DUTCH
SAFETY BOARD

Stick shaker warning on ILS final

Eindhoven Airport

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Stick shaker warning on ILS final

Eindhoven Airport 31 May 2013

The Hague, June 2014

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Dutch Safety Board

The aim in the Netherlands is to limit the risk of accidents and incidents as much as possible. If accidents or near accidents nevertheless occur, a thorough investigation into the causes, irrespective of who are to blame, may help to prevent similar problems from occurring in the future. It is important to ensure that the investigation is carried out independently from the parties involved. This is why the Dutch Safety Board itself selects the issues it wishes to investigate, mindful of citizens' position of independence with respect to authorities and businesses. In some cases the Dutch Safety Board is required by law to conduct an investigation.

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NB: This report is published in the Dutch and English languages. If there is a difference in interpretation between the Dutch and English versions, the English text will prevail.

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SYNOPSIS

A Boeing 737-800 was radar vectored by air traffic control for an ILS approach to Eindhoven Airport. The approach was flown under instrument meteorological conditions and with autopilot activated. The published approach was shortened by air traffic control, causing the aircraft to fly above the standard 3 degree glide slope area. The ILS was thus intercepted from above with help of the automated systems on board. During the glide slope intercept, the nose of the aircraft rose rapidly causing a stick shaker warning. After completion of the required stall warning recovery procedure, the crew performed a successful go-around and landed the aircraft uneventfully.

Recommendations were send to the Dutch Minister of Defence (responsible for the approach control of Eindhoven Airport) and the airline involved.

ABBREVIATIONS

AFDS	autopilot flight director system
AFE	above field elevation
ANU	aircraft nose up
AOA	angle of attack
AOCS (NM)	Air Operations Control Station (Nieuw Milligen)
APP	approach
AT	autothrottle
ATC	air traffic control
ATIS	Automatic Terminal Information Service
ATPL	airline transport pilot licence
B737	Boeing 737
B738	Boeing 737, variation 800
B737NG	Boeing 737 Next Generation
BEA	Bureau d’Enquêtes et d’Analyses pour la sécurité de l’aviation civile (France)
CAA	Civil Aviation Authority
CDU	control display unit
CMD-B	Command – B (automatic flight system B)
CTR	control zone
CVR	cockpit voice recorder
DGAC	Direction Générale de l’Aviation Civile (France)
DME	distance measuring equipment
DSB	Dutch Safety Board
EFIS	electronic flight instrumentation system
FAP	final approach point (also final approach fix, FAF)
FAS	final approach speed
FCC	flight control computer
FCTM	flight crew training manual
FDR	flight data recorder
FL	flight level
FMC	flight management computer
FMS	flight management system
FPM	feet per minute
FO	first officer
FOQA	flight operations and quality assurance
FSP	flight safety program

GPS	global positioning system
GPWS	ground proximity warning system
GS	glide slope
HAT	height above threshold
HDG	heading
hPa	hectopascal
ICAO	International Civil Aviation Organization
IF	intermediate fix
IFR	instrument flight rules
ILS	instrument landing system
ILS/DME	combined ILS and DME system
IMC	instrument meteorological conditions
JAR	joined aviation requirements
LNAV	Lateral navigation, navigating a ground track with guidance from an electronic device
LOP	local operating procedures
MCP	mode control panel
ME	multi engine
MHz	Megahertz
MPA	multi pilot aeroplane
N1	percentage of engine compressor turbine revolutions
NASA	National Aeronautics and Space Administration
NM	nautical mile(s)
NTSB	National Transportation Safety Board
PF	pilot flying
PFD	primary flight display
PM	pilot monitoring
QNH	local barometric pressure adjusted to sea level
RNLAF	Royal Netherlands Air Force
SA	situational awareness
SMS	safety management system
SOP	standard operating procedure(s)
STAR	standard arrival route
TAWS	terrain awareness and warning system
TOGA	take of / go around

VMC	visual meteorological conditions
VSD	vertical situation display
V/S	vertical speed
WQAR	wireless quick access recorder

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DEFINITIONS

The terms glide slope and glide path are used interchangeably in the aviation community. ICAO only uses the term glide path in ICAO Annex 10 Volume 1. In this report the term glide slope and glide path are used interchangeably.

ILS glide path	That locus of points in the vertical plane containing the runway centre line at which the DDM is zero, which, of all such loci, is the closest to the horizontal plane. [ICAO Annex 10 Volume 1]
ILS glide path angle	The angle between a straight line which represents the mean of the ILS glide path and the horizontal. [ICAO Annex 10 Volume 1]
False glide slope	That locus of points in the vertical plane containing the runway centre line at which the DDM is zero, which is not the closest to the horizontal plane.

The term "false glide slope" is used in the aviation community to describe a glide path which is not the normal glide path which an aircraft follows to the runway for landing. In some cases the report uses the term glide path with a glide path angle for clarity. In that case the 3 degree glide path is the "normal" glide path and in other cases it's the "false glide slope".

1 INTRODUCTION

1 INTRODUCTION

1.1 Reason for the investigation

1.1.1 Initial investigation

During the approach to Eindhoven Airport (the Netherlands) on 31 May 2013, a Boeing 737-800 was radar vectored towards runway 21 for a landing using the Instrument Landing System[1] (ILS) in Instrument Meteorological Conditions (IMC). During the approach the aircraft's rate of descent was less than required and therefore was high in altitude. After the localiser was captured, a glide slope intercept from above was executed. The automatic flight director system[2] (AFDS) and the autothrottle[3] (AT) were engaged. The approach mode was armed and the aircraft was configured for landing.

At short final, approximately 0.85 NM from the threshold at 1060 feet altitude, the glide slope was captured. Upon glide slope capture, a pitch increase of 24.5 degrees aircraft nose up (ANU) occurred in about 8 seconds. The crew pressed the 'take off/go around' (TOGA) button for a go around, almost simultaneously followed by the activation of the stick shaker warning. During the following approach to stall recovery manoeuvre there was a second stick shaker activation. The crew made a successful go around and landed at Eindhoven Airport.

The activation of the aircraft's stick shaker during an autopilot coupled ILS approach in close proximity to the runway was a factor of interest that prompted the Dutch Safety Board to start an investigation. The occurrence (henceforth: the Eindhoven incident) has been categorized by the Safety Board as a serious incident.

1.1.2 Significance of the Eindhoven incident

Findings from the Eindhoven incident revealed characteristics of ILS signals that were not generally known. During the investigation it became clear that the Eindhoven incident was not unique. Four[4] other incidents with autopilot commanded pitch-up during ILS approaches from above the 3 degree glide slope have occurred. These incidents took place with different types of aircraft, operated by different airlines, on approaches to different airports.

1 For detailed information regarding ILS, see paragraph 2.8.2.
2 The automatic flight system of the Boeing 737-800 consists of the autopilot flight director system and the autothrottle. The crew can make (mode) selections regarding heading, altitude, speed and other flight path commands on the mode control panel. These selections are presented on the primary flight display. These mode selections are the input for the aircraft's flight control computers and autothrottle, which command the flight controls and throttles in accordance with the selected modes.
3 An autothrottle (automatic throttle) allows a pilot to control the power setting of an aircraft's engines by specifying a desired flight characteristic, rather than manually controlling fuel flow.
4 Two of the four incidents were known before the Safety Alert was published.

These findings led the Dutch Safety Board to conclude that unknown ILS signal characteristics pose a significant threat to aviation safety, as they may result in unexpected aircraft behaviour and thus endanger the safety of passengers and flight crews. Because of the frequency of occurrence, combined with the potential severity of this hazard, the Dutch Safety Board decided to address this issue separately. Preliminary findings of the ILS signal anomaly were issued in a Safety Alert on 18 November 2013, see Appendix C.

This report represents the investigation of the Eindhoven incident. The final report of the ILS signal anomaly was issued contemporaneously on 26 June 2014.

1.2 Investigation questions and scope

The investigation into the Eindhoven incident sought to answer two main questions:

1. How did the actions of air traffic control and the flight crew contribute to intercepting the glide slope from above, and which factors explain these actions?
2. How did the actions of the flight crew contribute to the ILS pitch-up upset[5] and stall recovery, and which factors explain these actions?

The investigation focused on the air traffic control management and the flight crew management preceding the stick shaker and the recovery thereafter. Also the reporting of the incident and the actions taken by the operator were briefly considered. This investigation neither includes the investigation of similar occurrences worldwide, nor the behaviour of the autopilot in relation to ILS signals. These issues will be addressed by the report on ILS signal anomaly mentioned above.

The frame of reference including the relevant (international) legislation, regulations, guidelines, operating and training manuals for this investigation are described in Appendix D.

1.3 Objectives

The investigation has two objectives. Firstly, to draw lessons from the Eindhoven incident to prevent repetition, and to limit the consequences of similar occurrences in the future. Secondly, to inform the stakeholders - pilots, airline operators, air navigation service providers, aircraft manufacturers and regulators - of the potential severity of the hazard.

In accordance with Annex 13 to the Convention on International Civil Aviation, it is not the purpose of the investigation to apportion blame or liability. The sole objective of the investigation and the Final Report is the prevention of similar accidents and incidents.

5 An upset is described by the aircraft manufacturer as an unintentional situation whereby the nose of the aircraft is either more than 25 degrees nose up or 10 degrees down, the bank angle is more than 45 degrees, or the aircraft is operating within the prior parameters but the airspeed is not appropriate to the condition the aircraft is flying in.

1.4 Reader's guide

The International Civil Aviation Authority (ICAO) has established guidelines and recommended practices for investigating civil aviation accidents and serious incidents. These are included in Annex 13, 'Aircraft Accident and Incident Investigation'. A report based on Annex 13 has a set structure: factual information, analysis, conclusions and recommendations.

Chapter 2 describes the facts of the incident. Chapter 3 describes the underlying factors of the incident and contains the analysis of the facts. The following subjects were analysed: the line up of the aircraft for the approach by the air traffic controller, the approach flight path management by the flight crew, the pitch-up upset and recovery, the procedures for glide slope intercept from above, the distance versus altitude cross-check and the influence of automation on flight path management. The analysis ends with a summary of the actions taken by the parties concerned. Conclusions are presented in chapter 4. Chapter 5 contains recommendations.

2 FACTUAL INFORMATION

2 FACTUAL INFORMATION

2.1 History of the flight

The Boeing 737-800, with registration EI-ENL, left Palma de Mallorca (Spain) at approximately 07.00 hours local time[6] on a passenger flight with flight number FR3531 (flight 3531) to Eindhoven Airport. On board the aircraft were 124 passengers, four cabin crew members and three flight crew members. In the cockpit the captain was in the left-hand seat and the first officer (FO) occupied the right-hand seat. A third, supernumerary, crew member (trainee) was seated in the observer's seat in the cockpit as part of a type rating training to get familiar with the company's standard operating procedures (SOP). The first officer acted as pilot flying (PF) for the flight to Eindhoven, the captain was pilot monitoring (PM).

The flight crew received the Automatic Terminal Information Service (ATIS)[7] broadcast from Eindhoven Airport before the aircraft entered Dutch Airspace. The ATIS showed the active runway was 21. According to the flight crew the pre-landing briefing was carried out and all relevant checklists were performed before the descent from cruise level. The crew noted the possibility of a shorter route being offered by air traffic control (ATC) in the pre-landing briefing and was aware of the shorter route posing a possible complication during the descent as a consequence.

The aircraft entered Dutch Airspace near Maasbracht at approximately 7000 feet (flight level 70), and switched to Air Operations Control Station Nieuw Milligen (Dutch Mil) shortly after entering Dutch airspace. Dutch Mil cleared the crew to descend to 3000 feet. The flight crew was flying to OSGOS navigation point expecting GEMTI navigation point after that (see figure 1).

6 All times used in this report are Dutch local times unless otherwise specified. Because time stamps in aircraft data are not in sync with time stamps on the ATC transmission data, times used in this report are aircraft data related. Times used in Appendix E, are times recorded by ATC voice logging system and differ approximately one minute with aircraft times.

7 Automatic Terminal Information Service, or ATIS, is a continuous broadcast of recorded non control aeronautical information in busier terminal (i.e. airport) areas. ATIS broadcasts contain essential information, such as weather information, active runways, available approaches, and any other information required by the pilots. Pilots usually listen to an available ATIS broadcast before contacting the local control unit, in order to reduce the controllers' workload and relieve frequency congestion.

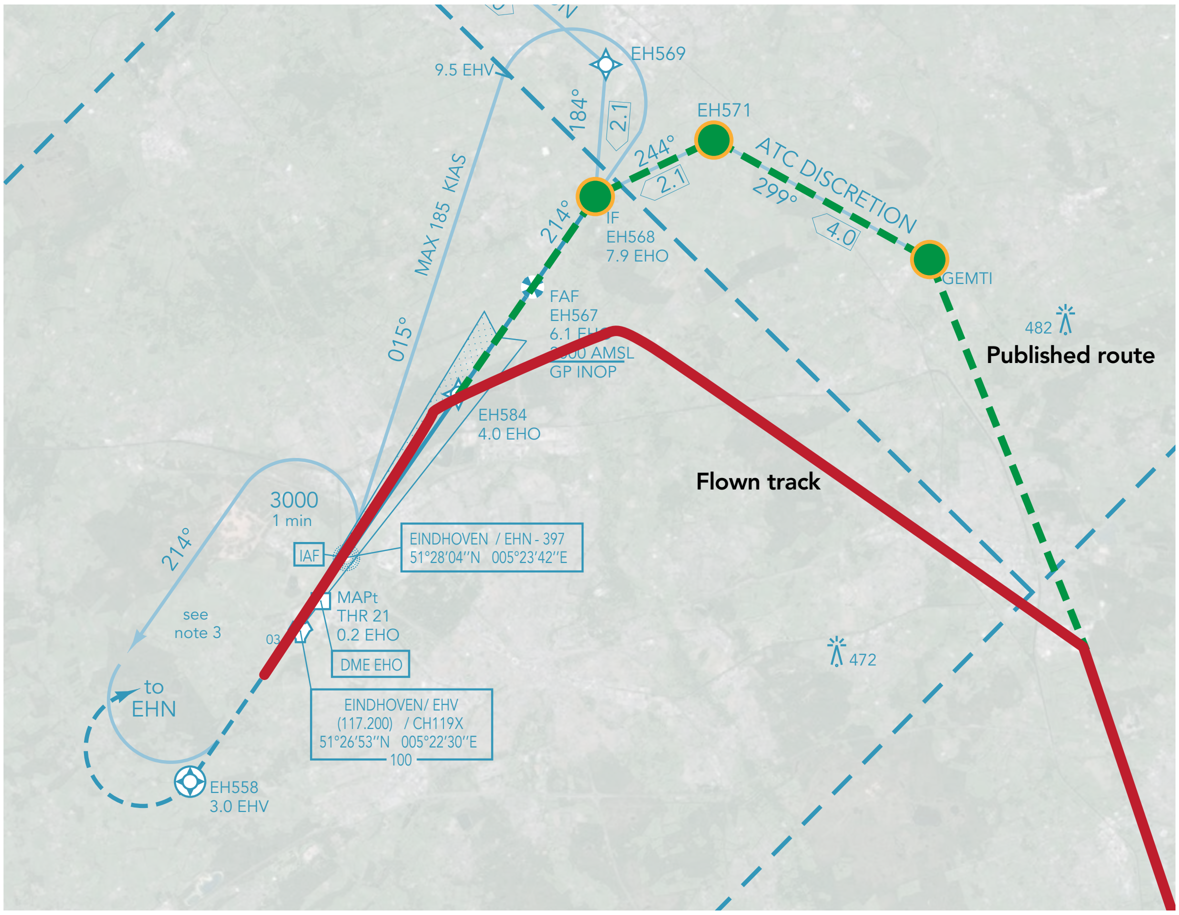

Figure 1: Top view of the published (green line) and the actual flown (red line) approach to Eindhoven Airport.

In the region of Venlo, the aircraft contacted Eindhoven Arrival Control (Eindhoven Arrival). The crew received radar vectors towards Eindhoven Airport in order to intercept the ILS for landing on runway 21. The autopilot flight director system (AFDS) and autothrottle (AT) were engaged during this phase of the flight. The flight was flown under instrument meteorological conditions (IMC).

Flight 3531 was the fourth flight of the day landing at Eindhoven Airport. Two earlier flights came from the southeast and east via ROTEK and OLNO reporting points, the third flight arrived from the west via REDFA. The third aircraft landed at 08.40 hours.

At 08.44 hours, while on a heading of 340 at approximately 4200 feet and 4 NM prior to reaching GEMTI, Eindhoven Arrival instructed flight 3531 to fly heading 310. The aircraft was flying with the autopilot in Vertical Speed Mode (V/S) and set at 500 feet per minute rate of decent.

Vertical Speed (V/S) Mode
In this mode the aircraft will either climb or descend with a selected vertical speed. The pitch commands of the AFDS will hold the selected vertical speed. In this mode the airspeed is controlled by the autothrottle.

At this time the crew was instructed to descend to 2000 feet. According to the Royal Netherlands Meteorological Institute (KNMI), the wind between 2000 and 3000 feet was from direction 010 at 30 knots. In the cockpit, the flight management system (FMS) calculated wind is presented on the Navigation Display.

The descent on base leg took approximately two minutes. While on a 6 NM base leg for the ILS approach, at approximately 3400 feet, the crew started configuring the aircraft for the approach. At around 3200 feet, flaps 5 were set and airspeed 160 knots was selected. At 08.46 hours Eindhoven Arrival instructed the aircraft to turn to heading 250 to intercept the final runway track, cleared the crew for the approach and requested the crew to report established on the ILS approach. As this new heading shortened the approach still further, the crew's workload increased.

The new heading of 250 positioned the aircraft on final between 4 and 5 NM from the runway threshold. The crew noticed they were high in altitude on the descent and decided to use the Level Change Mode of the AFDS in an attempt to increase the rate of descent.

Level Change (LVL CHG) Mode
With the autopilot engaged in this mode the aircraft will either climb or descend at a selected airspeed to the Mode Control Panel (MCP) selected altitude. The LVL CHG autopilot pitch mode and autothrottle co-ordinates pitch and thrust commands to make a climb or descent to a preselected altitude at a selected airspeed. The vertical speed is a resultant and not controlled directly. In this mode descents are flown with thrust in idle.

The approach mode of the AFDS was selected to follow the ILS approach and also the speed brake system was used in an attempt to regain the descent profile. After the speed brakes were retracted the flaps were selected to 15, just before the crew was instructed to contact Eindhoven Tower Control. Next the speed was set to 150 knots and the gear was selected down. The speed brakes were armed for landing and the flaps set to 30. The speed was now set to 140 knots as the crew contacted Eindhoven Tower Control. The crew configured the aircraft for landing by selecting flaps 40 and the final approach speed (FAS) of 135 knots, completing the landing checklist.

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Speed brakes
Speed brakes are a type of flight control surface used on aircraft to increase drag or decrease the flight path angle during the initial approach. Because of the associated high rates of descent the use of speed brakes are not available to crew when the flap setting greater than "Flaps 10" has been selected on approach. This is a structural limitation.

Virtually all jet powered aircraft have speed brakes or, in the case of most airliners, lift spoilers that also act as speed brakes.

At 08.47 hours Eindhoven Tower Controller cleared the aircraft for landing and reported the surface wind was from 330 at 8 knots, with a maximum of 16 knots. The crew confirmed the landing clearance and asked for the wind again, which was given as 310 at 10 knots, indicating the wind was variable during landing, with a small tailwind component. At approximately 1300 feet the captain informed the FO that it was very unlikely a successful landing would be possible and they should prepare to make a go around.

On final approach at 08.48 hours the aircraft pitch was 0.5 degrees nose down (-0.5 ANU), the computed airspeed was 140 knots and the aircraft was at an altitude of 1060 feet. The glide slope indicator on the PFD "came alive" and according to the crew went full down and then full up. The aircraft pitched up rapidly and the engine N1 increased from 30% to 90% on both engines in order to maintain the selected airspeed. Finding this behaviour unexpected, the PM called for a go around. The pitch further increased to 24 degrees nose up and the stick shaker warning activated. Almost at the same time the TOGA button was pushed once by the PF and the autopilot was deactivated.

Stall warning system – stick shaker
A stall is the situation where the airflow over the wings can no longer follow the wing profile due to an increase of the wing's angle of attack (AOA).[8] The wing loses lift to a large extent and the aircraft can become uncontrollable if the pilot(s) do(es) not intervene. The stall warning system is used to generate the required warning before a stall situation actually occurs to give the crew ample time to react and counter the situation. In Boeing 737 aircraft this stall warning consists of a distinct vibration of the control columns in combination with a loud vibrating noise (referred to as stick shaker). It should be noted that a stick shaker warning occurs prior to an actual stall situation. The aircraft is still flying at the AOA at which the stick shaker is activated. If the AOA increases further, the aircraft will actually stall and lose altitude rapidly, possibly resulting in a loss of control situation.

8 In aerodynamics, angle of attack specifies the angle between the chord line of the wing of a fixed-wing aircraft and the vector representing the relative motion between the aircraft and the atmosphere.

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On the 737 aircraft, the stick shaker warning is usually triggered by an exceedance of the AOA, rather than low airspeed. The stick shaker warning can activate when either the vane AOA increases above the stick shaker trip value or if airspeed drops below the speed floor of 90 knots.

For this event, both stick shaker warnings were triggered by an AOA above the trip value. The stick shaker speed displayed to the flight crew is a visual cue for the crew to estimate when stick shaker activation will occur and is based on the vane AOA stick shaker trip value. The Pitch Limit Indicator (PLI) on the flight director displays the pitch at which the stick shaker warning will activate.

At 08.48:51 hours the pitch had increased to 26.5 degrees nose up, the crew intervened, and two seconds later the minimum computed airspeed was recorded at 97.5 knots. The aircraft was at an altitude of 1267 feet flying at 0.65 NM from the runway threshold. The PF continued with the stall recovery manoeuvre and another two seconds later the warning ceased.

At 08.48:56 hours the stick shaker activated for a second time and the captain helped the FO to reduce the AOA in order to regain airspeed resulting in the warning ceasing after three seconds. The aircraft was at an altitude of 1429 feet and 0.45 NM from the runway threshold. The computed airspeed was 103 knots and increasing. The crew finished the stall recovery procedure and initiated a climb to 2000 feet to make a second attempt for landing. The crew then reconfigured the aircraft by raising the gear and retracting the flaps and informed Eindhoven Tower Control that a go around was initiated. Eindhoven Tower Controller instructed the crew to continue climbing to 2000 feet on runway heading and to contact Eindhoven Arrival Control.

The crew switched the radio frequency to Eindhoven Arrival and continued to fly a missed approach at 2000 feet. The crew then informed Eindhoven Arrival that they had encountered a false glide slope and were flying a go around for a second landing attempt. No further details were reported about the flight situation and the aircraft was positioned at a 10 NM final from Eindhoven Airport for a second approach for landing. This time the aircraft captured the 3 degrees ILS glide slope and the approach was completed uneventfully. The crew landed the aircraft at 08.59 hours and taxied the aircraft to the airport's terminal building.

The Eindhoven Arrival Controller did not make an entry in the ATC daily log of the go around. The Eindhoven Tower Controller did make an entry in the daily report, but since there was no mention of any dangerous situation, no air traffic management safety report was written.

At 09.10 hours the captain contacted the company's duty pilot by mobile phone. He informed the duty pilot about his recollection of the event and asked if the flight data and voice recorders should be preserved. At that time neither flight crew member was aware of the extent of the occurrence and therefore the extent was not articulated to the duty pilot. Based on the information provided to him, the duty pilot assessed the occurrence as being a minor stick shaker event, which did not require retention of the flight recorders' data. Having assured by the duty pilot that both pilots were fit to fly, the flight crew prepared for the return flight to Palma de Mallorca. At 09.30 hours the aircraft took off from Eindhoven Airport as scheduled.

2.2 Meteorological information

IMC conditions existed during the entire approach. Ground visibility was approximately 1900 meters with broken to overcast clouds at 300 feet. The surface wind was from 330 at 8 knots. The local atmospheric pressure (QNH) was 1010 hectopascal (hPa).

The weather report of the Royal Netherlands Meteorological Institute indicated that the winds at 2000 and 3000 feet altitude were from direction 010 at 30 knots.

Because of the weather situation, the flight into Eindhoven Airport was conducted under IMC with no ground visibility until shortly before landing.

2.3 Damage to the aircraft or other objects

There was no damage to the aircraft or to other objects.

2.4 Personnel information

The captain, who was Spanish, had approximately 3700 flying hours on Boeing 737 aircraft at the time of the event.

Flight crew experience - captain	
Licence	JAA airline transport pilot licence A (ATPL(A))
Rating	Boeing 737 300-900, ME IR
Last proficiency check	23 December 2012
Last line check	2 February 2013
Captain check/training	2 May 2013
Boeing 737 type rating	4 May 2011, valid until 28 February 2014
Medical certificate	6 February 2014
Flying experience	Total: 4260 hours Boeing 737: 3700 hours Last 90 days: 160 hours Last 24 hours: 0

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The first officer, who was Spanish, had approximately 410 hours total flying time on Boeing 737 at the time of the event.

Flight crew experience - first officer	
Licence	JAA ATPL(A)
Rating	Boeing 737 300-900, ME IR
Last proficiency check	15 March 2013
Last line check	15 May 2013
Boeing 737 type rating	17 September 2012, valid until 31 March 2014
Medical certificate	31 August 2014
Flying experience	Total: 670 hours Boeing 737: 410 hours Last 90 days: 295 hours Last 24 hours: 7 hours

The event flight was the first flight of the day. Prior to the flight the crew had the opportunity for adequate rest. The captain had a day off, the first officer had more than 15 hours of non-duty time. The minimum off-duty time between flying days is 12 hours.

On the morning of the event flight, both flight crew members reported for duty at the company's Palma base station. At the base station a trainee joined them in the cockpit as part of his type rating. During the flight, the trainee was sitting in the observers' seat and performed no functions in the cockpit.

2.5 Air traffic control

After entering Dutch airspace, the flight crew had radio contact with the general air traffic control agency (Dutch Mil), the approach control agency (Centralized Approach) and the local air traffic control agency of Eindhoven Airport (Eindhoven Tower Control).

General air traffic control, approach control and local air traffic control are provided by the Royal Netherlands Air Force (RNLAF). Eindhoven Arrival Control is not located at the airport but has direct telephone lines and intercom connections with Eindhoven Tower Control for internal communication.

Relevant for the investigation were the recordings of the conversations between the flight crew and the last two air navigation service providers, i.e. Eindhoven Arrival Control and Eindhoven Tower Control (Appendix E). These conversations were recorded on a voice logging system operated by the RNLAF. The recordings were available for the investigation.

The Eindhoven Arrival Controller was qualified as of December 2010 and handled both military and civil traffic for the Eindhoven and Volkel Air Bases for most of the time since qualification. Duty time history showed that the controller met the rules and standards of duty and rest times. Because the controller was operating the first shift of the working day, there was no handover of a preceding shift.

Experience - air traffic controller	
Date of certificate	2010
Total duty hours in 2012	1055
Total duty hours in 2013 per date of occurrence	295
Minimum duty hours required[9]	170 hours annually

2.6 Aircraft information

The aircraft was a Boeing 737 that had a valid certificate of airworthiness and no outstanding maintenance actions. According to the aircraft's mass and balance information of the event flight, the aircraft operated within the aircraft limits for mass and balance.

After the event the aircraft's ILS equipment was tested by the company's maintenance branch. The equipment did not show faults logged and was found to be serviceable.

2.7 Aerodrome information

Eindhoven Airport is part of Eindhoven Air Base operated by the Royal Netherlands Air Force and has a single bi-directional runway. The reciprocal magnetic headings of the runways are 035 degrees and 215 degrees. At the time of the incident the runways available were 03 and 21. The day before the incident the runways were renumbered from 04 and 22 to 03 and 21 as a result of the shifting of earth magnetic field (shifting variation). A change was made to all arrival and departure procedures and the runway change was incorporated in the ATC navigation and radar control software.

The military Air Base Eindhoven can be used for both civil aviation and military purposes. The air base has a civil enclave for the accommodation of commercial passenger aircraft (Eindhoven Airport). In this report, when spoken of the airport, it will be addressed as Eindhoven Airport.

The Air Base Eindhoven meets the latest ICAO Annex 14 and national requirements for the civil use of an airport (Airport Equipment, ATC, Rescue and Fire fighting).

9 As per "Regeling certificering opleidingsinstellingen en goedkeuring opleidingenplannen luchtverkeersdienstverlening en luchtvaartterreininformatieverstrekking" (Dutch national rules for training and certifying of ATC personnel), competence, paragraph 4.1., currency requirements for ATC personnel.

During initial and intermediate approach to Eindhoven Airport radar service may be provided by AOCS Nieuw Milligen (Dutch MIL), RAPCON[10] South and/or Eindhoven Arrival.[11]

The airport is equipped with the Thales (LS420) M-array ILS. The distance measuring equipment (DME) signal is coupled with the ILS glide path signal for both runways 03 and 21. This ILS passed a site acceptance check after installation in 2003 and its ILS system meets ICAO CAT II standards.

The airport is open for traffic from 06.00 hours to 23.00 hours from Monday to Friday, and from 07.00 hours to 23.00 hours during the weekend.

The runway in use at Eindhoven was runway 21. The reported surface wind at the time of the intended landing was from direction 330 at 8 knots.

2.8 Aids to navigation

2.8.1 Published Instrument Approach Eindhoven Airport

For landing on runway 21 at Eindhoven Airport coming from the south, the standard published instrument approach procedure is to fly to GEMTI navigation point and then turn left via navigation points EH571 and EH568. EH568 is the intermediate fix (IF).[12] At 6.1 NM, the final approach fix (FAF, or final approach point FAP) a minimum altitude of 2000 feet should be flown. After the FAF, the crew can expect ILS landing clearance and the final descent towards the landing runway may commence (see figure 2).

2.8.2 Instrument Landing System

General information

The ILS provides guidance to pilots to assist them in landing safely, even under conditions of reduced visibility and low cloud ceiling. The ILS is a ground-based radio wave system providing both lateral and vertical landing guidance to aircraft at airports under all weather conditions.

The ILS at Eindhoven Airport consists of a localiser for lateral guidance, a glide path for vertical guidance and DME for determining the distance to the runway. Eindhoven Airport is not equipped with Marker beacons, nor is it required to be. The localiser is not part of the investigation.

In the approach towards ILS final, aircraft follow a standard published instrument approach or fly according to directions (i.e. radar vectors) from an air navigation service station.

10 Radar Approach Control.
11 The arrival, instrument approach and holding procedures are based on ICAO Annex 2 and ICAO Doc 4444-ATM/501 (PANS-ATM), Doc 7030 (SUPPS) and Doc 8168-OPS/611 (PANS-OPS).
12 Aeronautical Information Publication Netherlands.

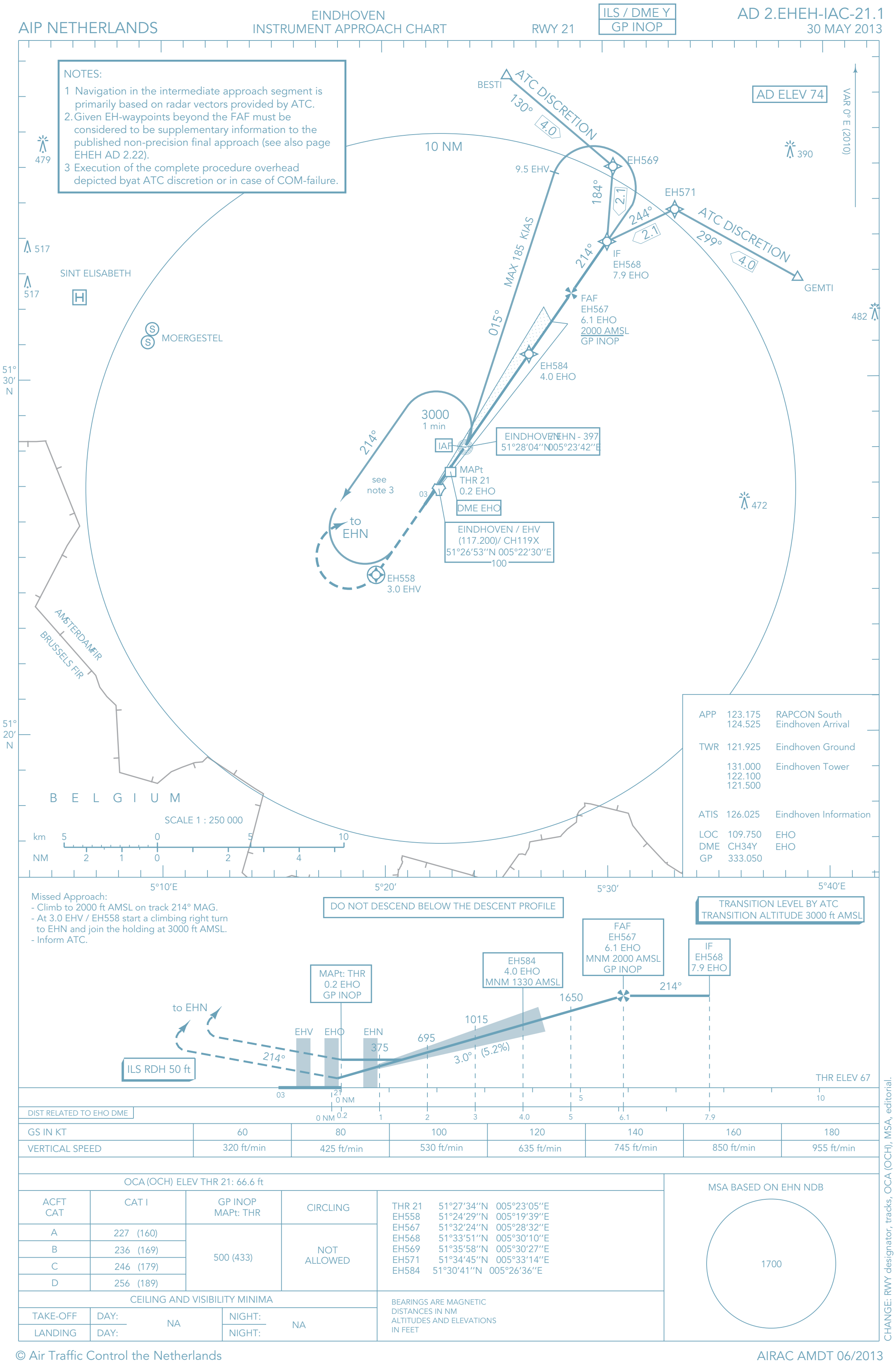

Figure 2: published instrument approach for runway 21 at Eindhoven Airport. Bron: AIP Netherlands

Glide slope – vertical guidance

The glide slope antenna is situated to one side of the runway touchdown zone and a signal is transmitted indicating the glide slope. The centre of the glide slope signal defines a glide path of approximately 3 degrees above horizontal (ground level).

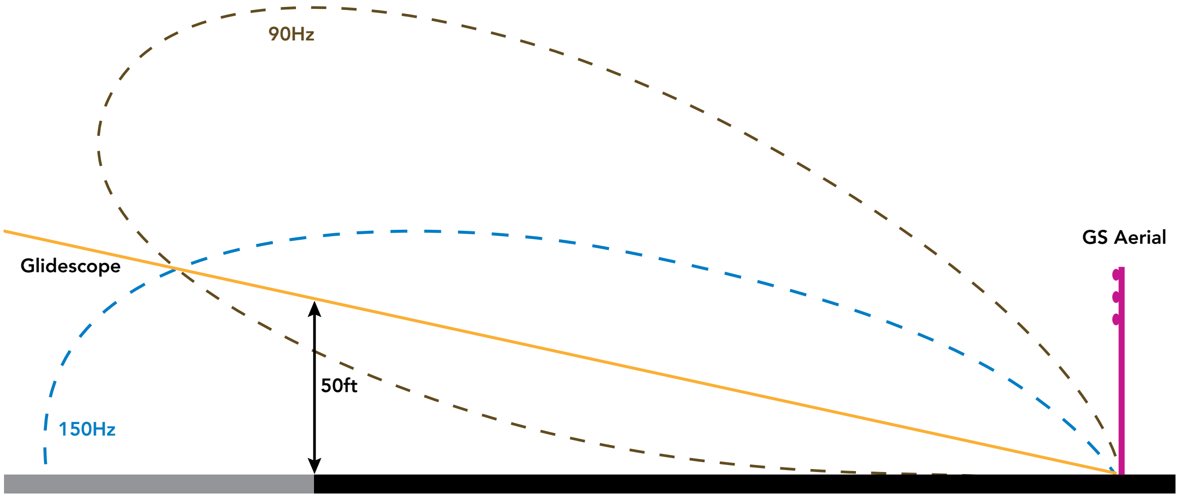

Figure 3: Vertical guidance signal.

The glide slope provides vertical guidance towards the runway. To follow the standard 3 degrees glide path, the pilot, or the automatic flight guidance system, controls the aircraft so that it flies on the imaginary 3 degrees approach line, and the glide slope indicator in the cockpit remains centred on the display.

Distance Measuring Equipment

Aircraft use distance measuring equipment (DME) to determine the distance to the DME beacon. A DME beacon can be co-located with an ILS localiser antenna installation where it provides an accurate distance to touchdown. At Eindhoven Airport co-located DME equipment is available.

ILS errors

An ILS is commonly perceived as transmitting a focused localiser and glide slope beam, which form a narrow electronic 'funnel' leading to the runway. In reality, ILS antennas transmit a complex radiation field. Due to the complexity of this field two different types of errors can be distinguished:

- Erroneous localiser or glide slope signal;
- False localiser or glide slope signal.

An erroneous signal is a deviation (multipath effect) of the signal due to an anomaly. The anomaly can be static, for instance when a hangar or fence is reflecting the ILS signal, or dynamic, when the erroneous signal is caused by the signal being reflected by moveable objects such as aircraft taxiing around the runway environment. Therefore ILS critical and sensitive areas are defined around ILS facilities in order to protect aircraft on approach from dynamic multipath effects that could cause the ILS signal to exceed allowable alignment and accuracy tolerances.

A second error type of the ILS signal is the false glide slope. This error is different as it is an artefact of the glide slope antenna itself. False glide slopes appear at 6, 9, 12 degrees, et cetera. Above the 3 degree ILS glide slope area signal deviations can occur which can result in unexpected movement of the glide slope indicator.[13]

2.8.3 ILS and DME system status

Electronic monitoring
The status of the airport ILS is permanently monitored electronically and displayed in the airport control tower by means of indicator lights, depicting the status of the system and ILS/DME system in use (active runway). The monitoring system in the Eindhoven control tower was serviceable at the time of the event and had not logged any problems before, during or after the incident.

Airborne flight inspection
ICAO mandates that radio navigation aids of all types, which are available for use by aircraft engaged in international navigation, are subject to periodic ground and flight checks.[14] Specially equipped aircraft, precisely positioned (laterally and vertically), are used to evaluate the signal-in-space and the instrument flight procedure twice a year. Flight inspection certifies instrument approaches to ensure that an aircraft at the lowest authorised altitude is guaranteed to be safe from obstacles.

During flight inspections the 3 degree ILS glide slope signal is inspected in different ways to verify a valid 3 degree glide slope signal. According to the manufacturer of the ILS antenna system, there are no regulations requiring checking the signal of the system above 5.25 degrees. Therefore the use of ILS above 5.25 degrees glide path is not certified.

The Eindhoven ILS for both runways were inspected on 23 April 2013. There were no anomalies and the system was deemed serviceable. There have been no pilot reports of any ILS or DME problems in the recent past regarding Eindhoven Airport.

2.9 Flight recorders

The Boeing 737-800 is equipped with a flight data recorder (FDR) and a cockpit voice recorder (CVR) for accident and incident investigation purposes, as mandated by regulations. The FDR stores 25 hours of flight data, the recording capacity of the CVR is 2 hours. After the recorders' memories are full, the recorded data is overwritten by new data, the oldest recorded data is thereby lost.

The company did not become aware of the full extent of the incident until the data was detected through the Flight Data monitoring (FDM) Program and reviewed on Tuesday 4 June 2014 following a public holiday. Once the extent of the incident became apparent it

13 As described in the Safety Alert issued by Dutch Safety Board.
14 ICAO ANNEX 10 Volume I, Chapter 2, 2.7.

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was immediately reported by the operator to the Dutch Safety Board and the Irish Air Accident Investigation Unit. The incident was reclassified as a Serious Incident. As the CVR/FDR data were lost on the aircraft's flights after the event, it was no longer possible to access this data.

As part of the flight operations and quality assurance program (FOQA) the Boeing 737 was equipped with a wireless quick access recorder (WQAR). This unit stores similar data to that of the FDR which is transmitted digitally to the home base, using the mobile network, after each flight. Upon request of the Dutch Safety Board the WQAR data was provided by the operator.

The data from the WQAR is recorded on a different medium than the FDR. This data is presented in Appendix F.

2.10 Tests and research

Following the analysis of recorded data, the Dutch Safety Board reconstructed the incident approach in a Boeing 737-800 simulator using information derived from the WQAR and the ATC transcript. During the simulator runs winds at 2000 and 3000 feet were programmed coming from direction 010 at 30 knots. The altitude of the aircraft at the turning point prior to heading 310 was 4300 feet.

The flight path in the simulator was flown according to the known ATC instructions and the position and parameters of the aircraft based on Eurocontrol and WQAR data. Turns were performed based on the given ATC instructions: '*FL070, descend 3000, left heading 310, continue descent to 2000, left heading 250 cleared ILS, call established*'. In the simulator the given heading of 310 led to a base leg track between 298 and 302, depending on the position of the aircraft when commencing the turn to heading 310 during the various simulator runs. The workload during the base leg was low since few actions had to be performed. The localiser was captured around 4 NM from the runway at about 1000 feet above the normal descent profile.

After the turn to heading 250 the aircraft was above the required altitude related to the distance from the runway. The tailwind resulted in an increased groundspeed and therefore in a reduction in time available to perform all required tasks; with the crew trying to capture the glide slope and preparing for landing, the workload in the cockpit increased.

During the simulator sessions no pitch-up reaction was observed while crossing the 9 degree glide path. During the actual incident flight, the autopilot started following the 9 degree false glide path. It was concluded that the 'false glide slope' is not programmed into the simulator's software. The simulator operator later verified this. Questions posed to other simulator operators yielded the same result. Between 1100 and 1200 feet altitude a manual upset was initiated by pulling the yoke backwards. During the simulated upset the nose of the aircraft was brought to 24 degrees nose up, resulting in a rapid speed decrease. The thrust levers moved forward as a result of the autothrottle

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attempting to maintain speed. After about 10 seconds a stall warning (stick shaker) was generated and a stall recovery was performed.

In another simulator run the flight path was flown as in the first run. However after instructions from ATC: '*left heading 310, continue descent 2000*' the decent rate was set to 1500 feet per minute as per Boeing Flight Crew Training Manual (FCTM) recommended technique for intercepting the glide slope from above. In this run also, the descent technique was not sufficient to capture the ILS glide slope in time and the aircraft was well above the glide path all the way.

Instead of using the Vertical Speed Mode, Level Change Mode was used to test if this mode would have made any difference. The same lateral profile was flown but, because of the speed reduction and flap extension on base leg, significant difference in the vertical profile was not observed. During both mode selections the throttle remained in idle during the descent.

To establish whether it was possible at all to intercept the required descent profile, after the turn to heading 310 the gear and flaps were extended early in another run. This resulted in the simulator in a level off at 2000 feet before the turn to heading 250 was instructed by ATC.

Because it was not possible to capture the glide slope during the incident flight, it was concluded that the influence of the wind on base leg, but even more on final, made it impossible to descend in a way that the glide slope could be captured once the turn to heading 310 was initiated without additional use of speed brakes.[15]

2.11 Organization and management information

2.11.1 Ryanair

General
The operator, operating more than 1600 daily flights (over 500,000 per year) from 186 airports in 30 countries, has a fleet of 303 Boeing 737-800 aircraft.

Flight Safety Programme
The operator has established and maintains an accident prevention and flight safety programme (FSP).[16] This programme forms a constituent element of the operator's safety management system and is described in detail in the company's safety manual.

Procedures for the handling, notification and reporting of occurrences are contained in the company's Operations Manual Part A –"Safety and Emergency Procedures". As part of the FSP the company or commander of an aircraft shall submit a report to the National

15 Boeing analysis shows that additional use of speedbrakes prior to urning onto the final approach leg would have allowed the crew to descend to the proper altitude to capture the normal 3 degree glideslope within the recorded airspeed targets.
16 In accordance with the Requirements of EU-OPS 1.037.

Civil Aviation Authority of any incident that has endangered or may have endangered the safe operation of a flight. Reports shall be despatched within 72 hours of the event, unless exceptional circumstances prevent this. The initial incident signal will be raised by the commander or the duty operations controller in accordance with the format given and the procedures contained in the safety manuals.

Under certain circumstances it is mandatory to preserve CVR and FDR data after an occurrence. The operators Operations Manual (OM) Part A states that after any incident, other than the ones mentioned in the OM, a commander believes that CVR data would be useful in a subsequent investigation, it is the responsibility of the captain to ensure that following a serious incident the yellow-collared CVR circuit breaker is pulled at the earliest opportunity on the ground. The company's procedure described in operations manual part A, chapter 8 does not include pulling the circuit breaker in the event of a stall warning or ILS upset. After the company became aware of the severity of the upset in combination with a near stall situation while trying to capture the ILS glide slope, an investigation was initiated. The company's internal report was available to the Dutch Safety Board.

Quality assurance program

The company operates a Flight Operation and Quality Assurance (FOQA) program. As part of this program the DFDR data is transmitted to the WQAR on board of the aircraft. After each flight, the encrypted data from the WQAR is transmitted to the company by means of the mobile network (GSM). The data is then loaded automatically into a data server (AirFASE) that analyses the data and presents it to a data analyst. All high & medium severity events are automatically raised and then reviewed by FOQA. Trigger settings for some 90 events have been set by the operator and programmed in AirFASE. The trigger settings are subject to an annual end-of-year review by a group of training captains and are used to increase safety. The trigger settings are also available to AirFASE users when reviewing a flight for the purpose of debriefing crews. The trigger settings are not made available to the general pilot body so they can not anticipate their flying behaviour based on the trigger settings.

2.11.2 Air traffic control

General

Air Operations Control Station New Milligen (AOCS NM) is part of the RNLAF organisation and is located in the centre of the Netherlands. The responsibilities of AOCS NM include general and approach air traffic control within Dutch Military Air Space, including incoming traffic to all air force bases, including Eindhoven Airport. Various direct phone and intercom connections exist between the approach controllers at AOCS NM and the local approach controllers at the various air bases.

Runway in use

At Eindhoven runway 21 was in use. Eindhoven Tower Control makes the choice of runway. According to Eindhoven Local Operating Procedures (LOP), the choice is made depending on wind direction, runway in use at the nearby Volkel Air Base, available navigation aids, visibility, runway and approach lighting and possible operational reasons. Only surface winds are available to the Eindhoven Tower Controller.

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Because of the layout of Eindhoven Airport, with the taxiway and apron on opposite sides of the runway, the choice of runway also influences the amount of traffic having to cross the active runway when taxiing, possibly resulting in delays or potentially unsafe situations. For that reason there is a tendency for the tower controllers to prefer runway 21. This implies that in some cases a tailwind is accepted, but only if the final tailwind component is less than 10 knots.

Flight Safety Programme
As part of the RNLAF Safety Management System (SMS), AOCS NM and Eindhoven Air Base have a Safety Management System. The RNLAF SMS involves reporting and investigating occurrences, including occurrences where ATC is involved. Procedures are laid down in the RNLAF Safety Management Handbook and the respective safety management handbooks of Dutch Mil and Eindhoven Air Base. Part of the SMS is the reporting of occurrences by means of an Air Traffic Management Safety Report (ATMSR). An ATMSR is written whenever ATC safety is involved (occurrences) or when lessons can be drawn (incidents). After completion, the ATMSR is sent to the base flight safety officer who starts an investigation when deemed necessary. If the investigation demonstrates that the severity of the occurrence is classified as major, the ATMSR is sent to RNLAF Headquarters Flight Safety Bureau for further investigation.

After the initiation of the go around the crew mentioned to the approach controller that a go around was initiated due to a false glide slope interception. At that time, a dangerous situation was not mentioned to ATC, nor was anything said about a near stall situation. It wasn't until the Dutch Safety Board started the investigation that ATC was aware that a potentially dangerous situation had occurred. The RNLAF did not start a separate investigation.

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3 ANALYSIS

3 ANALYSIS

3.1 General

The following factors did not affect the aircraft's flight path and did not have a causal relation with the occurrence:

- Both crew members were qualified and met the standards for flying. Duty time rosters showed they met the rules and standards of duty and rest times.
- The Eindhoven Arrival Controller was qualified. Duty time history showed that the controller met the rules and standards of duty and rest times.
- There are no indications the aircraft did not perform according to specifications.
- There were neither problems with the ILS equipment on board, nor with the autopilot or autothrottle.
- The Eindhoven ILS was released for use without any restrictions.
- The renumbering of the runway the day prior to the incident did not have effect on the occurrence of the incident.

The trigger settings of the FOQA program are not available to the general pilot body so they can not anticipate their flying behaviour based on the settings. No further investigation was done into the settings and use of the FOQA program.

The analysis in this chapter focuses on the effect of the upper winds, the approach, the intercept of the glide slope, influence of automation on flight path management, and actions taken by the parties concerned.

3.2 Weather and choice of runway

IMC weather conditions meant that the entire approach was flown without ground visibility. The crew was therefore totally dependent on flying on instruments for ground reference and positioning.

When making the choice of runway, only surface winds are available to the tower controller. The surface winds were from direction 330 at 8 knots. The use of runway 21 at Eindhoven Airport resulted in a crosswind at surface level with a slight tailwind component of around 2 knots. This tailwind was within the ATC operational limits to use the runway as landing runway. However, the winds at 2000 and 3000 feet from the North indicated a 30 knots crosswind was present on base leg for runway 21. This crosswind pushed the radar vectored aircraft towards the runway and thus reduced the length of the ground track to the threshold of the runway. Additionally, with the northerly winds at 2000 and 3000 feet, the aircraft encountered a tailwind on final. The tailwind increased the groundspeed on final requiring the crew to increase the rate of descent.

The Eindhoven Tower Controller was unaware of the winds at altitude, this information is not presented in the control tower. Based on the factors mentioned in paragraph 2.11.2, runway 21 and the corresponding approach were in use. The effect of the upper winds would have been significantly less if runway 03 had been in use. The effect of the wind on base leg would not have led to a decrease in the ground track to the runway threshold, more likely it would have led to an increase (See paragraph 3.3). On final, the resulting headwind would have given more time and a decreased rate of decent because of a decrease in ground speed.

Conclusions

Eindhoven Tower Control had no information available regarding to winds at altitude. The controller did not take into account the influence of the upper wind when deciding on the runway in use.

The use of runway 21 resulted in the upper winds influencing the flight path and descent rate to the extent that ILS glide slope capture was greatly impeded.

3.3 The approach

3.3.1 General

The aircraft entered Dutch airspace in the South at approximately 08.30 hours, and switched to Dutch Mil shortly thereafter. Dutch Mil instructed the flight crew to descend to 3000 feet. The crew was expecting to fly via GEMTI navigation point. In the region of Venlo, the aircraft was transferred to Eindhoven Arrival. From that point the crew received radar vectors towards Eindhoven Airport in order to intercept the ILS for landing on runway 21.

Prior to flight 3531 starting its approach, three other aircraft landed at Eindhoven Airport: at 08.11, 08.15 and 08.45 hours respectively. A fifth aircraft in line for landing was planned for the approach after flight 3531's scheduled landing time. There was no need for the arrival controller to have the aircraft fly a shorter route to save time or make room for this aircraft in line for landing. At the time of the occurrence, it was common practice to guide aircraft to Eindhoven Airport by means of radar vectors. Because the first three aircraft were all flying the published route and were thus responsible for their own navigation, the arrival controller was not aware of any wind corrections needed to maintain the ground track.

3.3.2 Radar vectors to base leg

At 08.44:19, the aircraft was passing 4300 feet in the descent from 7000 feet to 3000 feet, 4 NM prior to reaching GEMTI (figure 4, position ①). The Eindhoven Arrival Controller instructed the flight crew to fly heading 310 degrees and descend to 2000 feet. This heading was generally used by Eindhoven arrival to guide aircraft coming from the South to fly a route from the intersection of Eindhoven control zone (Eindhoven CTR) and Volkel CTR in the southeast, to a position approximately 8 NM on ILS final (from position ① to position ② in figure 4). Flying this route also keeps traffic clear of military air traffic from the nearby RNLAF Volkel Air Base positioned northeast of Eindhoven Airport. This way of vectoring aircraft is commonly used by ATC and should not be regarded as a "short ILS-line-up" for which special instructions apply.[17]

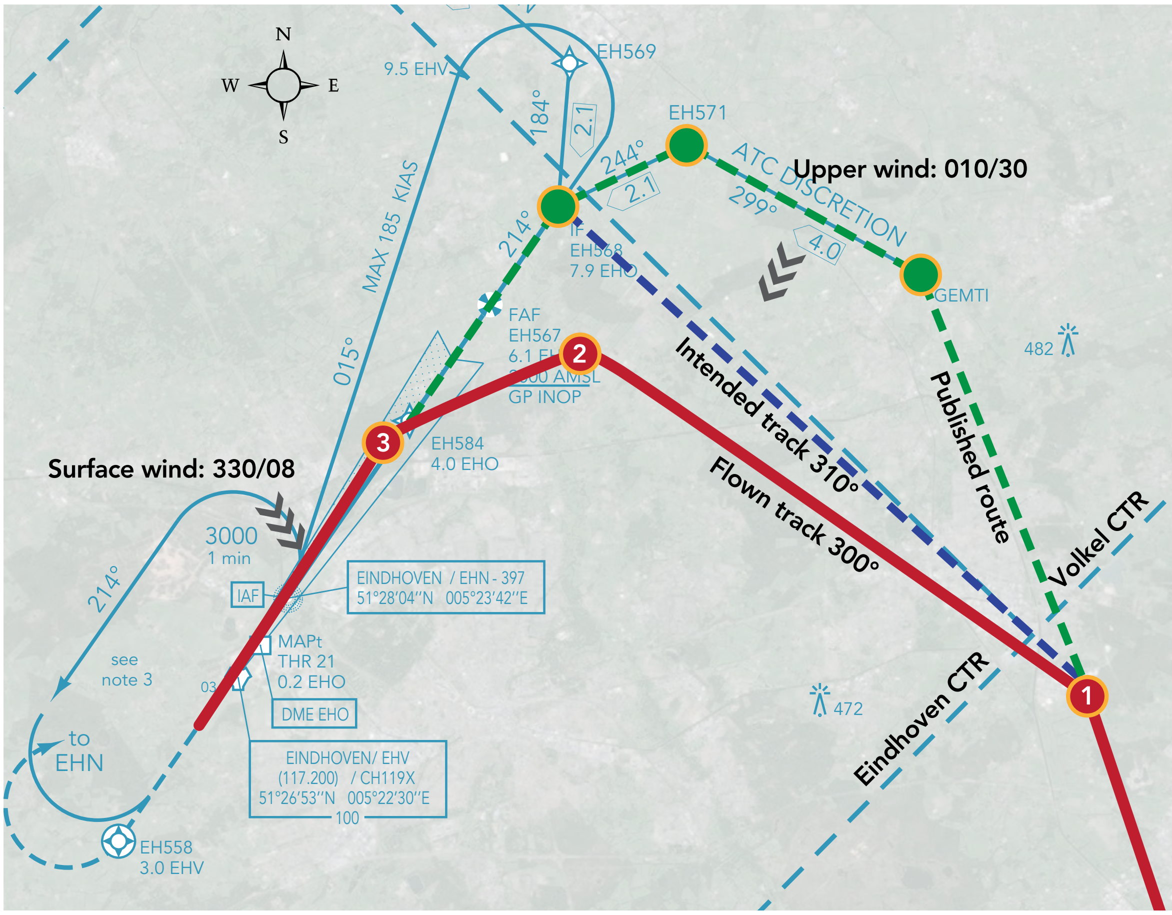

Figure 4: Top view of the planned (green line, published approach), the instructed (blue line) and the actual flown (red line) approach to Eindhoven Airport.

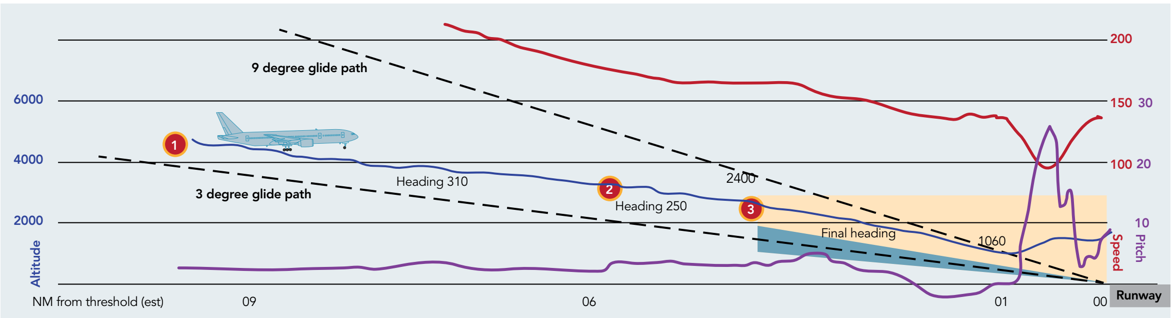

Figure 5: Schematic display of timeline and descent profile, detailed information is published in Appendix G. On the vertical height (left) speed and pitch (right) are depicted, on the horizontal the estimated distance from the runway threshold is shown.

17 The LOP AOCS NM is an internal handbook used by ATC AOCS NM. The LOP describes the procedures, rules and regulations used by military ATC, both arrival control and tower control at the RNLAF air bases.

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Both before and during the vectoring of the aircraft, the Eindhoven Arrival Controller gave no additional information about the intended flight track to the flight crew. According to *ICAO Doc 4444 Procedures for Air Navigation Services / Air Traffic Management* flight crews shall be informed when they will be radar vectored deviating them from their previously assigned route. The vector and the limit of the vector shall be specified. The air traffic controller was unaware of this procedure and therefore the flight crew was not given advance warning that they could expect radar vectors and a shorter than published approach. Despite the fact that the possibility of a shorter route was mentioned during the pre-landing briefing, it seems that the crew was not prepared to actually fly this. During an interview, the captain stated they were not fully aware of the flying distance they had left during the approach. The flight crew was prepared for the published instrument approach and the corresponding descent profile. They did not question the ATC's instruction to deviate from the published approach. They complied with the instruction and thereby accepted the shorter flight time and the need to adapt the flight pattern. Actions had to be taken quickly to follow the new descent profile and to change the aircraft configuration in order to be ready for the final approach.

3.3.3 Winds on base leg and final

On the day of the occurrence the winds at 2000 and 3000 feet altitude were from direction 010 degrees at 30 knots. This created a 30 knots crosswind on base leg resulting in the flown ground track of 300 degrees. According to WQAR and radar data the ground track flown was indeed 300 degrees, bringing the aircraft closer (approximately 2 NM) to the runway than was planned by the Eindhoven Arrival Controller, further decreasing the ground track and the time available for the descent. The Eindhoven Arrival Controller was unaware of the winds at altitude and therefore did not correct for the wind situation during the approach. Only surface winds are available to ATC and winds at altitude are not normally pre-planned for the approach. When needed, heading corrections are given if the flown traffic pattern deviates significantly from the pattern planned. When asked, multiple ATC controllers stated that wind corrections are made only after it is obvious that traffic is significantly influenced. Corrections are then applied to follow-on traffic.

Because flight 3531 was the first flight of the day where the ATC controller issued radar vectors, the controller was not aware of the wind influencing the traffic pattern. When the controller noticed the aircraft flying a different track than was planned, the controller was under the impression that the crew was flying a shorter route directly towards the FAF to save time. According to the controller this was not uncommon and was tolerated by ATC as long as shorter routes did not conflict with other traffic.

3.3.4 Base leg

Before the turn to base leg (heading 310), the aircraft roughly followed the vertical flight path calculated by the Flight Management System (FMS). After the turn to base leg, while flying heading 310, the captain updated the Flight Management Computer (FMC) to reflect the shorter route to 6 NM final for the ILS approach. Starting from the base leg, the aircraft was flying above the calculated vertical path. This was indicated by the vertical deviation scale and pointer in the right lower corner of the Navigation Display (ND). Because the aircraft was now on base leg with a high airspeed and above the predicted glide path, the aircraft had to descend and reduce airspeed quickly. The flight crew selected 180 knots and extended the flaps to 'flaps 5'. They used the vertical speed pitch mode of the AFDS with the vertical speed set to 500 feet per minute descent, and in doing so were able to reduce the airspeed more quickly.

The vertical speed mode was maintained until the speed reached around 184 knots. Because a vertical speed descent rate of 500 feet per minute was used, the altitude loss per NM was reduced, resulting in the aircraft being 1000 feet above the descent profile needed to follow the 3 degree glide path. When reaching 2650 feet at approximately 08.46 hours, level change mode was selected.

3.3.5 Turn to final

At 08.46 Eindhoven Arrival instructed the flight crew to fly heading 250 degrees to intercept the ILS, and asked them to report when established on the ILS. This was again a heading often used by the Eindhoven Arrival Controller to bring the aircraft from the intended track of 310 degrees, to a 6 NM final (FAF) to intercept the ILS. By turning to the left the crew factually reduced the required horizontal distance to the threshold. At the moment of the turn the aircraft was already at 6.85 NM from the runway at an altitude of approximately 3000 feet. Normally at that distance from the runway the preferred altitude is 2055 feet. On the MCP the heading 250 was selected. Ten seconds after the clearance was given to intercept the ILS, the approach mode was armed. The localiser was captured at 08.47:25 hours and the aircraft turned to the localiser heading of 215 degrees. At 4.1 NM the aircraft was established on the localiser. At that moment the altitude was 2400 feet, while the normal altitude at this point is 1300 feet.

After the turn to heading 250 the crew encountered a tailwind component during the intermediate leg and the beginning of final. WQAR data showed that on final approach the aircraft's groundspeed was 20 knots higher than its indicated airspeed. The combination of shortened distance, high initial altitude and tailwind required increased use of speed brakes to intercept the ILS glide slope in time to make a successful landing. This was confirmed during the simulator flights performed by the Dutch Safety Board after the incident (see paragraph 2.10) even with vertical speed selected to 1500 feet per minute during final, but without speed brake selection as was suggested by the manufacturer later in the investigation.

The aircraft was high and flying with a tailwind, but the arrival controller did not ask the crew for their intentions in relation to the altitude, nor did the controller adjust the flight path or the descent rate. The crew also made no remarks about the altitude in relation to the distance from the runway and did not ask for a change in routing. As a result the aircraft was about 1000 feet high on final, flying parallel to the glide slope.

Despite the fact the crew did not report established on the ILS, at 08.47 hours the Eindhoven Arrival Controller instructed the crew to contact Eindhoven Tower Control for landing. Normally, traffic is only transferred to the tower controller after it is established on the ILS approach and has so reported, or it is expected the aircraft will be established soon and coordination has taken place between the arrival controller and the tower controller. In this case, the tower controller was aware of incoming traffic, but the aircraft was high on the approach, just a few miles before the beginning of the runway and was

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not established. When the arrival controller cleared the crew to switch to Eindhoven Tower Control frequency for the landing clearance, the crew complied and made no remark about an impending go around.

Conclusions

Other traffic landing at Eindhoven Airport prior to flight 3531 made use of the published approaches. This traffic did not pose hinder or threat to flight 3531. The arrival controller did not gather wind information from these flights.

The use of radar vectors to guide aircraft to Eindhoven Airport, not following the standard published approach, was common practice at the time of the occurrence. The Eindhoven Arrival Controller did not inform the flight crew of the impending radar vectoring deviating the aircraft from the previously assigned route.

The Eindhoven Arrival Controller had no information regarding the winds at altitude. When the aircraft deviated from the planned track, the controller did not make any heading corrections and persisted in conducting the approach as planned.

The radar vectors provided by Eindhoven Arrival Control and the winds on base leg and final resulted in a reduction of the ground distance the aircraft had to fly to the runway. These factors caused the aircraft to be high in altitude during the approach.

Despite the fact the aircraft was high during the approach, neither the arrival controller nor the crew made remarks about the altitude in relation to the flight path or asked for a change in routing.

The flight crews' selection of 500 feet per minute descent rate on base leg meant the aircraft did not descend fast enough to compensate for the reduction in flight distance and time.

The Eindhoven Arrival Controller handed the aircraft over to the Eindhoven Tower Controller without coordinating with the tower controller, despite the fact the aircraft was not established on the approach.

3.3.6 Short final, upset and stall warning

At 08.47:45 hours the landing gear was selected down, followed 10 seconds later by arming of the speed brakes and the selection of flaps 30. At 08.48 hours, speed was selected at 140 knots, followed by flaps 40 and speed 135 knots. The captain informed the FO to "prepare for a go around". The operator's procedures prescribe that an approach should be discontinued and a go around initiated when the aircraft is not stabilised at 1000 feet while flying under IMC conditions. If the crew had become visual with the runway before reaching 1000 feet, company procedures would then allow them to continue the approach as long as a stabilised approach would be reached before passing 500 feet. Flight analyses showed that the after landing checklist was completed at approximately 1400 feet. From an aircraft performance standpoint, flight 3531 was unable to reach a position from where a safe landing was possible.

The crew performed a monitored approach as described by the operator's Flight Crew Operations Manual. This approach directs the captain to make the decision for a go around. The FO attempted to intercept the glide slope before the altitude of 1000 feet. The captain was already unsure if the approach would be successful well before reaching 1000 feet. While the aircraft was configured for landing and the checklist completed, no safety concerns were present in delaying the go around decision to see if the glide slope could be intercepted before the 1000 feet gate (decision point).

On final approach, if the crew had visibility of the runway or had better performed the crosschecks recommended in the Boeing FCTM, it would have been clear to them that a safe landing was impossible from their position. As the crew did not have ground contact during the approach, the situational awareness about altitude versus distance to the runway was insufficient to realise that a safe landing could not be made and a go around should have been initiated.

It is the Boards' opinion that if flight parameters indicate that a safe approach is doubtful, the crew should commence a go around. The operator has a no blame policy for go-arounds. The operator's crews are trained to go around at any stage of the approach if they feel it is unsafe to continue, despite the fact that the company's SOP mentions 1000 feet as the gate. The gate in this case would then be a last barrier for the decision to be made, not an altitude that the crew should wait for.

At 08.48:41 hours glide slope capture occurred at an altitude of 1060 feet at approximately 1 NM from the runway threshold. The crew later reported the glide slope indicator initially went full down and then up again. Analyses shows that the aircraft had flown parallel to the 3 degree glide slope and had intercepted the 9 degree false glide path which has a signal reversal. The aircraft crossed the 9 degree glide path and was now receiving the 9 degree false glide slope signal. The movement of the glide slope indicator in the cockpit gave the flight crew the impression that the glide slope was valid and 'alive'. Also no warning flag was presented to inform of any danger. Because ILS signals at 9 degrees glide slope are reversed from the normal 3 degree glide path signals, the aircraft received fly-up information rather than fly-down. The pitch started to increase rapidly from 0.5 degrees aircraft nose down (-0.5 ANU) as the aircraft flew through the 9 degrees glide slope beam and the deviation from the beam increased.

When the captain saw the glide slope movement and the following pitch up moment, he informed the other crew that it was probably a false glide slope and called for a go-around, 2 seconds before the stick shaker warning was activated. During this analysis and conversation he was not aware the speed dropped that much.

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Pitch-up upsets due to ILS false glide slope
During the investigation the Dutch Safety Board discovered several characteristics of the ILS that were not generally known to operators, flight crew and manufacturers. Furthermore, it became clear this incident was not unique. This led the Dutch Safety Board to conclude that these ILS characteristics are a possible threat to aviation safety; they may result in unexpected aircraft behaviour and may thus endanger the safety of passengers and flight crews. The Dutch Safety Board therefore started a separate investigation into pitch upsets and ILS glide slope characteristics. The report of this investigation was published contemporaneously with this report.

Prior to the capture, the following indications were available to the crew to build their situational awareness:

- The glide scope scale and pointer showed over 2 dots deviation for the duration of the approach until approximately DME 1.5 NM.
- The deviation was not decreasing as it normally would when approaching the 3 degree glide slope from below.
- The altitude range-distance derived from the DME distance and altimeters was different from normal.

No faults annunciated to indicate that a false glide slope had been captured. The capture of the glide slope signal allowed the crew to continue the approach as this is one of the checklist items. While the aircraft followed the glide slope commands the pitch increased above the normal attitude for an ILS approach, which is limited to only several degrees nose up. As the pitch kept increasing one of the criteria for an upset condition (pitch attitude greater than 25 degrees nose up) was met.

As the combination of a false glide slope and the aircraft auto flight systems following the reversed glide slope signal led to an upset, the event can be described as an automation surprise. Current simulator technology does not provide an opportunity for crew to be trained in false glide slope events and crew knowledge is restricted to theoretical technical knowledge that are not covered in any detail in current aircraft flight or training manuals. It is not an industry practice to train for these kind of scenarios. The flight crew therefore had neither sufficient knowledge about the false glide slope phenomenon, nor were they trained in simulator sessions to handle this automation induced upset. As has been confirmed by several simulator manufacturers and the operator, modern simulators are incapable of re-producing a false glide slope event. This prevents the provision of related skills training for pilots.

When the stick shaker activated during the upset, the pitch was immediately reduced by applying of full forward column. The increasing tailwind as perceived by the aircraft because of the increasing altitude led to a small performance decrease. Despite the initial upset recovery response, the AOA increased above the stick shaker trip value again. When the stick shaker activated for the second time, the captain assisted the FO in reducing the pitch of the aircraft.

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Investigation of the crew's training files regarding upset recovery training revealed that the captain's last stall recovery training was performed and assessed during a Multi Pilot Aeroplane (MPA) skill test in January 2011. The FO performed this skill test and the stall recovery training in September 2012.

The upset experienced by the flight crew is not normally addressed in simulator training in general, the simulator training does not reflect the magnitude of the upset and the required recovery technique during the incident flight. Simulators are normally not programmed to simulate upset scenarios accompanied by an increasing tailwind during the recovery manoeuvre. The normal upset recovery training performed in the simulator does not include a scenario wherein the aircraft is in a landing configuration at low airspeed, nose high attitude with maximum engine thrust. The effect of an increasing tailwind during an upset recovery is normally not trained for in the simulator.

Conclusions

The crew had a degraded awareness of their descent profile in relation to the position to the runway.

Before reaching the 1000 feet decision gate, the flight crew experienced an automation surprise followed by an upset.

The aircraft following the fly up signal from the 9 degrees false glide slope resulted in pitch up of the aircraft, and the AOA increased above the stick shaker trip value.

The upset experienced by the flight crew is not generally addressed in simulator training, the simulator training of the flight crew therefore did not reflect the magnitude of the upset and the required recovery technique during the incident flight.

The subsequent upset with an increasing tailwind is not a feature of simulator upset training scenarios.

The initial Stall Recovery Manoeuvre was executed adequately. Despite the initial upset recovery response, the AOA increased above the stick shaker trip value again. Consequently a second stick shaker warning occurred.

3.3.7 Effect of wind

During the approach a strong northerly wind influenced the flight path of the aircraft. It remains unclear if the flight crew observed the wind information presented on the Navigation Display. While flying the shorter route maximum effort was taken to decelerate the aircraft in order to be able to extend the flaps and gear. Initially also the speed brakes were used.

Either a different routing other than the flown track or extensive additional use of speed brakes during the intermediate and base leg of the approach would have significantly improved the descent profile and thereby lowering the flight altitude at the start of the final approach. With winds reported from 330 at speeds of 8 knots on the ground the crew did not have information nor could they predict when the wind speed would reduce from 30 knots to 8 knots. Therefore even if they had observed the wind readout on the FMS while flying on the base leg they could not have accurately predicted when the excessive altitude would have been lost and the three degree glide path intercepted. When the turn to final was initiated and the aircraft configured for landing nothing else could have been done to increase the rate of descent. Because of the tailwind on final the descent rate was equal to the descent rate required to maintain a 3 degree glide path. Without the tailwind descent rates of up to 1500 feet per minute would have been possible with an aircraft in landing configuration thereby quickly regaining the normal 3 degree glide path.

Conclusion
While flying the shorter route maximum effort was taken to decelerate the aircraft in order to be able to extend the flaps and gear. Initially also the speed brakes were used.

Only a different routing or extensive additional use of speed brakes during the intermediate and base leg of the approach would have significantly improved the descent profile at the start of the final approach.

3.3.8 Reporting the event
During the go around the crew switched to Eindhoven Arrival Control. They mentioned to the approach controller they had flown a false glide slope ILS approach in a calm voice. Nothing was mentioned to the controller about a near stall situation. Since the severity of the incident was unknown the Eindhoven Arrival Controller made no entry in the ATC daily log of the go around. The Eindhoven Tower Controller did make an entry, but since the severity of the go-around was unknown no air traffic management safety report was written; therefore the air navigation service provider did not investigate the event.

At 09.10 hours the captain contacted the company's duty pilot by mobile phone to inform him about the occurrence. During this conversation it was mentioned that a stick shaker had occurred and a go around was made. The captain informed the duty pilot about the event and asked if the flight recorders circuit breakers should be pulled prior to the next flight. According to the duty pilot the operator has over 1600 flights per day and momentary stick shakers occur from time to time, most often associated with turbulence on approach. The duty pilot was not alerted to the extent of this event during the phone conversation. According to him, the crew were engaged in maintaining control of the aircraft to the extent that they were unaware of the severity of the temporary decay in airspeed, and thus the occurrence was not adequately communicated.

The mandatory safety incident reporting was done when the crew returned to base at the end of the day. Due to a public holiday in Ireland the event was reported to the Dutch Safety Board on 4 June 2013, four days after the occurrence. The FDR and CVR were no longer available for the investigation and the crew was interviewed at a later date and the 'level of detail' of the available information was substantially reduced. Conducting an investigation without much contextual information, especially from the CVR and FDR, reduces the effectiveness of the investigation both in depth and time. Regulations and procedures are in place to conduct a safety investigation to learn from the event and prevent reoccurrence. Therefore notification of an event should be done without delay and to the appropriate authority. This will allow for a timely investigation where vital information is available to the investigative authority.

Conclusion
The Eindhoven occurrence was initially reported and assessed by the operator as a minor event which did not warrant CVR and FDR retention.

3.4 Intercepting the glide slope

3.4.1 The incident flight

An approach can be flown at different levels of automation. For non-ILS approaches it is recommended to choose a high level of automation to reduce flight crew workload. In normal operations an approach is flown using autopilot and autothrottle engaged. The operator has established a "landing gate" (decision height) at which point the aircraft should be "stabilised". If the aircraft is not stabilised by a defined altitude, a go around is mandatory. Depending on weather conditions, instrument or visual metrological condition, the gate is either 1000 feet or 500 feet respectively. Because of the reported IMC weather at Eindhoven the "landing gate" for this flight was 1000 feet.

According to the Boeing FCTM an approach may be flown using HDG SEL or LNAV for lateral tracking and VNAV, LVL CHG or V/S for altitude changes. VNAV is the preferred descent mode when the FMS flight plan is programmed for the planned arrival. When VNAV is not available, LVL CHG is set for altitude changes greater than 1000 feet. For smaller altitude changes, V/S is more appropriate for the descent rate.

When configuring the aircraft for landing, the crew used LVL CHG mode in the AFDS. In LVL CHG the autopilot uses pitch input to maintain the selected airspeed. In V/S a selected rate of descent is maintained. If the selected rate is high enough the possibility exists that, even with thrust set at idle, the airspeed will increase. Flap Limit Speeds can thus be exceeded easily. To attempt the glide slope intercept from above, the crew had to avoid a level off at the cleared altitude of 2000 feet. To do this they selected a lower altitude on the MCP. Initially 0 feet was set on the MCP but this was immediately changed to 600 feet. Boeing recommends that the glide slope should be captured prior to the FAF, but that a go around is not required until an altitude lower than 1000 feet.

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As the aircraft was configured for landing the speed decreased from 180 to 144 knots. Engine thrust was reduced to idle to make the speed reduction possible. Because LVL CHG mode was selected the change of altitude (vertical speed) was not directly controlled, primary control was the airspeed. As a consequence the aircraft did not descend at a rate which would make a capture of the 3 degree glide path possible. The aircraft continued to fly parallel to the 3 degree glide path, about 1000 feet higher. As was demonstrated in the simulator (paragraph 2.10), selection of V/S to capture the glide slope would have been unsuccessful also.

Conclusion
The selection of LVL CHG Mode during the approach resulted in insufficient loss of altitude. Simulator tests revealed that selection of Vertical Speed Mode also resulted in insufficient loss of altitude.

The aircraft was not in a position from where a successful intercept of the 3 degree glide slope was possible.

3.4.2 Intercepting the glide path from above

Boeing 737NG recommended techniques
In the Boeing 737 Next Generation FCTM guidance is given on how to intercept the glide slope from above in the section "Intercepting glide slope from above". The guidance starts with the explanation that normally the ILS profile is depicted with the aircraft intercepting the glide slope from below in a level flight altitude. However, there are occasions when flight crews are cleared for an ILS approach when they are above the glide slope. In this case there should be an attempt to capture the glide slope prior to the FAF. The map display can be used to maintain awareness of distance to go to the FAF. Boeing also recommends the use of the autopilot.

For ILS procedures the FCTM describes that the glide slope may be captured before the localiser in some aircraft. This is an option which is not available in all aircraft. It is mentioned that the glide slope may be captured from either above or below.

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Intercepting glide slope from above – Boeing 737NG FCTM June 2013 (excerpt from page 5.17 and 5.18)

"The following technique may be used for ILS (...), however it is not recommended for approaches using VNAV.

The following technique will help the crew intercept the glide slope safely and establish stabilised approach criteria by 1000 feet Above Field Elevation (AFE):

- *select APP on the MCP and verify that the glide slope is armed*
- *establish final landing configuration and set the MCP altitude no lower than 1000 feet AFE*
- *select the V/S mode and set -1000 to -1500 fpm to achieve G/S capture and be stabilised for the approach by 1000 feet AFE. Use of the VSD (as installed) or the green altitude range arc may assist in establishing the correct rate of descent.*

Monitor the rate of descent and airspeed to avoid exceeding flap placard speeds and flap load relief activation. At glide slope capture observe the flight mode annunciations for correct modes and monitor glide slope deviation. After glide slope capture, continue with normal procedures. Comply with the recommendations on the use of speed brakes found in chapter 4 of this manual.

Note: If glide slope is not captured or the approach is not stabilised by 1000 feet AFE initiate a go around. Because of glide slope capture criteria, the glide slope should be captured and stabilised approach criteria should be established by 1.000 feet AFE, even in VMC conditions."

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The goal of the recommended technique is to meet the stabilised approach criteria at an altitude of 1000 feet AFE. Vertical guidance is provided to intercept the glide slope from above. Boeing states it should be attempted to intercept the glide slope before the FAF, if this is unattainable, continuation to 1000 feet AFE is allowed. The Boeing FCTM provides guidance to verify the position of the aircraft with respect to the distance from the runway in the final approach section (page 5.16).

It is possible, using this technique, to continue the descent to 1000 feet AFE while the position and the energy state of the aircraft make a successful glide slope intercept impossible if the descent path is not actively being monitored and managed.

Additional crew actions beyond the technique described in the FCTM may be required as conditions require to achieve the desired descent profile. In this case the aircraft was flown at a distance much closer to the runway than it would normally be when intercepting the glide slope at 1000 feet. If descent path management to intercept and capture the 3 degree glide slope does not occur,. the risk of a false glide slope upset increases.

Air traffic procedures
In line with *ICAO Doc 4444 Procedures for Air Navigation Services Air Traffic Management*, the LOP for AOCS NM states that:

- The intercept altitude for ILS final is published in approach charts valid for the respective airfields/airports, the published altitudes shall be followed. The last vector to final shall be such that aircraft are able to intercept the localiser horizontally in order to be able to intercept the glide path from below. The intercept heading for ILS final is no more than 30 degrees from the final heading.
- During the final phase of the approach pilots' workloads are already high and short line-ups should be avoided. If ATC controllers do not anticipate short line ups adequately, aircraft will intercept the glide slope from above. This requires additional actions from the pilots in a shorter period of time, increasing the already higher workload. If for any reason a short line-up is flown, the altitude shall be adapted in order to accommodate intercepting the glide slope from below. In any case, the crew shall be informed.

The need for these procedures was published in a separate letter from the ATC squadron commander to all ATC personnel in July 2010. Although normally these letters are also part of the ATC training syllabus, when asked, the duty controller was unaware of the existence of this letter. The LOP AOCS NM Air Operations and Control Station Nieuw Milligen however is part of ATC training and day-to-day operations and the procedures for glide slope intercepts should be ready knowledge.

Conclusions
The Boeing 737NG Flight Crew Training Manual does not warn that false glide slope capture can result in a pitch-up upset when capturing the glide slope from above.

AOCS NM procedures dictate that whenever possible an ILS glide path should be intercepted from below.

ICAO Doc 4444 Procedures for Air Navigation Services Air Traffic Management states the last vector to final shall be such that aircraft are able to intercept the localiser horizontally in order to be able to intercept the glide path from below.

3.4.3 Distance versus altitude crosschecks
Distance to the runway in relation to the flown altitude can be checked by the flight crew using the following means. Not all options are available to all crews.

- Distance Measuring Equipment,
- FMS and Navigation Displays,

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- Vertical Deviation Indicator,
- Vertical Situation Display (VSD, was installed on flight 3551, but was not available to the crew).

This paragraph describes how these means can be used.

Distance Measuring Equipment
A way of checking the distance versus altitude is the use of the DME (slant range). DME distance is presented on the PFD. The distance presented should be checked in relation to the altitude flown during the approach procedure.

The best strategy is to periodically crosscheck the aircraft altitude against distance during descent. The DME is more appropriate to use as this is available on approach at all times. However, the interpretation of the DME distance may require some work. The altitude should be approximately 300 feet per NM of distance to the runway for a 3 degree glide slope.

FMS and Navigation Displays
The second option is to use FMS and Navigation Displays. The FMS gives the total distance to the runway which is presented on the corresponding Control Display Unit (CDU) page. The Navigation Display (ND) is able to present the distance to the runway in circles. These circles indicate the required distance to descend, decelerate and land from the present position.

The third option is to use the vertical deviation indicator. This is a symbol in the lower right hand corner of the ND that indicates the aircraft's vertical path computed by the Flight Management Computer (FMC). This symbol is displayed during the descent and approach phases of flight and informs the crew if the aircraft is high or low on the calculated descent path.

A fourth option is the use of the vertical situation display (VSD). The VSD is an extra mode (CTR MAP) of the Electronic Flight Instrumentation System (EFIS). The VSD gives a graphical picture of the aircraft's vertical flight path. The VSD works with the Terrain Awareness And Warning System (TAWS) to display a vertical profile of the aircraft's predicted flight path on the lower section of the Navigation Display.

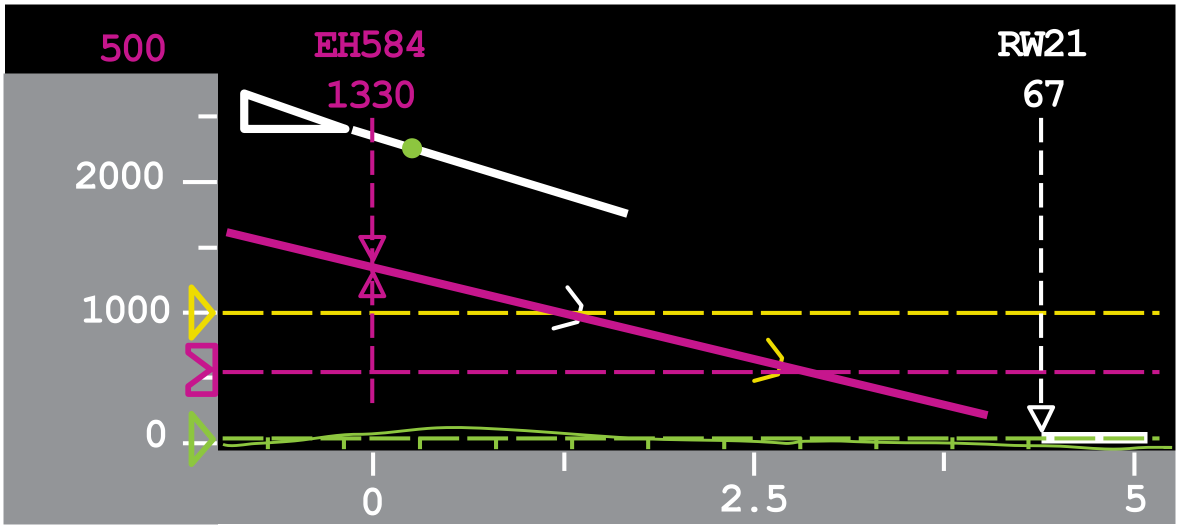

Figure 6: Example of the VSD when the aircraft is 1000 feet above the glide slope. The white triangle depicts the aircraft, the solid magenta line the 3 degree glide path, the 1000 feet (white) and 500 feet (yellow) decision gates (symbol).

The purpose of the VSD is to present a clear graphical picture of the aircraft's vertical flight path for enhancing the flight crew's vertical situation awareness. The VSD depicts the vertical situation of the aircraft relative to the terrain throughout all phases of flight. The VSD also depicts the vertical situation of the aircraft relative to the runway during final approach, allowing full-time monitoring of the aircraft position relative to the selected glide path. If navigation information is available a solid magenta line depicts the 3 degree glide path. Also the 1000 and 500 feet decision gates are displayed.

The VSD can be retrofitted to any B737NG but it requires software changes to the displays and FMC and also some additional hardware displays. This software is installed in the operator's B737 fleet. Pilots can only use this display if they are trained to do so. The crew of flight 3551 was not qualified to operate the VSD. During the investigation Ryanair indicated that it is developing an SOP for the introduction of VSD to line operations (see paragraph 3.6.1).

Conclusions
According to the Boeing 737NG Flight Crew Training Manual flight crew should perform distance-altitude checks and/or use VNAV path information to confirm the published ILS approach procedure is flown.

There are several means of crosschecking distance-altitude in order to determine that the vertical descent profile to the runway threshold can be achieved.

3.5 Flight Path Management and Automation

High levels of automation have become standard in modern aircraft, as is the situation in any other modern transport vehicle. Automation has improved flight safety, but it also changed the function of, and the demands on, pilots. Pilots have mitigated from hands-on flying, where they directly controlled the aircraft to the role of systems operators. From this perspective, the automation in aircraft has expanded the comfort zone of flight crews to operations made more complex by traffic congestion or environmental issues. This includes glide slope interceptions from above, safely executed on a daily basis. Several human factor studies showed that pilots place a lot of trust and dependency on the high level of automation because it has proved to be very reliable. This is a natural human state of mind as a consequence of a reliable human machine interaction. The Safety Board raised this issue in its investigation of the Turkish Airlines accident in 2009.[18]

Automation bias[19]
The availability of automation encourages pilots to adopt a natural tendency to follow the choice of least cognitive effort. When faced with making decisions pilots will rely on automation as a replacement for vigilance, and actively seeking and processing information, to control the flight path.

The Eindhoven incident flight crew was aware that they were flying on base leg above the vertical profile and on final above the 3 degree glide slope. They were also aware of the need to increase the descent rate in order to capture the 3 degree glide slope signal. Their predictions (flight path management) about where the 3 degree glide slope signal would be intercepted were incorrect and unrealistic. If the flight crew would have had visual contact with the runway then it would have been clear to them that the descent performance of their aircraft would have been insufficient. The distance versus altitude awareness in relation to the aircraft performance was degraded because of the IMC conditions.

For that reason additional means should be used in the cockpit or procedures developed for flight crew in order to protect aircraft entering the ILS false glide slope area in autoflight. This will help flight crews to decide whether continuation of the approach can be performed safely and warrants a decision to go around at an earlier stage. Vertical navigation displays are available on new aircraft and as a retrofit (as described in paragraph 3.4.3). These displays greatly enhance the distance versus altitude awareness of flight crew by graphically presenting the aircraft's position in relation to the runway and predicting where the present descent rate will position the aircraft in relation to the 3 degree glide path.

18 The report of this investigation is published on the internet site of the Dutch Safety Board: http://www.onderzoeksraad.nl/uploads/items-docs/1748/Rapport_TA_ENG_web.pdf.
19 Civil Aviation Authority (UK) (2004). Flight crew reliance on automation (CAA report no. 2004/10). Gatwick: CAA Safety Regulation Group (authored by S. Wood, Cranfield University).

While these additional displays or procedures can avoid flight crews flying in the critical ILS signal area with false glide slopes, they are not a substitute for distance versus altitude crosschecks by conventional methods belonging to basic flying skills. In that respect the Dutch Safety Board is concerned that the use of advanced automation can lead to situations where the flight crew's flight path management degrades. Flight crews should be made more aware of this. A recently published study of aircraft accidents between 1995 – 2009 and the role of cockpit automation confirms this, also see box below.[20]

Operational Use of Flight Path Management Systems
Two of the 18 recommendations in that final report state:

Flight path management: teach crew to concentrate on the flight path, not the automation, and to treat the automation as a tool to assist in flight path management.

Crews should be reminded that they should be prepared to tell ATC they are unable to comply with a request if it would be operationally challenging to carry out.

To improve aviation safety it is important that the adaptation and training of pilots keeps pace with the use and development of automation in aircraft. A balance must be found between the use of basic flying skills, knowledge and use of automation to control the flight path in the modern complex environment.

Conclusion
The high level of reliable automation in the cockpit can degrade pilots basic flying skills for flight path management.

3.6 Actions taken by parties concerned

3.6.1 Ryanair

In the immediate aftermath of the event, the operator issued a safety alert on their crew website. The alert also includes a recommendation on how to prevent similar incidents occurring.

The Eindhoven incident was also included in the November 2013 issue of the company safety newsletter Hotspots. The newsletter is available on the pilots website and is circulated in hard copy form at all bases.

20 Operational Use of Flight Path Management Systems, Final Report of the Performance-based operations Aviation Rulemaking Committee/Commercial Aviation Safety Team, Flight Deck Automation Working Group, September 5, 2013.

In addition to recent crew bulletins and articles in Hotspots Ryanair informed that a safety presentation was developed to highlight the threat of a false glide slope event to all crews. This presentation was rolled out across all of the operator's operating bases and was presented by the company's senior Flight Operations managers.

Following this incident, the preventive and recovery barriers in Ryanair's Loss of Control In-flight (LOC-I) Bow Tie have been reassessed and the operator is developing more prescriptive mitigating measures for intercepting the glide slope from above.

The revised policy includes a new horizontal landing gate for ILS interception from above; being the earliest of the following: the FAF, 5 DME, 4 NM for VMC operations and 5 NM for IMC operations. In addition to horizontal (and vertical) landing gates Ryanair is developing an SOP for the introduction of VSD to line operations. Ryanair has evaluated its new policies and procedures in the simulator.

An audio-visual e learning module has been developed that informs crew about the threats associated with False Glide Slope and explains the new horizontal landing gates.

A full flight simulator Flight Path Management module has been prepared and will be presented to all pilots between 1 May and 31 October 2014. The module will comprise theoretical elements and practical skills training.

Very shortly Ryanair will issue a revision to their Operations Manual which has received an NTO (No Technical Objection) from Boeing, prohibiting the automatic interception of the ILS Glidepath inside 5DME in IMC conditions (4DME VMC) thereby significantly reducing the exposure to False Glideslope events occurring.

3.6.2 Boeing

Boeing has announced that it will include a warning for pitch up when flying above the 3 degree glide slope in the next update of Boeing's 737 FCTM.

Boeing has also announced it will incorporate a software change to the B737NG Rockwell Collins Control Computer (FCC) as part of continuing improvements to its B737NG.

The FCC software change will incorporate a change that will limit the aircraft climb rate in glide slope mode. This change has been shown to eliminate the pitch up when the aircraft captures the reversed signal 9 degree glide slope beam.

The FCC software change is scheduled to be implemented in the 4th quarter 2014 on new B737NG aircraft. Operators will be informed by a Boeing Service Letter about the availability of the new FCC software; aircraft already in service can be retrofitted.

3.6.3 AOCS NM

Following the publication of the Safety Alert by the Dutch Safety Board the Safety Alert was circulated to all air traffic controllers. Accompanying the alert, personnel were reminded of the fact that procedures laid down in ICAO Doc 4444 and LOP AOCS NM regarding ILS approaches have to be followed whenever possible to avoid approaching the ILS from above.

During the 2013 annual flight safety awareness day additional information was given to all military air traffic controllers regarding the subject.

Dutch Air Force ATC regulations (Luchtverkeersvoorschrift voor de Koninklijke Luchtmacht, LVV, L5-1 par. 8) and the Local Operating Procedures AOCS NM (par. 3.5.2.5) were amended. They now state that whenever radar vectors are given for an ILS approach the glide path shall be approached from below.

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4 CONCLUSIONS

The analysis of the Eindhoven incident has led to ten main conclusions answering the two investigation questions:

- How did the actions of air traffic control and the flight crew contribute to intercepting the glide slope from above, and which factors explain these actions?
- How did the actions of the flight crew contribute to the ILS pitch-up upset and stall recovery, and which factors explain these actions?

Main conclusions

Eindhoven Tower Control

1. Eindhoven Tower Control, when deciding on the runway in use, did not have information available regarding the upper winds and thus did not take into consideration these winds in the IFR traffic pattern. The choice of landing runway resulted in the aircraft drifting on base leg and encountering a tailwind on final that influenced the rate of decent.

Eindhoven Arrival Control

2. Eindhoven Arrival Control had no information about the upper winds . The controller did not take into account the influence of the these winds when giving radar guided approaches. This resulted in a line up too short for the final approach.
3. Eindhoven Arrival Control did not follow the procedures correctly regarding the following:
   - inform the flight crew beforehand when radar vectors can be expected for the approach;
   - intercepting an ILS glide path should be executed from below in accordance with published procedures;
   - active monitoring of the aircraft flight path during vectoring;
   - transfer of aircraft from Arrival Control to Tower Control without confirmation that the aircraft is established on the ILS or without coordination.

Flight Crew

4. The flight crew did not take into account the influence of the upper winds. In combination with the aircraft's high vertical profile and high speed in relation to the runway distance, a landing in accordance with standard operating procedures became impossible.

5. The flight crew did not challenge air traffic control and postponed the decision to make a go-around. It is likely that the crew's high level of confidence in the very reliable automation in the cockpit contributed to this.
6. The flight crew did not have proper guidance procedures to avoid false glide slope capture in relation to the distance to the runway threshold (during an autopilot coupled ILS glide slope approach from above, under instrument meteorological conditions).
7. The flight crew initiated the actions for the stall recovery maneuver according to the Boeing FCTM. A second stick shaker warning occurred after the control column was relaxed and the crew again correctly initiated the stall recovery maneuver.

Boeing

8. During an autopilot coupled ILS approach the aircraft, flying at an altitude above the normal 3 degree glide slope, followed the fly-up signal after crossing the 9 degrees false glide slope. This resulted in a nose high position of the aircraft causing the stick shaker warning to occur.
9. The Boeing 737NG Flight Crew Training Manual did not warn of possible false glide slope capture with a pitch-up upset during an autopilot coupled ILS approach. This resulted in an 'automation surprise' for the flight crew.

Ryanair

10. The Eindhoven occurrence was initially reported and assessed by the operator as a minor event which did not warrant CVR and FDR retention.

Separate investigation into ILS

Findings from the Eindhoven incident revealed characteristics of ILS signals that were not generally known. During the investigation it became clear that the Eindhoven incident was not unique. Other incidents took place with different types of aircraft, operated by different airlines, on approaches to different airports.

These findings led the Dutch Safety Board to conclude that unknown ILS signal characteristics pose a significant threat to aviation safety and the Board decided to address this issue separately. The main conclusions of the separate investigation were:

1. The ILS Image Type antenna category signal characteristics of false glide paths and corresponding cockpit instrument warnings do not correspond with generally received wisdom and training.
2. Signal Reversal sometimes occurs at approximately 6 degree glide path and always at the 9 degree glide path angle. Additionally, cockpit instruments do not present corresponding ILS warnings.
3. The area above the certified 3 degree ILS which is the 5.25 degree glide path and onward, is not part of the ILS Flight Inspection programme and therefore not part of the ILS ICAO certified volume of operation. Consequently, aircraft flying above the certified volume of operation are exposed to risks related to ILS Signal Reversal and subsequent unexpected automatic flight system response resulting in severe pitch up.

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4. Automated systems on board of aircraft assist the aircrew in performing there tasks on board and should never endanger the aircraft, passengers or crew without giving a clear, recognizable warning and ample time for the crew to react.
5. Flight crews' decisions tot execute a go aurond or to challenge Air Traffic Control seem to be postponed too long when flying high above the normal vertical profile during an ILS apporach. There is reason to believe that the high level of very reliable automation in the cockpit contributes to this and that altitude versus distance basic flying skills are insufficiently practiced.

The report of the ILS signal anomaly was issued contemporaneously.

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5 RECOMMENDATIONS

Based on the findings and conclusions the Dutch Safety Board made the following recommendations.

The Safety Board made the following recommendations to the Minister of Defence (The Netherlands).

1. Ensure that approach control take into account the effect of upper winds during radar vectoring of civil air traffic in military airspace.
2. Ensure that when making the choice for the active runway, the influence of the upper winds during the approach should be part of the decision-making in addition to the effect of the surface wind.

The Safety Board made the following recommendations to the airline operator Ryanair.

3. Ensure that its list of reportable occurrences in the company Operations Manual specifically includes stick shaker and pitch-up upset events.
4. Ensure that when in doubt whether occurrences should be reported at first contact with the operator, to assess the occurrence properly including possible CVR and FDR retention.

APPENDIX

JUSTIFICATION OF INVESTIGATION

In accordance with international agreements, contact was made with the involved states; Ireland (the State of Registration of the aircraft as well as State of the Operator), United States of America (the State of Manufacturer and State of Design). Also the European Aviation Safety Agency was informed about the investigation.

In accordance with ICAO Annex 13, each of the above mentioned States appointed an Accredited Representative to participate in the investigation with Advisors to assist.

The following organisations participated in the investigation and provided information and documents:

- Royal Netherlands Air Force
  - Air Operations Control Centre Nieuw Milligen,
  - Eindhoven Air Base - Chief ATC,
  - Woensdrecht Air Base - Radar Maintenance Branch.
- Ryanair

The following investigations and activities were performed during the investigation:
- 21 June 2013: Voice Logging System Radio Communication ATC Eindhoven,
- 17 July 2013: Amsterdam Airport Schiphol – B737 simulator,
- 13-14 November 2013: Air Accident Investigation Unit - Technical Review meeting, operator and flight crew,
- 27 January 2014: Amsterdam Airport Schiphol – B737 Simulator.

The following interviews and/or discussions were held during the investigation:
- 1 July 2013: Flight crew at Eindhoven Airport,
- 26 July 2013: Arrival controller and Supervisor,
- 12 September 2013: Arrival controller,
- 13-14 November 2013: Ryanair Flight crew, Safety Manager, Chief Pilot,
- 26 November 2013: Arrival controller.

Guidance committee	
E.R. Muller	chairman
J.B. Benard	captain Boeing 747
P.M.J. Mendes de Leon	professor, University of Leiden
M. Mulder	professor Aerospace Human-Machine Systems, Technical University Delft
L.F.M. Ruitenberg	aviation safety consultant
R.M. Schnitker	judicial expert aviation

Project team	
K.E. Beumkes	Project Manager
G.J. de Rover	Senior Investigator
M.J. Schuurman	Senior Investigator
Dr. N. Smit	Advisor Research and Development
H. Kiffen	ATC Expert Dutch MAA
G. Stigter	Aviation Safety Expert Dutch Pilot Association
H. van Duijn	Investigation Manager

Assisting expert	
V.H. Telkamp	Captain Airbus 330

COMMENTS PARTIES INVOLVED

A draft report (without consideration) was submitted for inspection of factual inaccuracies to the parties directly involved in accordance with the Dutch Safety Board Act. In so far as non-textual, technical aspects and factual inaccuracies are concerned, the Safety Board has incorporated the comments received into the final report. The remarks which were not incorporated are mentioned in a seperate table with reasons why the Board has not amended the report on these points. The paragraph and chapter numbers refer to the numbering in the draft report and do not always correspond to the numbering in the final report. The table can be found at the investiagtion concernet on the Safety Board's website: www.safetyboard.nl.

The draft version of this report has been submitted to the following parties

- Captain of the aircraft
- First Officer of the aircraft
- Third flight crew member on the jumpseat
- Ryanair, Ireland
- Air Accidents Investigation Unit, Ireland
- Boeing Aircraft Company, United States
- Dutch Human Environment and Transport Inspectorate
- Ministry of Defence
  - Direction Operational Control
  - Military Aviation Authority
  - Commander of the Air Force
  - Commander Eindhoven Air Base
  - Approach Controller Eindhoven Airport

APPENDIX C

SAFETY ALERT

Date: November 18, 2013

UNEXPECTED AUTOPILOT BEHAVIOUR ON ILS APPROACH

Potential severe pitch-up upset when intercepting the instrument landing system (ILS) glide slope from above, which can lead to (approach to) stall conditions.

The particulars

- Different types of Instrument Landing System (ILS) glide slope systems are used worldwide. Signal characteristics in the area above the (standard) 3 degree glide slope are system dependent.
- Similar glide slope capture logic in automatic flight control systems (autopilot) is used for the majority of aircraft types currently in service worldwide.
- While intercepting the ILS glide slope signal from above the 3 degree flight path with the automatic flight control system engaged, the aircraft can capture a false glide slope resulting in an unexpected rapid pitch-up command (automation surprise).

Preliminary investigative findings

The Dutch Safety Board is investigating a severe and sudden pitch-up upset during an ILS approach to Eindhoven Airport in 2013. The airspeed dropped rapidly to a near stall situation (stick shaker). The crew carried out a go-around. During the investigation the Board has become aware of similar events. Analysis revealed that the common factor linking these events is the ILS antenna type; M-array (Capture effect) ILS antenna. The M-array ILS antenna type is used around the world, including at major airports and military air bases in the Netherlands.

Regulations mandate that ILS systems be periodically checked with a Flight Inspection in order to be certified for operational use. The Flight Inspection focuses exclusively on the 3 degree glide slope area. The signal characteristics in the area above the 3 degree glide slope were examined as part of the Dutch Safety Board's investigation. Flight tests were conducted to measure the M-array antenna signal and determine the 'glide slope field' characteristics above the 3 degree glide path while established on the localizer.

Analysis of the measurements show that between the 3 and 9 degree glide path, signal strength changes. For the pilot this can result in observable movement of the ILS glide slope marker on the primary flight display. At this time two important characteristics of the M-array ILS antenna 'glide slope field' have been identified:

1. A signal reversal was always present at approximately 9 degree glide path.
2. A signal reversal was sometimes present at approximately 6 degree glide path.[21]

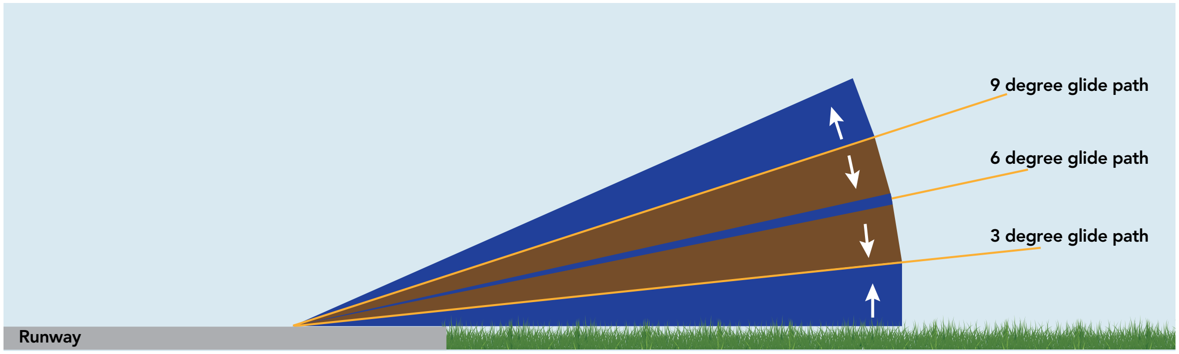

Figure 1: Cross section view of the M-array ILS antenna system. Schematic overview of the "Fly up"(blue) and "Fly down"(brown) indication.

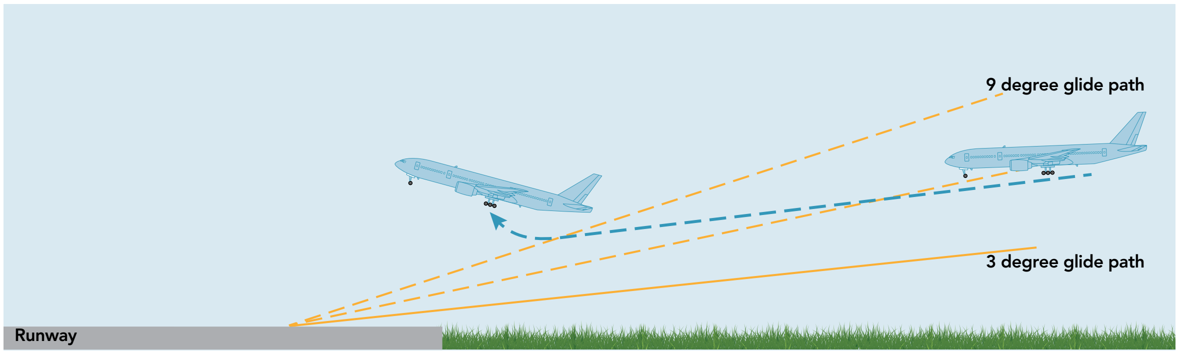

Figure 2: Example of glide slope capture with a pitch upset above 3 degree glide path.

Depending on the glide slope field, signal reversal occurs occasionally at 6 degree, and always at the 9 degree glide path. This reversal activates the glide slope capture mode after which the autopilot follows the glide slope signal without restrictions. During flight tests the reversal resulted in the automatic flight control system commanding a severe pitch-up. Immediate flight crew intervention was required to regain aircraft control.

21 During measurements at two different Airports in the Netherlands the 6 degree glide path reversal was not always present.

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Furthermore the flight tests have shown that commonly available information on false glide slope (internet, manuals and literature) does not necessarily reflect glide slope signal characteristics of all ILS antenna types in use worldwide. For example, in some aircraft manuals it is noted that a false glide slope signal can be identified by a higher than normal descent rate. This particular description does not accurately reflect what happens when a false glide slope of an M-array antenna is captured.

Thus far the investigation has revealed that aircraft from four different manufacturers operated by different airlines have experienced a pitch-up upset caused by a false glide slope either under test conditions or during operation.

This investigative information has led the Dutch Safety Board to issue this Safety Alert to address the following safety concern: to generate awareness of different ILS signal characteristics and the potential of aircraft pitch-up upset due to capturing a false glide slope, which can lead to (approach to) stall conditions.

Related incidents
During the ongoing investigation the Dutch Safety Board was notified of a similar event with a different aircraft type at Amsterdam Airport Schiphol in 2011.

In 2012 the French Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile (BEA) investigated a pitch upset of an Airbus A340 on approach to Charles de Gaulle Airport. Also in this case the airspeed dropped rapidly and the crew carried out a go-around. The Dutch Safety Board has been provided with information that the M-array antenna system is used at Charles de Gaulle Airport.

For more information www.bea.aero - report "*Approach above glide path, interception of ILS sidelobe signal, increase in pitch angle commanded by autopilot*", September 2013.

Information for pilots; what can you do?
Pilots should be aware of the ILS glide slope signal characteristics and the dangers accompanying flying in the area above the 3 degree glide path during the approach. In particular the aircraft behaviour while flying on autopilot with the glide slope mode armed should be noted.

Information for operators; what can you do?
Operators should consider the need to implement additional operational procedures or provide additional guidance in order to mitigate the risks of unexpected autopilot behaviour when on ILS approaches.

If after reading this Safety Alert you think a similar occurrence has taken place within your company, please contact your investigation authority agency and provide any relevant information of the event.

Information for Air Traffic Control; what can you do?
Adhering to prescribed navigation procedures reduces the flight crew workload and will position the aircraft to intercept the glide slope from below.

Information for Aircraft Manufacturers; what can you do?
Aircraft Manufacturers should consider the need to provide additional guidance in order to mitigate the risks of unexpected autopilot behaviour when on ILS approaches.

What can the Aviation Authorities do?
Thought should be given by the Aviation Authorities to monitor and enforce the need for mitigating actions by the relevant parties to reduce the risk of false glide slope encounters.

This Safety Alert is not intended to apportion blame or liability to any party. The sole purpose of the Safety Alert is to inform the aviation community of a safety concern which has been identified by the Dutch Safety Board during an investigation.

The publication of the Final Report (Stick shaker warning during ILS approach, Boeing 737-800, May 31, 2013 - Eindhoven Airport) is scheduled for May 2014.

T.H.J. Joustra
Chairman of the Dutch Safety Board

APPENDIX D

TERMS OF REFERENCE

The following relevant (international) legislation, regulations, guidelines, operating and training manuals for this investigation were used:

- Annex 13 Aircraft Accident and Incident Investigation, International Civil Aviation Organization, 10th edition July 2010
- Regulation (EU) No 996/2010
- ICAO Doc 4444, Procedures for Air Navigation Services – Air Traffic Management
- AIP Netherlands, Airport, Aerodromes, Eindhoven
- Local Operating Procedures Air Operations and Control Station Nieuw Milligen
- Luchtverkeersvoorschrift voor de Koninklijke Luchtmacht (RNLAF Air Traffic Control Manual)
- Ryanair Operations Manual Part A and Part B
- Boeing 737 Flight Crew Operations Manual
  - Go-Around and Missed Approach procedure
  - Approach to Stall or Stall recovery manoeuvre
- Boeing 737NG Flight Crew Training Manual
  - Intercepting Glide Slope from Above

ATC TRANSCRIPT 31 MAY 2013 INCIDENT FLIGHT

(local times as recorded by Eindhoven Voice Logging System)

Eindhoven Arrival Control

08.43:00	Arrival:	RYR 3531, left heading 310, continue descent A2000 feet
	RYR 3531:	Heading 310 degrees, descent 2000 feet RYR 3531
08.46:00	Arrival:	RYR 3531, left heading 250, cleared ILS 21, report established
	RYR 3531:	Heading 250 degrees ,approach rwy21, report established RYR 3531
08.47:00	Arrival:	RYR 3531, contact tower frequency 131.000
	RYR 3531:	131.000, RYR 3531

Eindhoven Tower Control

	RYR 3531:	Eindhoven, hello RYR 3531
	Tower:	RYR 3531 Eindhoven tower, good morning, rwy 21, cleared to land, the wind 330 8 knots maximum 16
	RYR 3531:	Cleared to land rwy21 and say again the wind please
	Tower:	330 10 knots, maximum 16
08.48:00	Tower:	RYR 3531, climb rwy track at 2000 feet, continue with arrival 124.525
	RYR 3531:	124.525, continue rwy track, 2000 feet RYR 3531

Eindhoven Arrival Control

	RYR 3531:	Eindhoven RYR 3531 go around
	Arrival:	RYR 3531, identified again after 3 DME right heading north
	RYR 3531:	Say again please
	Arrival:	Identified again after 3dme heading 360
	RYR 3531:	After 3dme right heading 360
	Arrival:	RYR 3531, right heading 040
	RYR 3531:	040 RYR 3531, uhm, just for your information, the reason for missed approach that we had a fault glide slope capture. And there I can't want to climb again. That's the reason we went around
	Arrival:	RYR 3531 copied
08.56:00	Arrival:	RYR 3531 right heading 130
	RYR 3531:	RYR 3531
	Arrival:	RYR 3531 right heading 190, cleared ILS rwy21
	RYR 3531:	Right heading 190, cleared ILS approach rwy21 RYR 3531

Eindhoven Tower Control

08.58:00	RYR 3531:	Eindhoven RYR 3531 established
	Tower:	RYR 3531 Eindhoven Tower good morning , the wind 320 10 knots maximum 14, rwy 21 cleared to land
	RYR 3531:	Cleared to land rwy21, RYR 3531
	Tower:	RYR 4021, contact Dutch mill 128 decimal 35 bye bye
	RYR 4021:	12835 goeiedag [Dutch, translated: good day] RYR 4021
09.00:06	Tower:	RYR 3531 Echo right, contact ground 121925
	RYR 3531:	Echo vacated (unintelligible) 1 (unintelligible) 75 RYR 3531

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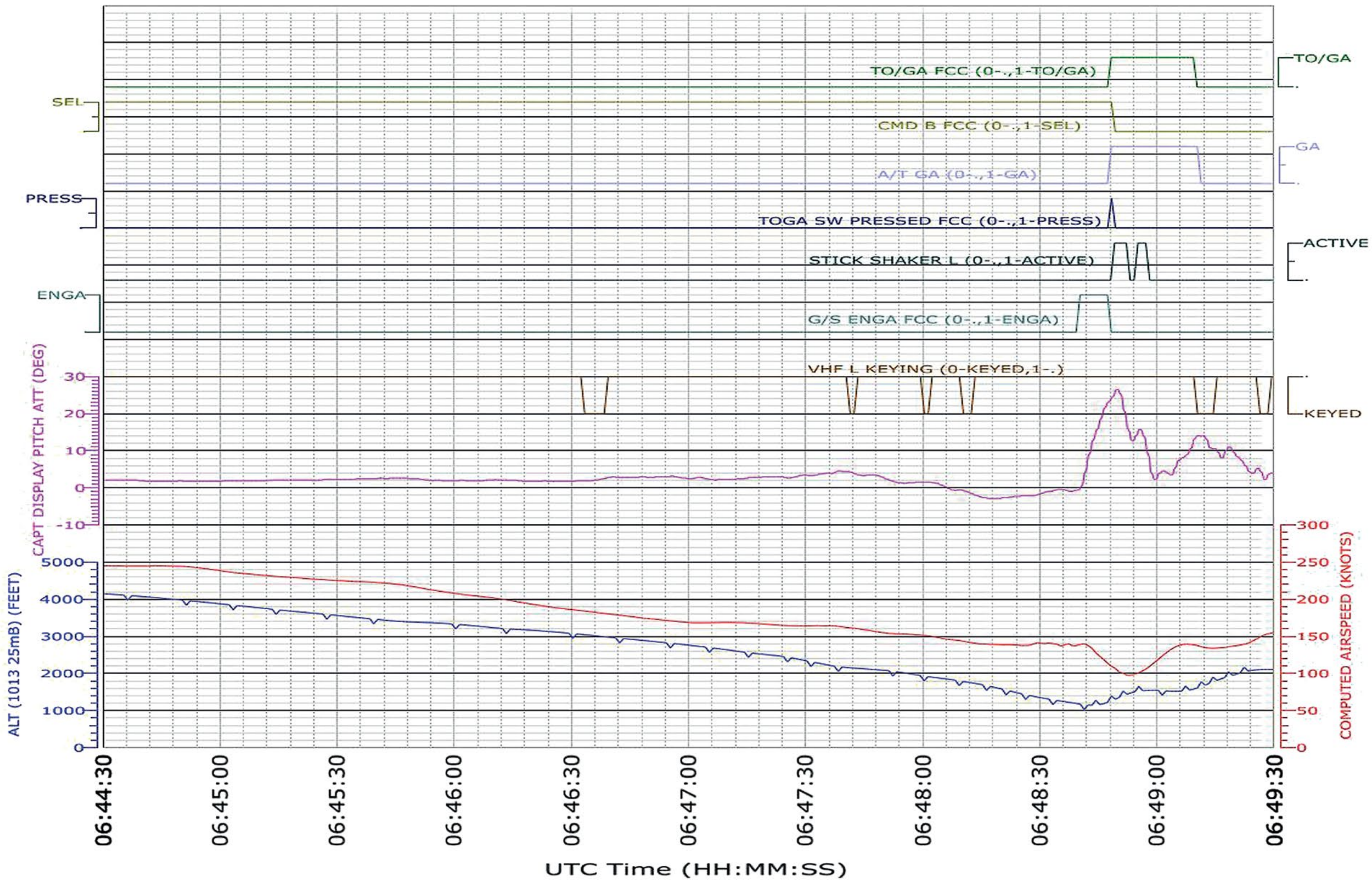
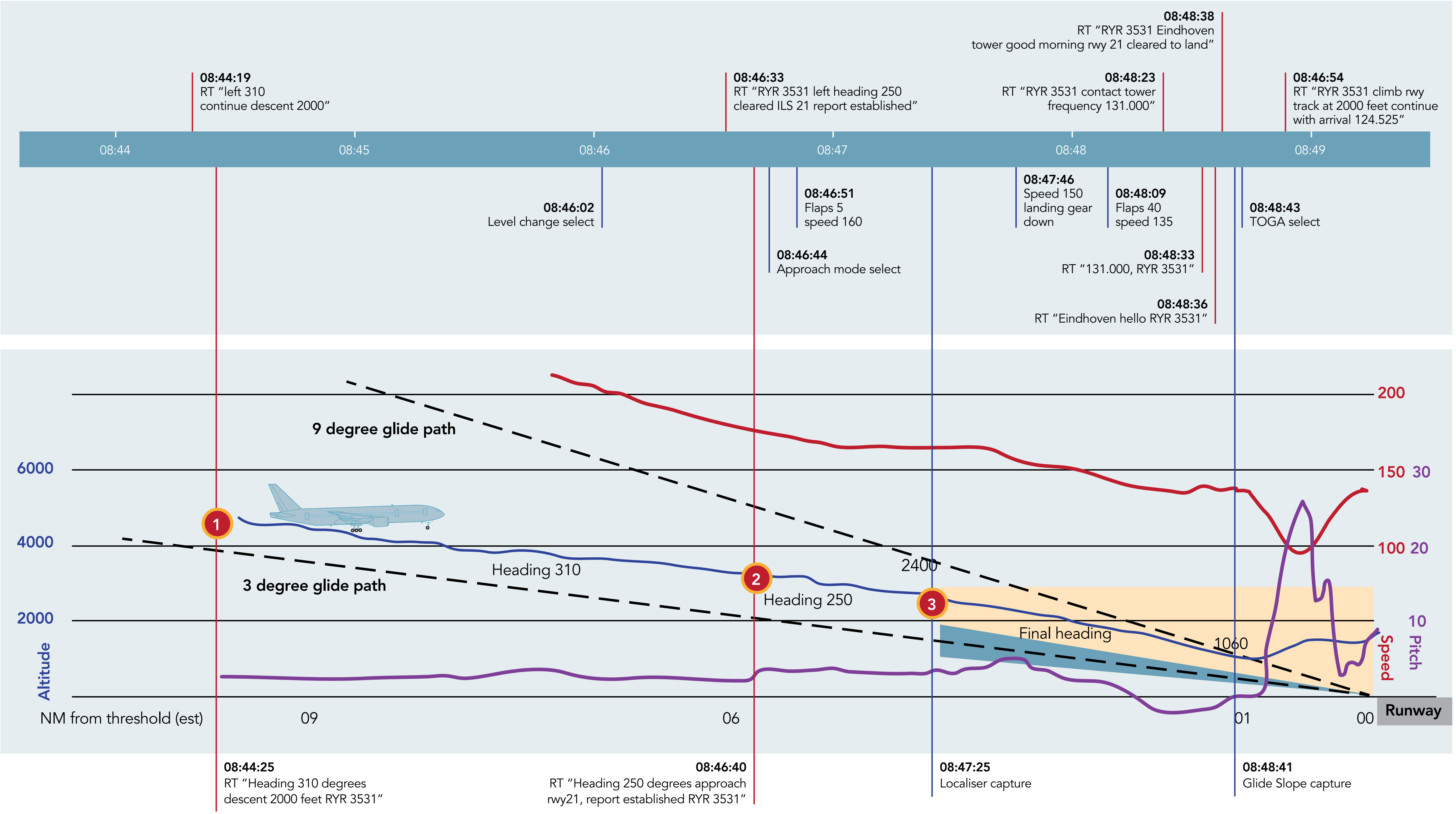
WQAR DATA PLOT



TIME LINE EVENT



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BOEING 737 FLIGHT CREW OPERATIONS MANUAL

BOEING
737 Flight Crew Operations Manual

Maneuvers — **Chapter MAN**
Non-Normal Maneuvers — **Section 1**

Approach to Stall or Stall Recovery

All recoveries from approach to stall should be done as if an actual stall has occurred.

Immediately do the following at the first indication of stall (buffet or stick shaker).

Note: Do not use flight director commands during the recovery.

Pilot Flying	Pilot Monitoring
• Initiate the recovery: • Hold the control column firmly. • Disconnect autopilot and autothrottle. • Smoothly apply nose down elevator to reduce the angle of attack until buffet or stick shaker stops. Nose down stabilizer trim may be needed.*	• Monitor altitude and airspeed. • Verify all required actions have been done and call out any omissions. • Call out any trend toward terrain contact.
• Continue the recovery: • Roll in the shortest direction to wings level if needed.** • Advance thrust levers as needed. • Retract the speedbrakes. • Do not change gear or flap configuration, except • During liftoff, if flaps are up, call for flaps 1.	• Monitor altitude and airspeed. • Verify all required actions have been done and call out any omissions. • Call out any trend toward terrain contact. • Set the FLAP lever as directed.
• Complete the recovery: • Check airspeed and adjust thrust as needed. • Establish pitch attitude. • Return to the desired flight path. • Re-engage the autopilot and autothrottle if desired.	• Monitor altitude and airspeed. • Verify all required actions have been done and call out any omissions. • Call out any trend toward terrain contact.

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Normal Procedures -
Amplified Procedures

BOEING
737 Flight Crew Operations Manual

PILOT FLYING	PILOT MONITORING
Verify airplane levels off at selected altitude.	
Call "AFTER TAKEOFF CHECKLIST."	Accomplish the AFTER TAKEOFF checklist.

Go–Around Procedure Single Channel or Manual - Pilot Flying and Pilot Monitoring < RYR >

PILOT FLYING	PILOT MONITORING
Push TO/GA switch. Call "GO-AROUND - FLAPS 15." If full G/A thrust is required, push the TO/GA switch again after reduced G/A thrust is established.	Confirm thrust advances toward G/A. Call "FLAPS 15", position FLAP lever to 15 and monitor flap retraction.
Rotate to go–around attitude and call "SET GO-AROUND THRUST."	
Verify mode annunciation.	
When positive rate of climb is indicated, call "GEAR UP" and monitor acceleration.	Verify that both VSI and altimeter indicate a positive rate of climb and call "POSITIVE RATE" and move the gear lever to the UP position.
Check flight instrument indications (MCP speed window blanks.)	
Above 400 feet, call for appropriate roll mode and commence flap retraction.	Verify annunciation. Position FLAP lever as directed, monitor flaps and slats retraction and call "FLAPS UP, NO LIGHTS." Call ATC.
Call "TUNE RADIOS FOR MISSED APPROACH."	Tune radios as directed.
Level off at selected altitude and maintain flaps-up maneuvering speed.	
Engage autopilot and call "COMMAND A/B."	Verify annunciation.
Call "AFTER TAKEOFF CHECKLIST."	Accomplish the AFTER TAKEOFF checklist.

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