Australian Government

Australian Transport Safety Bureau

Synthetic vision display error involving Pilatus PC-12 VH-OWA

Meekatharra Airport, Western Australia, 18 June 2016

ATSB Transport Safety Report

Aviation Occurrence Investigation

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Addendum

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Synthetic vision display error involving Pilatus PC-12, VH-OWA

What happened

On 18 June 2016, at about 0136 Western Standard Time (WST), the pilot flying and a check pilot (who was the pilot in command) of a Pilatus PC-12 47E aircraft, registered VH-OWA (OWA), prepared to conduct a medical retrieval flight from Meekatharra Airport to Paraburdoo, Western Australia, under the instrument flight rules.[1] Due to the remote area, the terrain surrounding the airport was dark, although the night was moonlit. The pilot flying was seated in the left seat, the check pilot in the right seat, and a flight nurse was also on board.

The pilot flying completed the pre-start, start and after-start checks. As the aircraft had been parked under a metal roof, the aircraft's two GPS units had not acquired enough satellites to complete their initialisation. The pilot flying therefore taxied the aircraft a short distance onto the taxiway before stopping. GPS 1 located all satellites as required, but GPS 2 failed to initialise and the crew received an UNABLE FMS-GPS MON caution message.[2] The pilot flying followed the quick reference handbook actions in response to that message, following which GPS 2 initialised and the caution cleared. The pilots then continued for a normal take-off from runway 09, at about 0145.

About 18 seconds after take-off, as the aircraft climbed through about 250 ft above ground level at an airspeed of about 110 kt, the pilots observed the radio altimeter (radalt) wind down to zero (see *Radio altitude*). The radalt low altitude awareness display rose to meet the altitude readout.

The synthetic vision image (see *Synthetic vision system*) on both pilots' primary flight displays (PFDs) then showed the runway move rapidly left and off the screen, and the ground representation on the PFD appeared to rise rapidly up to meet the zero pitch reference line (ZPRL).[3] As a result, the pilot flying pulled back on the control column and the flight data showed the flight path indicator (see *Aircraft reference symbols*) moved up to about 15°. No warnings or cautions were displayed, the stick shaker stall warning did not activate (as the aircraft angle of attack was not in the shaker range), and the crew did not receive any oral alerts from the terrain awareness and warning system (TAWS).

The pilot flying reported that the synthetic vision image created the impression that the aircraft was sinking rapidly towards the ground, and they responded by instinctively pulling back on the control column. There was no vestibular sensation[4] that the aircraft was descending, nor had there been any indication of a strong wind that may have caused the aircraft to drift off the runway centreline. The resulting sensory confusion caused the pilot flying to experience a level of motion sickness.

The check pilot immediately looked outside (there was no standby instrument on the right side of the cockpit), and was able to discern a visible horizon due to the moonlight. The check pilot cautioned the pilot flying that the aircraft had a nose-high attitude, which prompted the pilot flying to switch their focus to the electronic standby instrumentation system (ESIS) and closely monitor the attitude and the airspeed tape (see *Electronic standby instrumentation system*). The pilot flying

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1 Instrument flight rules (IFR): a set of regulations that permit the pilot to operate an aircraft to operate in instrument meteorological conditions (IMC), which have much lower weather minimums than visual flight rules (VFR). Procedures and training are significantly more complex as a pilot must demonstrate competency in IMC conditions while controlling the aircraft solely by reference to instruments. IFR-capable aircraft have greater equipment and maintenance requirements.

2 The monitor warning system continuously compares the positions between each FMS and each GPS and annunciates differences between any if the threshold is exceeded.

3 Zero pitch reference line is a true horizon tangential to the earth's surface but at the aircraft's altitude.

4 Sensation of body location, movement and balance controlled by the vestibular system of the inner ear.

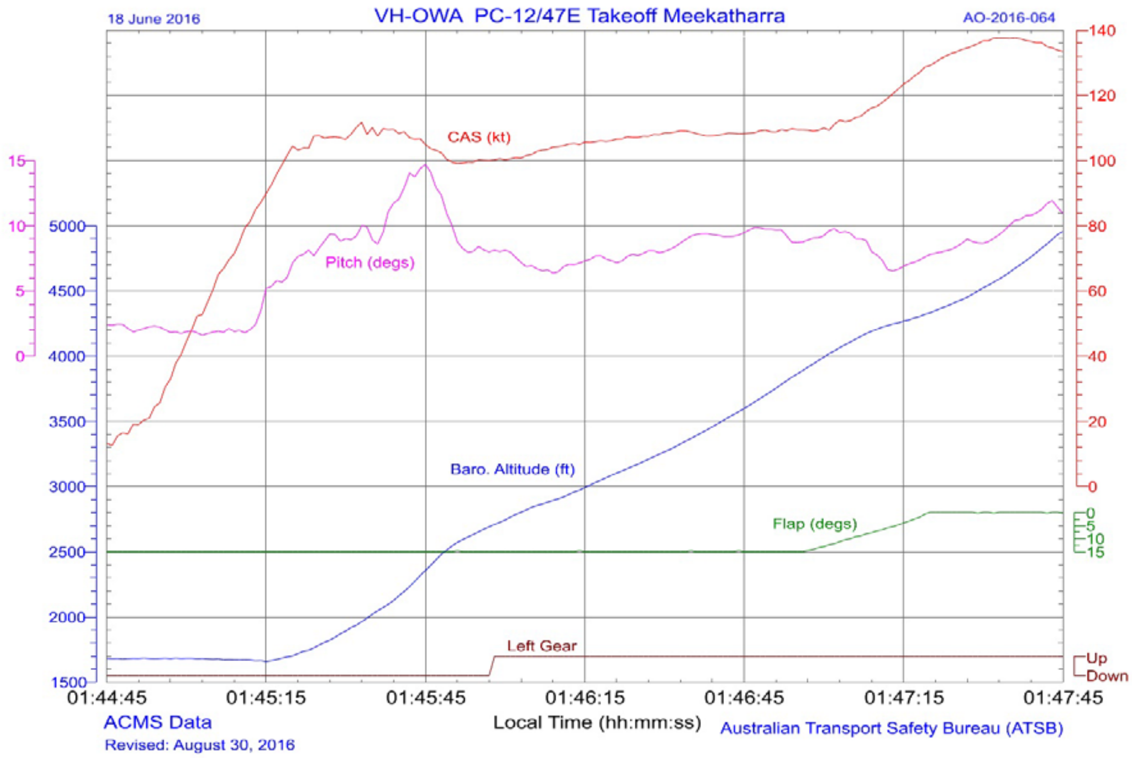
lowered the aircraft nose to regain an 8° pitch[5] attitude and the flight data showed that the airspeed, which had reduced to 101 kt, increased back to the target airspeed of 110 kt. The aircraft had continued to climb throughout the event.

Climbing through about 850 ft, the synthetic vision display corrected itself and all indications returned to normal. After retracting the landing gear and flap, the pilot flying deselected the synthetic vision mode on the left PFD. The check pilot continued to monitor the synthetic vision on the right PFD, and the issue did not recur during the flight. The aircraft subsequently landed at Paraburdoo Airport without further incident.

Flight data analysis

The flight data was downloaded from the aircraft condition monitoring system and analysed by the ATSB. Figure 1 depicts the calibrated airspeed and pitch angle from the start of the take-off roll. The change in pitch (pink line) from the pilot pulling back on the control column in reaction to the synthetic vision started at about 0145:30 in Figure 1.

Figure 1: Plot of selected data from the incident flight



Source: Aircraft flight data analysed by ATSB

Figure 2 shows the aircraft recorded GPS track, with the pink marker indicating the first significant increase in pitch attitude, and therefore the approximate point of radalt failure. The aircraft was then at about 250 ft above the runway.

5 The term used to describe the motion of an aircraft about its lateral (wingtip-to-wingtip) axis.

Figure 2: Deviation of OWA (travelling from left to right) from runway centreline showing the estimated point of the radalt failure (in pink)

Source: Google earth and aircraft flight data analysed by ATSB

Incorrect instrument indications

After the incident, an engineering assessment determined that both antennas associated with the radalt system (one for transmit and one for receive) had failed, and had been in service for over 9,000 hours. The antennas did not have a life limit, but were required to be replaced 'on condition', which essentially meant that the antennas remained in service until they failed. After consultation with the avionics manufacturer, engineers replaced both radalt antennas and also the radar transmitter/receiver. No subsequent similar event has occurred on the aircraft. The engineers also replaced the GPS 2 antenna due to slower than normal acquisition of satellite navigation after power up, and updated the GPS databases, although it was considered that these did not contribute to the incident.

The engineers reported that this failure of the radalt antennas was likely to have resulted in the radalt winding down to zero, and the radalt low altitude diagonal bars to appear on the altitude tape to show the aircraft was close to the ground (below 550 ft) (see Figure 4 in *Radio altitude* below). Additionally, the radalt information was used in conjunction with the runway (and obstacle) information in the database to provide the synthetic vision system display. This resulted in the runway appearing to rise up towards the aircraft reference symbol on the PFD.

The movement of the runway to the left of the screen was probably associated with a small displacement of the aircraft to the right of the runway centreline. The wind at the time was from 094° at 9–11 kt, therefore largely a headwind component and the lateral displacement of the aircraft was unlikely to be a result of the wind.

As the radalt senses that the aircraft is nearing the ground, smaller lateral deviations from the runway centreline generate significant movement of the synthetic vision runway image.

Radio altitude

The radalt display is shown in green numbers on the PFD when the radalt data is valid and less than 2,500 ft (Figure 6). If the radalt data becomes invalid, the radalt digital readout is replaced with a radar altitude data ('RAD') annunciator and an amber RA 1 FAIL crew alerting system ('CAS') message is displayed. The crew did not receive any annunciations during this incident to indicate that the radalt had failed.

When the altitude displayed on the radalt is below 550 ft above ground level, low altitude awareness is displayed using diagonal yellow lines (Figure 3). During this incident, the crew noticed that the low altitude awareness symbology was displayed.

Figure 3: Radalt low altitude awareness display

Source: Honeywell

Synthetic vision system

The synthetic vision system fitted to the aircraft is depicted in Figure 4. It supplies a three-dimensional view of surrounding terrain, obstacles and runways based on a terrain database. Normal attitude, altitude and airspeed information is overlayed on top of the terrain display. The TAWS terrain database provides geometric altitude (obtained from the GPS) in order to display synthetic vision terrain and terrain related items such as runways and obstacles. During this incident, the synthetic vision system provided no failure annunciations.

Figure 4: Synthetic vision system example display

Source: Honeywell

Figure 5 shows a sample image of the runway scale for an aircraft on final approach for reference.

Figure 5: Synthetic vision runway display on approach (at low altitude)

Source: Honeywell

The synthetic vision system was not to be used for primary input or navigation, with the following warning issued by Honeywell in the Pilot's Guide (used by the operator) to the avionics system:

> **WARNING**
>
> SYNTHETIC VISION SHOULD NOT BE USED FOR PRIMARY NAVIGATION, NOR SHOULD THE FLIGHT CREW RELY SOLELY ON SYNTHETIC VISION TO AVOID TERRAIN OR OBSTACLES.

A similar warning was contained in the Primus Apex Smart View supplement to the aircraft flight manual.

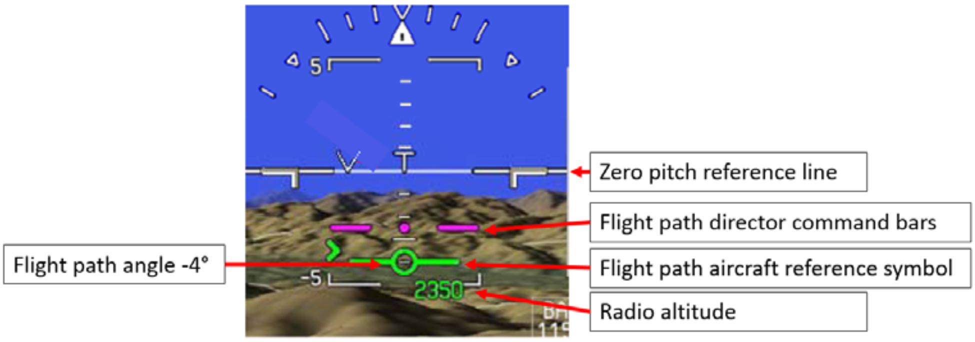
Both crew reported they were aware that the synthetic vision should not be used for primary navigation. When installed, the synthetic vision system is automatically activated at start-up but can be deselected by the pilot.

Aircraft reference symbols

The pilot flying was using the flight path indicator on the synthetic vision system. This consists of the flight director command bars (magenta symbol in Figure 6) and the flight path aircraft reference symbol (green symbol in Figure 6). The flight path indicator is a path-based mode and depicts the aircraft's predicted flight path (not just aircraft pitch) and is affected by pitch attitude and the aircraft's ground speed. It shows flight path angles[6] – up for increasing and down for decreasing flight path angles, whereas the traditional pitch-based mode depicts aircraft pitch angle. The flight path angle depicted in Figure 6 is -4°.

[6] The flight path angle is the angle between horizontal and the flight path (or velocity) vector, which describes whether the aircraft is climbing or descending.

Figure 6: Synthetic vision and flight path indicator symbols



Source: Honeywell

Electronic standby instrumentation system

An electronic standby instrumentation system (ESIS) (or electronic standby indicator (ESI)), was fitted to the left of the pilot flying's PFD. Figure 7 shows the pilot's side PFD with the ESIS to the left of the main screen in another Pilatus PC-12 aircraft (not OWA). Note in this photo, the synthetic vision is on and the aircraft is over water.

Figure 7: Electronic standby indicator and main PFD in flight (not OWA)

Source: ATSB

Pilot comments

The two pilots were highly experienced; the pilot flying had over 11,000 hours total aeronautical experience and over 2,600 on the aircraft type, and the check pilot had over 15,000 hours total experience and 3,000 hours on type.

Both pilots commented that they had previously experienced failure of primary flight instruments at low level and at night in different aircraft (without synthetic vision systems). They had been able to disregard the erroneous or failed instruments and reference the standby instruments to maintain control of the aircraft and situational awareness. However, the prominence of the synthetic vision display is such that it is difficult to ignore erroneous information and locate valid information. Additionally, the pilot flying reported feeling a level motion sickness, probably associated with the combined effects of the prominent synthetic vision display and conflicting vestibular sensory information.

The combination of the runway and the radalt speed tape moving up gave the very strong illusion that the aircraft was going to hit the ground. The pilot flying reported that they realised something was wrong but could not initially figure out what it was. The image of the ground rising up and the runway disappearing rapidly sideways took the focus of the pilot flying away from anything else.

The pilot flying commented that the check pilot's caution 'attitude' helped to redirect the pilot flying's attention to the standby indicator. The check pilot could not easily see the standby indicator. Both pilots commented that the situation may have been more serious if operating single pilot or if they had already flown more sectors that night and been more tired.

The pilots commented that it was impossible to discern the valid attitude information on the PFD (overlaid on top of the synthetic vision) and revert to flying 'power and attitude' given the prominence of the erroneous synthetic vision information. While it is possible to deselect the synthetic vision, it requires two button presses or the use of the cursor control device to do so. That is very difficult to do at low level while maintaining control of the aircraft – keeping the right hand on the thrust lever and the left hand on the control column.

The Pilot Advisory Letter issued in response to this incident (see *Safety action*) reminded pilots to look at the primary flight indications presented on the PFD at all times. The pilot flying commented that it should refer pilots to the standby attitude indicator instead. The screen at the time of failure was simply too confusing to start looking for two small, white attitude bars. Similarly, to break the fixation on the erroneous information, it is important to look somewhere else at a different instrument – the standby indicator.

Most of the pilots' training is done on board the aircraft, as they do not have access to a Pilatus PC-12 simulator. Although some system failures can be simulated, it is not possible to generate a false display as occurred in this incident.

Spatial disorientation

Spatial disorientation can occur when visual cues provide sensory inputs that are not matched by the motion sensed by the pilot through the vestibular senses. The discrepancy between the visual display showing the aircraft apparently descending towards the ground, and the lack of any consistent physical sensation, led to disorientation. The flight was conducted at night, and the pilot flying did not look outside for a visual reference. The check pilot did look outside and found that there was enough moonlight to provide some visual reference, sufficient to show the aircraft pitch and roll attitudes relative to the horizon.

ATSB research report *'An overview of spatial disorientation as a factor in aviation accidents and incidents'* describes this type of spatial disorientation as 'recognised'. That is, the pilot identified that they were sensing erroneous information. The conflict between their own perceptions and that given by the instruments alerted them to a problem, which they were then able to address. However, the crew reported feeling some level of disorientation stress, or motion sickness, which is indicative of a disagreement between the senses.

The visual system provides around 80 per cent of orientation information, hence the overriding presence of incorrect visual information deprived the pilots of the majority of orientation information.

Other factors such as tiredness or fatigue, and high workload, can contribute to a pilot's ability to assess and effectively deal with spatial disorientation. Both pilots commented that they wanted to share their experience because if they had been operating single pilot or near the end of a long shift, recovery from the instrumentation failure may have been much more difficult.

In addition, if the outside light conditions had been completely dark due to a lack of any moonlight in an area without terrain lighting, or the aircraft was in cloud, recognition of the spatial disorientation would have been reliant on the pilots being able to either extract the basic attitude, altitude and airspeed information from the primary display ignoring the background image, or revert to the accurate information depicted on the smaller standby indicator.

Pilots operating under instrument flight rules are trained to focus their attention on the visual information presented by the aircraft instruments and to 'believe' that information rather than the sensory information from the vestibular system, which can provide misleading cues.

The ATSB research report further states that:

> …instrumentation should present a clear and intuitive sense of position, which the pilot under conditions of high stress and workload can instantly achieve an idea of what the aircraft is doing.
>
> Failure of the aircraft instruments should hopefully never occur. However, in the event that it does, the pilot needs to receive clear and non-ambiguous indications of instrument failure. If a key instrument fails, such as the attitude indicator, the pilot needs to know that it has failed so they no longer depend on its information.

Manufacturer investigation

An investigation by the synthetic vision system manufacturer, Honeywell, found that the radio altimeter sent incorrect radio altitude data to the synthetic vision system while still indicating that the data was valid. Therefore, the synthetic vision display system continued to display the terrain information using incorrect data.

Safety action

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 safety action in response to this occurrence.

Aircraft operator

The aircraft operator has advised the ATSB that they have taken safety actions including the following:

- Engineering replaced the RADALT aerials across the fleet.
- The minimum equipment list has been amended to include synthetic vision.
- Flight crew were alerted to the potential hazard of a synthetic vision failure during flight through a safety communication on 1 July 2016. The potential for confusion or spatial disorientation during an event, particularly at night or in low visibility environmental conditions was highlighted.
- The event has been discussed by the Training and Check Department. They are reviewing the possibilities of incorporating scenarios related to ambiguous/incorrect information from the primary flight display into check flights and have commenced trialling a scenario.

Honeywell – avionics manufacturer

As a result of this occurrence, the avionics system manufacturer has advised the ATSB that they are taking the following safety actions:

Pilot advisory letter

Honeywell issued a Pilot Advisory Letter (PAL-APEX-01) to all pilots, chief pilots and flight operations managers on 11 August 2016. The letter included a description of the event. The letter also advised pilots that the use of synthetic vision is for situational awareness and should not be utilised for the indication of attitude or altitude in lieu of the primary flight display indications for pitch, roll, yaw, or altitude. The letter advises pilots to follow the primary flight indications presented on the PFD at all times.

The letter was also made available on the Pilatus ‘mypilatus’ website and all subscribers to that website were notified by email.

System solution

Honeywell is investigating ways to make the synthetic vision system more robust against a similar failure. The focus of their investigation is to prevent the synthetic vision display from continuing to display the image when the data is incorrect but assessed as valid by the Radalt.

Safety message

Incorrect instrument indications that are not associated with a failure mode present pilots with a complex and challenging situation. This situation may be exacerbated during single-pilot (rather than multi-crew) operations, where there is a lack of external visual references (such as at night or in instrument meteorological conditions), under high pilot workload conditions, or where a pilot is experiencing an elevated level of fatigue.

The image of terrain on the primary flight display is powerful and compelling. This incident highlights the manner in which an inaccurate synthetic vision image can rapidly lead to a degree of spatial disorientation. Pilots need to ensure that they are familiar with the limitations of the synthetic vision system and how to effectively deal with erroneous information as well as system failure modes. Organisations that operate aircraft fitted with similar technology should ensure that appropriate information and training is available to pilots, including when and how it should be used when it is not approved for primary navigation.

General details

Occurrence details

Date and time:	18 June 2016 – 0147 WST	
Occurrence category:	Serious incident	
Primary occurrence type:	Technical systems – Avionics/Flight Instruments	
Location:	Meekatharra, Western Australia	
	Latitude: 26° 36.70’ S	Longitude: 118° 32.87’ E

Aircraft details

Manufacturer and model:	Pilatus Aircraft PC-12	
Registration:	VH-OWA	
Serial number:	1115	
Type of operation:	Aerial Work - EMS	
Persons on board:	Crew – 2 (flight crew) 1 (flight nurse)	Passengers – 0
Injuries:	Crew – 0	Passengers – 0
Aircraft damage:	Nil	

About the ATSB

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

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to operations involving the travelling public.

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

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

It is not a function of the ATSB to apportion blame or determine liability. At the same time, an investigation report must include factual material of sufficient weight to support the analysis and findings. At all times the ATSB endeavours to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why, in a fair and unbiased manner.

About this report

Decisions regarding whether to conduct an investigation, and the scope of an investigation, are based on many factors, including the level of safety benefit likely to be obtained from an investigation. For this occurrence, a limited-scope, fact-gathering investigation was conducted in order to produce a short summary report, and allow for greater industry awareness of potential safety issues and possible safety actions.