Bundesstelle für
Flugunfalluntersuchung

German Federal Bureau of
Aircraft Accident Investigation

Investigation Report

Identification

Type of Occurrence:	Accident
Date:	11 July 2021
Location:	Kavala, Greece
Aircraft:	Airplane
Manufacturer:	Airbus
Type:	A320-214
Injuries to persons:	No injuries
Damage:	Aircraft substantially damaged
Other Damage:	None
State File Number:	BFU21-0555-2X

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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Abbreviations

Glossary of Abbreviations

AAIASB	Hellenic Air Accident Investigation and Aviation Safety Board	
AAIB	Air Accidents Investigation Branch	
ACARS	Automatic Communications And Reporting System	
AGL	Above Ground Level	über Grund
AMM	Aircraft Maintenance Manual	Luftfahrzeug-Instandhaltungshandbuchr
AMSL	Above Mean Sea Level	über dem mittleren Meeresspiegel
AOC	Air Operator Certificate	Luftverkehrsbetreiberzeugnis
AP	Autopilot	automatische Flugregelungs- und Steueranlage
ARC	Airworthiness Review Certificate	Bescheinigung über die Prüfung der Lufttüchtigkeit
ATC	Air Traffic Control	Flugverkehrskontrolle
ATHR	Auto Thrust	
ATPL	Airline Transport Pilot Licence	Verkehrspilotenlizenz
BFU	German Federal Bureau of Aircraft Accident Investigation	German Federal Bureau of Aircraft Accident Investigation
CAS	Calibrated Airspeed	Kalibrierte Fluggeschwindigkeit
CFDIU	Centralized Fault Display Interface Unit	
CFDS	Centralized Fault Display System	
COP	Co-pilot	Co-pilot
CVR	Cockpit Voice Recorder	
DFDR	Digital Flight Data Recorder	Digitaler Flugdatenschreiber
DME	Distance Measuring Equipment	Entfernungsmessgerät
EAS	Equivalent Airspeed	

EASA	European Aviation Safety Agency	Europäische Agentur für Flugsicherheit
ECAM	Electronic Centralized Aircraft Monitoring	
ELEV	Elevation	Ortshöhe über dem Meer
FAC	Flight Augmentation Computer	
FCL	Flight Crew Licensing	
FCOM	Flight Crew Operating Manual	
FD	Flight Director	
FDR	Flight Data Recorder	Flight Data Recorder
FL	Flight Level	Flugfläche
FMS	Flight Management System	
ft	Feet	Fuß (1 Fuß = 0,3048 m)
ft/min	Feet per minute	Fuß pro Minute
g	acceleration due to Earth's gravity (9,81 m/s²)	Beschleunigung durch die Erdanziehungskraft (9,81 m/s²)
GND	Ground	Grund
GS	Ground Speed	Geschwindigkeit über Grund
HDG	Heading	Steuerkurs
IAS	Indicated Airspeed	Angezeigte Fluggeschwindigkeit
ICAO	International Civil Aviation Organisation	Internationale zivile Luftfahrtorganisation
IFR	Instrument Flight Rules	Instrumentenflugregeln
IFTB	In Flight Turn Back	
IR	Instrument Rating	Instrumentenflugberechtigung
KIAS	Knots Indicated Airspeed	
kt	knot(s)	Knoten (1 kt = 1,852 km/h)
LGCIU	Landing Gear Control and Interface Unit	
LM	Landing Mass	Landing mass
METAR	Aviation Routine Weather Report	Routine Wettermeldung für die Luftfahrt
MLG	Main Landing Gear	Hauptfahrwerk
MLM	Maximum Landing Mass	Maximum landing mass

MPL	Multi-Crew Pilot Licence	Lizenz für Verkehrspiloten in mehrköpfigen Flugbesatzungen
MSA	Minimum Sector Altitude	Mindestsektorenhöhe über MSL
MSL	Mean Sea Level	Mittlerer Meeresspiegel
MTOM	Maximum T/O Mass	Maximale Startmasse
NDB	Non-Directional radio Beacon	
NLG	Nose Landing Gear	Bugfahrwerk
NM	Nautical Mile(s)	Nautische Meile(n)
OM	Operations Manual	Betriebshandbuch
PF	Pilot Flying	Pilot, der das Flugzeug steuert
PFD	Primary Flight Display	
PIC	Pilot in Command	Pilot in Command
PM	Pilot Monitoring	Pilot, der den PF unterstützt
QNH	altimeter pressure setting to indicate altitude AMSL	Luftdruck in Meereshöhe
QRH	Quick Reference Handbook	
RA	Radio Altitude	Radarhöhe
REV	Reverse	Umkehrschub
RTO	Rejected Take-Off	Startabbruch
RWY	Runway	Runway
SOP	Standard Operating Procedure	Standard-Betriebsverfahren
T/O	Take-Off	Start, Abheben
TOM	Take-Off Mass	Startmasse
UTC	Universal Time Coordinated	
V_1	T/O Decision Speed	
VDL	Correction for defective distant vision	Korrektur für eine eingeschränkte Sehschärfe in der Ferne
VFR	Visual Flight Rules	Sichtflugregeln
VHF	Very High Frequency	Ultra Kurz Welle
VOR	VHF Omnidirectional radio Range	
WOW	Weight on Wheel	

Synopsis

In the scope of this investigation, two occurrences were examined. The first occurrence was a rejected take-off at Heraklion Airport, Greece, on 10 July 2021, involving this aircraft and the second, a landing at Kavala Airport, Greece, on 11 July 2021 with a deflated nose landing gear shock absorber.

The reason for the rejected take-off at Heraklion Airport, just below the decision speed V1, was that the airplane veered right towards the runway edge which was caused by a right rudder pedal input.

After the rejected take-off, the aircraft had been returned to service with a severely damaged nose landing gear shock absorber and thus in a non-airworthy condition.

This was caused by:

- Shortly after the rejected take-off had been initiated, a dynamic rotation/de-rotation occurred which caused a very high de-rotation rate when the nose landing gear touched down again.
- After the rejected take-off, the damping of the nose landing gear shock absorber was still present in spite of the severe damage.
- The mechanics at Heraklion lacked the information from the flight crew about the dynamic rotation/de-rotation and the high lateral accelerations during the rejected take-off.
- After the rejected take-off, the damage at the right tire sidewalls of the two nose landing gear wheels remained undetected.
- The maintenance personnel at Heraklion released the aircraft to service again after they had replaced all four main landing gear wheels on 10 July 2021, even though they had no findings or information which could have explained why the airplane veered to the right and thus the reason for the rejected take-off.

After the landing at Kavala Airport on 11 July 2021, severe damage of the fuselage structure in the area of the nose landing gear was determined.

This was caused by:

- The initial deformation of the NLG shock absorber cylinder after the rejected take-off increased during the following flights so that finally after take-off at Kavala the NLG shock absorber no longer extended completely.

- Due to the previous flights and the accompanying loads, the crack in the cylinder had opened after take-off at Kavala and loss of pressure in the nose landing gear shock absorber occurred to which the cylinder's strong deformation and the damaged dynamic seal also contributed.
- It is highly likely that the combination of a high de-rotation rate during touch-down of the nose landing gear and the lack of nose landing gear damping resulted in the structural damage of the front fuselage during the landing at Kavala.

Due to the occurrences the operator had taken several safety measures and the aircraft manufacturer two. The BFU intends to issue one safety recommendation.

1. Factual Information

1.1 History of the Flight

1.1.1 Rejected take-off at Heraklion Airport on 10 July 2021

On 10 July 2021, a flight from Heraklion to Düsseldorf was planned with this aircraft. Six crew members and 122 passengers were on board. It was the second flight of the aircraft on this day. The Pilot in Command (PIC) was Pilot Monitoring (PM) and the co-pilot Pilot Flying (PF).

At about 1210 hrs[1], the flight crew received take-off clearance on runway 27. At the time, a crosswind component of 12 kt from the right prevailed. The co-pilot stated that he was aware that he had to counteract the aircraft's drift to the right during the take-off run with corresponding rudder inputs. The FDR recording and the statement of the co-pilot showed that during the initial 23 s long phase of the take-off run, up to a speed of 126 kt CAS, the co-pilot counteracted the crosswind with single left rudder inputs. Thereby the rudder was continually returned to the neutral position. The PIC stated that she had noticed the co-pilot's rudder pedal inputs during the take-off run.

At 1210:51 hrs, at 133 kt CAS, a rudder pedal input to the right occurred.

At the time when the airplane began to veer to the right the PIC briefly checked the engine parameters and according to both pilots, the co-pilot said in essence "Sorry, das Flugzeug zieht nach rechts (the airplane is pulling to the right)".

Subsequently, the PIC aborted take-off at a speed of 137 kt CAS, 2 kt below the decision speed V1. According to her own statement, she pulled the thrust lever to idle and then to full reverse. The PIC also executed a left rudder pedal input towards the runway centre line and pulled the side stick back. According to her statement, she cannot remember operating the side stick. Immediately afterwards, the nose landing gear lifted off. After she realised the lift-off of the aircraft's nose, she pushed the side stick forward and the nose landing gear touched down again. During ground contact, the airplane was in a yaw movement towards the left in the direction of the runway centre. According to the co-pilot, he heard a bang during the rejected take-off which he correlated with the touch-down of the nose landing gear.

[1] All times local, unless otherwise stated.

After the rejected take-off, the ground spoilers were extended automatically and the auto brake system activated in level MAX.

In the course of the described manoeuvre, the airplane changed heading by about 10° to the right to 281° and 4 s after initiation of the rejected take-off, was about 230 m beyond the intersection of runway 27 with runway 30, 3.7 m away from the right edge of runway 27.

During the braking action, the airplane moved back towards the runway centre line and came to a stop on runway 27 ahead of taxiway C.

After the airplane had come to a stop, the co-pilot informed the tower about the rejected take-off and requested the fire brigade. After a short stop at this position and the check of the brake temperatures, among other things, the flight crew decided to leave the runway and taxied to the assigned parking position 12.

The PIC informed the mechanics of the maintenance organisation subcontracted by the operator, that the take-off had been aborted because the airplane had pulled to the right, according to their statements. The operator was initially informed of the occurrence by the PIC via the Operations Control Center (OCC).

During their work on the airplane, the mechanics were in contact with the maintenance control center of the operator in Germany, from whom they also received their work orders.

According to their statements, the mechanics began with a “General Visual Inspection (GVI)” of the airplane, during which they determined that all four tires of the main landing gear, especially the outer tire of the right main landing gear (tire No. 4), had been damaged and had to be replaced. None of the tires was deflated.

Then they continued their work with the “AMM (Aircraft Maintenance Manual) Inspection 05-51-15 after a Tire Burst or Tread Throw or Wheel Failure”. At the same time, the aerodrome operator conducted an inspection of runway 27. Since none of the tires was deflated and no tire debris had been found after the rejected take-off during the runway inspection, the mechanics applied “AMM Inspection 05-51-16 after Brake Emergency Application or Overheat”.

On the evening of 10 July 2021, the four main landing gear wheels were replaced.

Figure 1 shows the rubber abrasion traces (take-off direction), which could be attributed to the rejected take-off on 10 July 2021 and had been caused by the tires of all three landing gears.

Fig. 1: Rubber traces on runway 27 caused by the rejected take-off Source: Operator

Figure 2 shows the rejected take-off tracks, reconstructed by the aircraft manufacturer (red line: left main landing gear track, green line: right main landing gear track, yellow line: aircraft centre of gravity track).

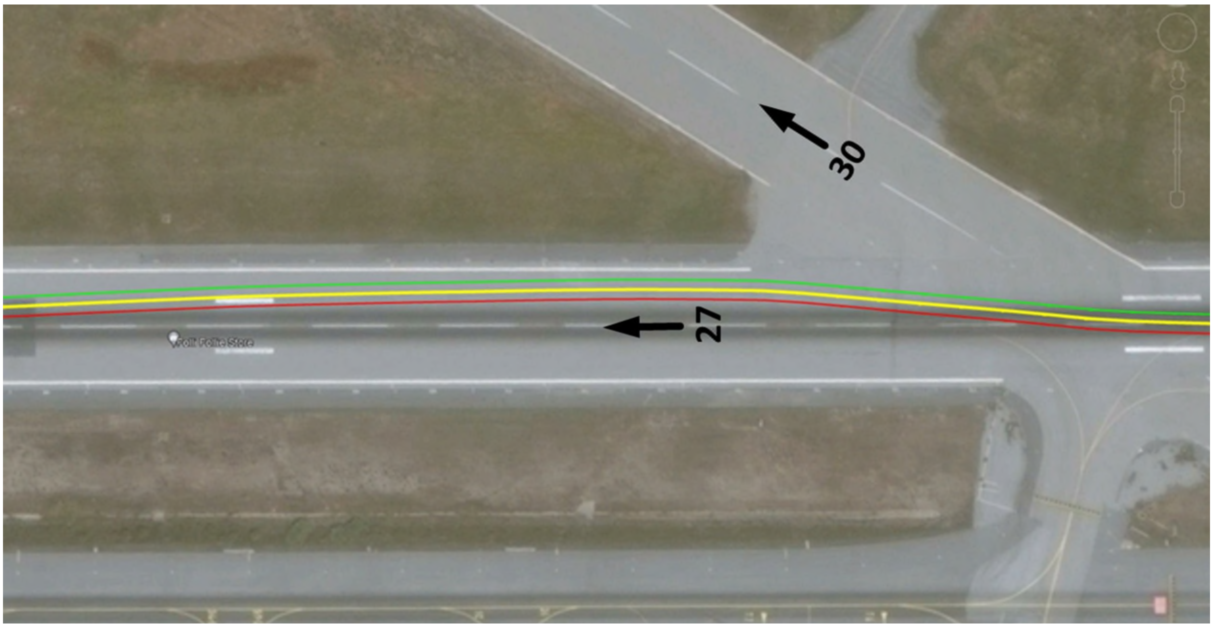

Fig. 2: Tracks of the rejected take-off on runway 27 at Heraklion Airport Source: Aircraft manufacturer

The next day (11 July 2021), the flight crew flew without passengers from Heraklion to Düsseldorf. During this flight, the PIC was PM and the co-pilot PF. The PIC performed the exterior walkaround prior to the flight. The flight went without further problems. The flight crew stated that the damping through the nose landing gear was not noticeably reduced.

1.1.2 Landing with a Deflated Nose Landing Gear Shock Absorber at Kavala Airport on 11 July 2021

On 11 July 2021, a flight from Kavala to Düsseldorf was planned with this aircraft. On board were 6 crew members and 74 passengers. It was the third flight of this aircraft on that day. The PIC was PF and the co-pilot PM.

The same flight crew had conducted the previous flight from Düsseldorf to Kavala. According to their statements, the co-pilot had performed the exterior walkaround prior to the flight from Düsseldorf to Kavala as well as the one prior to the planed flight from Kavala to Düsseldorf. The flight crew stated that the exterior walkaround at Dusseldorf had been delegated to the co-pilot by the PIC in accordance with Standard Operating Procedure (SOP) due to his high work load. The co-pilot stated that the chrome layer of the nose landing gear shock absorber had been visible during both exterior walkarounds.

According to the flight crew’s statement, on the flight from Dusseldorf to Kavala and the subsequent taxiing for take-off at Kavala, the damping through the nose landing gear had not been noticeably reduced.

After take-off from runway 23 at Kavala at 1942:15 hrs, the pilots were not able to retract the landing gear. The landing gear lever was blocked in position DOWN and the co-pilot could not move it into position UP. Shortly afterwards, the ECAM message L/G SHOCK ABSORBER FAULT was triggered. At 1942:39 hrs, the PIC switched on the autopilot (AP1) at 930 ft AMSL, which automatically disengaged again 8 s later. The ECAM messages AUTO FLT AP OFF and AUTO FLT A/THR OFF were triggered. Afterwards it was not possible to engage one of the two autopilots or the autothrust system. For the remainder of the flight the airplane was controlled manually. During climb, the co-pilot informed Kavala Tower that they could not retract the landing gear. At 1943:32 hrs, the PIC reduced speed to 220 kt and continued the flight in the direction of the runway.

Then the ECAM L/G SHOCK ABSORBER FAULT procedure was performed. By means of the landing gear indication panel and the ECAM WHEEL page, the pilots determined that all three landing gears were indicated as extended and downlocked.

At 1950:15 hrs, the pilots levelled off at FL 100. In agreement with the tower controller they flew within the 25 NM radius of VOR KPL above the Minimum Sector Altitude (MSA) along radials of VOR KPL with headings almost parallel to the runway (Fig. 3). VOR KPL was overflown several times. Since there was no radar coverage, support via radar vectors was not possible.

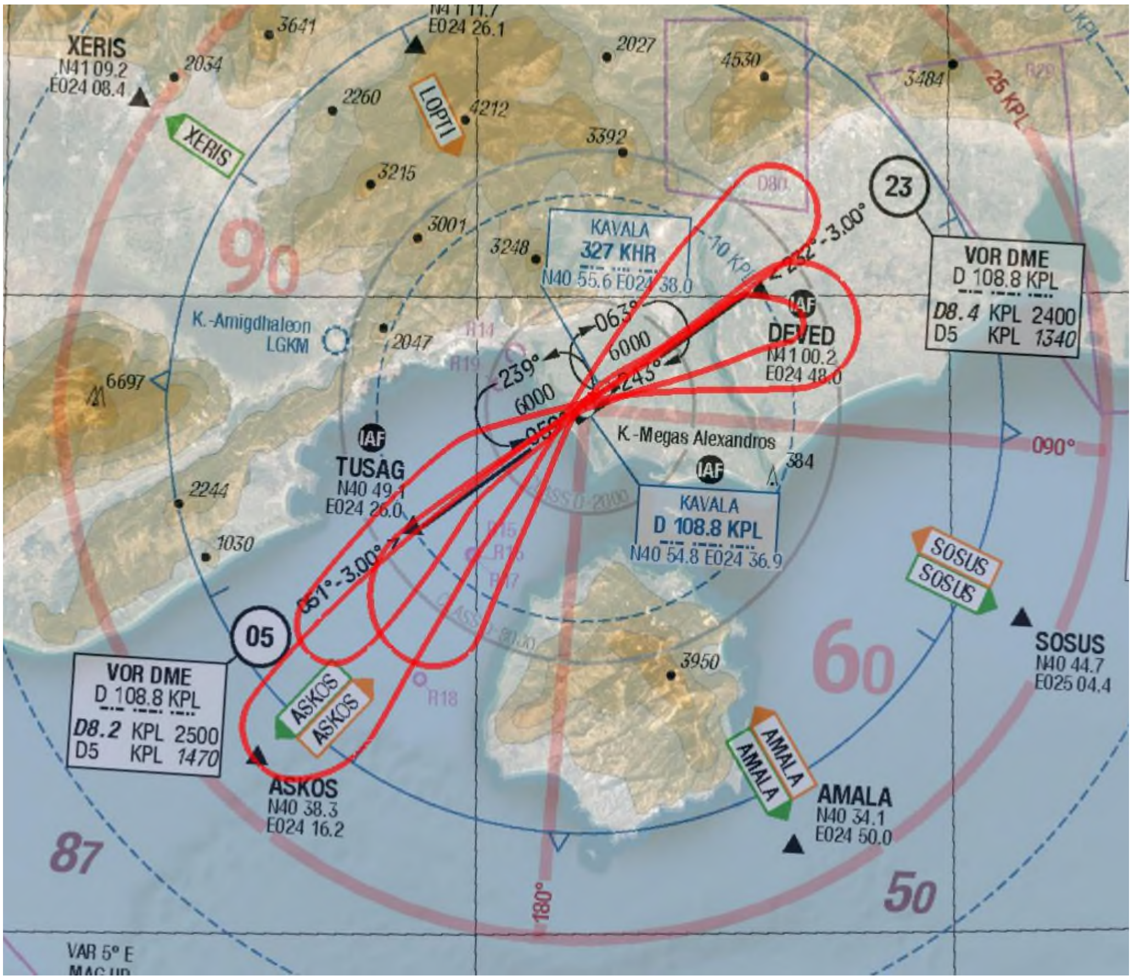

Fig. 3: Flight path of the aircraft involved Source: Operator, adaptation BFU

Fuel consumption was increased due to the extended landing gear, which both pilots realised. The remaining flight time was estimated to be about 2 hours. Prior to the decision-making process, the purser was informed about the current situation. The pilots applied the FORDEC[2] method and came to the decision to land at Kavala again.

According to their statements, it was not clear to them which landing gear was affected by the ECAM message L/G SHOCK ABSORBER FAULT. The pilots discussed a potential connection between the fault and the rejected take-off the day before at Heraklion. Prior to departure at Dusseldorf, the co-pilot had learned from a mechanic that the „AMM Inspection 05-51-15 after a Tire Burst or Tread Throw or Wheel Failure“ was performed after the rejected take-off. Based on this information, he assumed a landing gear shock absorber fault at one of the two main landing gears.

The flight crew could not contact the maintenance control centre of the operator via the Aircraft Communication and Reporting System (ACARS). During the occurrence, there was no data link and the system showed the status STBY (standby).

The co-pilot informed the tower controller about their decision to land at Kavala again. As precautionary action, the flight crew requested the fire brigade. Since the tower controller asked the flight crew for a Mayday call in order to alert the fire brigade, the co-pilot declared emergency after consulting with the PIC.

The PIC transferred manual control of the airplane to the co-pilot and then informed the cabin crew and the passengers of their decision to return to Kavala. The PIC prepared and briefed the VOR-DME approach to runway 23 of Kavala Airport. After taking back control, he performed the approach.

The pilots stated that because of the Mayday call Kavala Airport had stopped all VFR flights and kept them away from the airplane involved, respectively. At the time of the approach, no other approaching or departing IFR traffic was present in the area of Kavala Airport.

At 2035:03 hrs, the main landing gear touched down. The flight crew stated that the sinking of the nose landing gear into the shock absorber during the subsequent touch-down of the nose landing gear felt unusually hard. The airplane was decelerated with full reverse and auto brake medium. According to the flight crew, during taxiing a lack of nose landing gear damping was also felt.

After the airplane had been parked at the parking position, a deflated nose landing gear shock absorber and severe structural damage at the front area of the fuselage,

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[2] FORDEC is a method for structured decision finding. F = Facts, O = Options, R = Risks and Benefits, D = Decision, E = Execution and C = Check

especially in the area of Frame 20, was determined. At this time, there was no visible leakage of the nose landing gear shock absorber.

1.2 Injuries to Persons

Not applicable.

1.3 Damage to Aircraft

After the airplane had landed at Kavala Airport with a deflated nose landing gear shock absorber, severe damage at the fuselage structure in the area of the nose landing gear was determined.

1.4. Other Damage

There was no other damage to persons or property.

1.5 Personnel Information

1.5.1 Persons Involved with the Rejected Take-off at Heraklion

Pilot in Command

The 40-year-old PIC held an EU Airline Transport Pilot Licence (ATPL(A)) last issued on 5 April 2019 by the Luftfahrt-Bundesamt (LBA, German civil aviation authority) in accordance with Part-FCL (Flight Crew Licensing). The licence listed the rating as PIC on Airbus A320 and the respective instrument rating; each valid until 30 November 2021. Language Proficiency Level 6 for German and English, with no expiry date, were also listed.

Her class 1 medical certificate, with the restriction VDL, was issued on 11 August 2020 and valid until 11 August 2021.

She had a total flying experience of 9,870 hours; 3,052 hours of which on A320. In the last 90 days she had flown 26 hours on type.

Co-pilot

The 28-year-old co-pilot held an EU Multi-Crew Pilot Licence (MPL(A)) last issued on 5 August 2019 by the LBA in accordance with Part-FCL. The licence listed the rating as COP on Airbus A320 and the respective instrument rating; each valid until

31 July 2021. Language Proficiency Level 6 for German, with no expiry date, and Level 4 for English, valid until 31 May 2025, were also listed

His class 1 medical certificate was issued on 3 November 2020 and valid until 18 November 2021.

He had a total flying experience of 808 hours; 718 hours of which were on type. In the last 90 days he had flown 87 hours on type.

1.5.2 Persons Involved with the Landing at Kavala Airport

Pilot in Command

The 48-year-old PIC held an EU ATPL(A) last issued on 26 March 2020 by the LBA in accordance with Part-FCL. The licence listed the rating as PIC on Airbus A320 and the respective instrument rating; each valid until 31 December 2021. In addition, English Language Proficiency Level 4 valid until 30 November 2022 was listed.

His class 1 medical certificate, with the restriction VDL, was issued on 8 July 2021 and valid until 10 August 2022.

He had a total flying experience of 5,068 hours; 4,772 hours of which on A320. In the last 90 days he had flown 89 hours on type.

Co-pilot

The 34-year-old co-pilot held an EU MPL(A) last issued on 2 July 2019 by the LBA in accordance with Part-FCL. The licence listed the rating as COP on Airbus A320 and the respective instrument rating; each valid until 30 June 2022. Language Proficiency Level 6 for German and English, with no expiry date, were also listed.

His class 1 medical certificate, with the restriction VDL, was issued on 9 December 2020 and valid until 12 January 2022.

He had a total flying experience of 1,108 hours; 774 hours of which were on A320. In the last 90 days he had flown 101 hours on type.

1.6 Aircraft Information

1.6.1 General

The Airbus A320-214 is a short and medium range transport aircraft equipped with two turbofan engines.

Manufacturer: Airbus

Type:	A320-214
Manufacturer's Serial Number:	2142
Year of Manufacture:	2003
Total Operating Time:	50,290:27 hours, 18,375 cycles
Maximum take-off mass:	77,000 kg

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

The airworthiness review certificate was valid until 3 June 2022. On 10 July 2021 at 0449 hrs, the maintenance organisation issued the last aircraft certificate of release to service.

1.6.2 Nose Landing Gear Shock Absorber

Figure 4 shows the Nose Landing Gear (NLG) shock absorber which is filled with hydraulic oil and nitrogen. The sliding rod including the nose landing gear axle and nose landing gear wheels can move in vertical direction relative to the cylinder installed in the NLG strut. A dynamic seal exists in the upper part between the two components. The sliding rod is linked with the rotating tube of the nose wheel steering via torque links.

Figure 4 shows the nose landing gear shock absorber in the extended position, e. g. after take-off. In this case, the two target assemblies of the two respective sensor assemblies are just below these sensors so that the Landing Gear Control and Interface Units (LGCIU1 and LGCIU2) receive the signal "Flight" for the nose landing gear.

If the cylinder including the NLG strut moves downward due to the aircraft weight on the ground, the upper part of the torque link turns left (Fig. 4) so that the lever with the target assemblies moves forward via another link lever. As soon as the target assemblies are far enough away from the sensors the respective LGCIUs receive the signal "Ground".

The status "Ground" is maintained after take-off, if the sliding rod does not move to the extended position due to a damaged nose landing gear shock absorber in spite of the weight of the nose landing gear axle and wheels and the gas pressure of the absorber.

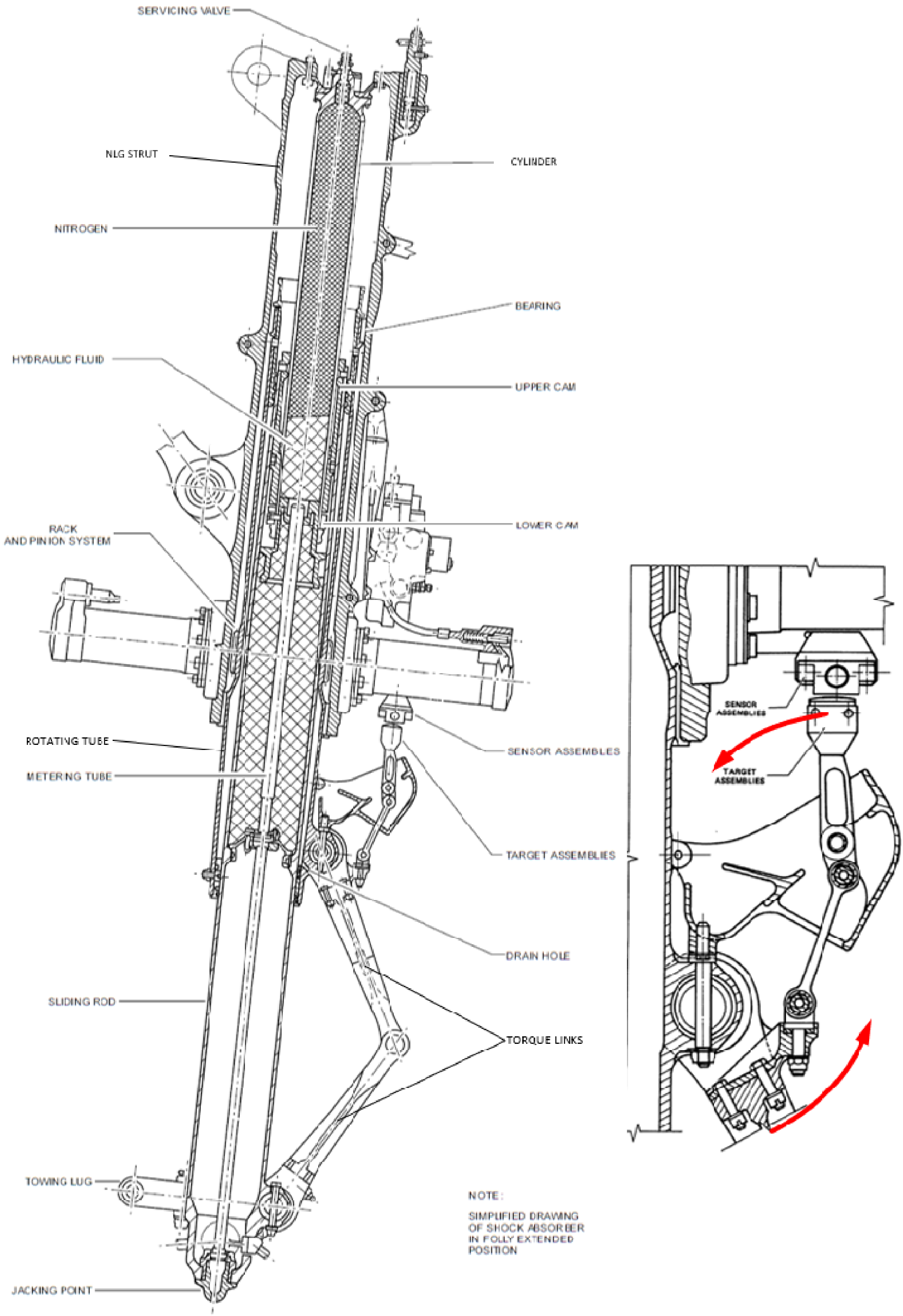


Fig. 4: Nose landing gear shock absorber in the extended position Source: Aircraft manufacturer, adaptation BFU

1.6.3 Interrelationship during Landing Gear Shock Absorber Fault

If one of the landing gear shock absorbers of the main or nose landing gear does not fully extend after take-off, the ECAM message L/G Shock Absorber Fault is triggered. The ECAM message does not indicate which landing gear shock absorber is affected.

The aircraft manufacturer provided the following information in regard to an occurrence on 10 April 2013 where also a L/G Shock Absorber Fault with a nose landing gear occurred (AAIB Report EW/C2013/04/01; AAIB Bulletin 7/2014). The interrelationship between the signals of the proximity sensors, the LGCIUs, the Flight Augmentation Computers (FAC) and the auto flight system is explained.

[…] *if the NLG did not fully extend due to some mechanical damage, the Nose Shock-Absorber discrete associated with the proximity sensor, and directly connected to the FAC […] from each LGCIU* […]*, will be set to the Nose Shock-Absorber 'ON GROUND' state.*

[…] *if the compression status of the nose landing gear differs from that of the main gears for more than 20 seconds, the LGCIU is considered invalid. Since both sets of proximity switches failed to register 'air mode', both LGCIUs were considered failed by the Flight Augmentation Computers (FACs)* […].

[…] *the invalid LGCIU status meant that the FACs, which, among other functions, provide flight envelope protection, would have no indication of landing gear position. This information is used in complex configuration and operational speed computation so the lack of it reduces the integrity of these calculations. This in turn can lead to errors in the weight and selectable speeds and is the reason why the Autopilot, Auto Thrust and flight directors cannot be engaged.* […]

[…] *In this case, AP1+2 and ATHR will be displayed in the INOP SYS on the ECAM* […] Status page.

The interrelationship described above with the consequence that the autopilots, the FD1+2 and the ATHR are disengaged automatically and are no longer usable, respectively, is commanded by the LGCIU Healthy Status Monitoring and is described by the aircraft manufacturer in the present case as follows:

[…] *This automatic disengagement of AP1, FD1+2 and ATHR and the inhibition of the re-engagement were commanded by the LGCIU healthy status monitoring, internal to automatic flight system (comparison of extension/compression status between the NLG and MLGs).* […]

The aircraft manufacturer notes that the LGCIU Healthy Status Monitoring has been enhanced in order to increase the availability of the AP, FD1+2 and ATHR in case of LGCIU failure, while maintaining the same monitoring efficiency. This enhancement will be introduced in a future LGCIU computer standard and able to keep AP, FD1+2 and ATHR available if the NLG shock absorber is not extended fully after take-off.

1.6.4 Centralized Fault Display System

The purpose of the Centralized Fault Display System (CFDS) is to make the maintenance task easier by displaying fault messages in the cockpit and permitting the flight crew to make some specific tests, as described in the Flight Crew Operating Manual (FCOM) chapter Aircraft Systems / Maintenance Systems / Description.

The CFDS consists of a Centralized Fault Display Interface Unit (CFDIU), the Built-In Test Equipment (BITE) for each electronic system, two Multipurpose Control and Display Units (MCDU), used also for the Flight Management and Guidance System (FMGS), and a printer.

The CFDS has two operating modes. In flight the reporting mode and on the ground the interactive mode is active. In reporting mode, fault messages are only displayed via the MCDU or the printer. In the interactive mode, on the ground, system tests can be initiated, among other things.

It is one of the main tasks of the CFDS to obtain and store the fault messages from the BITEs of the electronic systems or from the Flight Warning Computer (FWC). The FWC messages are ECAM messages or warning/maintenance status messages. The BITE system messages are failure messages.

Both types of fault messages can be viewed during the flight on the MCDU or as print-out in the Current Flight Report of the CFDS. After landing, the Post Flight Report, instead of the Current Flight Report, is generated, which includes all warning/maintenance status messages and failure messages that occurred during the flight.

If the NLG shock absorber does not fully extend after take-off, the ECAM message L/G Shock Absorber Fault is triggered. In addition, the BITEs of the two LGCIUs generate the following failure messages:

N L/G EXT PROX SNSR 25GA TGT POS

N L/G EXT PROX SNSR 24GA TGT POS

These indicate that LGCIU1 and LGCIU2 did not receive a valid “Flight” signal from the proximity sensors of the nose landing gear after take-off.

The ECAM message L/G Shock Absorber Fault and both failure messages can be viewed during the flight via the Current Flight Report and after landing via the Post Flight Report.

1.6.5 Fuselage Structure in the Area of the Nose Landing Gear

The nose landing gear loads are transferred via the NLG Torque Box and the struts into the fuselage structure. Figure 5 shows the nose landing gear and the outlines of the inner structure of the NLG Torque Box (red).

Figure 6 shows a sketch of the fuselage cross section of Frame 16 and Frame 20, both located in the area of the nose landing gear. The struts (blue) transfer the loads from the NLG Torque Box to the cross beams of the fuselage structure (green) located above.

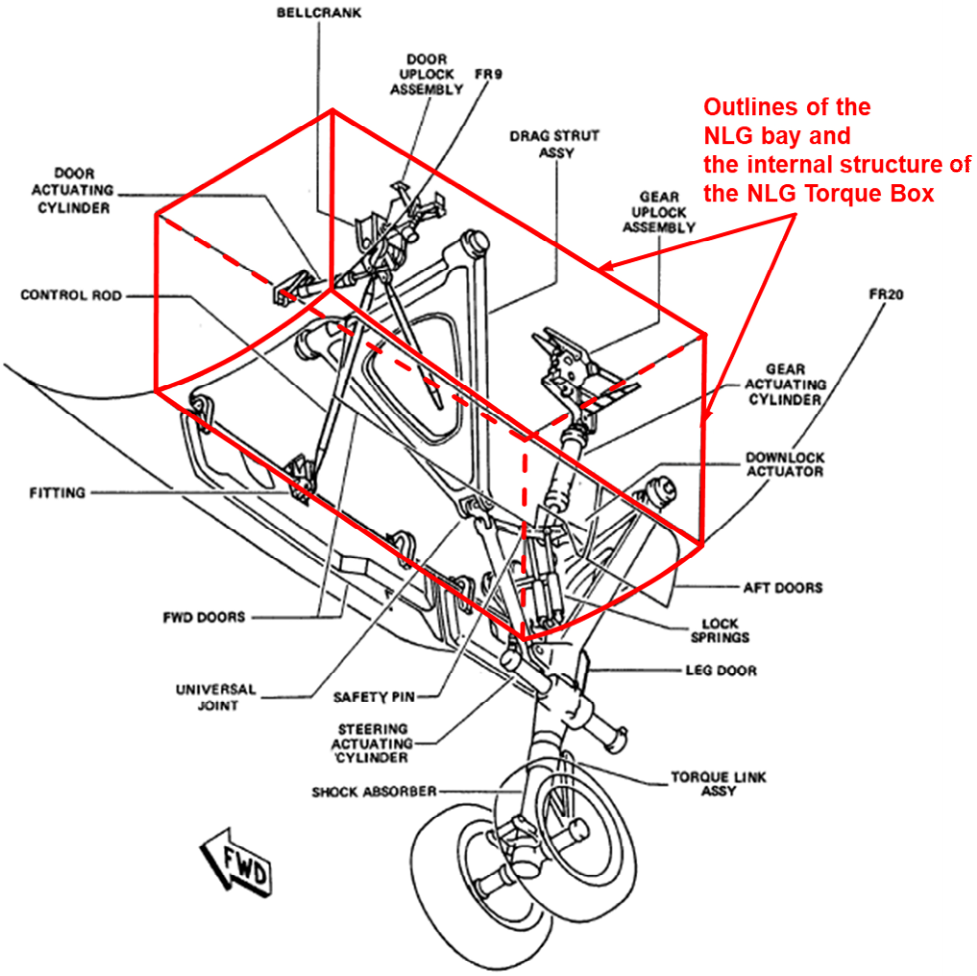


Fig. 5: Nose landing gear including landing gear well Source: Aircraft manufacturer, adaptation BFU

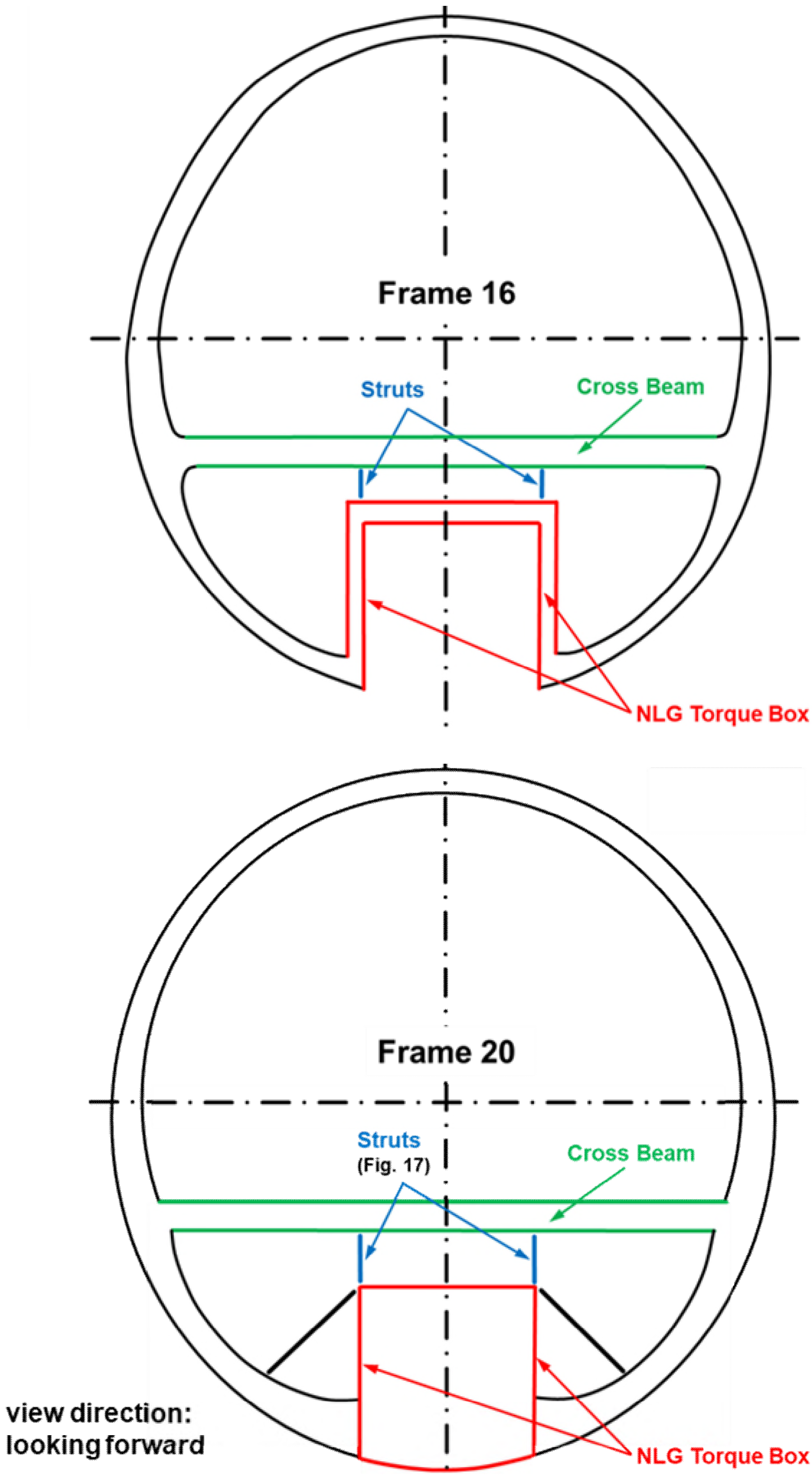


Fig. 6: Sketch of the fuselage cross section at Frame 16 and Frame 20 Source: BFU

1.7 Meteorological Information

At the time of the rejected take-off at Heraklion, the following weather conditions prevailed, according to the aviation routine weather report (METAR) of Heraklion Airport of 10 July 2021 at 0850 UTC:

Wind:	310°, 20 kt
Visibility:	More than 10 km
Cloud:	1 to 2 octas with a lower limit of 2,500 ft AGL
Temperature:	28°C
Dewpoint:	19°C
QNH:	1,009 hPa

At the time of take-off at Kavala, the following weather conditions prevailed, according to the aviation routine weather report (METAR) of Kavala Airport of 11 July 2021 at 1620 UTC:

Wind:	230°, 7 kt
Visibility:	More than 10 km
Cloud:	1 to 2 octas with a lower limit of 3,000 ft AGL
Temperature:	30°C
Dewpoint:	17°C
QNH:	1,010 hPa

At the time of landing at Kavala, the following weather conditions prevailed, according to the aviation routine weather report (METAR) of Kavala Airport of 11 July 2021 at 1720 UTC:

Wind:	220°, 6 kt
Visibility:	More than 10 km
Cloud:	1 to 2 octas with a lower limit of 3,000 ft AGL
Temperature:	28°C
Dewpoint:	20°C

QNH: 1,010 hPa

1.8 Aids to Navigation

The originally planned flight on 11 July 2021 from Kavala to Düsseldorf and the subsequent landing at Kavala were conducted under instrument flight rules. VOR KPL with the respective distance measuring equipment was used for navigation in Kavala airspace and for the approach to runway 23.

1.9 Radio Communications

Radio communications between the flight crew and the air traffic control units were recorded for both occurrences. The Hellenic Air Accident Investigation and Aviation Safety Board (AAIASB) provided the BFU with a transcript of the recordings.

1.10 Aerodrome Information

1.10.1 Heraklion Airport

Heraklion Airport (LGIR, Fig. 7) is located about 7 km east of Heraklion city centre at 35 m (115 ft) AMSL. It was equipped with a 2,714 m long and 45 m wide asphalt runway with the direction 091°/271° and a second 1,566 m long and 50 m wide asphalt runway with the direction 122°/302°. At the time of the rejected take-off, runway 27 was in use.

There are two names for the airport: Iraklion and Heraklion. In this report the name Heraklion is used.

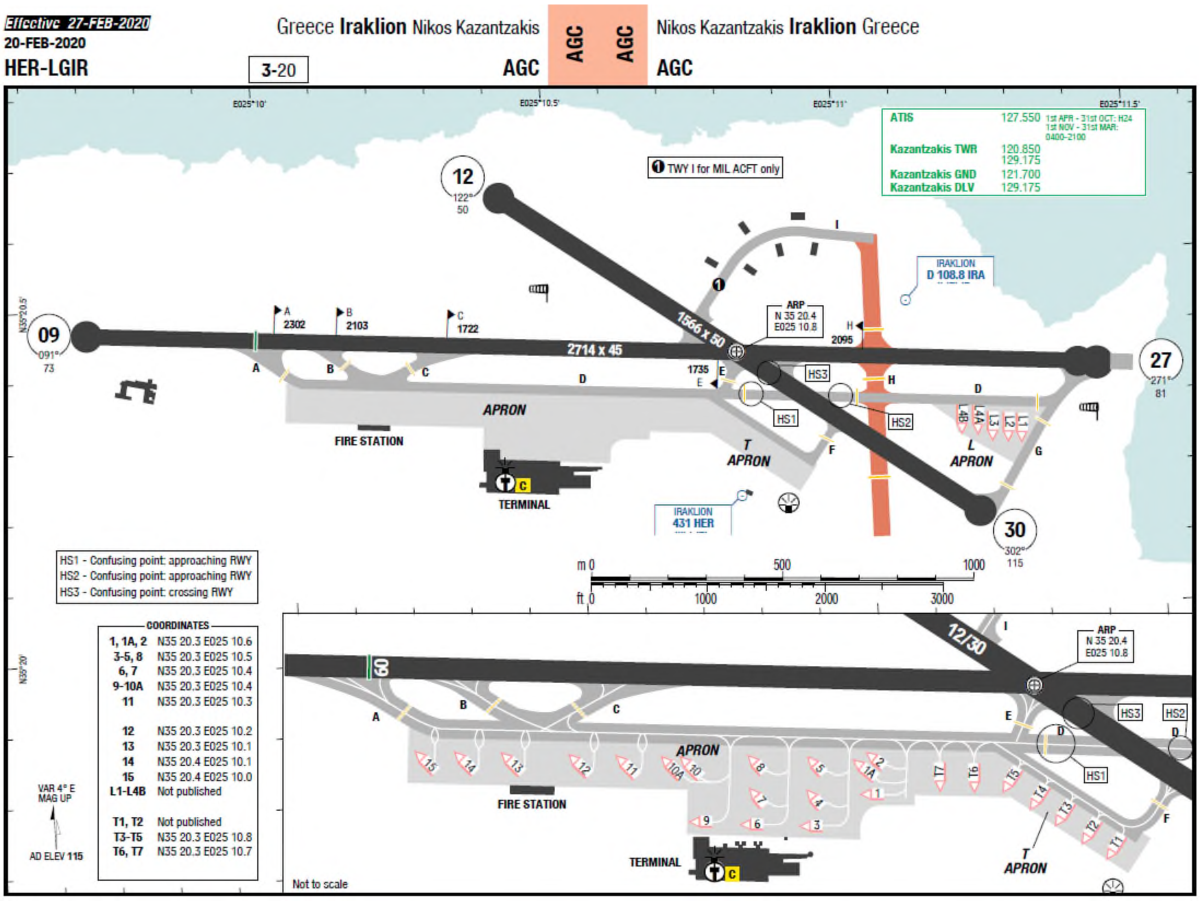


Fig. 7: Heraklion Airport Source: Operator

1.10.2 Kavala Airport

Kavala Airport (LGKV) is located about 18 km east of Kavala at 5 m (18 ft) AMSL. It was equipped with a 3,000 m long and 45 m wide asphalt runway with the direction 050°/230°. At the time of the accident, runway 23 was in use.

1.11 Flight Recorders

The FDR and the CVR were available to the BFU for investigation purposes. Both recorders could be read out.
The CVR data did not include any audio recording of the rejected take-off at Heraklion.

1.11.1 Recorder Information

FDR

Manufacturer Allied Signal

Part number 980-4700-042

Serial number 5534

CVR

Manufacturer Honeywell

Part number 980-6022-001

Serial number CVR120-12085

1.11.2 FDR Graphs

1.11.2.1 Rejected take-off at Heraklion Airport on 10 July 2021

Figure 8 shows essential FDR parameters between 25 s prior to and 20 s after the initiation of the rejected take-off at Heraklion.

Between 0910:31 UTC and 0910:50 UTC, positive left rudder deflections can be seen, which continued to return to neutral. At the time, magnetic heading was about 272°. At 0910:51 UTC, a right rudder deflection of -12° was recorded. In the following 2 s, magnetic heading increased to 281°. At 0910:52 UTC, a rudder deflection in the opposite direction, to the left, to +25°was made.

This occurred at approximately the same time as take-off was aborted at a speed of 137 kt CAS. Within the next 3 s both thrust levers (throttle lever position engine 1 and 2) were moved from 40° to -20° (full reverse). Prior to deceleration, speed increased to a maximum of 140 kt CAS.

Figure 8 shows that at the time the rejected take-off was initiated, the PIC pulled the side stick back for about one second. The pitch angle increased to 2.8° and the Weight on Wheel (WOW) sensors of the nose landing gear reported the nose landing gear as in the air (“Air”). At 0910:54 UTC, a forward side stick input of the PIC, which initially remained constant, was recorded. At that moment, negative pitch rate increased to a maximum of -9.7°/s and the WOW sensors of the nose landing gear reported the nose landing gear on the ground (“GND”). At the time of the touch-down of the nose landing gear, a maximum yaw rate to the left of -8°/s existed. The yaw movement led the airplane back towards the runway centre line, the roll angle towards the right increased to a maximum of 1.4°. At the time the nose landing gear touched down again, a maximum vertical acceleration of 1.7 g was recorded. During the rejected take-off, lateral acceleration was between -0.36 g and +0.53 g.

Since the pitch rate (Fig. 8) was not directly available as FDR parameter, pitch was derived with respect to time. Therefore, it is subject to a certain inaccuracy. The aircraft involved was equipped with a Digital AIDS Recorder (DAR) which records the Pitch Rate significantly more accurately calculated by the ADIRUs (Air Data Inertial Reference Unit). Using the more accurate DAR pitch rate is used, the same maximum value of -9,7°/s is obtained for the time of the nose landing gear touching down again.

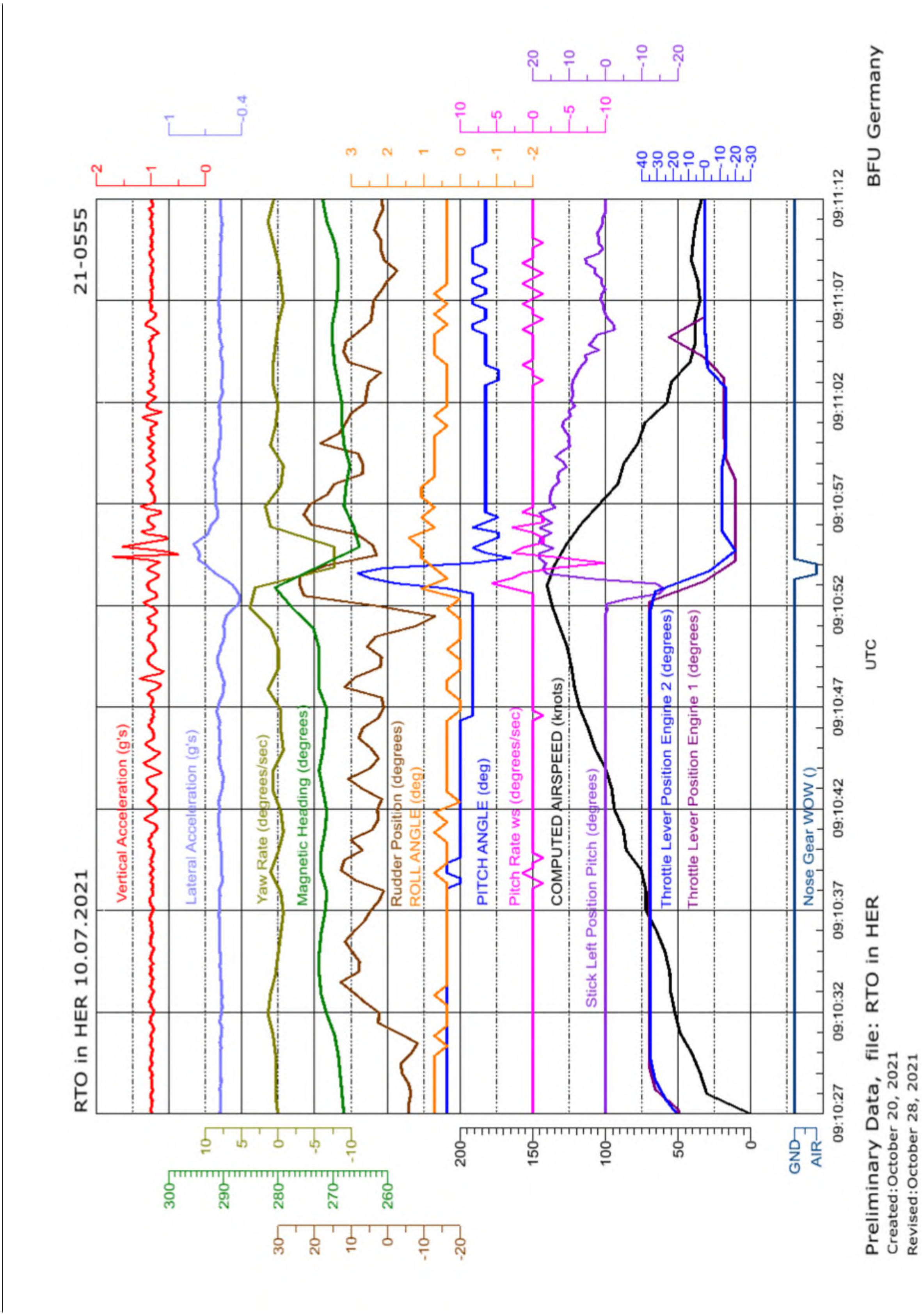


Fig. 8: FDR data of the rejected take-off at Heraklion on 10 July 2021 Source: BFU

1.11.2.2 Take-off at Heraklion Airport on 11 July 2021

Figure 9 shows essential FDR parameters between 26 s prior to and 11 s after take-off at Heraklion, one day after the rejected take-off.

The aircraft manufacturer determined at about 2.5 s after rotation and increase in pitch angle at about 0722:35 UTC, the respective WOW sensors (right and left gear WOWs) initially reported the main landing gears as in the air (“Air”). Only 1.6 s later, the nose gear WOW sensors reported position “Air”.

The common sequence during take-off that first the nose gear WOW and then the main gear WOW sensors report their respective gears as in the air differed only during this flight. All other flights recorded on the FDR, before the rejected take-off and on the flight from Düsseldorf to Kavala on 11 July 2021, show a normal sequence of the WOW positions between nose landing gear and main landing gear.

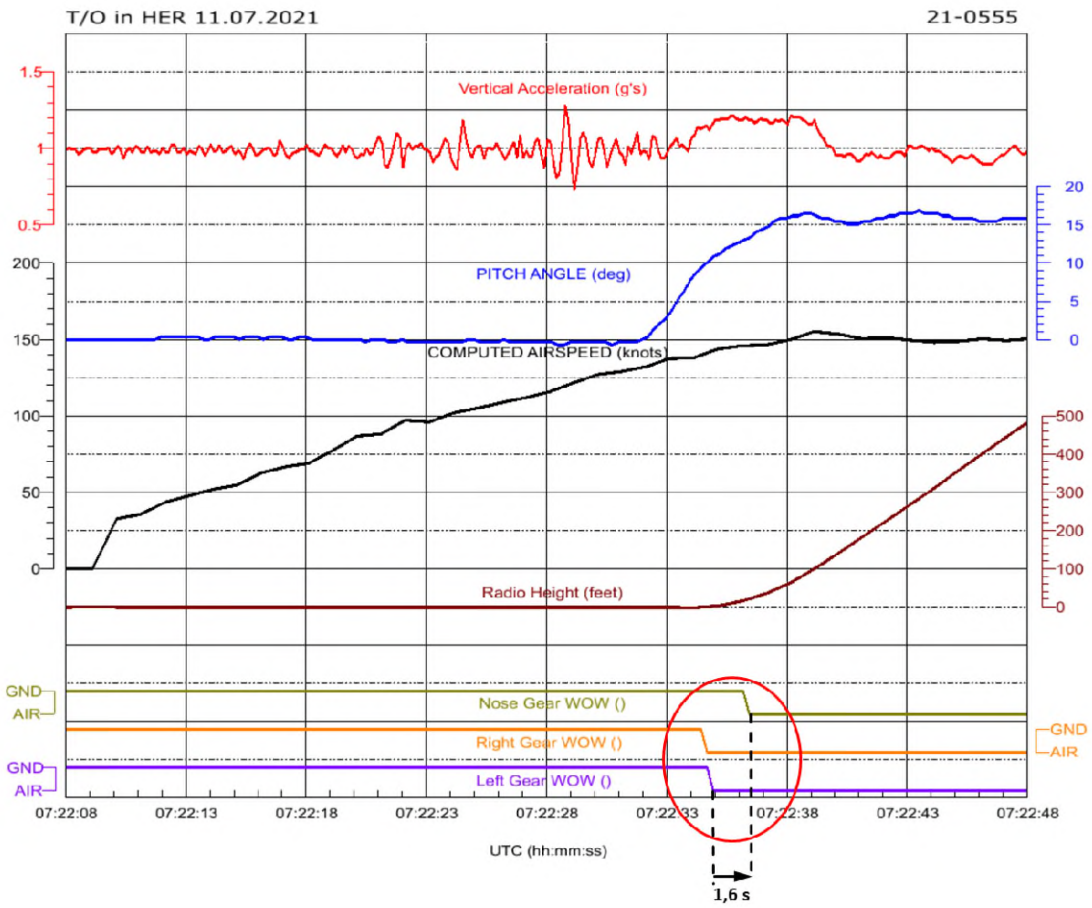


Fig. 9: FDR data of the take-off at Heraklion on 11 July 2021 Source: BFU

1.11.2.3 Landing with a Deflated Nose Landing Gear Shock Absorber at Kavala Airport on 11 July 2021

Figure 10 shows essential FDR parameters between 21 s prior to and 19 s after main landing gear touch-down at Kavala, following an In Flight Turn Back (IFTB), due to a non-retractable landing gear.

Shortly before touch-down, the pitch angle of the airplane was 6°. Both main landing gears touched down at 1735:03 UTC and the respective WOW sensors reported the main landing gear on ground (“GND”). One second later, the WOW sensors of the left main landing gear briefly reported “Air” and then “GND” again. Vertical acceleration during touch-down of both main landing gears was 1.29 g.

The nose gear WOW sensors reported “GND” during the entire flight. It was not possible to determine the time of nose gear touch-down with the WOW sensors.

Since the uncommonly loud noise of the nose landing gear’s ground contact could be heard on the CVR recording, it was possible to calculate the touch-down time of the nose landing gear with 1735:05 UTC by synchronisation of the FDR and CVR times and the known take-off time of 1642:21 UTC.

Shortly before the main landing gears touched down, at a radio height of about 50 ft, an oscillating side stick movement of the PIC in pitch (stick left position pitch) could be seen, which was continued after touch-down of the main landing gears with a forward movement of the side stick beyond the neutral position. During the de-rotation phase, the negative pitch rate increased to a maximum of -5.6°/s, which was reached at about the same time the nose landing gear touched down.

The landing was performed with auto brake MED and full reverse. This corresponded with a thrust lever position of -20°.

The pitch rate depicted in Figure 10 is also subject to a certain inaccuracy, the same as the one in Figure 8. Using the more accurate DAR pitch rate, a lower maximum value - 4,6°/s (instead of - 5,6°/s) is obtained during nose landing gear touch-down. Further considerations were based on this value.

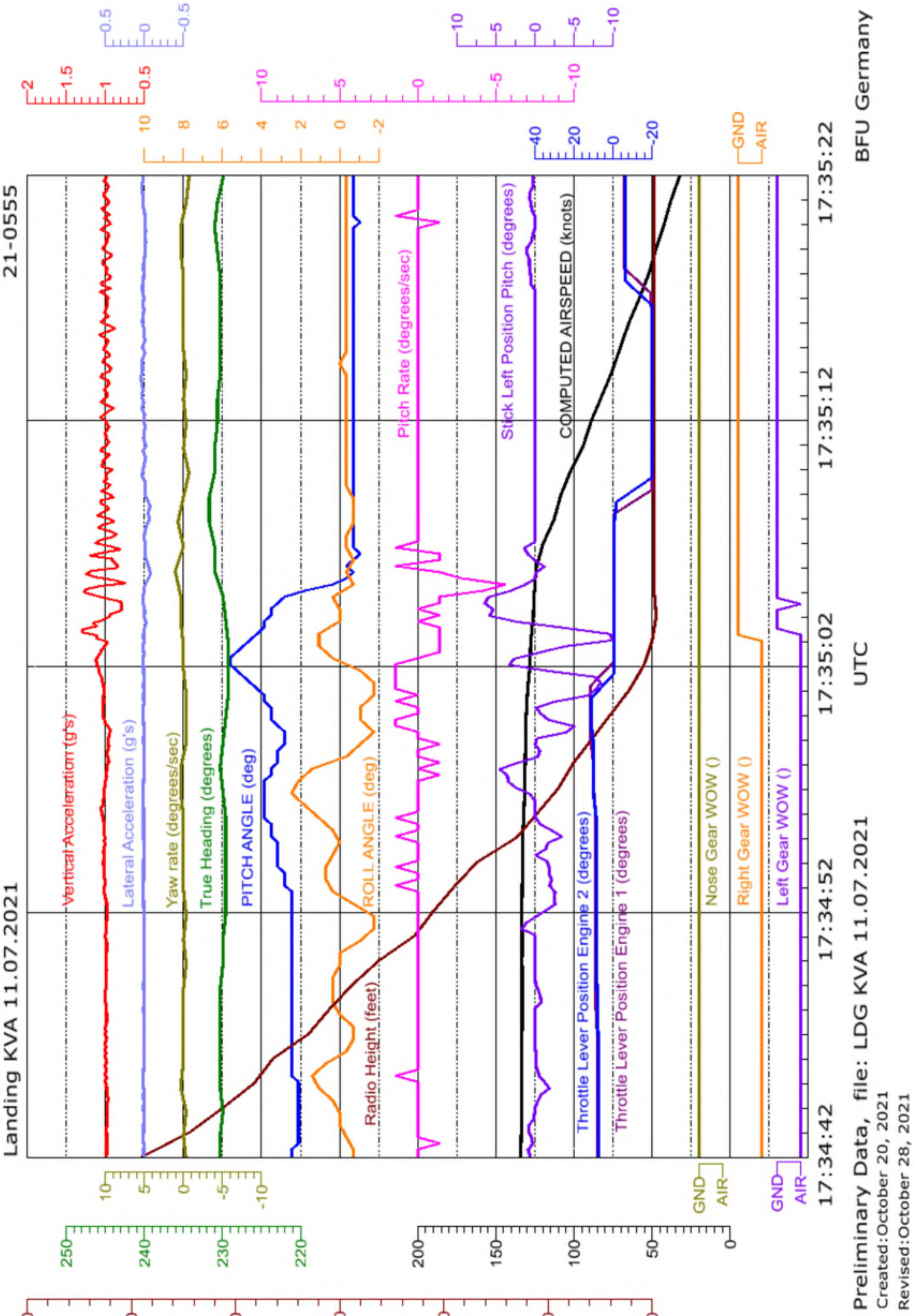


Fig. 10: FDR data of the landing at Kavala on 11 July 2021 Source: BFU

1.12 Wreckage and Impact Information

1.12.1 Rejected take-off at Heraklion Airport

Figure 1 shows the rubber abrasion traces of all landing gear tires caused by the rejected take-off. Employees of Heraklion Airport measured the closest distance between the right main landing gear tire trace (tire No. 4) and the right runway edge with 3.7 m (Fig. 11). This position was located about 230 m beyond the intersection of runway 27 and runway 30.

Fig. 11: Closest distance between the right main landing gear tire marks and the right runway edge

Source: Operator

Figure 12 shows the rubber abrasion traces of both nose landing gear tires shortly after they touched down again. The five rubber abrasion traces (Fig. 13) of the five treads of the left nose landing gear tire are clearly visible. A sixth rubber abrasion trace, which is darker, runs for about 5 m right of the two nose landing gear tire rubber marks.

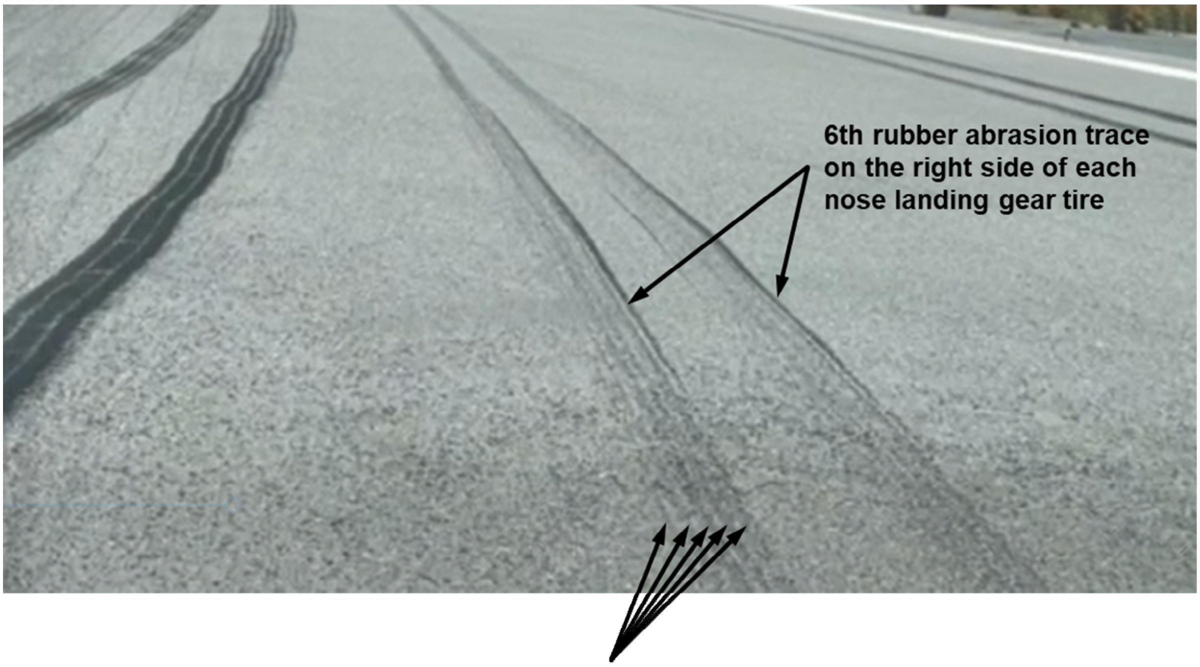


Fig. 12: Rubber abrasion traces of the nose landing gear tires Source: Heraklion Airport, adaptation BFU

Fig. 13: Nose landing gear tire treads Source: BFU

Figure 14 shows the relative position of the nose landing gear traces with respect to the main landing gears traces. It can be seen that after the nose landing gear touched down again, the traces of the two nose landing gear tires run over a longer distance closer to the traces of the left main landing gear than to those of the right. This is approximately the distance for which the aircraft manufacturer calculated a positive drift angel of 6° to 7° by reconstruction of the rejected take-off track.

Fig. 14: Relative position of the nose landing gear traces and the main landing gears traces

Source: Operator

1.12.2 Landing with Deflated Nose Landing Gear Shock Absorber at Kavala Airport

1.12.2.1 Structural Damage at the Front Fuselage

After the landing at Kavala with a deflated nose landing gear shock absorber, numerous structural damage was determined at the front fuselage area.

Figure 15 shows the deformation of the fuselage skin in the area of Frame 20 at the lower left fuselage side. Figure 16 shows almost the same damage at the right lower fuselage side, also in the area of Frame 20. Other deformations were found at the lower fuselage area at Frame 21 and in the upper at Frame 24.

Fig. 15: Damage of the fuselage skin on the left side
Source: Operator

Fig. 16: Damage of the fuselage skin on the right side
Source: Operator

The struts between NLG torque box and the cross beams above were bent at their junctions in the area of Frame 20 and Frame 16, among others.

Figure 17 shows the two bent struts on the left and right in the area of Frame 20.

Fig. 17: Struts between NLG torque box and cross beam of Frame 20 Source: Operator

The cross beams in the areas of Frame 20 and Frame 16 shown in Figure 6 (green) were deformed; in longitudinal as well as in cross direction.

At Frame 20, the left lower side showed a crack (Fig. 18, left) and at the right lower side deformation (Fig. 18, centre). On the right side of Frame 20, the connection between a stringer and the frame had separated (Fig. 18, right).

Fig. 18: Damage of Frame 20 Source: Operator

1.12.2.2 Nose Landing Gear Shock Absorber

After the landing, the nose landing gear shock absorber was found depressurised. The chromium layer of the shock absorber's sliding rod was no longer visible (Fig. 19, left). Initially, there was no leakage at the nose landing gear shock absorber; it occurred the next day (12 July 2021). Figure 19 right shows the hydraulic oil spill below the shock absorber.

A boroscope inspection of the nose landing gear shock absorber at Kavala revealed metallic-looking chips in the area of the cylinder, among other things.

The entire nose landing gear including the shock absorber was removed at Kavala and examined at the landing gear manufacturer's facilities.

Fig. 19: Deflated nose landing gear shock absorber Source: BFU

Leakage at the nose landing gear shock absorber Source: Operator

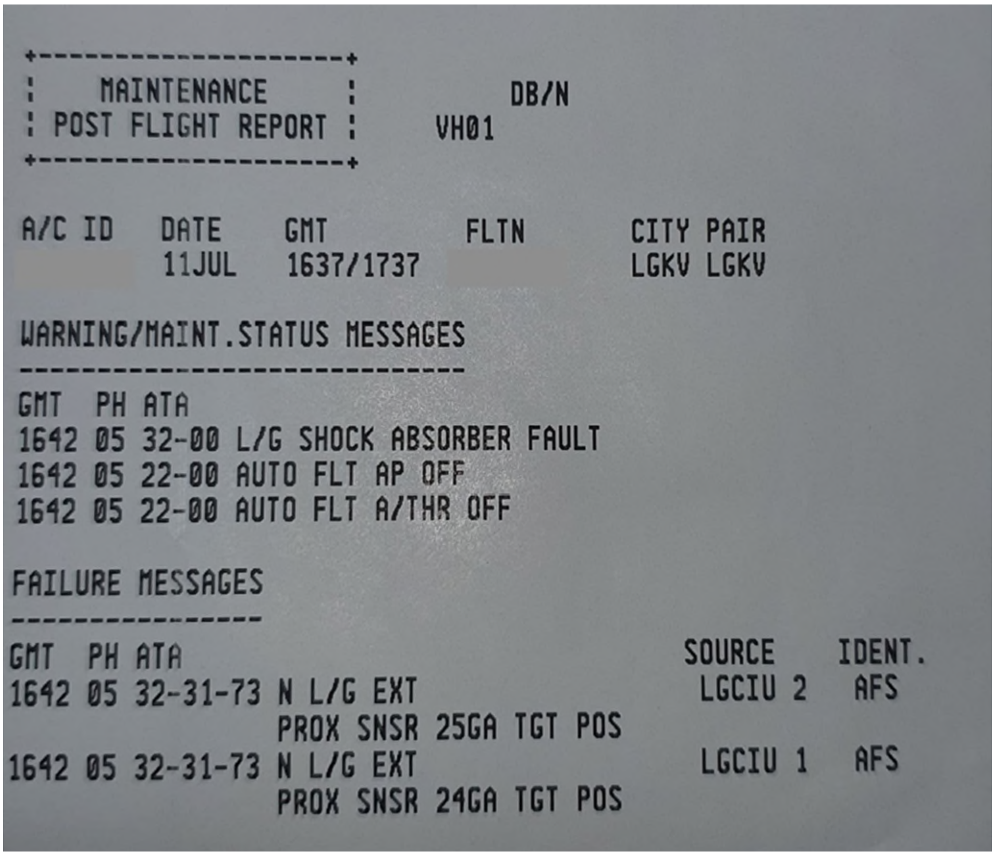
1.12.2.3 Nose Landing Gear Tire

Both nose landing gear tires showed clearly visible damage at their respective right tire sidewalls (Fig. 20).

Fig. 20: Damage at the right tire sidewalls of the nose landing gear tires Source: BFU

1.12.2.4 Post Flight Report

Among others, the PIC printed the Post Flight Report (PFR) after the landing. It contained the warning/maintenance status messages and failure messages depicted in Figure 21.



```
+--------------------+
:    MAINTENANCE     :        DB/N
: POST FLIGHT REPORT :    VH01
+--------------------+

A/C ID   DATE    GMT          FLTN       CITY PAIR
         11JUL   1637/1737               LGKV LGKV

WARNING/MAINT.STATUS MESSAGES
-----------------------------
GMT  PH ATA
1642 05 32-00 L/G SHOCK ABSORBER FAULT
1642 05 22-00 AUTO FLT AP OFF
1642 05 22-00 AUTO FLT A/THR OFF

FAILURE MESSAGES
----------------
GMT  PH ATA                                   SOURCE    IDENT.
1642 05 32-31-73 N L/G EXT                     LGCIU 2   AFS
                 PROX SNSR 25GA TGT POS
1642 05 32-31-73 N L/G EXT                     LGCIU 1   AFS
                 PROX SNSR 24GA TGT POS
```

Fig. 21: Post Flight Report after the landing at Kavala Source: Operator

1.12.3 Examination of the Nose Landing Gear at the Manufacturer

1.12.3.1 Nose Landing Gear Shock Absorber

- Cylinder of the nose landing gear shock absorber

At the landing gear manufacturer's, a severely deformed nose landing gear shock absorber cylinder was found during disassembly. It was so severely deformed that it was difficult to remove it from the sliding tube. It was also difficult to detach the upper cam from the cylinder. In the area of the strongest deformation, which ran inwards, there was a 160 mm long crack on the outside (Fig. 22). On the piston's inside, the crack was 120 mm long.

Fig. 22: Crack and deformation of the cylinder Source: BFU

Figure 23 shows the cylinder's location within the nose landing gear shock absorber. The piston's deformation was measured using a 3D scan and are highlighted in colour (Fig. 23). Blue to violet areas are inward deformations and green to red are outward ones.

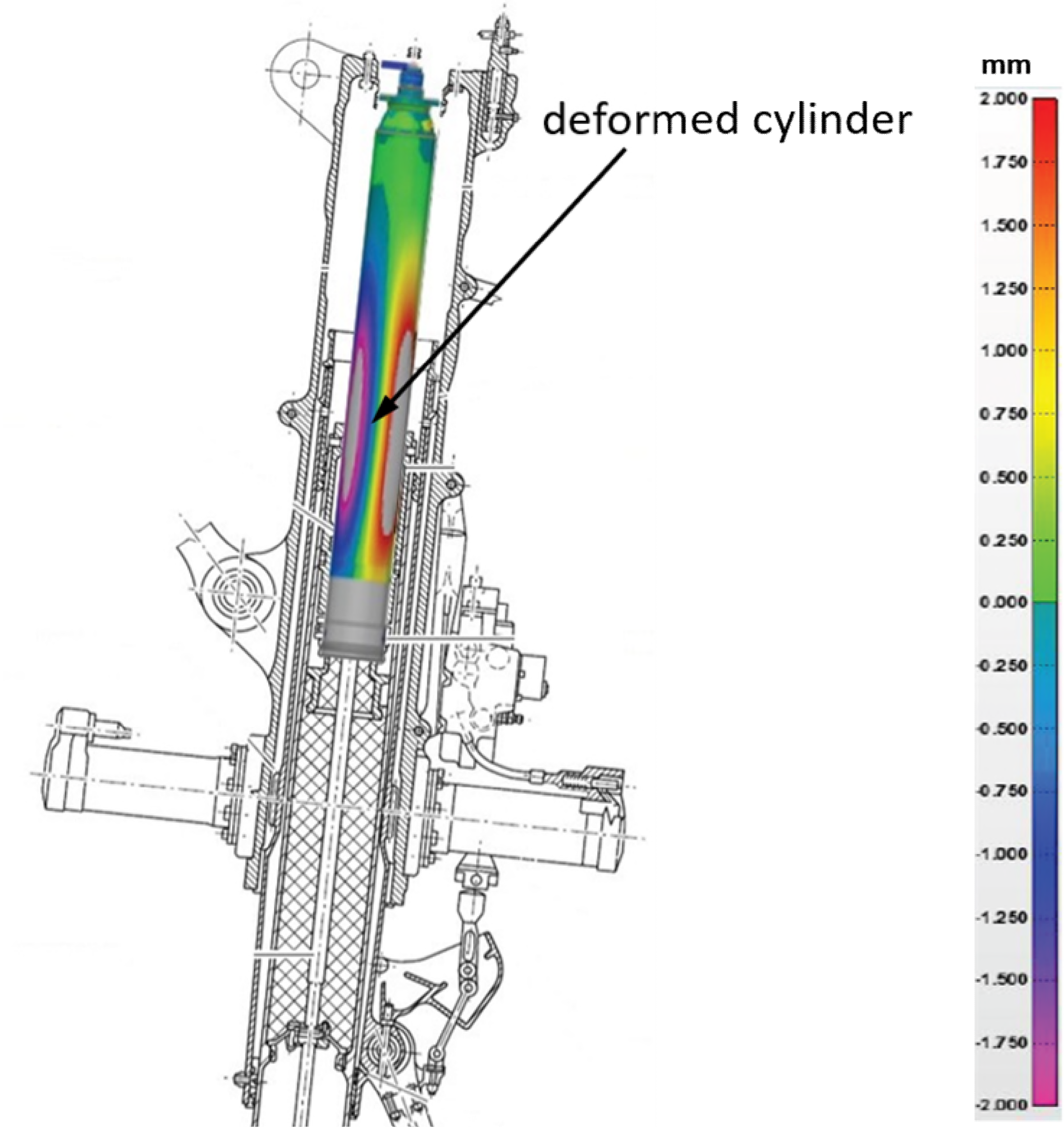


Fig. 23: Location of the deformed cylinder within the nose landing gear shock absorber

Source: Landing gear manufacturer, adaptation BFU

- Crack Surface Examination of the Cylinder

The landing gear manufacturer performed a fractographic analysis of the crack surfaces. Different arrest lines were found. Figure 24 shows the main arrest line which is marked with red arrows, a second with yellow arrows. Generally, arrest lines indicate a change in crack growth rate or a local variation in propagation direction. According to the landing gear manufacturer, the arrest line marked with red arrows indicates that the crack propagated from inside to outside. The arrest line marked with yellow arrows, which is closer to the outer diameter, indicates that the complete crack occurred in several steps.

Shear lips were found on both sides of the wall section which indicate the location of the final overload fracture, according to the landing gear manufacturer.

The fractographic analysis shows that the entire crack was the result of a succession of ductile cracks running from the inner to the outer diameter of the cylinder, according to the landing gear manufacturer. The analysis of the arrest lines indicates that an overload event was the origin of the initial crack and that at least two more load events followed until the crack finally opened through the cylinder's wall.

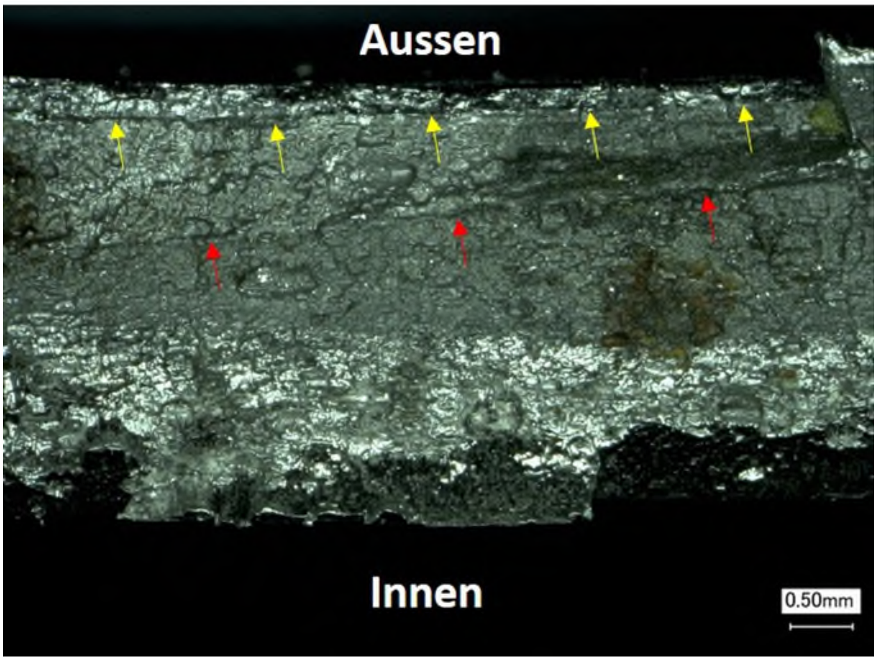


Fig. 24: Different arrest lines in the crack's surface Source: Landing gear manufacturer

- Cylinder deformation during de-rotation rate

According to the landing gear and aircraft manufacturers, the cylinder buckling is a characteristic damage pattern in case of nose landing gear touch-down with high de-rotation rate. It is caused by a high differential pressure between the cylinder's outside and the inside in the area of recoil chamber B. If the nose landing gear shock absorber's retraction speed exceeds the approval range, the recoil chamber B is filled faster with hydraulic oil by chamber C than chamber A. The nose landing gear shock absorber's different chambers are depicted in Figure 25.

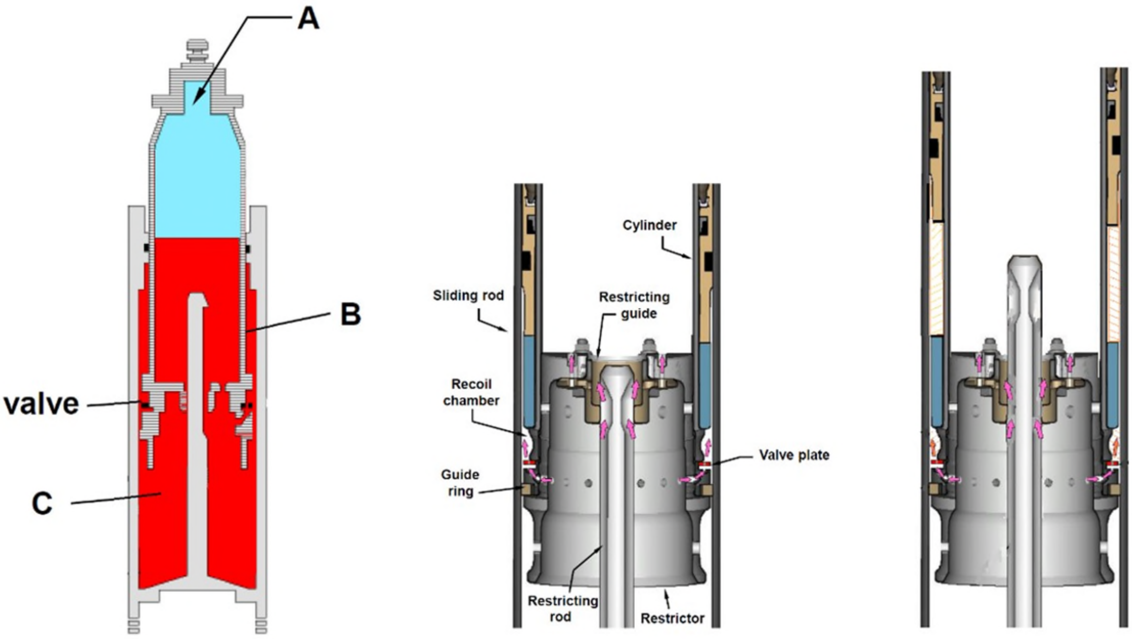


Fig. 25: The nose landing gear shock absorber's different chambers Source: Landing gear manufacturer

According to the landing gear manufacturer, the high de-rotation rate while the nose landing gear touched down again during the rejected take-off at Heraklion resulted in the initial buckling of the cylinder and the beginning of the crack. These were enlarged by the following flights where the crack became an open crack. The final deformation of the cylinder and the open crack contributed to the complete loss of pressure and the external leakage of the nose landing gear shock absorber. Finally, the severe deformation of the cylinder resulted in the jamming of the nose landing gear shock absorber after take-off at Kavala and no longer extended fully.

- Potential contact surfaces between restrictor and sliding tube

The landing gear manufacturer's examination determined that a strong mechanical contact between the lower restrictor surface and the corresponding surface inside the sliding tube, which would have caused a deformation of the components, could be ruled out. Only slight contact traces were found, which are depicted in Figure 26.

Fig. 26: Slight contact traces at the lower surface of the restrictor Source: Landing gear manufacturer

- Dynamic seal of the nose landing gear shock absorber

The dynamic seal is located at the inner diameter of the upper cam. Typically, it contributes to the sealing between sliding tube and cylinder. The landing gear examination revealed that the seal had been damaged (Fig. 27) at the area where the cylinder with the crack showed the largest defect. The landing gear manufacturer stated that the cylinder's damage was the cause for the damage of the dynamic seal which finally contributed to the deflation and the external leakage of the landing gear shock absorber.

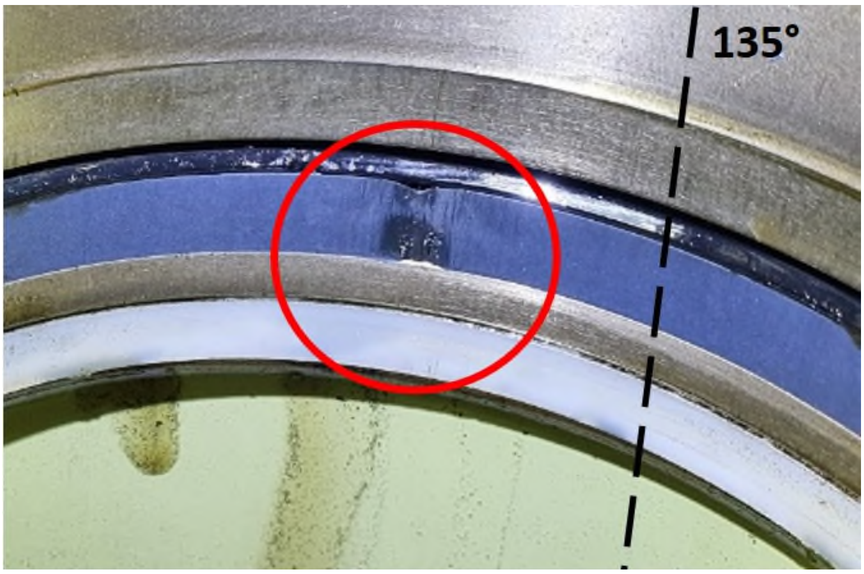


Fig. 27: Damage of the dynamic seal Source: Landing gear manufacturer

1.12.3.2 Barrel Hinge Pins

During the nose landing gear examination, the two barrel hinge pins were found to be deformed to various degrees. The barrel hinge pins are one of the main connection components between the nose landing gear and the attaching elements of the front fuselage structure. Therefore, they are located at the main force transmission points to the front fuselage structure (Fig. 28).

The deformation of the barrel hinge pins was measured using a 3D scan, among others. Figure 29 depicts the measuring results in different colours. The degree of deformation of the right barrel hinge pin was slightly larger than the left.

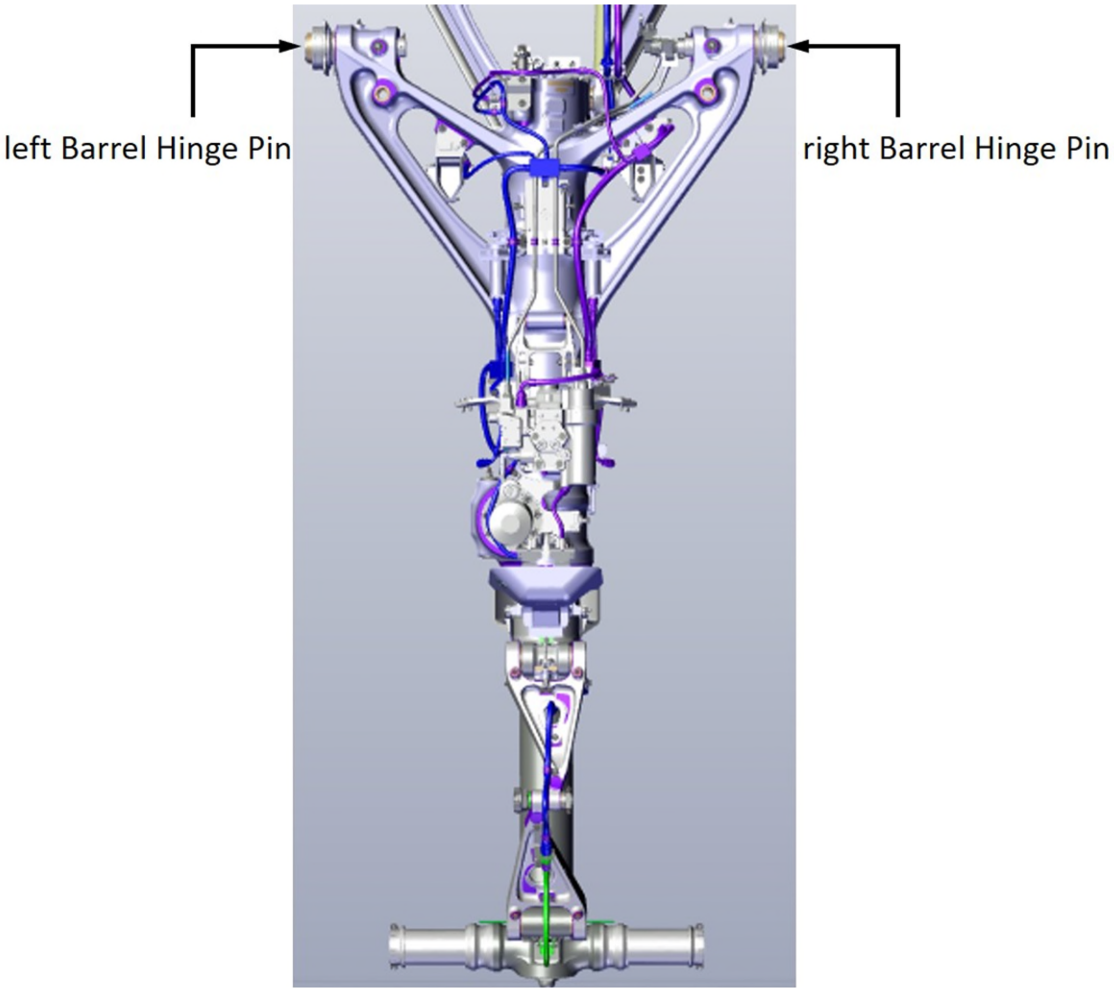


Fig. 28: Location of the barrel hinge pins (view in flight direction)

Source: Landing gear manufacturer, adaptation BFU

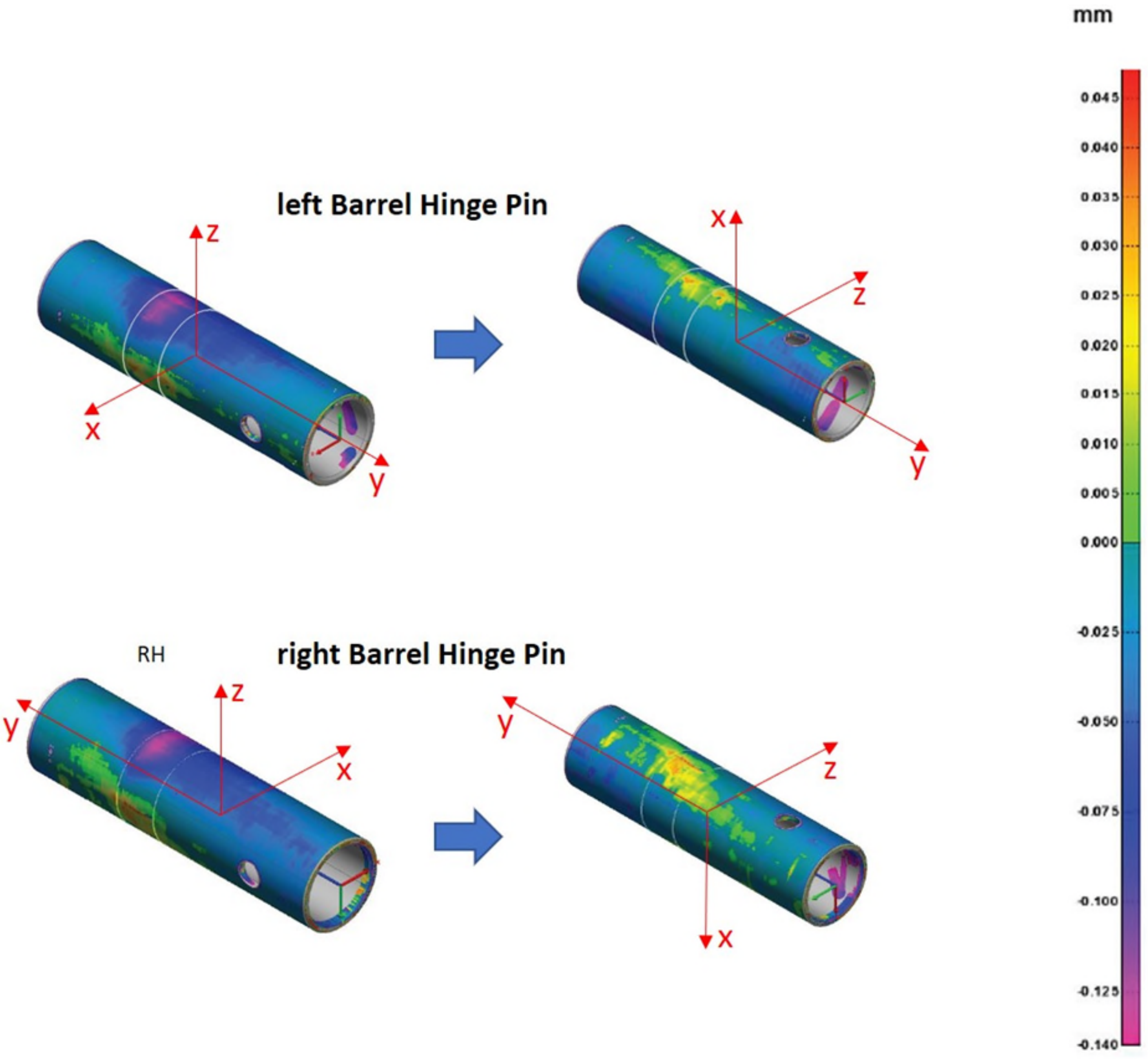


Fig. 29: Deformation of the two barrel hinge pins Source: Landing gear manufacturer

1.13 Medical and Pathological Information

Not relevant.

1.14 Fire

There was no evidence of fire.

1.15 Survival Aspects

Not relevant.

1.16 Tests and Research

Not relevant.

1.17. Organisational and Management Information

1.17.1 Technical Inspections after a Rejected Take-off

1.17.1.1 Criterion for the Selection of the correct AMM Inspection after a Rejected Take-off

According to the aircraft manufacturer and the AMM, there are no general AMM Inspections the maintenance personnel has to perform after a rejected take-off. The AMM Inspection to be applied is essentially based on the information or descriptions of the pilots. Based on this information, a suitable AMM Inspection is selected.

The mechanics stated that after the rejected take-off the PIC had given them the information that the aircraft had pulled to the right. The PIC’s entry in the technical logbook read: Aborted TO at V 120 KTS.

1.17.1.2 Performed Inspections and Findings after the Rejected Take-off

- General Visual Inspection

The BFU interviewed the mechanics, who stated that initially they had performed a General Visual Inspection (GVI) and determined that all four tires of the main landing gear, especially the outer tire of the right main landing gear (Fig. 30), had been damaged and had to be replaced. None of the tires was deflated. The mechanics stated that the GVI included a visual inspection of the nose landing gear area, the nose landing gear bay and the front fuselage section, among other things. The results of the inspection of these areas were not documented in detail.

Fig. 30: Condition of the tires No. 3 and 4 after the rejected take-off Source: Operator

- AMM Inspection 05-51-15 after a Tire Burst or Tread Throw or Wheel Failure

The mechanics stated that after the GVI they continued the check with the "AMM Inspection 05-51-15 after a Tire Burst or Tread Throw or Wheel Failure".

- AMM Inspection 05-51-16 after Brake Emergency Application or Overheat

After no tire debris had been found during the examination of runway 27 by the aerodrome operator and because none of the tires was deflated, the mechanics applied "AMM Inspection 05-51-16 after Brake Emergency Application or Overheat". E-mail correspondence between the mechanics and the maintenance control centre of the operator in Germany proves this. No other damage was determined except for the four main landing gear tires.

The "AMM Inspection 05-51-16 after Brake Emergency Application or Overheat" is limited mainly to the main landing gear wheels and brakes.

The performed "AMM Inspection 05-51-16" and the replacement of all four main landing gear wheels had been entered into the technical logbook of the airplane.

- Other information concerning the inspections performed and findings

According to the statements of the mechanics, they had also completed the started "AMM Inspection 05-51-15 after a Tire Burst or Tread Throw or Wheel Failure", which included the inspection of the front fuselage area (4. Procedure / B. Inspection of the Fuselage (FR1 to FR34)), the nose landing gear and the nose landing gear bay (4. Procedure / C. Inspection of the NLG and the NLG Well). They also stated that they had measured the visible length of the nose landing gear shock absorber with 7 inches.

The technical logbook of the aircraft did not list any information as to the performance of the „AMM Inspection 05-51-15“ and the measurement of the visible length of the nose landing gear shock absorber.

1.17.1.3 AMM Inspection to be Applied after a Rejected Take-off with High Lateral Acceleration

If high lateral accelerations occurred during a rejected take-off, the “AMM 05-51-44 Inspection after Aircraft Operation with high Lateral Acceleration” should be applied first. If lateral acceleration exceeds 0.42 g, “AMM 05-51-11 Inspection after a hard Landing” should be applied.

- Load Report 15

The A320 family are equipped with a Load Report 15 which shall support the decision-making process of the maintenance personnel in selecting the appropriate AMM Inspection in case of High Load Events.
With the airplane involved the so-called Enhanced Load Report 15 was used, which is generated automatically, if the lateral acceleration limit is exceeded, among other things. A Load Report 15 is not triggered during a rejected take-off, even if these limits are exceeded, because the airplane is neither in flight nor in the touch-down phase.

1.17.1.4 AMM Inspection to be Applied after a Rejected take-off with High De-rotation Rate

If during the de-rotation phase a high pitch down rate during touch-down of the nose landing gear occurred, “AMM 05-51-11 Inspection after a hard Landing” should be applied. This high pitch down rate can occur during landing or, as in this case, during a rejected take-off with subsequent rotation and de-rotation phase.

1.17.2 Outside Check

The FCOM chapter Procedures / Normal Procedures / Standard Operating Procedures – Exterior Walkaround described the outside check which includes a visual inspection of both nose landing gear tires and their conditions, among other things (Fig. 31).

EXTERIOR WALKAROUND

Ident.: PRO-NOR-SOP-05-A-00010361.0001001 / 04 MAY 15
Applicable to: ALL

[...]

NOSE L/G

Nose wheel chocks.. IN PLACE
Wheels and tires.. CONDITION
Nose gear structure.. CONDITION
Taxi, Takeoff and Runway Turnoff lights.. CONDITION
Hydraulic lines and electrical wires.. CONDITION
Wheel well.. CHECK
Safety pin.. REMOVED

[...]

Fig. 31: Outside Check Source: Operator

1.17.3 L/G Shock Absorber Fault Procedure

The FCOM chapter Procedures / Abnormal and Emergency Procedures / L/G described the ECAM procedure L/G SHOCK ABSORBER FAULT (Fig. 32). It is applied if a landing gear shock absorber does not extend fully after lift-off.

If, as in the present case, the landing gear is not uplocked, the landing gear lever should remain in the "Down" position. The speed and Mach limit of 280 KIAS or 0.67 for an extended landing gear is therefore valid.

Due to the extended landing gear, fuel consumption is increased. The Quick Reference Handbook (QRH) chapter OPS Fuel Penalty Factors / ECAM Alert Table shows the appropriate factor for the increase in fuel consumption. In the present case, increase in consumption was 180%.

This procedure in the FCOM included a note that with this fault autopilot and autothrust may also be lost.

L/G SHOCK ABSORBER FAULT
(SHOCK ABSORBER NOT EXTENDED AFTER LIFTOFF)

Applicable to: ALL

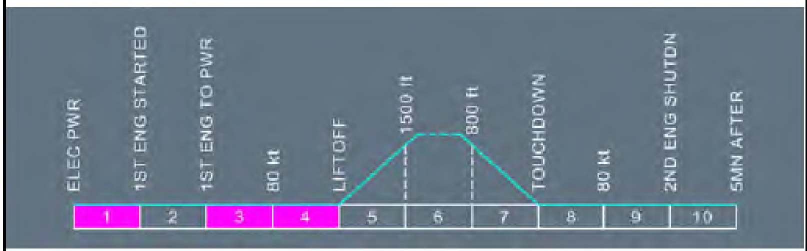
Ident.: PRO-ABN-LG-A-00018062.0001001 / 21 MAR 16

ANNUNCIATIONS

Triggering Conditions:

This alert triggers when one shock absorber is not extended when airborne.

Flight Phase Inhibition:



Ident.: PRO-ABN-LG-A-00011058.0003001 / 25 FEB 14

- **Shock absorber not extended after liftoff and L/G uplocked :**

  Crew awareness.

- **Shock absorber not extended after liftoff and L/G not uplocked :**

  MAX SPEED...280/.67

  - **If L/G lever still down :**

    L/G...KEEP DOWN

  - **If L/G lever selected up :**

    L/G...DOWN

  FUEL CONSUMPT INCRSD
  FMS PRED UNRELIABLE

STATUS

● **If L/G not uplocked:** MAX SPEED.......................280/.67 L/G.......................KEEP DOWN FUEL CONSUMPT INCRSD FMS PRED UNRELIABLE *See* [1]	**INOP SYS** L/G RETRACT

(1) *If the flight is continued (to destination or to alternate) with landing gear extended:*

- *Disregard FMS fuel predictions. Refer to QRH/OPS Fuel Penalty Factors/ECAM Alert Table in order to find the applicable Fuel Penalty Factor*
- *Disregard FMS altitude and speed predictions. Time predictions are only valid in cruise*
- *Do not use the managed speed mode (except in approach)*
- *Do not use the CLB and the DES autopilot modes.*

Note: *In few cases, autothrust and autopilot may also be lost.*
If WHEEL N.W. STEER FAULT is also displayed, then the nose wheels may be at maximum deflection. (Turned 90 ° from center.) During landing, delay nose wheel touchdown for as long as possible.

Fig. 32: ECAM Procedure L/G Shock Absorber Fault Source: Operator

1.17.4 Flare

The Flight Crew Techniques Manual (FCTM), chapter Procedures / Normal Procedures / Standard Operating Procedures – Landing / Flare and Touchdown described how the PF has to control the airplane in pitch during flare:

[…]

<u>Pitch Control</u>

[…] *During flare, PF will have to apply a progressive and gentle back stick order until touchdown.*

[…]

- *Start the flare with positive (or "prompt") backpressure on the sidestick and holding as necessary*
- *Avoid forward stick movement once Flare initiated (releasing back-pressure is acceptable)*

[…]

1.17.5 De-rotation Phase

The FCTM chapter Procedures / Normal Procedures / Standard Operating Procedures - Landing / Flare and Touch-down (Fig. 33) described that the pilot must land the nose landing gear smoothly but without delay after the main landing gear had touched down. It was also noted that the use of auto brake MED may lead to a hard nose gear touch-down.

A320/A321 **FLIGHT CREW** **TECHNIQUES MANUAL**	**PROCEDURES** **NORMAL PROCEDURES** STANDARD OPERATING PROCEDURES - LANDING

After touch down, the pilot must "fly" the nosewheel smoothly, but without delay, on to the runway, and must be ready to counteract any residual pitch up effect of the ground spoilers. However, the main part of the spoiler pitch up effect is compensated by the flight control law itself.
It is not recommended to keep the nose high in order to increase aircraft drag during the initial part of the roll-out, as this technique is inefficient and increases the risk of tail strike. Furthermore, if auto brake MED is used, it may lead to a hard nose gear touch down.

Fig. 33: Landing of the nose landing gear Source: Operator

1.18 Additional Information

1.18.1 Statistical Values regarding the Pitch Down Rate

The aircraft manufacturer's AMM had not stipulated a maximum limit for the pitch down rate during the de-rotation phase. The "AMM Inspection 05-51-11 after a Hard Landing" required to send the flight data to the aircraft manufacturer for analysis purposes in case of a high pitch rate de-rotation landing. The Load Report 15 should not be used for confirmation of a high pitch down rate.

The BFU asked the aircraft manufacturer and the operator to provide statistical values, so that the pitch down rate values during touchdown of the nose landing gear, which occurred during the rejected take-off at Heraklion and the landing at Kavala, could be compared and classified.

The aircraft manufacturer considered 38,348 flights of two operators and their A320 CEO (Current Engine Option) fleets. On average, the pitch down rate during touch-down of the nose landing gear was -2°/s. One percent of these cases showed a pitch down rate of about -4.5°/s or less and 0.1% of -5.4°/s or less. Pitch down rates of -7°/s or less did not occur. The ADIRUs calculate the pitch down rate directly and record it with a rate of 4 Hz.

The operator considered 2,750 flights of their A320 CEO fleet. On average, the pitch down rate during touch-down of the nose landing gear was -1.7°/s. At about 3.8% of these cases, pitch down was -4.2°/s and in 0.1% it was -5.6°/s. Pitch down rates of less than -5.6°/s did not occur. It should be mentioned that with the statistical analysis of the operator an uncertainty of the pitch down rate calculation of up to 2.8°/s may be possible.

1.18.2 Load Analysis of the Landing Gear Manufacturer

With the load estimation, the landing gear manufacturer focused on the deformation of the barrel hinge pins.

The highlighted area in Figure 34 shows the critical area of the barrel hinge pin in regard to plastic deformation.

According to the landing gear manufacturer, the maximum vertical load limit in the critical area is 232 kN. At a load of 310 kN or higher the barrel hinge pin begins plastic deformation. Therefore, the landing gear manufacturer assumes that during the rejected take-off both barrel hinge pins were subject to a vertical load of 310 kN or more each.

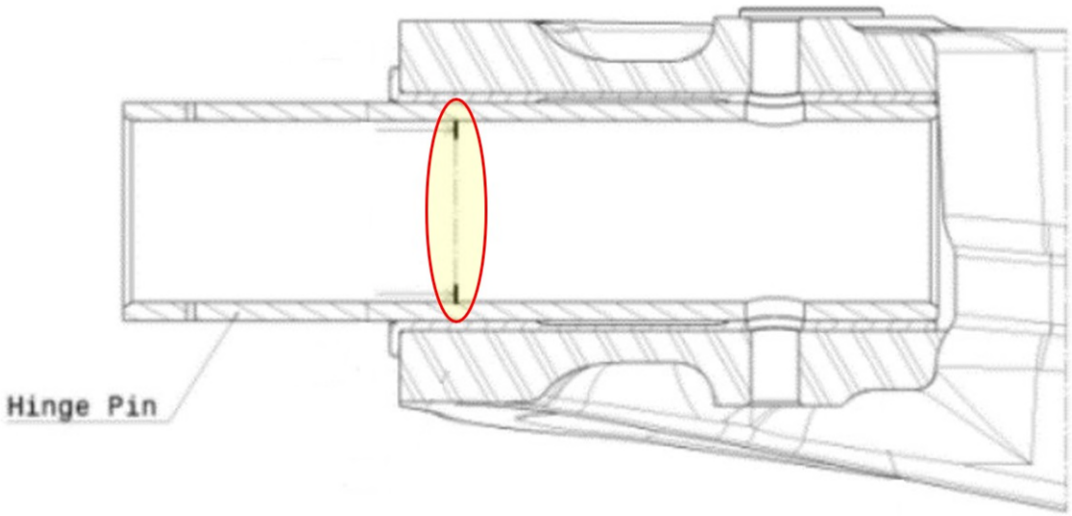


Fig. 34: Critical area of the barrel hinge pin Source: Landing gear manufacturer, adaptation BFU

1.18.3 Load Analysis of the Aircraft Manufacturer

The aircraft manufacturer used their own load simulation program to estimate the dynamic loads which occurred during the rejected take-off at Heraklion where the nose landing gear touched down hard. This program is used by the aircraft manufacturer mainly for design, certification activities and the assessment of hard landings. The forces between the ground and the nose landing gear tires / shock absorber are calculated as function of time based on vertical movement, among others. The loads at different levels of the fuselage structure are then calculated as function of time by modelling the known stiffness and damping characteristics of the nose landing gear tires and shock absorber.

Since the stiffness and damping characteristics of the nose landing gear shock absorber change in case of damage and are then unknown, the simulation program cannot predict how the loads are distributed to the nose landing gear components and the fuselage structure if damage occurs on this component, according to the aircraft manufacturer.

The simulation program did not consider the lateral acceleration at the time the nose landing gear touched down during the rejected take-off. Compared to the vertical acceleration, it was lower.

The simulation results showed that during the rejected take-off, at the time the nose landing gear touched down again, the critical vertical load beyond which it can cause buckling of the NLG shock absorber cylinder was reached.

The exceedance of this critical vertical load was not only the result of the high vertical speed of the nose landing gear during touch-down but also of additional vertical forces. These were caused by the pitch down moment of the airplane due to full commanded nose down elevator deflection and the brake pressure built-up by the auto brake system.

The load simulation was no longer valid above this critical load due to the change and then unknown stiffness and damping characteristics of the damaged shock absorber. From reaching this critical load, it was not possible to make statements regarding loads on components of the nose landing gear and the fuselage structure.

1.18.4 High Load Event Reporting

The Airbus Safety First Magazine #26 Article „High Load Event Reporting“ (July 2018) described the importance of reporting high load events by flight crews as primary means of detecting such events.

1.18.5 Similar Occurrence

On 10 April 2013, another high load on the NLG event involving an A320 occurred as take-off was rejected during a touch and go maneuver after the airplane had already begun to rotate.

The de-rotation rate was -9,8°/s. The British AAIB investigated the occurrence (AAIB Bulletin 7/2014, EW/C2013/04/01). The flight crew were aware of a hard touchdown on the nose landing gear but did not consider it was excessive. They considered that it did not constitute a heavy landing and it was decided that an inspection was not required. They did not terminate the flight and proceeded with the flight training session.

After a short stay, the airplane took off again. After take-off, the landing gear could not be retracted and the ECAM message L/G SHOCK ABSORBER FAULT was triggered.

The base training was aborted and the airplane flown to the operator's maintenance facility.

The landing gear manufacturer's examination of the nose landing gear revealed a deformed cylinder of the nose landing gear shock absorber which blocked full and free movement.

1.18.6 Crucial Additional Information Provided by the CFDS

The operator performed an analysis of all ECAM warning messages (related to A32x) to determine, for which of these warning messages the CFDS would provide in flight crucial additional information via the Current Flight Report, that was not included in the ECAM procedure or the QRH or FCOM. "Crucial additional information" meant information without which the status of the aircraft in case of an ECAM warning was not clearly defined for the flight crew.

According to the operator, the L/G SHOCK ABSORBER FAULT (SHOCK ABSORBER NOT EXTENDED AFTER LIFTOFF) was the only ECAM warning message where the CFDS provided such crucial additional information in flight.

1.18.7 Human Factors

1.18.7.1 Slip

In publications regarding human performance and error management, human error is called a slip if it is executed unintentionally, previously unplanned in a basically correct, known, course of action.

The following articles give these descriptions of slips, among others:

SKYbary article "Human Error Types" (28.02.2023)[3]:

[…] *In a familiar and anticipated situation people perform a skill-based behaviour. At this level, they can commit skill-based errors (slips or lapses). In the case of slips and lapses, the person's intentions were correct, but the execution of the action was flawed - done incorrectly, or not done at all.* […]

SKYbary article "Error Management (OGHFA BN)" (28.02.2023)[4]:

[…] *Slips and lapses are an unfortunate byproduct of the useful human capability to perform actions "automatically," without full attention. The mechanisms causing slips*

[3] www.skybrary.aero/articles/human-error-types

[4] www.skybrary.aero/articles/error-management-oghfa-bn

and lapses function at an unconscious level. Therefore, even if slips and lapses can be reduced through good design of the working interfaces, procedures and environments, it is impossible to prevent all of them. […]

Airbus, Flight Operations Briefing Notes, Human Performance - Error Management (December 2005):

[…] *Slips and lapses are failures in the execution of the intended action. Slips are actions that do not go as planned, while lapses are memory failures. For example, operating the flap lever instead of the (intended) gear lever is a slip. Forgetting a checklist item is a lapse.* […]

1.18.7.2 Startle effect

In aviation "startle effect" is defined as […] *an uncontrollable, automatic muscle reflex, […], elicited by exposure to a sudden, intense event that violates a pilot's expectations.* […] FAA Advisory Circular 120-111, Upset Prevention and Recovery Training, 14.04.2015).

The SKYbary article "Startle Effect" includes the following description of the Startle effect, its effects and consequences:

[…]

Description

The startle effect includes both the physical and mental responses to a sudden unexpected stimulus. While the physical responses are automatic and virtually instantaneous, the mental responses - the conscious processing and evaluation of the sensory information - can be much slower. In fact, the ability to process the sensory information - to evaluate the situation and take appropriate action - can be seriously impaired or even overwhelmed by the intense physiological responses. […]

[…]

Effects

[…] studies have determined that, following a startling stimulus […], basic motor response performance can be disrupted for as much as 3 seconds […]

[…]

Consequences

[…] *In aviation, the immediate impact of the startle reflex may induce a brief period of disorientation as well as short term psychomotor impairment which may well lead to task interruptions and/or a brief period of confusion. […]*

1.19. Useful or Effective Investigation Techniques

Not relevant.

2. Analysis

2.1 Aircraft

The airplane was certified in accordance with aviation regulations and prior to the rejected take-off at Heraklion continuously maintained. As a result of the two occurrences, it was severely damaged.

2.1.1 Rejected take-off at Heraklion Airport

The mechanics on site, the operator, the aircraft manufacturer and the BFU did not determine any technical causes for the rejected take-off at Heraklion. The damage on the main landing gear tires, which were later replaced, were caused by the braking and relatively large drift of 6° to 7° after the rejected take-off had been initiated.

That the airplane veered to the right towards the runway edge had been caused by the right rudder input which the FDR had recorded shortly before the rejected take-off.

During the take-off run, the co-pilot had counteracted the low crosswind component of 12 kt with single left rudder pedal inputs. After each of these rudder inputs he moved the rudder pedals back to neutral so that the airplane repeatedly drift away to the right and slightly off the centre line. He did not attempt to keep the airplane on the centre line with a continuous adjusting rudder pedal input.

Up until the right rudder pedal input, this course of action did not result in the airplane deviating more than 2 m off the centre line so that the PIC had no reason to take over control. She could not anticipate the subsequent right rudder pedal input.

The PIC stated that she had noticed the co-pilot’s rudder pedal inputs during the take-off run. Therefore, it is very likely that she also noticed the sudden right rudder pedal input.

Within 1.5 seconds after this input, she rejected the take-off and immediately applied a left rudder pedal input. The decision to reject the take-off, including the short moment to check the engine parameters, was made swiftly.

Shortly after the rejected take-off was initiated, a dynamic rotation/de-rotation occurred. When the nose landing gear touched down again, the de-rotation rate was very high at - 9,7 °/s which is 4.9 times higher than the mean de-rotation rate of - 2 °/s and outside the statistics the aircraft manufacturer and the operator provided (1.18.1). The rotation was caused by a side stick input of the PIC. At the time the nose landing gear touched down again, the airplane was in a left yaw movement towards the runway centre line, therefore, the nose landing gear was not only subject to vertical but also to lateral loads. After the nose landing gear touched down a drift of 6° to 7° occurred which also caused lateral loads on the NLG.

Both pilots consciously noticed the de-rotation during the rejected take-off. After she had realised the lift-off of the aircraft nose, the PIC consciously performed the de-rotation. The co-pilot had heard a bang during the rejected take-off which he associated with the touch-down of the nose landing gear.

When the nose landing gear touched down again, the very high de-rotation rate caused the initial deformation of the nose landing gear shock absorber's cylinder and the beginning of the crack. Additionally, the load analysis of the aircraft manufacturer showed that the critical load which can cause buckling of the cylinder had been exceeded during the rejected take-off.

With the rubber abrasion traces (Fig. 12), which had been created during the rejected take-off on runway 27 at Heraklion, the respective additional traces right of the ones from the nose landing gear tires could be clearly attributed to the damage on the respective right NLG tire sidewalls. The damage of the nose landing gear tires (Fig. 20) were thus caused by the rejected take-off shortly after the nose landing gear had touched down again.

The initial deformation of the two barrel hinge pins was caused by the rejected take-off because the different degree of deformation between the right and the left barrel hinge pin indicate a manoeuvre in which the nose landing gear was not only subject to high vertical loads but in the area of the nose landing gear axis also to lateral loads. This was the case when the nose landing gear touched down again during the rejected take-off. During the subsequent flights such a combination of vertical and lateral loads concerning the nose landing gear did not occur. The aircraft manufacturer shares this opinion.

2.1.2 Flights after the Rejected Take-off

Since the cylinder's crack was not yet open after the rejected take-off, there was still damping by the nose landing gear shock absorber which was confirmed by the statement of the flight crew regarding the two subsequent flights and the taxi out at Kavala. Additionally, the mechanics at Heraklion and the pilots who had performed the outside checks prior to the subsequent flights confirmed that the nose landing gear shock absorber's chromium layer was visible.

The next day during take-off at Heraklion, the cylinder's deformation due to the RTO caused the associated WOW sensors to report first the main landing gear as in the air and then the nose landing gear which allows the conclusion that the nose landing gear shock absorber's free and full movement was limited.

The cylinder's deformation after the RTO increased during the following flights so that after take-off at Kavala the nose landing gear shock absorber no longer extended fully. Subsequently, the landing gear lever could no longer be moved into position UP and the ECAM message L/G SHOCK ABSORBER FAULT was triggered.

The cylinder's crack had opened after take-off at Kavala because of the previous flights and the accompanying loads. The result was loss of pressure in the nose landing gear shock absorber to which the cylinder's severe deformation and the damaged dynamic seal also contributed. One day later, a visible external hydraulic oil leakage at the nose landing gear shock absorber was the result.

During the landing at Kaval, shortly before the main landing gear touched down, at a radio height of about 50 ft, there was an oscillating movement of the PIC's side stick in pitch between pulling and pushing (Fig. 10). This movement was continued after touch-down of the main landing gear with a forward motion of the side stick towards push. As a result, the negative pitch rate increased during de-rotation phase to a maximum of - 4,6°/s at NLG touch down.

This tendency to over-control in pitch during the flare phase and especially after the main landing gear had touched down in spite of good weather conditions with a light wind from nearly landing direction contributed to a high de-rotation rate. In this case it had not resulted in excessive vertical acceleration during the main landing gear's touch-down.

This course of action does not correspond with the procedure the aircraft manufacturer had described in the FCTM, where the PF should apply a progressive and gentle back stick order during the flare, and then after the main landing gear had touched down, has to land the nose landing gear smoothly.

According to the statistics the aircraft manufacturer (1.18.1) provided, the de-rotation rate of -4,6 °/s at NLG touch down during the landing at Kavala was more than 2.3 times higher than the mean de-rotation rate of - 2 °/s and occurred only in 1% of cases.

The relatively symmetrical damage of the front fuselage surface area and the lack of reports concerning outer fuselage damage after the rejected take-off by the maintenance personnel at Heraklion and the pilots after three further outside checks make it likely that they occurred during the landing at Kavala. The aircraft manufacturer shares this opinion.

It is highly likely that the combination of the high de-rotation rate of -4,6°/s during touch-down of the nose landing gear and the lack of nose landing gear damping resulted in the structural damage of the front fuselage area during the landing at Kavala.

It must be said that due to the unknown damping and stiffness values of the damaged nose landing gear shock absorber, an accurate estimation and a full explanation regarding the magnitude of the front fuselage's structure damage at the time of the landing at Kavala was not possible. Without these values, the aircraft manufacturer's load simulation program cannot provide such an estimate.

To what extent a structural damage to the fuselage, caused by the rejected take-off at Heraklion, which was not visible during the technical or outside checks, had contributed to the damage at Kavala could also not be estimated.

2.2 Crews

2.2.1 Crew Involved in the Rejected Take-off at Heraklion

Both pilots held the necessary licenses and ratings required for the conduct of the flights.
Due to the total flying experience and the flight time on type, the PIC has to be viewed as experienced and the co-pilot as still little experienced.

2.2.2 Crew Involved in the Landing at Kavala Airport

Both pilots held the necessary licenses and ratings required for the conduct of the flights.
Due to the total flying experience and the flight time on type, the PIC has to be viewed as experienced and the co-pilot as still little experienced.

2.3 Weather

At the time of the rejected take-off on runway 27 at Heraklion on 10 July 2021, a crosswind component of 12 kt from the right prevailed. Gusts, which could have explained the airplane's veering to the right during the take-off run, were not reported or recorded.

At the time of the final landing on runway 23 at Kavala on 11 July 2021, good weather conditions with a light wind from nearly landing direction prevailed. It can therefore be ruled out that the weather conditions had any influence on the event.

2.4 Organisation and Procedures

2.4.1 Selection of Technical Inspections after the Rejected Take-off

The mechanics at Heraklion would very likely have applied the „AMM 05-51-11 Inspection after a hard Landing (high pitch rate de-rotation)“ after the rejected take-off, if they had had the information concerning the rotation with subsequent high de-rotation . This inspection would have included a full and free movement check of the nose landing gear shock absorber in case of a potential high de-rotation (Subtask 05-51-11-210-176-A); the airplane would have been jacked up at the front attachment point. In doing so, it is highly likely that the sluggish extension of the nose landing gear shock absorber, which was identified the next day during take-off, would have been determined. This would have prevented that the airplane returns to service in a non-airworthy condition.

If the mechanics had had the information regarding the high lateral accelerations, which occurred during the rejected take-off, it is very likely that they would have applied „AMM 05-51-44 Inspection after Aircraft Operation with high Lateral Acceleration“. Since the lateral accelerations during the rejected take-off had exceeded 0.42 g, they would have eventually switched to „AMM 05-51-11 Inspection after a hard Landing“ and very probably determined the limited movement of the nose landing gear shock absorber. Thus, this information would also have prevented that the airplane returns to service in a non-airworthy condition.

The mechanics' lack of information concerning the rotation/de-rotation and the high lateral accelerations during the rejected take-off were an essential reason why they did not determine the limited movement of the nose landing gear shock absorber.

2.4.2 Pilot Reporting of High Load Events

The pilot reporting, especially of high load events, as in this case, as primary source for the correct selection of maintenance actions is essential to prevent that the airplane returns to service in a non-airworthy condition. In this case, the information of the flight crew and the TLB entry were not sufficient for the mechanics to select the suitable AMM inspection.

The Airbus Safety First Magazine #26 Article „High Load Event Reporting“ also described the importance of reporting high load events by the flight crew as primary means of detecting such an event.

It is important that the operator involved emphasises to their flight crews the significance of pilot reporting, especially high load events. Moreover, it is necessary to give the pilots a guideline in case of a high load event which allow them to relay essential information to the maintenance personnel to prevent similar occurrences in the future. Such guideline could not be found in the operator’s operations manuals.

In a discussion with other operators, it turned out that such a guideline is only partially or not at all part of their operations manuals.

The European Aviation Safety Agency (EASA) should therefore require operators to include such guideline in their operations manuals.

2.4.3 Technical Checks due to Nose Landing Gear Tire Damage

The technical checks by the mechanics at Heraklion and the three subsequent outside checks by the pilots included, among other things, a visual inspection of the nose landing gear tires for their conditions. Everyone involved in these checks missed the visible damage of the right sidewalls of the two nose landing gear tires which had occurred during the rejected take-off (Fig. 20). Thus, the checks had not been performed thoroughly in these areas.

If these damages had been detected during the technical checks after the RTO or the subsequent outside checks, this might have prompted the mechanics to apply the „AMM 05-51-44 Inspection after Aircraft Operation with high Lateral Acceleration“, because the damage suggests a high drift of the airplane and therefore high lateral accelerations during the rejected take-off. This finding might have prevented the second event at Kavala.

2.4.4 Release to Service after the Rejected Take-off

The maintenance personnel at Heraklion released the aircraft again to service (in consultation with the operator’s maintenance control centre in Germany) on 10 July 2021, even though they had no findings or information which could have explained why the airplane veered to the right and thus the reason for the rejected take-off. The damages on the main landing gear tires, all of which were replaced, were mainly caused by the braking action and the relatively large drift of 6° to 7° after the rejected take-off had been initiated and cannot explain the swerving of the airplane.

There was no tire blow-out, none of the tires was deflated and during the runway inspection no tire debris was found. The mechanics should have requested further information from the flight crew to find out the reason for the swerving of the airplane.

2.4.5 Load Report 15

In case of high load events, the Load Report 15 is used to assist the maintenance personnel in selecting the appropriate AMM inspection. But it does not cover every possible high load event and is not intended as a substitute for the primary reporting by pilots.

If a Load Report 15 is not generated, this does not necessarily mean that there was no high load event. A high de-rotation rate with a hard landing of the nose landing gear, as in the present event, is an example of such a case.

If a high de-rotation rate which resulted in a hard nose landing gear landing is not perceived as such by the pilots and/or is not reported, it is likely that subsequently no corresponding „AMM 05-51-11 Inspection after a hard Landing“ will be performed unless there are other findings which serve as indicators. Therefore, the airplane involved could be kept in service in a non-airworthy condition, as in this case, and in the 2013 one the AAIB investigated.

To prevent this in the future, the BFU is of the opinion that the decision making of the maintenance personnel in selecting the appropriate AMM inspection can be improved by a Load Report 15 which allows the detection of a hard nose landing gear landing. This should be possible during rejected take-off, touch and go and landing.

In addition, the awareness of flight crews for reporting such a suspected high load event to maintenance personnel could also be improved through the help of such a modified Load Report 15.

2.4.6 Current Flight Report

According to the pilots' statements, it was not clear to them after take-off from Kavala which landing gear was affected by the ECAM message L/G SHOCK ABSORBER FAULT. The co-pilot assumed a landing gear shock absorber fault at one of the two main landing gears due to the rejected take-off the previous day and the replacement of all four main landing gear tires. During the occurrence there was no data link available so that the flight crew could not reach the maintenance control centre via ACARS and ask about it.

Via the Current Flight Report of the CFDS, it would have been possible to determine in flight that the L/G SHOCK ABSORBER FAULT concerned the nose landing gear shock absorber. The CFDS was in the reporting mode where only fault messages are indicated. Initiation of system tests was in this mode not possible and thus an incorrect operation with negative effects was excluded.

The use of the CFDS in flight by the pilots had thus far not been part of the operator's trained procedures in case of a fault. According to the aircraft manufacturer the CFDS Current Flight Report has not been designed and tested to be used by the flight crew when applying any abnormal procedures. The CFDS has been designed to support maintenance activities only.

The operator performed an analysis of all ECAM warning messages to determine, for which of these warning messages the CFDS would provide in flight crucial additional information via the Current Flight Report, that was not included in the ECAM procedure or the QRH or FCOM. According to the operator, the analysis showed that this was only the case for the L/G SHOCK ABSORBER FAULT (SHOCK ABSORBER NOT EXTENDED AFTER LIFTOFF). Therefore, the BFU and the operator recommend to include a note in the OM-B under the ECAM procedure L/G SHOCK ABSORBER FAULT (SHOCK ABSORBER NOT EXTENDED AFTER LIFTOFF) indicating the use of the Current Flight Report of the CFDS in flight to ensure which landing gear is affected by this fault.

For the flight crew it would have been helpful to know that it was a nose landing gear shock absorber fault. It is possible that the PF would then have deliberately tried to keep the de-rotation rate low during the landing. However, it must be mentioned that in the aircraft manufacturer's FCTM it is described that the pilot always has to land the nose landing gear smoothly after the main landing gear touch-down.

2.5 Human Factors

2.5.1 Right Rudder Input at 133 kt

According to his statement, even though the co-pilot had planned to counteract the right crosswind component with appropriate (left) rudder pedal inputs during the take-off run, a significant right rudder pedal input occurred at about 133 kt.

Human performance and error management publications describe such actions as slips. This is an error, which is executed unintentionally, previously unplanned and in a basically correct, known course of action.

The co-pilot's course of action to give single left rudder pedal inputs instead of a continuous, adjusting rudder pedal input to keep the airplane on the centre line during the take-off run resulted in the airplane repeatedly drifting to the right with neutral rudder position. This might have contributed to the impression that so far, the wrong rudder pedal had been pushed during the take-off run.

2.5.2 Rotation/De-rotation during the Rejected Take-off

The PIC cannot remember pulling the side stick after the rejected take-off was initiated, according to her statement. Once she realised the nose of the aircraft was lifting, she pushed the side stick forward and initiated de-rotation, so that the nose landing gear touched down again.

Pulling the side stick was also a slip and therefore an error which was unconscious, unintentional and previously unplanned. It was performed in a basically correct and repeatedly trained course of action, the rejected take-off.

The BFU does not see any indication that the pull on the side stick was a reflex due to startle effect triggered by the sudden right rudder pedal input. The startle effect would have resulted in a disruption and delay of the rejected take-off procedure. However, these ran parallel to the pull on the side stick.

3. Conclusions

3.1 Findings

- All pilots involved in the occurrences at Heraklion and Kavala held the required licences and ratings to conduct the flights.
- The airplane was properly certificated and maintained in accordance with existing regulations and approved procedures.
- Indications of technical defects as cause for the rejected take-off at Heraklion were not found.
- At the time of the rejected take-off on runway 27 at Heraklion, a crosswind component of 12 kt from the right prevailed. Gusts were neither reported nor recorded.
- The swerving of the airplane to the right towards the runway edge was caused by a right rudder pedal input.
- Shortly after the rejected take-off had been initiated, a dynamic rotation/de-rotation occurred with a very high de-rotation rate as the nose landing gear touched down again.
- The nose landing gear was not only subject to vertical but also to lateral loads when it touched down again, since the aircraft was in a yaw movement.
- After the nose landing gear touched down, a drift of 6° to 7° occurred initially which also caused lateral loads on the nose landing gear and resulted in damage of the main landing gear tires and of the right sidewalls of both nose landing gear tires.
- The very high de-rotation rate of -9,7°/s caused the initial deformation of the nose landing gear shock absorber's cylinder and the beginning of the crack when the nose landing gear touched down again.
- Since the cylinder's crack was not yet open, there was still damping by the nose landing gear shock absorber.
- The initial deformation of the two barrel hinge pins was caused by the rejected take-off because their damage differed between the right and the left and allowed the conclusion that it was caused by a manoeuvre with lateral loads.

- After a rejected take-off, there is no general AMM Inspection the maintenance personnel perform. The AMM Inspection to be applied is essentially based on the information or description of the pilots or the technical logbook entry.
- The pilot reporting, especially of high load events, as primary source for the correct selection of maintenance actions is essential to prevent that an airplane returns to service in a non-airworthy condition.
- The mechanics at Heraklion did not have the information about the dynamic rotation/de-rotation and the high lateral accelerations during the rejected take-off.
- After the rejected take-off, the mechanics first performed a general visual inspection of the airplane where they determined that all four main landing gear tires were damaged. Then they continued their work with the “AMM Inspection 05-51-15 after a Tire Burst or Tread Throw or Wheel Failure”.
- Since none of the tires was deflated and no tire debris had been found after the rejected take-off during the runway inspection, the mechanics eventually applied “AMM Inspection 05-51-16 after Brake Emergency Application or Overheat”.
- After the rejected take-off, all four main landing gear tires were replaced. No other airplane damage was detected.
- The damage at the right tire sidewalls of the two nose landing gear tires, which had occurred during the rejected take-off, remained undetected.
- The maintenance personnel at Heraklion released the aircraft to service again on 10 July 2021, even though they had no findings or information which could have explained why the airplane veered to the right and thus the reason for the rejected take-off.
- On the day following the rejected take-off, the airplane returned to service even though it was not airworthy due to the undetected severe damage of the nose landing gear shock absorber.
- During take-off at Heraklion the following day, the cylinder’s deformation caused the NLG shock absorber to extend with a delay, so that the associated WOW sensors reported the nose landing gear later in the air than the main landing gears.

- The cylinder's deformation increased after the rejected take-off during the following two flights so that the nose landing gear shock absorber no longer extended fully after take-off at Kavala on 11 July 2021.
- Shortly after take-off at Kavala, the landing gear lever was blocked in the position Down and the ECAM message L/G SHOCK ABSORBER FAULT triggered, due to the jammed nose landing gear shock absorber.
- The cylinder's crack had opened after take-off at Kavala because of the previous flights and the accompanying loads. The result was loss of pressure in the nose landing gear shock absorber to which the cylinder's severe deformation and the damaged dynamic seal also contributed.
- At the time of the final landing at Kavala, good weather conditions with a light wind from nearly landing direction prevailed.
- During touch-down of the nose landing gear at Kavala, a high de-rotation rate of -4,6°/s occurred which was 2.3 times higher than the average de-rotation rate of -2°/s and was reached in only 1% of cases, according to statistics.
- The relatively symmetrical damage of the front fuselage surface area and the lack of reports concerning outer fuselage damage after the rejected take-off by the maintenance personnel at Heraklion and the flight crews after three further outside checks make it likely that they occurred during the landing at Kavala.
- It is highly likely that the combination of a high de-rotation rate during touch-down of the nose landing gear and the lack of nose landing gear damping resulted in the structural damage of the front fuselage area during the landing at Kavala.

3.2 Causes

After the rejected take-off at Heraklion, the airplane had been returned to service with a severely damaged nose landing gear shock absorber and thus in a non-airworthy condition.

This was caused by:

- Shortly after the rejected take-off had been initiated, a dynamic rotation/de-rotation occurred which caused a very high de-rotation rate when the nose landing gear touched down again.
- After the rejected take-off, the damping of the nose landing gear shock absorber was still present in spite of the severe damage.
- The mechanics at Heraklion lacked the information from the flight crew about the dynamic rotation/de-rotation and the high lateral accelerations during the rejected take-off.
- After the rejected take-off, the damage at the right tire sidewalls of the two nose landing gear wheels remained undetected.
- The maintenance personnel at Heraklion released the aircraft to service again after they had replaced all four main landing gear wheels on 10 July 2021, even though they had no findings or information which could have explained why the airplane veered to the right and thus the reason for the rejected take-off.

After the landing at Kavala Airport on 11 July 2021, severe damage of the fuselage structure in the area of the nose landing gear was determined.

This was caused by:

- The initial deformation of the NLG shock absorber cylinder after the rejected take-off increased during the following flights so that finally after take-off at Kavala the NLG shock absorber no longer extended completely.
- Due to the previous flights and the accompanying loads, the crack in the cylinder had opened after take-off at Kavala. Loss of pressure in the nose landing gear shock absorber occurred to which the cylinder’s strong deformation and the damaged dynamic seal also contributed.
- It is highly likely that the combination of a high de-rotation rate during touch-down of the nose landing gear and the lack of nose landing gear damping

resulted in the structural damage of the front fuselage during the landing at Kavala.

4. Safety Recommendations

Safety Actions of the Operator

After the accident, the operator issued a publication for flight crews, in order to inform pilots that after the occurrence of high lateral accelerations on the ground, especially those exceeding 0.42 g, a maintenance inspection is required. Since a Load Report 15 is not generated on the ground, except during the touch-down phase, the subjective impression of the pilots is crucial. If the flight crew noticed high lateral accelerations on the ground, this shall be entered into the Technical Logbook and the maintenance organisation be notified accordingly.

In addition, the operator included the following guideline for pilots in the OM-A chapter 8.1.11.3.1 for the case of a high load event which allows them to relay essential information to the maintenance personnel after such an event to prevent similar occurrences in the future:

[…]

8.1.11.3.1 High Load Event

Following a high Load Event in Flight or on Ground, the Commander shall provide the information listed below at the earliest possible time after the occurrence. The information can be transmitted via electronic means, or by verbal briefing to Maintrol. In any case a TLB entry is always required and should contain as many details as possible.

High Load Event in Flight:

- *Was a Load Report triggered? (only relevant for Airbus)*
- *Was the high Load Event caused by large movements in Pitch, Roll or Yaw?*
- *Was the high Load Event caused by Turbulence?*
- *Was the high Load Event caused by System Failures?*
- *Was the high Load Event caused by recovery actions (e.g. from abnormal attitude, overspeed, deviation from original flight path, …)?*

High Load Event during Touch-Down Phase or during Ground movement:

- *Was a Load Report triggered? (only relevant for Airbus)*
- *Do you suspect a Hard Landing?*
- *Do you suspect high de-rotation at NLG Touch Down?*
- *Do you suspect high lateral loads due to a high drift angle at Touch Down (e.g. Cross Wind Landing) or during Rejected Take-off?*
- *Do you suspect high lateral loads due to lateral oscillation after Touch Down or during Rejected Take-off?*
- *Do you suspect high lateral loads during Taxiing?*
- *Was the aircraft rotating / de-rotating during the Rejected Take-Off?*

- Was the high Load Event caused by System Failures?

Mention important parameters, like:
- speed
- flight attitude
- kind of acceleration and forces felt
- time (UTC) and duration of the high load event
- Autopilot engaged or manual flight
- flight control inputs
- system failures
- weather
- any further parameters valuable for the event
In any case the pilots should describe the high Load Event as accurate as possible.
[…]

Furthermore, the operator performed a flight data analysis based on the first occurrence at Heraklion, where the airplane kept drifting away to the right and slightly off the centre line during the take-off run up to 133 kt CAS, due to the crosswind component. It was determined that in the past comparable cases with other crews had occurred. These had also attempted to use single rudder pedal inputs instead of a continuous, adjusting rudder pedal input to keep the airplane on the centre line during the take-off run. As a result, in the subsequent simulator sessions, among other things, the operator had pilots trained take-off with crosswind conditions to ensure that pilots continuously maintain the centre line during the take-off run in such conditions.
As an additional measure, a note was added by the operator in the FCOM under the ECAM procedure L/G SHOCK ABSORBER FAULT (SHOCK ABSORBER NOT EXTENDED AFTER LIFTOFF) to indicate the use of the CFDS in flight (MCDU MENUE – CFDS – ECAM LEG REPORT) to ensure for the flight crew which landing gear is affected by this fault.

Safety Actions of the Aircraft Manufacturer

In order to prevent in the future a possible NLG lift off during a RTO from going undetected when applying the „AMM Inspection 05-51-16 after Brake Emergency Application or Overheat“ following a rejected take-off, the aircraft manufacturer changed the AMM (1 August 2022). The first paragraph of the AMM Inspection 05-51-16 instructs the maintenance personnel to change to „AMM Inspection 05-51-11-200-004 After a Hard Landing for NLG high pitch-rate de-rotation“ if the nose landing gear had lifted off during the rejected take-off.

A note highlights that the flight crew and the DFDR data can be used to clarify whether the nose landing gear had lifted off.

The BFU originally intended to issue a Safety Recommendation requesting the aircraft manufacturer, based on the current hardware, to study the possibility to include in the next Load Report 15 software standard the capability to detect hard landings on NLG during rejected take-off, touch and go or landings.

The aircraft manufacturer has therefore studied the possibility to include in the Load Report 15 software standard this capability. The study showed that it cannot be implemented in the current legacy hardware platform for technical reasons. A new hardware platform is under development with certification in the coming years. This new platform will be the opportunity to study new algorithms able to detect hard landings on NLG during rejected take-off, touch and go or landings. It will be proposed in forward fit & retrofit with potential aircraft adaptation.

The BFU will issue the following safety recommendation:

Safety Recommendation 5/2024

The European Aviation Safety Agency (EASA) should prompt airline operators to ensure that pilots have clear guidelines in their Operations Manual or any other documentation to help them report key issues to maintenance personnel in the case of a High Load Event so that mechanics have sufficient information to apply the appropriate AMM Inspection. Furthermore, this should clarify to pilots the importance of their report as the primary means of detection High Load Events.

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Braunschweig, 29 April 2024

5. Appendices