Estonian
Safety
Investigation
Bureau

INVESTIGATION REPORT

ACCIDENT, LOSS OF CONTROL WITH AIRBUS A320-214 NEAR TALLINN AIRPORT ON 28.02.2018

TALLINN 2019

SAFETY INVESTIGATIONS

Estonian Safety Investigation Bureau (ESIB) safety investigations are conducted in accordance with the provisions of the European Parliament and of the Council of regulation No. 996/2010 and Annex 13 to the convention of International Civil Aviation Organization (ICAO).

The aim of the safety investigation of civil aviation accidents and incidents is to establish the facts, the conditions and the circumstances of the accident and incident to determine its probable causes and factors in order to undertake appropriate measures to prevent similar accidents or incidents ever occurring.

ESIB safety investigations are conducted with the sole objective of improving aviation safety and are not intended to apportion individual or collective blame or liability. ESIB investigations are independent, separate and are conducted without prejudice to any judicial or administrative action that may be taken to determine blame or liability.

Contents

Abbreviations used in this report

ADR	Air Data Reference
AGB	Accessory Gear Box
AMC	Acceptable Means of Compliance
AOA	Angle of Attack
AOC	Air Operator Certificate
APU	Auxiliary Power Unit
ARINC	Aeronautical Radio INC (technical standard for avionics data bus)
ATC	Air Traffic Control
ATO	Approved Training Organization
ATP	Acceptance Test Protocol
ATPL	Airline Transport Pilot License
BEA	*Bureau d`Enquêtes et d`Analyses pour la sècuritè de l´aviation civile*
BITE	Built-In Test Equipment
CAA	Civil Aviation Administration
CAS	Calibrated Airspeed
CBT	Computer Based Training
CFDIU	Centralized Fault Display Interface Unit
CFDS	Centralized Fault Display System
CLR	Clear
CMM	Component Maintenance Manual
CONF	Configuration
CPL	Commercial Pilots License
CRC	Continuous Repetitive Chime
CS	Certification Specifications
CSS	Cockpit System Simulator
CVR	Cockpit Voice Recorder
DAL	Development Assurance Level
DCDU	Datalink Control and Display Unit
EASA	European Aviation Safety Agency
EC	European Commission
ECAA	Estonian Civil Aviation Administration

ECAM	Electronic Centralized Aircraft Monitoring
ECU	Engine Control Unit
EFCS	Electronic Flight Control System
EFIS	Electronic Flight Instrument System
EIS	Electronic Instrument System
ELAC	Elevator Aileron Computer
ESIB	Estonian Safety Investigation Bureau
EWD	Engine and Warning Display
F/CTL	Flight Control
FAA	Federal Aviation Administration
FCDC	Flight Control Data Concentrator
FCOM	Flight Crew Operating Manual
FCTS	Flight Crew Training Standards Manual
FCU	Flight Control Unit
FDAL	Functions Development Assurance Level
FDR	Flight Data Recorder
FFS	Full Flight Simulator
FHA	Functions Hazards Assessment
FIFO	First In, First Out
FMA	Flight Mode Annunciator
FMEA	Failure Modes and Effects Analysis
FMGC	Flight Management Guidance Computer
FMS	Flight Management System
FOD	Foreign Object Damage
FWC	Flight Warning Computer
GEN	Generator
GM	Guidance Material
ICAO	International Civil Aviation Organization
IR	Internal reference
L/G	Landing Gear
LGCIU	Landing Gear Control Interface Unit
LH	Left Hand
LLER	Last Leg ECAM Report
LLR	Last Leg Report

M	Motor
MCC	Multi Crew Coordination
MCDU	Multipurpose Control and Display Unit
MRO	Maintenance and Repair Organisation
ND	Navigation Display
NVM	Non-Volatile Memory
O/B	Outboard
OEM	Original Equipment Manufacturer
OM	Operations Manual
OVM	Override Mechanism
P/B	Push Button
PASA	Preliminary Aircraft Safety Assessment
PF	Pilot Flying
PFD	Primary Flight Display
PFR	Post Flight Report
PLR	Previous Leg Report
PNF	Pilot Not Flying
QRH	Quick Reference Handbook
RA	Radio Altitude
RAT	Ram Air Turbine
RH	Right Hand
SC	Single Chime
SD	System Display
SPD BRK	Speed Brakes
SSA	System Safety Assessment
TGB	Transfer Gear Box
THS	Trimmable Horizontal Stabilizer
THSA	Trimmable Horizontal Stabilizer Actuator
TM	Training Manual
TOGA	Take-Off/Go-Around
TSD	Trouble Shooting Data
UTC	Universal Time Coordinated

ESIB: A2802118

EECAIRS: EE0180

Synopsis

Aircraft type	A320-214
Aircraft registration	ES-SAN (Estonian register)
Date and time	28.02.2018 at 15:04 UTC
Place	EETN, Tallinn Lennart Meri-Airport, Estonia
Type of flight	Training
Persons on board	7 (Captain, Safety pilot, 4 students, ECAA inspector)
Damage to persons	minor trauma
Damage to aircraft	beyond repair, write off
Other damage	no other damage

On 28th February 2018 at 10:02[1], the Smartlynx Airlines Estonia Airbus A320-214 registered ES-SAN took off from Tallinn airport Estonia to perform training flights with 2 crew members (captain and safety pilot), 4 students and 1 ECAA inspector on board. Following several successful ILS approaches and touch-and-go cycles, at 15:04, after a successful touch down with the runway, the aircraft did not respond as expected to sidestick inputs when reaching rotation speed. After a brief lift-off, the aircraft lost altitude and hit the ground close to the end of the runway. In the impact, the aircraft engines impacted the runway and the landing gear doors were damaged. After the initial impact, the aircraft climbed to 1590 ft from ground level and pitched down again. The pilots were able to stabilize the flight path by using manual pitch trim and engine thrust and make a U-turn back towards the runway. The crew declared an emergency and the aircraft was cleared for an emergency landing. During the approach, the aircraft lost power in both engines. The aircraft landed 150 m before the threshold of runway at 15:11. On landing, aircraft tires burst, and the aircraft veered off the runway and finally came to a stop 15 m left to the runway. The safety pilot and one of the students suffered minor impact trauma in this accident. The aircraft landing gear doors, landing gears, both engine nacelles, engines and aircraft fuselage suffered severe damage in this accident resulting in aircraft hull loss.

The Estonian SIB launched an investigation of this accident according to ICAO Annex 13 and EU Regulation 996/2010.

The investigation determined as the cause of this accident being a combination of the following factors:

- **the intermittent THSA override mechanism malfunction allowing to cause the loss of pitch control by both ELACs.** This malfunction was due to the use of an inappropriate lubricating oil. The fact that the aircraft maintenance documentation does not require any test of the OVM during aircraft regular maintenance checks could have contributed to the result that the wrong oil in the OVM was left unnoticed during aircraft exploitation.
- **SEC design flaw allowing for a single event, the left landing gear temporary dedecompression, to cause the loss of pitch control by both SECs**. The absence of ground spoilers arming for landing in the context of touch and go's training may have contributed to the temporary dedecompression of the left main landing gear.

[1] All time references in this report are UTC. EETN time zone UTC+2

- **The training instructor's decision for continuation of the flight despite repetitive ELAC PITCH FAULT ECAM caution messages.** The lack of clear framework of operational rules for training flights, especially concerning the application of the MEL, and the specific nature of operations that caused pressure to complete the training program may have impacted the crew's decision-making process.

Organisation of the investigation

In accordance with ICAO Annex 13, the state of occurrence is responsible for the conduct of the safety investigation. The investigation obligation lies on the state established independent investigation authority and, in this case, on Estonian Safety Investigation Bureau.

ESIB launched an investigation and with the provisions of Annex 13 and the regulation 996/2010. Accredited Representatives from the State of Design and Manufacturer of the aircraft and engines (France) *Bureau d`Enquêtes et d`Analyses pour la sècuritè de l´aviation civile* (BEA), from the State of Design and Manufacturer of the Flight Control Data Concentrator Units (Germany) Bundesstelle für Flugunfalluntersuchung (BFU), from the state of the maintenance organization of the Trimmable Horizontal Stabilizer Actuator (USA) National Transport Safety Board (NTSB), Finnish Safety Investigation Authority (OTKES *Onnettomuustutkintakeskus*) and technical advisers from the manufacturers (Airbus, Safran, Thalès, Litef, Collins) participated in the investigation.

1 Factual information

1.1 History of the flight

Note: The following information is based on aircraft documentation, data recorders (FDR and CVR), ATC recordings, airport CCTV recordings and crew statements.

This Airbus A320-214 was purchased by Smartlynx Airlines Estonia and registered at Estonian Civil Aviation Administration (ECAA) as ES-SAN on 10th Feb 2018. Before the day of the event, 28th Feb 2018, Smartlynx Airlines Estonia had operated the aircraft for 68 hrs and on the day of the event the aircraft was used by Smartlynx Estonia ATO (registered at ECAA) for training flights.

In the morning of 28th Feb 2018 instructor, safety pilot, 4 students and an ECAA inspector carried out a safety briefing and boarded the aircraft with the intention of performing training flights. Each student, seated on the right seat, was to perform a training session, consisting of 5 touch-and-go cycles, 1 go-around and 1 complete full stop landing. The instructor was sitting on the left seat and the safety pilot was sitting on the jump-seat behind the student. The ECAA inspector was sitting on the second jump seat behind the instructor. The rest of the students were seated in the cabin.

The flight crew started the training session with the first student at 10:08 UTC. The session began with touch-and-go cycles. At each approach, the instructor decided not to arm the ground spoilers. At each touchdown, in order to set the THS at the correct calculated take-off position, the instructor used Airbus FCTM procedure, adjusting the trim setting by grabbing the trim wheel while the THS was automatically returning to 0°.

During the flight with the first student, two ELAC1 + ELAC2 PITCH FAULTs were triggered (the first and third touch-down, see Appendix I) at the moment when the instructor was manually stopping the trim wheel at around 1° Nose Up when the THS was returning to 0° after touch down (ground setting). Flight control (FLT CTL) pitch normal LAW switched to alternate 1 law. Due to the fact that ELAC PITCH FAUT message is inhibited by the system in flight phases 4, 5, 7 and 8 (see Figure 21), these failure messages were not displayed on the ECAM display until the aircraft reached 1500 ft. As for this flight with the first student, each time when the aircraft reached 1500ft the ECAM alert F/CTL ELAC 1(2) PITCH FAULT were displayed on the Engine Warning Display (see Figure 1), and a single chime (SC) was triggered related to the reversion of the F/CTL LAW in Alternate. Both ELAC-s were then reset by the crew according to the manufacturers' operational documentation during the following level flight of the flight pattern. FLT CTL pitch normal law was recovered each time after the reset.

The rest of the training session with the first student was uneventful. The training session with the students was completed with a complete full stop landing, after which a new student was seated on the right seat in the cockpit and the whole session was repeated.

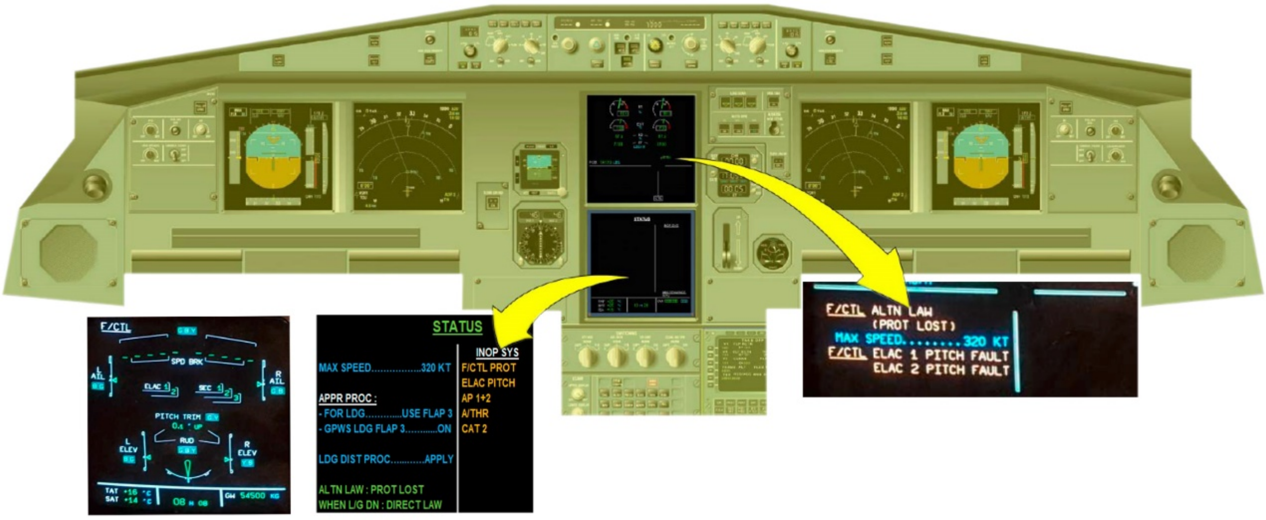


Figure 1. Messages displayed on ECAM on F/CTL ELAC 1 and 2 PITCH FAULT - ECAM F/CTL system page, ECAM status page, ECAM Engine/Warning display

During the flight with the second student, one single ELAC1 PITCH FAULT was triggered while the instructor was manually stopping the trim wheel at around 1° Nose Up as the THS ground setting was returning to 0°, as it had happened previously. The fault was displayed again on the ECAM FLT CTL display as the aircraft reached 1500 ft, only this time, as there was only a single ELAC PITCH FAULT, there was no degradation of flight LAW, and therefore no SC was triggered by the system (see Figure 2). ELAC1 was then reset by the crew after it was displayed on the ECAM display during the following level flight of the flight pattern. The rest of the session with the second student was uneventful.

Figure 2. ECAM FC CTL system page, ECAM status page, ECAM Engine/Warning display on the event of ELAC 1 PITCH FAULT

While performing the training session with the third student, during the first and third touch-and-go cycles, an ELAC1 PITCH FAULT was triggered. These failures were again triggered in the same conditions as it had happened for previous occurrences. Each time, as the fault was displayed on the ECAM, ELAC1 was reset by the crew according to manufacturers' procedures during the level flight of the flight pattern. Another ELAC1 PITCH FAULT was triggered during the following touch-and-go in the same conditions. This time the fault was not reset by the crew and it remained faulty until the end of the whole flight (including the accident). CVR recordings showed that no single chime was generated with this last ELAC1 PITCH FAULT, as per system design, but a single chime had been emitted concomitantly with the previous one. The origin of this single chime could not be determined by the investigation.

An ELAC2 PITCH FAULT was then triggered during the fifth touch-and-go, leading F/CTL pitch normal law reversion to alternate 1 LAW. When reaching 1500 ft, ELAC2 PITCH FAULT was displayed on the ECAM display and as there was a LAW change, an SC was also triggered. ELAC2 was then reset by the crew and FLT CTL pitch normal LAW was recovered. As the ELAC1 was not reset, it was left in a faulty condition.

The fourth student started with the training session approximately at 14:25 UTC. During the second touch-and-go cycle, an ELAC2 PITCH FAULT was again triggered during the THS ground setting, as it had happened with all previous occurrences, while the instructor was manually stopping the trim wheel at around 1.5° Nose Up. FLT CTL pitch normal LAW again reverted to alternate 1 LAW. The fault was indicated at the ECAM display and SC was triggered as the aircraft climbed over 1500ft. ELAC2 was again reset by the crew during the following level flight of the flight pattern and FLT CTL pitch normal LAW was recovered.

1[1](see Figure 3). During the third touch-and-go at 15:05:05, an ELAC2 PITCH FAULT was again triggered in the same conditions. FLT CTL pitch normal LAW reverted to alternate 1 LAW, but stayed engaged only for 1 second[2]. As the ELAC2 PITCH FAULT failure message is inhibited during this phase of a flight, so that the flight crew had no indication by the aircraft systems of the aircraft condition at this moment. As the aircraft was reaching rotation speed the instructor asked the student to rotate, after which the student initiated the rotation by pulling the sidestick, and by putting the thrust levers in the TOGA detent. The elevator position was 6.5° Nose Down and started to move towards 0°, the THS position was 3.5° Nose Up and the airspeed was 130 kt. As the instructor noticed the aircraft not rotating, the instructor commanded "Rotate! Rotate!", to which the student replied that he is Rotating (see Figure 4).

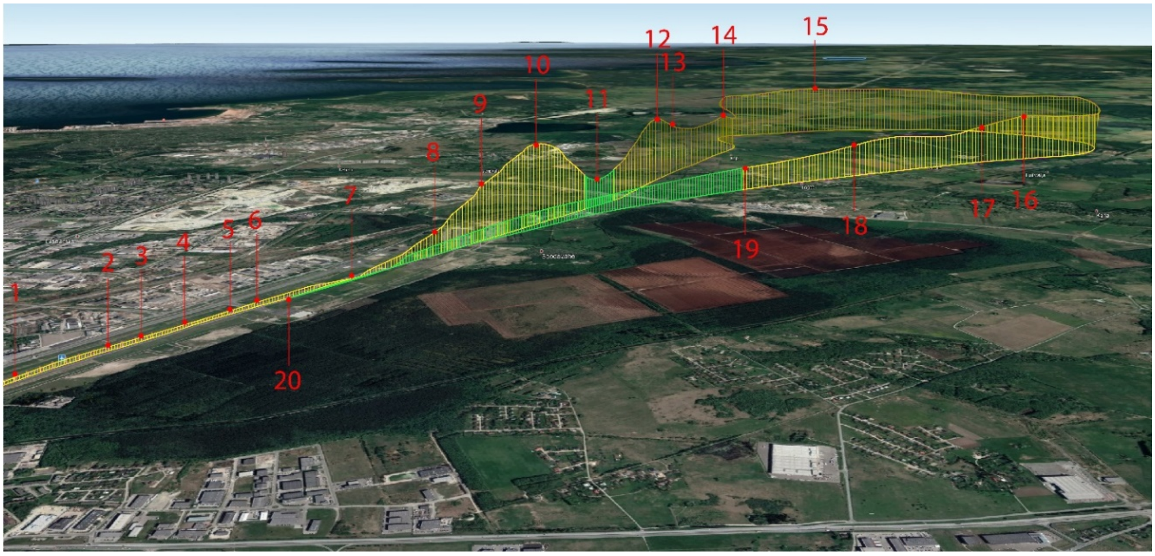


Figure 3. Final flight path. The yellow hatched part of the flightpath is derived from the FDR data. Green parts are reconstructed on the base of aerodrome camera footage, witness statements and CVR recordings. FDR data is lost when both of the engines spooled down.

[1] The numbering refers to the position of the aircraft on Figure 1
[2] FDR data sampling rate is 1s

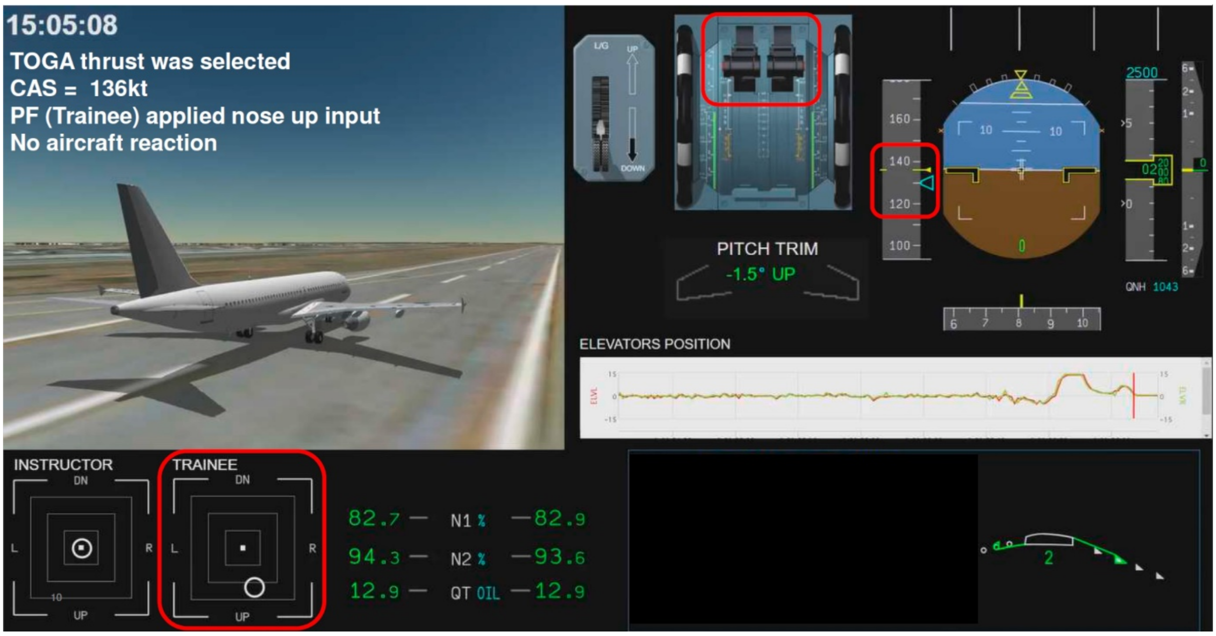


Figure 4. Cockpit inputs and indications at 15:05:08

2. At 15:05:10, F/CTL L+R ELEV FAULT ECAM warning, a red message “MAN PITCH TRIM ONLY” on the PFD and a continuous repetitive chime (CRC) was triggered. At this stage, the aircraft flight control system was in mechanical backup mode in pitch and in direct LAW in roll axis. The student was still pulling the sidestick (up to 13° Nose Up). The THS position was 1.5° Nose Up and both elevators at 0°. Elevators were both steady and remained in that position until the end of the flight. The aircraft started slightly to lift off as the airspeed was 152kt and pitch attitude was 0.3° Nose Up. The student’s sidestick Nose Up inputs were close to full sidestick deflection.

3. At 15.05.12 the instructor started to pull at the sidestick, dual sidestick input aural warning was triggered, after which the instructor pushed priority to the left on the sidestick and stated of taking over the priority over sidestick control, stating “I have control”.

4. At 15:05:15, the student released the orders on the sidestick while pitch attitude was still 0.3° Nose Up and the aircraft was airborne. The instructor was close to full Nose Up sidestick deflection (this position was kept for 14 seconds) and giving side stick roll position commands +5 and -5 degrees (Figure 5).

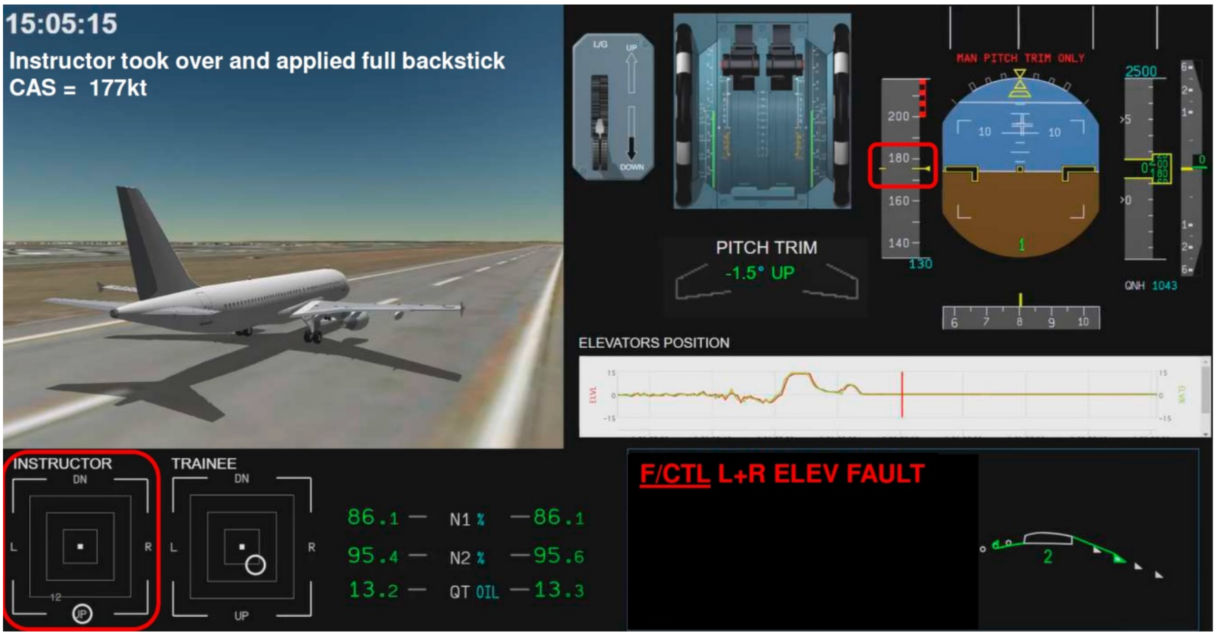


Figure 5. Cockpit inputs and indications at 15:05:15

5. Four seconds later, while the aircraft was approximately 950m from the end of the runway 08, flying with the airspeed of 190 kt, at 19 ft, pitch attitude maximum of 2.8° Nose Up was reached, thrust levers were moved to IDLE and the flap lever was moved from CONF2 to CONF1, moving the flaps from conf. 2 to 1+F.

6. At 15:05:21 the instructor commanded "gear up" and the gear lever was selected to GEAR UP position. Two seconds later the aircraft reached its maximum altitude over the runway – 48ft and started to descend. The pitch attitude was 0.3° Nose Up, THS remained in 1.5° Nose Up position, and thrust levers were set back to TOGA (Figure 6).

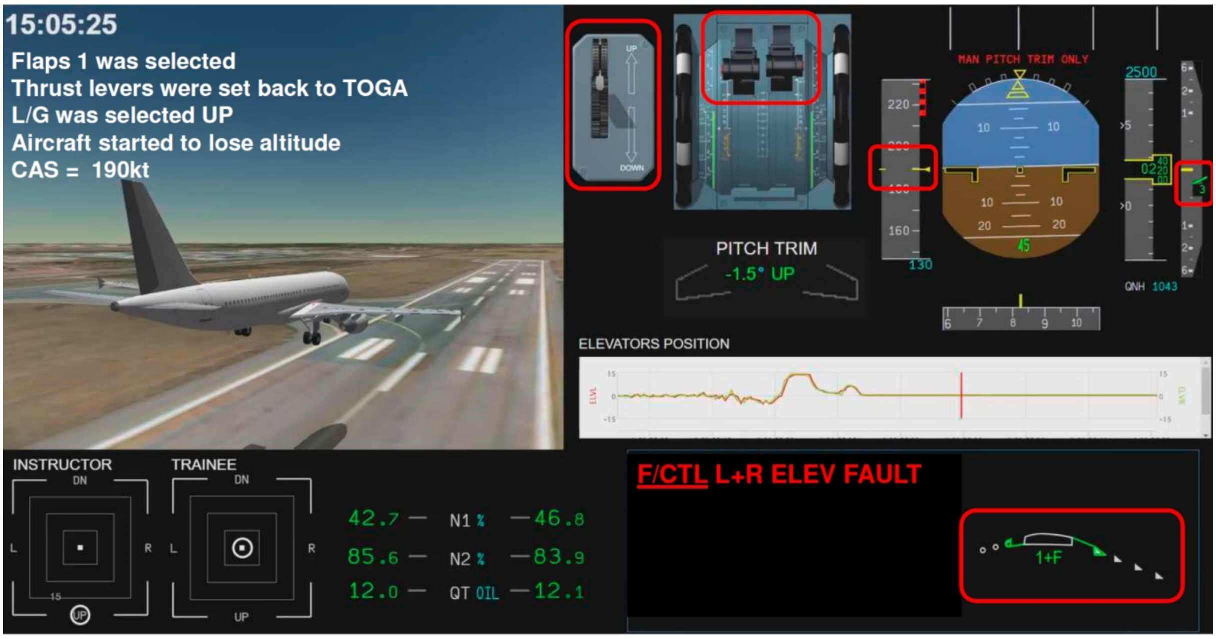


Figure 6. Cockpit inputs and indications at 15:05:25

7. While the landing gear was in transit, the aircraft hit the ground with aircraft engines approximately 200m from the end of the runway at 15:05:28 with the vertical acceleration of 2,85 g (see Figures 7 and 8). The pitch attitude was 0.7° Nose Up. The airspeed was 192 kt. Two seconds after the impact, the airspeed increased to 206 kt, the pitch attitude to 9,1° Nose Up and the aircraft started to gain altitude at 6000 ft/min.

Figure 7. Cockpit inputs and indications at 15:05:28 and 15:05:29

Figure 8. Aircraft hitting the ground (screenshots from the recordings of Tallinn Airport surveillance cameras)

8. Seven seconds later, a FLAPS LOCKED and an ENGINE 2 FIRE were triggered with a MASTER WARNING and audio CRC. The aircraft was at 337 ft, the airspeed was 207 kt and the pitch attitude 19.3° (reaching its maximum of 21.8° pitch up at 15:05:38) (Figure 9).

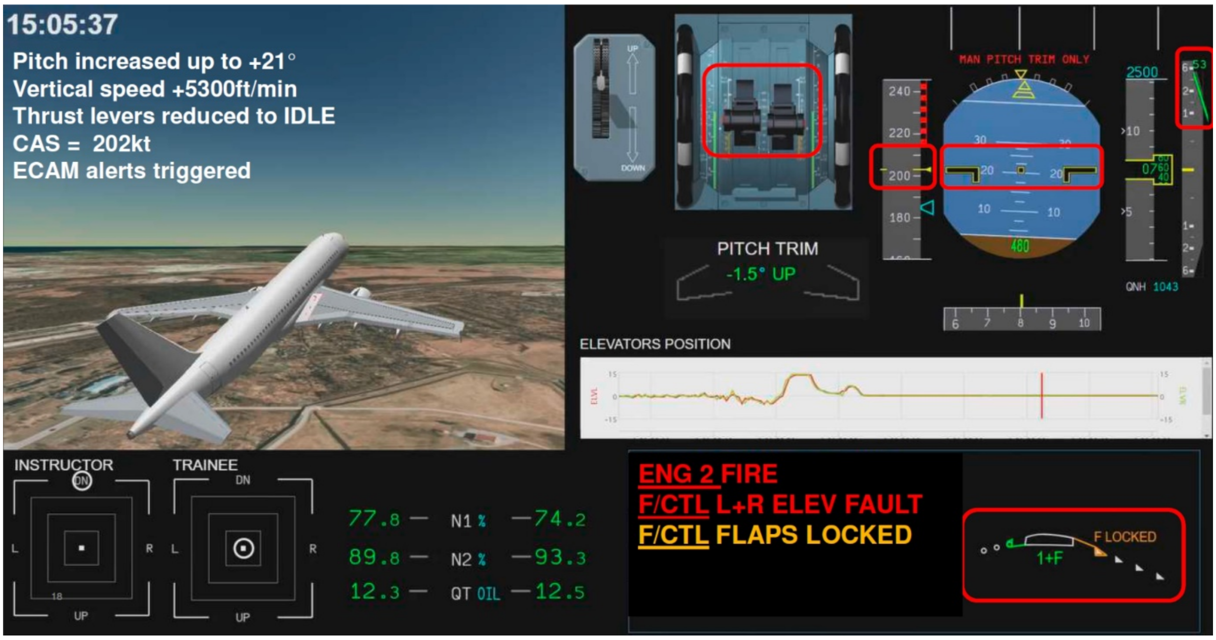


Figure 9. Cockpit inputs and indications at 15:05:28 and 15:05:37

9. At 15:05:42, while the aircraft was in climb and the instructor still applying sidestick inputs in roll and pitch axis (and continued doing this until the end of the flight), the safety pilot declared "Manual pitch trim only, manual pitch trim only" (reads from PFD display). The Pitch attitude was 20,4°, and the altitude was increasing. The THS moved to 0.9° Nose Down, when the crew started to control the pitch of the aircraft by moving the THS with the pitch trim wheel and by engine thrust, by moving the thrust levers to 17° and then to IDLE. The pitch started to decrease.

10. At 15:05:53, the airspeed was 144kt the aircraft reached maximum height of 1590 ft (see Figure 3) the pitch started to decrease rapidly and the aircraft started to lose altitude.

11. The aircraft went into a dive, descending at 7200 ft/min. The instructor moved the thrust levers to 42° (TOGA) and five seconds later started to move the THS towards 4.2° nose up. The pitch attitude reached 25.7° nose down before increasing again. The aircraft reached a minimum height of 596 ft at

15:06:04 and normal acceleration reached +2,44 g. During this part of the flight, in addition to the existing MASTER WARNING, audio CRC and warning messages, several TAWS alerts were triggered SINK RATE, PULL UP, TERRAIN-TERRAIN and TOO LOW, TERRAIN.

12. At 15:06:23, as the instructor managed to stabilize the trajectory of the aircraft at an altitude around 1200ft and airspeed around 155kt by sidestick inputs on roll, and trim and thrust inputs on pitch axis. The instructor asked "Do we have engines" to which the safety pilot replied "We have engine two fire".

At this point, the aircraft had L+R ELEVATOR FAULT (ELAC 1 PITCH FAULT, ELAC 2 PITCH FAULT, SEC1 and SEC2 lost control in pitch), pitch control in MECHANICAL BACKUP MODE, roll in DIRECT LAW, yaw in ALTERNATE LAW, engines 1 and 2 damaged from the impact, engine 2 on fire, flaps inoperative (FLAPS LOCKED).

13. At 15:06:29 the instructor declared to the tower "Mayday, Mayday, Mayday" (this call was not transferred to ATC). Seven seconds later, the safety pilot started to read loudly the ECAM display: "So we have flaps lock, flight control law, left right elevator fault, maximum speed 320, manual pitch trim use, do not use speed brakes". The following 29 seconds the aircraft remained stable at around 1300 ft. The pitch attitude varied between 8° Nose Down and 16° Nose Up, with an average at 5° Nose Up.

14. At 15:06:58, the instructor declared again to the tower "Mayday, Mayday, Mayday". The safety pilot took over the conversation by declaring: "Mayday, Mayday, Mayday, we have flight control fail". The instructor proposed to turn right, got it confirmed by the safety pilot, and declared it to the tower and informed about making a right turn and visually flying back to the runway.

15. At 15:07:44 the instructor commanded the safety pilot and the student to change their seats. At this point, the ECAA inspector and the student left the cockpit and were seated in the cabin.

34 seconds later, MASTER WARNING push button was pushed and the CRC ended. The instructor asked "what is the heading of the runway", safety pilot replied "262" and changed the heading in the FMS. The safety pilot declared to the tower: "Tallinn Tower, we are going for runway 26" and at 15:08:28 declared engine two fire to the tower and requested for a fire brigade.

16. Around 15:08:50, the safety pilot suggested moving the engine 2 lever to idle because of the fire. Instructor confirmed, but stated: "If I am losing (an engine) and manual flying, I prefer (to land) when engines are working". The thrust lever was moved to idle, but 3 seconds later it was moved back to the previous position to keep the engine working while flying the aircraft manually.

17. At 15:09:00 the instructor requested: "Gear down".

18. At 15:09:19, engine 2 spooled down following a 100 second fire alarm and ECAM message ENG 2 FAIL. The Safety pilot informed: "Engine two is shut down".

Twelve seconds later, the Instructor stated "Gear is down, flaps three", to which the safety pilot stated "speed is checked, flaps three", moving the slat/flap lever to position 3.

19. At 15:09:39, engine 1 spooled down. Both CVR and FDR stopped recording.

As the RAT automatically deployed, the CVR started recording again at 15:09:54. At this point the aircraft had lost electrical power in buses AC and DC1 and 2, electrical power in RH primary flight display (PFD) and navigation display (ND) and cabin light.

The safety pilot states: "Gear is down. We don't have engines" and starts reading the speed indication from the LH PFD to the instructor. At 15:09:56 "Speed 150", at 15:10:00 "Speed 130", At 15:10:02 "Speed 120".

Approximately 15:10:12 the aircraft touched down hardly 150m before the runway threshold, burst all tires, decelerated on the runway and veered off stopping close to the left runway edge (20) (see Figures 10 and 11). During the impact, safety officer and one student suffered minor impact trauma.

All the persons on board evacuated the aircraft using the escape slide.

Figure 10. Aircraft touching down (screenshots from the recordings of Tallinn Airport surveillance cameras)

Figure 11. Aircraft position after coming to a full stop (a screenshot from the recordings of Tallinn Airport surveillance cameras)

The aircraft landing gear doors, landing gears, both engine nacelles, engines and aircraft fuselage suffered severe damage in this accident resulting in aircraft hull loss.

1.2 Injuries to persons

	Injuries		
	Fatal	Serious	Minor/None
Crew	-	-	2
Passengers	-	-	-
Other	-	-	5

1.3 Damage to aircraft

Total loss of aircraft

1.4 Other damage

No other major damage.

1.5 Personnel information

Captain (TRI) (age 63)	Holding a valid ATPL(A) license and I class Medical Certificate. Last proficiency check 05.11.2017	
Experience, hours:	Last 90 days	Total
On A320	40	13 500
All types	112	24 046
As an instructor	72	7856

Safety pilot (age 34)	Holding ATPL(A) license and I class Medical Certificate. Last proficiency check 05.12.2017	
Experience, hours:	Last 90 days	Total
On A320	224	2 622
All types	-	3 024

Student (age 43)	Holding CPL license and I class Medical Certificate. Last proficiency check 15.02.2018	
Experience, hours:	Last 90 days	Total
On A320	0	0
All types	0	228

The crew was well rested and the Flight and Duty Time requirements were met.

1.6 Aircraft information

Airbus A320-214 is a twin-engine narrow-body airliner. The aircraft type certificate is held by Airbus S.A.S registered in 2 Rond-Point Emile Dewoitine, 31700 Blagnac, France. The aircraft was registered in Estonia as ES-SAN and had a valid Certificate of Airworthiness and a valid Airworthiness Review Certificate.

1.6.1 Airframe

Aircraft information	
Manufacturer	Airbus S.A.S
Model	A320-214
Serial number	1213
Year of manufacture	2000
Registration	ES-SAN
Certificate of registration (issue and validity)	Issued 12.02.2018
Certificate of airworthiness (issue and validity)	Issued 12.02.2018
Airworthiness review certificate (issue and validity)	12.02.2018 - 11.02.2019
Owner	GECAS
Operator	Smartlynx Airlines Estonia
Lessor	GECAS
Maximum Operational Passenger Seating Configuration (MOPSC)	180
Passenger seat configuration	180
Operational Empty Weight (OEW)	42045 (kg)
Maximum Zero Fuel Weight (MZFW)	61000 (kg)
Maximum Landing Weight (MLW)	64500 (kg)
Maximum Take-Off Weight (MTOW)	77000 (kg)
Total aircraft flying time (before the accident)	44997:51
Total aircraft flight cycles (before the accident)	21839
Last maintenance check	20.01.2018
Last maintenance service	28.02.2018
Last weigh-in	18.01.2018
Fuel on board before the event	(lb) (kg) 17800 kg
The weight of the aircraft at take-off (at event)	(lb) (kg) 60965 kg

Aircraft history				
Date	Note	Registration	Operator	Owner
12.02.2018	Registered with the Estonian register	ES-SAN	Smartlynx Airlines Estonia	Lsd from GECAS
01.04.2015	Registered with the Ukrainian register	UR-AJA	AtlasGlobal Ukraine	
01.12.2014	Registered with the Ukrainian register	UR-AJA	Atlasjet Ukraine	
14.05.2014	Registered with the Ukrainian register	UR-AJA	Zagros Airlines	
26.03.2014	Registered with the Ukrainian register	UR-AJA	Atlasjet Ukraine	Lsd from GECAS
12.08.2010	Registered with the Barbadian register	VQ-BHS	Vladivostok Avia	
22.11.2006	Registered with the Jamaican register	6Y-JMF	Air Jamaica	
01.09.2005	Registered with the Irish register	EI-DKF	EirJet	
22.05.2000	Registered with the Jamaican register	6Y-JMF	Air Jamaica	Lsd from GECAS

1.6.2 Engines

	Engine #1	**Engine #2**
Manufacturer	CFM international	
Model	CFM M56-5B4/P	
Serial no.	ESN 779721	ESN 779722
Total time (hours)	41351:32	42690:08
Total cycles (hours)	20311	20818
Time since the last check (hours)	3003	1989
Cycles since last check	1396	962
Last overhaul (hours)	9689	9182

1.6.3 Flight controls

1.6.3.1 General description

The Flight Control System of the Airbus A320 has a "fly by wire‟ concept (figure 12). The flight control surfaces are all electrically-controlled, and hydraulically-activated, except the THS and the rudder, which can also be mechanically-controlled through a wire cable (figure 14).

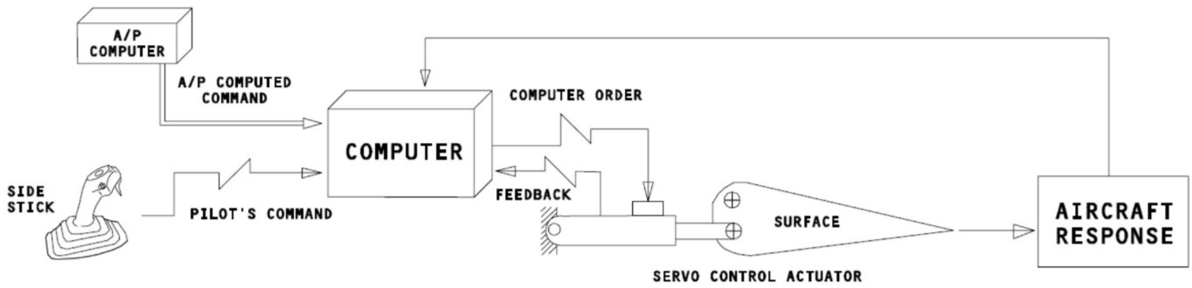


Figure 12. Airbus Fly By Wire logic.

Each pilot has a sidestick controller on the lateral consoles (Figure 13). When a side stick is not used, it is spring-loaded to a neutral position. The two sidesticks are not coupled mechanically, and they send separate sets of signals to the flight control computers. When only one pilot operates the sidestick, a single set of control signals are received by the computers, when both sidesticks are moved, and neither takes priority, the system adds the signals from both inputs. A pilot can deactivate other sidestick and take full control by pressing, and keeping pressed (to latch priority condition, the button must be kept pushed for more than 40 sec.) the priority takeover button on the sidestick. In the event of simultaneous input on both sidesticks, two green SIDE STICK PRIORITY lights will be illuminated in the cockpit and "DUAL INPUT" voice message is activated.

The mechanically interconnected trim wheel is on each side of the centre pedestal to control the THS (Figure 13). The mechanical control of the THS is always available from the pitch trim wheel at any time, if either the green or yellow hydraulic system is functioning. Trim positioning is indicated in degrees on a scale adjacent to each trim wheel. 5 sec after touchdown (i.e. Both Main L/Gs compressed), THS and thus trim wheel automatically returns to 0°, as the pitch attitude becomes less than 2,5°. This feature is known as the ground setting.

Figure 13. Sidestick and Trim wheel location

Sidesticks and a trim wheel (Figure 13) are used to fly the aircraft in pitch and roll (and in yaw, indirectly, through turn coordination). In nominal condition (i.e. no failure and normal law), the THS (and therefore the trim wheel) is automatically controlled by the F/CTL computers and it does not require pilot action on the trim wheel to control the aircraft pitch. Computers interpret pilot input on the sidestick and move the flight control surfaces, as necessary, to follow their orders. Although it is the primary task of the pilot flying to maintain the aircraft within the limits of the normal flight envelope, sometimes under certain circumstances there might be violations of these limits. Therefore, in order to keep the aircraft in normal flight envelope, there are system protections built in the aircraft fly-by-wire system. These protections are intended to reduce the risks of over-controlling or overstressing the aircraft and to provide the pilot with immediate procedures for controlling the aircraft. On the A320, the conversion of side-stick inputs into flight control surface deflection orders generated by the flight computers are called "*laws*". The flight control computers - ELACs, SECs and FACs elaborate the flight control laws, including flight envelope protection.

1.6.3.2 Flight control computers

A computer arrangement consisting of seven flight control computers process pilot and autopilot inputs according to flight control laws.

- 2 ELACs (Elevator Aileron Computer) for:
  - normal elevator and THS control
  - aileron control.
- 3 SECs (Spoilers Elevator Computer) for:
  - spoilers control
  - standby elevator and THS control (SEC1 and SEC2 only).
- 2 FACs (Flight Augmentation Computer) for electrical rudder control.

In addition, there are 2 FCDC (Flight Control Data Concentrators) which acquire data from the ELACs and SECs and send it to the electronic instrument system (EIS) (two Primary Flight Displays (PFD); two Navigation Displays (ND) for Electronic Flight Instrument System (EFIS); one engine warning display; one system display for ECAM) and the centralized fault display system (CFDS) (see Figure 18).

In normal operations, ELAC2 controls the elevators and the THS. When ELAC2 is engaged on pitch control, the THS is controlled by No. 1 of three electric motors (see Figure 14) and the screwjack is driven by two hydraulic motors. Therefore, the flight computers only have control over the THS if either the green or yellow hydraulic system is functioning.

If a failure occurs in ELAC2 or in its associated systems, the system shifts pitch control to ELAC1. In this case, the THS is controlled by the No. 2 electric motor. If neither ELAC1 nor ELAC2 is available, the system shifts pitch control either over to SEC1 or to SEC2, (depending on the status of the associated circuits – generally SEC2 then SEC1) and the flight control law reverts to alternate law (see chapter 1.6.3.3) and the THS is then controlled by motors No. 2 or No.3.

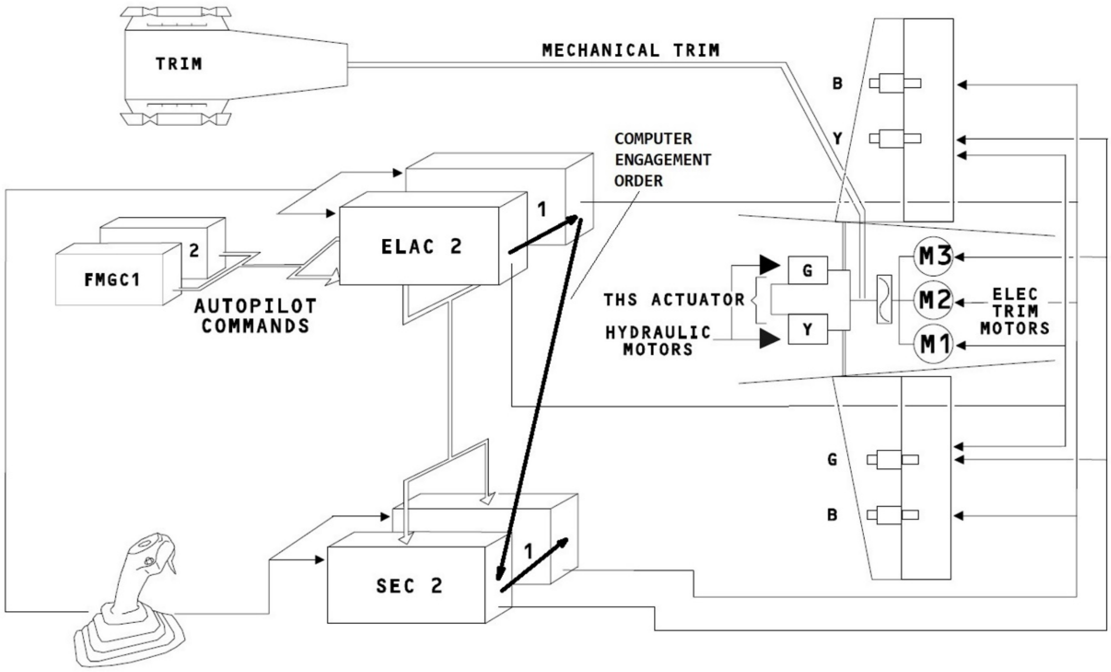


Figure 14. Flight control system diagram

It is important to note that an ELAC can only be engaged in pitch control if all of its 3 servo loops – left and right elevator, and THS – are valid. A SEC can be engaged in pitch if at least one of its 3 servo loops is valid (left elevator, right elevator or THS).

ELAC and SEC computers are composed of 2 channels – a command channel (COM) and a monitoring channel (MON). The command channel ensures the function of the allocated computer and the monitoring channel ensures that the command channel functions correctly. These two sub computers within each computer are functioning simultaneously and adjacent to each other. COM channel releases command data packages to the subsystems (for example control surface actuators), and MON side monitors the reactions (the movement of the actuator). These COM and MON channels are not synchronized. Computers are consolidating their data internally (between COM and MON channel) and between them (for example between SEC1 and SEC2) but not their clocks. Therefore, for a given piece of information computers are using data with a different timestamp. When the results of one of these two channels diverge over a predetermined threshold, a failure is detected, and the computer releases the engagement and a standby computer takes over the control. As soon as the active computer interrupts an operation, standby computer almost instantly changes to active mode with a small jerk on the control surfaces (can be observed on FDR data, Appendix 1)

1.6.3.3 Flight control laws

The flight control surface deflection orders, generated by the flight computers are called “*laws*” (Figure 15). In nominal operation, the flight control law is called *normal law*. Under certain conditions, depending on the failures occurring to the flight control system, or to its peripherals, the normal law can be replaced by three degraded *control laws:*

- *alternate law*
- *direct law*
- mechanical backup.

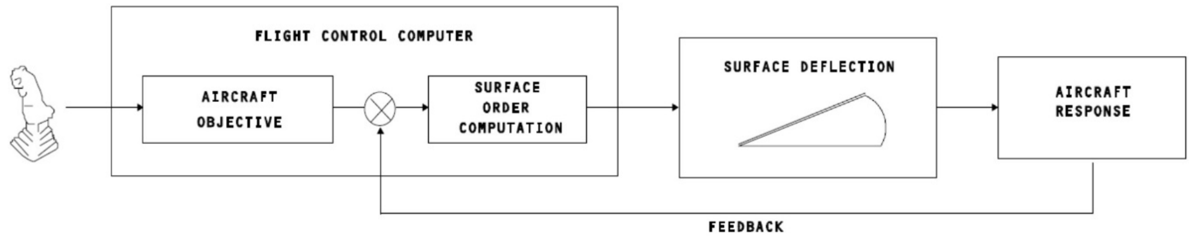


Figure 15 Basic principle of control laws

Under *normal laws*, there are three principal control modes:

- *Flight mode*
- *Flare mode*
- *Ground mode*

The *direct law* and mechanical backup do not have any control modes.

Normal law

In *Normal law* ***flight mode***, the sidesticks set the load factor on the elevators and THS proportional to the stick deflection and independent of speed. *Normal law* offers protections in attitude (the pitch and bank values are limited), in load factor, in over speed and at a high angle of attack (AOA). Pitch trimming is ensured automatically by the auto-trim. Turn is coordinated, with the rudder minimizing the sideslip through the yaw damper function.

Pitch trim is automatic both in manual mode and when the autopilot is engaged. In normal turns (up to 33° of bank) the pilot does not have to make any pitch corrections once the turn is established.

Normal law ***ground mode*** is a direct relationship between sidestick deflection and elevator deflection, without auto trim. The rudder deflection is controlled through a direct mechanical linkage by the pedals and the yaw damper function is available.

F/CTL law starts to transition from *Flare mode* to *Ground mode* 5 sec after touchdown (i.e. Both Main L/G compressed) and when Pitch attitude is lower than 2.5°. The transition from flare to ground mode is fully effective in 5 sec.

Ground mode automatically sets the THS at 0° and when the aircraft reaches 75kt during the take-off roll, it reduces the maximum up elevator deflection from 30° to 20°. The *ground mode* transitions into *flight mode* after lift-off, when the main landing gear shock absorbers are extended with pitch attitude confirmation.

In Touch and Go manoeuvres, in order to ensure that the aircraft is handled similarly to a normal take-off, a pilot can alter the THS ground setting by manually adjusting the pitch trim wheel. The manual take-over of the pilot has priority over the ground setting and in this case, micro-switches are actuated by the override mechanism ensuring that the computers remain synchronized with the manually-selected position (see chapter 1.6.3.5).

Note: ground setting has a different F/CTL priority order:

ELAC1 → ELAC2 → SEC2 → SEC1

Alternate law

The *alternate laws* are automatically introduced as soon as the *normal laws* are lost. In *alternate law*, the sidesticks control the load factor according to the airplane normal axis as for *normal law*, but with fewer protections. In roll, they directly control, as they do in *direct law*, the ailerons and the spoilers.

The reversion passage from *normal law* to *alternate law* is accompanied by a MASTER CAUTION amber light, SINGLE CHIME aural warning and an ECAM message. The green dashes that mark the pitch attitude protection limitations and bank angle protection in normal law (see Figure 16) are replaced by amber crosses indicating loss of protection. When automatic pitch trim is no longer available, the PFD indicates this with an amber "USE MAN PITCH TRIM" message below FMA.

In *alternate law*, when the landing gear is extended, the pitch control law passes to *direct law* because *alternate law* does not provide a *landing mode*.

On the ECAM display it is displayed:

FLT CTL ALT LAW (PROT LOST)

MAX SPEED 320kt

Direct law

Direct law is the lowest level of computer flight control and it is automatically activated on ground or it can be activated in flight following failures if the *normal* and the *alternate laws* can no longer be performed. In *direct law*, there is no automatic pitch trimming. Trimming is performed manually using the trim wheel. The orders to the flight control surfaces are a direct function of the control inputs on the side-stick and all of the protections are lost.

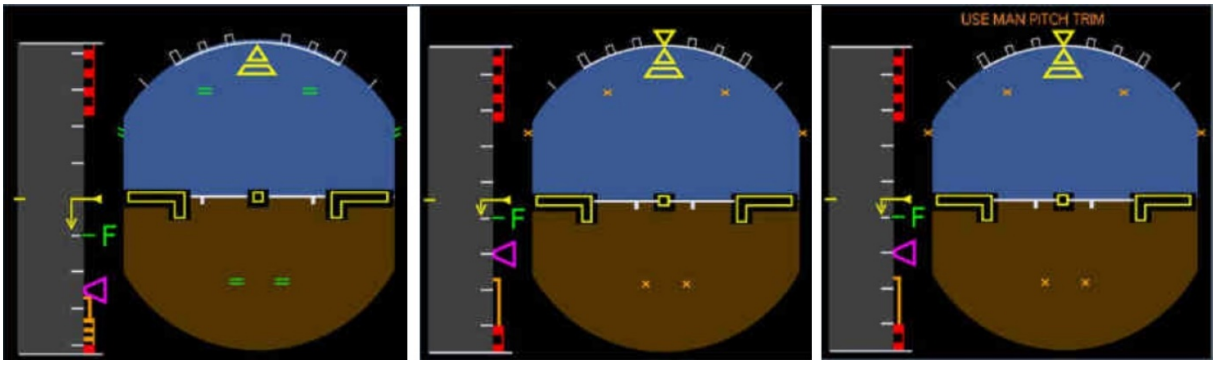
The passage to *direct law* is accompanied by a MASTER CAUTION amber light, SINGLE CHIME aural warning and an ECAM message. In Direct law the auto trim is lost. The display on the PFD is identical to that in alternate law, with in addition the amber USE MAN PITCH TRIM message.

On the ECAM display it is displayed:

FLT CTL DIRECT LAW (PROT LOST)

MAX SPEED 320kt

MAN PITCH TRIM USE



Normal Law Alternate Law Direct Law

Figure 16. Fly-by-wire status awareness via the PFD

Mechanical back-up

The mechanical back-up permits the aircraft to be controlled during a temporary loss of electrical power, loss of both elevators (the four elevator actuators are in centering mode), total loss of ailerons and spoilers or loss of five flight control computers. The longitudinal control is achieved using the trim wheels as the elevators are kept at zero deflection, and engine thrust. The lateral control is achieved by rudder pedals. In mechanical back-up the sidestick has no control over the aircraft control surfaces.

In this mode, the only method of controlling the aircraft in pitch is manual adjustment of the THS using the pitch trim wheel. To indicate this a “MAN PITCH TRIM ONLY” appears in red on the PFD (Figure 17).

When F/CTL L+R ELEV FAULT is triggered, the active laws are: MECHANICAL BACK UP in pitch, DIRECT law in roll (by default provided by ELACs), ALTERNATE law in yaw (provided by FACs). There is no message "Mechanical Back-up" displayed on the ECAM. The information is indicated through the message "MAN PITCH TRIM ONLY" on the PFD and " F/CTL L+R ELEV FAULT and MAN PITCH TRIM...USE" in the ECAM procedure (figure 17). A CRC and a MASTER WARNING are also triggered to indicate the aircraft condition.

Figure 17 PFD display in PITCH mechanical back-up, ECAM procedures displayed in mechanical backup.

Law reconfiguration

The transfer from normal to alternate laws is automatic and depends on the number and nature of failures.

The law reconfiguration is separate in the pitch axis and in the lateral axis. The alternate laws are automatically introduced as soon as the normal laws are lost. The alternate laws provide reduced or no protection depending on failures (Figure 18). The roll axis is degraded into roll direct law.

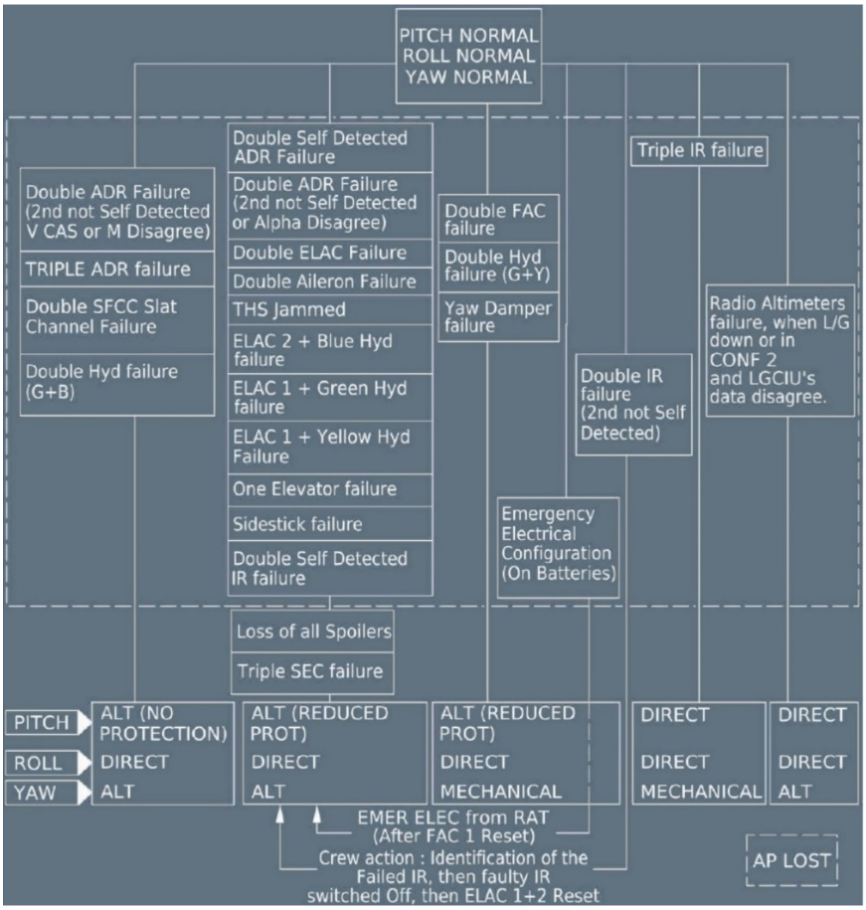


Figure 18 Control Law reconfiguration

1.6.3.4 Indicaton systems

The Electronic Instrument System (EIS) presents data for the Electronic Flight Instrument System (EFIS) and for Electronic Centralized Aircraft Monitoring (ECAM). EFIS Primary Flight Display (PFD) presents the flight parameters necessary for short term aircraft control and on the EFIS Navigation Display (ND) navigation and radar information is presented. ECAM upper display – Engine and Warning Display (EWD), presents engine indications, fuel quantity, and Flaps/Slats position. The lower display – System Display (SD), presents either system pages synoptics or status messages (Figure 19).

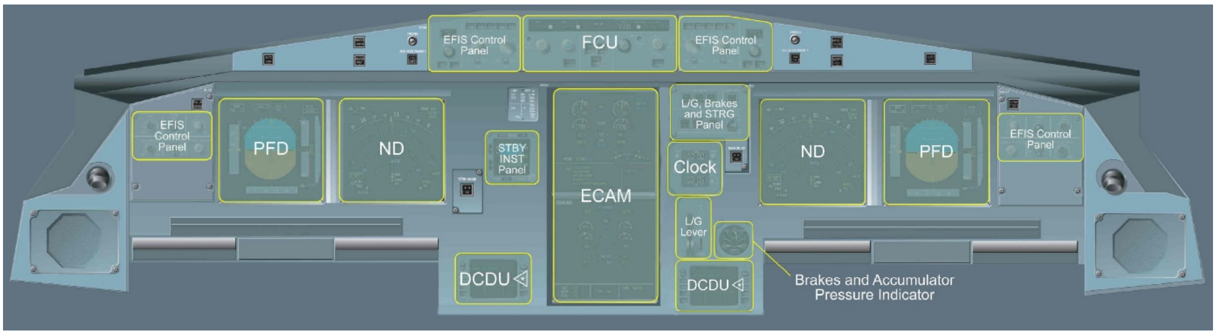


Figure 19 EIS layout

ELAC/SEC Indication

ELAC and SEC labels are always displayed in white on the ECAM SD. The computer number is normally in green and boxed in grey. The number and box become amber if the computer fails, or is switched OFF (Figure 20).

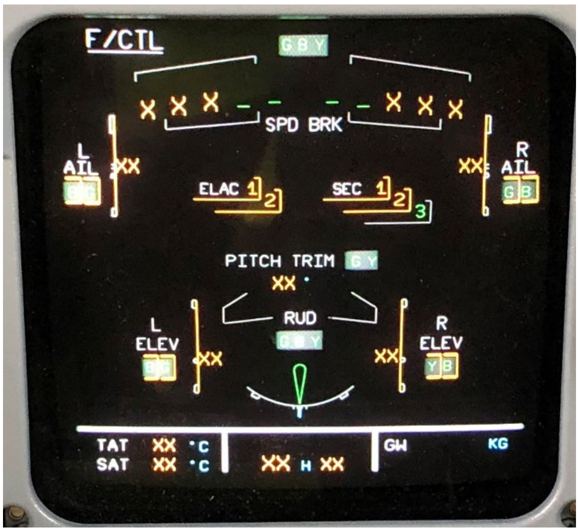


Figure 20 ECAM F/CTL page with SEC 3 active

Elevator position indication

On ECAM elevator position is indicated with a white scale and green index on the SD. The index becomes amber when neither of the associated actuators are available.

Pitch trim position indication

The pitch trim numbers are normally indicated in green on ECAM SD. They become amber if green and yellow hydraulic system pressure decreases. The "PITCH TRIM" legend is normally displayed in white. It becomes amber if the THS jams.

Advisory and failure indication

ECAM caution messages are presented on the ECAM EWD display and the affected systems on the SD.

The alerts are classified in three levels. The level of the alert depends on the importance and urgency of the corrective actions required.

- Level 3 being the highest priority, corresponds to an emergency configuration. Corrective or palliative action must be taken by the crew immediately. These alerts are associated with CRC and master warning light flashing in red.
- Level 2 corresponds to an abnormal configuration. Immediate crew awareness is required, but no immediate corrective action is mandatory. These alerts are associated with SC, and master caution light in amber.
- Level 1 corresponds to a configuration requiring crew monitoring, mainly failures leading to a loss of redundancy or degradation of a system.

As soon as the Flight Warning Computer (FWC) detects a failure, and if there is no flight phase inhibition, a title or the failure and actions to be taken are displayed on the EWD. On the bottom left side of the EWD, warning and caution messages of primary failures are displayed. Secondary failures are displayed on the right. As caution messages appear, CLR pushbuttons come on and stay on, as long as the failure is not cleared. An example of EWD and SD displays is shown in Figure 21. It is not fully representative of what was displayed during the event but is provided for illustratory purposes.

Figure 21 ECAM EWD and SD

During the event, the crew received several ELAC 1 (or 2) PITCH FAULT messages. As a single ELAC pitch fault does not degrade aircraft law and just reduces the redundancy of the system, it is classified as Level 1 alert and therefore is not associated with a master warning or caution and there is no aural warning being triggered. For the crew awareness of **ELAC fault**, the F/CTL page is automatically displayed (Figure 20) indicating the failed computer in amber. However, in case of ELAC 1 (or 2) **PITCH FAULT,** the whole computer is not faulty, only the capability to engage on the pitch axis. Then on the F/CTL page all of the computers are indicated in green (Figure 1, Figure 2).

In case of ELAC 1 (2) PITCH FAULT (as it happened before this accident) on the bottom left side of the ECAM Engine/Warning display F/CTL ELAC 1 (or 2) PITCH FAULT is displayed and on the ECAM status page CAT3 SINGLE ONLY is displayed on the left, and INOP SYS CAT 3 DUAL on the right side of the display (Figure 2). No aural warning or Master Caution Light is triggered. This crew awareness message is inhibited in flight phases 3, 4, 5, 7, 8 (Figure 21) and thus postponed.

In case of a dual ELAC PITCH FAULT, the following alerts are triggered on the same time on the bottom left side of the ECAM Engine/Warning display (Figure 1):

F/CTL ALTN LAW,

ELAC 1 PTCH FAULT,

ELAC 2 PITCH FAULT.

As there is a law reconfiguration and the control law is degraded from normal to alternate law in pitch axis (pitch control is ensured by SEC and SEC can not perform in NORMAL law), this condition is classified as Level 2 alert, and it will be indicated on ECAM first (before ELAC PITCH FAULT), as it has higher priority.

In this case, for the crew awareness F/CTL page is automatically displayed (all computers indicated in green). On the left of the ECAM status page the following information is displayed (once the previous ECAM alerts are cleared) (see Figure 1):

MAX SPEED…320KT,

APPR PROC:

-FOR LDG…….USE FLAP 3,

-GPWS LDG FLAP 3…..ON,

LDG DIST PROC……APPLY,

ALTN LAW: PROT LOST,

WHEN L/G DOWN: DIRECT LAW,

On the right side of the ECAM F/CTL page, the following information is displayed (see Figure 1):

INOP SYS,

F/CTL PROT,

ELAC PITCH,

AP 1+2,

A/THR

CAT 2

Single chime aural warning and a Master Caution Light are also triggered. The F/CTL ALTN LAW ECAM alert is inhibited in flight phases 4, 5, 7, 8 (Figure 22).

In case of a L+R ELEVATOR FAULT the aircraft is degraded into Mechanical back-up in pitch (Direct law in roll, Alternate law in yaw). This condition is classified as Level 3 alert and corresponds to an emergency configuration and the alerts are not inhibited in any flight phases. A CRC aural warning and MASTER WARNING are triggered. The F/CTL page is automatically called. On the left side of the ECAM status page the following information is displayed (Figure 17):

F/CTL L+R ELEV FAULT

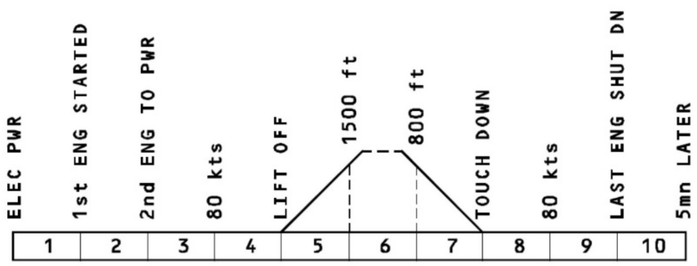
MAX SPEE…320KT

MAN PITCH TRIM…USE

SPD BRK…DO NOT USE

Alert inhibition

To avoid alerting the pilots unnecessarily at times when they have high workload, the FWC inhibits some warning and cautions for certain flight phases (Figure 22).



Failure	SYS Display Called	Master Light	Master Warning	Flight Phase Inhibition
ELAC 1/2 PITCH FAULT	F/CTL	NIL	NIL	3, 4, 5, 7, 8
ALTERNATE LAW	NIL	CAUT	SC	4, 5, 7, 8
STABILIZER JAM	F/CTL	CAUT	SC	4, 5

Figure 22 Alert inhibition in flight phases

1.6.3.5 Flight controls in pitch

Actuation

The aircraft pitch control is achieved by two elevators and the THS. The maximum elevator deflection is 30° nose up and 17° nose down. The maximum THS deflection is 13.5° nose up, and 4° nose down. All the flight control surfaces are hydraulically operated by actuators which receive electrical signals from the computers. The rudder and THS can additionally be mechanically controlled. All the hydraulic actuators are powered by one of the three hydraulic circuits, except the rudder trim actuator, the rudder travel limitation actuator and the THS servo-motors which are electrically driven.

Two electrically-controlled hydraulic servo jacks drive each elevator. Each servo jack has three control modes:

- Active: the jack position is electrically-controlled.
- Damping: the jack follows surface movement.
- Centering: the jack is hydraulically retained in the neutral position.

In normal operation:

- One jack is in active mode.
- The other jack is in damping mode.
- Some manoeuvres can cause the second jack to become active.

The relationship between the actuators and computers is indicated on Figure 23. The left or right elevator actuators are connected to two computers, one ELAC and one SEC.

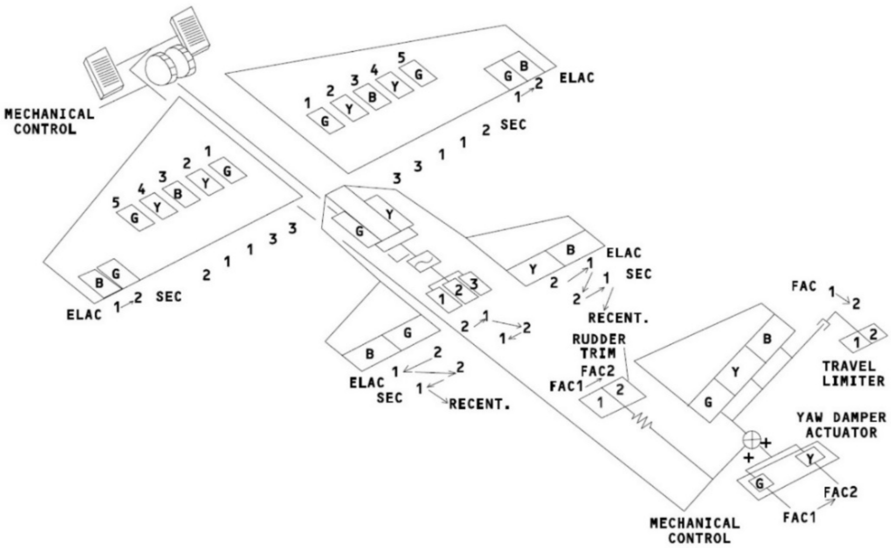


Figure 23 Actuation of flight control surfaces

In normal operation, ELAC2 controls the elevators and the horizontal stabilizer and the green and yellow hydraulic jack drive the left and right elevator surfaces respectively. One servo control actuates the surface, the second which follows the surface deflection is in damping mode. In case of a failure, the damping servo control and the related computer are set to active mode and the failed jack is automatically switched to damping mode. If neither jack is being controlled electrically (by F/CTL computers), both are automatically switched to the centering mode.

If a failure occurs in ELAC2, or in the associated hydraulic system or actuators, the system shifts pitch control to ELAC1. ELAC1 then controls the elevators via blue hydraulic jacks and controls the THS via no.2 electric motor.

If neither ELAC1 nor ELAC2 is available, the system shifts pitch control to either to SEC1 or to SEC2 and the THS motor no.2 or no.3

When only manual pitch trim is available, the centering mode is applied to the elevators and the actuators are hydraulically maintained in a neutral position.

Pitch trim wheel

Both pitch trim wheels provide mechanical control of the THS and have priority over electrical control.

The mechanical control of the THS is always available from the pitch trim wheel at any time, if either the green or yellow hydraulic system is functioning.

Crew action on the pitch trim wheel does not disconnect the ELAC`s. The mechanical linkage forces the OVM piston to act on the micro-switches located at the OVM (see figure 25) and by that ensuring that the computers remain synchronized with the manually-selected position.

The THS is manually-controlled on ground for the THS setting, before take-off and in flight, when in direct law.

At landing, five seconds after the ground condition (Both Main landing gears compressed), and when Pitch attitude is lower than 2.5°, THS ground setting is a function that automatically brings back the THS position to 0°. A ground setting can also be triggered after the reset of a F/CTL computer on ground.

THS

The trimmable horizontal stabilizer (THS) is operated by the Trimmable Horizontal Stabiliser Actuator (THSA) (Figure 24) to achieve the longitudinal pitch trim control of the aircraft.

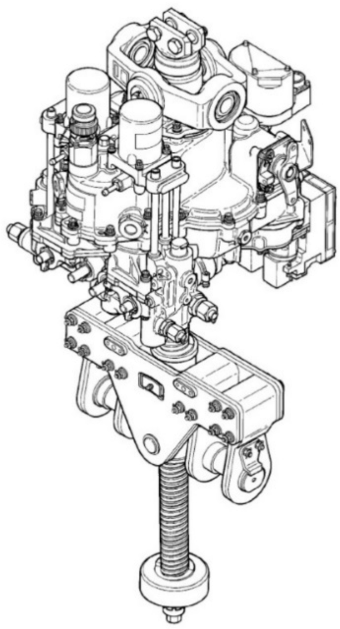


Figure 24 Trimmable horizontal stabiliser actuator

The THSA mechanically controls THS deflection by means of a servo system whose input signal is an electrical position order transmitted by the ELACs and SECs to the Pitch Trim Actuator (PTA) which is part of the THSA and drives the control loop.

The THSA is by default controlled by ELAC2 and if it detects that the system is not responding to its commands, it will hand the pitch control over to ELAC1. When both ELACs detect that the stabiliser is not following the commands, the control over the THSA is taken over by SEC2 and if further conflict is detected then by SEC1.

A conventional mechanical input link, coupled to the control loop through an Override Mechanism (OVM), enables the pilot to override the ELAC and SEC signal.

A screw jack is driven by two hydraulic motors drives the stabilizer (Figure 14). The two hydraulic motors are supplied by Yellow and Green hydraulic systems and are controlled by:

- one of three electric motors (ELAC2 for M1, ELAC1/SEC1 for M2, SEC2 for M3), or
- the mechanical trim wheel.

Position transducers are installed to feed back the actual position of the Override Mechanism (OVM) (a part of the THSA) output and of the ball screw position to the F/CTL computers.

In case of a dual engine failure, the two hydraulic motors lose hydraulic supply from Yellow and Green hydraulic systems and the THS is no more controllable by the crew. If residual pressure still exists in hydraulic systems or the engines N2 speed is at least 12% thanks to windmilling, it is possible that the THS may still be moved by the crew.

THS Override mechanism

When Auto Trim is active, the F/CTL computer in command (ELAC in normal condition or SEC in case of dual ELAC failure) send its electrical order to the THSA via the pitch trim actuator (PTA). The PTA contains three individual electric motors which control the hydraulic control valve and what regulates the power of two hydraulic motors that drive the ball screw (that is mechanically connected to the horizontal stabilizer). An OVM which is part of the THSA gearbox is downstream of the PTA. This mechanism gives the priority to pilot manual input, through the trim wheel, and enables the pilot to override the PTA electrical input signal and mechanically control the hydraulic motors that drive the ball screw.

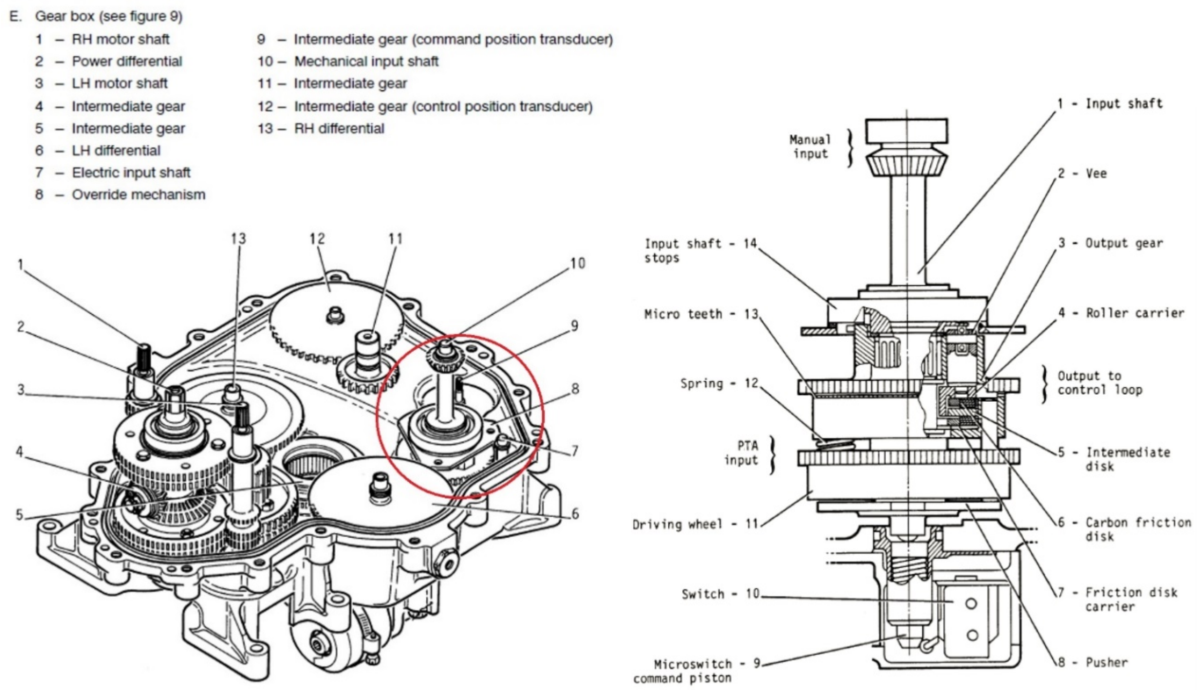


Figure 25 Override Mechanism

When the crew touches the trim wheel, torque is applied on the mechanical input shaft (Figure 25, item 1). If the applied torque is greater than or reverse of the PTA input (from the electrical motors), the roller carrier and roller (4) will disengage from the vee (2), push the roller carrier and friction disk carrier (7) downwards, thus physically disconnecting the PTA (by disconnecting the micro teeth) from the downstream components of the OVM.

As the disk assembly is pushed downwards, the micro-switch piston moves downwards and acts on the switch roller-pusher (Figure 25, item 10). In this condition, the micro-switch command piston activates all 3 micro-switches that send an electrical ground signal to the F/CTL computers (Figure 26 and 27). These signals give the information to the F/CTL computers that they are overridden and that the THSA is controlled mechanically by the pilot. ELAC/SEC will stop Auto Trim (electrical orders to the electrical PTA motors) and give the priority to the pilot.

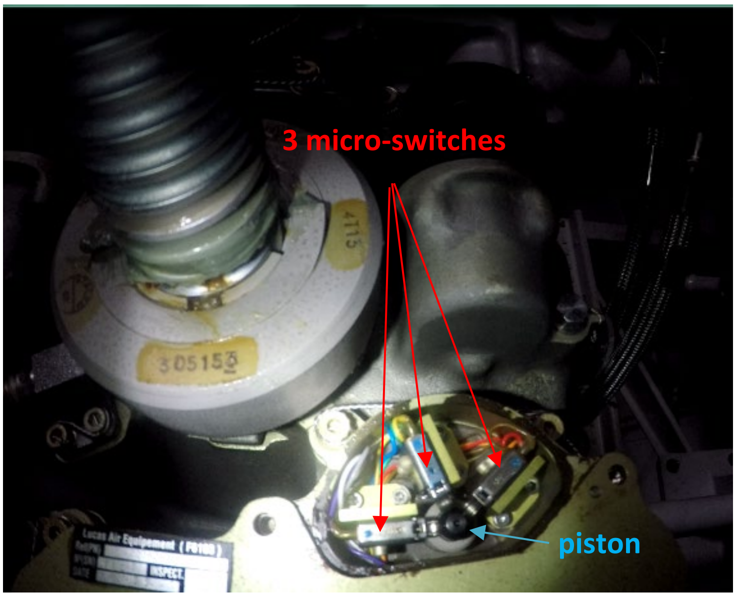


Figure 26 PTA micro-switches

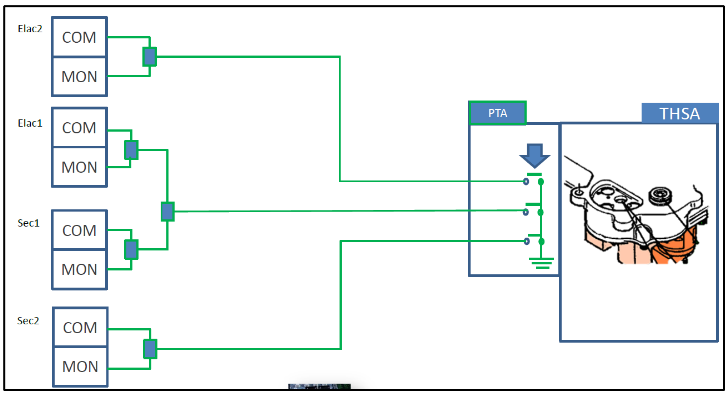
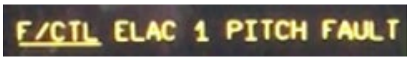


Figure 27 Wiring diagram of PTA micro-switches

When Auto Trim is active the commanded stabilizer position is measured by the COM transducer. A reduction gear assembly in the THSA transfers the commanded stabilizer position to the COM transducer (Figure 25). A separate MON transducer measures the actual stabilizer ball screw position. The ELACs and SECs monitor both COM and MON transducers and if there is a discrepancy in the measured results fault message will be generated.

If the OVM does not work properly and for instance does not trigger the microswitches (or the microswitches do not trigger the signal) when the pilot is taking over the Trim Wheel (while the F/CTL computer in command is active on the THS), no signal is sent to the F/CTL computer and therefore the electrical motors keep driving the THS without any effect as they are mechanically disconnected. However, the F/CTL will keep monitoring the THS position and as the pilot is ordering some inputs on the Trim wheel, the actual THS position is no longer consistent with the THS position commanded by the F/CTL computer. When this discrepancy exceeds a certain threshold F/CTL computers will detect a movement of the THS MON transducer that is not consistent with the electrical command (COM transducer position), the THS servo-loop monitoring is triggered resulting in the loss of electrical control of the THS by the F/CTL computer in command and the triggering of ECAM alerts and associated failure messages:

- If an ELAC is in control, the ECAM message "F/CTL ELAC 1(2) PITCH FAULT" will be displayed (THS ACTR POS ERROR 9CE of ELAC 1 (2) if ELAC is in command)



- If a SEC is in control, the ECAM message "F/CTL STABILIZER JAM" will be finally displayed when both SECs will have lost the THS control.

THS position monitoring by ELAC

The THS position monitoring by the ELAC (only active when Auto trim is active) is detecting any THS runaway i.e. an unexpected discrepancy between the actual THS position and the commanded THS position.

A discrepancy can be also encountered when the pilot manually takes over the THS control while the THS Auto trim is active. Therefore, in order to discriminate between these two situations (and leave the THS control to the pilot when the pitch trim is manually taken over), the Pitch trim Actuator (PTA) of the THSA includes a manual takeover detection system (i.e. an Override Mechanism (OVM) and three microswitches).

- If the manual takeover detection system functions correctly, during the Ground Setting (after landing), ELAC1 is normally in command of the THS. If both ELACs become faulty on Pitch control during the Ground Setting, SECs do not take over from the ELACs and the Ground Setting is stopped (manual THS control by the pilot remains available).

  During the Ground Setting (after landing), three different scenarios can be encountered:

  - No manual takeover and no THS position discrepancy detected: Ground Setting stops when THS position reaches 0° (normal condition).
  - Manual takeover detected (followed by a normal THS position discrepancy): Ground Setting stops and THS control is left to the pilot (priority to the pilot) (normal condition).
  - No manual takeover but THS position discrepancy detected (i.e. THS runaway): ECAM alert F/CTL ELAC 1 PITCH FAULT (associated with the Failure Message *THS ACTR POS ERROR 9CE OF ELAC 1*) is triggered and the ELAC 2 takes over the THS control. If the runaway is also detected by ELAC 2, then Ground Setting is stopped (SEC do no

takeover), F/CTL laws revert in Alternate law (Pitch control on SEC) and THS control is left to the pilot (abnormal condition).

- If the manual takeover detection system is not functioning (no detection possible), the system is then no longer able to make the difference between a manual THS takeover by the pilot and a THS runaway. Therefore, any THS position discrepancy (including a manual takeover) will be considered as a THS runaway and sanctioned as such (i.e. "F/CTL ELAC (1)2 PITCH FAULT").

1.7 Meteorological information

Wind at 070°, 09G15 kt; visibility 10 kilometres; QNH 1043hPa; clouds 2/8 at 1100 ft; air temperature -13°C.

1.8 Aids to navigation

Not relevant.

1.9 Communications

Not relevant.

1.10 Aerodrome information

Asphalt runway of 3 480 meters (11417 ft) in length and 45 meters (147 ft) width. The directions are 08 and 26 (figure 28).

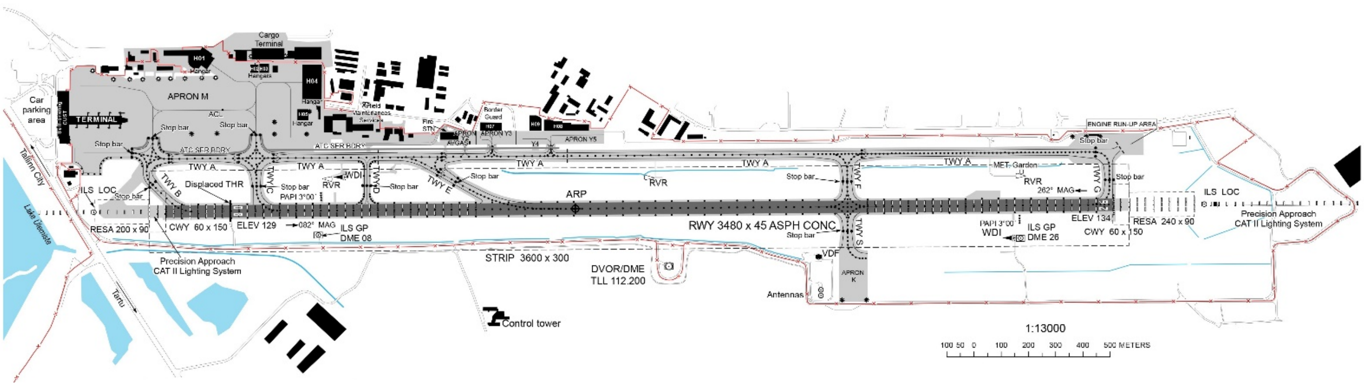


Figure 28 Tallinn Airport runway and taxiways

1.11 Flight recorders

The aircraft was equipped with both FDR and CVR. After the event the recorders were removed from the aircraft and brought to BEA for readout. Both recorders were in good condition.

<table>
<tr><td>Cockpit Voice Recorder CVR</td><td>Flight Data Recorder FDR</td></tr>
<tr><td>Honeywell 6022</td><td>Honeywell 4700</td></tr>
<tr><td>P/N: 980-6022-001</td><td>P/N: 980-4700-003</td></tr>
<tr><td>S/N: 04712</td><td>S/N: 2827</td></tr>
<tr><td>
</td><td>
</td></tr>
</table>

1.11.1 FDR readout

FDR was in good condition. The readout was performed with the manufacturer's official equipment and resulted in a file with 18 MB of flight data (approximately 26 flight hours), including the event flight.

FDR plots are appended in Appendix I.

1.11.2 CVR readout

CVR was in good condition. Reading out the CVR with the manufacturer's official equipment resulted in 5 audio tracks, including the event flight.

1.11.3 Synchronization and power interruption

Time information was available in the FDR recording. The FDR and CVR recordings were synchronized using the *VHF keying* parameter recorded in the FDR. UTC parameters recorded in the FDR were used as reference for time stamping.

FDR is powered through 115VAC NORM BUS (AC BUS 2). CVR is powered through 115VAC ESS BUS.

During the event:

- Around 15:09:21, engine 2 spools down in flight
    - a power interruption of the FDR was observed between 15:09:21.125 and 15:09:22.124 (1 second letting the reconfiguration of the 115VAC NORM BUS from AC BUS 2 to AC BUS 1).
- Around 15:09:38 (end of FDR valid data), engine 1 spool down in flight (Figure 29),
    - a power interruption of the FDR was observed at 15:09:38.125.
    - a power interruption of the CVR was also observed at that time.

- Between 15:09:38 and 15:10:54 (76 seconds duration),
  - CVR was powered and was recording for 41 seconds, but no time signal was available (airplane in flight – FDR not powered).
- At 15:10:54 till 15:13:15 (end of data)
  - FDR and CVR were powered (airplane on ground and APU was running).

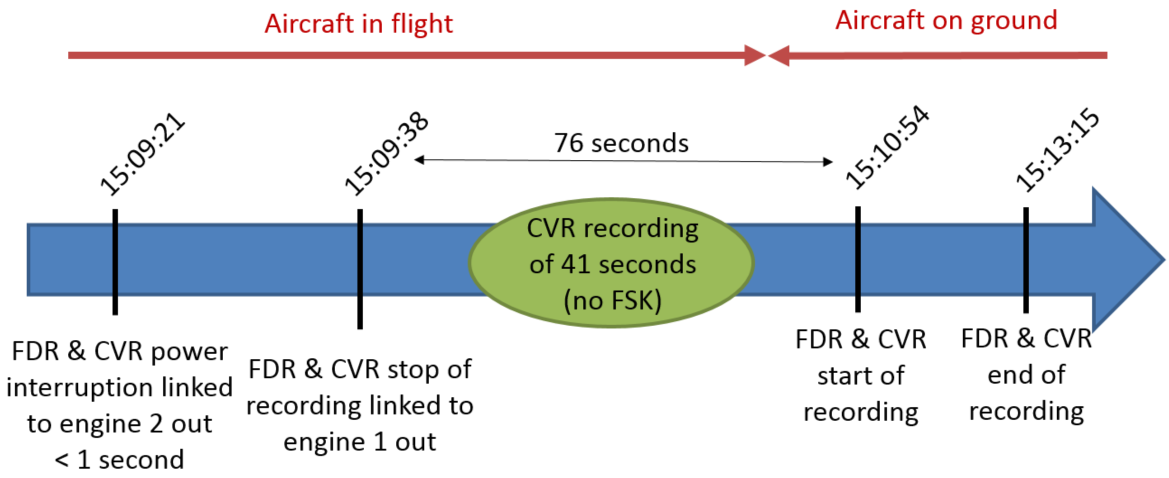


Figure 29 Power interruption of FDR and CVR

In normal configuration, in flight, engine 1 supplies AC BUS 1 and engine 2 supplies AC BUS 2. AC BUS 1 supplies AC ESS BUS. In case of failure of one engine (i.e. engine generator), the system automatically replaces the failed generator with the:

- APU GEN if available
- Opposite engine generator.

Thus, when engine 2 spooled down at 15:09:21, the FDR was supplied by AC BUS 2, powered by engine 1 generator. The CVR was supplied by AC ESS BUS also powered by engine 1 generator.

In case of failure of all main generators, if both AC BUS 1 and AC BUS 2 are lost and the aircraft speed is above 100kt, the Ram Air Turbine extends automatically. This powers the blue hydraulic system, which drives the emergency generator by means of a hydraulic motor. This generator supplies the AC ESS BUS. Thus, when engine 1 spooled down at 15:09:38, the CVR was supplied by AC ESS BUS powered by the RAT. Time for RAT deployment and activation resulted in a temporary low of AC ESS BUS supply.

The CVR recording was lost for 35sec, which corresponds to:

- the RAT extension time in flight (typically between 8 and 10s) plus,
- the time between the loss of the RAT efficiency on ground (around 100kt) and the recovery of the electrical power via the APU.

On ground, from 15:10:54, as the APU was on, it was able to supply both FDR and CVR. At that time, the aircraft was immobile.

1.12 Wreckage and impact information

The accident occurred at the end of Tallinn airport runway 08. During the take-off phase, the aircraft hit the ground with the engines and L/G doors 200m before the end of the runway, flew for 2 minutes, then turned around and landed 150m before the threshold of runway 26 and came into stop 600m from the runway threshold (Figure 30).

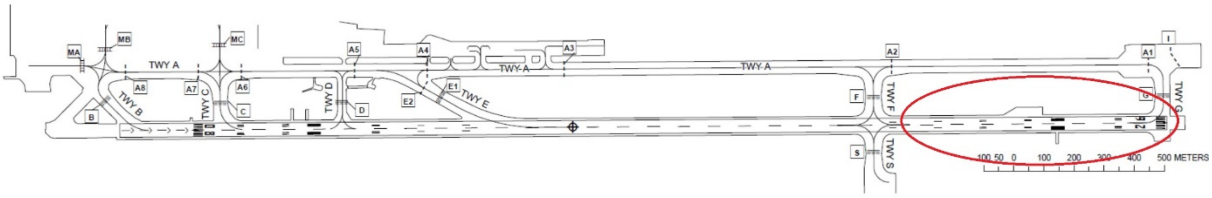


Figure 30 Runway of Tallinn Airport, debris area

The debris and skid marks from the first impact and the landing were therefore mixed and covered an area approximately 900m in length and 200m in width. Some larger pieces of the landing gear doors were collected a few kilometres from the airfield.

Aircraft structure

Fuselage was punctured at different locations (Figure 31). All the wing-to-body fairings on the right side were punctured and suffered extensive delamination. Wing to body fairing supporting structure had deformation in a number of areas. Fuselage skin structure was buckled/wrinkled from Frame 1 to 24 from approximately S25 to S35 L/H and R/H, sheared rivets internally. The right wing inboard leading edge slat was dented, punctured and had deformation in a number of areas. Right hand landing light was broken. The antenna located aft of the wing to body fairings was missing.

All observed damages were consistent with post-impact damages.

Figure 31 A/C skin wrinkled, fairings damaged by landing lights; slat punctured

Engines and pylons

Left engine (engine #1):

Damage observed on the nacelle, fan cowls, AGB, TGB and thrust reversers. Attrition lining was scrapped off at 6 to 7 o clock position. Inlet cowl inner barrel aft panel was missing trailing edge material, eroded by the fan blades. AGB lower surface was heavily abraded perforated and no more oil was present inside, internal parts were found damaged. AGB was seized and the N2 rotor was stuck.

Several pipes at 6 to 7 o clock position crushed. Drain mast at the rear of the thrust reverser cowl was damaged with its lower part missing. Inlet cowl aft bulkhead at 6 o clock was distorted with several stiffeners bent and rivets sheared. Most fan blades had tip curl and edge rubbing (Figure 32). Magnetic contaminator indicator was popped up.

All damage was consistent with an impact with the ground.

Figure 32 Bound gears in AGB; minor tip curl at compressor stage 4; Perforated AGB case; Fan blade tip curl and scraped lining.

Right engine (engine #2):

Pylon fairing was cracked. Inlet cowl lip skin was dented, perforated and torn. Inlet cowl outer barrel casing has impact damage from airport approach lighting. Aft bulkhead was buckled, inner barrel surfaces were perforated and dented in several locations. Inlet cowl attrition lining was worn through to the metal at 6 to 7 o clock position. Fan blades had tip curl and evidence of FOD (Figure 33). Right fan cowl door and thrust reverser presented fire traces, engine core, ECU and harness were damaged by fire. The AGB and TGB had lower surface abrasion. The thrust reversers halves and fan cowls had evidence of fire and impact damage. All compressor blades showed signs of tip rub, with material build-up at blade tips.

All damage was consistent with an impact with the ground.

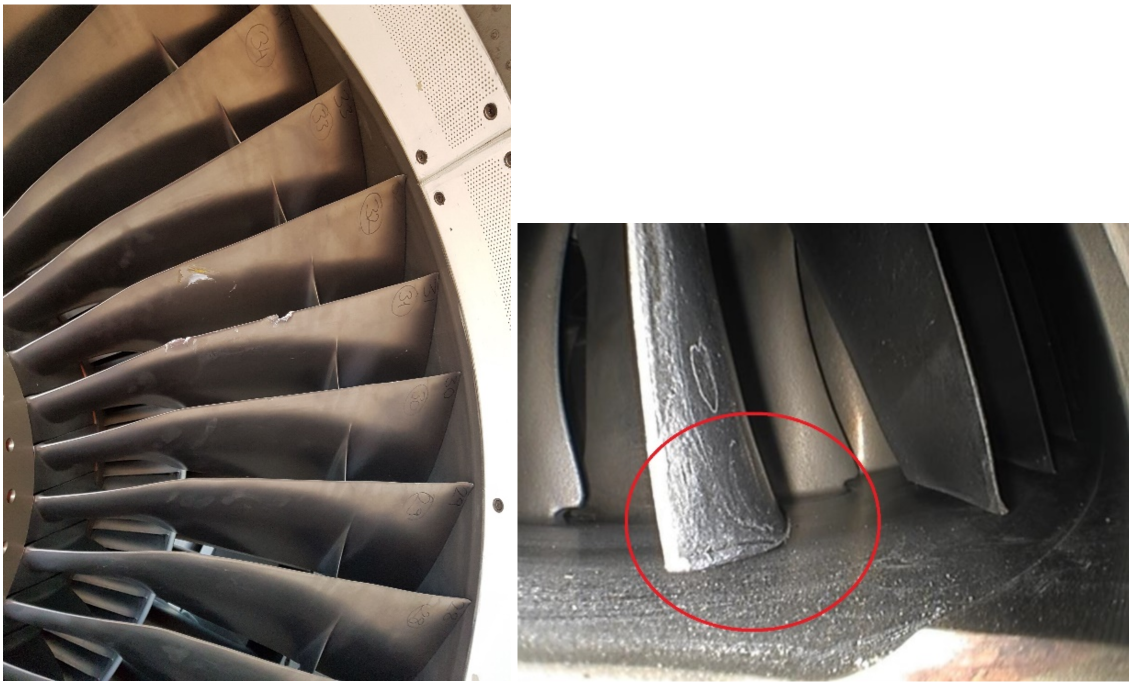


Figure 33 FOD on fan blades; tip rub at compressor stage 3

Landing gears and landing gear doors

Left main landing gear

Main door, lower lip was completely missing, strut door attach rods sheared and door actuator piston rod bent (Figure 34). Both tires were burst with a flat spot. Hydraulic fluid leakage from O/B of the Rib 5 area.

Figure 34 Bent LH landing gear actuator and damaged door

Right main landing gear

Main door was completely missing (Figure 35), hinge points remained intact, door actuator was in retracted position. Strut door actuator piston rod was bent. Both tires were burst with a flat spot. Evidence of significant Hydraulic fluid leakage, Rib 5 area.

Figure 35 RH landing gear actuator and missing door

Nose landing gear

Actuator rod was sheared at the actuator body end (Figure 36). Strut was fully compressed. Turn off lights and taxi lights assemblies were broken and some of them missing. Both tires were burst, and RH tire ripped off from the wheel. RH wheel suffered major abrasion damage.

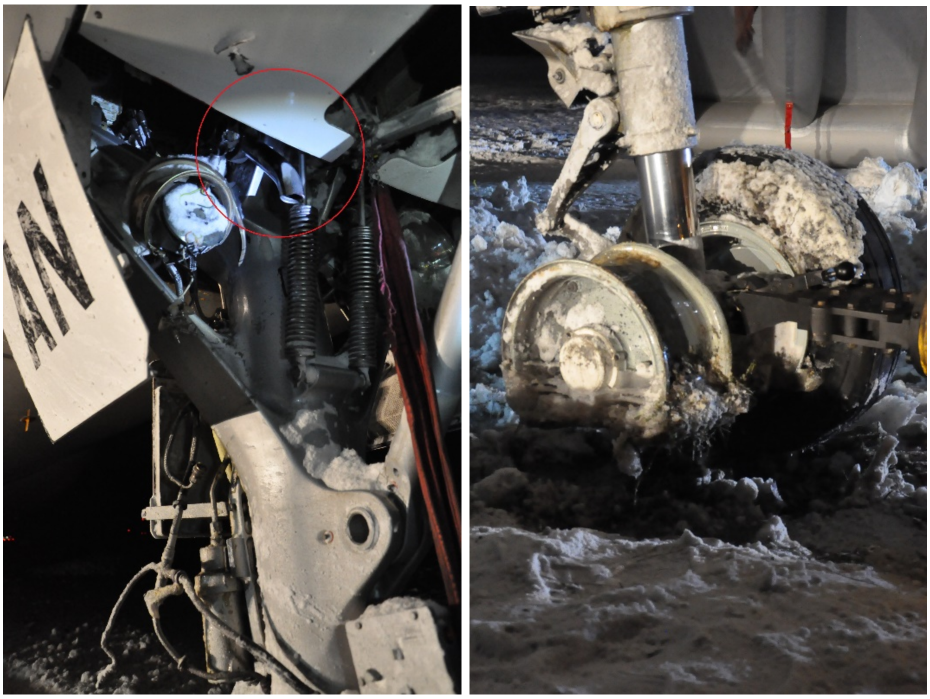


Figure 36 Sheared front landing gear actuator; abraded front wheel

Ram Air Turbine (RAT)

RAT was deployed, blade tips were damaged from the contact with the right RAT doors (Figure 37). RAT door link damper was broken and bent, one was missing.

Figure 37 Damaged RAT blade tips and rat doors

Flight controls

THS was around 5° Nose Up, consistent with the THS index, Flaps lever in CONF3 and Ground Spoilers disarmed.

1.13 Medical and pathological information

Not relevant.

1.14 Fire

Not relevant.

1.15 Survival aspects

Not relevant.

1.16 Tests and research

1.16.1 Maintenance reports

The A320 maintenance data are processed by the Centralized Fault Display System (CFDS). The Centralized Fault Display Interface Unit (CFDIU) contains the recorded maintenance data.

Recorded maintenance data is directly printable after the end of the flight from the cockpit through the MCDU. The following recordings are:

Last Leg ECAM Report (LLER)

LLER contains ECAM Warnings / Caution messages seen by the crew, sent by the FWS to the CFDIU during the last flight leg. The CFDS can store up to 40 warnings in this report.

Last Leg Report (LLR)

LLR contains failure messages detected by the systems BITE and recorded by the CFDS during the last flight leg. The CFDS can store up to 40 failures in this report.

Previous Legs Report (PLR)

At each new flight, the content of the LLR is transferred into the PLR. The CFDS can store up to 200 failures over the last 64 flight legs.

Post Flight Report (PFR)

PFR contains the LLER (Warning/Maintenance status) and LLR (failure messages) in one single report. PFR stops when aircraft speed <80kt + 30s or 4s after both engines are shut down.

UTC time used in all maintenance reports is based on Clock information sent by CFDIU to the system.

During the wreckage survey, prior to recover these recordings, the following computers were removed:

- ELAC #1 & ELAC#2,
- SEC#1, SEC#2 & SEC# 3,
- FCDC #2.

The FCDC #1 was not removed to allow the maintenance data recovery (by interrogating the EFCS1).

The following data were recovered:

- PFR
- LLR
- PLR
- LLER

The PFR of the event flight is presented on Figure 38. It started with the last student take-off, at 14:30 and thus included the three touch-and-go of the last student and the event flight. ECAM Warnings are presented on the left side and Failure Messages on the right side.

```
+--------------------+
:    MAINTENANCE     :
: POST FLIGHT REPORT :
+--------------------+

A/C ID   DATE    GMT        FLTN      CITY PAIR
.ES-SAN  28FEB   1429/1511  MYX9001   EETN EETN

ECAM WARNING MESSAGES

GMT  PH ATA
1430 05 27-00 F/CTL ELAC 1 PITCH FAULT
1430 07 21-61 AIR PACK 1+2 FAULT
1431 06 21-61 AIR PACK 1 FAULT
1455 04 27-00 F/CTL ALTN LAW
1455 04 27-00 F/CTL ELAC 2 PITCH FAULT
1456 06 27-00 F/CTL ELAC 2 FAULT
1505 08 27-00 F/CTL ALTN LAW
1505 04 27-00 F/CTL ELAC 2 PITCH FAULT
1505 04 27-00 F/CTL L+R ELEV FAULT
1505 05 27-00 F/CTL
1505 05 34-00 NAV ADR 2 FAULT
1505 05 27-00 F/CTL FLAPS LOCKED
1505 05 32-00 BRAKES AUTO BRK FAULT
1505 05 26-00 ENG 2 FIRE
1505 07 34-00 NAV TCAS FAULT
1505 05 26-00 ENG 2 FIRE
1505 06 32-00 L/G GEAR NOT UPLOCKED
1506 05 27-00 F/CTL SPD BRK DISAGREE
1506 05 26-00 ENG 2 FIRE
1506 07 21-61 AIR PACK 1 FAULT
1507 06 77-00 ENG VIB SYS FAULT
1507 06 77-00 ENG 1 OIL LO PR
1507 06 26-00 ENG 2 FIRE
1507 06 77-00 ENG 2 SENSOR FAULT
1508 06 77-00 ENG 2 FADEC
1508 06 77-00 ENG 2 CTL VALVE FAULT
1508 06 77-00 ENG 2 COMPRESSOR VANE
1509 06 32-00 L/G WOORS NOT CLOSED
1509 06 32-00 L/G LGCIU 2 FAULT
1509 07 77-00 ENG 2 FAIL
```

```
FAILURE MESSAGES

GMT  PH ATA                                  SOURCE     IDENT.
1430 05 46-21-34 INVALID ATSU CONFIG/ATSU     ACARS MU
                 1(1TX1)
1430 06 21-61-51 P2 RAM AIR IN ACTUATOR       TEMP CTL
1430 06 27-93-34 AFS:ELAC1                    AFS
1455 05 27-44-51 THS ACTR POS ERROR 9CE       EFCS 1     EFCS 2
                 OF ELAC2
1455 05 27-93-34 AFS:ELAC2                    AFS
1456 06 27-93-34 ELAC2                        EFCS 1     EFCS 2
1505 07 27-94-34 SEC1-MON OR WIRING TO        EFCS 1     EFCS 2
                 L B ELEV SERVO VLV 34CE3
1505 05 32-31-73 R L/G DOOR OPEN              LGCIU 2
                 PROX SNSR 34GA TGT POS
1505 06 32-31-73 L L/G DOOR OPEN              LGCIU 1
                 PROX SNSR 33GA TGT POS
1505 06 32-31-73 R L/G DOOR OPEN              LGCIU 1
                 PROX SNSR 32GA TGT POS
1506 05 32-31-73 L L/G DOOR OPEN              LGCIU 2
                 PROX SNSR 35GA TGT POS
1505 05 32-42-57 TACHOMETER4(22GG)/           BSCU 2
                 BSCU(18GG)
1505 07 27-50-00 FLP 2 OVERSPEED LH           SFCC 2
                 CHECK FLP MECH DRIVE
1505 07 27-51-00 FLP SYS LOCKED               SFCC 2
                 CHECK SFCC 1 & SFCC 2
1506 05 27-50-00 FLP 1 OVERSPEED LH           SFCC 1
                 CHECK FLP MECH DRIVE
1506 05 27-51-00 FLP SYS LOCKED               SFCC 1
                 CHECK SFCC 1 & SFCC 2
1505 06 34-11-17 ADM7 (19FP7)/                ADR 2      EFCS 1
                 ADIRU2 (1FP2)                           EFCS 2
                                                         ADR 2/AFS
                                                         EIS 2
                                                         BSCU 1
1505 07 34-52-33 ATC2 (1SH2) / TCAS (1SG)     TCAS
1505 07 34-43-00 DMC3: NO  TCAS  DATA         EIS 3      EIS 1
                                                         EIS 2
1511 01 34-43-00 DMC3: NO  TCAS  DATA         EIS 3
1511 01 31-53-34 NO FWC 1 DATA                CFDS
1511 01 24-00-00 AOA SENSOR (3FP1) SUPPLY     ADR 1      ADR 2
                 /ADIRU1 (1FP1)
1511 01 27-51-34 SFCC1 (21CV)/SFCC2           ADR 2
                 (22CV)
1511 01 34-11-17 ADM7 (19FP7)/                ADR 2      ADR 2
                 ADIRU2 (1FP2)
```

Figure 38 PFR of the last student flight

It is important to note that the FCDC does not re-record in its BITE memory a failure message that has been already triggered during the same flight leg as it is developed for maintenance purposes and does not need to record every occurrence of the same failure.

1.16.2 Maintenance data

Trouble Shooting Data (TSD) is associated to failure messages linked to the Electronic Flight Control System (EFCS). It provides notification of the status of the two ELAC and of three SEC before and after a failure. All the decoded TSD are originated from the EFCS, and span from 46 legs prior to the last flight performed prior to the extraction.

The printed maintenance data was shared with THALES to decode the TSD using their dedicated tool - eTroubleshooting (Figure 39).

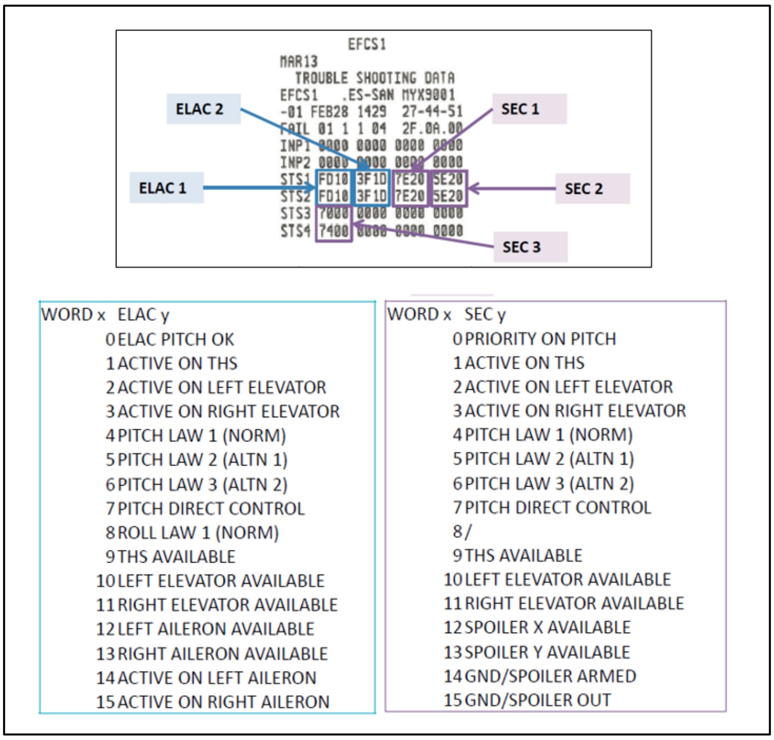


Figure 39 TSD decoding and information stored.

In the PFR, the failure messages of interest related to EFCS are listed in the table below:

Touch and Go Cycles	GMT	ECAM Warnings	Failure messages	Source
N-3	14:30	F/CTL ELAC 1 PITCH FAULT	AFS : ELAC1	AFS
N-1	14:55	F/CTL ALTN LAW	THS ACTR POS ERROR 9CE of ELAC 2	EFCS 1 ident. EFCS 2
		F/CTL ELAC 2 PITCH FAULT	AFS : ELAC2	AFS
	14:56	F/CTL ELAC 2 FAULT	ELAC2	EFCS 1 ident. EFCS 2
N	15:05	F/CTL ALTN LAW F/CTL ELAC 2 PITCH FAULT F/CTL L+R ELEV FAULT F/CTL F/CTL FLAPS LOCKED	SEC1-MON OR WIRING TO L B ELEV SERVO VLV 34CE3	EFCS 1 ident. EFCS 2

Three successive events are notable in the maintenance data:

- N-3 – around 14h30;
- N-1– around 14h55;
- N (event) – around 15h05.

N-3 cycle – around 14h30

"F/CTL ELAC 1 PITCH FAULT ECAM alert is triggered if ELAC1 is unable to drive one of its servo-loops linked to:

- left/right elevators servo-control or

- THSA"

F/CTL ELAC 1 PITCH FAULT was triggered at 13:47 and was not reset. Consequently, it was recorded at 14:30 UTC in the new PFR that opened at 14:29 UTC (as still present from previous leg). It is linked to the following Failure Message: THS ACTR POS ERROR 9CE OF ELAC1. Its TSD indicates that ELAC #1 is no more available on THS, ELAC2 is active.

N-1 cycle – around 14h55

F/CTL ELAC 2 PITCH FAULT was triggered on the ECAM which means that ELAC2 disengaged on THSA motor 1. As ELAC1 pitch fault was still present, it led to F/CTL ALTN LAW.

PFR indicates that ELAC2 has triggered the THSA servo-loop monitoring at 14:55: THS ACTR POS ERROR 9CE OF ELAC2. Its TSD indicated that SEC2 has priority on pitch and was engaged on THSA and on both sides' elevators. Moreover, THS and both elevators were available in SEC #1.

At 14:56, the F/CTL ELAC 2 FAULT indicated the ELAC #2 reset.

Event cycle (N) – around 15h05

The same two ECAM warnings appeared: F/CTL ELAC 2 PITCH FAULT and F/CTL ALTN LAW while the ELAC #1 was still not reset.

The F/CTL L+R ELEV FAULT ECAM warning was triggered.

PFR and FCDC memory indicated the following failures:

- SEC1 MON OR WIRING TO L B ELEV SERVO VLV 34CE3
- SEC1 MON OR WIRING TO R B ELEV SERVO VLV 34CE4
- SEC2 MON OR WIRING TO L G ELEV SERVO VLV 34CE1

The associated TSD indicated that before the failure (i.e. F/CTL L+R ELEV FAULT), SEC2 was active on both elevators and THS and both elevators were available in SEC1. Nevertheless, after the failure, SEC1 and SEC2 were no longer engaged on both sides' elevators.

Therefore, before the event, the F/CTL system nominally reconfigured several times for elevator control:

- on ELAC2 when ELAC1 was faulty,
- on SEC2 when ELAC1 and ELAC2 were faulty (similarly like at 14:55),

but during the event, although the reconfiguration to back-up computers (SEC1 and SEC2) took place, both computers were unable to control Left and Right elevator and THS.

1.16.3 Examination of computers

The following computers were removed from the airplane to be examined:

Computer	Manufacturer	PN	SN
FCDC1	Northrop Grumman LITEF	115370-1216	2613
FCDC2	Northrop Grumman LITEF	115370-1216	1020
ELAC2	Thales	3945128215	ELACVB019656
ELAC1	Thales	3945128215	ELACVB019645

SEC3	Thales	B372BAM0515	5048
SEC1	Thales	B372BAM0515	5580
SEC2	Thales	B372BAM0515	852
ECU1	Safran	2123M56P04	LMDN3948
ECU2	Safran	2123M55P01	LMDN2605

Figure 40 List of computers removed from the aircraft for examination

Examination of ELACs and SECs

The ELAC and SEC computers were examined at Thales facilities in Châtellerault (France) in order to extract the non-volatile memory (NVM), recover any potentially recorded faults and to perform the Acceptance Test Protocol (ATP).

The ATP test was conducted on the five computers and no abnormality that was found on the units that could be linked to the event.

Examination of FCDCs

The FCDCs were examined at Litef facilities in Freiburg (Germany). The purpose of the examination was to extract the NVM in order to recover any potentially recorded fault and to perform the Acceptance Test Protocol.

FCDC1 was used on-site to download and print out the maintenance data. As FCDC1 and 2 are designed to be fully redundant in terms of recorded information, the FCDC2 was removed prior to any on-site test to keep the recorded information unaltered.

17 fault entrees were identified as associated with the event flight in both FCDC1 and 2 (Figure 41).

FCDC	Failure number	Time	fault_code	Decoded fault code
#1	1	10:14	46 2F0A00h	THS ACTR POS ERROR 9CE OF ELAC 1
	2	10:14	46 2F0D00h	THS ACTR POS ERROR 9CE OF ELAC 2
	3	10:19	46 0A0000h	ELAC1
	4	10:19	46 0D0000h	ELAC2
	1	12:24	26 2F0A00h	THS ACTR POS ERROR 9CE OF ELAC 1
	2	12:27	26 0A0000h	ELAC1
	1	13:05	66 2F0A00h	THS ACTR POS ERROR 9CE OF ELAC1
	2	13:07	46 0A0000h	ELAC1
	3	13:57	26 2F0A00h	THS ACTR POS ERROR 9CE OF ELAC 1
	4	13:59	26 0D0000h	ELAC2
	1	14:29	26 2F0A00h	THS ACTR POS ERROR 9CE OF ELAC 1
	2	14:55	46 2F0D00h	THS ACTR POS ERROR 9CE OF ELAC 2
	3	14:56	26 0D0000h	ELAC2
	4	15:05	26 034F41h	SEC1-MON OR WIRING TO R B ELEV SERVO VLV 34CE4
	5	15:05	26 034F31h	SEC1-MON OR WIRING TO L B ELEV SERVO VLV 34CE3

	6	15:05	27 E60000h	ADR2
	7	15:05	27 E2430Ah	IR2 OR BUS3 TO ELAC1
#2	1	10:14	46 2F0A00h	THS ACTR POS ERROR 9CE OF ELAC 1
	2	10:14	46 2F0D00h	THS ACTR POS ERROR 9CE OF ELAC 2
	3	10:19	46 0A0000h	ELAC1
	4	10:19	46 0D0000h	ELAC2
	1	12:24	26 2F0A00h	THS ACTR POS ERROR 9CE OF ELAC 1
	2	12:27	26 0A0000h	ELAC1
	1	13:05	66 2F0A00h	THS ACTR POS ERROR 9CE OF ELAC1
	2	13:07	46 0A0000h	ELAC1
	3	13:57	26 2F0D00h	THS ACTR POS ERROR 9CE OF ELAC2
	4	13:59	26 0D0000h	ELAC2
	1	14:29	26 2F0A00h	THS ACTR POS ERROR 9CE OF ELAC 1
	2	14:55	46 2F0D00h	THS ACTR POS ERROR 9CE OF ELAC 2
	3	14:56	26 0D0000h	ELAC2
	4	15:05	26 034F31h	SEC1-MON OR WIRING TO R B ELEV SERVO VLV 34CE3
	5	15:05	26 064F39h	SEC2-MON OR WIRING TO L G ELEV SERVO VLV 34CE1
	6	15:05	27 E60000h	ADR2
	7	15:05	27 E2430Ah	IR2 OR BUS3 TO ELAC1

Figure 41 Fault entrees in FCDC 1 and 2

No abnormal functioning was noticed on FCDC1 and FCDC2, ATP was conducted on both computers. ATP was successfully passed.

The examination revealed:

In the PFR (see Figure 38), only the FCDC1 was interrogated and one wiring fault was popped out: the wiring between SEC 1 and the left blue servo valve (SEC1-MON OR WIRING TO L B ELEV SERVO VLV 34CE3 fault). The examination showed that this fault was also recorded in the FCDC 2.

Moreover, 2 similar faults were recorded:

One related to the wiring between SEC 1 and the right blue servo valve;

One related to the wiring between SEC 2 and the left green servo valve.

In normal operation, FCDC1 and 2 record the same information but the FCDCs are not synchronized. Differences observed may result from confirmation time validation. The reason for a message to disappear shortly after a specified confirmation time might happen when one FCDC has the confirmation time validated and reports the message and the other FCDC does not see the confirmation time validated and does not report the message.

The fact that the failure message “SEC2 MON OR WIRING TO R Y ELEV SERVO VLV 34CE2” was not caught by any FCDC and neither FCDCs captured the same messages is most likely due to the fact that these failure messages were all triggered in a very short period of time.

The examination of the FCDCs did not determine why the PFR did not bring out the second wiring fault recorded in FCDC1.

Examination of the ECUs

The ECU computers were examined at Safran facilities in Massy (France). The purpose of the examination was to understand the engine shutdown sequence, through the following steps:

- extracting the NVM in order to recover any fault potentially recorded that could help in the understanding of the event;
- perform the Acceptance Test Protocol and any additional test to confirm the good functioning of the computers.

Both ECUs were in normal condition, except the presence of soot on ECU from engine 2, S/N LMDN2605 (consistent with fire on engine 2).

The NVM data is presented in Appendix 2.

The examination revealed:

In **ECU from engine no1**, the NVM data was not properly timestamped so that none of the recorded faults were dated from the day of the event. The reason why ECU1 had failed in providing a timestamp was not determined by the examination.

In **ECU from engine no2**, except N1 FEEDBACK SIGNAL FAULT dated from 15:07, all the recorded faults were dated between 15:08 and 15:09 on the day of the event. At this time, in the FDR data, the FIRE engine #2 Boolean was triggered.

Continuity tests were performed on the engine electrical harnesses J2, J3, J9, J10, J11. Test showed insulation damages which may have induced multiple partial short-circuits in between different wires that likely resulted in the multiple FADEC faults and final engine #2 spool down:

- N1 sensor harness thermally damaged- resistance values are not accurate, wires have a short circuit between each other and on aircraft ground.
- all J11 wires have short circuits on aircraft ground- obviously through the shields.

During the ATP tests, 3 types of faults were recorded by both ECUs at all temperatures:

- EXHAUST GAS TOTAL TEMP (both ECUs)
- RAM MEMORY TEST (ECU 2)
- NVM RETENTION (ECU 2)

It was confirmed that EXHAUST GAS TOTAL TEMP fault was a false failure triggered by the test bench.

Although the ATP did not pass for both units, no fault that could contribute to the event was found.

1.16.5 Investigation of flight control system failures

Background data

According to the FDR recording:

- At 13:47:06, an ELAC1 PITCH FAULT was triggered (and was not reset in level flight)
- At 13:57:46, an ELAC2 PITCH FAULT was triggered (pitch normal law reverted to alternate law)
- At 13:59:40, ELAC2 was reset (back to pitch normal law)
- Between, 14:19:34 and 14:30:02, crew changed: new student flying
- At 14:55:00, an ELAC2 PITCH FAULT was triggered (pitch normal law reverted to alternate law)
- At 14:56:50, ELAC2 was reset (back to pitch normal law)
- At 15:04:55, the aircraft landed for the last touch-and-go
- At 15:04:59, the THS starting to move from 4° pitch up according to the ground setting logic (THS back to 0° during landing roll)
- At 15:05:05, an ELAC2 PITCH FAULT was triggered (pitch normal law reverted to alternate law). THS position was 1.5°
- At 15:05:06, elevators started to move according to pilot inputs
- At 15:05:10, LEFT + RIGHT ELEVATOR FAULT was triggered, followed by a MASTER WARNING. The THS position was 1.5° pitch up and both elevators position was centered at 0° till the end of the recording.
- At 15:05:48, the THS started to move according to pilot inputs. THS was used to fly the aircraft pitch

As the DFDR revealed that the ELAC PITCH FAULT was triggered when the instructor was manually stopping the pitch trim wheel while the THS was automatically returning to 0°, it was decided to assess the THS ground setting behaviour and THSA manual override behaviour to identify the origin of the flight control computer fault messages.

Before the tests, all control surfaces and actuators linked to the THS and elevators were visually examined on ground. No evidence of damage or problem was observed.

Some minor repairs to the hydraulic lines on all landing gears were made in order to reduce hydraulic fluid leaks.

ELAC 1, 2, SEC 1, 2, 3 and FCDC 1 were connected and FCDC 2 disconnected in order to keep the accident related recorded information unaltered.

Ground setting

Ground setting of the THS (see chapter 1.6.3.3) on different F/CTL computers is automatically launched when the aircraft is on ground and the F/CTL computers are powered up. The ground setting automatically sets the THS at 0º.

Before launching a ground setting test, each time the THSA was manually set to a value (other than 0º) and the ground setting was launched by resetting the F/CTL computer.

The capability of different F/CTL computers (ELAC or SEC) to engage on the elevator servo controls at reset with their dedicated hydraulic circuits available was checked.

No malfunction was observed; elevators were correctly driven to neutral position at F/CTL computer reset.

Servocontrol actuation through sidestick inputs in the cockpit (light and sharp movements, up to full deflection) was tested with different F/CTL computers engaged on pitch control to reveal any anomalies in the servocontrol actuation.

No behaviourmisbehaviour was observed.

A continuity test was carried out between the wires running from F/CTL computers and servocontrols.

The tests did not reveal any anomalies.

No hardware (servo controls, wires and flight controls) malfunction was observed during the tests performed on ground.

The ground tests for the functioning of the ground setting did not reveal any reference to an error source.

Manual override during a ground setting

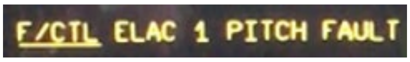
During the event flight the captain stopped the ground setting by grabbing the pitch trim wheel while the THS was automatically returning to 0°. Similar system behaviour can be reproduced on ground by launching the ground setting and then stopping the pitch trim wheel returning to 0^o.

A series of tests were performed with stopping the trim wheel during the ground setting test started by a F/CTL computer reset on ground. The THS was positioned in a pitch up position, ground setting was launched and the trim wheel was manually stopped 5 to 7 degrees before reaching 0^o. Several configurations were tested with different computers in control during the reset (ELAC or SEC), with their dedicated hydraulic circuits available (Figure 42).

Figure 42 Actuation of the pitch trim wheel

Several failures were triggered:

- With an ELAC in control, the ECAM alert was “F/CTL ELAC X* PITCH FAULT”



- with only one SEC is in control, the ECAM alert was “F/CTL STABILIZER JAM”

The failures were not triggered systematically and appeared generally after a period of rest of the system. The outside air temperature was -2,6°C.

In the MCDU, when the ECAM alert “F/CTL ELAC 1 PITCH FAULT” was triggered, the ground scan displayed the THS ACTR POS ERROR 9CE OF ELAC1 message.

In order to confirm the physical actuation of the OVM piston and the 3 micro-switches at the PTA (see chapter 1.6.3.5) and to verify the ground signal triggering by the PTA micro-switches and the signal reception at ELACs and SECs (steadily enough to be captured by the computers), a series of tests were carried out.

A camera was placed under the PTA (Figure 44) to verify the OVM piston movement, an oscilloscope was wired to the ELAC/SEC COM/MON lines (Figure 45) at the avionics bay to monitor the electrical signal. Ground setting was launched from the cockpit and the trim wheel was stopped before reaching 0°. ECAM messages, PTA signal profile and piston movement were then simultaneously monitored (Figure 43). Several test configurations were run several times with different computers in control (ELAC or SEC), with their dedicated hydraulic circuits available (hydraulic pressure was provided by the hydraulic ground power unit).

Computers racked	Computers deracked, oscilloscope monitoring	Hydraulc circuits
ELAC1 (in control) ELAC2 SEC2 SEC3	SEC1 (COM and MON monitored)	G+Y+B
ELAC1 ELAC2 SEC2 (in control) SEC3	SEC1 (COM and MON monitored)	G+Y+B
SEC1 SEC2 (in control) SEC3	ELAC1 (COM and MON monitored)	Y+B
SEC1 SEC2 (in control) SEC3	ELAC1 out (COM and MON monitored) ELAC2 out	Y+B
SEC3 SEC1 (in control)	ELAC1 out ELAC2 out (COM and MON monitored) SEC2 out	Y+B
ELAC1 SEC1 (in control) SEC2 SEC3	ELAC2 (COM and MON monitored)	G+Y+B

*Dependent onf the ELAC engaged on pitch control the ECAM message referrs to the engaged computer ELAC1 or 2 that failed

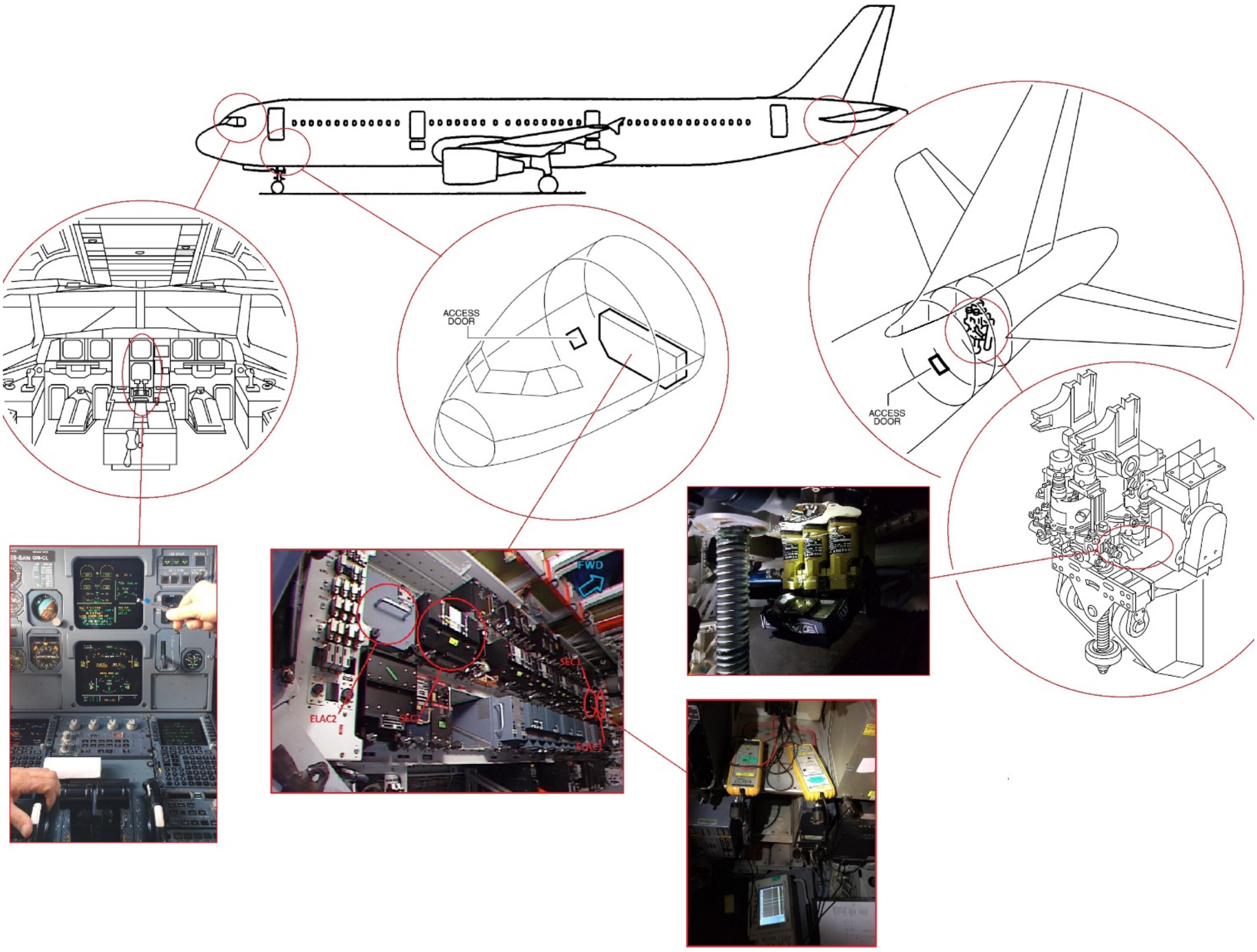


Figure 44 System behaviourbehaviour examination setup

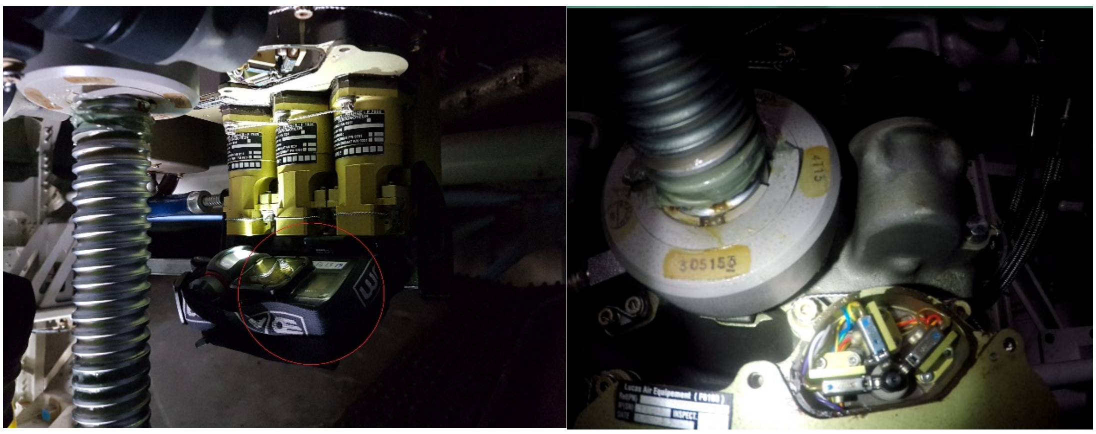


Figure 43 Camera recording the PTA micro-switch movement

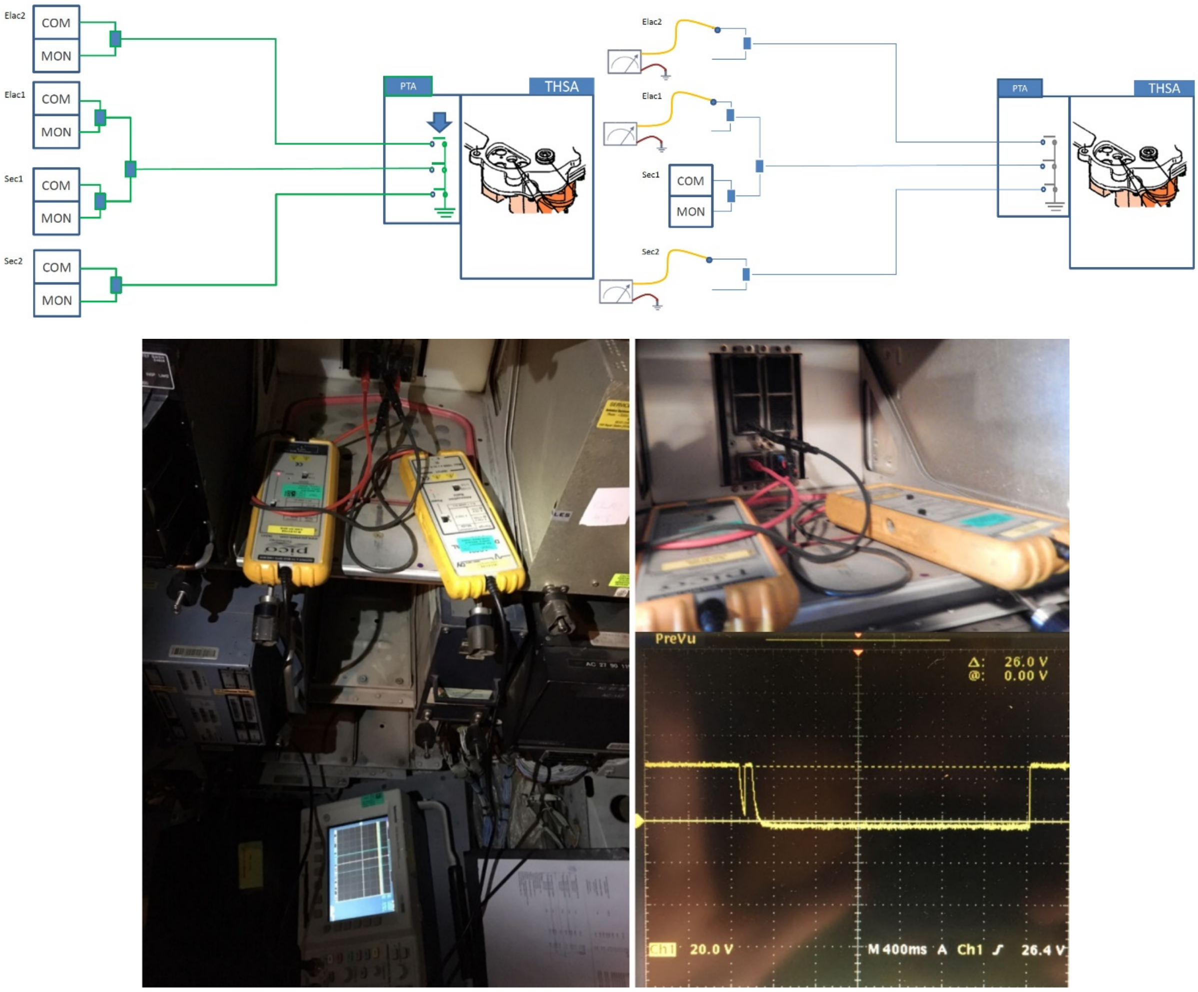


Figure 45 Wiring diagram of PTA override micro-switches; Signal measuring points; Oscilloscope monitoring signals from PTA, connected at SEC1 COM and MON rack

The electrical signal was measured between the computer unit +28 V and the micro-switch ground. This signal commutes from ground to open circuit when there is a manual input on the trim wheel (and corresponds to a change from 28 V to 0 V on the oscilloscope).

Several electronic signatures coming from the PTA were observed:

- No signal – Figure 46,
- Single spike – Figure 47,
- Spike and a step – Figure 48,
- Multiple spikes – Figure 49.

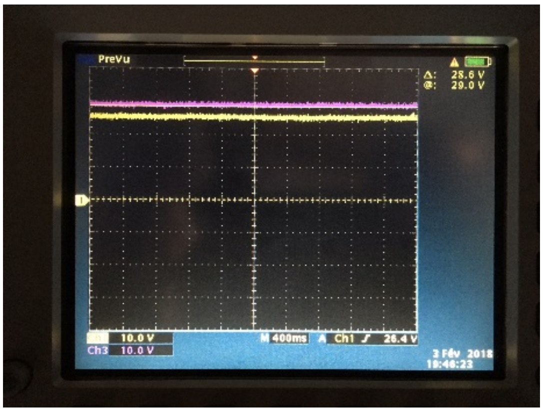


Figure 46 No signal
(SEC active on ground setting)

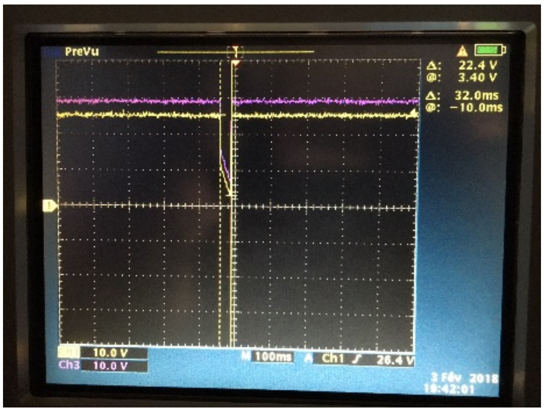


Figure 47 Single spike
(ELAC active on ground setting)

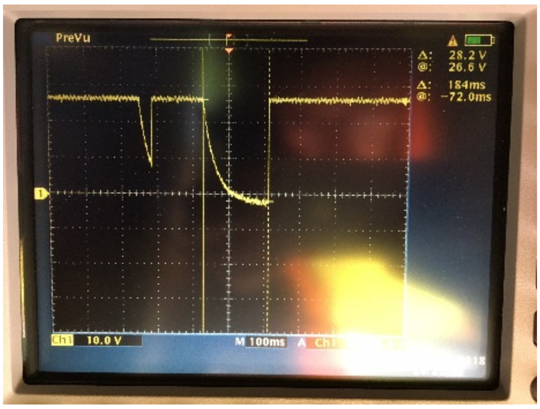


Figure 48 Spike and a step
(ELAC active on ground setting)

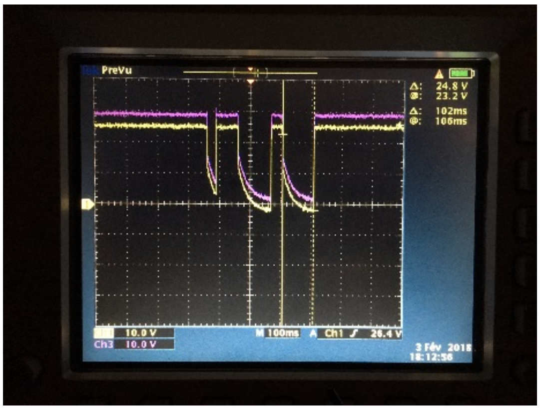


Figure 49 Multiple spikes
(SEC active on ground setting)

Movements of PTA micro-switches and OVM piston could be seen during all the tests.

Tests revealed again, that the failures were intermittent and present during the first tests of a day or after longer rest period (temperature measured at PTA level below 10°C).

A wiring check was performed for the wires between ELAC1, ELAC2, SEC1, SEC2 and PTA in order to detect intermittent wiring issues at each intermediate connector to reveal an error source for the previously observed phenomena. All checked wires and connectors were in good condition and the resistance values were consistent and no resistance fluctuation was recorded.

To rule out any mechanical linkage related sources that could contribute to the PTA signal anomalies the THS mechanical control linkage inspection was carried out. The correct routing and tensioning of the cable loop, correspondence for the trim wheel position with input THSA position and the general state of the cable-chain loop was checked (Figure 50).

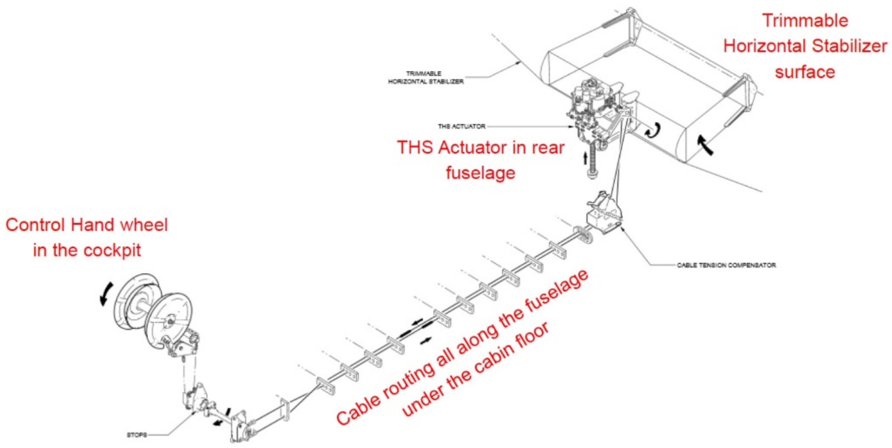


Figure 50 THSA mechanical control linkage

No hardware (servo controls, wires and flight controls) malfunction was observed.

As the ELAC PITCH FAULT/STABILIZER JAM could be reproduced during THSA manual override (manual stop of the trim wheel, during THS ground setting) and not as per design signals from the THS micro-switches were monitored at SEC1 COM/MON. The THSA with its PTA was removed for further investigation.

THSA and PTA examination

The THSA inspection and tear-down was carried out at Collins facilities in Saint-Ouen-l'Aumône (France).

The unit was functionally tested in a designated test bench (figure 51) in order to try to reproduce the faulty signals observed on tests carried out on the aircraft in Tallinn (Estonia).

Figure 51 THSA at a test bench; PTA being chilled

Several tests of the THSA were carried out with the PTA at ambient temperature and below 0°C. During the tests, erratic triggering of the micro-switches of the PTA at ambient and cold temperature was observed on several test runs, even if the mechanical overriding function was reached (Figures 52, 53, 54).

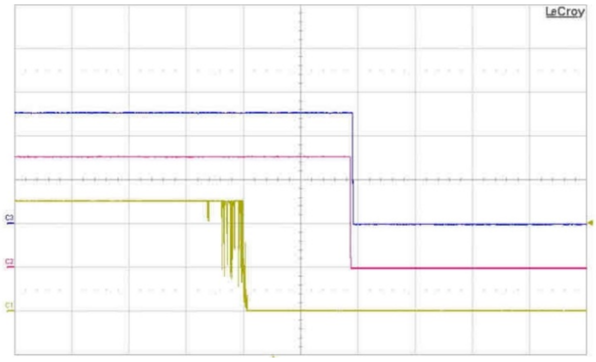


Figure 52 While ground setting is launched and manual input is held, switch 1 signal is activating with abnormal spikes. Switch 2 and 3 appears with delays after 2s.

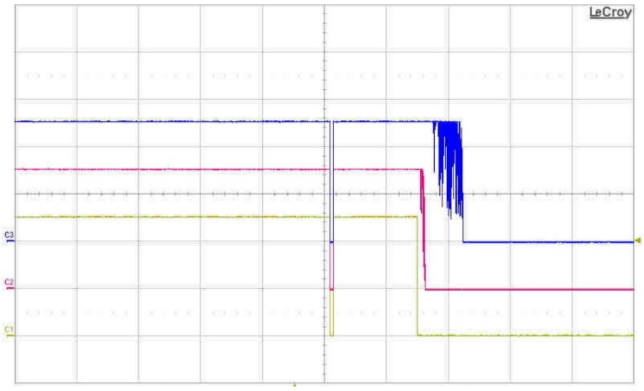


Figure 53 While ground setting is launched and manual input is held, switch 1, 2, 3 signal is transiently compliant for 100ms, disappears for 1,2s activating with abnormal spikes. Switch 2 and 3 appears with delays after 2s.

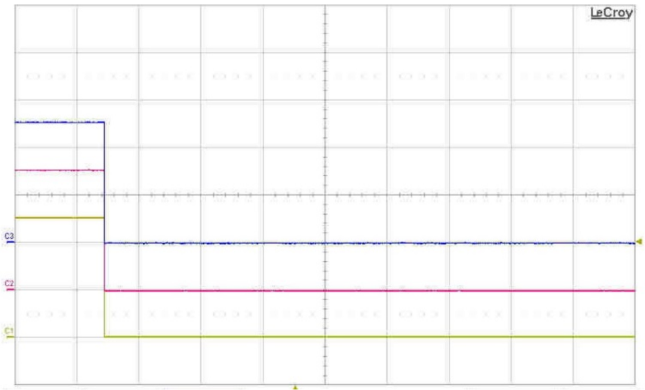


Figure 54 Nominal signals from all 3 switches while ground setting is launched and manual input is held

During these erratic signal phases non-standard displacement of the OVM output piston was observed. The OVM finger stroke was not sufficient to allow the correct triggering of the PTA micro-switches.

The THSA was disassembled. Disassembly revealed that there were several issues referring to the opening of the THSA gearbox - wire locking of different components was not compliant with the CMM, tab-washers were re-used, the shimming of the OVM had not been done accordingly to CMM.

The OVM was removed from the gearbox and the friction curve was measured in a workbench, as the OVM functioning depends on the friction characteristics.

The results revealed that the friction curve was slightly under the required criteria (Figure 55).

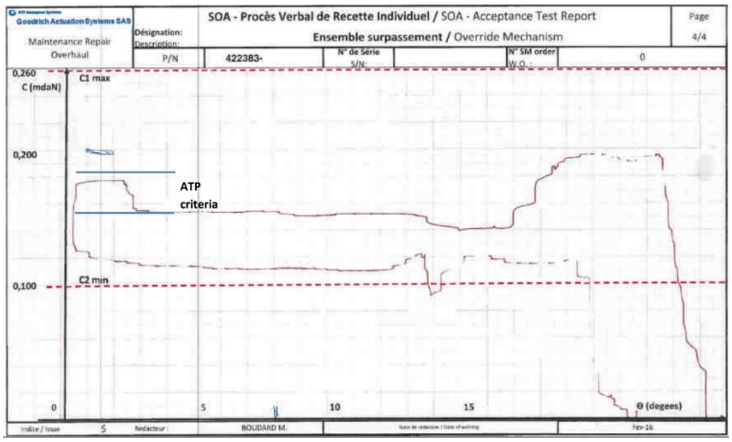


Figure 55 Override test results, the actual friction curve is slightly under the required criteria

The composition and viscosity analysis of the oil used in the THSA was carried out at SGS Vernolab France. The viscosity analysis revealed that the viscosity parameter was 24,1 mm^2/s at 40°C. The required (i.e. per Turbonycoil 160 or any other oil as per CMM) viscosity parameter for the oil is 13 mm^2/s at 40°C. Therefore, the oil that was used in the gearbox was non-compliant to the CMM and can in itself explain the change in the friction curve and the intermittent misbehaviour of the OVM that led to the ELAC PITCH FAULT conditions during the event.

The maintenance documentation of the THSA was reviewed.

The inspection revealed that this THSA unit 47145-147 SN 1110 had entered into service on 19 Oct 1999 (with PN 47145-131, and SN 1110) and had last been repaired in a US MRO "Safe Fuel System", holding an FAA Repair Station Certificate (14 CFR Part 145 no. SLGR312X) and EASA Part-145 approval (EASA.145.5667). This MRO was a non UTAS approved repair station (not listed on the CMM 27-44-51) on 13 February 2017, meaning that this MRO does not receive valid CMM documentation from the THSA OEM.

According to the maintenance documentation, during the last maintenance check (teardown report from 13 April 2017), some missing parts and oil contamination was revealed during the preliminary inspection (at the maintenance center). Several maintenance tasks were performed on this THSA, including replacement of the oil and OVM operational checks. According to the maintenance documents the oil replaced in the THSA was CHEMTURA ROYCO 808 MIL-PRF-7808 (recommended by the THSA CMM) and the OVM functional checks did not reveal any anomalies or discrepancy from the parameters set by the CMM and this THSA was released into service with an FAA FORM 8130-3 (issued on 13 April 2017).

This THSA was installed to A320 MSN1213 (at that time UR-AJA, operated by ATLAS GLOBAL) on 29 April 2017.

The analysis of the maintenance documentation also revealed that during the aircraft regular base maintenance checks, the aircraft maintenance documentation does not require to perform any functional checks to the OVM. The only time when the OVM is checked functionally is during overhaul. Therefore, the potential deviations from the normal functioning of the OVM clutch unit are not being revealed during regular maintenance checks.

The analysis of the maintenance documentation of the THSA could not therefore determine when and where the non-compliant maintenance action to the THSA was performed.

Investigation of SEC behaviour

According to the troubleshooting data of the EFCS, SEC2 was confirmed to be engaged on THS and elevators at 15:05:05.
Although the FDR and TSD data refer to SEC2 engagement on THS, the recorded ECAM warning F/CTL L+R ELEVATOR FAULT indicates that both SEC lost the control of the pitch leading to no flight control law engaged in pitch. Therefore, in order to analyze the behaviour of SEC computers, investigation of SEC was undertaken."

SECs are used for:

- spoilers control
- standby elevator and THS control, when ELAC computers are not available.

SECs are composed of 2 lanes:

- COM, principally for command
- MON, principally for monitoring

SEC Spool Valve Runaway Monitoring

The objective of the SEC spool valve runaway monitoring is to prevent an actuator from runaway when there is a failure in the spool valve control system (current, spool valve, sensors, wiring or COM/MON order discrepancy). The SEC spool valve monitoring compares the current calculated in the MON channel to the equivalent current measured on the spool valve position sensor, computed and commanded by the COM lane (Figure 56).

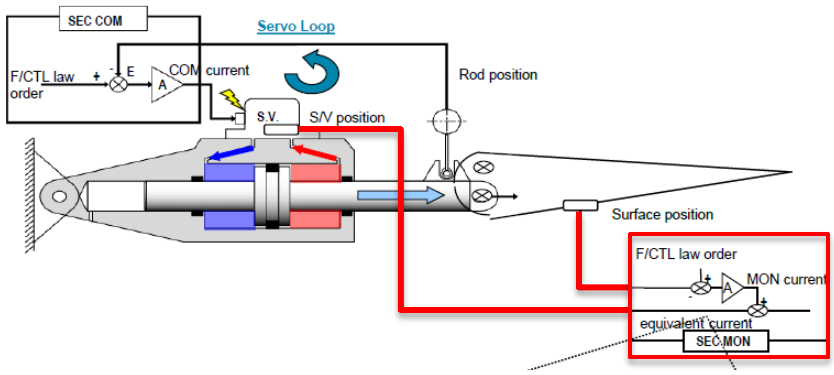


Figure 56 SEC spool valve runaway monitoring principle

For SEC spool valve monitoring, a trend monitoring principle is used (rather than position monitoring), which can detect erroneous control surface movement (e.g. surface movement in the opposite direction of the given order). If a spool valve runaway signal is detected, a centering command is launched, and the control is released to the next computer.

FCDC BITE messages confirm the triggering of the spool valve runaway monitoring on both elevators in SEC1 and LH elevator in SEC2 during the event. ECAM warning in the PFR confirms the loss of control of both elevators by SEC1 and SEC2 and the FDR data confirms the THS moving to 1,5° and elevators centering to 0°.

As there were no technical problems found either on the actuators nor the wiring of the controls, in order to understand the nature of the recorded failures, the SEC COM/MON discrepancy on the surface deflections orders and the triggering of the spool valve runaway monitoring on both elevators in SEC1 and SEC2 is was investigated on desktop simulations.

SEC logic for ground/flight mode

SEC ground/flight logic uses a parameter called BGND. That parameter is computed independently by each SEC unit (COM and MON) based on the information they receive from the LGCIUs. Based on the information received from Landing Gear Control Interface Unit (LGCIU) 1 and 2, SECs determine the flight/ground mode (condition) (Figure 57):

- SEC1/2 COM lane receives L/G compression data from LGCIU1:
  - LH Shock Absorber Compressed = L1
  - RH Shock Absorber Compressed = R1
- SEC1/2 MON lane receives L/G compression data from LGCIU2:
  - LH Shock Absorber Compressed = L2
  - RH Shock Absorber Compressed = R2

Note: L1, R1, L2 and R2 are Booleans with the following convention: Ground=1, Flight=0.

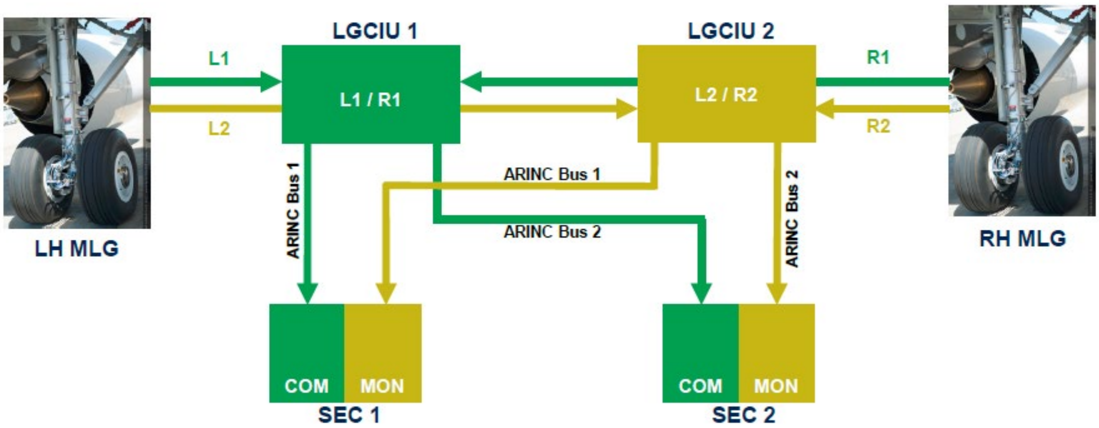


Figure 57 LGCIU-SEC communication architecture

By design, as soon as one main landing gear is seen decompressed for more than 1.02s by a SEC COM or MON lane, this channel will open a 20s window during which the aircraft will be considered in flight mode. It is important to note, when launching a flight or ground law, the initial orders sent to servos are opposite on different laws (Figure 58).

The two following simulations (Figure 58) compare the elevator positions observed during the event with two different situations:

- In cyan - A SEC2 takeover in Ground law
- In magenta - A SEC2 takeover in Flight law

The conclusions of these two simulations are:

- During the event, SEC2 took over in Flight law (Evolution of the elevator positions of the simulation line in magenta is similar to the event up to the re-centering at 0°)
- Evolutions of the elevator positions in Flight and Ground law are different and sometimes opposite.

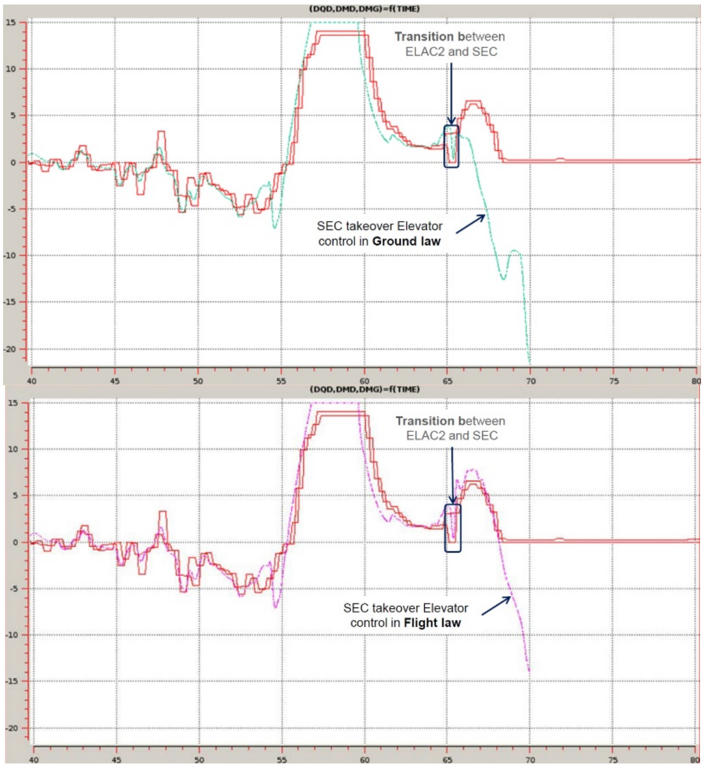


Figure 58 Spike from SEC takeover, initial opposite surface deflection in SEC flight and ground law. On the graph, red lines represent the event, green and magenta lines simulator replay

The SEC COM and MON channels as well as LGCIU1 and LGCIU2 units are by design not synchronized. Each LGCIU sends L/G information through the different channels (Figure 57) to both SECs synchronously (it is important to note that as the LGCIU units are not synchronized, although the data sets are sent synchronously, the L/G information is not synchronized). SEC COM and SEC MON received information from their respective LGCIU in every 120 ms and from the other LGCIU every 30ms (Figures 57 and 59). The ground/flight condition is computed by SEC in every 30 ms.

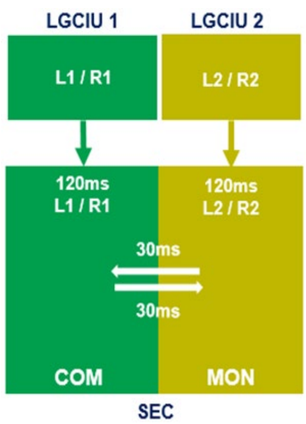


Figure 59 SEC logic is used to consolidate the ground or flight mode

Lab simulations showed that, with current SEC design, asynchronism between COM and MON channel may activate Flight law in one channel while Ground law remains in the other channel, causing the loss of pitch control by both SECs and thus the loss of the control of both elevators in case of dual ELAC pitch faults.

During the event (see Appendix 1), the left landing gear was decompressed during around 1 second (the sampling rate of the parameter is 1 second and does not allow to determine the exact duration – between 0 and 2 seconds), before the aircraft was firmly on the ground (3 landing gears recorded compressed).

To simulate the event conditions, signals with sequences of 1s rebound were generated through LGCIU A429 input and SEC COM/MON law order was monitored (Figure 60 and 61).

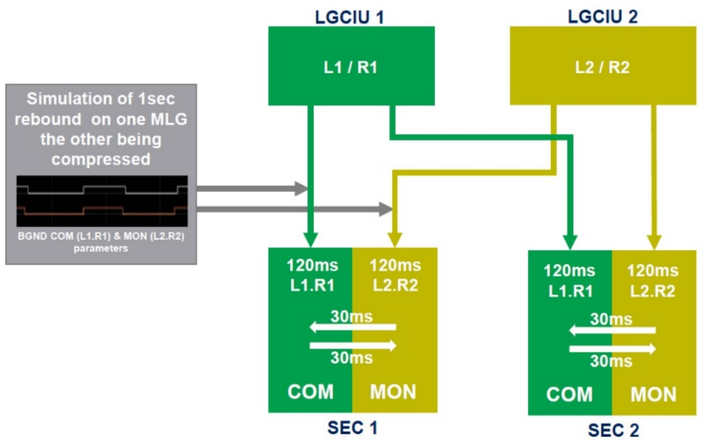


Figure 60 Test set up to simulate the loss of one SEC

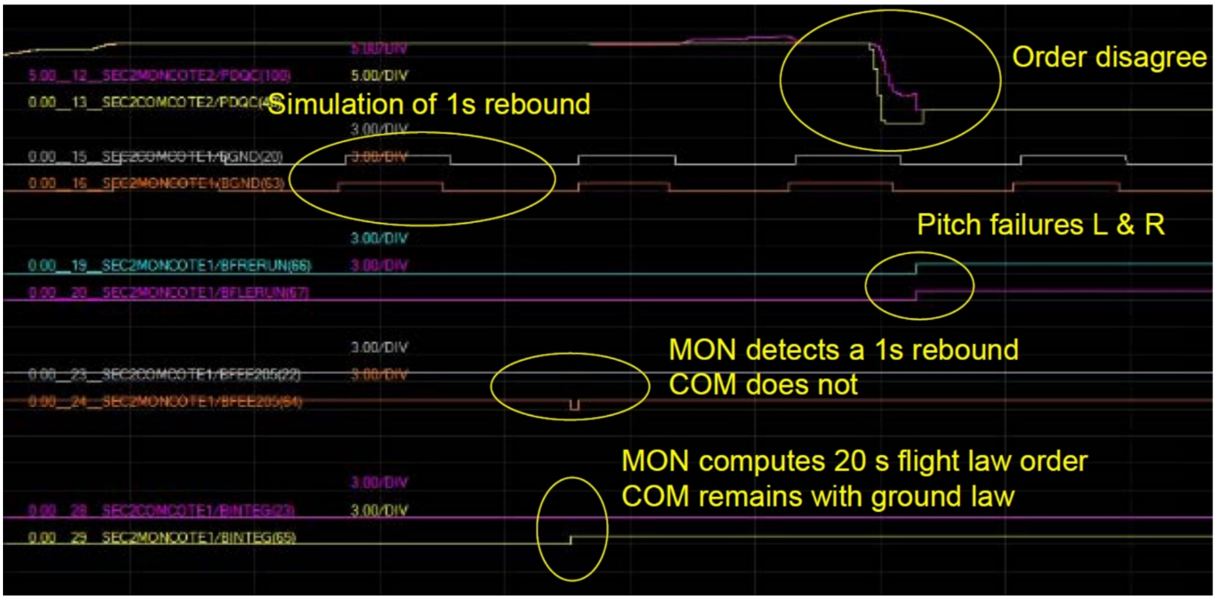


Figure 61 SEC behaviour simulation. COM remains in Ground law, MON reverts in Flight law

Loss of SEC by the discrepancy between COM and MON in the ground/flight condition was reproduced and confirmed in a simulator.

As per design LGCIU1 and LGCIU2 are not synchronous, within one LGCIU the same information is sent through ARINC BUS1 and 2. This information is sent synchronously on BUS1 and BUS2 and it is refreshed in every 100ms (see Figure 57).

To understand the loss of both SECs, a lab simulation test was carried out.

The LGCIUs and SECs were set up in order to simulate real-time asynchronism of the units. A replay of the event sequence was again simulated, by introducing 1s rebound on one MLG at LGCIUs` inputs (Figure 62), and side-stick input in SEC1, 2 and the failure of ELAC2 were simulated.

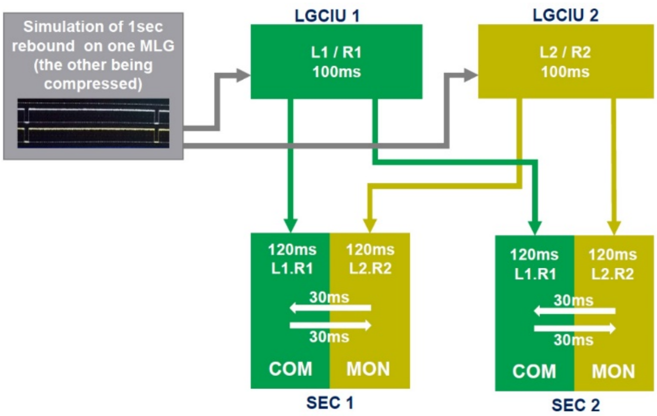


Figure 62 Simulation setup for MLG 1s rebound test

A set of simulation tests were carried out and the sequence where SEC COM initiates a flight condition and MON remains in ground condition was reproduced at several occasions (Figure 63).

Figure 63 Rebound test with two LGCIUs and SECs. SEC COM and MON seeing ground/flight condition

The loss of elevator control by both SECs by the discrepancy between COM and MON Ground/Flight condition was observed on several test runs (Figure 64).

Figure 64 Loss of ELEV control by the two SECs by the discrepancy between SEC COM and MON Ground/Flight condition

1.17 Organizational and management information

1.17.1 EASA and type certification

The European Aviation Safety Agency (EASA) is an authority that is appointed by the European Commission to, amongst other things, certify and approve products and organizations in aviation domain. An approved design organization must demonstrate to EASA the compliance of their product to the applicable technical conditions, certification specifications and special conditions during certification program confirmed by EASA.

EASA is involved in a product certification process in an early stage, to validate the selected means of compliance and the required documentation to be presented on certification.

The requirements for designing and testing large aeroplanes are laid down in Guidance Material (GM) and Certification Specifications (CS) published by EASA.

At the time of the A320 initial type certification the relevant regulations were issued by Joint Aviation Authorities as JAR-s (Joint Aviation Requirements) and they were recognized by the national aviation authorities. The initial certification of the A320 was done accordingly to the applicable A320 certification basis.

The valid A320 type certificate (issue 16) at the time of the accident was issued by EASA.

CS 25.671 states: (c) The aeroplane must be shown by analysis, test, or both, to be capable of continued safe flight and landing after any of the following failures or jamming in the flight control system and surfaces (including trim, lift, drag, and feel systems) within the normal flight envelope, without requiring exceptional piloting skill or strength. Probable malfunctions must have only minor effects on control system operation and must be capable of being readily counteracted by the pilot.

- Any single failure not shown to be extremely improbable[1], excluding jamming, (for example, disconnection or failure of mechanical elements, or structural failure of hydraulic components, such as actuators, control spool housing, and valves).
- Any combination of failures not shown to be extremely improbable, excluding jamming (for example, dual electrical or hydraulic system failures, or any single failure in combination with any probable hydraulic or electrical failure).
- Any jam in a control position normally encountered during take-off, climb, cruise, normal turns, descent and landing unless the jam is shown to be extremely improbable, or can be alleviated. A runaway of a flight control to an adverse position and jam must be accounted for if such runaway and subsequent jamming is not extremely improbable.

CS 25.1309 states: (b) The aeroplane systems and associated components, considered separately and in relation to other systems, must be designed so that:

- Any catastrophic failure condition[2]
    - is extremely improbable; and
    - does not result from a single failure; and
- Any hazardous failure condition is extremely remote[3]; and
- Any major failure condition is remote[4].

[1]Probability of $1x10^{-9}$ or less per flight hour
[2]Failure condition which could prevent continued safe flight and landing
[3]Probability of $1x10^{-7}$ or less per filght hour but greater than $1x10^{-9}$
[4]Probability of $1x10^{-5}$ or less per filght hour but greater than $1x10^{-7}$

To demonstrate the compliance with the failure condition probability requirements described in the JAR25 (later CS25) the approved design organization can use different safety assessment techniques (System Safety Assessment (SSA), Failure Modes and Effects Analysis (FMEA), Preliminary Aircraft Safety Assessment (PASA), Functions Hazard Assessment (FHA) etc.)

CS 25 Book 2 article 11 requires for complex systems where functional redundancy is required, a qualitative Failure Modes and Effects Analysis (FMEA) supported by failure rate data and qualitative fault tree analysis.

A320 applicable certification basis requires for complex systems where functional redundancy is required, a quantitative Failure Modes and Effects Analysis (FMEA) supported by failure rate data and qualitative fault tree analysis.

FMEA is a structured, inductive, bottom-up analysis, which is used to evaluate the effects on the system and the aeroplane of each possible element or component failure. These FMEAs are put together by the equipment designer/manufacturer with their best knowledge and experience on the equipment and on its failure modes and mechanisms, based on exhaustive testing data.

The results from the FMEAs are taken into account amongst with other safety assessments, and compiled together into system safety assessment (SSA). The SSA contains the definite list of system failure conditions and associated probabilities, enabling to check the compliance with the required safety level.

1.17.2 A320 flight control system safety assessment

During the training flights, as the TRI was acting on the trim wheel, the intermittent failure of the OVM in disengaging the PTA from the downstream components of the OVM and the failure to trigger the 3 micro-switches at the bottom of the OVM, lead to the loss of ELAC control on pitch axis.

The SEC ground/flight logic (by design) that enabled the temporary decompression of the main landing gear to lead both SEC to disengage the control on pitch axis.

These two defaults emerged prior and during the event and caused a loss of control of both elevators and both being locked in a neutral position.

To understand how the failure condition - loss of both elevators - was taken into account in the SSA, two documents, both extracted from the SSA document related to ATA270 (flight control systems on aeroplanes), were shared by Airbus and analysed:

1. A selection of Failure Conditions, related to the loss of both elevators.
2. A selection of FMES items for THSA Actuator, Spoiler and Elevator Computer and EFCS wiring.

It is important to note that since the SEC ground/flight logic was functioning as per design, however, an unknown design default was revealed with this event, it was not expected to be have taken into account in the SSA.

Failure Conditions, related to the loss of both elevators

The Failure Condition (FC) that best fits the examined failure was entitled in the SSA as “**Loss of control of both elevators, both locked neutral**”. This FC was classified as hazardous for A320. Airbus specified that this classification was evaluated through three flight tests including Approach and landing performed in full mechanical back-up. The conclusion was made that the aircraft was “controllable with reasonable work-load including flare”. The described safety effects were described followingly:

- Pitch control is achieved through the THS mechanical control.
- Disconnection of both AP.
- Both elevators are locked at neutral, a specific warning being displayed to the crew.
- Crew Detection*:* «F/CTL L+R ELEV FAULT MAX SPEED... 320/.77 MAN PITCH TRIM USE... SPD BRK... DO NOT USE» red warning on upper ECAM + MW + CRC and «MAN PITCH TRIM ONLY» red indication on both PFD.

The mentioned safety effects, crew detection and crew actions are in line with what was met during the event flight.

Loss of control of one or both elevators by one SEC, associated ELAC unaffected is per design a hidden failure. Hidden failures are taken into account in the dependence diagram. Such failures are checked at a certain moment of the aircraft life. The SSA defines the time interval between the required maintenance tasks included in the aircraft maintenance program.

Failure condition “***Loss of control of the elevators by one ELAC***” was met several times during the event flight. At the event time, both ELAC had lost the control of the elevators. The described safety effects for this FC were:

- Loss of control of the elevators by one ELAC, associated SEC unaffected.
- Pitch control is ensured by the second ELAC.
- Above 100ft, loss of automatic landing Cat. IIIB.
- The «F/CTL ELAC1 (2) PITCH FAULT» caution is displayed on upper ECAM CRT.

These safety effects are consistent with what was met during the event:

- The control from the faulty ELAC switched to the next computer according to the reconfiguration logic;
- “F/CTL ELAC1 (2) PITCH FAULT” message displayed on upper ECAM display.

Failure Mode and Effects Summary

The FMES item which is the most analogous to the examined failure is: **“Permanent electrical mode signal from 3 micro switches”.** This failure is described as a single failure coming from the override mechanism.

During the event flight, the non-activation of the OVM lead to a non-activation of the 3 micro switches. This default was not permanent but intermittent and lead to the loss of both ELAC on the pitch axis.

In the FMES, the failure mode „Permanent electrical mode signal from 3 micro switches“ is considered to have no effect as a single failure as it requires a human action on the trim wheel to have an effect on the systems. Airbus specified that in normal operations such a human action is never requested by any procedure when the auto-trim is active, however the Airbus FCTM described pilot action "monitor/adjust the trim movement towards the green band" during touch and go.

During the investigation, it was checked that even considering this human action, the probability of the failure condition “Loss of control of both elevators, both locked neutral” still meets the safety objective.

The THSA FMEA to OVM describes failures leading to non-activation of overriding THSA micro switches when operating in mechanical mode in the following failure modes:

- jamming,
- seizure or jamming,
- breaking parts or wear of parts,
- breaking,
- wear.

Based on the OVM examination, the observed effect on equipment was that the piston did not have a sufficient displacement in order to activate the 3 micro switches. The lack of friction, in this case due to a low viscosity oil (as revealed by the oil analysis) was not taken into account in the FMEA. There is no maintenance task that is required by Airbus to detect this type of OVM failure as this failure is combined with additional failures leading to having effect on the system. FC diagram only considers failures or events and does not consider human actions and thus this failure needs an additional and independent failure (like for instance jamming of the mechanical linkage between the Trim Wheel and the THSA) in order to loss the pitch control by both ELAC's through an OVM failure.

1.17.3 Operational procedures

Quick Reference Handbook

The QRH contains procedures applicable for abnormal and emergency conditions. For aircraft fitted with ECAM system (like this A320), the QRH procedures are used whenever the ECAM is not able to detect a failure or malfunction and provide steps for remedial actions.

During the event, the crew received several ELAC 1 (or 2) PITCH FAULT messages. As these faults are classified as Level 1 alerts (see section 1.6.3.4), the associated ECAM messages indicated are for crew awareness and there is no associated procedure to be followed after receiving these messages. As per the ECAM management philosophy, the flight crew can consider a system reset if it is authorized by the QRH system reset table. The System reset Table applicable at the time of the event was the following (figure 65):

SMARTLYNX A318/A319/A320/A321 QUICK REFERENCE HANDBOOK	ABNORMAL AND EMERGENCY PROCEDURES	02.02A 04 JAN 18

Continued from the previous page

ECAM System	System malfunction or ECAM Alert (Affected System)	Reset Procedure
ENG	ENG 1(2) FADEC A(B) FAULT (FADEC)	**On ground only:** If this alert triggers at engine start, apply the following procedure: - Set ENG MASTER (affected) pb-sw to OFF - Wait until N2 speed below 5 % - Pull C/B A04 or A05 on 49VU for ENG 1(2) FADEC channel A - Pull C/B R41 or Q40 on 121VU for ENG 1(2) FADEC channel B - Wait 5 s before pushing the C/Bs - After ECU power-up sequence, the Flight Crew can restart the engine.
F/CTL	F/CTL ELAC 1(2) FAULT (one or both computer failed) (ELAC)	**On ground, or in flight** - Set ELAC 1(2) pb to OFF - Wait 3 s - Set ELAC 1(2) pb to ON. **WARNING** Do not reset more than one computer at a time. **Note:** - *When an ELAC reset is performed on ground, the flight crew must check the pitch trim position.* - *If a reset is performed on ground, the flight crew must then perform a flight controls check.*
F/CTL	ELAC or SEC malfunction (ELAC or SEC)	ELAC or SEC may be reset. **WARNING** Do not reset more than one computer at a time. - It is possible to reset the flight control computers in flight, even if not requested by the ECAM, provided only one reset is performed at a time. **Note:** - *When an ELAC reset is performed on ground, the flight crew must check the pitch trim position.* - *If a reset is performed on ground, the flight crew must then perform a flight controls check.*
FUEL	Loss of fuel quantity indication or Simultaneous triggering of FUEL L OUTER XFR CLOSED and FUEL R OUTER XFR CLOSED although FUEL SD indicates no anomaly. (FQIC)	**On ground, or in flight:** - Pull the three C/Bs: • Channel 1 (A13 on 49VU) • Channel 2 (M27 on 121VU) • Channel 1 and 2 (L26 on 121VU). - Wait 5 s, before pushing the three C/Bs. *Note: The fuel quantity indication will be re-established within 1 min.*

Figure 65 QRH System reset Table

Flight Crew Operations Manual

THE FCOM contains the primary reference for the flight crew for the operation of the aircraft under normal, abnormal and emergency conditions.

The operational procedures concerning the management for ELAC PITCH FAULT and L+R ELEV FAULT in the Smatlynx FCOM were the following (Figure 66):

ESIB: A2802118

EECAIRS: EE0180

SMARTLYNX A318/A319/A320/A321 FLIGHT CREW OPERATING MANUAL

PROCEDURES

ABNORMAL AND EMERGENCY PROCEDURES

[RESET] SYSTEM RESET

Continued from the previous page

ECAM System	System malfunction or ECAM Alert (Affected System)	Reset Procedure
Ident.: PRO-ABN-ABN-RESET-B-00012652.0001001 / 20 MAR 17		
F/CTL	F/CTL ELAC 1(2) FAULT F/CTL ALTN LAW F/CTL ELAC 1(2) PITCH FAULT (ELAC)	*Refer to PRO-ABN-F/CTL section for associated procedure*, if applicable.
	ELAC or SEC malfunction (ELAC or SEC)	ELAC or SEC may be reset. **WARNING** Do not reset more than one computer at a time. It is possible to reset flight control computers in flight, event if not requested by the ECAM, provided only one reset is performed at a time. *Note: When an ELAC reset is performed on ground the crew must check the pitch trim position. If a reset is performed on ground, the flight crew must then perform a flight control check, Refer to PRO-NOR-SOP-10-TAXI.*
Ident.: PRO-ABN-ABN-RESET-B-00012653.0018001 / 20 MAR 17		
FUEL	Loss of fuel quantity indication or Simultaneous triggering of FUEL L OUTER XFR CLOSED and FUEL R OUTER XFR CLOSED, although FUEL SD indicates no anomaly. (FQIC)	**On ground, or in flight:** - Pull the 3 C/Bs: • Channel 1 (A13 on 49VU) • Channel 2 (M27 on 121VU) • Channel 1 and 2 (L26 on 121VU). - Wait 5 s, before pushing the 3 C/Bs. *Note: The fuel quantity indication will be re-established within 1 min.*
Ident.: PRO-ABN-ABN-RESET-B-00012655.0002001 / 20 MAR 17		
FWC	FWS FWC 1(2) FAULT (FWC)	**On ground:** Pull, then push, the C/B of the affected FWC: - FWC 1 (F01 on 49VU) - FWC 2 (Q7 on 121VU). Wait 50 s after pushing the C/Bs. **In flight:** Pull, then push, the C/B of the affected FWC: - FWC 1 (F01 on 49VU) - FWC 2 (Q7 on 121VU).

Continued on the following page

SMARTLYNX A318/A319/A320/A321 FLIGHT CREW OPERATING MANUAL

PROCEDURES

ABNORMAL AND EMERGENCY PROCEDURES

F/CTL

F/CTL ELAC 1(2) PITCH FAULT

Applicable to: ALL

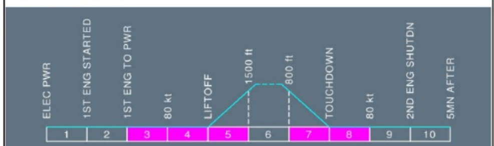
Ident.: PRO-ABN-F_CTL-H-00016977.0001001 / 21 MAR 16

ANNUNCIATIONS

Triggering Conditions:

L2 This alert triggers when there is a failure of pitch channel in ELAC 1(2).

Flight Phase Inhibition:



Ident.: PRO-ABN-F_CTL-H-00018447.0001001 / 21 MAR 16

Crew awareness.

Ident.: PRO-ABN-F_CTL-H-00018448.0001001 / 21 MAR 16

STATUS

CAT 3 SINGLE ONLY

INOP SYS

ELAC PITCH (1)
CAT 3 DUAL

(1) *(If ELAC 1 and 2 PITCH FAULT)*

SMARTLYNX A318/A319/A320/A321 FLIGHT CREW OPERATING MANUAL

PROCEDURES

ABNORMAL AND EMERGENCY PROCEDURES

F/CTL

F/CTL L+R ELEV FAULT (Cont'd)

Ident.: PRO-ABN-F_CTL-O-00018492.0009001 / 22 MAR 17

L12

STATUS

MAX SPEED..320/.77
SPD BRK..DO NOT USE

APPR PROC

FOR LDG..USE FLAP 3
This line is replaced by "FOR LDG : USE FLAP 3" when CONF 3 is selected, as a reminder
GPWS LDG FLAP 3..ON
Will be displayed when flaps in CONF 3.
MAN PITCH TRIM..USE
APPR SPD..VREF+10
LDG DIST PROC..APPLY

PITCH MECH BACK UP
ROLL DIRECT LAW

INOP SYS

L+R ELEV
ELAC PITCH
AP 1+2
CAT 2
GLS AUTOLAND
STEEP APPR

Figure 66 FCOM procedures for ELAC PITCH FAULT and L+R ELEV FAULT

Minimum Equipment List

A minimum equipment list is a list that describes specific conditions for the operation of the aircraft with particular equipment inoperative. If a fault or unserviceability should exist before the flight, MEL should be consulted for each individual item to check if there are any incompatibilities of the associated dispatch conditions. The ultimate decision to whether to accept these incompatibilities for the flight rests on the aircraft commander (in cooperation with the operator).

SMARTLYNX ESTONIA
A320
MINIMUM EQUIPMENT LIST

MEL ENTRIES
27 - FLIGHT CONTROLS

ECAM Alert: F/CTL ELAC 1 FAULT

Ident.: ME-27-00007946.0001001 / 18 JUL 12
Applicable to: ALL

AIRCRAFT STATUS	CONDITION OF DISPATCH
NIL	*Refer to Item 27-93-01 ELAC 1*

ECAM Alert: F/CTL ELAC 1 PITCH FAULT

Ident.: ME-27-00007945.0001001 / 18 JUL 12
Applicable to: ALL

AIRCRAFT STATUS	CONDITION OF DISPATCH
NIL	*Refer to Item 27-93-01 ELAC 1*

ECAM Alert: F/CTL ELAC 2 FAULT

Ident.: ME-27-00007948.0001001 / 18 JUL 12
Applicable to: ALL

AIRCRAFT STATUS	CONDITION OF DISPATCH
NIL	NO DISPATCH

ECAM Alert: F/CTL ELAC 2 PITCH FAULT

Ident.: ME-27-00007947.0001001 / 18 JUL 12
Applicable to: ALL

AIRCRAFT STATUS	CONDITION OF DISPATCH
NIL	NO DISPATCH

ECAM Alert: F/CTL ELEV SERVO FAULT

Ident.: ME-27-00007949.0001001 / 18 JUL 12
Applicable to: ALL

AIRCRAFT STATUS	CONDITION OF DISPATCH
If the servo-control is affected.	NO DISPATCH
If the servo-control position transducer is affected.	*Refer to Item 27-34-02 Elevator Servo-Control Position Transducer*

MYX A320 FLEET ME-27 P 3/12
MEL I to M 05 JAN 18

SMARTLYNX ESTONIA
A320
MINIMUM EQUIPMENT LIST

MEL ITEMS
27 - FLIGHT CONTROLS
27-93 - ELAC System (Elevator Aileron Computer)

27-93-01 ELAC 1

Ident.: MI-27-93-00008385.0008001 / 17 JAN 17
Applicable to: ALL

27-93-01A

Repair interval	Nbr installed	Nbr required	Placard
C	1	0	Yes

(o) (m) ELAC 1 or any ELAC 1 function may be inoperative provided that:

1) ETOPS is not conducted, and
2) All SECs, SFCCs, LGCIUs, RAs, ADIRS and FACs are operative, and
3) The pairs of spoilers 2, 3, 4, and 5 are operative, and
4) The TR 1 and the TR 2 are operative, and
5) Both accelerometers associated with the ELAC 2 are checked operative before each flight, and
6) All sidesticks transducers associated with the ELAC 2 and the three SECs are checked operative before each flight, and
7) The DC TIE contactor 1PC1 is checked closed, before each flight, and
8) The elevators and roll spoilers control is checked operative through the SECs before each flight.

Note: *F/O take-over pb cannot disengage AP 1.*

Reference(s)

(o) *Refer to OpsProc 27-93-01A ELAC 1*
(m) *Refer to AMM 27-93-00-040-001*

27-93-02 ELAC 2

Ident.: MI-27-93-00008386.0001001 / 22 MAR 10
Applicable to: ALL

27-93-02A

Repair interval	Nbr installed	Nbr required	Placard
–	1	1	No

Must be operative.

MYX A320 FLEET MI-27-93 P 1/2
MEL A to B 15 MAR 15

Figure 67 MEL pages on ELAC PITCH FAULT

During the flights as the crew received several ELAC PITCH FAULTs the TRI decided to follow the QRH, reset the failed computer and continue with the flights. Nevertheless, at 13:47 a F/CTL ELAC1 PITCH FAULT was triggered, that was not reset by the crew and what remained faulty until the end of the whole flight (including the accident).

After finishing the training session with the third student at around 14:20 when the aircraft came to a full stop and before starting a training session with the forth student, the crew performed normal preparations for the flight. During that period MEL (figure 67) was not considered by the flight crew. This might be due to the fact that the crew was not aware of the fact that ELAC 1 was (still) faulty and because at the time of the event Airbus FCTM did not require to consider MEL on touch-and-go and stop-and-go training.

In order to determine if this ECAM alert F/CTL ELAC1 PITCH FAULT that was left un reset was displayed (at 13:47 or later, due to inhibition), an analysis for the relevant FDR parameters was undertaken. The analysis showed that at 13:47:06, when the aircraft was touching the ground, the parameter "*EL1PF*" was switching to 1, referring to ELAC 1 PITCH FAULT being triggered, but not being displayed. At 13:47:42, when the aircraft was at 1668 ft RA, F/CTL page was called by the system. At 13:48:34, when the aircraft reached 2200 ft RA the F/CTL page was replaced by the STATUS page and at 13:48:38, the STATUS page was replaced by the CRUISE page.

In case there are too many ECAM messages for the amount of space available in the lower part of the E/WD, a green arrow appears at the bottom of the display, pointing down to show that the information has overflowed off the screen. The pilot can scroll down to view additional messages by pushing the CLR pushbutton on the ECAM control panel (on the pedestal, just below the lower ECAM DU). It is important to note that when the messages are cleared, they do not reappear until the end of the flight.

Cleared ECAM messages can be recalled when pushing the RCL pushbutton. In normal operations, this recall is requested by SOP before each flight during the Preliminary Cockpit Preparation and done by the flight crew by pressing the Recall (RCL) pushbutton during 3sec, displaying all alerts previously cleared via the CLR pushbutton that are still active and all alerts previously cancelled via the EMER CANC pushbutton.

The sequence of SD pages is consistent with an ECAM alert F/CTL ELAC 1 PITCH FAULT displayed at 13:47:42, and cleared by the flight crew (by pressing the CLR p/b) at 13:48:34, and the same for the STATUS page at 13:48:38.

1.17.4 Operator

Smartlynx Airlines Estonia AS holds an AOC approval issued by ECAA. The procedures for operating the aircraft (ES-SAN) are duplicates of the procedures found in the Airbus Flight Crew Operating Manual (FCOM) and Quick Reference Handbook (QRH).

According to the Smartlynx Airlines Estonia FCOM and QRH (provided by Airbus), the ECAM philosophy recommend to consider a system reset by applying the associated guideline. For the alert F/CTL ELAC1(2) PITCH FAULT the reset of ELAC 1(2) should be done by setting the ELAC 1(2) pushbutton to OFF, wait 3s and then set pushbutton back to ON. In the manuals there is no reference to the maximum number allowed resets. The QRH states that, ELAC or SEC may be reset in flight, with a warning, not to reset more than one computer a time.

1.17.5 Training Organization

Smartlynx Estonia ATO holds an approval issued by the Estonian Civil Aviation Agency for conducting Airbus A320 Type Rating Courses.

The aim of the courses is to bring pilots with different previous experience to a skill level to safely operate A320 family aircraft.

These type rating courses are provided to students who are previously qualified on multi-pilot commercial jets or turboprops and have some experience in commercial aeroplane operations or to students who have a minimum CPL license, frozen ATPL theory with MCC course and with and without previous experience in commercial aeroplane operations.

The training program consists of:

- Cockpit System Simulator (CSS) session conducted in the class room (equipped with A320 cockpit paper target and CBT trainer for FMGC and ECAM training);

- 9 Full Flight Simulator (FFS) sessions (total 12 sessions excluding Skill Test);
- Flight Training on an Aircraft including: 4 - 6 take off and landings depending on student previous experience. Four landings means 3 touch and go landings + 1 go around + 1 full stop landing. 6 landings means 5 touch and go landings + 1 go around + 1 full stop landing.

Training procedures and the syllabi is described in ATO operations manual (ATO OM) and ATO training manual (ATO TM).

According to the seating policy described in ATO OM, students occupy their respective operating seats under the supervision of their instructor until cockpit preparation is complete. The instructor will then occupy the appropriate non-flying pilot's seat. Normally, Captain-student will occupy the left seat, First Officer-student the right seat. The observers' seat will be occupied by the non-flying student pilot (left observers seat) and by the safety pilot (right observer's seat).

The instructor is responsible for all radio communications and maintaining a visual lookout for conflicting air traffic. The safety pilot should be encouraged to back up the instructor in this regard and to immediately inform him of any potential conflict.

If any reportable occurrence happens during the Flight Training on an Aircraft, instructor and safety pilot shall submit a report according to SMS procedures.

During Flight Training, in case of any abnormal situation or emergency, Captain has to take over the control of the aircraft and became PF. Safety pilot will continue radio watch on active ATC and 121,5 frequencies. PF will then control the A/C Flight-path, speed, configuration, engines and deal with navigation and communication. PF will initiate the ECAM action to be done by PM (student pilot in this case) and check that the actions are properly completed.

PNF reads ECAM and C/L, executes the ECAM actions on PF command, asks for PF confirmation to clear,executes the actions required by PF. The PNF never touches the Thrust Levers even if so asked by the ECAM. When a failure or abnormal situation occurs, the general scheme of actions is as follows:

- the first pilot to recognize the problem announces the MASTER WARNING or CAUTION - TITLE OF THE FAILURE;
- the PF controls the aircraft until it is properly stabilized.

Although a safety pilot is required to be on board the aircraft during base training by the Smartlynx Estonia ATO OM, there is no specific role defined for the Safety pilot neither in normal or abnormal operations (other than radio watch).

Touch and go

AMC to the ORA.ATO.125 (a) (1) states that, when developing the training program for a type rating course, in addition to complying with the standards included in the operational suitability data (OSD), as established in accordance with Regulation (EC) 1702/20031 for the applicable type, the ATO should also follow any further recommendations contained therein.

The aircraft manufacturer provides guidance for ATOs for putting together base training syllabi and developing air exercise procedures.

According to the Airbus A320 Flight Crew Training Program (FCTP) (Issue 13, Mar 2016) flight training policy for touch-and-go base training, prior to every touch and go training, the instructor must confirm with the trainee that reverse thrust is not used and brakes (auto or manual) are not to be used. The trainee will land the nosewheel after main gear touchdown, track the runway centerline using pedal inputs only. The instructor will disarm the spoilers at nose wheel touch down by pushing the SPREEDBRAKE lever (with the objective to initiate immediate spoiler retraction and not to wait their automatic retraction while advancing the thrust levers) with a reference to a procedures diagram (figure 68).

There is no reference in the Airbus FCTP or FCTM (in the versions published before the event) to consider MEL for training continuation on “touch and go” or “stop and go” training.

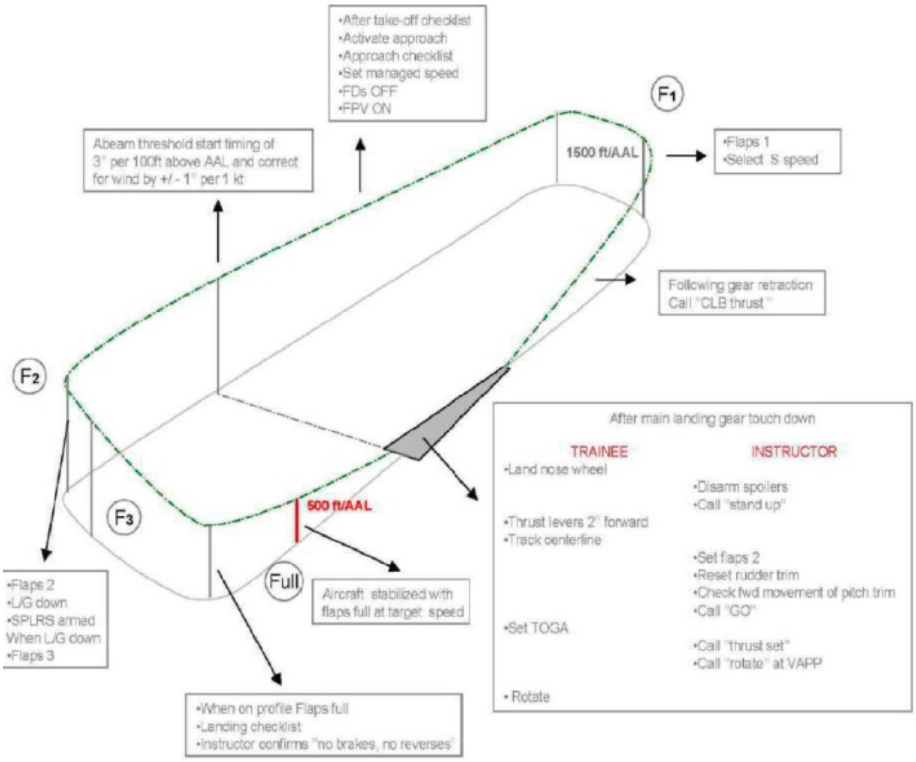


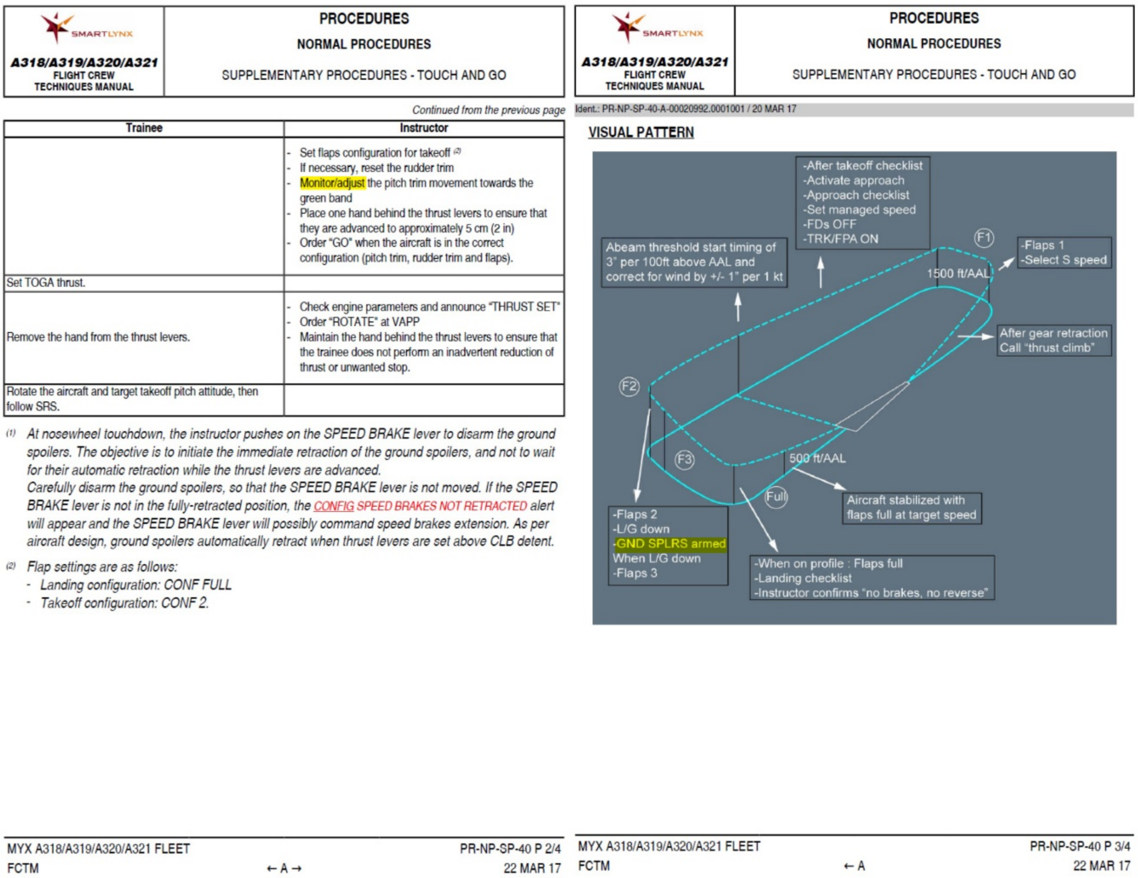
Figure 68. Airbus A320 base training syllabi, Touch-And-Go procedures

Smartlynx Estonia ATO TM provides guidelines for Pre-flight briefing, stressing that special attention of students has to be brought to NO BRAKES and NO REVERSE during touch and go phase, but neither the Touch-And-Go air exercise section nor the Final Approach and Landing section give a reference for arming or disarming the spoilers on touch-and-go training. There is no clear reference in the Smartlynx Estonia ATO TM Touch-And-Go air exercise section to consult additional procedures, however, there is an illustration (identical to the illustration from Airbus A320 Base Training Syllabi, indicated on Figure 65) in the Air Exercise paragraph under Aerodromes section, that gives a procedure for the instructor to:

- disarm the spoilers after the main landing gear has touched down,
- set flaps 2,
- reset rudder trim,

- check FWD movement of pitch trim,
- call „GO“,
- call „power set“,
- call „rotate“ at V_{APP}.

Additionally, there is a procedure in the **operators** (Smartlynx Airlines Estonia - the AOC holder) Flight Crew Techniques Manual (FCTM) that detail the touch-and-go procedures accordingly to Airbus FCTM (Figure 69).


A318/A319/A320/A321 FLIGHT CREW TECHNIQUES MANUAL

PROCEDURES

NORMAL PROCEDURES

SUPPLEMENTARY PROCEDURES - TOUCH AND GO

Continued from the previous page

Trainee	Instructor
	- Set flaps configuration for takeoff [2] - If necessary, reset the rudder trim - Monitor/adjust the pitch trim movement towards the green band - Place one hand behind the thrust levers to ensure that they are advanced to approximately 5 cm (2 in) - Order "GO" when the aircraft is in the correct configuration (pitch trim, rudder trim and flaps).
Set TOGA thrust.	
Remove the hand from the thrust levers.	- Check engine parameters and announce "THRUST SET" - Order "ROTATE" at VAPP - Maintain the hand behind the thrust levers to ensure that the trainee does not perform an inadvertent reduction of thrust or unwanted stop.
Rotate the aircraft and target takeoff pitch attitude, then follow SRS.	

(1) At nosewheel touchdown, the instructor pushes on the SPEED BRAKE lever to disarm the ground spoilers. The objective is to initiate the immediate retraction of the ground spoilers, and not to wait for their automatic retraction while the thrust levers are advanced.
Carefully disarm the ground spoilers, so that the SPEED BRAKE lever is not moved. If the SPEED BRAKE lever is not in the fully-retracted position, the CONFIG SPEED BRAKES NOT RETRACTED alert will appear and the SPEED BRAKE lever will possibly command speed brakes extension. As per aircraft design, ground spoilers automatically retract when thrust levers are set above CLB detent.

(2) Flap settings are as follows:
- Landing configuration: CONF FULL
- Takeoff configuration: CONF 2.

MYX A318/A319/A320/A321 FLEET FCTM ←A→ PR-NP-SP-40 P 2/4 22 MAR 17

A318/A319/A320/A321 FLIGHT CREW TECHNIQUES MANUAL

PROCEDURES

NORMAL PROCEDURES

SUPPLEMENTARY PROCEDURES - TOUCH AND GO

Ident.: PR-NP-SP-40-A-00020992.0001001 / 20 MAR 17

VISUAL PATTERN

MYX A318/A319/A320/A321 FLEET FCTM ←A PR-NP-SP-40 P 3/4 22 MAR 17

Figure 69 Smartlynx Airlines Estonia FCTM procedures for touch-and-go

Training for aircraft mechanical back-up

The A320 Flight Crew Training Standards Manual (FCTS) recommends that during a pilot initial Type Rating course, each trainee should experience the mechanical backup situation in flight (during cruise), in order to practice the pitch control of the aircraft with the use of the pitch trim only. To experience the progressive degradation of flight control law from normal law to mechanical backup situation, it has been decided to trigger it by a triple failure: HYD B RSVR LO LVL + F/CTL ELAC 2 FAULT + F/CTL SEC 2 FAULT. Then the flight crew exit the mechanical backup situation with a computer reset (requested by ECAM).

The degradation of the flight control law to mechanical back up is part of the A320 SSA but due to its extremely remote probability, it has been considered (by Airbus) not to perform training for this situation in approach and landing.

Therefore, for the initial type rating training neither the TRI or the Safety pilot had performed a training element which would have included aircraft being in mechanical backup at take-off during the rotation.

1.18 Pilot Accounts

The persons seated in the cockpit during the event flight (TRI, safety pilot, fourth student and the CAA inspector) were interviewed.

According to the TRI-s statements, when performing the touch-and-go flights, at each approach he decided not to arm the ground spoilers and at each touch-down, he decided to grab the trim wheel while the THS was automatically returning to 0°to stop the THS at the calculated take off position (calculated on the basis of aircraft weight before the training session of each student).

According to the statements of all flight crew members, during the flight, each time as the ECAM display indicated the alert(s) F/CTL ELAC 1 and/or 2 PITCH FAULT, they acted accordingly to the QRH and reset the F/CTL computer(s). None of the crew members interviewed remember having ELAC 1 PITCH FAULT at 13:47 (during the flights with the third student), that was left in a faulty condition, nor they remember seeing[1] the fault on the ECAM display when they started (nor during) the flight with the fourth student, however during approach they remember seeing CAT 3 SINGLE ONLY being presented on the ECAM status page.

As the crew received several ELAC PITCH FAULTs, they remember having doubts about continuing the flight, but as the number of received faults was not limited in the FCOM or in the QRH, the TRI decided to continue with the flights.

According to the TRI`s statements, after taking over the control over the aircraft the aircraft was diving to the ground while he was pulling full back on the side-stick. After the impact he started to trim manually, trying to keep the pitch attitude. When the flight path was more or less stabilized the TRI decided to land as soon as possible (make a right turn back to the RWY26).

Once he got the runway in sight, he chose to fly directly to the threshold (with 10° misalignment) in order to go the shortest way. In "final", when both engines successively stopped at 1000 ft and then 750 ft and when engine 1 was lost the cockpit went totally dark and the RAT deployed. The TRI landed the aircraft using the trim wheel until landing. He did remember having some pitch control over the aircraft while flying the aircraft at this stage. The speed was about 100 kt at touch down. During the ground roll, he tried to use the rudder pedals but the aircraft veered to the right and stopped a few meters off the runway edge.

After the aircraft stopped the Safety pilot performed the QRH procedure „emergency evacuation" and discharged the fire extinguisher. The TRI commanded to evacuate the aircraft.

[1] Analysis for the relevant FDR parameters show (see 1.17.3) that on the basis of the sequence of SD pages that were triggered and changed during that period gives reason to assume that the alert could have been **cleared** by the flight crew (by pressing the CLR p/b) at 13:48:34, and the same for the STATUS page for at 13:48:38. The fact that when the messages are cleared, they do not reappear until the end of the flight could explain why the crew might not remember seeing these faults being displayed.

2 Analysis

The investigation did not reveal any evidence of an additional factor that could have caused or contributed to the loss of control of the aircraft other than flight control computers, the THS and the aircraft operation procedures. Therefore, ESIB focused in this accident analysis on these three main topics.

Training flights

Due to the high cost of an aircraft flight hour, an aircraft type training course practical element is often conducted in a simulator and some parts of it on a real aircraft. The proportions, which training elements and how many flight hours of the total training program is performed on the aircraft and how much of it is done in a simulator, is defined in the ATO TM.

As the ATOs often do not have a designated aircraft for their type training flights they use an aircraft that is normally operated for some commercial flight operations, for a very short period, to carry out the required training element.

As for this event, Smartlynx Estonia ATO was using an aircraft that was normally operated by Smartlynx Airlines Estonia. To organize such practical training elements, it requires the availability of the aircraft, training instructors, students, suitable weather etc. Therefore, considering the logistics of this type of flights the performance pressure to complete the training program planned for the day cannot be ruled out when evaluating the decision making process.

With the addition to the performance pressure, the framework of operational rules for training flights in normal and abnormal situations in this case was not as well developed as for generic commercial flights. Therefore, the crew did not have a clear procedural base from the documentation for making the decision to discontinue the flights in case of this repetitive failure:

- Airbus A320 Base Training Syllaby, in the Air Exercise paragraph under Aerodromes section, describes a procedure for the instructor to disarm the spoilers **after** the main landing gear has touched down. However, Smartlynx Estonia ATO TM does not provide a clear requirement to arm the spoilers when performing touch-and-go training element. The lack of procedures and the lack of understanding of the importance of arming the spoilers on touch-and-go training, formed a base for the TRI to make a decision not to arm the spoiler during this training element.
- At the time of the event Airbus QRH did not define the maximum allowed number of resets for the flight control computes and the FCTM did not require to consider MEL (any ELAC2 fault is a NO DISPATCH item) on touch-and-go and stop-and-go training. This enabled the TRI to make a decision to continue with the flights when having several ELAC1 and ELAC2 PITCH FAULT ECAM messages as there was no procedure that would forbid the continuation of the flight.
- Smartlynx Estonia ATO OM defines the roles and responsibilities of the management and administrative personnel, including the training instructors. It also gives a description of the actions to be taken in aircraft handling and for PF/PNF task sharing in the cockpit, but it gives a very brief definition for the role in the cockpit for the Safety Pilot (second experienced pilot). The regulations set by EC and EASA for arranging the training flights do not detail the use of Safety Pilot in the cockpit, leaving it open for the ATOs. The fact that the role of the Safety Pilot

is not clearly defined, shaped the crew performance in a way that the task sharing had to be improvised in a very stressful situation.

ELAC PITCH FAULT messages

During the training flights the aircrafts` F/CTL system triggered several ELAC PITCH FAULTs while the instructor was manually stopping the trim wheel when the THS was returning to 0° after touch down (ground setting).

The investigation revealed that the ELAC PITCH FAULT messages were originated from the intermittent failure of the THSA OVM. The ELAC PITCH FAULT was triggered by the computer in control (ELAC1 or ELAC2) due to erratic signals coming from the PTA micro-switches. The incorrect triggering of the PTA micro-switches was caused by a non-standard displacement of the OVM output piston which, in turn, was caused by a non-standard friction curve of the OVM clutch unit. The oil in the OVM was measured to be with almost twice of the viscosity of the oil required by the manufacturer. The higher viscosity of the oil most probably contributed to having a non-standard friction curve in the OVM clutch unit. The investigation could not confirm this hypothesis it by experiment data nor could determine a documented origin of the wrong oil in the THS.

The fact that the aircraft maintenance documentation does not require any test of the OVM during aircraft regular maintenance checks could have contributed to the result that the wrong oil in the OVM was left unnoticed during aircraft exploitation.

Additionally, as the ECAM caution messages were inhibited during approach, landing and take-off (see figure 22) and as they appeared after the aircraft passed 1500 ft, it made it hard for the flight crew to make a link between a hardware failure on landing and a repetitive computer failure messages appearing in level flight. This might have lead them to underestimate the problem as it was apparently solved by a single reset.

The fact that the ELAC 1 was left un-reset by the crew following the last F/CTL ELAC1 PITCH FAULT cannot be fully explained by the investigation. It has to be noted that the F/CTL ELAC 1(2) PITCH FAULT ECAM alert is for crew awareness and therefore has no associated procedure and aural warning. The flight crew can consider a system reset if it is authorized by the QRH system reset table (as for this case, it was). The absence of single chime for this ELAC1 PITCH FAULT situation as per system design, compared to the previous one for which a single chime of unknown origin was concomitant (and that was followed by ELAC reset by the crew) may have played a role in the absence of computer reset by the crew.

The analysis of the FDR data shows:

- At 13:47:06, when the aircraft was touching the ground, the parameter “EL1PF” switching to 1, referring to ELAC 1 PITCH FAULT being triggered, but not being displayed;
- At 13:47:42, when the aircraft was at 1668 ft RA, F/CTL page is called by the system;
- At 13:48:34, when the aircraft reached 2200 ft RA: the F/CTL page is replaced by the STATUS page;
- At 13:48:38, the STATUS page is being replaced by the CRUISE page.

This sequence of SD pages is consistent with an ECAM alert F/CTL ELAC 1 PITCH FAULT displayed at 13:47:42, and cleared by the flight crew (by pressing the CLR p/b) at 13:48:34, and the same for the STATUS page at 13:48:38, but none of the interviewed flight crew members confirm having seen this ECAM alert.

Once an ECAM alert is cleared this alert message will not be triggered again until the end of the flight. In normal operations, this recall is requested by SOP before each flight during the Preliminary Cockpit Preparation and done by the flight crew by pressing the Recall (RCL) pushbutton during 3sec." Subsequently, the crew reset ELAC 2 without resetting ELAC 1. This might indicate that the crew was not aware of the fact that ELAC 1 was (still) faulty and was therefore not reset by the crew.

Loss of elevator control

According to the DFDR data, a ground setting was commanded by ELAC2 at 15:05:00 (5 s after ground condition). Ground Setting continued by ELAC2 until 15:05:05 when stopped before 0°. ELAC2 pitch fault was triggered and pitch normal law reverted to alternate law at 15:05:05. Both ECAM alerts were not displayed due to inhibition phase. At 15:05:10 F/CTL L+R ELEV FAULT ECAM warning was triggered, followed by a MASTER WARNING. According to the troubleshooting data of the EFCS, SEC2 was confirmed to be engaged on THS and elevators at 15:05:05.
Although the FDR and TSD data refer to SEC2 engagement on THS, the recorded EACM warning F/CTL L+R ELEVATOR FAULT indicates that both SEC lost the control of the pitch leading to no flight control law engaged in pitch. Therefore, in order analyze the behaviour of SEC computers, investigation of SEC was undertaken.

The inability to control the THS and the elevators can be explained by the short rebound of the landing gear during the event flight. As the touch-and-go training was performed without spoilers being armed, it caused the aircraft to have more lift on touchdown and contributed to having the aircraft shortly bounce on the runway. The left landing gear was decompressed during around 1 second (the sampling rate of this parameter is 1 second and do not allow to determine the exact duration – between 0 and 2 seconds) (figure 70). Due to asynchronism between SEC COM and MON lanes, and due to the update of the input parameters (gear compression), one channel can apply Flight mode flight control deflection orders (one landing gear seen decompressed for more than 1.020 seconds) whereas the other one Ground mode orders (one landing gear seen decompressed for less than 1.020 seconds).

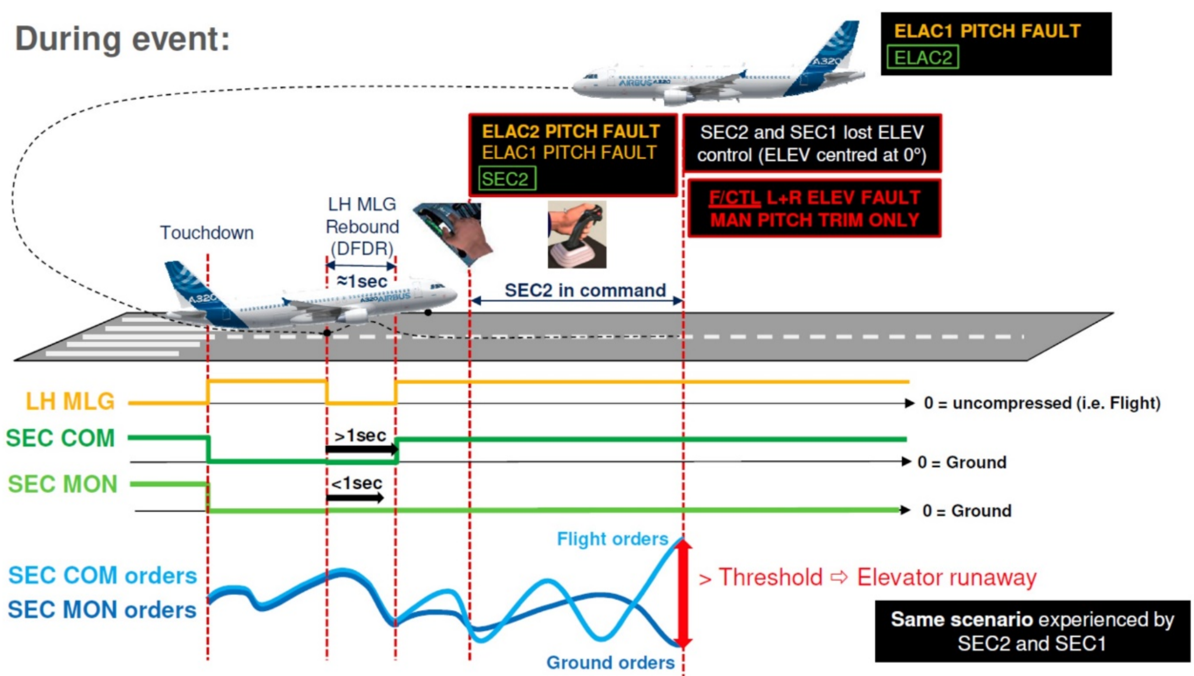


Figure 70 Sequence of events, discrepancy in SEC COM and MON orders

This condition can only be met if the decompression lasts around 1 second. Simulations were performed on Airbus test bench, with signal monitoring and this condition could be reproduced, leading to the triggering of the SEC fault messages (SEC-MON OR WIRING TO x y ELEV SERVO VLV) linked to the spool valve runaway monitoring.

As the LGCIU 1 and 2 send the same information through the same ARINC BUS, both SEC computers received the same landing gear information and therefore, during the event, both SEC saw the same inputs from LGCIUs and triggered the same fault messages, resulting in the loss of elevator control by both SECs.

The discrepancy of the SEC`s COM and MON lanes can be determined as the root cause for the loss of **elevator control** by both SECs. This system behaviour, which cannot be seen as a failure, as it is part of the SEC design (hence not covered by SSA), should be considered as a weakness of the design that was revealed during this accident.

Rejection of take off

During the event, as the TRI commanded „GO“ at 15:05:03, the student started to move the thrust levers to 42° (TOGA). The levers reached 42° at 15:05:07. At 15:05:13 the TRI discovers that the aircraft is not rotating and takes over the control. By that time CAS was 170 kt, and the aircraft was 1600 m from the end of the runway.

The decision to reject a take-off is normally a rule-based decision with clearly defined failure events and a calculated V1 decision speed. The manufacturer advises that a touch-and-go should not be rejected once TOGA is set, unless the commander is certain the aircraft will not safely fly and notes that there is no V1 decision speed on a touch-and-go.

As for this accident, by the time the TRI realizes that the aircraft is not rotating and as he takes over the control, TOGA power had already been selected and kept for 6 seconds. At this time the crew do not fully understand the condition of the aircraft, and on basis of the normal operational procedures, aircraft speed, location, engine speed, the TRI decides not to reject the take-off.

Impact with the runway and pitch up

The FDR and CVR data reflects that when the TRI takes over the control of the aircraft and commands at 15:05:19 „Gear Up“, shortly after, at 15:05:22 the aircraft radio altitude was 38 ft (and slowly increasing), the CAS 191 kt and THS stable in position 1,5° up.

This initial lift-off and slow increase in altitude was caused by the THS being in pitch up position (1,5° UP) and by the increase of the aircraft airspeed.

At 15:05:19 both thrust levers were retarded to IDLE detent for almost 4sec (before being selected back to TOGA detent) and at 15:05:25 when the flaps and slats reached CONF 1+F the aircraft started to lose altitude and hit the ground at 15:05:27.

The fact that the aircraft lost altitude can be explained by the thrust levers retard to IDLE detent for almost 4sec and by the decrease of lift from the flap/slat configuration change.

At 15:05:28 the aircraft starts rapidly to pitch (approximately 6000 ft/min) up.

As the aircraft landing gear was in transition when the aircraft hit the ground, the initial pitch up movement (from -1,7° to +8,8°) can be explained by the front landing gear hitting the runway and changing the aircraft pitch, leading to pitch increase up to +20° with the contribution of the THS being in position 1,5° UP and both thrust levers in 42° (TOGA) position (CAS approximately 200kt).

Crew performance and coordination

At 15:05:13, as the TRI realized that the aircraft does not rotate and as he took over the control of the aircraft, the PFD indicated MANUAL PITCH TRIM ONLY and L+R ELEVATOR FAULT on the ECAM display (and a continuous repetitive chime was triggered at 15:05:10). At that time, no crew member announced the L+R ELEV FAULT and MAN PITCH TRIM ONLY. The fact that initially there was no reaction to the ECAM warning (and the master warning) was probably due to information overload and confusion from the unexpected situation:

- the TRI was performing in performing 2 roles - Pilot Monitoring and as an instructor. Thus the task sharing was different from a normal situation,
- the aircraft control handover and the role change might have caused a delay in understanding the situation,
- the student pilots` performance compared to an experienced pilot was most probably lower in a stressful emergency situation,
- the fact that the aircraft was not responding to the inputs on sidestick might have generated a very high stress in this time limited and dynamic phase for which actions are normally learned to be executed in a very quick and automatic way,
- the fact that the role of the Safety Pilot is not clearly defined might have caused confusion because the task sharing had to be improvised under a stressful situation.

At 15:05:42 while the aircraft was in climb, the Safety pilot started to read out loud the PFD message "MAN PITCH TRIM ONLY" to attract the TRI`s attention on the flight controls while the TRI and the student shared their lack of understanding of the situation. **36 s** after the triggering of these messages the TRI started to control the aircraft pitch by using the pitch trim wheel and engine thrust, however kept applying inputs on the side stick (in all control axis) even it had no effect over aircraft pitch control.

Due to the rare nature of this situation – having the aircraft in mechanical backup during rotation – and the fact that the TRI had to take over the control of the aircraft and to understand the condition of it, caused confusion and the lack of understanding of this situation. The fact that there is no training for the crew for aircraft being in Mechanical back-up at rotation, the TRI had to learn and adapt flying the aircraft in pitch with trim and engine thrust while handling this unexpected situation.

As the role of the Safety pilot was not clearly defined in the ATO OM, the lack of pre-defined tasks and task sharing, led to the need for improvising and taking initiative by the Safety pilot in a very stressful situation, resulting this delay in understanding the situation and taking necessary actions to manage the situation.

After the crew had stabilized the aircraft flight path at 15:06:29 the TRI tried to make radio contact with the ATC tower and declare "Mayday, mayday, mayday". Due to high workload of the TRI the communication was discontinued and at 15:07:00 the Safety pilot took initiative in taking over the radio communication. During the radio communication with the tower at 15:07:02 the crew made a decision to directly turn back, change the runway in the MCDU, and try to land the aircraft on the opposite runway. During this period the TRI never calls for ECAM actions. The Safety pilot takes initiative in this situation again at 15:06:39 and starts to read out loud the ECAM messages. At 15:07:44 after the command from the TRI, the student pilot and the Safety pilot change seats and the Safety pilot starts to support the TRI in radio communication and as PM.

Although engine 2 indicated fire, and engine 1 indicated oil low pressure issues, the TRI decided to keep the engines running as long as possible (until engine no. 2 spooled down at 15:09:21 and engine no. 1 spooled down at 15:09:38).

The crew actions in managing the prioritization of tasks – following the “golden rule” – fly, navigate, communicate, the initiative from the Safety pilot and the prompt decision to turn back, approach the runway as directly as possible (with the aircraft not being aligned with the runway axis) and keep the engines running as long as possible, enabled the crew to manage this situation, keep the aircraft under control and land the aircraft without casualties.

Loss of engine- and hydraulic power

As the THS actuation is performed by two hydraulic motors, driven by the Green and Yellow hydraulic systems (Figure 14), no matter whether these hydraulic motors are mechanically controlled (by the trim wheel) or by the 3 electrical motors, if the hydraulic pressure is lost in both Green and Yellow system, the THS actuation is lost. During the event, both engines suffered major impact damage leading to engine 2 spool down at 15:09:21 and engine 1 spool down at 15:09:38. As the Green hydraulic pressure pump is driven by the engine no 1. and the Yellow system pressurized by a pump driven by the engine no 2. the hydraulic pressure and thus the THS actuation should have been lost[1]. According to the pilots` statements, the pitch control of the aircraft was potentially not completely lost after both engines spooled down. This could be explained by the fact that the wind-milling of the engine 2 was enough to provide a limited authority. As the AGB of engine 1 was seized and as it operates hydraulic pump that pressurizes the Green system, the wind-milling of engine 1 could have not contributed in pressurizing the hydraulic system.

[1]In case power is lost in both engines, the hydraulic pressure is available down to around 12% N2 speed. At low aircraft speed (below 150kt), the engine wind-milling will no longer be able to provide hydraulic pressure (N2 speed will drop to 0).

3. Conclusion

3.1 Findings

- The accident happened during training flights with 7 persons on board.
- TRI, Student, Safety Pilot and an ECAA inspector were in the cockpit during the event flight.
- The aircraft had no known technical problems before the flight.
- The crew had the licenses and qualifications required for the flight.
- The aircraft had a valid airworthiness certificate.
- The aircraft weight and balance were within operational limits.
- The meteorological situation was what could be expected at that time of the year, with no significant weather phenomena.
- Smartlynx Estonia ATO OM does not give a clear definition for the role of the Safety Pilot.
- Smartlynx Estonia ATO TM does not give a clear reference for the procedure for arming ground spoilers on Touch and Go training.
- The TRI did not arm the ground spoilers on touch and go training.
- For the Touch and Go training, the TRI adjusted the trim setting by grabbing the trim wheel while the THS was returning to 0° (i.e. during the ground setting) to adjust the proper THS setting for take-off.
- Several ELAC PITCH FAULT warning messages were triggered as the TRI was manually stopping the trim wheel (at around 1° Nose Up) while the THS was returning to 0° after touch down. Due to an inhibition logic, these ECAM messages were displayed with a delay - when the aircraft was 1500 ft above ground level.
- ELAC PITCH FAULT messages were originated from the intermittent failure of the THSA OVM. The ELAC PITCH FAULT was triggered by the computer in control (ELAC1 or ELAC2) due to erratic signals coming from the PTA micro-switches. The incorrect triggering of the PTA micro-switches was caused by a non-standard displacement of the OVM output piston which, in turn, was caused by a non-standard friction curve of the OVM clutch unit. The oil in the OVM was measured to be with almost twice of the viscosity of the oil required by the manufacturer. The higher viscosity of the oil might have contributed to having a non-standard friction curve in the OVM clutch unit. The investigation could not confirm this hypothesis it by experiment data nor could determine a documented origin of the wrong oil in the THS.
- The crew made 5 resets to ELAC1 and 4 resets to ELAC2 according to QRH.
- ELAC1 was not reset after ELAC 1 PITCH FAULT triggered at 13:47.
- None of the crew members can recall the ELAC 1 PITCH FAULT being triggered nor displayed at 13:47 or any time later.
- On the final Touch and Go (before the accident) the computer engaged on pitch control was ELAC2. When the TRI was grabbing the trim wheel while the THS was automatically returning to 0°, ELAC2 PITCH FAULT was triggered.

- Six seconds before the ELAC2 PITCH FAULT was triggered and the pitch control was taken over by SEC2, the LH main L/G of the aircraft bounced (i.e. become decompressed) between 0 to 2 sec.
- Once the pitch control was taken over by the SEC2, this LH Main L/G rebound (more than 1,02 sec) generated a discrepancy between the SEC COM and MON units, leading one unit to be computing elevator orders in flight law while the other unit was computing orders in ground law. This COM/MON discrepancy on the Flight/Ground condition was permitted due to the combination of a weakness of the COM/MON consolidation logic of this Flight/Ground condition and of the asynchronies between the COM and MON units. This discrepancy resulted in the triggering of the Elevator spool valve runaway monitoring leading to the loss of control of both elevators by both SECs and to elevators moving and locking at neutral position. As the LGCIU 1 and 2 send the same information through ARINC BUS 1 and 2 to SEC1 and SEC2, both SEC computers received the same landing gear information and therefore almost simultaneously lost pitch control.
- The loss of all flight computers` control over aircraft pitch during ground roll caused the aircraft being in PITCH Mechanical Backup and in Roll direct Law, resulting the inability to control the aircraft pitch by acting on the sidestick.
- The FMES "Permanent Electrical mode signal from 3 micro switches" (OVM failure) combined with pilot action on trim wheel during touch and Go is not used in the fault tree of the failure condition "Loss of control of both elevators, both locked neutral" in Airbus A320 System Safety Analysis. During the investigation, it was checked that even with this combination of an OVM failure and a human action, the probability of the failure condition “Loss of control of both elevators, both locked neutral” still meets the safety objective.
- A red ECAM warning F/CTL L+R ELEV FAULT was displayed on the E/WD (with a CRC audio warning) and the message "MAN PITCH TRIM ONLY" was indicated red on the PFD.
- The increasing airspeed caused the aircraft to become airborne and slowly gain altitude.
- The TRI took over the control of the aircraft (from the student).
- The TRI commanded to retract the landing gear, to which the trainee acted accordingly.
- The change in the flap/slat configuration and the temporary trust lever movement to IDLE detent, caused the aircraft lift and pitch decrease, leading to loss of altitude and impact with the runway.
- The impact with the aircraft nose landing gear, with the addition of THS position (1,5° UP) and increasing airspeed caused the aircraft to pitch up and rapidly gain altitude.
- Engine no 1. AGB lower surface got heavily abraded and perforated during the impact with the ground. The AGB oil was rapidly lost through the perforation, leading to AGB seizure and engine spool down.
- Engine no 2. AGB lower surface got heavily abraded and the impact damage caused engine to catch on fire. As a result of the fire, the engine wiring harness got damaged and caused loss of data communication from/to ECU, resulting engine no 2 spool down.
- On climb out, the TRI and the student did not understand the situation and shared their lack of understanding. The safety pilot starts to read the MAN PITCH TRIM ONLY message to attract the TRI`s attention on the flight controls. The action on the trim wheel was initiated 36 s after the triggering of the MAN PITCH TRIM ONLY.

- The TRI started to control the aircraft pitch by using the pitch trim wheel and engine thrust, however keeping applying inputs (on all control axis) on the side stick even when it had no effect in pitch.
- The TRI was able to stabilize the flight path.
- The TRI made radio communication but did not call for ECAM actions.
- Safety pilot started to read ECAM and took over radio communication and declared flight controls fail.
- The TRI commanded to change the runway in the MCDU, the command was executed.
- The student and the safety pilot changed seats and the student and ECAA inspector were seated in the cabin.
- The TRI decided not to apply the engine fire procedure to keep the engines running as long as possible.
- During the final approach the aircraft lost power in both engines which resulted in a loss of Green and Yellow hydraulic power.
- RAT was deployed and the APU was powered up.
- The aircraft landed hardly 150 m before the runway threshold.
- Hard landing of the aircraft burst all tires.
- The aircraft decelerated on the runway, veered off and stopped close to the left runway edge.
- During the impact, two persons on board suffered minor impact trauma.
- The aircraft suffered damage beyond reasonable limits for repair, resulting in aircraft hull loss.

3.2 Causal factors

This accident results from the combination of the following factors:

- **The intermittent THSA override mechanism malfunction allowing to cause the loss of pitch control by both ELACs.**

  The repetitive triggering of the ELAC PITCH faults was caused by the non or late activations of the PTA micro-switches, which were due to the OVM piston insufficient stroke. The insufficient OVM stroke was caused by the THSA OVM clutch unit non-standard friction. The oil in the THSA OVM casing appeared to be with a higher viscosity than defined in the CMM. The higher viscosity might have reduced the friction of the OVM clutch unit, causing the THSA OVM non-standard friction.

- **SEC design flaw allowing for a single event, the left landing gear temporary dedecompression, to cause the loss of pitch control by both SECs.**

  The absence of ground spoilers arming for landing in the context of touch and go's training may have contributed to the temporary decompression of the left main landing gear.

- **The training instructor`s decision for continuation of the flight despite repetitive ELAC PITCH FAULT ECAM caution messages.** The lack of clear framework of operational rules for training flights, especially concerning the application of the MEL, and the specific nature of operations that caused pressure to complete the training program may have impacted the crew decision-making process.

3.3 Contributory factors

- Smartlynx Estonia ATO TM does not **clearly** define the need for arming spoilers when performing touch-and-go training (ATO procedures not in accordance with Airbus SOP). The fact that there is no clear reference in the Smartlynx Estonia ATO TM Touch-And-Go air exercise section to additional procedures that should be used, in combination with lack of understanding of the importance for arming the spoilers during this type of flights contributed to TRI making a decision to disarm the spoilers during touch and go training enabling landing gear bounce on touch down.
- At the time of the event Airbus QRH did not define the maximum allowed number of resets for the flight control computers.
- At the time of the event Airbus FCTM did not require to consider MEL on touch-and-go and stop-and-go training.
- The oil in the THS OVM casing was with higher viscosity than defined in the CMM. The higher viscosity might have reduced the friction of the OVM clutch unit.
- The aircraft maintenance documentation does not require any test of the OVM during aircraft regular maintenance checks.
- Smartlynx Estonia ATO OM does not clearly specify the role in the cockpit for the Safety Pilot. The lack of task sharing during the event caused the ECAM warnings to be left unnoticed and unannounced for a long period.
- The crew not resetting the ELAC 1. The fact that ELAC 1 PITCH FAULT was left unreset lead to the degradation of the redundancy of the system.

Considering the remoteness of the loss control of both elevators, there is no specific crew training for MECHANICAL BACKUP in pitch during approach, landing and take-off. This condition of the aircraft occurred for the crew in a sudden manner on rotation and during training flight, where the experienced TRI is not in PF role and cannot get immediate feedback of the aircraft behaviour and condition. Despite these difficult conditions the crew managed to stabilize and land the aircraft with no major damage to the persons on board. The crew performance factors that contributed to the safe landing of the aircraft are the following:

- The TRI followed the golden rule of airmanship (fly, navigate, communicate), by stabilizing the aircraft pitch by using the trim wheel and by keeping the aircraft engine power as long as possible;
- The Safety Pilot started to play a role in the cockpit by assisting the TRI and student by informing them about the status of the aircraft and later on taking the role of the PM.

4. Safety Recommendations

4.1 Actions taken so far

1. The "touch and go" and "stop and go" training procedures in Airbus A320 FCTM have been modified in December 2018 with the following:

TOUCH AND GO

If any failure occurs during the touch and go training, the flight crew must first perform the ECAM/QRH/OEB actions. Then, during the decision process, the instructor should consider MEL for assessment of the training continuation. For the determination of the MEL repair interval, consider each "touch and go" or "stop and go" as one flight.

STOP AND GO

Before the next takeoff, the flight crew should perform all of the following actions:
- Consider MEL (if applicable). For the determination of the MEL repair interval, consider each "touch and go" or "stop and go" as one flight.

DURING TOUCH AND GO

Trainee	Instructor
- Perform usual flare and landing technique - Maintain the runway centerline.	
	- Disarm the ground spoilers (1) - Order "STAND UP".
Move forward the thrust levers approximately 5 cm (2 in), in order to prevent the reduction of engines to ground idle.	
	- Set flaps configuration for takeoff (2) - If necessary, reset the rudder trim - Monitor the pitch trim movement towards the green band - Place one hand behind the thrust levers to ensure that they are advanced to approximately 5 cm (2 in) - Order "GO" when the aircraft is in the correct configuration (pitch trim, rudder trim and flaps).
Set TOGA thrust.	
Remove the hand from the thrust levers.	- Check engine parameters and announce "THRUST SET" - Order "ROTATE" at VAPP - Maintain the hand behind the thrust levers to ensure that the trainee does not perform an inadvertent reduction of thrust or unwanted stop.
Rotate the aircraft and target takeoff pitch attitude, then follow SRS.	

2. Following this event, Airbus has decided to be more restrictive in terms of ELAC reset following a F/CTL ELAC 1(2) PITCH FAULT ECAM alert in order to forbid multiple resets in flight. However, a review of the possible failure conditions leading to a F/CTL ELAC 1(2) PITCH FAULT ECAM alert has been performed and has demonstrated that in some specific conditions a subsequent ELAC reset could have adverse effects.

   Airbus finally decided to totally forbid ELAC reset following a F/CTL ELAC 1(2) PITCH FAULT ECAM alert in flight and to restrict the number of ELAC reset to one if this alert triggers on ground with additional actions to ensure that the reset has been successful.

As a result, Airbus A318/A319/A320/A321 QRH System Reset table has been updated from 06.06.2018 with regard to ECAM alerts F/CTL ELAC 1(2) PITCH FAULT as followed:

AIRBUS A318/A319/A320/A321 QUICK REFERENCE HANDBOOK	ABNORMAL AND EMERGENCY PROCEDURES	02.02A 06 JUN 18

SYSTEM RESET TABLE

ECAM System	System malfunction or ECAM Alert (Affected System)	Reset Procedure
F/CTL	F/CTL ELAC 1 PITCH FAULT (ELAC)	<u>In flight:</u> - Not authorized. <u>On ground:</u> CAUTION - Do not reset ELAC in case of dispatch with MMEL item SEC 1 or SEC 2. - Do not attempt more than one reset. - Set ELAC 2 pb-sw to OFF - Set pitch trim to 5 UP position - Set ELAC 1 pb-sw to OFF - Wait 3 s - Set ELAC 1 pb-sw to On - After 15 s, check pitch trim at 0 position - Perform a flight control check - Set ELAC 2 pb-sw to On - Set pitch trim to takeoff CG <u>Note:</u> *Record the ELAC 1 reset in the logbook (successful or unsuccessful).*
	F/CTL ELAC 2 PITCH FAULT (ELAC)	<u>In flight:</u> - Not authorized. <u>On ground:</u> CAUTION - Do not reset ELAC in case of dispatch with MMEL item ELAC 1, SEC 1 or SEC 2. - Do not attempt more than one reset. - Set ELAC 1 pb-sw to OFF - Set pitch trim to 5 UP position - Set ELAC 2 pb-sw to OFF - Wait 3 s - Set ELAC 2 pb-sw to On - After 15 s, check pitch trim at 0 position - Perform a flight control check - Set ELAC 1 pb-sw to On - Set pitch trim to takeoff CG <u>Note:</u> *Record the ELAC 2 reset in the logbook (successful or unsuccessful).*

3. Airbus has issued a Flight Operations Transmission (FOT) to all A318/319/A320/A321 operators about the renewed system reset table.

4. Airbus has initiated an ELAC software modification development for monitoring the THS during the THS Ground Setting phase (i.e. From 5 s after ground condition and THS back to 0^{o} position). The aim of the modification is to mitigate the consequences of a non-detection of a manual takeover of the THS (the failure that caused the triggering of the ELAC PITCH FAULT).

The certification of the ELAC software improvement with a worldwide retrofit is planned for mid-2020.

5. Airbus has initiated a SEC software modification development to improve SEC COM/MON consolidation logics. The aim of the modification is to improve SEC robustness against landing gear bounce around logic triggering threshold (1 s) at touchdown.

   The certification of the SEC software improvement is planned with the next upcoming SEC standard.

6. Smartlyx ATO OM has been modified with the following:

1.7 APPROVAL/ AUTHORISATION OF FLIGHTS

The following approvals/ authorisations have to be obtained before Flight Training on an Aircraft:

– aircraft with less than 1 (one) year of maintenance records with SmartLynx Estonia/SmartLynx Airlines cannot be used to conduct Base Training flights.

1.10.1 Duties and Responsibilities of Commander

Commander is responsible:

– To monitor the level of fatigue of all the crew members from the moment of the reporting time

1.10.1.1 Prior to Flight

Commander shall:

– Ensure an aircraft does not depart with any defect affecting airworthiness that has not been processed in accordance with the MEL/CDL. Moreover Base Training flights cannot be conducted if one or any combination of the following ATA defects are affecting the aircraft status, also if in accordance with MEL: (22) Auto Flight, (27) Flight Controls, (28) Fuel, (32) Landing Gear, (34) NAV Navigation, (70) Engines.

1.10.1.2 During the Flight

Commander can decide to stop the flight activity anytime due to:

• the level of fatigue of the crew members;

• the occurence of technical faults;

• the degradation of weather condition;

• increase of air traffic into airport CTR.

1.16 FLIGHT DUTY PERIOD AND FLIGHT TIME LIMITATIONS

1.16.2 Students

Flight Training on an Aircraft

When the student operates flight training on an aircraft, the following limitations shall be met:

– total block time as PF shall not exceed 3 hours

– flight duty period shall not exceed 10 hours

– the number of approaches and landings as PF shall not exceed 10

4.2 Recommendations

Although the loss of elevator control by SEC was primarily caused by the internal logic of the SEC units, the safety actions initiated by Airbus are prioritizing the modifications to ELAC. As the ELAC is the primary system for the aircraft pitch control, and the degradation to SEC is already a failure condition, the modifications to the ELAC prevent the ELAC PITCH fault to occur when the trim wheel is stopped on touch down and therefore reduce the risk of having ELAC PITCH FAULT and degrading the control to SEC.

ESIB is considering these safety actions proposed by Airbus to be proportional and sufficient to mitigate this risk to the required standard.

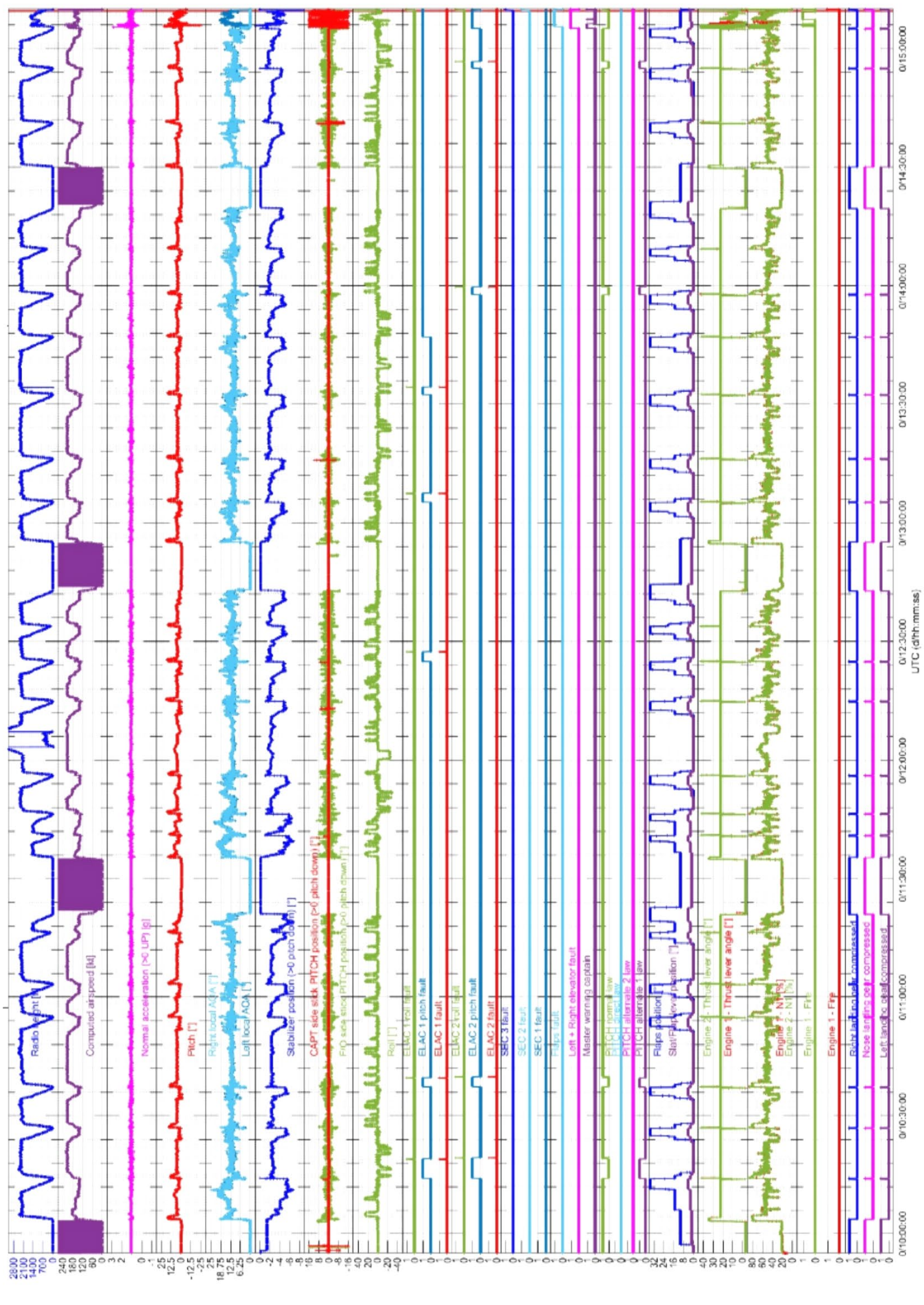
Additionally Estonian Safety Investigation Bureau recommends:

- **Airbus to consider amending A320 maintenance program with procedures necessary to ensure that the condition OVM clutch unit is kept as per design throughout its whole life cycle**.
- **Smartlynx Estonia ATO to include in the ATO OM procedures clear definition of the role and the tasks of the Safety Pilot**.
- **Smartlynx Estonia ATO to modify the ATO TM with touch-and-go procedures accordingly to the Airbus FCTP.**
- **All Aviation Safety Agencies to ensure the compliance of training manual procedures for touch and go training, with the Airbus FCTP of the ATOs performing type rating training on Airbus A320 under their oversight.**
- **All Aviation Safety Agencies to promote the use of a Safety Pilot when performing flight training on complex aircraft.** This accident has revealed the importance of the role of a Safety Pilot when handling abnormal situations during flight training.

APPENDIXES

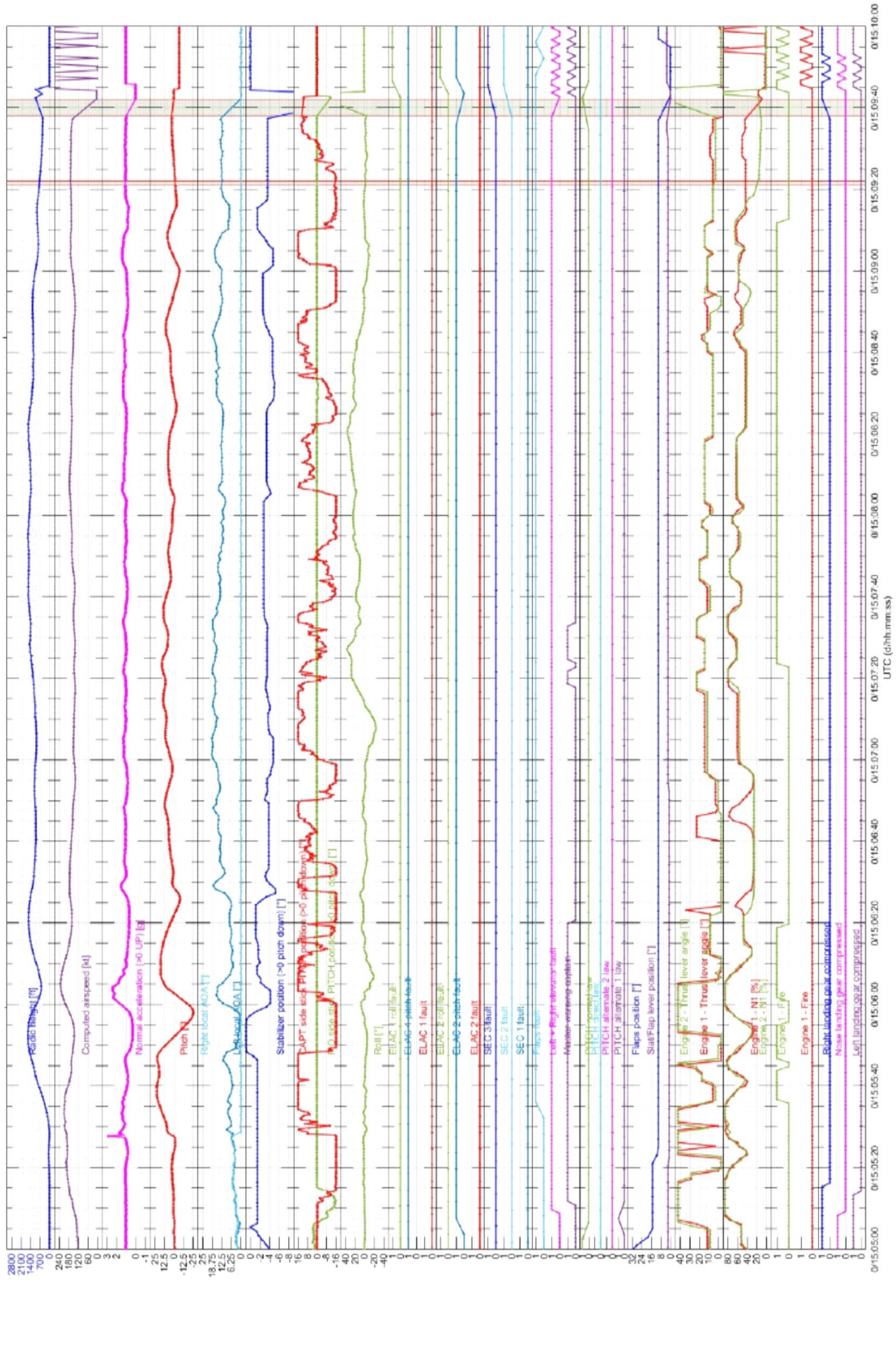
Appendix 1 FDR Plots

FDR data, all day



ESIB: A2802118

EECAIRS: EE0180

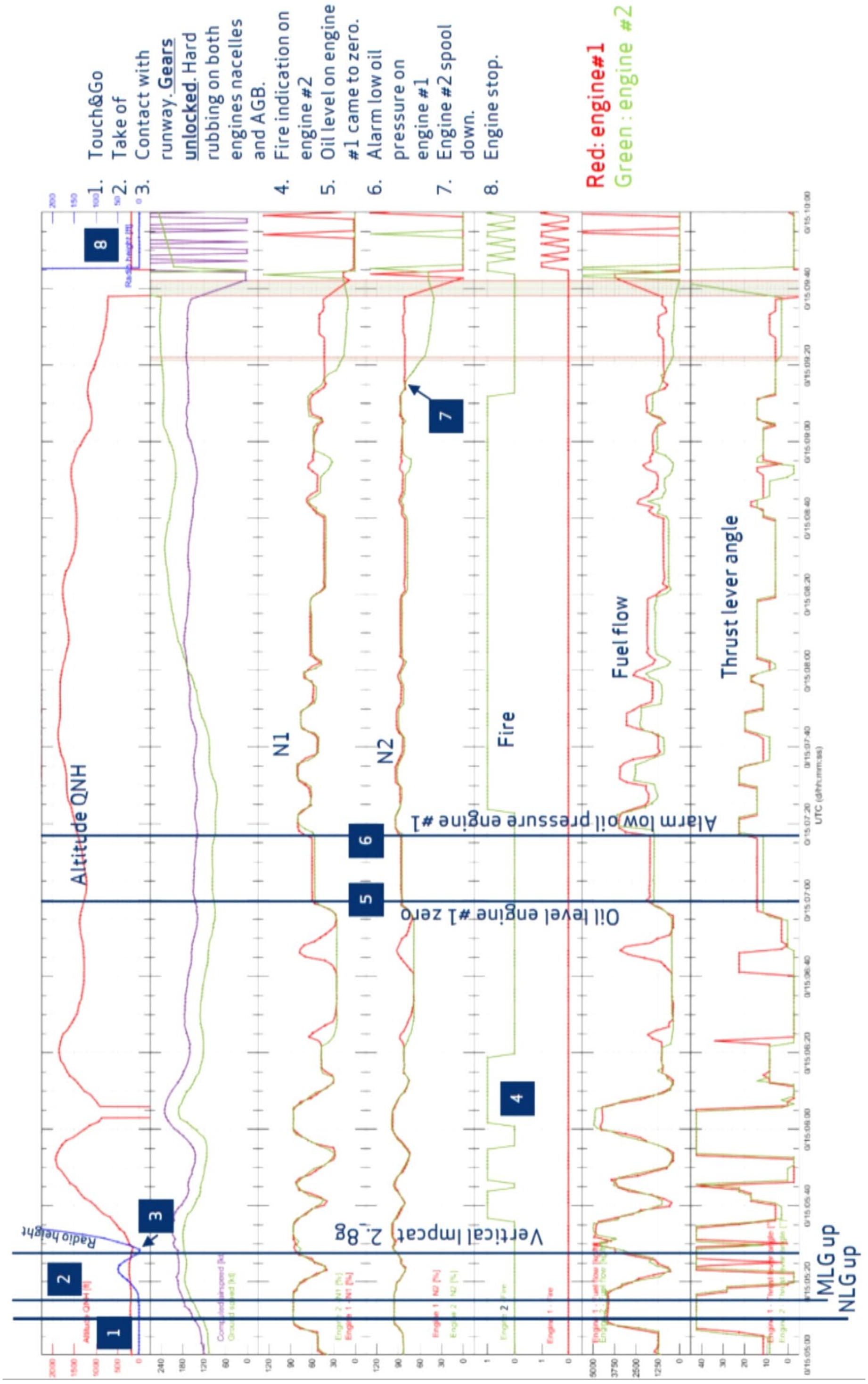


FDR data, event flight

ESIB: A2802118

EECAIRS: EE0180

FDR data, engine parameters



Appendix 2 ECU - NVM SUMMARY

- **ECU #1 (S/N : LMDN3948)**

Several class 1/2 and class 3 failures were recorded on the channels A and B of ECU #1.

Channel A recorded 4 class 1/2 failures (see table 1) and 2 class 3 failures (see Table 2).

Date	Time	Failure	Fault code
-	-	115VAC NO 2 UNAVAILABLE	62d
-	-	N2 FEEDBACK SIGNAL	42d
-	-	ALTERNATOR POWER	5d
25/02	13:19	FUEL MASS FLOW SIGNAL	47d

Table 1: ECU 1 - channel A - class 1/2 faults

Date	Time	Failure	Fault code
21/11	-	GMT VALIDATION FAULT	53d
25/02	13:19	FUEL MASS FLOW SIGNAL	47d

Table 2: ECU 1 - channel A - class 3 faults

Channel B recorded 5 Class ½ failures (see Table 3) and 9 class 3 failures (see Table 4).

Date	Time	Failure	Fault code
-	-	N2 FEEDBACK SIGNAL	42d
-	-	LABEL 030 UNAVAILABLE	56d
25/02	13:19	FUEL MASS FLOW SIGNAL	47d
-	-	ALTERNATOR POWER	5d
-	-	115VAC NO 2 UNAVAILABLE	62d

Table 3: ECU 1 - channel B - class 1/2 faults

Date	Time	Failure	Fault code
-	-	GMT VALIDATION FAULT	53d
25/02	13:19	FUEL MASS FLOW SIGNAL	47d

-	-	N2 FEEDBACK SIGNAL	42d
-	-	155EIU VALIDATION FAULT	60d
-	-	DATE VALIDATION FAULT	54d
-	-	FLGTPHEIU FAULT	55d
-	-	227EIU VALIDATION FAULT	59d
-	-	ECSD DEMAND UNAVAILABLE	51d
-	-	VBV FEEDBACK SIGNAL	18d

Table 4: ECU 1 - channel B - class 3 faults

Note:

- *ECSD : Environmental Control System Demand*
- *EIU : Engine Interface Unit*
- *FLGTPHEIU : FLiGhT PHase EIU*
- *FMV : Fuel Metering Valve*
- *HPTC : High Pressure Turbine Clearance*
- *N2 : Core speed*
- *T25 : High Pressure compressor Inlet Total temperature*
- *TBV : Transient Bleed valve*
- *VBV : Variable Bleed Valve*
- *VSV : Variable Stator Valve*

- **<u>ECU #2 (S/N : LMDN2605) :</u>**

Several class 1/2 and class 3 failures were recorded on the channels A and B of ECU #2.

Channel A recorded 12 Class 1/2 failures (see Table 5) and 6 class 3 failures (see Table 6), see Table 3.

Date	Time	Failure	Fault code
28/02	15:08	BSV SWITCH SIGNAL	3d
28/02	15:08	VBV FEEDBACK SIGNAL	18d
28/02	15:08	TBV VLV Feedback signal	121d
28/02	15:08	HIGH OIL Temperature	72d
28/02	15:09	OIL TEMP FEEDBACK SIGNAL	39d
28/02	15:09	VSV FEEDBACK SIGNAL	17d
28/02	15:09	HPTC VLV FEEDBACK SIGNAL	22d
28/02	15:09	115VAC NO2 UNAVAILABLE	62d
28/02	15:09	LABEL 030 UNAVAILABLE (EIU J3)	56d
28/02	15:09	T25 FEEDBACK SIGNAL	40d

28/02	15:09	FMV FEEDBACK SIGNAL	19d
28/02	15:09	ECSD DEMAND UNAVAILABLE (EIU J3)	51d

Table 5: ECU 2- channel A - class 1/2 faults

Date	Time	Failure	Fault code
28/02	15:09	FLGTPHEIU FAULT	55d
28/02	15:09	227EIU VALIDATION FAULT	59d
28/02	15:09	GMT VALIDATION FAULT	53d
28/02	15:09	OIL TEMP FEEDBACK SIGNAL	39d
28/02	15:09	155EIU VALIDATION FAULT	60d
28/02	15:09	DATE VALIDATION FAULT	54d

Table 6: ECU 2- channel A - class 3 faults

Channel B recorded 12 Class ½ failures (see Table 7) and 12 class 3 failures (see Table 8).

Date	Time	Failure	Fault code
28/02	15:08	VSV FEEDBACK SIGNAL	17d
28/02	15:08	BSV SWITCH SIGNAL	3d
28/02	15:08	T25 FEEDBACK SIGNAL	40d
28/02	15:08	VBV FEEDBACK SIGNAL	18d
28/02	15:08	TBV VLV Feedback signal	121d
28/02	15:08	HIGH OIL Temperature	72d
28/02	15:09	OIL TEMP FEEDBACK SIGNAL	39d
28/02	15:09	HPTC VLV FEEDBACK SIGNAL	22d
28/02	15:09	115VAC NO2 UNAVAILABLE	62d
28/02	15:09	LABEL 030 UNAVAILABLE	56d
28/02	15:09	FMV FEEDBACK SIGNAL	19d
28/02	15:09	ECSD DEMAND UNAVAILABLE	51d

Table 7: ECU 2 - channel B - class 1/2 faults

Date	Time	Failure	Fault code
28/02	15:08	HPTC VLV FEEDBACK SIGNAL	22d
28/02	15:08	FMV FEEDBACK SIGNAL	19d

28/02	15:08	HIGH OIL TEMPERATURE	72d
28/02	15:09	155EIU VALIDATION FAULT	60d
28/02	15:09	DATE VALIDATION FAULT	54d
28/02	15:09	FLGTPHEIU FAULT	55d
28/02	15:09	227EIU VALIDATION FAULT	59d
28/02	15:09	ECSD DEMAND UNAVAILABLE	51d
28/02	15:07	N1 FEEDBACK SIGNAL	43d
28/02	15:08	LPTC VLV FEEDBACK SIGNAL	21d
28/02	15:08	VBV FEEDBACK SIGNAL	18d
28/02	15:08	TBV VLV FEEDBACK SIGNAL	121d

Table 8: ECU 2 - channel B - class 3 faults