Bundesstelle für
Flugunfalluntersuchung

German Federal Bureau of
Aircraft Accident Investigation

Investigation Report

Identification

Type of Occurrence:	Serious Incident
Date:	1 January 2020
Location:	Frankfurt/Main Airport
Aircraft:	Airplane
Manufacturer:	Airbus
Type:	A350-941
Injuries to Persons:	No injuries
Damage:	Aircraft not damaged
Other Damage:	None
State File Number:	BFU20-0002-EX

This investigation was conducted in accordance with the regulation (EU) No. 996/2010 of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation and the Federal German Law relating to the investigation of accidents and incidents associated with the operation of civil aircraft (*Flugunfall-Untersuchungs-Gesetz - FlUUG*) of 26 August 1998.

The sole objective of the investigation is to prevent future accidents and incidents. The investigation does not seek to ascertain blame or apportion legal liability for any claims that may arise.

This document is a translation of the German Investigation Report. Although every effort was made for the translation to be accurate, in the event of any discrepancies the original German document is the authentic version.

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Glossary of Abbreviations

ACARS	Automatic Communications And Reporting System	
AFS	Auto Flight System	
AMSL	Above Mean Sea Level	
AOC	Air Operator Certificate	Luftverkehrsbetreiberzeugnis
APM	Approach Path Monitor	
ATC	Air Traffic Control	Flugverkehrskontrolle
ATS	Air Traffic Service	
A/THR	Auto Thrust	
MO-ATS	Manual of Operations Air Traffic Services	
BAF	Federal Supervisory Authority for Air Navigation Services	
CAS	Calibrated Airspeed	Kalibrierte Fluggeschwindigkeit
CONF	Configuration	
CoSNET	Cooperative Safety Nets	
CRM	Crew Resource Management	
CRP	Cruise Pilots	
CTR	Control Zone	Kontrollzone
EGPWS	Enhanced GPWS	
ELEV	Elevation	Orts Höhe über dem Meer
FAF	Final Approach Fix	Endanflugpunkt
FCOM	Flight Crew Operating Manual	
FCTM	Flight Crew Training Manual	
FCU	Flight Control Unit	
FD	Flight Director	
FL	Flight Level	Flugfläche
FMA	Flight Mode Annunciator	
FMS	Flight Management System	
G/S	Glideslope	
GPS	Global Positioning System	
GPWS	Ground Proximity Warning System	
HDG	Heading	

IAF	Initial Approach Fix	Anfangsanflugpunkt
IAS	Indicated Airspeed	Angezeigte Fluggeschwindigkeit
ISA	International Standard Atmosphere	
LOC	Localizer	
MAP	Missed Approach Procedure	Fehlanflugverfahren
MCDU	Multipurpose Control and Display Unit	
MCP	Mode Control Panel	
MSA	Minimum Sector Altitude	Mindestsektorenhöhe über MSL
MSAW	Minimum Safe Altitude Warning	
ND	Navigation Displays	
OPENDES	Airbus Mode – Open Descent	
PF	Pilot Flying	
PFD	Primary Flight Display	
PGT	Predicted General Terrain	
PM	Pilot Monitoring	
RA	Radio Altitude	
SOP	Standard Operating Procedure	Standard-Betriebsverfahren
SRS	Speed Reference System	
SVS	Selected Vertical Speed	
TAWS	Terrain Awareness and Warning System	
THR IDLE	Airbus Mode - Thrust Idle	
TOGA	Take Off And Go Around	
V_{APP}	Approach Speed	
V_{CAS}	Calibrated Air Speed	
V_{REF}	Approach Reference Speed	
V/S	Vertical Speed	Steig-/Sinkgeschwindigkeit
V_{TGT}	Target Speed	Zielgeschwindigkeit im Landeanflug
VD	Vertical Display	
VMC	Visual Meteorological Conditions	Sichtflugwetterbedingungen
V/S	Vertical Speed	

Abstract

After a shortened final approach, the Airbus A350-941 was flying at night in good visual meteorological conditions unstabilized on instrument approach to runway 07R of Frankfurt/Main Airport. The glide slope of the instrument landing system was flown through from above. Starting at 3,300 ft AMSL, the flight path was continuously below the glisdesope. The cockpit crew aborted the instrument approach and initiated a go-around procedure about 6 NM ahead of the runway threshold 07R at 668 ft AGL, i.e. far below the glide slope.

The investigation determined:

- Errors in the programming of the waypoints in the flight management system
- Errors in the handling of the auto flight system for the approach
- Reduced situational awareness of the pilots in regard to the spatial position
- Communications and cooperation deficiencies within the flight crew

1. Factual Information

1.1 History of the Flight

At 1240 hrs[1] on the day of the occurrence, the Airbus A350-941 took off from Phuket Airport, Thailand. The flight was conducted under instrument flight rules to Frankfurt/Main Airport, Germany. It was a scheduled passenger flight. On board were 4 pilots, 14 cabin crew members and 306 passengers.

The Pilot in Command (PIC) occupied the left-hand seat and was Pilot Monitoring (PM) during this flight. The co-pilot, in the right-hand seat, was Pilot Flying (PF). During the approach, two other co-pilots were present in the cockpit as observers. According to the Cockpit Voice Recorder (CVR), cockpit communication in regard to briefings and discussions between PF and PM were largely held in Thai. According to the recording, between 1800 hrs and 2004 hrs, there was no talk about the approach route and the instrument approach.

At about 1915 hrs, the aircraft, autopilot engaged, passed VOR Charlie of the southern Standard Arrival Route to runway 07R of Frankfurt/Main Airport at 18,500 ft AMSL. According to the statement of the flight crew, during the approach they were following a preceding aircraft. The PM assumed they would land on runway 07R after the preceding aircraft. The approach route and the instrument approach had been entered into the FMS.

At 1924:26 hrs, shortly before turning into the downwind leg of runway 07R (Fig. 1), the radar approach controller (Pick-up) asked the flight crew if it was correct that they had an ill person on board. The crew confirmed this. The controller also asked if they needed additional support. The crew answered that they had already asked for medical assistance for the passenger at the parking position. This had been preceded by a report via ACARS about 4 hours before the intended landing at Frankfurt/Main Airport to the operator's OPS Center. This message included the information that at the parking position an ambulance was needed for the passenger.

At 1927:22 hrs, the radar controller instructed the flight crew to change to the radio frequency of the Feeder. The Feeder instructed the flight crew at 1927:38 hrs to increase descent.

[1]All times local, unless otherwise stated.

At 1927:59 hrs, the controller issued the air traffic control instruction to fly towards 340° and descend to 3,000 ft AMSL. With an additional directional instruction the controller instructed the flight crew to fly towards 040° for intercept of the localizer and simultaneously issued the clearance for the instrument approach ILS 07R. The flight crew also received the instruction to fly with a speed of 170 kt IAS or faster.

The relevant times, the altitudes and the flight path are depicted in Figure 1. This data, the Flight Mode Annunciator and other aircraft configurations are based on the FDR data. At 1928:48 hrs, at 5,790 ft AMSL, the flaps were put into position 1. At the time, the autopilot of the co-pilot (AP2), both Flight Directors and the OPDES / HDG Mode were active. Shortly afterwards the speed brakes were fully extended and the flaps put into position 2. At 4,800 ft AMSL, the landing gear was extended. At 1929:55 hrs (at 4,200 ft AMSL), the autothrottle mode was active as THR IDLE. At the time, the rate of descent was approximately minus 2,000 ft/min.

At 1930:20 hrs, at 3,680 ft AMSL / 3,480 ft AGL, deviation from the localizer was about 0.25 Dots right of the extended runway centre line. At 1930:22 hrs, the aircraft was at 3,610 ft AMSL / 3,390 ft AGL, about 9 NM from the runway threshold and had flown through the runway extended centerline as the APPR button was pushed, which activated the approach mode arm. In addition, autopilot No. 1 was activated. The aircraft was 0.75 Dots above the glide slope and the rate of descent was minus 2,420 ft/min.

At 1930:23 hrs, the aircraft passed 3,570 ft AMSL /3,350 ft AGL in OPDES mode. At the time, the aircraft was 0.6 Dots above the glide slope and the PF selected a vertical speed of minus 3,200 ft/min on the FCU. The PF changed the selected flight altitude on the FCU from 3,000 ft to 6,000 ft. Shortly afterwards, the glide slope was passed through with a rate of descent of minus 3,000 ft/min. The speed brakes were retracted at 3,160 ft AMSL / 2,965 ft AGL and the pitch down increased from minus 3° to minus 8° and the calibrated airspeed increased. The autopilot was disengaged and the speed brakes extended at 2,715 ft AMSL / 2,500 ft AGL were passed. At the time, rate of descent was minus 3,350 ft/min.

At 1930:54 hrs, at 2,060 ft AMSL / 1,820 ft AGL, the Flight Mode Annunciator (FMA) showed LOC Captured[2] (LOC*).

[2] LOC* was captured as it met the capture criteria of being less than 2.3 dots from the LOC beam, within 115º between track and LOC course, and able to capture it with a single turn.

When the aircraft was on the localizer of runway 07R with the mode Localizer Captured, the rate of descent reached a maximum value of minus 4,009 ft/min.

At 1931:03 hrs, at 1,610 ft AMSL / 1,340 ft AGL, the GPWS warning sink rate and glide slope[3] could be heard twice on the CVR recording. At the time, the rate of descent was minus 3,370 ft/min and the aircraft was more than 4 Dots below the glide slope. At 1,505 ft AMSL / 1,240 ft AGL, the PF selected an altitude of 5,000 ft on the FCU, this corresponded with the go-around altitude in accordance with the precision approach chart for runway 07R. The autopilot mode changed from LOC* / V/S to LOC* / OPCLIMB[4]. The rate of descent was minus 3,300 ft/min and CAS 201 kt.

At 1931:06 hrs, the aircraft was at 1,450 ft AMSL / 1,185 ft AGL. The PF selected an altitude of 100 ft and a SVS of minus 3,200 ft/min on the FCU. The mode LOC* / OPCLIMB changed to LOC* / V/S. At 1,400 ft AMSL / 1,135 ft AGL, the rate of descent was minus 3,000 ft/min and the autopilot mode LOC* / V/S.

At 1931:13 hrs, at 1,120 ft AMSL / 936 ft AGL, the PF commanded to initiate a go-around procedure. At the time, CAS was 210 kt and the thrust levers were put into the TOGA position. The sensor of the co-pilots sidestick recorded a value of minus 18° (full nose up deflection).

[3] GPWS Mode 5 – Descent below the Instrument Landing System glide slope
[4] Airbus Mode – Open Climb

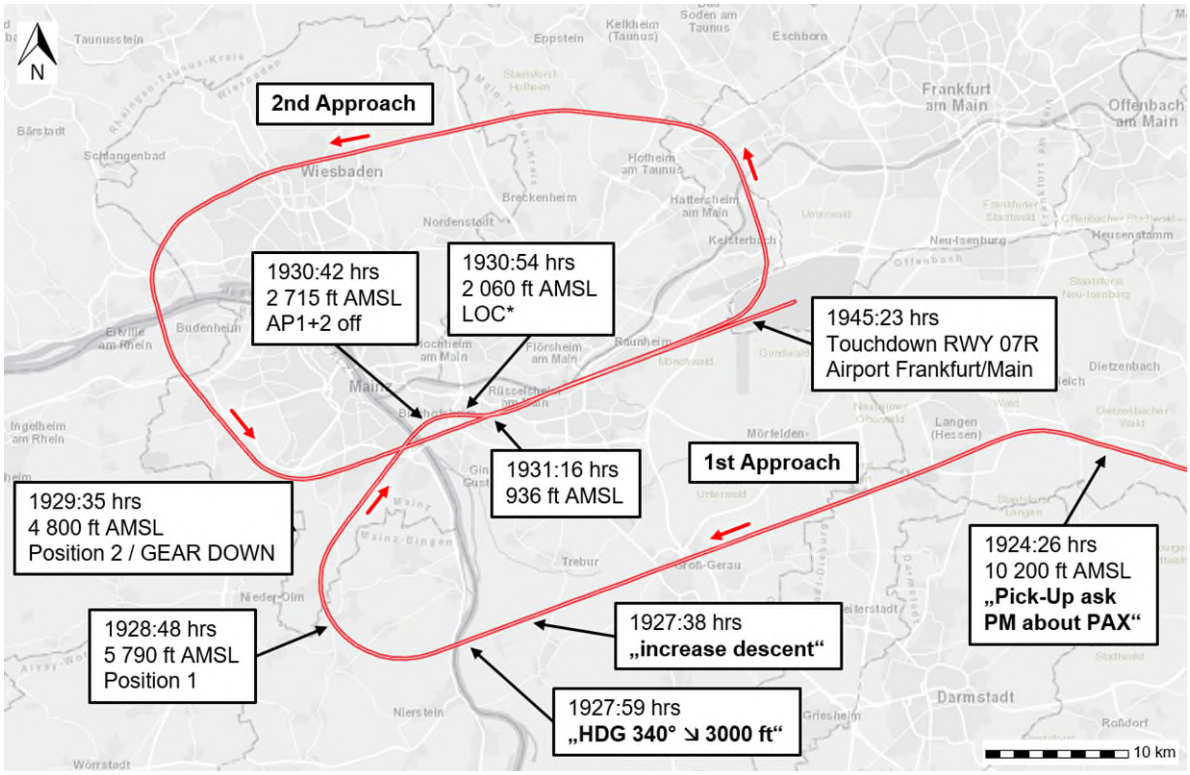


Fig. 1: Depiction of the first approach, the go-around and the second approach to runway 07R

Source: Air navigation service provider, OpenTopoMap, adaptation BFU

After the go-around procedure was initiated the aircraft descented another 184 ft. The lowest altitude was 668 ft AGL (936 ft AMSL) at a distance of 6.43 NM to the runway threshold 07R. At the time, the aircraft was 4.1 Dots below the glide slope (Fig. 2).

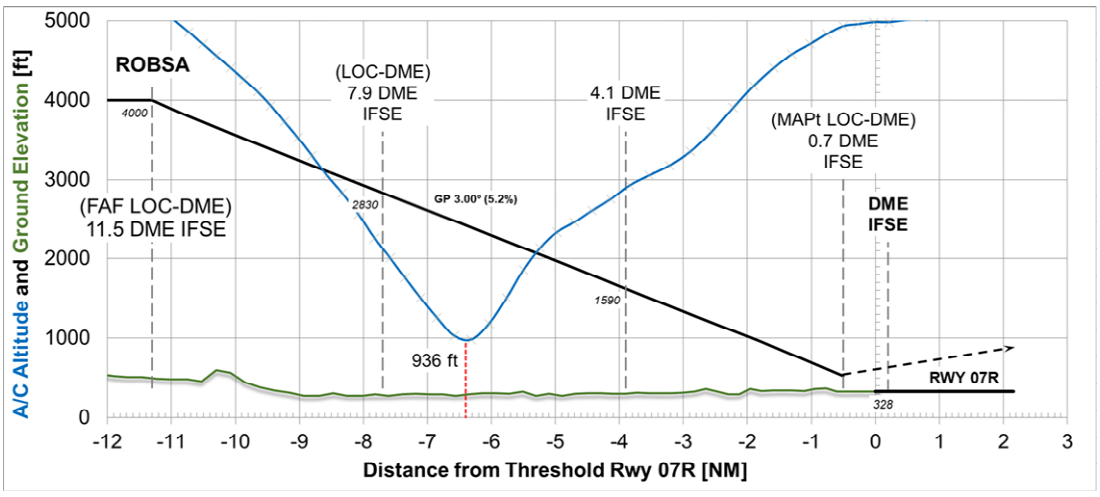


Fig. 2: Vertical profile of the first approach to runway 07R

Source: BFU

During the first radio contact with the tower controller of Frankfurt/Main Airport, the PM informed him that they had initiated a go-around procedure. During the go-around CAS increased up to 217 kt and the V_{FE}[5] OVERSPEED warning was generated. The slats and the flaps were in CONFIG 2. The on-board system changed the slats and flap configuration automatically into CONFIG 1.

The second approach was conducted with the use of the ILS of runway 07R. The 3° glide path of runway 07R was captured from about 2,500 ft AGL.

During the second approach (Fig. 3), the aircraft was at 2,238 ft AGL at that point. The subsequent landing at 1945 hrs on runway 07R occurred without any further problems.

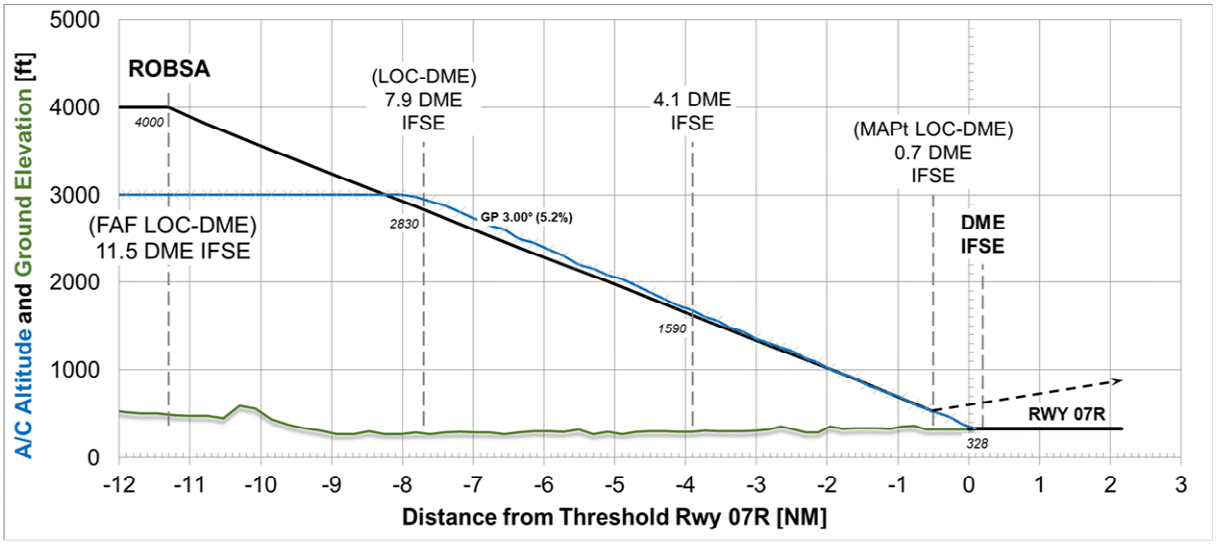


Fig. 3: Vertical profile of the second approach to runway 07R Source: BFU

1.2 Injuries to Persons

Injuries	Crew	Passengers	Total in aircraft	Other
Fatal				
Serious				
Minor				NN
None	18	306	324	NN
Total	18	306	324	

[5] Maximum Flap Extended Speed

1.3 Damage to Aircraft

The aircraft was not damaged.

1.4. Other Damage

There was no other damage.

1.5 Personnel Information

1.5.1 Pilot in Command

The 43-year-old PIC held an Air Transport Pilot Licence (ATPL(A)) issued on 10 January 2008 by the Thai civil aviation authority. The licence was valid until 9 January 2023. It listed the following ratings:

Aircraft type	Licence entry	Valid
Airbus A330 and A350	PIC IR	21 June 2020

The licence also listed the Language Proficiency Level 4 for English in accordance with ICAO Annex 1. The BFU was provided with a class 1 medical certificate valid until 5 December 2020.

According to the PIC's statement, he had a total flying experience of about 8,000 hours, of which about 400 hours were flown on Airbus A350. For him this was the first flight of the day.

1.5.2 Co-pilot

The 36-year-old PIC held an ATPL(A) issued by the Thai civil aviation authority on 20 December 2016. The licence was valid until 19 December 2021. It listed the following ratings:

Aircraft type	Licence entry	Valid
Airbus A330 and A350	COP IR	30 September 2020

The licence also listed the Language Proficiency Level 5 for English in accordance with ICAO Annex 1. The BFU was provided with a class 1 medical certificate valid until 20 September 2020.

According to the statement of the co-pilot, he had a total flying experience of approximately 4,000 hours, of which about 1,500 hours were flown on A350. For him this was the first flight of the day.

1.5.3 Additional Co-pilots

The operator's OM-A, Rev 16, 13.03.2019, Chapter 1.5.2, described the function of so-called Cruise Pilots. The two additional pilots had to be seated in the jump seats in the cockpit during take-off and landing until and from FL200, respectively. The Cruise Pilots' task was to monitor the flight crew, recognise potential errors and provide guidance accordingly. The two additional co-pilots held ATPL(A) licences issued by the Thai civil aviation authority. The licences were valid and listed the type ratings for A330 and A350.

1.5.4 Flight Duty and Rest Time

The operator provided the BFU with the duty roster of the flight crew.

This showed that the flight crew checked in at Phuket at 1110 hrs local time. Departure was at 1240 hrs and landing at Frankfurt/Main at 1945 hrs. This results in 14:05 hours of flight duty time, including 30 min check-out. The maximum permissible flight duty time for this workday was 20 hours[6]. Prior to this flight, the two actively flying pilots had had a day off in Phuket.

1.5.5 Flight Crew Interview

The BFU interviewed the pilots individually. An employee of the operator, who was the Handling Agent at Frankfurt/Main Airport, participated in the interviews as interpreter.

Both pilots actively involved in the conduct of the flight stated that they were familiar with the approach and Frankfurt/Main Airport. Among other things, they were asked to explain why they had approached below the glide slope of the ILS and initiated the go-around procedure at about 6.4 NM at low altitude. They did not give a statement regarding these questions.

The two Cruise Pilots were also interviewed. They were asked whether they had realised that the aircraft had been too low during the approach and had they given guidance to the two pilots. Both questions were answered in the negative.

[6] According to OM-A, Chapter 7.3.1 FDP Extension for Flight Deck Crew, Rev 15

1.5.6 Air Traffic Control

1.5.6.1 Approach Radar Controller (Pick-up)

The 26-year-old controller held an air traffic controller's licence issued by the Federal Supervisory Authority for Air Navigation Services (BAF), valid until 19 January 2021.

1.5.6.2 Approach Radar Controller (Feeder)

The 53-year-old controller held an air traffic controller's license issued by the BAF, valid until 26 August 2020.

1.5.7 Controller Interviews

The BFU interviewed the Approach Radar Controller (Feeder). He stated that his coordinator controller of Frankfurt Tower had informed him that a medical problem existed on board the Airbus. He had confirmed this with the flight crew. In such cases it is common that a short approach without delay is provided. It had been his plan to feed the Airbus into the ILS approach ahead of other aircraft.

The flight crew received the information from the approach controller that the remaining flight path above ground would be shortened. He also saw that the aircraft had passed through the localizer. The aircraft had neither been too fast nor too high. Overshooting the localizer occurs often, e.g. to reduce height. Since the aircraft had been in descent, he assumed it was on the glide slope. In his opinion, otherwise it would not have descended further. The flight crew had asked if they had the clearance for the ILS approach. He had confirmed this. He had seen that the aircraft had already turned back to the localizer after it had overshot it. Subsequently, he had instructed the flight crew to change frequency to Frankfurt Tower. Shortly afterwards he had heard a colleague ask: „[…] was macht der Thai da? (what is the Thai doing)". At the time, the flight crew had no longer been on his frequency.

On enquiry whether it was standard procedure to shorten the approach of aircraft with a medical problem on board, the controller answered in the affirmative. As soon as the information is received the approach is shortened. There is basically no difference between PAN PAN or emergencies. Since Frankfurt has a Feeder who monitors the final approach, reports of flight crew whether they are established on the glide slope are not required. Some flight crew still do it. If the final approach "looks good" for the Feeder, he can transfer the airplane involved to the Tower. There is always the option to instruct a missed approach procedure.

1.6 Aircraft Information

1.6.1 General

The Airbus A350-941 is a wide-body aircraft of carbon fibre reinforced polymer designed for long range flights. The airplane is equipped with two turbofan engines. As is typical for Airbus, the cockpit is a two-pilot glass cockpit with sidesticks and folding tables with keyboards. Two Headup Displays and a depiction of the overflown vertical profile are provided. On the six LCD monitors, the content can be selected freely.

The aircraft had a Thai certificate of registration and was operated by a Thai operator in commercial passenger transport.

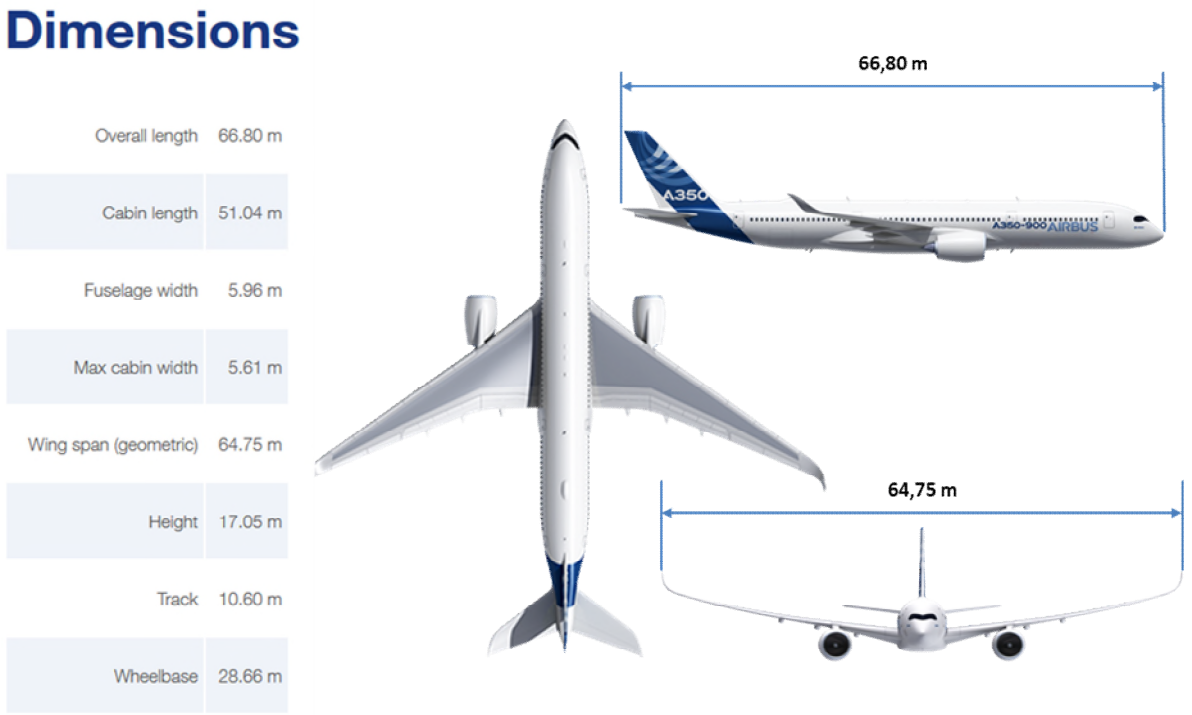


Fig. 4: Three-way view of the Airbus A350-900 Source: FCOM DSC-20-20-10, 10.11.2016, adaptation BFU

Manufacturer	Airbus
Year of manufacture	2017
MSN (Manufacturer Serial Number)	00123
Operating Time	11,577 hours
Landings	1,987
Engines	Rolls Royce Trent XWB-84
MTOM	275,000 kg
MLM	207,000 kg

The operator provided the BFU with technical documentation[7] of the last four weeks prior to the occurrence flight. Based on this information, there were no technical deficiencies concerning the Multipurpose Control and Display Unit or the on-board ILS receiving installation.

According to the FDR data, no warnings of technical errors or system failures were recorded.

1.6.2 Aircraft Systems

1.6.2.1 Primary Flight Display

The Primary Flight Display indicates all primary flight parameters required to control the aircraft. In the following passage, some of the essential PFD indications essential for the present case are depicted and explained.

[7] Retrieve Aircraft Complaints and Actions – Techlog entries

1.6.2.2 Localizer and Glide Slope Deviation Indication on the PFD

The symbols of the localizer and glide slope deviation are depicted on the PFD as follows:

- as diamond symbol if the LOC and/or glide slope deviation is less than 2 Dots (Fig. 5).
- as half diamond symbol at the corresponding edge if the deviation is more than 2 Dots (Fig. 6).

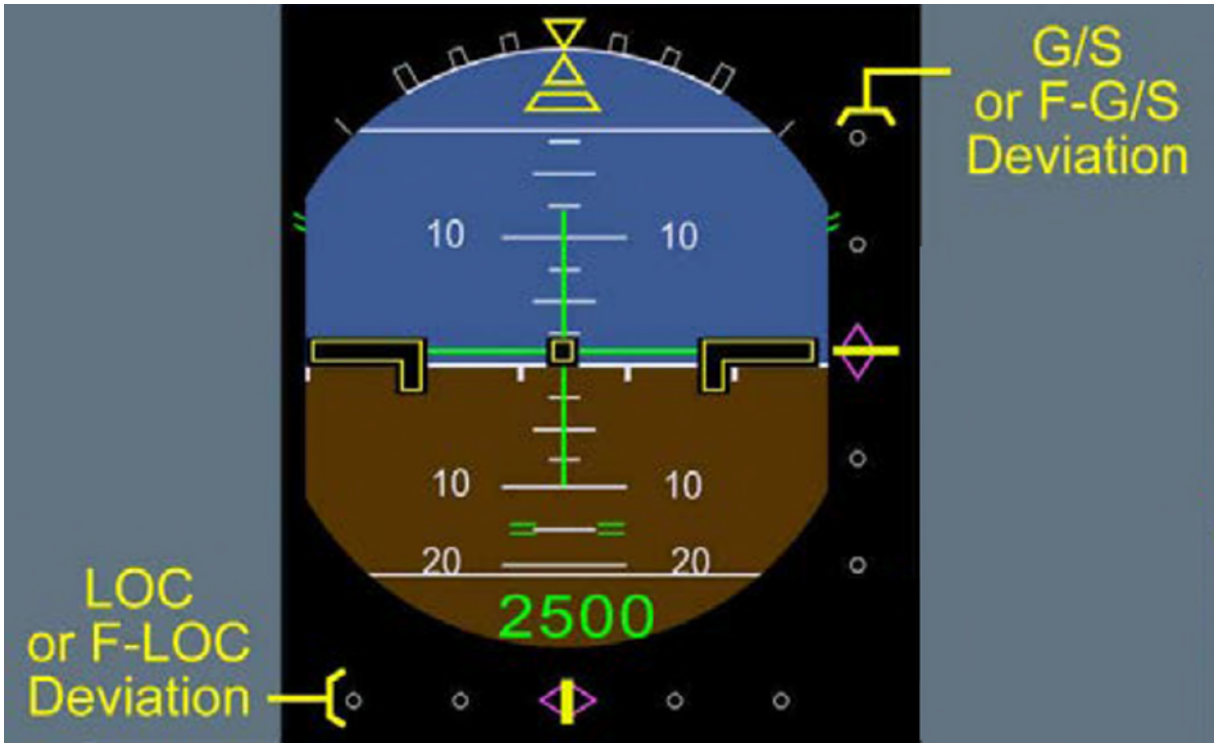


Fig. 5: Symbols of the LOC and G/S deviation on the PFD Source: FCOM, adaption BFU

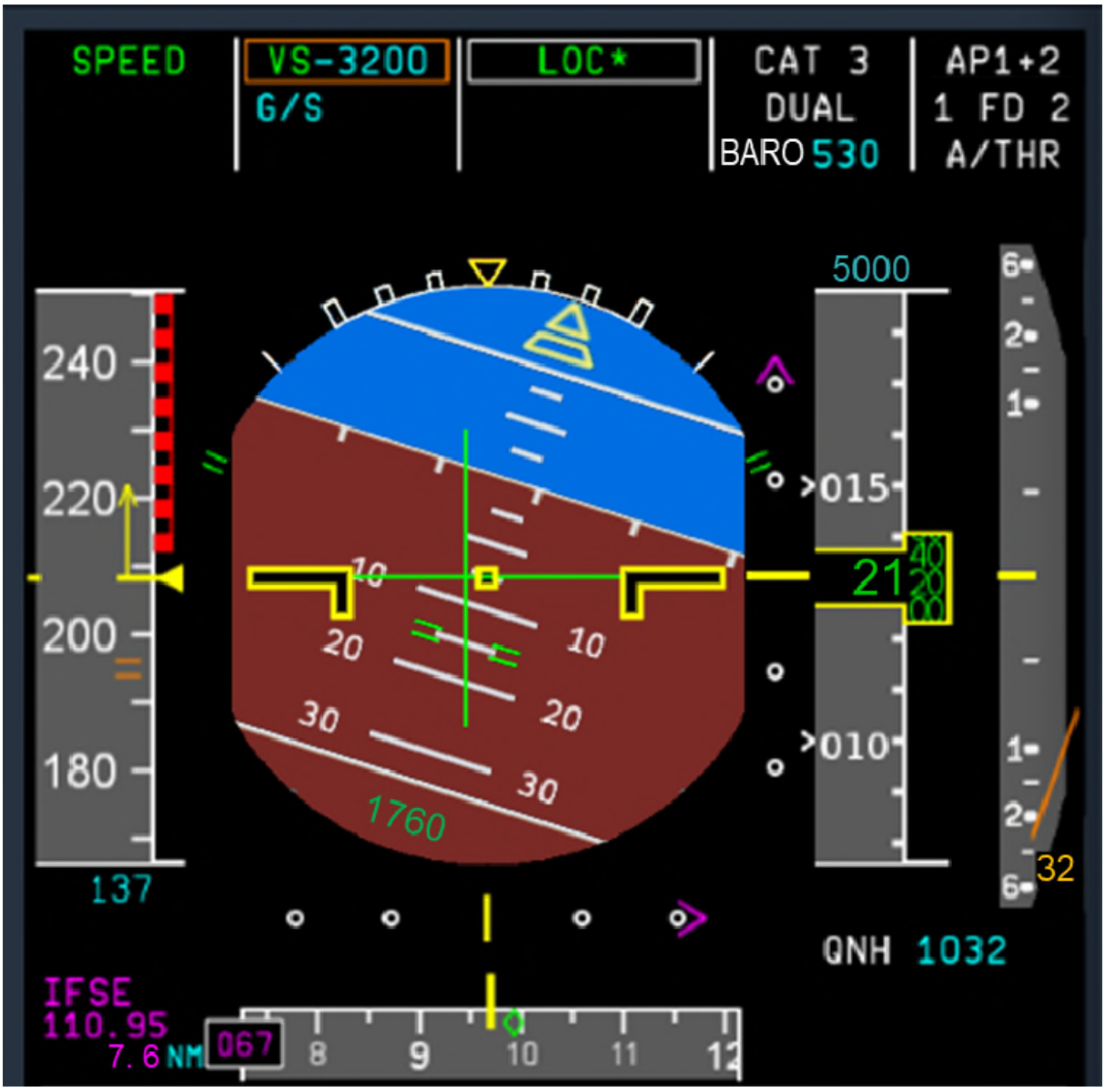


Fig. 6: Simulated PFD indication as LOC was captured during final approach Source: BFU

1.6.2.3 Descent Speed Indication on the PFD

The Vertical Speed is indicated in orange instead of green to warn pilots that the sink speed is unusually high depending on the actual Radio Altitude.

At a Radio Altitude between 1,000 ft AGL and 2,500 ft AGL - typically during approach - descent speed is indicated in orange if it is more than minus 2,000 ft/min (Fig. 6). At an RA below 1,000 ft this already occurs at a descent speed of more than minus

1,200 ft/min. If the V/S-Mode is active at the time, the corresponding Flight Mode Annunciator indication is highlighted with an orange box (Fig. 6).

1.6.2.4 Flight Mode Annunciator

The indication of the Flight Modes, the so-called Flight Mode Annunciator, is located in the upper area of the PFD. The change of a flight mode is indicated with a white box in the FMA indication. In case of an automatic flight mode change (Mode Reversion) this is also indicated by flashing of the FDs (for the duration of 10 s) and a triple clicking sound.

Figure 6 shows the simulated indication of the PFD as the LOC was captured during final approach. Therefore LOC* is encircled by a white box. The aircraft had overshot the LOC 33 seconds before and was then returning to the LOC. As the LOC was captured, as depicted in Figure 6, the aircraft turned with a left-hand turn back to the approach heading.

In addition, the aircraft was in descent with a selected V/S of minus 3,200 ft/min and a RA of 1,760 ft AGL. Calibrated air speed was about 210 kt, 2 kt below the V_{FE} speed of 212 kt.

The LOC and the G/S deviation were indicated at the right and upper edge of the indication as half diamond symbol, respectively. The aircraft was left of the LOC with a deviation of more than 2 Dots and below the G/S of more than 2 Dots.

At the time, vertical speed was minus 3,200 ft/min. Therefore, vertical speed was indicated on the PFD in orange and the flight mode V/S of minus 3,200 ft/min was highlighted with an orange box.

1.6.2.5 Vertical Display

The Vertical Display is located below the navigation displays (Fig. 7). According to the FCOM DSC-31-CDS-40-50-10, 02 Oct 14, Chapter Aircraft Systems, 31 – Control and Display System, EFIS – VD, it is a secondary navigation system which improves the observation of the flight crew in regard to the vertical position of the aircraft.

> *[…] The VD is a secondary means of navigation that increases the flight crew's awareness of the aircraft vertical location. […].*

The VD is only indicated if the ND Mode selector at the EFIS control panel is in ROSE-NAV or ARC.

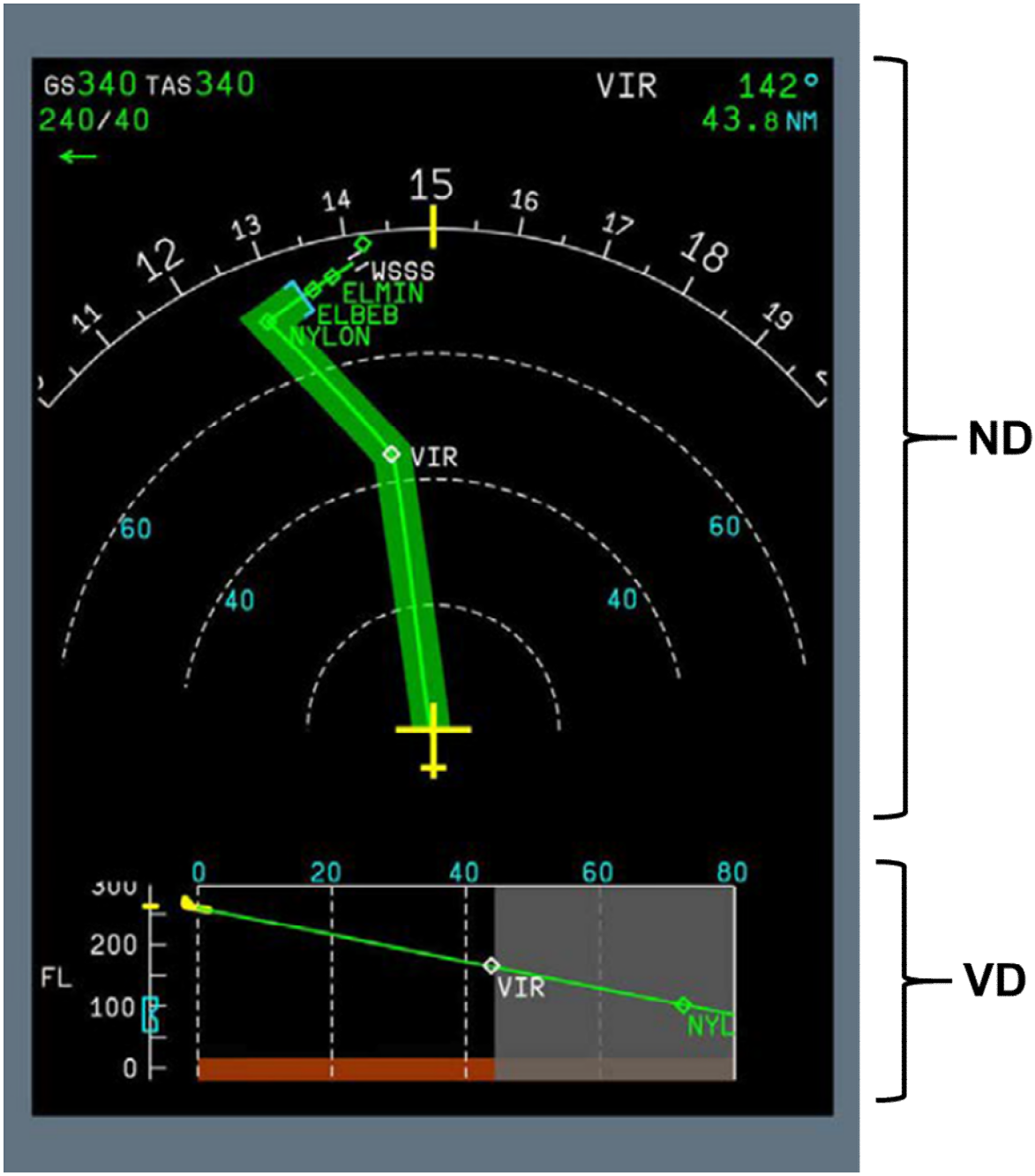


Fig. 7: Navigation Display (ND) and Vertical Display (VD) Source: FCOM, adaption BFU

Figure 8 shows the simulated VD indication as the aircraft was at about 2,100 ft AMSL during the final approach. An ND range of 10 NM was chosen for the depiction.

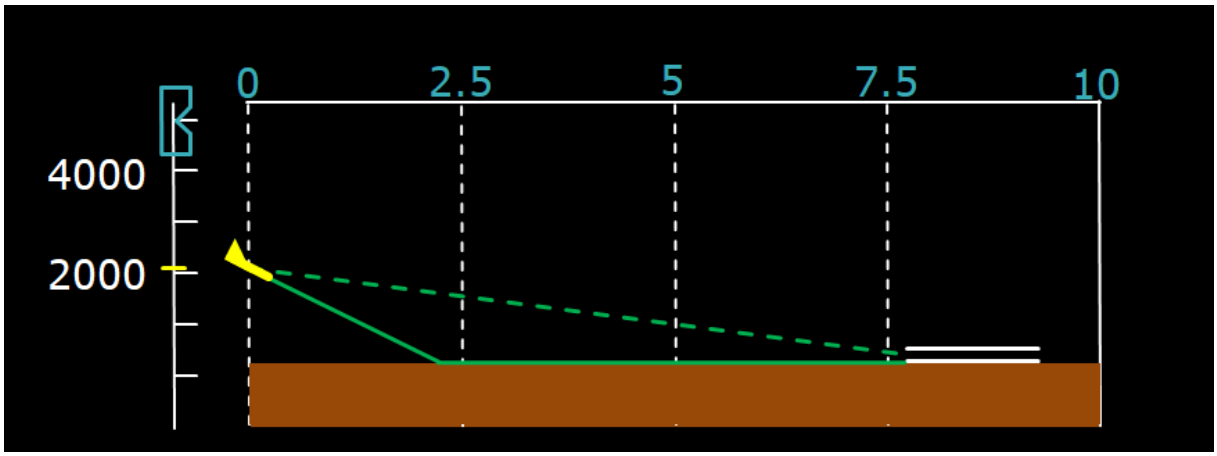


Fig. 8: Simulated VD indication at about 2,100 ft AMSL during final approach Source: BFU

The green line shows the actual vertical flight profile and the broken green line the one from the FMS calculated based on waypoint information. The pilots can use the VD to change the V/S selection at the FCU so that the green and the broken lines coincide and the actual vertical flight profile corresponds with the one calculated by the FMS.

1.6.3 Flight Modes

1.6.3.1 Approach Mode

Initially the LOC and G/S modes are selected (armed) for a planed ILS approach. The APPR button at the FCU panel or the LOC button, if only the LOC mode is to be selected, is pushed. In the FMA indication (second line) the modes are indicated in blue (Fig. 9).

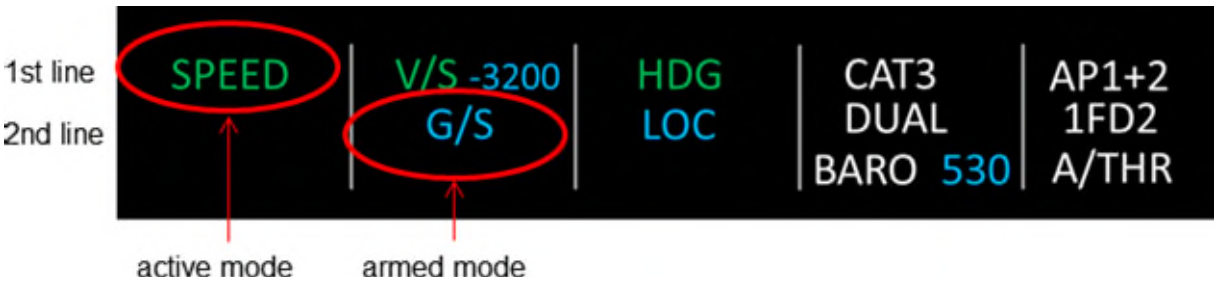


Fig. 9: FMA display; G/S and LOC modes armed Source: BFU

If the Auto Flight System captures the LOC, the LOC* becomes active and the FMA indication (1st line) green (Fig. 10). Once the AFS captures the glide slope, the G/S*

becomes active and is indicated accordingly. The conditions for the activation of the LOC* and the G/S* are described below.

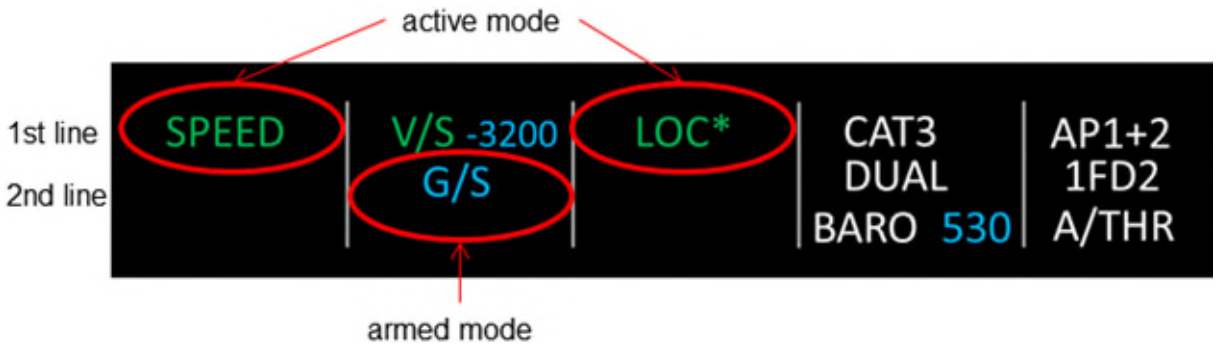


Fig. 10: FMA display; LOC* Mode active Source: BFU

Once the aircraft has captured the localizer, the AFS changes from LOC* to the Localizer Track mode (LOC) and follows the localizer. A corresponding change from the G/S* to the Glide Slope Track mode (G/S) occurs if the aircraft captured the G/S or is sufficiently close. The aircraft then follows the glide slope.

1.6.3.2 Localizer Capture Mode

The FCOM DSC-22-FG-70-80-10, 10 Nov 16, Chapter Aircraft Systems, 22 – AFS – Flight Guidance, AP / FD Modes – Approach Modes and Landing Modes described the area where the localizer is captured so that the Localizer Capture mode (LOC*) becomes active.

CAPTURE ZONE OF THE LOC BEAM

The aircraft reaches the capture zone of the LOC beam, when one of the following occurs:

- The LOC deviation is less than 2.3 dots, and:
  - The difference between the track and the LOC course is less than 115 °, and
  - The roll order is such that LOC* will capture the LOC beam with a single turn.
- The LOC deviation is less than 1.3 dot, and the difference between the track and the LOC course is less than 15 °.

Fig. 11: Conditions for the LOC Capture mode (LOC*) Source: FCOM

1.6.3.3 Glide Slope Capture Mode

The FCOM DSC-22-FG-70-80-30, 03 Dec 2015, Chapter Aircraft Systems, 22 – AFS – Flight Guidance, AP/FD Modes – Approach Modes and Landing Modes described the conditions for the activation of the Glide Slope Capture mode (G/S*).

ENGAGEMENT CONDITIONS

Ident.: DSC-22-FG-70-80-30-00005875.0001001 / 03 DEC 15
Applicable to: ALL

G/S* engages when the aircraft reaches the capture zone of the G/S beam, and all of the following conditions are applicable:

- G/S is armed
- LOC* or LOC is engaged.

L2 The aircraft reaches the capture zone of the G/S beam, when one of the following occurs:

- Passage far from the G/S beam:
  - The G/S deviation is less than 2 dots
  - The pitch order is such that G/S* will capture the G/S beam with a single resource.
- Passage near the G/S beam: The G/S deviation is less than a threshold depending on the radio altitude.
  This threshold is between 0.1 and 1/3 dot.

Fig. 12: Conditions for the G/S Capture mode (G/S*) Source: FCOM

1.6.4 Terrain Awareness and Warning System

The Terrain Awareness and Warning System recognises dangers due to ground approximation, shows terrain data and generates corresponding acoustic and visual warnings.

Among other things, it consists of the Ground Proximity Warning System with five Basis Modes. Two of these modes are relevant for the current case.

1.6.4.1 Excessive Rate of Descent

The GPWS Mode Excessive Rate of Descent (Mode 1) was described in the FCOM DSC-34-SURV-20-10-10, 30 Apr 14, Chapter Aircraft Systems, 34 – Surveillance, TAWS – System Description as follows:

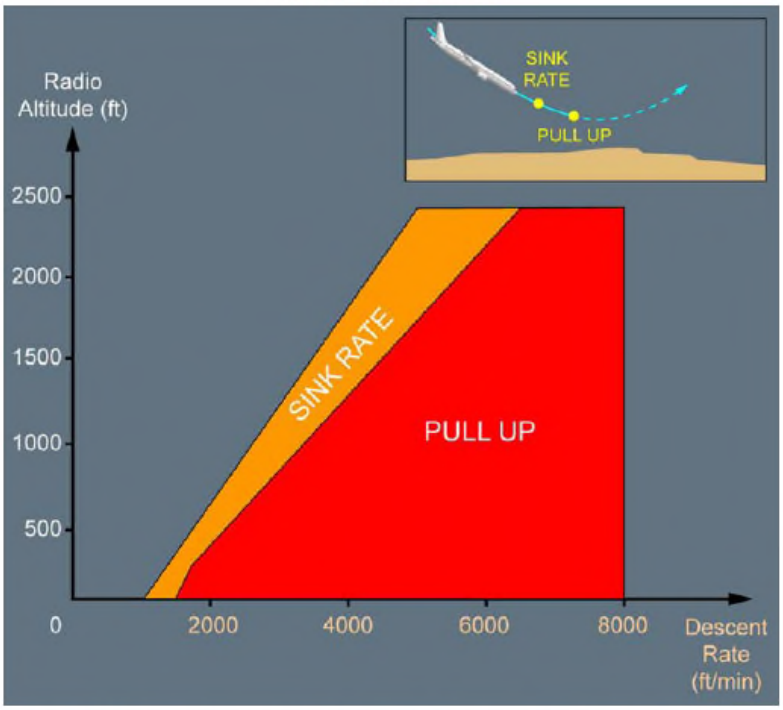
EXCESSIVE RATE OF DESCENT (MODE 1)

If a high rate of descent is detected at low altitude, the following alerts are triggered:
- The "SINK RATE, SINK RATE" audio indicator
- The SINK RATE visual indicator on the PFD.

If this rate is, or becomes excessive, the alert will change to:
- The "PULL UP" audio indicator that repeats as long as the aircraft descends at an excessive rate
- The PULL UP visual indicator on the PFD.

L2 Mode 1 is inhibited when the aircraft is close to the ground.

Excessive Rate of Descent



The "SINK RATE" envelope moves to the right, when the aircraft is above the glide slope beam, in order to avoid any undue alert during a glide slope capture.

L3 The descent rate data is the barometric vertical speed, or the inertial vertical speed, if the barometric vertical speed is not available.

Fig. 13: GPWS Mode 1 Source: FCOM

1.6.4.2 Descent below Glide Slope

The GPWS Descent below Glide Slope (Mode 5) was also described in the FCOM DSC-34-SURV-20-10-10, 30 Apr 14, Chapter Aircraft Systems, 34 – Surveillance, TAWS – System Description.

DESCENT BELOW GLIDE SLOPE (MODE 5)

If the aircraft descends below the glide slope by more than 1.3 dots during precision approaches, the following alerts are triggered:

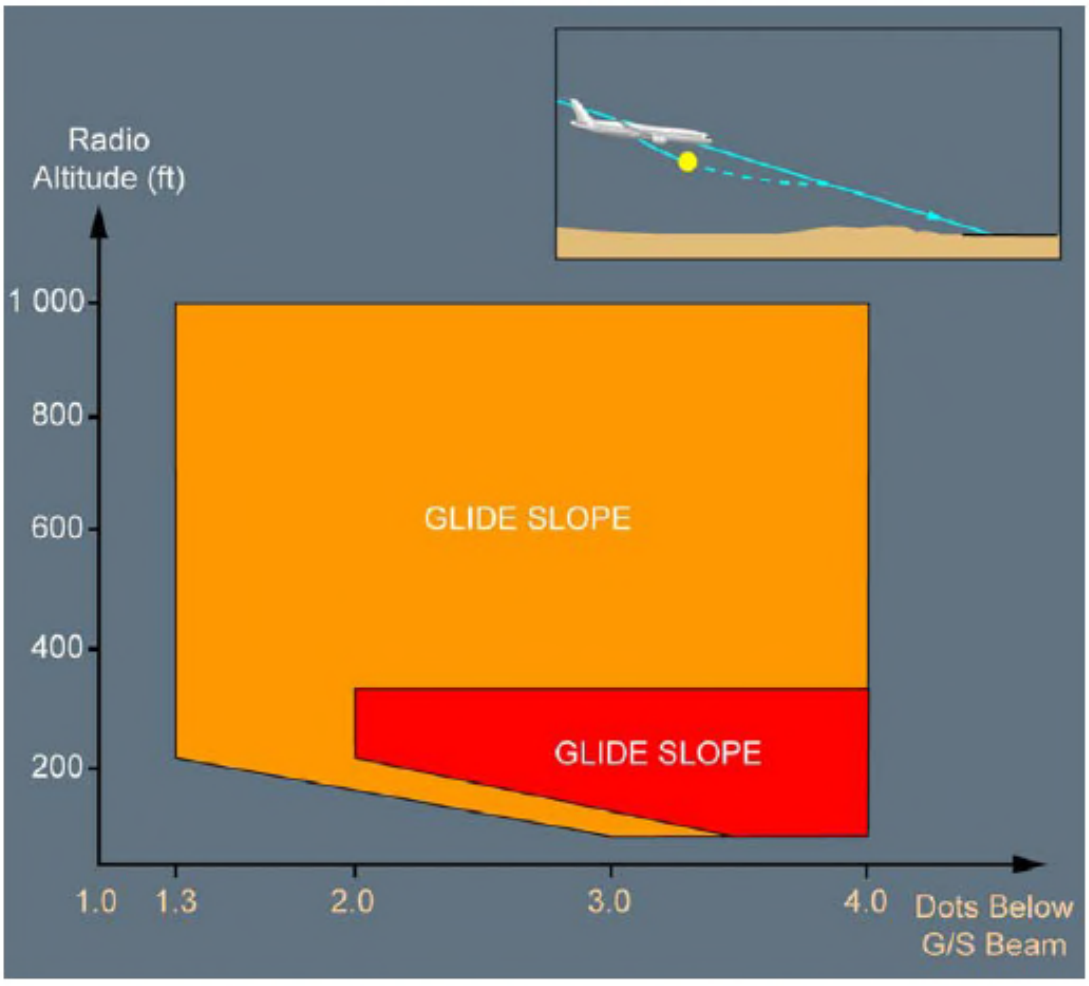
- The "GLIDE SLOPE" aural indicator that repeats as long as the aircraft remains below the glide slope
  If the glide slope deviation is more than 2 dots below 300 ft, the audio indicator becomes louder, and repeats more and more frequently.
- The GLIDE SLOPE visual indicator on the PFD.

L2 Mode 5 is active during approach, if the landing gear is down, and the aircraft is below 1 000 ft AGL.

L1 In order to deactivate mode 5, the flight crew can:

- Set the G/S MODE button to OFF on the CONTROLS page of the MFD, or
- Set the G/S MODE pb to OFF on the SURV panel.

Descent Below Glide Slope



Note: *Usually, the GLIDE SLOPE alert is only triggered, if the landing gear is down. For some airports, the landing gear down condition is not applicable.*

Fig. 14: GPWS Mode 5 Source: FCOM

1.6.4.3 Priority Logic

If the GPWS Modes 1 and 5 are present at the same time, the acoustic and visual GLIDE SLOPE warning is suppressed in favour of the SINK RATE warning, since the GPWS Mode 1 has a higher priority than the GWPS Mode 5.

1.7 Meteorological Information

At the time of the incident it was night. According to the METAR of Frankfurt/Main Airport of 2020 hrs, horizontal visibility was more than 10 km. Wind direction was 060° with 8 kt. The cloud base was not determined. Temperature was 1°C, dewpoint 1°C, and QNH 1,032 hPa.

1.8 Aids to Navigation

1.8.1 Approaches

Both approaches were conducted as precision approaches CAT I to runway 07R. The ILS Z 07R approach began at waypoint ROBSA at 4,000 ft AMSL.

For runway 07R a precision approach from a lower altitude was also available. The glide slope for ILS X approach (effective 23 May 2019) began at 1,660 ft AMSL.

Figure 15 shows the two approaches drawn into the precision approach chart ILS Z 07 R.

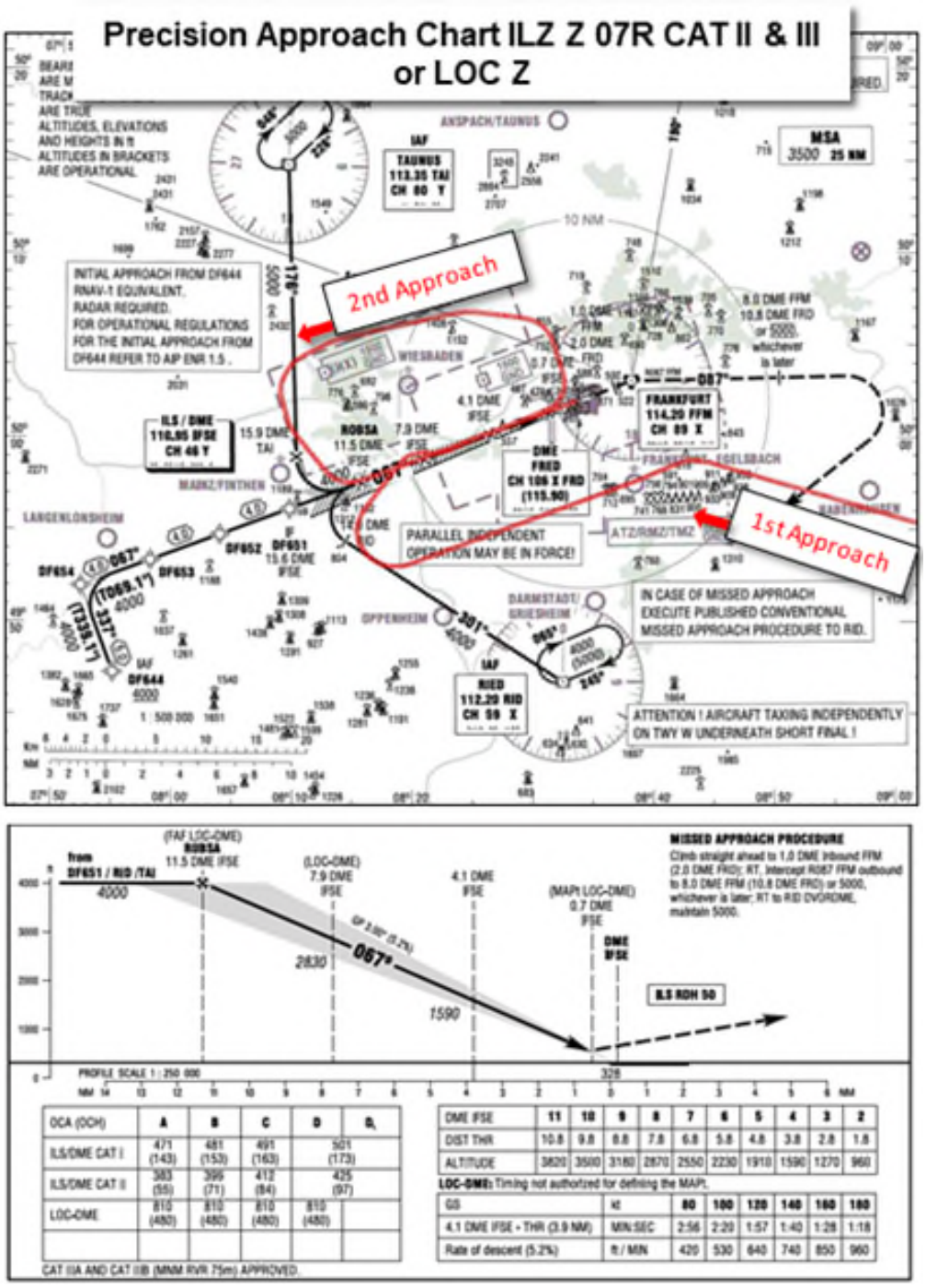


Fig. 15:Flight paths (red) in the precision approach chart ILS Z 07 R Source: AIP, adaptation BFU

The approach, beginning at about 5,000 ft AMSL, was drawn into the Google Earth™ map and depicted in respect to the 3° ILS approach. The FMA indications compiled by the BFU are depicted at the appropriate positions (Fig. 16).

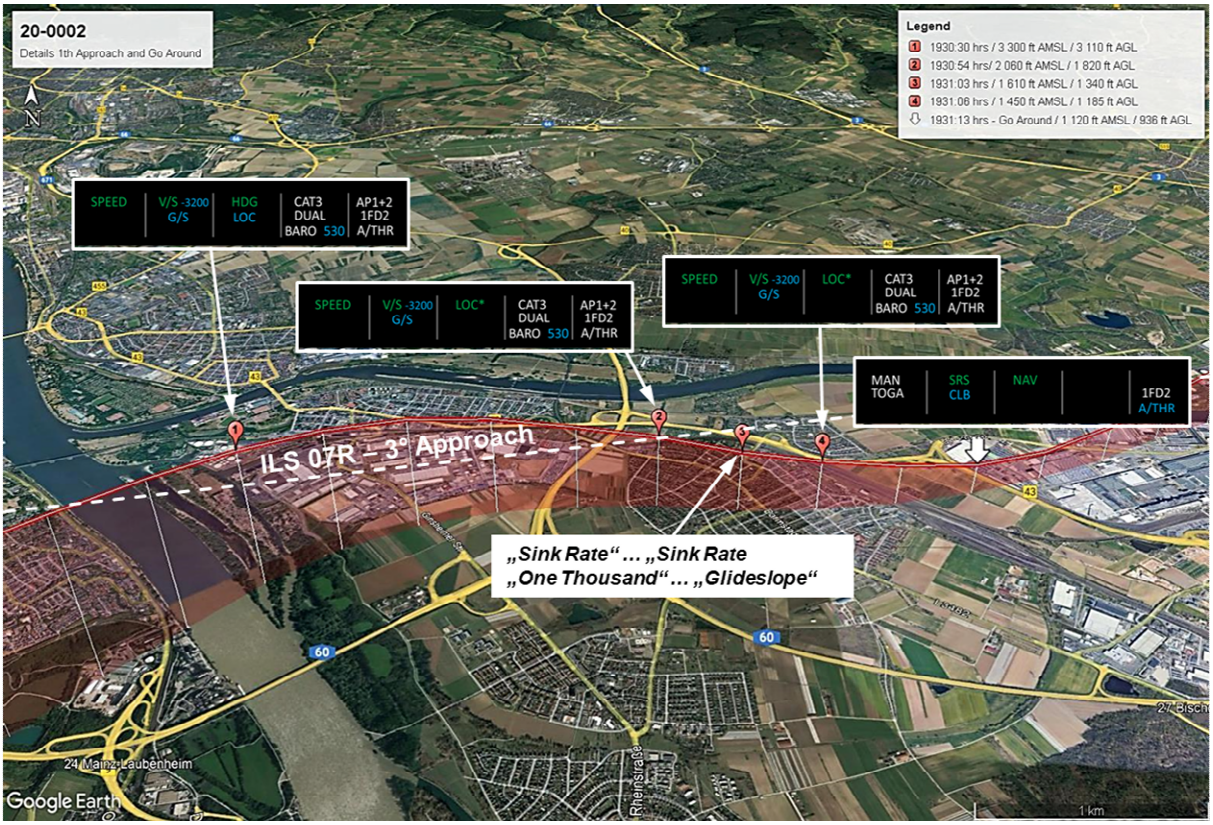


Fig. 16: First approach including FMA indications Source: Google Earth™, adaptation BFU

1.8.2 Approach Path Monitoring

At Frankfurt/Main Airport no approach path monitoring components were available for the approaches. The Eurocontrol Guidelines for Approach Path Monitor – Part I, 2017 defined the following:

> *[…] APM is a ground based safety net; its sole purpose is to enhance safety and its presence is ignored when calculating sector capacity; it is designed, configured and used to make a significant positive contribution to avoidance of controlled flight into terrain accidents by generating, in a timely manner, an alert of aircraft proximity to terrain or obstacles during final approach.[…]*

1.9 Radio Communications

The air navigation service provider provided the BFU with the radio communications transcripts of the flight crew with Center Langen (Pick-up/Director) 125,355 Mhz between 1919:02 hrs and 1927:27 hrs; with the Feeder 127,28 Mhz between

1927:27 hrs and 1931:18 hrs and with the Tower Controller (EDDF TWR) 118,780 Mhz between 1931:18 hrs and 1932:28 hrs.

Communications were conducted by everyone involved in English.

1.10 Aerodrome Information

Frankfurt/Main Airport (EDDF) is located 12 km south-west of Frankfurt. Aerodrome elevation is 364 ft AMSL. Runway 07R has the orientation 70°. It had an asphalt surface and the dimensions 4,000 m long and 45 m wide. It was equipped with approach lighting with Light Intensity High (LIH) and sequence flashing. The touch-down zone of the runway was also equipped with LIH - lights[8].

The air navigation service provider provided the BFU with status reports (31 Dec 2019, 1617:36 hrs to 1 Jan 2020, 2347:46 hrs) of the different approach systems and their monitoring systems. No system failures had been recorded.

1.11 Flight Recorders

The airplane was equipped with a Flight Data Recorder (FDR) and a Cockpit Voice Recorder (CVR). The navigation service provider provided the BFU with the recorded radar data of the flight path. These were compared with the corresponding FDR parameters. The position data, which the aircraft determined, and the position data of the radar unit are chronologically synchronous.

Manufacturer FDR	L-3 Aviation Recorders
Model	FA 2100
Part Number	2100-4245-00
Serial Number	001207389

Manufacturer CVR	L-3 Aviation Recorders
Model	FA 2100
Part Number	2100-1227-02
Serial Number	001203075

After the FDR and CVR had been seized, the data was read out at the BFU flight data recorder laboratory.

[8] The information was taken from the Aeronautical Information Publication (AIP) Germany, published on 25 April 2019.

1.11.1 Cockpit Voice Recorder

The recorders were undamaged. Four audio files (Captain, First Officer, Mixed and Area Channel) were available for evaluation purposes. Each of the four channels had a recording time of 2 hours and 4 minutes. The audio quality of all channels was assessed as “good”. It has to be noted that in the background the on-board entertainment music can quietly be heard on the channels of the PIC and the co-pilot.

The CVR recording showed that large parts of the flight crew’s conversation was held in Thai. The BFU charged an officially appointed interpreter to translate the conversations.

The interpreter confirmed that during the recorded time (1800 hrs to 2004 hrs) the communication in the cockpit during the descent was largely held in Thai. The approach path and the instrument approach were not part of the conversation. Corresponding briefings which the FCOM PRO-NOR-SOP-160-160, 25 Apr 14, stipulated, were not performed.

Standard callouts of the PM could not be heard on the CVR recording, during the approach.

In addition, there was no discussion of the pilots about a possible deviation or route discontinuity of the approach route selected at the MCDU[9].

1.11.2 Depiction of the FDR Data

Parameters of the FDR data were used to analyse the occurrence flight. Three FDR plots were compiled (Appendix 5.2). The times of the x-axis are in UTC. This is local time at Frankfurt minus one hour. Based on the International Standard Atmosphere (medium northern latitude of 40°, a temperature of 15° and a QNH of 1,013.25 hPa) the altitude and the values for QNH and temperature were corrected.

In regard to the PF’s handling of the autopilot and the degree of control automation, the analysis of the FDR and the CVR showed a detailed chronology of the first approach until the go-around manoeuvre. Appendix 5.1 shows a detailed listing of the active flight control modes with the corresponding Flight Mode Annunciator depictions the BFU compiled. The FDR plots show an overview of the occurrence close to the ground during the first approach. At 1831:20 UTC (1931:20 hrs local) the lowest

[9] The MCDU is a combination of keyboard and a high-performance Liquid-Crystal Display that allows pilots to enter and modify flight plans. It works in conjunction with the flight management system.

altitude of 668 ft AGL or 936 ft AMSL, respectively, was recorded. The second approach was also analysed but is not depicted as FDR plot.

1.12 Wreckage and Impact Information

Not applicable.

1.13 Medical and Pathological Information

Not applicable.

1.14 Fire

There was no evidence of in-flight fire or fire during the landing.

1.15 Survival Aspects

Not applicable.

1.16 Tests and Research

Not applicable.

1.17. Organisational and Management Information

1.17.1 Organisation and Procedures of the Operator

1.17.1.1 Crew Resource Management

The operator described the Crew Resource Management (CRM) in the OM-A (Rev 17, 19.07.2019) Chapter 5.2.16, Page 12 as follows:

> *[…] Crew Resource Management is the application of team management concepts and the effective use of all available resources to operate a flight safely. […]*
>
> *[…] CRM is defined as the effective utilization of all available resources, equipment, and people to achieve safe and efficient flight operations. Resources include autopilots and other avionics systems, operating manuals, and people*

such as crew members, air traffic controllers, and others involved in the flight operations. […]

[…] Situational awareness, the ability to accurately perceive what is going on in the flight deck and outside the aircraft, requires on going questioning, cross-checking, communication and refinement of perception. […]

1.17.1.2 Standard Callouts

In the OM-A, PRO-NOR-SCO-FLP-00020439.0001001, 30.03.2017, the operator described the standard callouts during approach as follows:

APPROACH

The PM announces:

- "SPEED" if the speed goes below the speed target – 5 kt, or goes above the speed target + 10 kt

- "SINK RATE" if the descent rate goes above 1 200 ft/min

- "BANK" if the bank angle goes above 6 °

- "PITCH" if the pitch attitude goes above 10 °, or below 0 °

- "LOC" if the LOC, F-LOC or LOC B/C deviation goes above ½ dot

- "GLIDE" if G/S or F-G/S deviation goes above ½ dot

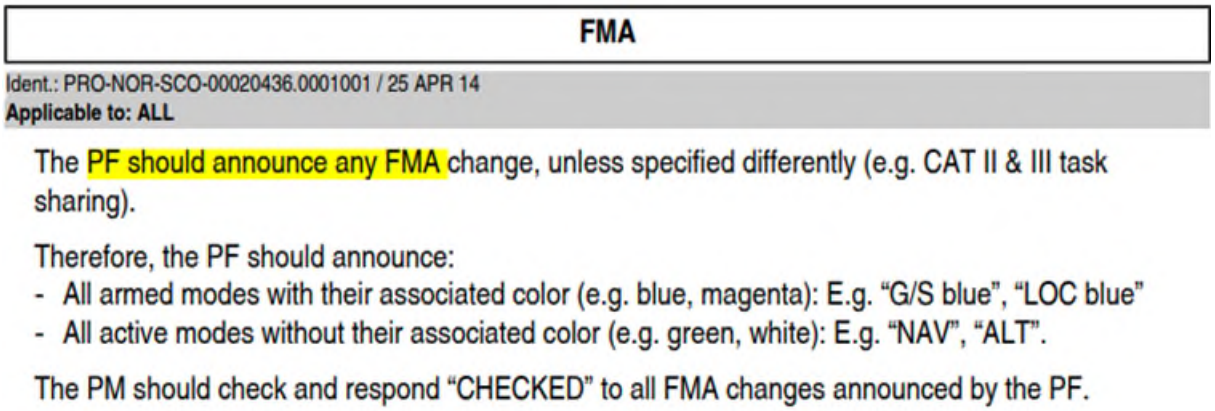
- "CROSS TRACK" if the XTK goes above 0.1 NM

- "COURSE" if the course goes above ½ dot or 2.5 ° (VOR) or 5 ° (ADF □)

- "__ FT HIGH (LOW)" at altitude checks point

1.17.1.3 Flight Mode Annunciator

In the FCOM PRO-NOR-SCO, 25 Apr 14, the operator described the Flight Mode Annunciator procedure as follows:



FMA

Ident.: PRO-NOR-SCO-00020436.0001001 / 25 APR 14
Applicable to: ALL

The PF should announce any FMA change, unless specified differently (e.g. CAT II & III task sharing).

Therefore, the PF should announce:
- All armed modes with their associated color (e.g. blue, magenta): E.g. "G/S blue", "LOC blue"
- All active modes without their associated color (e.g. green, white): E.g. "NAV", "ALT".

The PM should check and respond "CHECKED" to all FMA changes announced by the PF.

Fig. 16: Flight Mode Annunciator Source: FCOM

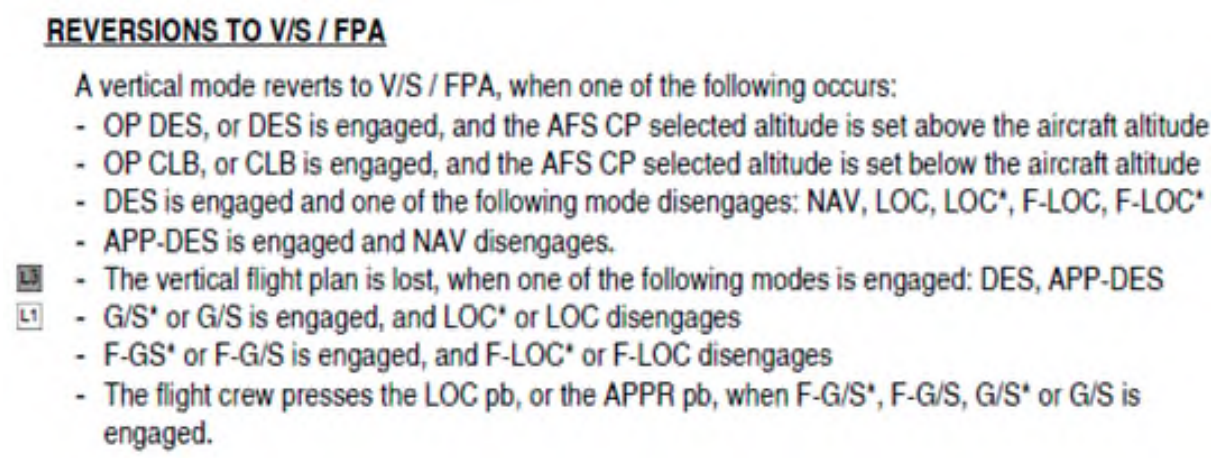
1.17.1.4 Rate of Descent

In the OM-A, 8.9.6, Rev 18 of 30.10.2018 Page 15, the operator described the maximum permissible rate of descent depending on the altitude as follows:

> *[…] ● 2,000 ft/min maximum when the aircraft is at or below MSA + 2,000 ft. Exceptions may be made only during daylight with visible surrounding terrain or when a greater rate of descent is part of an approved ATC procedure according to RM. When a rate of descent of more than 2,000 ft/min is permitted below the mentioned altitudes, all pilots shall pay special attention to flight instruments and to lookout. […]*

1.17.1.5 Open Climb Mode

The FCOM DSC-22-FG-70-70, 04 May 16, Chapter Aircraft Systems, 22 – AFS – Flight Guidance, AP/FD Modes – V/S FPA Modes, described how the so-called open climb should be flown. If Mode OPCLIMB is active and the altitude selected at the FCU is lower as the actual altitude, the V/S Mode is activated automatically. The vertical speed is maintained as new target:



REVERSIONS TO V/S / FPA

A vertical mode reverts to V/S / FPA, when one of the following occurs:

- OP DES, or DES is engaged, and the AFS CP selected altitude is set above the aircraft altitude
- OP CLB, or CLB is engaged, and the AFS CP selected altitude is set below the aircraft altitude
- DES is engaged and one of the following mode disengages: NAV, LOC, LOC*, F-LOC, F-LOC*
- APP-DES is engaged and NAV disengages.
- The vertical flight plan is lost, when one of the following modes is engaged: DES, APP-DES
- G/S* or G/S is engaged, and LOC* or LOC disengages
- F-GS* or F-G/S is engaged, and F-LOC* or F-LOC disengages
- The flight crew presses the LOC pb, or the APPR pb, when F-G/S*, F-G/S, G/S* or G/S is engaged.

Fig. 17: Reversions to V/S / FPA Source: FCOM

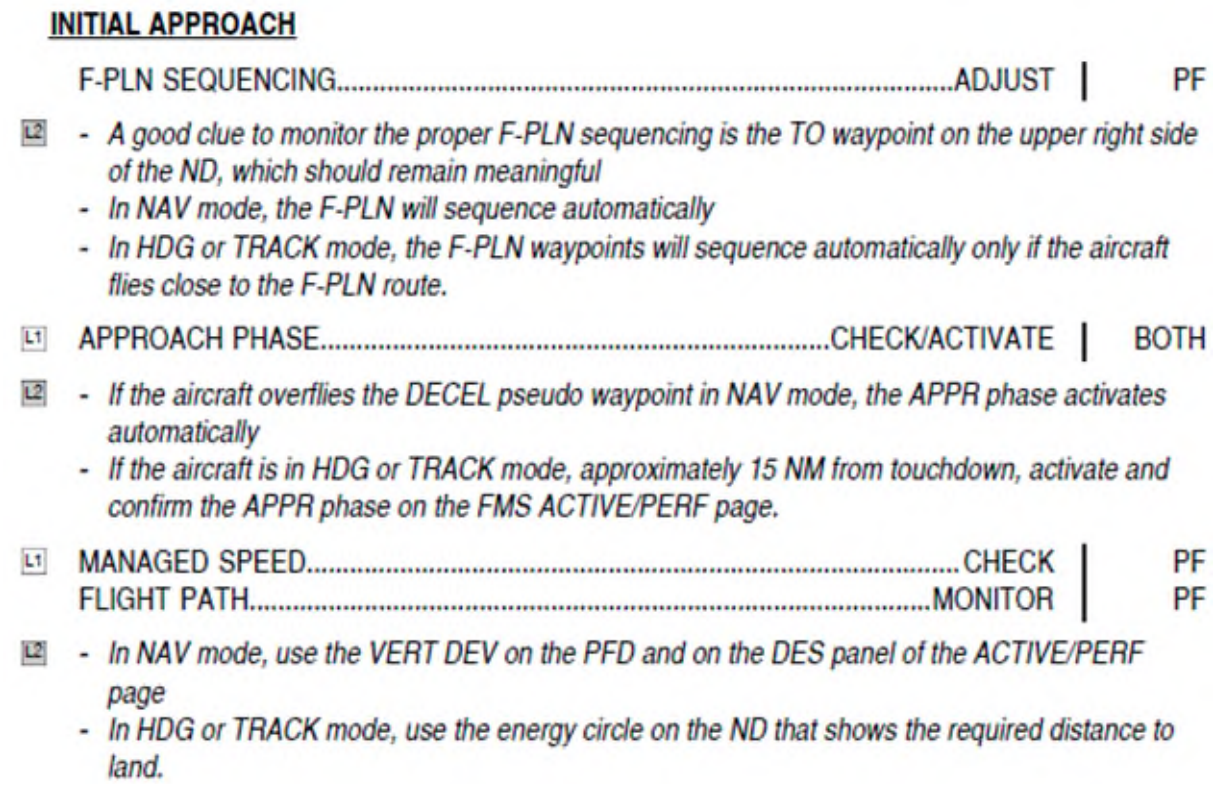
1.17.1.6 Initial Approach

Entering the flight plan (F-PLN) into the MCDU with no Route Discontinuity shortly before final approach is required for the correct calculation of the vertical and lateral flight path.

In the FCOM, PRO-NOR-SOP-180-B-A-00018931.0001001, 06.08.2014 INITIAL APPROACH was a separate item:

[…] F-PLN SEQUENCING ADJUST PF […]

Chapter PRO-NOR-SOP-180-B P1/6, 5 Feb 19, Chapter Procedures, Normal Procedures, Standard Operating Procedures – Approach, Initial Approach of the FCOM described:



INITIAL APPROACH

F-PLN SEQUENCING.....ADJUST | PF

L2 - *A good clue to monitor the proper F-PLN sequencing is the TO waypoint on the upper right side of the ND, which should remain meaningful*
- *In NAV mode, the F-PLN will sequence automatically*
- *In HDG or TRACK mode, the F-PLN waypoints will sequence automatically only if the aircraft flies close to the F-PLN route.*

L1 APPROACH PHASE.....CHECK/ACTIVATE | BOTH

L2 - *If the aircraft overflies the DECEL pseudo waypoint in NAV mode, the APPR phase activates automatically*
- *If the aircraft is in HDG or TRACK mode, approximately 15 NM from touchdown, activate and confirm the APPR phase on the FMS ACTIVE/PERF page.*

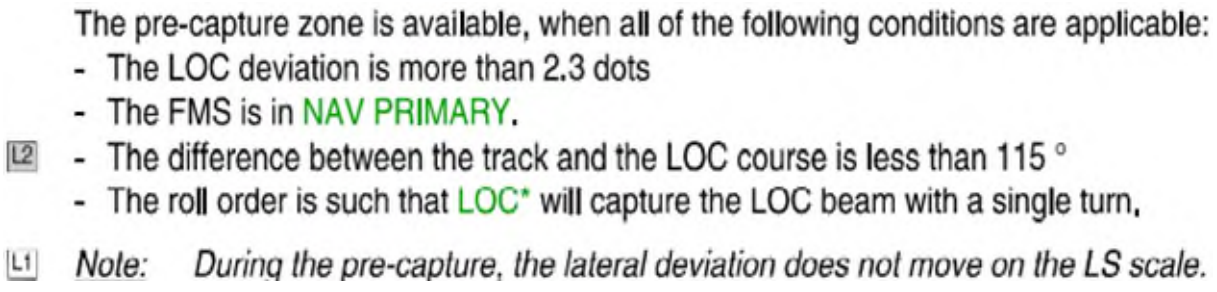
L1 MANAGED SPEED.....CHECK | PF
FLIGHT PATH.....MONITOR | PF

L2 - *In NAV mode, use the VERT DEV on the PFD and on the DES panel of the ACTIVE/PERF page*
- *In HDG or TRACK mode, use the energy circle on the ND that shows the required distance to land.*

Fig. 18: Initial approach procedure Source: FCOM

1.17.1.7 LOC Engagement Conditions

The operator's FCOM described in DSC-22-FG-70-80-10-00005864, 29 Sep 16, Engagement Conditions the preconditions for the localizer to change from Armed Mode to Capture Mode.



The pre-capture zone is available, when all of the following conditions are applicable:
- The LOC deviation is more than 2.3 dots
- The FMS is in NAV PRIMARY.

L2 - The difference between the track and the LOC course is less than 115 °
- The roll order is such that LOC* will capture the LOC beam with a single turn.

L1 *Note: During the pre-capture, the lateral deviation does not move on the LS scale.*

Fig. 19: Conditions of the localizer capture mode Source: FCOM

1.17.1.8 ILS Approach

The operator described in FCOM PRO-NOR-SOP-180-C P4/20, 5 Sep 19, Procedures, Normal Procedures, Standard Operating Procedures – Approach, F-G/S (G/S) Interception From Above that in case the glide slope is intercepted from above, the aircraft has to be established on the localizer and only a maximum rate of descent of minus 2,000 ft/min shall be flown.

The FCOM, PRO-NOR-SOP-180-C-A-00018958.0001001, 09.03.2018, described the procedure for the flight crew if the airplane is guided from above on to the vertical localizer of the ILS as follows:

> ***F-G/S (G/S) INTERCEPTION FROM ABOVE***
>
> *The following procedure should only be applied when established on the F-LOC (LOC) (LOC B/C) beam. The flight crew must react without delay to meet the stabilization criteria.*
>
> *APPR pb on the AFS CP* *PRESS* *PF*
>
> *AFS CP ALTITUDE* *SET ABOVE A/C ALTITUDE* *PF*
>
> *Select an altitude above the aircraft altitude, in order to prevent inadvertent ALT* engagement.*
>
> *V/S / FPA knob* *ADJUST FOR CAPTURE AND PULL* *PF*
>
> *Do not exceed -2 000 ft/min.*

In regard to the final approach, the operator described the following procedure for the PM in FCOM, PRO-NOR-SOP-180-C-A-00018959.0001001, 06.08.2014:

> ***FINAL APPROACH***
>
> *FLIGHT PARAMETERS* *MONITOR* *PM*
>
> *The PM calls out if excessive deviation occurs:*
>
> - *F-LOC (LOC) (LOC B/C): ½ dot*
> - *F-G/S (G/S): ½ dot*

1.17.2 Stabilised Approach

The criteria for a stabilised approach are described in the operator's OM-A, Rev 18, 30.10.2019, Page 33 as follows:

8.9.9 Stabilized Approach

An approach is stabilized when the aircraft is flown:

● along the desired flight path in landing configuration

● with appropriate thrust setting, usually above idle, to maintain the desired flight path

● at the approach speed between V_{REF} and V_{REF} + 20 kt

● while maintaining an acceptable rate of descent, and not exceeding 1,000 ft per minute

● when all briefings and checklist have been performed.

Notes:

1. ILS approach must be flown within 1 dot of the glide slope and localizer. A CAT II/III Approach must be flown within the expanded localizer band.

2. Unique approach procedure or abnormal conditions requiring a deviation from the above elements of a stabilized approach require a special briefing.

3. All flights must be stabilized by 1,000 ft above airport elevation in IMC or 500 ft above airport elevation in VMC. During a circling approach, wings should be leveled on final when the aircraft reaches 300 ft above airport elevation.

4. The approach that becomes non-stabilized or destabilized below 1,000 ft above airport elevation in IMC or 500 ft above airport elevation in VMC requires an immediate go-around.

1.17.3 Flight Plan

The operator described in the Flight Crew Training Manual PR-NP-SOP-170 P2/, 8 Aug 19 the procedure for the Managed Vertical Mode. In order to have a correct vertical flight plan, waypoints, among other things, have to be entered into the FMS (MCDU) in the correct order. Entry errors or an open routing (Route Discontinuity) result in an incorrect calculation or indication of the vertical flight path on the PFDs.

MANAGED VERTICAL MODE

The slope of the managed descent profile from high altitude is approximately 2.5 °.
The flight crew should estimate the distance to touchdown in order to monitor the descent profile. Therefore, they must ensure that the FMS ACTIVE/F-PLN page reflects the expected approach routing. Any gross error noticed in the descent profile is usually the result of a false routing entered in the FMS, or of waypoints not sequenced by the FMS, that lead to an erroneous distance to touchdown.

Fig. 21: FCTM Managed Vertical Mode Source: Operator

1.17.4 Air Navigation Service Provider

At Frankfurt/Main Airport a Feeder monitors the final approach. Reports of flight crews whether they are established on the localizer are not required.

The Manual of Operations Air Traffic Services (MO-ATS) documented the following:

> *[…]*
>
> *463.9 If an aircraft is vectored to intercept a pilot-interpreted final approach, the pilotshall be instructed to report when established on the final approach track. This report is not required if the aircraft is vectored by a separate feeder.*
>
> *463.91 When such a report is received and a deviation to the reported position is discernible on the situation display the pilot shall be advised of this deviation463.92 If the aircraft is already on the frequency of aerodrome control/aviationsupervision office (Luftaufsicht), they shall be informed about the deviation.*
>
> *[…]*

1.17.4.1 Ground Based Safety Systems

The air navigation service provider stated that two safety net services warn the air traffic control personnel if aircraft fly too low or deviate from the approach path: MSAW and APM

These services are provided by the ATS System CoSNET which have been in operation at Langen since 2013. So far, no APM components had been adapted for approaches to the runways of Frankfurt/Main Airport because a high number of false alarms is expected due the close proximity of the runways and other airports in the vicinity (Wiesbaden Erbenheim, Mainz Finthen). For approaches to Frankfurt/Main

Airport only the MSAW is available which provides General Terrain Monitoring. The MSAW uses a ground model, which has the elevation coded in tiles of 0.5 NM side length, for the alarm calculation. Using altitude and vertical speed of the aircraft, the MSAW calculates ground approach. A Predicted Alert is generated if this ground approach is less than the ground height + 750 ft within the next 30 seconds. The corresponding radar target and its label are framed and depicted in green. Above the frame the abbreviation PGT appears. In addition, a single acoustic warning is generated. These warnings are similar to the warnings of the safety system STCA[10]. The difference is, that the STCA alert colours two radar targets and their labels and the abbreviation PCA appears instead of PGT.

The controller stated that it is not immediately recognisable as to which alert is indicated. He could not say if he had realised the alert or interpreted it as false alarm. Because of the STCA there are many false alarms. Since the following aircraft had been far enough away, it is possible that he interpreted it as false alarm. It is often blinking green. He had not considered that the alert had been generated due to ground approach because there was no mountain in the vicinity. In any case, he would not have done anything differently because in his opinion the aircraft had been on the glide slope. He could not say whether the MSAW generates an acoustic warning.

The MSAW generates a Current Alert at an altitude which is lower than the ground height + 750 ft.

In the present case, two Predicted Alerts were generated and indicated for the controller. All other alerts were suppressed by CoSNET due to the active inhibition area EDDF. These areas have the aim to prevent inadvertent alerts in the area of the final approach where approaching aircraft are flying close to the ground in any case. According to the original logic, the MSAW is not designed to monitor approaches but hazardous ground approximations outside of published approach procedures.

According to the statement of the air navigation service provider, the APM is basically the more suited system to monitor ILS approaches. It is designed to generate alerts as soon as an aircraft leaves a defined funnel either laterally or downward.

The air navigation service provider stated that they would take the current case and examine whether is is feasible and possible to equip Frankfurt/Main Airport with APM components, due to improved technology.

[10] Short Term Conflict Alert

1.18 Additional Information

1.18.1 Definitions

The Federal Aviation Administration (FAA) defined Controlled Flight into Terrain and Situational Awarness, among other things, as follows:

> *[…]*
>
> *a. Controlled Flight into Terrain: CFIT occurs when an airworthy aircraft is flown, under the control of a qualified pilot, into terrain (water or obstacles) with inadequate awareness on the part of the pilot of the impending collision. […]*
>
> *c. Situational Awareness: Situational awareness means the pilot is aware of what is happening around the pilot's aircraft at all times in both the vertical and horizontal plane. This includes the ability to project the near term status and position of the aircraft in relation to other aircraft, terrain, and other potential hazards. […]*

1.18.2 Human Factors

As part of occurrence investigations of flight operations a number of studies regarding Human Error were conducted and recommendations for improvement of flight safety compiled. As possible countermeasures to Human Error fault-tolerant design, warning devices to recognise errors or technical solutions were proposed. Below are some exemplary excerpts:

The Australian Civil Aviation Safety Authority, SMS for Aviation - Human Factors a Practical Guide, 2012:

> *[…] Error is a normal and natural part of everyday life - it is generally accepted that we will make errors daily. In fact, research suggests that we make between three to six errors every waking hour, regardless of the task being performed. Managing error: If you want to find actual solutions for the problems human errors cause, you often need large systemic changes. […]*
>
> *[…] For example, the most common types of errors (slips and lapses) involve attention, vigilance and memory problems. Therefore, developing procedures (checklists that act as memory aids), designing human-centred equipment (alarms and warning devices if operationally critical items are forgotten) and training programs to raise awareness of human factors issues, are all common tools. […]*

In 2005, Airbus published the Flight Operations Briefing Notes, Human Performance - Error Management:

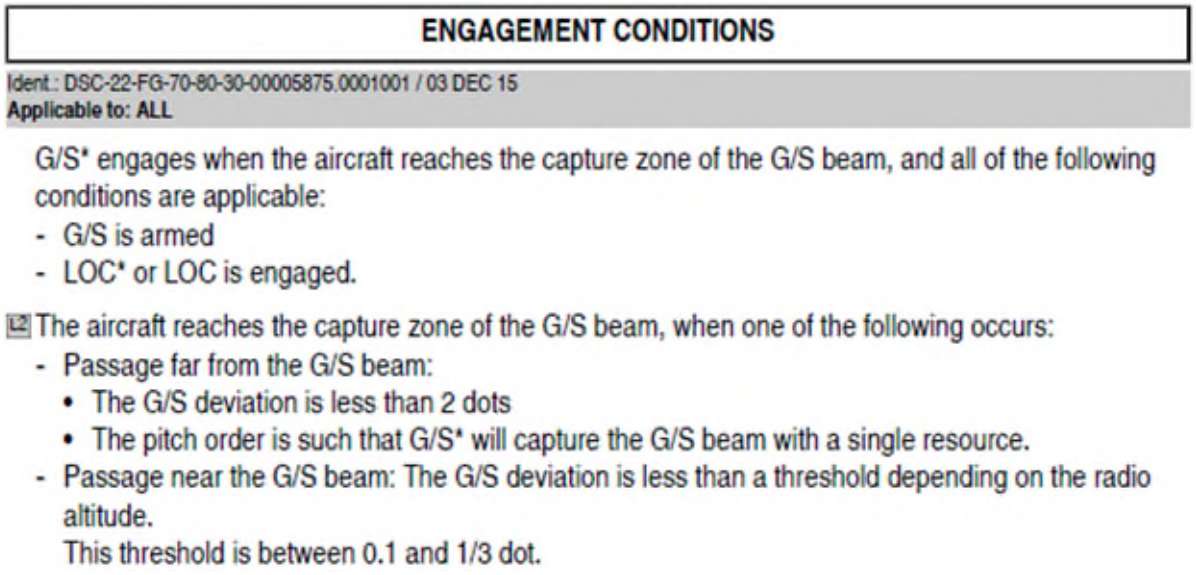
> *[…] Real solutions for human error require systemic improvements in the operation. One way consists of improving working conditions, procedures, and knowledge, in order to reduce the likelihood of error and to improve error detection. Another way is to build more error tolerance into the system, i.e. limit the consequences of errors. Error Prevention aims at avoiding the error all-together. This is possible only in some specific cases and, almost without exception, requires design-based solutions. […]*
>
> *[…] Error Tolerance aims at making the system as tolerant as possible towards error, i.e. minimizing the consequences of errors. […]*

1.18.3 Report of the Aircraft Manufacturer

In his report, the aircraft manufacturer analysed the turning towards the localizer.

> *[…] When the APPR mode was armed, the aircraft had crossed the extended runway centreline and as such, it was not able to capture the LOC with a single turn. It also did not meet a difference between LOC course and aircraft track of less than 115 ° (aircraft heading was 41° and runway was 68 °). […]*

The FCOM DSC-22-FG-70-80-30, 14. Mar 16, Chapter Aircraft Systems, 22 – AFS – Flight Guidance, AP / FD Modes – Approach Modes and Landing Modes described the Glide slope and Localizer Engagement Conditions.



ENGAGEMENT CONDITIONS

Ident.: DSC-22-FG-70-80-30-00005875.0001001 / 03 DEC 15
Applicable to: ALL

G/S* engages when the aircraft reaches the capture zone of the G/S beam, and all of the following conditions are applicable:

- G/S is armed
- LOC* or LOC is engaged.

The aircraft reaches the capture zone of the G/S beam, when one of the following occurs:

- Passage far from the G/S beam:
  - The G/S deviation is less than 2 dots
  - The pitch order is such that G/S* will capture the G/S beam with a single resource.
- Passage near the G/S beam: The G/S deviation is less than a threshold depending on the radio altitude.
  This threshold is between 0.1 and 1/3 dot.

Fig. 22: Glide slope Engagement Conditions Source: FCOM

1.18.4 Similar Occurrence

A similar incident occurred in 2017. During the approach to Domodedovo Airport, Moscow, Russia, an Airbus A380 descended below the glide slope and initiated a go-around procedure.

> *The Russian Federal Air Transport Agency (FATA) as the representation of the State of Occurrence delegated the Investigation to the AAIS being the State of Registry and of the Operator. After the Initial Investigation phase, the occurrence was classified as a 'Serious Incident', and the AAIS assigned an investigation file number, AIFN/0010/2017, to the case.*

The following is an excerpt of the report “AAIS Case No: AIFN/0010/2017, Airbus A380-861, 10. September 2017, Descent below Cleared Altitude during Approach and FMS not reconfigured following a reset during the Second Approach”:

> *Synopsis*
>
> *[…] During approach into Domodedovo International Airport, the Aircraft was cleared for the runway 14R ILS approach when it was on the base leg. The Aircraft descended below its cleared altitude of 500 meters QFE prior to establishing on the localizer. The Radar Controller alerted EK131 to stop the descent. The flight crew then performed a go-around and requested vectors for a second approach. During the go-around, the minimum radio altitude reached*

was 395 feet above ground level, and EGPWS "Glideslope" and "Terrain Ahead - Pull Up" alerts were activated. […]

The Air Accident Investigation Sector determines that:

(a) The descent below the cleared altitude during the first approach can be explained by an erroneous flight crew perception that the Aircraft would capture the 3° glideslope from above, and by insufficient coordination between the flight crewmembers. After the Co-pilot carried out the glide interception from above procedure, he focused on the horizontal position of the aircraft to establish on the localizer and neither of the two pilots maintained a correct awareness of the Aircraft vertical position.

(b) The cause of the discontinued approach on the second approach was the selection by the flight crew of a waypoint using the DIR TO function and after a relatively long discussion between them due to:

- the unavailability of the flight plan on the ND, as the FMS1, reset after the go-around, was not reconfigured by re-sequencing the flight plan as per the SOP; and. […]

Safety Actions taken by the Aircraft Manufacturer

Based on the findings regarding the FMS multi-waypoint sequencing of the flight plan and the FMS auto-reset, two mitigations are under review by the Aircraft manufacturer;

- *For the design aspect: the rectification and implementation will be discussed with the supplier (FMS manufacturer) for incorporation at the next FMS standard update.*
- *For the operational aspect: a system description and development of procedures are under review taking into account that a nominal situation is recovered if the FMS is reconfigured to perform the approach after the single FMS auto-reset.*

The auto-reset was confirmed by the FMS manufacturer/supplier as a real time computation issue, and not systematic. This problem had already been identified as being applicable to FMS provided by this supplier and equipping other Airbus programs. A rectification has been developed, certified and entered into service on Airbus A330 and A350 FMS standards. The solution will be

implemented on the Airbus A380 FMS L3 standard and is planned to be available at the end of 2020.

1.19. Useful or Effective Investigation Techniques

Not applicable.

2. Analysis

2.1 Persons

Both pilots held the required and valid aeronautical licences and ratings. Corresponding with their ratings and flying experiences they were scheduled as pilot in command and co-pilot. The two additional pilots, who the operator had deployed in accordance with internal procedures as observes for the flight phase below FL200, also held valid licences.

The BFU rated the PIC, the co-pilot and the two additional co-pilots as experienced due to their long aeronautical occupation and high total flying experience.

2.2 Flight Crew Actions

The co-pilot conducted the descent and final approach up until the go-around procedure.

The aircraft was flying behind another aircraft, during the descent and approach. Therefore, the flight crew assumed for their own flight path planning that they would start their approach to runway 07R after the preceding aircraft. The flight plan had been entered into the MCDU accordingly.

The controller informed them that due to the medical status the approach would be shortened and they would no longer land after the preceding aircraft. The controller instructed them to fly north toward the localizer of runway 07R. This reduced the remaining distance significantly. The CVR recording showed that the flight crew's stress level increased. The PF's orders were no longer clear and partially formulated as question.

The FCOM Chapter Initial Approach described that the flight plan had to be adjusted in the MCDU so that the vertical flight guidance could calculate the correct path and indicate it on the PFD. It was not possible to reconstruct the pilots input in the MCDU because the FDR is not designed to record these inputs.

A discussion of the pilots regarding a possible route discontinuity in the MCDU could not be heard on the CVR recording. Based on the chronological sequence of the aircraft configuration and the actual flight path, the BFU assumes that the flight plan had not been entered correctly into the MCDU. It is likely that the remaining distance above ground the flight crew had programmed in the MCDU was significantly longer

than the actual one. It is very likely that the indication on the PFD of the calculated vertical flight path did not correspond with the mental image of the pilots.

Presumably, the flight crew had the impression to be much too high above the required flight path to approach the ILS glide slope of runway 07R. In this phase, the flying experience of the flight crew should have taken effect. Altitude, speed and the configuration have to be taken into consideration in order to estimate in which situation they are and then act accordingly. The BFU assess the situational awareness[11] in this situation as insufficient.

Based on the FDR data it was possible to reconstruct that the PF controlled the descent with the Open Descent procedure. In order to increase the rate of descent, at constant high speed, the landing gear was extended and at times even the speed brakes and the flaps to increase drag. The flaps were also used to reduce speed. These were extended to their permissible operating limit. At the Flight Control Unit initially an altitude of 6,000 ft and then of 5,000 ft was selected.

The PF attempted to steer the aircraft in the HDG SEL Mode on to the localizer. Initially, the localizer was overshot toward the north.With heading entries the flight path was corrected towards east. The APPR Mode had not been activated, however, and therefore the LOC Capture Mode was not active. At about 1930:54 hrs, at 2,060 ft AMSL, the localizer was captured and the FMA indicated on the PFD LOC Captured[12]. After the aircraft had captured the localizer of runway 07R with the mode Localizer Engaged, the mean rate of descent was about minus 2,000 ft/min and reached a maximum of minus 4,009 ft/min. The aircraft was flown with high speed at the permissible operating limit of flaps position 2.

The operator had stipulated in the OM-A, chapter Stabilized Criteria, that during approach below 1,000 ft a maximum rate of descent of minus 1,000 ft/min shall be flown. According to the Standard Callouts, the PM should inform the PF about deviations from certain parameters. On the CVR no such standard callouts could be heard, even though several significant deviations from such values existed.

During the final approach phase, the aircraft was not configured for landing, speed did not correspond with the landing configuration, the rate of descent was above the limit

[11] Definition: the perception of the elements in the environment within a volume of time and space; the comprehension of their meaning; the projection of their status in the near future (Endsley, M., (1995) Toward a Theory of Situation Awareness in Dynamic Systems. Human Factors Journal 37(1), 32-64. Human Factors: The Journal of the Human Factors and Ergonomics Society. 37. 32-64. 10.1518/001872095779049543).

[12] LOC* was captured as it met the capture criteria of being less than 2.3 dots from the LOC beam, within 115º between track and LOC course, and able to capture it with a single turn

of 1,000 ft/min and the landing checklist had not been completed. Therefore, the approach was not stabilized in accordance with the OM-A requirements.

The PF disengaged the autopilot and initiated a go-around manoeuvre at 936 ft AMSL and 6.43 NM from the threshold of runway 07R.

The TAWS did not generate a Terrain Pull-up Warning, because the aircraft had not approached the ground far enough that it would have been triggered.

The flight crew could not explain to the BFU why they had flown so far below the glide slope. It was not possible for the BFU to draw any conclusions in regard to their intentions, from the interviews and the CVR recording.

The OM-A stipulated that two other co-pilots have to be present in the cockpit of the A350 fleet during take-off and landing. The pilots in their function as observers served as safety to recognise possible errors of the acting flight crew and intervene if necessary. Neither of the two pilots pointed out that the approach was too low.

2.3 Cockpit Communication

The recorded cockpit communication was mostly held in Thai. There were no briefings in regard to the approach route and the instrument approach. These were stipulated in FCOM PRO-NOR-SOP-160-160, 25 Apr 14.

The CVR analysis shows that during descent from cruise level a relaxed atmosphere prevailed in the cockpit. The first communications problem occurred on the radio frequency of the radar controller about four min prior to turning into the extended runway centre line. The radar controller asked about the ill passenger. This communication occurred outside the regular phraseology. The PM had problems to understand the content of the questions and asked the controller several times to repeat them.

The CVR recording showed that the flight crew’s stress level increased continuously. This fact is proven by the instructions of the PF which were no longer clearly worded. The instructions for the PM were partially formulated as questions.

During the interview the BFU perceived that the PM could follow the conversation only to a limited extent. The BFU is of the opinion that the PM was not capable to follow the English questions.

Up until engine shut-off, the CVR recording did not contain any discussion of the flight crew in regard to the first approach occurring too low. After the first failed approach it would have been appropriate to carry out an error analysis.

2.4 Aircraft

As part of the Air Operator Certificate (AOC)), the aircraft was certified for commercial passenger transport. In accordance with aviation regulation, the aircraft had a certificate of registration. The documentation (Retrieve Aircraft Complaints and Actions) provided by the operator did not contain any entries which indicated any defects of the navigation and receiver equipment for the localizer or glide slope antenna.

Based on the FDR data no warnings or parameter were identified which indicated any technical malfunctions.

2.5 Weather Conditions

At the time of the Serious Incident it was night. Visibility of light was more than 10 km and the airplane was free of clouds. Therefore, no visibility limitations existed. It is highly likely that the lighting of the near-by city of Frankfurt am Main and the ground lighting was easily recognisable for the flight crew. On that evening, barometric air pressure was 19 hPa higher than the ISA pressure. Due to the prevailing good weather conditions, they had no influence on the occurrence. On the contrary, due to the optimal meteorological conditions the flight crew could have realised early on that the airplane was at the wrong position and too low.

2.6 Airport

Frankfurt/Main Airport had the required permissions and inspection records for the instrument approach procedure ILS 07R. The status report of the approach system and its monitoring units did not show any failures. Therefore, the instrument landing system functioned properly and transmitted correct signals.

2.7 Air Navigation Service Provider

2.7.1 Defences

The MSAW functioned within the prescribed parameters. However, it could not alert the controller in regard to the impending ground approximation of the aircraft. The insufficient differentiation between MSAW and STCA alerts in combination with the

blunting of the personnel due to frequent false alarms of the STCA can reduce the effectiveness of the MSAW.

2.7.2 Organisational Influence

The air navigation service provider did not have any guidelines for the air traffic control personnel as to how to handle special situations, e.g. ill passenger, but the aircraft or its personnel is not directly affected, as this is the case for an emergency, for example. The Feeder instructed the flight crew to increase descent and shorten the flight path. The BFU is of the opinion that this was not necessary because there was no medical emergency which would have justified such an instruction. This instruction exposed the flight crew to time stress. The subsequent actions of the flight crew were uncoordinated and resulted in the loss of situational awareness. The BFU considers the instruction to increase the descent and shorten the flight path as contributory factor. In situations such as this, it would have been important to enquire as to the intentions of the flight crew and then to support them accordingly.

2.8 Human Factors

The flight crew was surly aware that the approach had to be stabilized. Nevertheless, the glide slope was approached from above and then underflown with a high rate of descent. In addition, the Feeder instructed the flight crew to shorten the approach. This surely posed a time problem for the flight crew to configure the aircraft in time and reduce height.

The mental image of both pilots in regard to the position of the aircraft deviated from its actual position. The PM did not question the PF’s actions. There was no discussion with corrections and no use of the standard phraseology.

3. Conclusions

3.1 Findings

Flight path

- For the flight crew unexpectedly, the Feeder instructed them to increase the descent and shorten the flight path.
- The waypoints of the approach route were not entered correctly into the MCDU.
- The Approach Mode was activated too late and as a result the localizer could not be captured.
- The glides slope was passed through from above and then underflown.
- During final approach the rate of descent was above the maximum allowable value of the operator.
- The approach was not stabilized and aborted late.

Basic Conditions

- Prior to departure, all weather data and NOTAMS required for the conduct of the flight were available.
- During the approach at night, the weather conditions were good.
- The aircraft was equipped for flights in accordance with instrument flight rules and with a Terrain Awareness and Warning System.
- Indications of technical defects were not found.
- The airport had the required approvals for the instrument approach procedure CAT I.
- At the time of the occurrence, no take-offs or approaches took place, which could have interrupted the localizer or glide slope signals.
- The unequivocal discernibility of MSAW and STCA warnings was not given for air traffic control personnel.

Persons and their Actions

- The pilots held the required licences and ratings and were experienced on type due to their flight hours.
- The Feeder’s instruction generated time stress for the flight crew.

- The PF changed the FCU Modes several times which resulted in operating errors.
- The PF steered the aircraft to a vertical profile below the glide slope.
- The procedures and stipulations of the operator were neither completely implemented nor adhered to.
- The Crew Resource Management of the flight crew was insufficient.
- There were no Standard Callouts or corrections by the PM.
- During the approach, the situational awareness was occasionally lost.
- The pilots did not recognise the ground approximation.
- The unstabilized approach was realised at low altitude and a go-around procedure initiated.

3.2 Causes

After a shortened final approach, the Airbus A350-941 was flying at night in good visual meteorological conditions unstabilized on instrument approach to runway 07R of Frankfurt/Main Airport. The glide slope of the instrument landing system was flown through from above. Starting at 3,300 ft AMSL, the flight path was continuously below the glisdesope. The cockpit crew aborted the instrument approach and initiated a go-around procedure about 6 NM ahead of the runway threshold 07R at 668 ft AGL, i.e. far below the glide slope.

The investigation determined:

- Errors in the programming of the waypoints in the flight management system
- Errors in the handling of the auto flight system for the approach
- Reduced situational awareness of the pilots in regard to the spatial position
- Communications and cooperation deficiencies within the flight crew.

4. Safety Actions

4.1 Safety Actions of the Air Navigation Service Provider

According to the statement of the air navigation service provider, they are taking the current case as reason to have examined whether it is feasible and possible to equip Frankfurt/Main Airport with APM components, due to improved technology.

The air navigation service provider informed the BFU in March 2022 that the APM for approaches to Frankfurt/Main Airport had been parametrisied and activated.

Investigator in charge: N. Kretschmer

Assistance: H. Bielfeldt, E. Schubert, C. Blanke, B. Dreyer

Braunschweig, 07 July 2022

5. Appendices

5.1 Chronology of the First Approach up until the Go-Around Procedure

Original position of the autopilot:

- The autopliot of the co-pilot (AP2) and both Flight Directors were active
- OPDES / HDG Mode active

1928:48 hrs / 5,790 ft AMSL

- Flaps were put in position 1

1929:17 hrs / 5,375 ft AMSL

- Speed brakes were fully extended

1929:26 hrs / 5,165 ft AMSL

- Flaps were put in position 2

1929:37 hrs / 4,800 ft AMSL

- The landing gear was extended

1929:55 hrs / 4,200 ft AMSL

- A/THR was active in the THR IDLE Mode
- The selected speed on the FCU was 175 kt
- The rate of descent was about minus 2,000 ft/min
- The selected altitude on the FCU was 3,000 ft
- The selected flight direction on the FCU was 40°
- The ILS frequency of 110,95 MHz Mhz for runway 07R was active

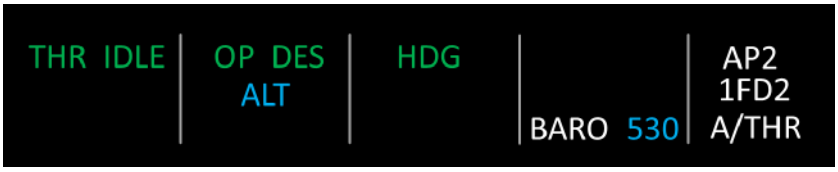


Fig. 23: FMA parameter indication Source: BFU

1930:20 hrs / 3,680 ft AMSL / 3,480 ft AGL

- On the FCU, the selected flight direction was changed from 40° to 60°
- The LOC parameter was minus 18 µA[13] (the aircraft was about 0.25 Dots right of the extended runway centre line) and decreased further

1930:22 hrs / 3,610 ft AMSL / 3,390 ft AGL

- Distance to the runway threshold was approximately 9 NM
- Autopilot No. 1 was also activated
- After the extended runway centre line had been overflown, the APPR push button was pushed and hence the localizer and glide slope receiver unit put into Arm Mode[14].
- The G/S parameter was + 53 µA (the aircraft was 0.75 Dot above the glide slope)
- The LOC parameter was + 12 µA (the aircraft was 0.25 Dots left of the extended runway centre line)
- Rate of descent was minus 2,420 ft/min
- On the FCU, the selected altitude was 3,000 ft
- Flight direction was 41°

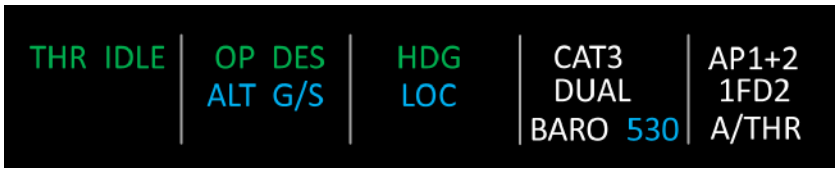


Fig. 24: FMA parameter indication Source: BFU

[13] A localizer signal of 75µA equals 1 Dot deviation. This is indicated on the primary flight display
[14] ARM APPROACH Mode prior reaching Initial Approach Fix (IAF)

1930:23 hrs / 3,570 ft AMSL / 3,350 ft AGL

- The descent was conducted in the OPDES Mode
- The aircraft was 0.6 Dots above the glide slope
- A vertical speed of minus 3,200 ft/min was selected
- A/THR was active in the SPEED Mode
- On the FCU, the selected flight altitude was changed from 3,000 ft to 6,000 ft.

Fig. 25: FMA parameter indication Source: BFU

1930:30 hrs / 3,300 ft AMSL / 3,110 ft AGL

- On the FCU, the selected flight direction was increased from 60° to 96°
- Flight direction was 47.5°
- At the time, bank angle was about 25°
- Rate of descent was minus 3,000 ft/min
- The autopilot was active in the V/S and HDG Modes
- LOC deviation was + 126 µA (aircraft was 1.6 Dots left of the extended runway centre line)
- G/S deviation was + 4 µA
- The glide slope was passed through with a rate of descent of minus 3,000 ft

Fig. 26: FMA parameter indication Source: BFU

1930:33 hrs / 3,160 ft AMSL / 2,965 ft AGL

- The speed brakes were retracted
- Pitch Down increased from minus 3° to minus 8°

1930:35 hrs / 3,065 ft AMSL / 2,870 ft AGL

- CAS increased (the speed selected on the FCU was 176 kt)
- On the FCU 5,000 ft were selected this corresponds with the go-around altitude in accordance with the precision approach chart for runway 07R

1930:42 hrs / 2,715 ft AMSL / 2,500 ft AGL

- On the CVR the automatic altitude announcement *Two Thousand Five Hundred* could be heard, at the same time the autopilot was disengaged

1930:43 hrs / 2,670 ft AMSL / 2,445 ft AGL

- CAS was 190 kt (on the FCU a speed of 137 kt was selected)
- The Speed brakes were extended
- Rate of descent was minus 3,350 ft/min
- Pitch Down was minus 4°

1930:54 hrs / 2,060 ft AMSL / 1,820 ft AGL

- LOC Captured[15]
- LOC deviation was + 176 µA (2.3 Dots left)
- Rate of descent was minus 3,230 ft/min
- CAS was 210 kt

[15] LOC* was captured as it met the capture criteria of being less than 2.3 dots from the LOC beam, within 115º between track and LOC course, and able to capture it with a single turn.

- Flight direction was 91°, bank angle 19° left
- The glide slope deviation was minus 240 µA (3.2 Dots below the glide slope)

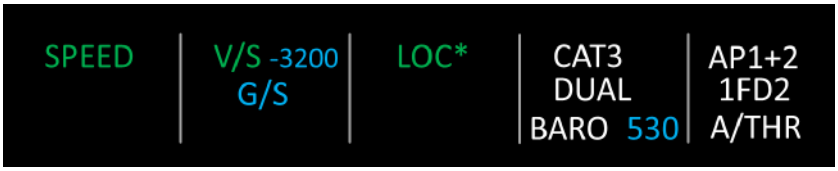


Fig. 27: FMA parameter indication Source: BFU

1931:03 hrs / 1,610 ft AMSL / 1,340 ft AGL

- On the CVR *Sink Rate* could be heard twice
- Rate of descent was minus 3,370 ft/min
- G/S deviation increased to minus 307 µA (more than 4 Dots below the glide slope)
- On the CVR the warnings *One Thousand* and *Glide Slope* could be heard

1931:05 hrs / 1,505 ft AMSL / 1,240 ft AGL

- The autopilot mode changed from LOC* / V/S to LOC* / OPCLIMB
- Rate of descent was minus 3,300 ft/min
- CAS was 201 kt
- The altitude button on the FCU was pulled
- On the FCU, 5,000 ft were selected
- A/THR Mode changed to THRCLB
- Engine thrust increased

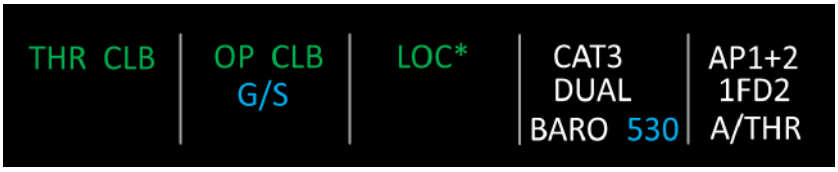


Fig. 28: FMA parameter indication Source: BFU

1931:06 hrs / 1,450 ft AMSL / 1,185 ft AGL

- On the FCU, 100 ft was selected
- The mode LOC* / OPCLIMB changed to LOC* / V/S.
- On the FCU, a rate of descent of 3,200 ft/min was selected
- A/THR Mode changed to Managed SPEED with a selected speed of 137 kt
- CAS was 205 kt
- Engine thrust decreased up to idle

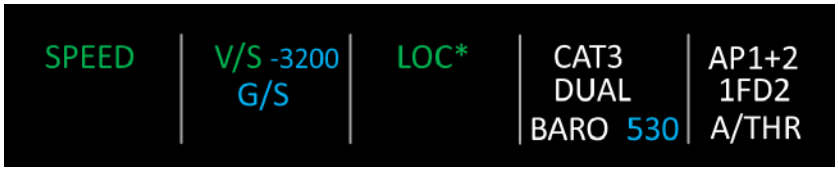


Fig. 29: FMA parameter indication Source: BFU

1931:07 hrs / 1,400 ft AMSL / 1,135 ft AGL

- On the FCU, 3 000 ft was selected
- Rate of descent was minus 3,000 ft/min
- Autopilot Mode was LOC* / V/S

1931:13 hrs - go-around manoeuvre / 1,120 ft AMSL / 936 ft AGL

- Ten seconds after the warning *Sink Rate*, the PF gave the command to initiate go-around
- CAS was 210 kt
- The engine levers were put in position TOGA
- A/THR was deactivated
- The autopilot was disengaged
- Both FDs changed to the SRS / NAV Mode

- The N1 rpm of the engines increased
- The sensor of the co-pilot's sidestick recorded a value of minus 18° (full nose up deflection).

Fig. 30: FMA parameter indication Source: BFU

5.2 FDR Plots

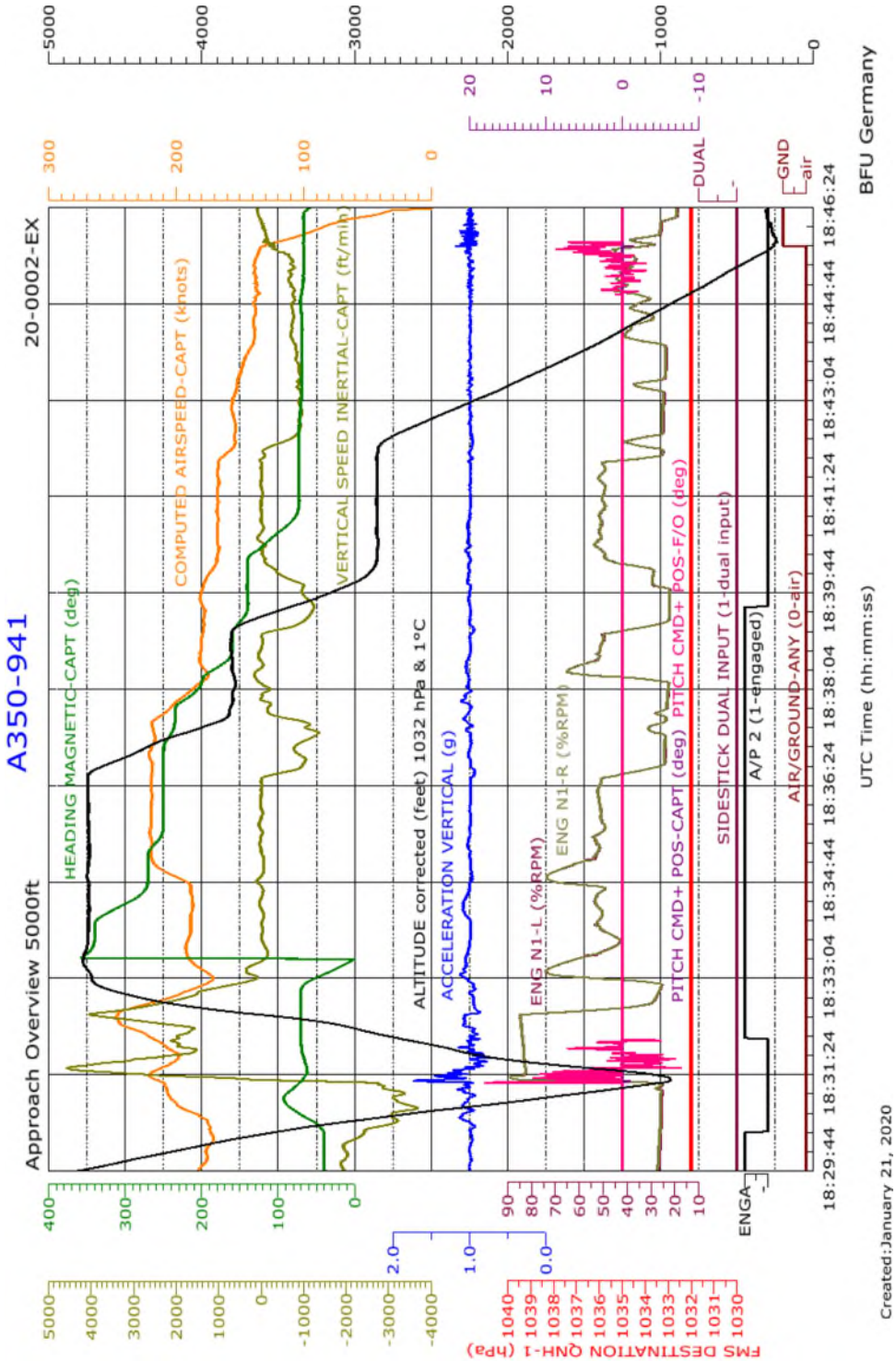


Fig. 31: Approach phase from about 5,000 ft AMSL on Source: BFU

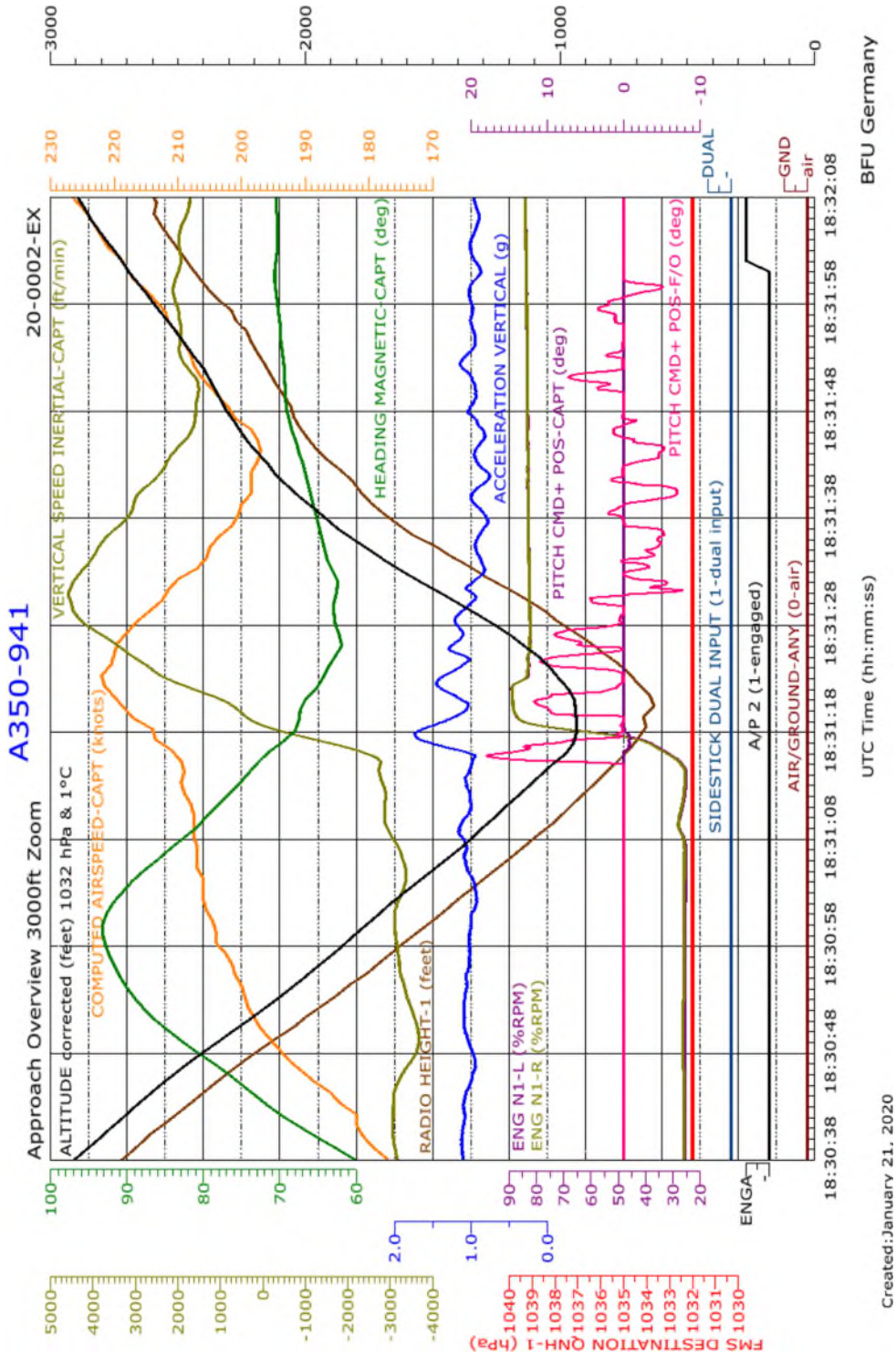


Fig. 32: Occurrence close to the ground

Source: BFU

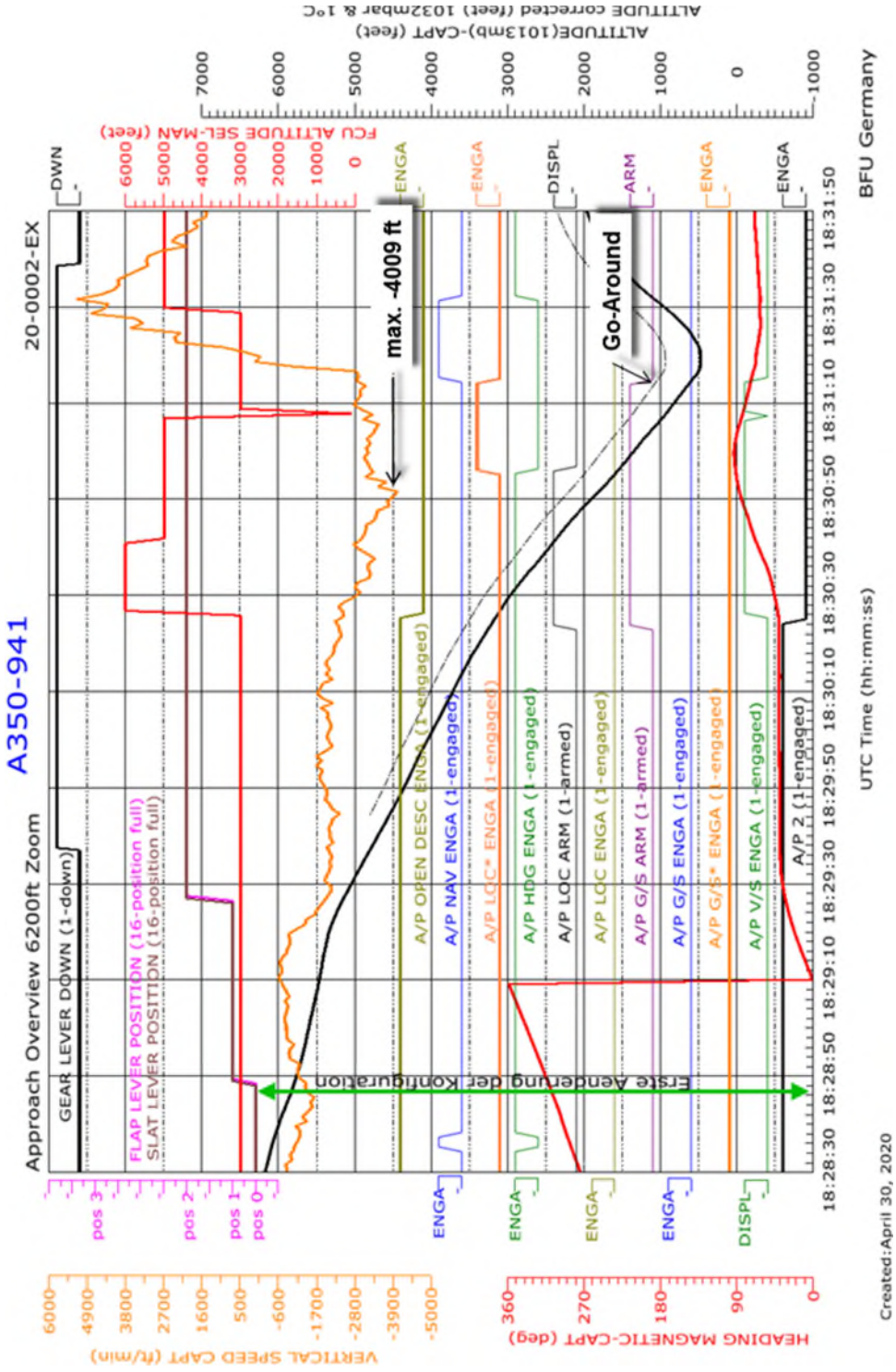


Fig. 33: Autopilot modes during the approach up until the go-around Source: BFU