A global safety deficiency
False glide slope capture affecting aircraft

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HOW IT BEGAN

On 31 May 2013, a Boeing 737-800 received radar vectors for the approach to the active landing runway at Eindhoven Airport. During the approach, a 30-knot crosswind at 2,000 - 3,000 feet on base leg and a tailwind on final approach contributed to the aircraft being closer and higher to the runway than normal. The influence of the crosswind and tailwind on the flight path remained unnoticed by both the air traffic controller and flight crew. At approximately 1,300 feet, the Captain informed the First Officer (FO) that it was very unlikely that a successful landing would be possible, and that they should prepare to make a go-around.

At approximately 1,060 feet and 0.85 nautical miles (NM) from the runway threshold, the aircraft pitched up rapidly at 3 degrees per second while both engines N1 increased from 30 to 90 percent automatically in order to maintain the selected airspeed. Finding this behaviour unexpected, the Captain called for a go-around. The aircraft pitch further increased to approximately 24.5 degrees nose up and the stick shaker warning was activated. Almost at the same time, the take-off/go-around button was pushed by the FO and the autopilot was deactivated. The aircraft was levelled and a second approach was flown to the airport where it landed safely.

At first, the occurrence report did not gain much attention, but after reviewing the flight and radar data, an investigation was initiated. As the investigation progressed, two main questions were formulated. The first was to determine the cause of the pitch-up upset while flying the ILS glide slope with automatic systems engaged. During the investigation, DSB became aware of four similar pitch-up upset incidents. This led to the second question of how current and implemented safety management systems (SMS) dealt with previous pitch-up upset occurrences.

BACKGROUND

Similar Events

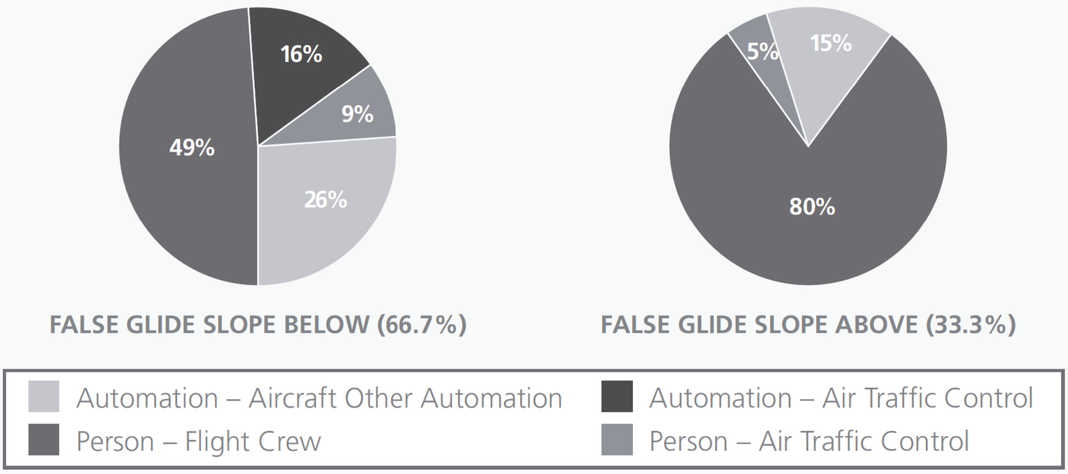
The fact that four other ILS false glide slope-induced pitch-up occurrences were identified during the investigation prompted DSB to perform a detailed database search for such incidents. A database search of the Occurrence Analysis Bureau, the Netherlands, revealed one case, which was already identified by DSB.

In France, there was one reported pitch-up upset case – an Airbus A340 at Paris Charles de Gaulle, experienced a pitch-up from 1 degree to 26 degrees in 2012. This incident was investigated by the French Bureau of Investigation and Analysis for Civil Aviation Safety (BEA). In the final stages of the investigation, DSB was informed by BEA that a similar pitch-up upset occurrence had been reported by an operator to Airbus. This occurrence pre-dated the A340 pitch-up upset.

A database search in the US performed by both the NTSB and Boeing yielded no similar incidents. By contrast, a search and analysis of the National Aeronautics and Space Administration (NASA)'s Aviation Safety Reporting System (ASRS) database revealed that 57 occurrences were reported between 1998 and 2013 where "False Glide Slope" was mentioned in the narrative.

For statistical purposes, ASRS attributed a problem to each event. The ASRS assessment of these events is not definitive, but the database suggests that human factors and navigation facility equipment played a major part. For the investigation, DSB analysed these ASRS events in more detail, and found that a distinction could be made between glide slope events from "Above" and "Below" the 3-degree glide slope (See Figure 1). The analysis shows a difference in assessment of the contributing factors. In cases of "Above" 3-degree glide slope events, the database suggests the problem is mostly related to the flight crew. But does this reflect what is really going on? What do we know about the ILS glide slope antenna?

Figure 1 - ASRS Database Overview Problem Description Above and Below Glide Slope



ILS Glide Slope Antenna

The ILS is a navigational aid used worldwide to facilitate the approach and landing of aircraft. ILS is a ground-based radio wave system providing both lateral and vertical guidance to aircraft at airports in any weather condition.

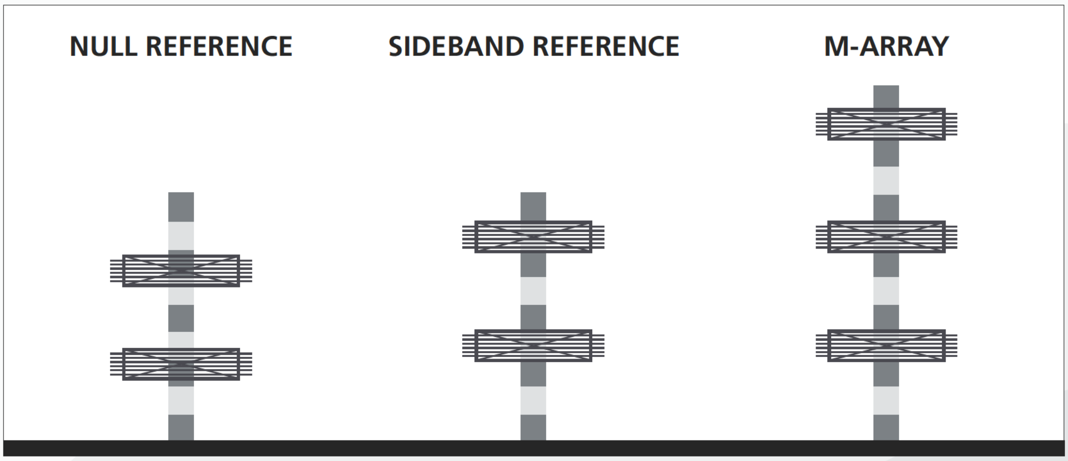
An aircraft either follows a standard published instrument approach, or is given directions (i.e. radar vectors) from Air Traffic Control (ATC) to the ILS coverage area, where localiser and glide slope signals would be transmitted to its systems for it to make an automatically guided landing. An ILS can consist of the following ground based components:

- Localiser transmitter – which transmits the lateral guidance signal
- Glide slope transmitter – which transmits the vertical guidance signal
- Marker beacons – which transmit vertical signals
- Distance measuring equipment – which transmits a signal for distance away from a fixed point, usually the runway threshold

The glide slope antenna is situated on one side of the runway touchdown zone. The centre of the glide slope signal is arranged to define a glide path of approximately 3 degrees above touchdown ground level. The glide slope receiver on the aircraft measures the difference in the depth of modulation of the 90 Hz and 150 Hz signals, similar to that of the localiser. For a standard 3-degree glide path, the relative signal strength of the "Fly Up" (150 Hz) command and the "Fly Down" (90 Hz) command is equal (Null).

Five types of glide slope antenna systems are used worldwide. Three of which are imaging type antennas referred to as Null Reference, Sideband Reference, and Capture Effect or M-array (See Figure 2). The two non-imaging type antennas are the Endfire and Waveguide. The non-imaging type antennas were excluded from the investigation because they are infrequently used. The M-array antenna is most frequently used at airports worldwide.

Figure 2 - ILS Glide Slope Imaging Type Antennas



THE KEY OUTCOMES

ILS Glide Slope Flight Tests

The DSB conducted flight tests to measure the ILS-signal field characteristics of the M-array antenna. As the Sideband and Null Reference antennas were not available in the Netherlands, these were measured by the Federal Aviation Administration, USA, at the request of NTSB. An ILS flight test plan was formulated and flown into the Netherlands and USA by several different specialised aircraft normally used to certify the ILS for operational use. The ILS flight test data was subsequently analysed by DSB, and the ILS signal characteristics were determined.

The first false glide slope type is defined as a False Null. This glide path resembles the normal 3-degree glide slope signal (null), but is actually either at the wrong location in space or has a steeper angle. A False Null signal will result in an aircraft having a higher than normal descent rate. The second type of false glide slope that can be distinguished is the Signal Reversal. This Signal Reversal is "unstable" as the ILS signal changes from "Fly Down" to "Fly Up". When the autopilot is engaged in the appropriate mode, the "Fly Up" signal will result in a command to pitch-up the aircraft.

Both Null Reference and Sideband Reference antennas have one characteristic signal field which was identified through flight tests. Several measurements on the M-Array antenna showed that it did not have one unique signal field but two fields depending on the operational configuration. Therefore, the M-Array antenna system can have two different fields.

In summary, the measurements performed on the three imaging type category ILS Glide slope antenna systems revealed two different slide slope signal characteristics (See Table 1):

a. Signal reversal sometimes occurs at an approximately 6-degree glide path angle.
b. Signal reversal always occurs at the 9-degree glide path angle.

Table 1 - Overview Measurements ILS Glide Slope Image Type Antennas

<table>
<tr><th rowspan="2">ILS glide slope antenna system type</th><th colspan="9">Glide path angle [degrees]</th></tr>
<tr><th>0 - 3</th><th>3</th><th>3 - 6</th><th colspan="3">6</th><th>6 - 9</th><th>9</th><th>9 - 12</th></tr>
<tr><td>Null Reference</td><td>↑</td><td>O</td><td>↓</td><td>R</td><td>↑</td><td>O</td><td>↓</td><td>R</td><td>↑</td></tr>
<tr><td>Sideband Reference</td><td>↑</td><td>O</td><td>↓</td><td colspan="3">↓</td><td>↓</td><td>R</td><td>↑</td></tr>
<tr><td>M-Array 1</td><td>↑</td><td>O</td><td>↓</td><td>R</td><td>↑</td><td>O</td><td>↓</td><td>R</td><td>↑</td></tr>
<tr><td>M-Array 2</td><td>↑</td><td>O</td><td>↓</td><td colspan="3">↓</td><td>↓</td><td>R</td><td>↑</td></tr>
</table>

↑ GS signal “Fly Up” ↓ GS signal “Fly Down” **O** Null glide path **R** Signal reversal

Accessible information for the aviation community and understanding of both flight crew and air traffic controllers did not make a distinction between two types of false glide slope – False Null and Signal Reversal. As a result, the false glide slope phenomenon was not fully understood.

Furthermore, there was no information available to pilots (charts or other) on which ILS antenna type is used at the airport. Contrary to published information available, a “Flag” (warning) will precede a false glide slope but during flight testing, no “Flags” were recorded or displayed on the flight instruments.

Based on these results and other similar events in the past, a SA was published by DSB (2013). The SA warns pilots of a potential hazard when ILS approaches from above the 3-degree Glide Slope are performed in auto flight, resulting in unexpected and severe pitch-up upset. Following the SA, the industry and several aviation authorities worldwide have taken actions to prevent a recurrence.

For example, the European Aviation Safety Agency (EASA) announced that its experts in Flight and Avionics have reviewed the SA and the recommendations in the BEA report of the Paris Charles de Gaulle 2012 A340 incident. A Safety Information Bulletin (EASA, 2014) was issued to officially inform the European aviation community and highlight the issue.

Certified Volume of Operation

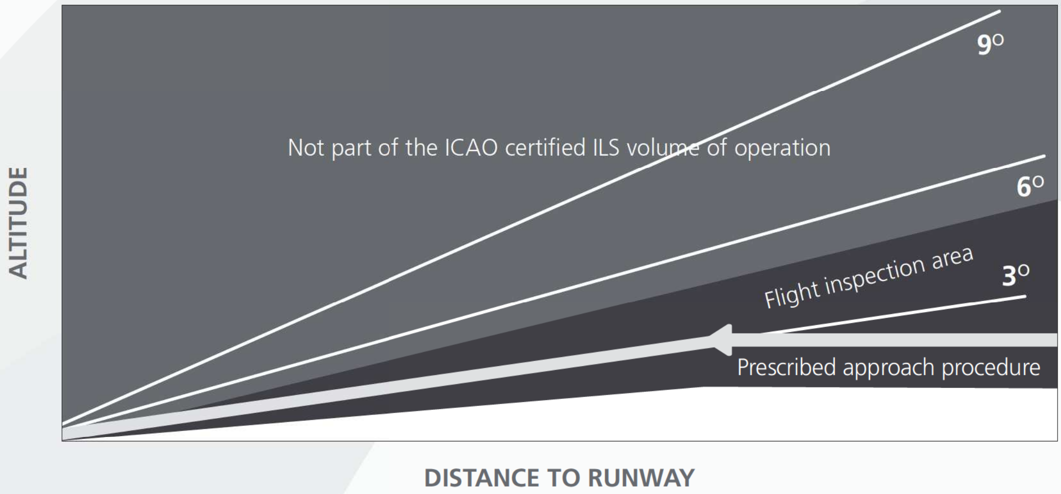
ICAO mandates that all types of radio navigational aids available for use by aircraft engaged in international navigation shall be subjected to periodic ground and flight checks. Ground measurements cannot completely assure the quality of the signal-in-space due to the effects of terrain, man-made obstructions, radio frequency interference, and reflective surfaces such as snow, water and other aircraft. The use of specially equipped aircraft, precisely positioned (laterally and vertically), is the only effective method of evaluating a signal-in-space or instrument flight procedure. Flight inspections certify instrumental approaches and ensure that an aircraft at the lowest authorised altitude is safe from ground obstacles.

Flight inspection is traditionally based on inflight measurements of the signal-in-space produced by air navigation systems on board a calibration aircraft. During flight inspections, the 3-degree ILS glide slope signal is inspected in different ways, including at a prescribed flight offset, to verify a valid 3-degree glide slope signal.

The inspected area is normally situated between 0 and 10 NM from the runway threshold and approximately 35 degrees left and right of the runway heading (localiser). The ILS antenna system is checked and if required adjusted at least once a year.

The measurements to determine the glide slope field as performed in DSB investigation were not part of a normal flight inspection, which is performed on the 3-degree glide path. Above an angle of 5.25 degrees, the glide slope field characteristic is not required by ICAO regulations to be inspected (See Figure 3). This means that when flying above the 5.25-degree glide path, the aircraft is flying beyond the reliability threshold, which is certified and periodically checked by flight inspection. The pitch-up upset events were all flying in the area above the 5.25-degree glide path.

Figure 3 - ILS Glide Slope Certified Volume of Operation



Aviation Safety Management System

The occurrence at Eindhoven Airport and the subsequent four similar events gave rise to the question: why did aviation SMS not identify the ILS glide slope signal reversal as a potential serious safety deficiency?

ICAO mandates all Contracting States to implement a State Safety Programme (SSP) wherein aviation organisations are required to establish SMS. SSP and SMS are complementary to each other. The European Union (EU) adapted the ICAO requirements for safety management in two Regulations (EU, 2012a and 2012b). In some cases, this regulation pre-dated the events described in this investigation. The overall SMS structure for all organisations is based on the following four components (See Table 2), also known as "pillars of the SMS".

Table 2 - SMS Pillars

Pillars of the Safety Management Systems	
Safety Policy Management Support Responsibilities and Authorities	**Safety Assurance** Process Evaluation Safety Performance Monitoring
Safety Risk Management Proactive Hazard Identification Risk Assessments and Control Measures Corrective and Preventive Actions	**Safety Promotion** Safety Communications and Culture Safety Training

Individual Level – Operators

The level of development and implementation of SMS depends on the size, nature and type of operation. Depending on the number of aircraft and destinations, an operator can have thousands of flights per week with hundreds of safety reports being filed. All these safety reports must be captured, assessed and analysed to identify risks, and for deciding if further investigation and corrective actions are necessary.

Operators rate occurrences using a risk identification matrix as part of SMS methodology. The combination of severity and probability of the occurrence results in a total safety risk assessment. Depending on the level of safety risk, mitigating measures are required. In the matrix, three different levels of safety risk can be distinguished:

1. Intolerable – mitigating measures should be taken
2. Tolerable – mitigating measures could be taken
3. Acceptable – no measures are required

Following the risk assessment process, the operators assessed the pitch-up upset events as tolerable and an internal investigation was initiated. During the internal investigations, hazards and barriers related to the occurrence were identified. Thereafter, recommendations were formulated to prevent reoccurrence. However, the internal operator reports did not fully identify the cause of the pitch-up upset as false glide slope reversal.

National Level – Occurrence Databases

The objective of the national occurrence database is to identify and monitor safety performance within the State. The type of safety data to be collected may include accidents, incidents, non-compliance or hazard reports. The data are statistically analysed to identify safety deficiencies and to enable effective decisions to improve safety. The following report (See box) from the national occurrence database system in 2011 was received from the Netherlands' Occurrence Analysis Bureau:

CAA-NL Occurrence Database Report
Title: Go-around due to Unstable Approach
Date of Occurrence: 12-2-2011
Summary: Aircraft became high, above glide slope, on ILS approach RWY 06 AMS. Believe aircraft at one point eventually picked up a false glide slope, during go-around stick shaker activated, pitch lowered in response to this. After go-around another successful approach and landing to RWY 06 was made.

This occurrence report shows that reference is made to a stick shaker and a false glide slope but no additional data is available. No factors explaining why the aircraft gained altitude are identified; only the result: after go-around a successful landing was made. This does not allow the reader to ascertain the essence of the false glide slope characteristic and the associated autopilot response.

SMS methodologies were applied and resulted in data being captured in the mandatory state occurrence databases and individual operators' SMS databases. However, the investigation indicated that due to event coding and insufficient detail in the event descriptions, the complexity of the occurrence was not identifiable.

The initial mandatory reports in the involved State's occurrence database were not always appended with the results of the follow-up investigations conducted by the operators. Furthermore, the root cause of the events was not identified during the operator's investigation. The result was that due to the absence of valuable additional background information, the possible detection of a safety deficiency in the future became remote. As the investigated SMS are mainly driven by statistical analysis, a limited number of reports are statistically insignificant and on that basis no action was required.

Despite SMS methodologies and previous investigations, the reported pitch-up upset incidents occurred in airspace, which is not part of the ICAO certified ILS volume of operation. None of the parties identified this latent safety deficiency.

This investigation has shown that despite the implementation of SMS, the global aviation system was unable to "connect the dots" when related serious incidents occurred. On a national level, occurrences are analysed mathematically and the identified risk indicators are monitored to serve as the present safety state. As shown in this investigation, the unidentified or misidentified indicators which in some cases are mathematically insignificant, but nevertheless important, are not dealt with in current SMS occurrence report analysis methodology. This shows that new techniques and information sharing strategies are required to be embedded in SMS to search for and identify latent safety risks at present and in the future.

The large amount of reports and information available has meant that the current implemented SMS occurrence reporting analysis framework, using mathematical methodologies and assessments, might be reaching its potential limit for safeguarding safety.

It could be argued that a more holistic systems approach in risk identification might be a way to supplement current SMS occurrence report analysis methodology in the future. As an example, in the fourth quarter of 2013 the Flight Safety Foundation and MITRE announced collaboration in creating Transform Global Aviation Analytics. The background to the collaboration was given as the complexity of today's global air navigation system; the analysis of diverse types of data is essential to establish the correlation of multiple attributes accurately, which in combination has the potential to identify systemic vulnerabilities that elevate safety risks. This is an example of a possible approach in addressing the safety challenge of the future.

CONCLUSION

In conclusion, the pitch-up upset events were reported to the European national occurrence databases and the voluntary NASA's ASRS database. Analysis of similar events found in several databases suggests that aircraft pitch-up upsets have occurred with a variety of aircraft types from different manufacturers. The pitch-up upsets were attributed to ATC equipment failures and human factors and included in national and international databases for future analysis.

The root cause of the pitch-up upsets was not identified by databases, SMS and internal operator investigations. New insights were gained only when the ILS glide slope signal characteristics were closely examined by DSB investigation. A "reversal of knowledge" was required to identify an issue resulting in aircraft pitch-up upsets.

Despite SMS methodologies and previous investigations, the reported pitch-up upset incidents occurred in airspace which is not part of the certified volume of operation. None of the parties identified this latent safety deficiency.

The SMS risk management pillar to proactively identify risk needs to be addressed to identify potential future safety issues. The implemented SMS and its methodology have certain flaws which can be improved. Enhancement can be made through a holistic approach of using knowledge, experience and data to identify potential safety issues which have not yet occurred.

As a result of the investigation, DSB formulated six recommendations. The recommendations focus on changes being implemented in the short and long term in the areas of training, operational (stabilised approach criteria) and technical measures to prevent recurrence.

Furthermore, DSB made recommendations to enhance current occurrence reporting and analysis and took measures to achieve the goal of the system to identify potential safety deficiencies in a timely manner.

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