, with revision dates 2013-2014. The CAA website provided the following information about their CFIT risk assessments:

> The structure of the CFIT bowties is such that generic issues related to arrivals and departures are considered in bowtie 3.1 'Large CAT fixed-wing arrival or departure (general)/ Terrain separation deteriorating below normal requirements'.
>
> Issues specific to non-precision or precision approaches have been addressed in their own bowties 3.2 and 3.3 respectively (e.g. both of these bowties should be considered in conjunction with the generic issues).

International Air Transport Association report

In 2018, the International Air Transport Association (IATA) published their CFIT research and analysis report for the period 2008-2017. They found that the highest frequency of accidents occurred in the approach phase of flight (24 from 47 accidents) and that 'adverse weather' was cited as a contributing factor in 51% of CFIT accident reports, 'poor visibility / IMC'[37] in 46%, and 'lack of visual reference including darkness and black hole effect' in 33%. In addition, their report made the following observation about the role of situational awareness:

> It is evident that most of the CFIT accidents result from a pilot's breakdown in situational awareness (SA) instead of aircraft malfunction or a fire. In other words, these accidents are, for the most part,

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[37] Instrument meteorological conditions (IMC): weather conditions that require pilots to fly primarily by reference to instruments, and therefore under instrument flight rules (IFR), rather than by outside visual reference. Typically, this means flying in cloud or limited visibility.

entirely preventable by the pilot. SA refers to the accurate perception by flight crew of the factors and conditions currently affecting the safe operation of the aircraft, and their vertical and/or horizontal position awareness in relation to the ground, water, or obstacles. The data shows that 49 percent of CFIT accidents had vertical, lateral or speed deviations as a contributing factor to CFIT accidents.

Network Aviation bowties

In 2019-2020, the Qantas Group Flight Operations Steering Committee (FOSC) downloaded, reviewed and amended the UK CAA bowties for CFIT 3.1, 3.2 and 3.3. After completing each review, the bowties were amended to 'QF Group FOSC' as the author and distributed to the operators within the group. The operators had the software and therefore could customise the bowties to their own operation if required. Network Aviation retained the FOSC copies of CFIT 3.1, 3.2 and 3.3 without amendment.

Following the incident, the ATSB asked the operator if they had a risk assessment relating to flight crews experiencing weather below the landing minima. They did not have a specific risk assessment for this scenario but provided a copy of their CFIT 3.1 with threat 8: *Flt [flight] crew operate below the appropriate minimum altitude (exc. instrument approach)* leading to the top event of *terrain separation deteriorating below normal requirements* during arrival or departure with the consequence of *CFIT leading to hull loss*. They considered this to be the closest risk assessment to the incident under investigation. On review of the CAA CFIT 3.1, it was noted that the original threat 8 was *Flt crew continue approach below the MDA/DH without visual reference*, with the note *Commonly exposed*. The remaining 7 threats were unchanged between the CAA bowtie and operator's bowtie.

The operator's bowtie preventive controls included *Visual reference* and *Flt crew detect and recognise error via maintaining SA [situational awareness] …* In addition, while their threat 8 captured their *altimetry procedures* as a control, it omitted some of their other existing procedural controls, such as their *arrival briefing* and *approach checklist*.

The CAA CFIT 3.1 threat 8 did not use *Visual reference* or *Flt crew detect and recognise error via maintaining SA…* as controls. However, situational awareness was used as a control by the CAA for other threats in CFIT 3.1 and in other bowties. This included CFIT 3.2, where *Flt crew maintain SA via effective monitoring* was included as one of the controls for the threat of *Flt crew loss of Situational Awareness (SA) during a NPA [non-precision approach]* and was reproduced in the operator's CFIT 3.2 bowtie.

At interview, the operator acknowledged that they had treated *Visual reference* as a control, rather than as an aspect of the threat. On consideration of why threat 8 had been changed, they reported that CFIT 3.1 was considered from the arrival perspective – from the top of descent to the relevant lowest safe altitude, followed by a visual approach – and that CFIT 3.2 and 3.3 dealt with threats specific to an instrument approach. However, while the operator's CFIT 3.2 and 3.3 were amended from the CAA versions, neither of them included the CAA CFIT 3.1 threat 8 of *Flt crew continue approach below the MDA/DH without visual reference*.

According to the Qantas Group *Safety Management System Manual*, the risk owner/risk assessment owner/risk register owner was responsible for:

- ensuring that a comprehensive risk assessment is performed, and the progress and implementation of risk treatment plans is monitored
- confirming that existing controls are fit for purpose and operating, designed, and periodically monitored.

Therefore, the ATSB queried the operator's safety assurance, specifically whether the bowtie risk controls were subject to audit as part of their risk management review process. The operator reported that, in the design of their system-based audit of consequences, they utilised the bowtie as an audit tool, so the bowtie controls will be assessed as part of the audit. This was consistent with the ICAO *Safety Management Manual*, Doc 9859 (2013), which included the following:

> The safety assurance process complements that of quality assurance, with each having requirements for analysis, documentation, auditing and management reviews to assure that certain performance criteria are met. While quality assurance typically focuses on the organization's compliance with regulatory requirements, safety assurance specifically monitors the effectiveness of safety risk controls.

System safety design order of precedence

According to Stolzer et al. (2008), the field of system safety provided a categorisation scheme for evaluating hazard (risk) controls, and that it was important for the safety practitioner to understand this scheme so that appropriate decisions could be made. This scheme was the system safety design order of precedence (also known as the hierarchy of hazard control) and was described in the United States Department of Defence *System Safety Standard Practice Manual* (MIL-STD-882E)[38] in the following manner:

> The goal should always be to eliminate the hazard if possible. When a hazard cannot be eliminated, the associated risk should be reduced to the lowest acceptable level within the constraints of cost, schedule, and performance by applying the system safety design order of precedence. The system safety design order of precedence identifies alternative mitigation approaches and lists them in order of decreasing effectiveness.

From MIL-STD-882E, the system safety design order of precedence was as follows:

- eliminate hazards through design selection
- reduce risk through design alteration
- incorporate engineered features or devices
- provide warning devices
- incorporate signage, procedures, training, and personal protective equipment.

The use of humans to monitor, detect and correct problems, are not risk controls within the design order of precedence. Rather, it is the incorporation of controls in accordance with this scheme that shapes the required level of safety and human performance within the system. This is described in the ICAO *Human Factors Training Manual*, Doc 9683 (1998), as follows:

> The control of human error requires two different approaches. First, it is necessary to minimize the occurrence of errors by: ensuring high levels of staff competence; designing controls so that they match human characteristics [reduce risk through design]; providing proper checklists, procedures, manuals, maps, charts, SOPs [procedural controls] … Training programmes aimed at increasing the co-operation and communication between crew members will reduce the number of errors [training controls] ... The second avenue to the control of human error is to reduce the consequences of the remaining errors by cross-monitoring and crew co-operation [procedural and training controls]. Equipment design which makes errors reversible and equipment which can monitor or complement and support human performance also contribute to the limitation of errors or their consequences [engineered features and warning devices].

The description for managing the risk of human error in ICAO Doc 9683 (1998) included design to reduce risk, procedural and training controls, and the incorporation of engineered features and warning devices. A similar approach was employed by IATA (2018) in their CFIT research and analysis report section on mitigation strategies, which targeted the 3 categories of *human*,

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[38] While MIL-STD-882E, dated 2012, was the current version at the time of this incident, the original version was issued in 1969.

procedural and *technological*. They included the following explanation for the meaning of human-related mitigation strategies:

> The available human mitigations involve improving and maintaining pilots' knowledge, their awareness and their competence, and each of these can be achieved by a comprehensive training program embracing classroom, simulator and flight training.

Hence, the level of safety and human performance is managed by the design of the system, which is consistent with the approach suggested by Stolzer et al. (2008).

Similar occurrences

A search of the ATSB's database for the period 2012-2021 for unforecast weather and low fuel events in the air transport high-capacity sector found 114 occurrences, of which 10 involved both events in the same occurrence. For unforecast weather events, this involved 67 occurrences (64 incidents, 2 serious incidents and 1 accident), and low fuel events found 57 occurrences (53 incidents and 4 serious incidents). There were no previous incidents reported for Paraburdoo Airport within this 10-year dataset.

The following is a summary of previous destination weather related occurrences, both in Australia and overseas.

Aircraft Accident Investigation Bureau of India

On 18 August 2015, a Boeing 737-800, departed Doha, Qatar, for Cochin, India. On arrival at Cochin, the weather had deteriorated, and 3 missed approaches were conducted. The fuel reserve fell below the minimum required alternate of Bangalore during the third missed approach and the flight crew redesignated Trivandrum as their alternate. However, the weather conditions deteriorated at Trivandrum when they arrived, and a missed approach was conducted. This was followed by a MAYDAY fuel declaration and a request to attempt a visual approach. Three visual approaches were attempted with a landing made from the third. The fuel on shut down, after 7 approaches, was 349 kg, which was insufficient for any further approaches.

United Kingdom Air Accidents Investigation Branch (1/2016)

On 23 August 2013, a Eurocopter AS332 L2 Super Puma helicopter, collided with water while the flight crew were attempting to gain visual reference after reaching their MDA on approach to Sumburgh Airport, UK. The actual cloud base was lower than the original TAF forecast and the cloud base at their nominated alternate had also deteriorated, which probably would have precluded the flight crew from making a successful approach at their alternate.

ATSB investigation (AO-2013-100)

On 18 June 2013, 2 Boeing 737 aircraft were on scheduled flights to Adelaide, South Australia. On nearing Adelaide, the forecast improvement in weather conditions had not occurred and as a result, both aircraft diverted to Mildura, Victoria. Upon arrival at Mildura, the actual weather conditions were significantly different to those forecast, with visibility reduced in fog. The flight crew of the first aircraft conducted an instrument approach and landed below the minima. The flight crew of the second aircraft also conducted an instrument approach and landed below the minima in fog with fuel below the fixed reserve.

ATSB investigation (AO-2009-072)

On 18 November 2009, an Israel Aircraft Industries Westwind 1124A aircraft was operated on an air ambulance flight from Apia, Samoa to Norfolk Island, Australia. When the flight was planned, the aerodrome forecast for Norfolk Island indicated the weather conditions at the time of arrival would be above the alternate minima. However, on arrival at Norfolk Island, there was low cloud and the aircraft had insufficient fuel to divert to another airport. After 4 unsuccessful approaches, the flight crew ditched the aircraft 6.4 km west-south-west of the airport.

National Transportation Safety Board (AAR-91/04)

On 25 January 1990, a Boeing 707 flight from Bogota, Columbia, to New York, United States, was placed in a holding pattern 3 times due to poor weather conditions in the north-eastern part of the United States for a duration of about 1 hour and 17 minutes. During the third period of holding, the flight crew reported they could not hold longer than 5 minutes, that they were running out of fuel, and could not reach their alternate airport. Subsequently, they executed a missed approach and then lost power to all engines due to fuel starvation and collided with terrain while attempting a second approach.

Safety analysis

Introduction

On the morning of 22 November 2021, a Network Aviation Fokker Aircraft F100, registered VH-NHV and operating as flight QF1616, departed Perth Airport on a scheduled passenger service to Paraburdoo Airport, Western Australia. On arrival at Paraburdoo, the flight crew conducted 3 missed approaches due to unforecast low cloud. On the fourth approach, the flight crew continued the approach below the landing minima without visual reference to the runway due to the aircraft's fuel state.

This analysis will discuss the flight crew's decision not to divert, the eventual landing below minima, and the reason for the unforecast low cloud. The delay in an air traffic control weather update, and limitations associated with in-flight access to weather while holding at Paraburdoo and weather forecasting at the airport, will also be discussed. It will also consider the operator's procedural guidance and risk management for unforecast weather.

Decision not to divert

After downloading and reviewing their flight plan before take-off, the flight crew noted they had a 60-minute holding fuel requirement for Paraburdoo. However, both the mean and holding weather conditions indicated the lowest cloud was forecast to be above their landing minima. Therefore, they departed Perth with the expectation of landing from their first approach. This expectation was likely reinforced by the automatic weather information service (AWIS) broadcast prior to top of descent, which indicated the lowest cloud was 2,100 ft above the airport. Consequently, their first missed approach at Paraburdoo was unexpected.

The 0730 AWIS update during the descent indicated that low cloud had started to develop at 500 ft above the aerodrome, which was below their landing minima. However, the concurrent air traffic broadcasts on the other radio may have interfered with the flight crew hearing this information as the captain reported that the QNH was the only change noted. Since an accurate QNH must be obtained within 15 minutes of commencing an approach for the minima to be reduced by 100 ft, it was likely that this was their reason for listening to the AWIS during the descent.

When they conducted their first approach, the flight crew momentarily became visual with the runway but realised they would have been too steep to attempt the landing. However, the combination of the visual contact and tailwind on the first approach, provided them with confidence that a second approach to the opposite runway would be successful. Further, the cloud they encountered on the first approach was lower than forecast, which suggested to them that the first approach was likely flown in the worst of the expected conditions. They did not consider at this stage that the conditions might worsen. Therefore, they elected to immediately conduct a second approach, which was also unsuccessful due to low cloud obscuring the runway.

It was after the second missed approach that the flight crew realised the weather was more concerning than expected. At this stage, the deterioration in the actual conditions at Paraburdoo likely resulted in them losing confidence in their flight plan weather forecasts for decision-making purposes.

The weather reports for the airports under consideration for diversion by the flight crew indicated that Karratha Airport was the only suitable diversion. After the second missed approach, the flight management computer (FMC) indicated they were at minimum fuel to divert to Karratha, but the captain was cognisant that this did not allow for the winds they might experience or for an instrument approach on arrival at Karratha if required. In this case, they could not determine if they could reach Karratha with their fixed fuel reserve remaining. Consequently, without knowledge of the actual weather conditions, they elected to disregard Karratha as an option.

Instead, the flight crew requested a weather update for Newman Airport since it was closer, and another aircraft had landed there recently. However, the captain was aware the forecast had a holding requirement and was reluctant to commit to a diversion unless the actual conditions were better than forecast. Solomon Airport was also considered after the third missed approach but was disregarded due to having a higher landing minima than Paraburdoo.

Therefore, as they were still within their 60-minute holding fuel period and did not have immediate access to actual improved weather conditions elsewhere, the flight crew elected to conduct further approaches at Paraburdoo.

Landing below minima

The ATSB’s review of their estimated fuel load found that the flight crew likely had sufficient fuel to divert to Karratha or Newman immediately after their second missed approach, but not after their third missed approach. According to the forecasts and actual conditions, Karratha was suitable, but Newman was not, and an immediate decision was required to divert to Karratha. However, it was only after the second missed approach that the flight crew started to discuss diversion options and the fuel consumption during this period consequently precluded Karratha as an option.

After their third missed approach, a diversion to Solomon was their only other option. However, as the lowest landing minima at Solomon was higher than at Paraburdoo, they disregarded it. At the time, the cloud base at Solomon was below the minima and therefore it would not have been a suitable diversion if the flight crew had received the latest actual weather. Consequently, the flight crew were committed to conducting a fourth approach at Paraburdoo.

Before they commenced their fourth approach the flight crew briefed their plan and duties, and their contingency plan if the approach became unsafe. They subsequently descended below the runway 24 MDA of 584 ft above aerodrome level without visual reference on the approach. On achieving their visual reference at about 293 ft, the aircraft was stable on the glidepath and close to the extended runway centreline, which enabled them to land without further incident, 57 minutes after their first missed approach.

Cloud base

On the night prior to the incident flight, there were no meteorological observations from the Pilbara region of persistent low cloud. In addition, there was a layer of mid-level cloud overnight that should have limited the overnight surface cooling and had also obscured satellite imagery of any low-level cloud. Therefore, the presence of scattered cloud at 1,000 ft above aerodrome level at the surrounding aerodromes at 0200 was used as the justification for forecasting mean conditions at Paraburdoo of scattered cloud at 1,000 ft, with TEMPO conditions for broken cloud at 1,000 ft. This was above the flight crew’s landing minima for runway 06 and 24 of 604 ft and 684 ft respectively.

There was also an expectation that surface heating would lift the cloud base after sunrise. However, the lifting trend in the modelling did not occur and the cloud base lowered, remaining below the highest alternate minima from 0730 for 3 hours 26 minutes.

Distinct from the forecast conditions, at 0730, 16 minutes before the first missed approach, scattered cloud at 500 ft was reported by the automatic weather station (AWS). This deteriorated to broken cloud at 400 ft before the last approach. The AWS was still reporting broken cloud at 400 ft at 0900, 17 minutes after the aircraft landed. This deterioration was consistent with the flight crew's observations that they experienced low cloud at the approach minima for all 4 approaches, and broadcast after landing that patches of low cloud were present at 250-300 ft.

It was likely that evaporation of rainfall added moisture to the atmosphere (wet bulb effect), as indicated by a reduction in the reported visibility from greater than 10 km at 0730 to 6,000 m at 0751. While the surface wind had not yet backed around to the west, the tailwind component reported by the flight crew on their first approach to runway 06 suggested the winds above the surface already had a westerly component. Airflow from the west is forced to rise over the terrain to the west of the airport and will cool, which results in the development of low cloud if the air becomes saturated (orographic uplift). Therefore, the low cloud that developed below the forecast conditions, was likely a combination of moistening of the airmass from rainfall and orographic uplift from the local terrain.

These conditions were considered difficult to forecast due to the absence of low cloud observed on the evening prior, any low-level cloud being obscured on the satellite imagery, and the lifting trend in the modelling not occurring. This discrepancy between the forecast and actual conditions resulted in the flight crew losing confidence in their flight plan aerodrome forecasts for diversion decision-making purposes, and initially misled them to believe that conditions would not deteriorate further after their first missed approach.

In-flight access to weather information

A decision to divert is a procedure-based decision-making exercise, which is also known as rule-based decision-making. This is dependent on the situational awareness or knowledge of the problem, and knowledge of options (Flin, O'Connor, Crichton, 2008). When the flight departed Perth, the flight crew had incorrect knowledge of the weather situation that would unfold at Paraburdoo when they arrived. Although they passed within range of the Meekatharra automatic en route information service (AERIS), which would have provided them with the current weather for Karratha, there was no operational need for it at that stage, based on their assessment of the forecast conditions.

After the second missed approach, the flight crew's discussions and actions indicated they had updated their assessment of the situation and were now actively seeking additional information about the weather conditions. This included the Paraburdoo AWIS (which was checked before each approach), air traffic control, and the Paraburdoo safety car officer. At this stage, they were holding at about 4,100 ft, which meant they were out of range of the Meekatharra AERIS, which required an altitude of about 36,500 ft to receive the broadcast.

The aircraft was fitted with the hardware for the aircraft communications addressing and reporting system (ACARS), which could be used to immediately access current weather information. However, the system was not operational, and therefore could not be used. If the system had been operative, they would have required a satellite link to use it, as they were holding below the required altitude of at least 11,000 ft to receive information from the nearest VHF datalink service at Newman. Therefore, with no other means to obtain current weather information while holding at Paraburdoo, the flight crew were reliant on air traffic control (ATC) to access weather information for alternate aerodromes.

If the flight crew had access to updated weather information using the AERIS or ACARS, it would have informed them that the cloud base was above 10,000 ft and visibility was greater than 10 km at Karratha. This would have indicated that Karratha was a suitable diversion location. However, without current weather information for alternative aerodromes, the flight crew elected to remain at Paraburdoo.

Atmospheric data

During the incident, a rain band and associated middle and high-level cloud was observed across north-western Australia by the Bureau of Meteorology (BoM). Their model traces had indicated saturated levels through to near to the surface. However, modelling in northern Australia was subject to false alarms for widespread low cloud. Therefore, some form of surface verification and/or satellite observations were required for the BoM to have confidence in the modelling. On the night prior to the incident, mid-level cloud made it difficult to utilise satellite observations to observe low cloud and confirm the modelling.

Light rain or drizzle had been falling at Paraburdoo. However, the extent of the rain was uncertain as Paraburdoo was outside the optimal range for the nearest weather radar stations. Therefore, it appeared clear on their weather radars at the time of the incident, despite the presence of low cloud and rain.

According to the BoM, the depth of moisture through the atmosphere is important in determining the potential for low cloud development. The sources available to indicate the depth of moisture are weather balloons and aircraft meteorological data relay (AMDAR). Data obtained from weather balloons allow forecasters to plot an aerological diagram and forecast cloud bases and tops. However, the nearest weather balloon stations were more than 160 NM from Paraburdoo and may not necessarily be representative of the conditions experienced at Paraburdoo. Furthermore, as Paraburdoo was not part of the AMDAR network, no AMDAR profiles were available to support the BoM forecasts for Paraburdoo.

The accuracy of forecasting is dependent on the data available. As Paraburdoo did not have the means to provide forecasters with a vertical profile of the moisture through the atmosphere, and satellite imagery was not available due to being obscured by mid-level cloud, the forecast was dependent on observations at other airports in the region. Therefore, the lack of atmospheric measurements increased the risk of an inaccurate projection of the conditions for Paraburdoo including unforecast low cloud below the instrument approach landing minima. While the current BoM plans for upgrading weather balloon and weather radar stations around Australia do not include Paraburdoo Airport, the ATSB did not identify a trend from the last 10-years of data associated with this airport to warrant a safety issue at this stage.

Diversion procedure

The forecast conditions for Paraburdoo required 60 minutes TEMPO holding fuel, but no alternate was required. Despite this, the flight crew were expecting to obtain visual reference with the runway before reaching their minimum descent altitude for the approach. This expectation was likely reinforced by the AWIS recording before top of descent, which indicated the lowest cloud base was 2,100 ft above the aerodrome. However, on arrival, the flight crew were confronted with 2 unforecast weather hazards. The cloud base had deteriorated below their landing minima, and it did not lift within the 60-minute TEMPO period.

As discussed previously, a diversion is a procedural decision-making exercise, which requires knowledge of both the problem and the options available (Flin, O'Connor, Crichton, 2008). Therefore, a diversion decision-making procedure should serve the purposes of guiding the flight crew to correctly assess the problem and then select an appropriate course of action.

The operator had published a procedure, which limited the number of missed approaches to 2, but they did not believe a prescriptive decision-making procedure was necessary. However, even after the first missed approach, the flight crew were expecting to land from their second approach and there was no discussion of the limits to conducting missed approaches nor consideration of their fuel reserve for a diversion.

After the second missed approach, the flight crew only had a few minutes in which to decide to divert to Karratha, which was the nearest suitable alternate airport. However, they had not briefed this option. Therefore, instead of committing to a diversion after the second missed approach, they entered a holding pattern and started to diagnose the actual weather conditions and their options.

The operator's limit to missed approaches did not provide guidance for flight crew to brief their divert options before arrival or on encountering unforecast weather at their destination. The arrival briefing procedural guidance from the International Civil Aviation Organization (Doc 8168, 2018) included 'alternate aerodromes and fuel considerations', and while this was within the context of 'relevant conditions', unforecast weather is a hazard frequently reported to the ATSB and that has been the subject of previous accident and incident investigations. In this case, if the flight crew had briefed their divert options before arrival, they would have been better placed to manage the unforecast weather conditions they encountered at Paraburdoo. Therefore, a diversion procedure should be considered within an organisation's risk controls and the absence of this decision-making guidance increased the risk that flight crew would not be prepared for a diversion.

Risk management

The 3 United Kingdom Civil Aviation Authority's (CAA) bowtie risk assessments for controlled flight into terrain (CFIT) were largely retained by the Qantas Group Flight Operations Steering Committee (FOSC) and subsequently Network Aviation, with minor amendments. One of the notable amendments was the replacement of the CAA CFIT 3.1 threat 8: *Flt crew continue approach below the MDA/DH without visual reference* with the FOSC CFIT 3.1 threat 8: *Flt crew operate below the appropriate minimum altitude (exc. instrument approach)*. This was considered by the operator to be the closest risk assessment to the incident.

It was also noted that the operator's CFIT 3.2 and 3.3 risk assessments for instrument approaches had not captured CAA CFIT 3.1 threat 8. Consequently, there were no weather-related threats identified in the operator's CFIT bowties. In which case, there was no requirement to identify controls or treatment plans to manage these threats, despite a recent CFIT research and analysis report finding that adverse weather was cited as a contributing factor in 51% of accidents (IATA, 2018).

The operator's CFIT threats relied on preventive risk controls such as visual reference and human performance for monitoring, detecting and correcting problems to maintain situational awareness. While the latter appeared to be inherited from the UK CAA bowties, research conducted by the International Air Transport Association indicated that operating in adverse weather conditions, poor visibility, and a lack of visual reference were considered contributing factors or threats to CFIT rather than risk controls. It was also noted that other procedural controls were used by the operator, but not included in the bowtie risk assessment. These included their arrival briefing and approach checklist, which, according to International Civil Aviation Organization (ICAO) Doc 8168 (2018), are designed to enhance situational awareness and therefore reduce the likelihood of an unintentional descent below the minimum altitude.

A reliance on human performance as a control to monitor, detect and correct problems within a risk assessment can result in an inherently unsafe system. If there is a human performance safety requirement associated with a specific threat, then this should be managed with the appropriate controls, such as training, procedures, and warning devices, as indicated by the International Air Transport Association CFIT mitigation strategies (2018) and ICAO (Doc 9683, 1998). They would then be subject to the safety assurance activities for that risk assessment.

The key environmental threat from this investigation that operators and flight crew need to manage is unforecast instrument meteorological conditions below minima at the destination. While forecast weather below minima is routinely effectively managed with a prescriptive ruleset, unforecast weather may be more likely to result in the need for an approach below minima without visual reference due to the development of a fuel-critical situation. Therefore, the absence of this threat from the operator's CFIT risk assessment increased the risk that controls required to manage this threat would not be developed, monitored, and reviewed at a management level.

Weather update delay

Although the flight crew were aware that Newman had similar conditions to the Paraburdoo forecast, including a 60-minute holding fuel requirement, another aircraft had landed there between QF1616's first and second missed approaches. This suggested to the flight crew that Newman might be a suitable diversion. As such, the captain informed ATC that they had conducted a second missed approach due low cloud at Paraburdoo and requested the latest weather for Newman. However, there was no urgency associated with this request and ATC asked them to standby for a response. Following this request, the flight crew and ATC diverted their attention to their other tasks, which included traffic inbound to Paraburdoo.

There was a delay of about 15 minutes before ATC queried if the flight crew still required the weather for Newman. At this stage, they had conducted a third missed approach and were likely below the minimum fuel required to divert to Newman, therefore the captain declined. While this delay precluded the flight crew considering the option of a diversion to Newman, both the cloud and weather data groups for Newman were not available for the period from 0600-1000. Without a meteorological observer at Newman, the latest METAR was the only current weather ATC could have provided the flight crew. In addition, the captain was reluctant to divert to another airport that had a holding fuel requirement they could not meet and might be subject to a similar weather pattern as Paraburdoo, unless the actual weather was better than forecast. As the current METAR did not provide an improvement to the forecast, it was unlikely that the provision of the latest weather information would have influenced the flight crew to divert to Newman and the delay was not considered contributory to the incident.

Despite this, ATC was the only option for the flight crew to obtain current weather for an alternate airport and the report of missed approaches at Paraburdoo associated with the request for the latest weather for Newman suggested this was likely a time-critical request. While the flight crew were within their TEMPO fuel holding period at Paraburdoo, they were approaching a fuel critical situation for a diversion to Newman. In this scenario, the inclusion of 'minimum fuel' with their request for the latest Newman weather could have reduced the likelihood of a delay, but probably would not have changed the outcome.

Newman automatic weather information service

The Airservices Australia new filtering system for SPECI reports was dependent on the conditions that trigger such reports being detected at the aerodrome. On the morning of the incident flight, there were 11 weather reports issued from the Newman AWS from 0600-1000. This included 2 SPECI reports for a reduction and subsequent improvement in visibility at 0934 and 0944. However, the cloud and weather data groups were not available throughout this period, which meant that Newman could have entered SPECI conditions undetected during this period.

As there was a delay in the information and the captain subsequently declined the weather update for Newman, this did not influence their decision to remain at Paraburdoo. However, if a SPECI condition is not detected at the source by an AWS, unforecast weather conditions may not be captured and disseminated by ATC to airborne aircraft as a hazard. While this is not a substitute for flight planning and in-flight weather update requests before reaching a point-of-no-return, the broadcast of unforecast SPECI conditions may provide a timely alert to flight crew to avoid a fuel-critical situation developing.

Findings

ATSB investigation report findings focus on safety factors (that is, events and conditions that increase risk). Safety factors include 'contributing factors' and 'other factors that increased risk' (that is, factors that did not meet the definition of a contributing factor for this occurrence but were still considered important to include in the report for the purpose of increasing awareness and enhancing safety). In addition 'other findings' may be included to provide important information about topics other than safety factors.

Safety issues are highlighted in bold to emphasise their importance. A safety issue is a safety factor that (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.

These findings should not be read as apportioning blame or liability to any particular organisation or individual.

From the evidence available, the following findings are made with respect to the unforecast weather and flight below minimum altitude involving Fokker Aircraft F100, registration VH-NHV, at Paraburdoo Airport, Western Australia, on 22 November 2021.

Contributing factors

- The flight crew lost confidence in their flight plan weather forecasts after two missed approaches at Paraburdoo Airport. Without immediate access to actual weather information, they elected to conduct further approaches instead of diverting.
- After the third missed approach, the flight crew had insufficient fuel to divert to a suitable airport and were committed to landing in conditions below their landing minima due to the continuing deteriorating cloud base.
- The actual weather conditions encountered by the flight crew on arrival at Paraburdoo Airport were worse than the flight plan forecast, below the landing minima and deteriorating. This event was difficult to forecast accurately due to the lack of observed lower cloud, satellite imagery and meteorological modelling limitations.
- The aircraft was not fitted with an operational aircraft communications addressing and reporting system (ACARS) and was out of range of the Meekatharra automatic en route information service (AERIS) while holding at Paraburdoo Airport. Therefore, the flight crew were reliant on air traffic control to access actual weather information for alternate aerodromes.
- Paraburdoo Airport did not have a means of detecting the moisture content in the atmosphere above the surface. This increased the risk that low cloud below the instrument approach landing minima might not be forecast.
- **Network Aviation did not provide their flight crew with a diversion decision-making procedure for the circumstances where their flights encountered unforecast weather below landing minima. This increased the risk that their flight crew would not anticipate and be adequately prepared for a diversion.** (Safety issue)
- **Network Aviation did not include the threat of unforecast weather below landing minima in their controlled flight into terrain risk assessments. This increased the risk that controls required to manage this threat would not be developed, monitored, and reviewed at a management level.** (Safety issue)

Other factors that increased risk

- The flight crew did not convey a sense of urgency to air traffic control when they requested the actual weather information for Newman Airport. This, combined with the controller's workload at the time, resulted in a delay of about 15 minutes before the information was offered. However, Newman Airport had a holding fuel requirement the flight could not comply with and as the actual weather did not include an improvement of conditions it was unlikely that this information would have influenced their decision to divert.
- The Newman Airport automatic weather station cloud and weather data groups were not available at the time the flight crew requested the latest weather from air traffic control. While this did not influence the flight crew’s decision to remain at Paraburdoo, it increased the risk that a deterioration in the cloud base below the forecast conditions at Newman would not be broadcast by air traffic control to airborne aircraft as a hazard.

Safety issues and actions

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues. The ATSB expects relevant organisations will address all safety issues an investigation identifies.

Depending on the level of risk of a safety issue, the extent of corrective action taken by the relevant organisation(s), or the desirability of directing a broad safety message to the aviation industry, the ATSB may issue a formal safety recommendation or safety advisory notice as part of the final report.

All of the directly involved parties are invited to provide submissions to this draft report. As part of that process, each organisation is asked to communicate what safety actions, if any, they have carried out or are planning to carry out in relation to each safety issue relevant to their organisation.

The initial public version of these safety issues and actions will be provided separately on the ATSB website on release of the final investigation report, to facilitate monitoring by interested parties. Where relevant, the safety issues and actions will be updated on the ATSB website after the release of the final report as further information about safety action comes to hand.

Diversion procedure

Safety issue description

Network Aviation did not provide their flight crew with a diversion decision-making procedure for the circumstances where their flights encountered unforecast weather below landing minima. This increased the risk that their flight crew would not anticipate and be adequately prepared for a diversion.

Issue number:	AO-2021-048-SI-01
Issue owner:	Network Aviation
Transport function:	Aviation: Air transport
Current issue status:	Closed – Adequately addressed
Issue status justification:	The ATSB notes that Network Aviation have introduced several diversion decision-making tools for their Fokker Aircraft F100 flight crew. They included an amendment to their flight plans to include an 'alternate summaries' section for all flights, the top of descent arrival brief procedure to include 'minimum divert fuel', and the introduction of an F100 *Company Procedures Manual* with pre-populated standard divert calculations for their F100 destinations. The ATSB is satisfied that the inclusion of these tools will address the safety issue.

Proactive safety action taken by Network Aviation

Action number:	AO-2021-048-PSA-47
Action organisation:	Network Aviation
Action status:	Closed

Network Aviation have produced a Fokker Aircraft F100 *Company Procedures Manual* incorporating standard pre-populated divert procedural information for their F100 destinations.

Proactive safety action taken by Network Aviation

Action number:	AO-2021-048-PSA-48
Action organisation:	Network Aviation
Action status:	Closed

Network Aviation amended their Fokker Aircraft F100 *Flight Crew Operating Manual* arrival briefing procedure to raise awareness around fuel status and increase flight crew coordination. Where alternate fuel requirements were previously only briefed 'if applicable', it is now mandatory for all arrival briefings to include the minimum fuel required to divert to an alternate.

Proactive safety action taken by Network Aviation

Action number:	AO-2021-048-PSA-49
Action organisation:	Network Aviation
Action status:	Closed

Network Aviation amended their flight plan format to include an alternate summaries section at the top of each flight plan for 2 alternate aerodromes. While this was previously provided for flight plans that legally required an alternate aerodrome, it is now provided for all flight plans.

Risk management

Safety issue description

Network Aviation did not include the threat of unforecast weather below landing minima in their controlled flight into terrain risk assessments. This increased the risk that controls required to manage this threat would not be developed, monitored, and reviewed at a management level.

Issue number:	AO-2021-048-SI-02
Issue owner:	Network Aviation
Transport function:	Aviation: Air transport
Current issue status:	Closed – Adequately addressed
Issue status justification:	The ATSB notes that Network Aviation have taken action to update their controlled flight into terrain risk assessments to capture the threat of adverse weather, which addresses the safety issue.

Proactive safety action taken by Network Aviation

Action number:	AO-2021-048-PSA-46
Action organisation:	Network Aviation
Action status:	Closed

In response to the draft report, Network Aviation advised that ATSB that:

> Through a review conducted by representatives of the Qantas Groups Flight Operations Safety Committee (FOSC) and safety risk specialists in the business a threat line has been added to the Controlled Flight into Terrain (CFIT) Bowtie including both the non-precision and precision approach bowties. The threats and controls were reviewed based on the event and the learnings from that event. As a result, all CFIT bowties have been updated. We have added escalation factors and escalation factor controls to the Visual Reference control on bowtie 3.1. And we have added the "Flt Crew operate below the appropriate minimum altitude (i.e. lowest safe altitude, DA, MDA)" threat line in its entirety to bowties 3.2 and 3.3.

Safety action not associated with an identified safety issue

Whether or not the ATSB identifies safety issues in the course of an investigation, relevant organisations may proactively initiate safety action in order to reduce their safety risk. The ATSB has been advised of the following proactive safety action in response to this occurrence.

Additional safety action by Network Aviation

Internal safety advisory notice

Network Aviation issued an updated internal safety advisory notice to their flight crew, which highlighted the operating parameters and limitations associated with automatic weather information services (AWIS).

Airport risk assessment

Network Aviation updated their Paraburdoo Airport risk assessment to capture the risk of variable weather conditions and the procedural risk controls introduced in response to this incident.

Company fuel policy

Network Aviation amended their company fuel policy to mandate additional alternate fuel requirements for nominated airports (operator approved variations). Airport classification is assessed based on alternate availability, instrument approach availability, aerodrome forecast reporting and historical accuracy, local mesoscale weather phenomena, and topography/terrain.

Access to expanded port briefings

Network Aviation established access for flight crew to obtain expanded briefings on ports (with operator fuel policy approved variations) from internal company meteorologists.

Update to the Aerodrome and Route Manual

Network Aviation updated the company's *Aerodrome and Route Data Manual* to provide a new section on weather planning tools and resources, and a new section explaining the limitations of ceilometers and visibility meters installed in automatic weather information stations throughout the company network.

Enhanced training reference library

Network Aviation enhanced the company's training reference library for flight crew to support pilot knowledge and decision making. Additional content in the library is focused on company learnings from QF1616, which includes:

- fuel management
- threat management and contingency planning
- time management in areas of vulnerability
- pilot in command responsibilities.

Update to take-off and landing data cards

Network Aviation have updated their take-off and landing data cards to provide a dedicated section for recording the alternate aerodrome, estimated time interval, fuel burn and fuel on arrival.

General details

Occurrence details

Date and time:	22 November 2021 - 0843 WST	
Occurrence class:	Serious incident	
Occurrence categories:	Flight below minimum altitude, unforecast weather, low fuel, missed approach/go-around	
Location:	Paraburdoo Airport, Western Australia	
	Latitude: 23° 10.267' S	Longitude: 117° 44.717' E

Aircraft details

Manufacturer and model:	Fokker Aircraft B.V. F28 MK 0100	
Registration:	VH-NHV	
Operator:	Network Aviation Pty Ltd	
Serial number:	11482	
Type of operation:	Air transport high capacity-passenger	
Activity:	Commercial air transport-scheduled-domestic	
Departure:	Perth Airport, Western Australia	
Destination:	Paraburdoo Airport, Western Australia	
Persons on board:	Crew – 5	Passengers – 92
Injuries:	Crew – 0	Passengers – 0
Aircraft damage:	None	

Glossary

AAL	Above aerodrome level
ACARS	Aircraft communications addressing and reporting system
AIP	Aviation information publication
AMDAR	Aircraft meteorological data relay
ATC	Air traffic control
AWIS	Automatic weather information service
AWS	Automatic weather station
BoM	Bureau of Meteorology
CAA	Civil Aviation Authority (UK)
CFIT	Controlled flight into terrain
DH	Decision height
FL	Flight level
FMC	Flight management computer
FMS	Flight management system
FO	First officer
GNSS	Global navigation satellite system
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
LNAV	Lateral navigation
MDA	Minimum descent altitude
METAR	Meteorological aerodrome report
PAPI	Precision approach path indicator
PF	Pilot flying
PM	Pilot monitoring
RNAV	Area navigation
SA	Situational awareness
SPECI	Special meteorological aerodrome report
TAF	Aerodrome forecast
UK	United Kingdom
VHF	Very high frequency (radio frequency in the range 30-300 MHz)
VNAV	Vertical navigation
YMEK	Meekatharra Airport
YNWN	Newman Airport

YPBO	Paraburdoo Airport
YPKA	Karratha Airport
YSOL	Solomon Airport

Sources and submissions

Sources of information

The sources of information during the investigation included:

- Aerodrome Management Services
- the Bureau of Meteorology
- Civil Aviation Safety Authority
- data from the cockpit voice recorder and flight data recorder
- the flight crew
- Network Aviation management personnel:
  - chief pilot
  - manager fleet technical
  - safety manager
  - manager fleet safety and regulatory compliance.

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Submissions

Under section 26 of the *Transport Safety Investigation Act 2003*, the ATSB may provide a draft report, on a confidential basis, to any person whom the ATSB considers appropriate. That section 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 following directly involved parties:

- flight crew
- Network Aviation management personnel
- Civil Aviation Safety Authority
- Bureau of Meteorology
- Airservices Australia
- Air Accidents Investigation Branch (United Kingdom).

Submissions were received from:

- the United Kingdom Air Accidents Investigation Branch
- Airservices Australia
- Civil Aviation Safety Authority
- Bureau of Meteorology
- Network Aviation Management.

The submissions were reviewed and, where considered appropriate, the text of the draft report was amended accordingly.

Australian Transport Safety Bureau

About the ATSB

The ATSB is an independent Commonwealth Government statutory agency. It is governed by a Commission and is entirely separate from transport regulators, policy makers and service providers.

The ATSB's purpose is to improve the safety of, and public confidence in, aviation, rail and marine transport through:

- 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, as well as participating in overseas investigations involving Australian-registered aircraft and ships. It prioritises investigations that have the potential to deliver the greatest public benefit through improvements to transport safety.

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

Purpose of safety investigations

The objective of a safety investigation is to enhance transport safety. This is done through:

- identifying safety issues and facilitating safety action to address those issues
- providing information about occurrences and their associated safety factors to facilitate learning within the transport industry.

It is not a function of the ATSB to apportion blame or provide a means for determining 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. The ATSB does not investigate for the purpose of taking administrative, regulatory or criminal action.

Terminology

An explanation of terminology used in ATSB investigation reports is available on the ATSB website. This includes terms such as occurrence, contributing factor, other factor that increased risk, and safety issue.