Bundesstelle für
Flugunfalluntersuchung

German Federal Bureau of
Aircraft Accident Investigation

Investigation Report

Identification

Type of Occurrence:	Serious Incident
Date:	20 December 2012
Location:	Phuket, Thailand
Aircraft:	Airplane
Manufacturer:	Airbus Industries
Type:	A330-223
Injuries to Persons:	No injuries
Damage:	Minor damage to aircraft
Other Damage:	None
State File Number:	BFU 6X015-12

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

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

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

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Abbreviations

AC	Advisory Circular	
ACARS	Automatic Communications And Reporting System	
ACAS	Airborne Collision Avoidance System	
AD	Airworthiness Directive	Lufttüchtigkeitsanweisung
ADF	Automatic Direction Finder	Radio compass
AFM	Airplane Flight Manual	Flight Manual
AGL	Above Ground Level	über Grund
ALD	Actual Landing Distance	Tatsächliche Landestrecke
AIP	Aeronautical Information Publication	Luftfahrthandbuch
AMC	Aero-Medical Center	flugmedizinisches Zentrum
AME	Aero-Medical Examiner	flugmedizinischer Sachverständigte
AMS	Aero-Medical Section	flugmedizinische Dienst
AMSL	Above Mean Sea Level	über dem mittleren Meeresspiegel
ANSP	Air Navigation Service Provider	Flugsicherungsorganisation
AOC	Air Operator Certificate	Luftverkehrsbetreiberzeugnis
AOM	Airplane Operating Manual	Flugbetriebshandbuch
AP	Autopilot	automatische Flugregelungs- und Steueranlage
APU	Auxiliary Power Unit	Hilfstriebwerk
ARC	Airworthiness Review Certificate	Bescheinigung über die Prüfung der Lufttüchtigkeit
ATC	Air Traffic Control	Flugverkehrskontrolle
ATHR	Auto Thrust	Automatische Schubsteuerung
ATIS	Automatic Terminal Information Service	Automatische Ausstrahlung von Lande- und Startinformationen
ATPL	Airline Transport Pilot Licence	Lizenz für Verkehrspiloten
ATS	Air Traffic Services	Flugverkehrsdienste
ATQP	Alternative Training and Qualification Program	Alternatives Trainings- und Qualifizierungsprogramm

AZF	General Flight Radiotelephone Operator's Certificate	Allgemeines Sprechfunkzeugnis für den Flugfunkdienst
BFU	German Federal Bureau of Aircraft Accident Investigation	German Federal Bureau of Aircraft Accident Investigation
BOAS	Blade Outer Air Seal	Triebwerksschaufelabdichtung
BZF	Restricted Flight Radiotelephone Operator's Certificate	Beschränkt gültiges Sprechfunkzeugnis für den Flugfunkdienst
CA	Cabin Attendant	Flugbegleiter(-in)
CAS	Calibrated Airspeed	Kalibrierte Fluggeschwindigkeit
CAVOK	Ceiling And Visibility OK (for VFR flights)	Bewölkung und Sichtweiten in Ordnung (für Flüge nach VFR)
CCM	Cabin Crew Member	Flugbegleiter/-in
CFI	Chief Flight Instructor	Leitender Fluglehrer
CM1	Cockpit Member Number 1	Captain
CM2	Cockpit Member Number 2	Co-pilot
COP	Co-pilot	Co-pilot
CPL	Commercial Pilot Licence	Berufspilotenlizenz
CRM	Crew Resource Management	
CSO	Cycles since Overhaul	Betriebszyklen seit Überholung
CTR	Control Zone	Kontrollzone
CU	Cockpit Unit	Maßeinheit für die Cockpitanzeige
CVR	Cockpit Voice Recorder	Stimmenrekorder
DFDR	Digital Flight Data Recorder	Digitaler Flugdatenschreiber
DME	Distance Measuring Equipment	Entfernungsmessgerät
E/WD	Engine Warning Display	Warnungsanzeige für Triebwerksparameter
EAS	Equivalent Airspeed	
EASA	European Aviation Safety Agency	Europäische Agentur für Flugsicherheit
EBT	Evidence Based Simulator Training	Ereignisbezogene Simulatorausbildung

ECAM	Electronic Centralized Aircraft Monitoring	Zentrale elektronische Flugzeugüberwachungsanzeige
EDP	Engine Driven Pump	Pumpe, vom Triebwerk angetrieben
EFB	Electronic Flight Bag	
EGPWS	Enhanced GPWS	
EGT	Exhaust Gas Temperature	Abgastemperatur
EICAS	Engine Indication and Crew Alerting System	Elektronisches Flugüberwachungssystem
ELEV	Elevation	Ortshöhe über dem Meer
EPR	Engine Pressure Ratio	Triebwerksdruckverhältnis
ETA	Estimated Time of Arrival	Voraussichtliche Ankunftszeit
ETD	Estimated Time of Departure	Voraussichtliche Abflugzeit
FAA	Federal Aviation Administration	Amerikanische Luftfahrtbehörde
FADEC	Full Authority Digital Engine Control	voll-digitale Triebwerkssteuerung
FAF	Final Approach Fix	Endanflugpunkt
FCL	Flight Crew Licensing	
FCOM	Flight Crew Operating Manual	Flughandbuch
FCTM	Flight Crew Training Manual	
FDM	Flight Data Monitoring	Flugdatenüberwachung
FDR	Flight Data Recorder	Flight Data Recorder
FI	Flight Instructor	Fluglehrer
FIR	Flight Information Region	Flight Information Region
FIS	Flight Information Service	Fluginformationsdienst
FL	Flight Level	Flugfläche
FMS	Flight Management System	
FNPT	Flight and Navigation Procedures Trainer	synthetisches Flugübungsgerät
FOBN	Flight Operations Briefing Note	
FSOV	Fire Shut Off Valve	Brandhahn
FSPB	Fire Shut Off Valve Push Button	Brandhahnauslöseknopf
FWS	Flight Warning System	
ft	Feet	Fuß (1 Fuß = 0,3048 m)

ft	Feet - Flight Altitude	Fuß - Flughöhenangabe
ft/min	Feet per minute	Fuß pro Minute
g	acceleration due to Earth's gravity (9,81 m/s²)	Beschleunigung durch die Erdanziehungskraft (9,81 m/s²)
GA	General Aviation	Allgemeine Luftfahrt
GAFOR	General Aviation Forecast	Vorhersage für die Allgemeine Luftfahrt
GND	Ground	Grund
GNSS	Global Navigation Satellite System	globale Satellitennavigationssysteme
GPS	Global Positioning System	
GPWS	Ground Proximity Warning System	
GS	Ground Speed	Geschwindigkeit über Grund
HDG	Heading	Steuerkurs
HPT	High Pressure Turbine	Hochdruckturbine
HSMU	Hydraulic System Monitoring Unit	Hydrauliksystem Überwachungseinheit
IAF	Initial Approach Fix	Anfangsanflugpunkt
IAS	Indicated Airspeed	Angezeigte Fluggeschwindigkeit
IATA	International Air Transport Assosiacion	Verband von Unternehmen des internationalen Linienluftverkehrs
ICAO	International Civil Aviation Organisation	Internationale zivile Luftfahrtorganisation
IFR	Instrument Flight Rules	Instrumentenflugregeln
ILS	Instrument Landing System	
IMC	Instrument Meteorological Conditions	Instrumentenwetterbedingungen
IR	Instrument Rating	Instrumentenflugberechtigung
IR	Inertial Reference	
KCAS	Knots Calibrated Airspeed	
KIAS	Indicated Airspeed in Knots	Angezeigte Fluggeschwindigkeit in Knoten
kt	knot(s)	Knoten (1 kt = 1,852 km/h)
KTAS	Knots True Airspeed	
LAPL	Light Aircraft Pilot Licence	Leichtluftfahrzeug-Pilotenlizenz

LBA	Federal Aviation Office (Germany)	Luftfahrt-Bundesamt
LDA	Landing Distance Available	Verfügbare Landestrecke
LDR	Landing Distance Required	Erforderliche Landestrecke
LM	Landing Mass	Landing mass
LOC (auch LLZ)	Localizer	Landekurssender
LOFT	Line Oriented Flight Training	
LOSA	Line Operations Safety Audit	Analyse von sicherheits-relevanten Daten im Flugbetrieb
LPC	Licence Proficiency Check	
LPT	Low Pressure Turbine	Niederdruckturbine
LTA	Airworthiness Directive	Lufttüchtigkeitsanweisung
LU	Air Operator	Operator
MAC	Mean Aerodynamic Chord	Mittlere aerodynamische Flügeltiefe
MAP	Missed Approach Procedure	Fehlanflugverfahren
MCC	Multi Crew Coordination	
MCTOM	Maximum Certified T/O Mass	maximale zugelassene Startmasse
MDA	Minimum Descent Altitude	Sinkflugmindesthöhe
ME	Multi Engine	
MEP	Multi Engine Piston	
METAR	Aviation Routine Weather Report	Routine Wettermeldung für die Luftfahrt
MFD	Multi-Function Display	
MLM	Maximum Landing Mass	Maximum landing mass
MN	Magnetic North	Magnetisch Nord
MP	Multi Pilot	
MSA	Minimum Sector Altitude	Mindestsektorenhöhe über MSL
MSL	Mean Sea Level	Mittlerer Meeresspiegel
MTOM	Maximum T/O Mass	Maximale Startmasse
N_1	Engine fan or LP compressor speed	
NDB	Non-Directional radio Beacon	
NfL	Publications of aviation authorities in Germany	Nachrichten für Luftfahrer (German Language Publication for Aviation)

N_g	Gas generator rotation speed (rotorcraft)	
NM	Nautical Mile(s)	Nautische Meile(n)
NOTAM	Notice to Airmen	Ergänzende Informationen zur AIP
NOTECHS	Non-technical Skill	Fertigkeiten, die über das Beherrschen der Technik hinausgehen
N_P	Propeller Speed	Propellerdrehzahl
N_R	Main rotor rotation speed (rotorcraft)	
NTSB	National Transportation Safety Board	Unfalluntersuchungsbehörde der USA
OAT	Outside Air Temperature	
OCA/H	Obstacle Clearance Altitude / Height	Hindernisfreiheit über Meeresspiegel / Flugplatz bzw. Schwelle
OCL	Valid only as co-pilot	Gültig nur als Copilot
OFP	Operational Flight Plan	Flugdurchführungsplan
OM	Operations Manual	Betriebshandbuch
OML	Valid only as or with qualified co-pilot	Gültig nur als/oder mit qualifiziertem Copiloten
OPC	Operator Proficiency Check	
OSL	Valid only with safety pilot and in aircraft with dual controls	Gültig nur mit Sicherheitspilot und in Luftfahrzeugen mit Doppelsteuer
P/F Check	Preflight Check	Vorflugkontrolle
PA	Passenger Address	Durchsagesystem zur Information der Passagiere
PAPI	Precision Approach Path Indicator	Präzisionsgleitwegbefeuerung
PF	Pilot Flying	Pilot, der das Flugzeug steuert
PFD	Primary Flight Display	
PFR	Post Flight Report	Technischer Bericht nach dem Flug
PIC	Pilot in Command	Pilot in Command
PIC/IR	Pilot In Command/Instrument Rating	Verantwortlicher Luftfahrzeugführer mit Instrumentenflugberechtigung

PL	Power Lever	Leistungshebel
PNF	Pilot non Flying	Pilot, der den PF unterstützt
POH	Pilot's Operating Handbook	
psi	pounds per square inch	(14,5 psi = 1 bar)
QFE	Altimeter pressure setting to indicate height above aerodrome	
QNH	Altimeter pressure setting to indicate altitude AMSL	Luftdruck in Meereshöhe
QRH	Quick Reference Handbook	
RA	Radio Altitude	Radarhöhe
RA	Resolution Advisory	
RAT	Ram Air Turbine	Staudruckturbine
REV	Reverse	Umkehrschub
REV-AME	Review-Aero-Medical Examiner	Kontrolle durch Flugmedizinischen Sachverständigen
rpm	revolutions per minute	Umdrehungen pro Minute
RTO	Rejected Take-Off	Startabbruch
RVR	Runway Visual Range	Sichtweite auf der Piste
RWY	Runway	Runway
SAR	Search and Rescue	
SB	Service Bulletin	
SD	System Display	Elektronische Anzeige von Systemparametern
SEP	Single Engine Piston	
SIA	Safety Investigation Authority	Sicherheitsuntersuchungsstelle
SID	Standard Instrument Departure Route	Standard-Instrumentenabflug
SIGMET	Information concerning en-route weather phenomena which may affect the safety of aircraft operations	Informationen bezüglich Wettererscheinungen auf der Flugstrecke, welche die Sicherheit des Flugbetriebs beeinträchtigen können
SOP	Standard Operating Procedure	Standard-Betriebsverfahren
SP	Single Pilot	
SPA	Single Pilot Aeroplane	Flugzeug mit einem Piloten

SSR	Secondary Surveillance Radar	
T/D	Touch Down	Aufsetzen, Landung
T/O	Take-Off	Start, Abheben
TA	Traffic Advisory	
TAC	Total Aircraft Cycles	Gesamtzahl der Landungen des Luftfahrzeuges
TAF	Terminal Aerodrome Forecast	Flugplatzwettervorhersage
TAS	True Airspeed	Wahre Fluggeschwindigkeit
TAT	Total Aircraft Time	Gesamtflugzeit des Luftfahrzeugs
TAWS	Terrain Awareness and Warning System	
TCAS	Traffic Collision Avoidance System	
TEM	Threat and Error Management	Gefahren- und Fehlermanagement
TGT	Turbine Gas Temperature	
TLA	Thrust Lever Angle	Winkel des Schubhebels
TML	Restriction of the period of validity of the medical certificate	
TODA	T/O Distance Available	
TOM	Take-Off Mass	Startmasse
TQ	Engine Torque in %	Drehmoment des Triebwerks in Prozent
TR	Temporary Revision	Vorläufige Änderung
TR	Type Rating	Musterberechtigung
TRA	Thrust Resolver Angle	Winkel des Gebers des Schubhebels
TRE	Type Rating Examiner	Prüfer für Musterberechtigungen
TRI	Type Rating Instructor	Ausbilder für Musterberechtigungen
TSO	Time Since Overhaul	Betriebszeit seit der Überholung
UERF	Uncontained Engine Rotor Failure	
USG	US gallons	(1 USG = 3,79 l)
UTC	Universal Time Coordinated	
VASI	Visual Approach Slope Indicator	
V_{APP}	Approach Speed	Approach Speed
V_{CAS}	Calibrated Air Speed	

V_{NE}	Never exceed Airspeed	
V_R	Rotation Speed	Rotationsgeschwindigkeit
V_{REF}	Approach Reference Speed	
VS	Vertical Speed	Steig-/Sinkgeschwindigkeit
V_{TGT}	Target Speed	Zielgeschwindigkeit im Landeanflug
V_1	T/O Decision Speed	
V_2	T/O Safety Speed	
VFR	Visual Flight Rules	Sichtflugregeln
VHF	Very High Frequency	Ultrakurzwelle
VMC	Visual Meteorological Conditions	Sichtflugwetterbedingungen
VML	Correction for defective distant, intermediate and near vision	Muss optimal korrigierende multifokale Brille tragen und ebensolche Ersatzbrille mitführen
VNL	Correction for defective near vision	Muss optimal korrigierende Brille tragen und ebensolche Ersatzbrille mitführen
VOR	VHF Omnidirectional radio Range	

Abstract

During the flight from Phuket, Thailand, to Abu Dhabi, United Arab Emirates, with an Airbus A330, left engine damage occurred. The flight crew shut off the engine. The engine damage caused leakage at the green hydraulic system. This leakage resulted in the failure of this hydraulic system.

During the approach, after the engine shut-down, the windmilling[1] of the engine reduced and no longer generated sufficient pressure to maintain the blue hydraulic system operative. This means that the control surfaces operated by the green and blue hydraulic systems as well as the brake antiskid system were no longer available.

A perhaps necessary go-around was only possible with a limited climb performance. The necessary actual landing distance was not known. The combination of technical failures, the flight crew's performance and the prevailing environmental conditions resulted in the fact that the landing was conducted without assessment or knowledge of the safety margin.

During landing the aircraft was slightly damaged. There was no personal injury.

The occurrence was classified as serious incident because in addition to the engine damage two hydraulic systems were inoperable which resulted in a multiple failure scenario. The limited functioning of the aircraft systems and landing performance significantly reduced the safety margins during the landing.

Prompted by findings determined by the investigation of the serious incident, the BFU discussed aspects of multiple failure scenarios in combination with actions of flight crews with different professional parties for flight safety and external flight safety experts. The BFU deemed it necessary to publish the results of the investigation of the serious incident even at a late date as final report.

[1] Windmilling describes the engine being rotated by the airflow

1. Factual Information

1.1 History of the Flight

The following is based on the recordings of the FDR and CVR as well as on the flight crew's statements they made to the BFU.

1.1.1 Take-off and Departure

At 1341 UTC (2041 hrs, local), the aircraft took off from runway 27 at Phuket, Thailand, with 241 passengers and 10 crew members on board to a flight to Abu Dhabi, United Arab Emirates. According to the load sheet, actual take-off mass was 203,638 kg. Climb heading was north-west.

Autopilot No. 1 was activated in CLB/NAV mode. Auto thrust (ATHR) was active in Thrust Managed mode. The Pilot in Command (PIC) acted as Pilot Flying (PF) and the co-pilot as Pilot non Flying (PNF).

1.1.2 Engine Damage

At 1354 UTC at FL220 during climb, the flight crew heard a loud bang and noticed strong vibrations. The RPM of the low pressure compressor (N1) decreased and the RPM of the high pressure compressor (N2) of the left engine (ENG1) increased. At 1354:06 UTC, the FDR recorded the increase in vibrations on the shafts of the high and low pressure compressors (4.2 CU[2] and 10.0 CU, respectively). The Exhaust Gas Temperature (EGT) increased to a maximum value of 720°C[3]. The N1 decreased to about 38%. At 1354:14 UTC, the master warning was triggered. At the time the PIC called: „Engine Failure".

The Electronic Centralized Aircraft Monitoring (ECAM) showed the information ENG1 EGT Overlimit and ENG1 N2 Overlimit[4].

The flight crew then reduced the position of the left thrust lever to flight idle. The recorded Thrust Lever Angle (TLA) decreased to 0°[5]. Immediately afterwards EGT decreased, fell below the maximum allowable limit of 600°C after about 1:15 min. and then reached a value of 430°C.

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[2] CU: Cockpit Unit, dimensionless unit for vibrations
[3] Maximum allowable EGT: 600 °C
[4] The information on the ECAM is not saved. For this report they were derived from the statements of the crew and the CVR recordings, respectively.
[5] The FDR recorded a Trust Resolver Angle (TRA)) of 0°, which corresponds with a TLA of 0°.

At 1354:32 UTC, immediately after the reduction of the engine thrust, the co-pilot announced his intention to declare emergency. The PIC replied with “Ja (Yes)”. Then the co-pilot asked: “Zurück nach Phuket (return to Phuket)?“, to which the PIC replied with “Ja”. This was followed by: “Lumpur Control [Call Sign], Mayday, Mayday, Mayday. We have engine fire. Request to return to Phuket.”

At 1354:38 UTC, the thrust lever of the right engine was changed to a TLA of 64.7°.

At 1355:40 UTC, the PIC initiated the completion of the ECAM actions with the words: “Continue ECAM“. The co-pilot called the following instructions: “Autothrust - OFF“, “Clear Autoflight“,“Engine One EPR Mode Fault“ and „Engine N1 Mode - On“ each of which the PIC acknowledged with “Ja”.

At 1355:52 UTC, the PIC interrupted the completion of the ECAM actions requesting the co-pilot:“[…] direct Papa Uniform Tango“. Subsequently, communications with the responsible air traffic control unit were conducted and inquiries from the cabin crew regarding the situation answered.

At 1356:56 UCT, they began again to complete other items of the ECAM concerning the engine damage. After the PIC had given the command “Engine One N1 Mode OFF“, the co-pilot realised that the Engine Pressure Ratio (EPR-Mode) was recoverable[6]. The EGT increased again and after about 25 s the maximum allowable limit of 600° was exceeded once again.

At 1359:47 UTC, the PIC gave the instruction to shut off the left engine. He was interrupted by more radio communications with the controller.

Immediately after the engine had been shut off, the Auxiliary Power Unit (APU) was switched on. In addition, the flight crew processed further ECAM actions. The CVR shows that the co-pilot made the following call-outs:

- Engine Start Switches
- Fuel Imbalance Monitored
- TCAS mode selector auf (to) TA
- Abnormal Bleed Configuration; Cross Bleed open
- Pack one off, air pack one is off
- Start the APU

[6] The FDR recording shows that from 1359:06 UTC on the signal “ENG EPR CMD“ no longer oscillated.

The completion of the ECAM actions was interrupted by radio communications with the air traffic control unit. At 1402:24 UTC, autothrust was engaged again.

During an interview, the PIC stated that due to the sounds and vibrations he had acted on the assumption that severe engine damage had occurred and was sure that the engine had to be shut off.

1.1.3 Approach and Landing Preparation

The CVR recording shows that immediately after the engine damage had occurred the decision to return to Phuket had been made. After the engine had been shut off approach and landing preparations were continued. At 1401 UTC, the co-pilot initiated landing preparations with the words: “So, status for landing use flaps three“. The PIC confirmed this. The co-pilot added: “Ich geb den RNAV Approach Runway Zero Nine ein (I’ll set RNAV Approach Runway Zero Nine)“. The PIC acknowledged this.

At 1404:02 UTC, the co-pilot began the calculation of the landing distance, after the PIC had made a remark. The calculation was based on a landing mass of about 200 t. Both pilots agreed that an overweight landing would be required. A factored landing distance of 2,986 m was calculated, based on the braking mode low.

The air traffic control unit had issued the clearance for an approach and descent to 3,000 ft AMSL. At 1405:14 UTC, the PIC corrected the intent to land because he wanted to have more time to prepare for landing. The air traffic control unit was informed that they would approach holding PUT and remain at 5,000 ft AMSL.

At 1410:28 UTC, the co-pilot detected that no holding above Phuket was published. The PIC replied: “na wir fahren einfach da rein (we simply go in there)“ which the co-pilot acknowledged with “ja (yes)”.

The flight crew determined a Minimum Sector Altitude (MSA) of 4,600 ft AMSL and therefore changed the intended altitude to 6,000 ft AMSL.

At 1411:57 UTC, the co-pilot initiated a FORDEC[7] procedure: “Okay, FORDEC“. The PIC answered: with “okay”. The co-pilot remarked: “Viel zu sagen, (a lot to say), ne?“.

At 1412:01 UTC, the PIC announced to hand over controls of the aircraft to the co-pilot: “Pass auf […] ich habe seit 8 Wochen keine Landung mehr gemacht fühlst du dich in der Lage (Listen, I have not made any landing within the last 8 weeks, do you feel up to it)?“. The co-pilot acknowledged this: “Ja, ja auf jeden Fall, kann ich machen

[7] FORDEC is a method for structured decision-making (Facts, Options, Risks & Benefits, Decision, Execution, Check)

(Yes, yes, in any case, I can do it)". The PIC justified his decision with the higher flight practice of the co-pilot and the short safety margin of the landing distance. Subsequently, the landing distance was calculated once again. The braking mode was changed from low to medium. The landing distance changed to 2,270 m which the flight crew estimated to be sufficient and safe.

At 1413:19 UTC, the PIC informed the air traffic control unit of the intention to approach VOR PUT in order to fly "a kind of holding pattern" at 6,000 ft AMSL and then possibly start the approach. Afterwards the co-pilot addressed the overweight landing procedure. The subsequent course of the flight above the airport corresponded with a Racetrack Approach Procedure.

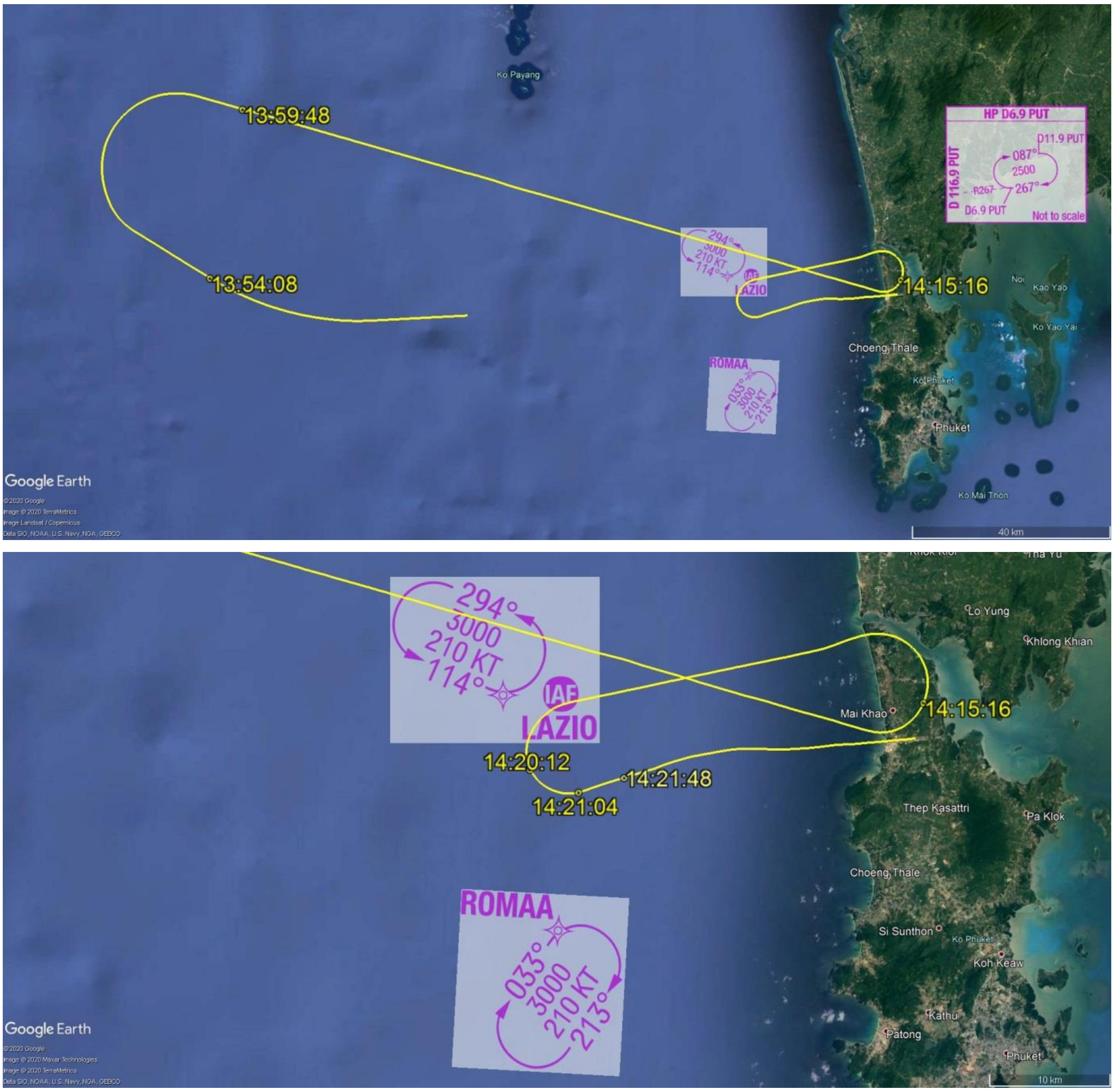

Fig. 1: Flight path yellow line: actual flight path, purple boxes: Holding Procedures

Meaning of the time mark (times relate to recorded GPS points and therefore do not coincide exactly with the occurrence times of the FDR/CVR):

13:54:08	Engine damage
13:59:48	Engine Shut Down
14:15:15	Leakage Green System
14:20:14	Low Pressure Blue System
14:21:04	Low Level Green System
14:21:48	Low Pressure Blue + Green Systems

Source: Google Earth™, adaptation BFU

1.1.4 Hydraulic Systems Failures

At 1415:14 UTC, another warning sounded in the cockpit. On the CVR the flight crew could be heard saying: “Hydraulic System G Leak“. The co-pilot began to determine the leak rate, in doing so he said twice: “Dreitausendfünfzig (3,050)”. Immediately afterwards the PIC talked about the decision to land at once. At 1415:42 UTC, in preparation for the landing, the co-pilot began reading the ECAM instructions. In addition, he advised about the maximum allowable vertical speed of 360 ft/min during landing. The PIC interrupted this and pointed out that they had to focus on the green hydraulic system. The co-pilot acknowledged that the ECAM instruction Leak Rate Monitor was completed.

At 1416:18 UTC, after the PIC had asked him, the co-pilot called the air traffic control unit and requested landing clearance. The PIC and the co-pilot coordinated the entry of the navigation data and the further course of the flight. Between 1417:23 UTC and 1417:55 UTC, several items about the green hydraulic system and the hydraulic leak rate were mentioned. The co-pilot said: “ja die (yes it) decreased, also wir haben jetzt dreitausend, die bleibt eigentlich so (now we have 3,000 it actually stays the same), ne?“.

Alternately, PIC and co-pilot described the hydraulic pumps with “Green Engine One Pump”, “Green Engine Two Pump” and “OFF”. The FDR parameters show that at that time no reduction of the hydraulic pressure in the green hydraulic system was recorded. Another discussion between PIC and co-pilot regarding the hydraulic leak rate followed.

At 1417:42 UTC, control of the aircraft changed from the PIC to the co-pilot with the standard phraseology (You have control - I have control). During a later conducted interview the PIC stated that at the time it had not been clear to him which problems existed and he therefore had decided to hand over control of the aircraft to the co-pilot in order to view the ECAM and the system pages. At 1418:36 UTC, the PIC said: „hydraulic ist neunundzwanzig null eins (is 29 01)“.

At 1419:58 UTC, the PIC said that: “flaps 2 fault“ was indicated at the ECAM and asked “Sollen wir flaps two machen (shall we set flaps 2)?” The co-pilot requested “flaps 2”. At 1420:14 UTC, another warning sounded and the co-pilot said: “Blue system low pressure”.

At 1421 UTC, the flight crew decided to extend the landing gear. According to the FDR recording, at 1421:42 UTC the warning HYD G+B SYS LO PR[8] was triggered. Shortly afterwards the co-pilot said: “Green reservoir low level“ and ordered: „ECAM action“ and „Green electric pump“. At 1421:42 UTC, autopilot 1 changed to mode OFF. On the CVR recording the autopilot disconnect warning (Cavalry Charge) could be heard.

1.1.5 Approach and Landing

The approach to runway 09 of Phuket Airport was flown with the respective RNAV non-precision approach procedure.

The CVR recording shows that during the approach, the PIC tried to obtain clarity regarding the technical condition of the aircraft. He voiced his concern about the braking system: “Wir haben keine Bremsen mehr (we have no brakes any more)” and “Also, wir haben nur noch Accu-Brakes, wahrscheinlich nur noch (we still have accu brakes probably only)“. At 1423:28 UTC, the co-pilot ordered “flaps three”[9]. The FDR recording shows that the flaps travelled to the 22° position (target: 22°) and the slats to the 21° position (target: 24°). According to the FDR recording, at 1423 UTC at about 2,000 ft AMSL, control changed to operating mode Alternate Law (F/CTL ALTN LAW).

During the final approach, the PIC in his function as PM voiced information concerning the rate of descent and the need to descend further. At 1426:17 UTC, at an altitude of 56 ft, the warning Dual Input occurred for the first time. This recurred a total of four times after touchdown.

At 1426 UTC, an overweight landing within the touchdown zone of runway 09 with a landing mass of about 198 t was conducted. The measured acceleration in Z-direction was about 1.22 g. The FDR recording shows different sidestick inputs (pitch and roll commands). The following dual sidestick inputs were recorded:

Pitch: -16° (co-pilot, back) +6.3° (PIC, forward)

Roll: -10° (co-pilot, right) +10° (PIC, left)

During the roll the wheel brakes, the spoilers and also the reverser of the still operating right engine were used. While braking, brake pressures of 1,920 psi[10] (left) and

[8] For readability the warning was shortened.
The complete warning reads: HYD G+B SYS LO PR / G ELEC PMP / G HYD – RSVR / G CUDU

[9] This means the landing flap position: Three

[10] pounds per square inch

1,700 psi (right) were recorded. Several tires were damaged. The aircraft came to a stop after about 1,630 m.

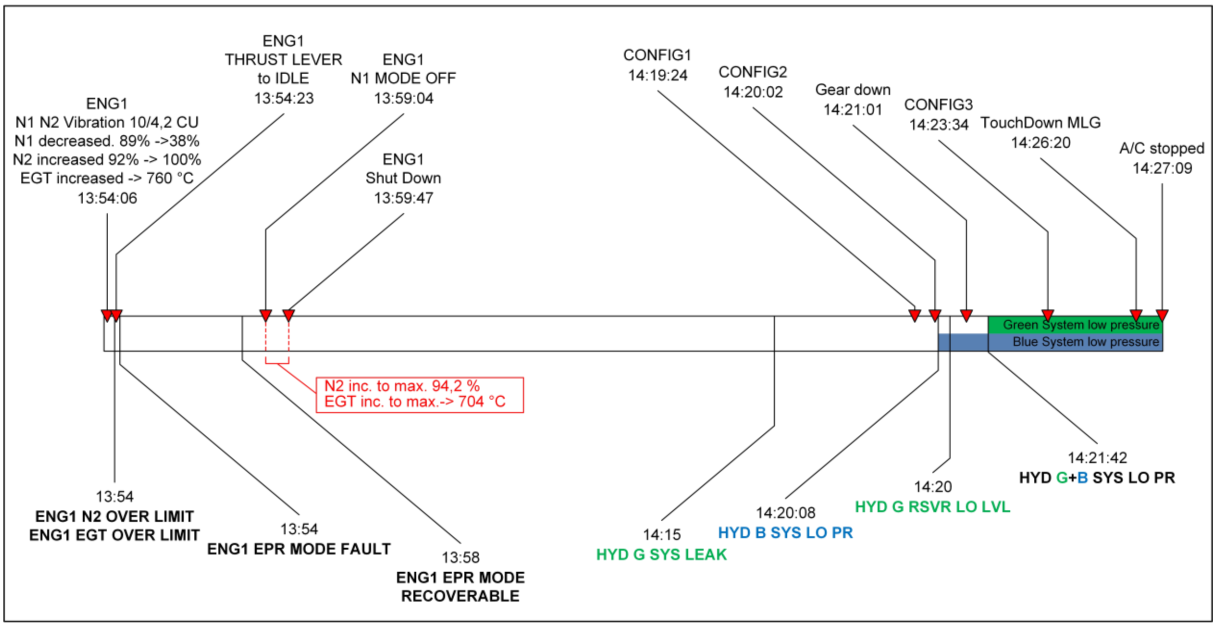

Fig. 2: Sequence of events Source: BFU

At 1426:53 UTC, the PIC ordered the cabin crew via intercom “Crew on station”. The tower controller was asked repeatedly if the aircraft had caught fire. He denied this. At 1429:08 UTC, the order “normal operation” was given to the cabin crew. The passengers were able to disembark via stairs. No one was injured.

1.2 Injuries to Persons

Injuries	Crew	Passengers	Total in aircraft	Other
Fatal				
Serious				
Minor				NN
None	10	241		NN
Total				

Tab. 1: Injuries to Persons

1.3 Damage to Aircraft

Due to damage of the left engine's 4th Low Pressure Turbine (LPT) stage, guide vanes and rotor parts of this and subsequent stages were torn off. Some fragments punctured the engine cowling. The liberated parts damaged the inner wall of the thrust reverser. Leakage at the green hydraulic system and damage of the engine pylon accompanied the damage of the engine. During landing, the tires of the main landing gear were damaged.

1.4. Other Damage

There is no information regarding other damage.

1.5 Personnel Information

The pilots stated that they had had sufficient sleep and felt rested (72 h anamnesis).

1.5.1 Pilot in Command

Age: 60		Sex: Male	
	Type:	Initially issued:	Validity
Licence:	ATPL (A)	5 February 1986	19 September 2014
Ratings:	A318/319/320/321 PIC/IR A330 PIC/IR		 31 December 2013 30 June 2013
Medical certificate:	Class 1	Last 30 October 2012	22 February 2013
Limitations or restrictions: [11]	REV-AME, TML, VML, OML, OCL		
Total flying experience as pilot:		14,811 hours	
Flight time during the last 90 days:		115 hours	
Duty time during the last 24 hours:		6 hours	
Type experience (A330-200/300):		2,219 hours	

[11] Abbreviations

Flight time during the last 90 days	115 hours
Duty time during the last 24 hours:	6 hours

Tab. 2: Pilot in command

The previous medical certificate (issued on 30 July 2012, valid until 22 November 2012) listed the same limitations/restrictions.

	Date	Limitations					
Issued:	2 May 2012		OML	OSL	TML	VML	REV
Valid until:	22 Aug 2012		OML	OSL	TML	VML	REV
Issued:	30 July 2012	OCL	OML		TML	VML	REV
Valid until:	22 Nov 2012	OCL	OML		TML	VML	REV
Issued:	30 Oct 2012	OCL	OML		TML	VML	REV
Valid until:	22 Feb 2013	OCL	OML		TML	VML	REV
Issued:	31 Jan 2013		OML	OSL	TML	VML	REV
Valid until:	22 May 2013		OML	OSL	TML	VML	REV

Tab. 3: Overview of limitations/restrictions in the medical certificates

The pilot stated that there was no medical necessity for the OLC entry. The entry was a "händischer Fehleintrag (a hand-written faulty entry)".

The Aero Medical Examiner (AME), who had issued the medical certificates mentioned above, informed the BFU that he had no records which would justify the OLC limitation. He confirmed that it had been a faulty entry. The Aero-Medical Center (AMC) confirmed that there was no medical indication for the OCL entry in connection with the temporary unfitness to fly.

The BFU had the simulator training documentation of the PIC of the years 2010 to 2013 available. All checks had been passed. The documentation did not show any negative trend concerning Crew Resource Management or decision making.

The documentation of the Line Check of 4 August 2012 listed under CRM evaluation: Good CRM and Above Standard CRM SK[12]: as PF+PNF. During a Line Training Flight

[12] „SK": Skill

on 17 February 2012 the CRM skills, Team, Leadership, Situational Awareness, and Decision Making were estimated as ST+ (good).

1.5.2 Co-pilot

Age: 49		Sex: Male	
	Type:	Initially issued:	Validity
Licence:	ATPL (A)	20 February 1997	26 November 2014
Ratings:	A318/319/320/321 COP/IR A330 COP/IR		 31 March 2013 30 September 2013
Medical certificate:	Class 1	Last 13 November 2012	26 November 2013
Limitations or restrictions:	VNL		

Total flying experience:	10,429 hours
Flight time during the last 90 days:	165 hours
Duty time during the last 24 hours:	6 hours
Type experience (A330-200/300):	3,921 hours
Flight time during the last 90 days:	165 hours
Duty time during the last 24 hours:	6 hours

Tab. 4: Co-pilot

The BFU had the simulator training documentation of the co-pilot of the years 2010 to 2013 available. All checks had been passed. The documentation did not show any negative trend concerning Crew Resource Management or decision making.

The documentation of the Line Check of 29/30 March 2011 showed the CRM skills Team, Leadership, and Decision Making as SR+ (good) and Situational Awareness as SR (Standard).

1.6 Aircraft Information

1.6.1 General

Aircraft Information	
Manufacturer:	Airbus Industries
Type:	A330-223
Manufacturer's Serial Number (MSN):	0288
Year of Manufacture:	1999
Maximum Take-off Mass (MTOM):	230,000 kg
State of Registry:	Germany
Airworthiness Review Certificate Validity:	14 April 2013
Engine Involved	
Manufacturer:	Pratt & Whitney
Type:	PW4168A
Serial Number:	733 525
Aircraft History	
Total airframe time:	59,156 hours
Cycles:	10,585
Engine History	
Total operating time:	45,221 hours
Cycles:	7,228
TSO:	8,266 hours
CSO:	1,072
LPT Module (S/N 33 525) TSO:	17,287 hours
LPT Module (S/N 33 525) CSO:	2,206
LPT Module overhaul	December 2008

Tab. 5: General Aircraft Information

The maximum allowable landing mass was 182,000 kg. According to the Flight Crew Operating Manual (FCOM), Chapter Limitations, in emergency situations the manufacturer allowed landing with a landing mass of more than the maximum allowable structural landing mass.

Excerpt FCOM – Limitations (Appendix 8):

> *In exceptional conditions (inflight turn back or diversion), an immediate landing at weight above maximum landing weight is permitted, provided that the pilot follows the overweight landing procedure.*

1.6.2 Hydraulic System

1.6.2.1 General

The aircraft is equipped with three hydraulic systems, which are named green, blue and yellow. The three systems have the functions depicted in Figure 2.

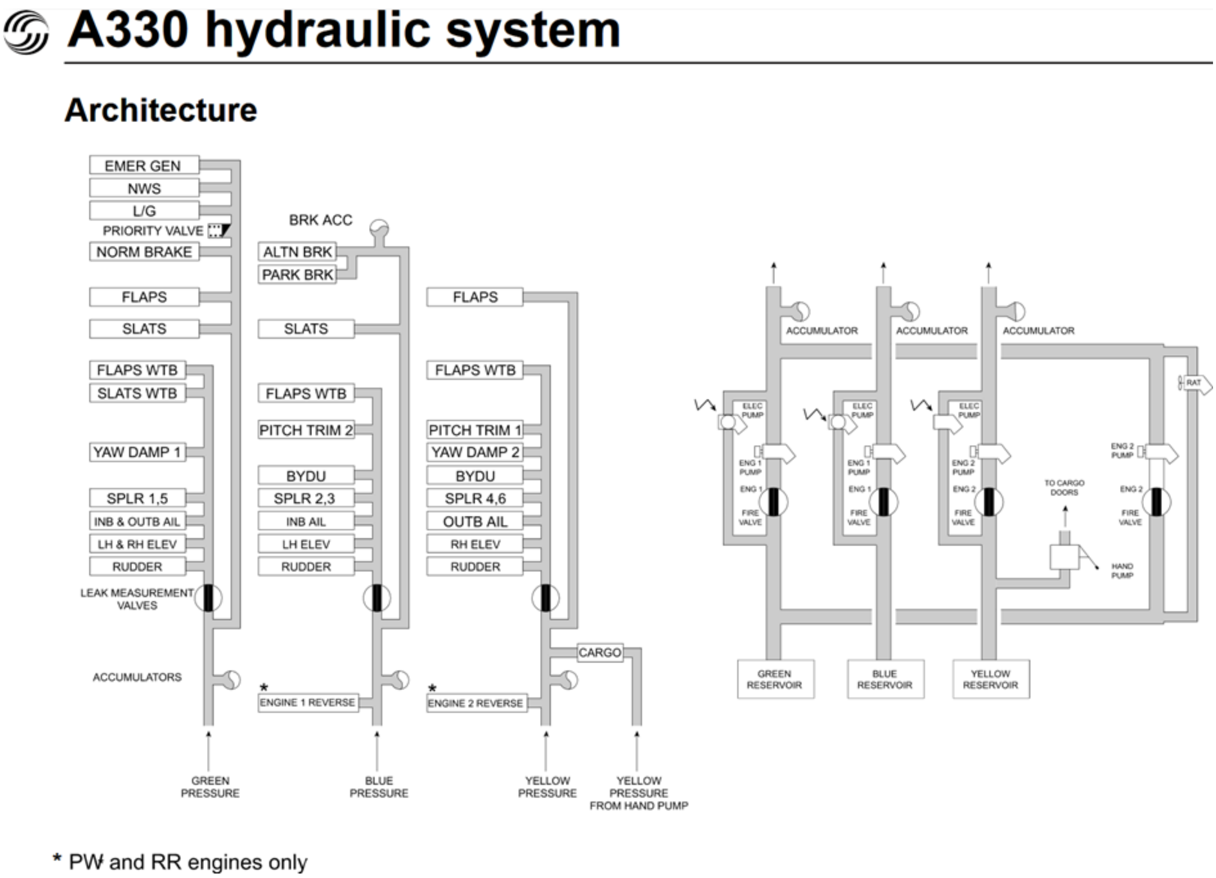

Fig. 3: Hydraulic systems (green, blue, yellow) and their functions Source: Airbus

All three systems have their own reservoir. The blue system is supplied by an Engine Driven Pump (EDP) of the left engine. The EDP of the yellow hydraulic system is powered by the right engine. For each hydraulic system an Electric Pump AC is available. The Hydraulic System Monitoring Unit (HSMU) monitors the hydraulic system.

The green hydraulic system is supplied by two EDP (left and right engines). It supplies the most applications on board. That is why this system has a Ram Air Turbine (RAT) installed for emergency situations. The RAT deploys automatically in flight under the following conditions:

- Loss of performance of both engines
- Reservoir green and yellow hydraulic systems low level
- Reservoir green and blue hydraulic systems low level

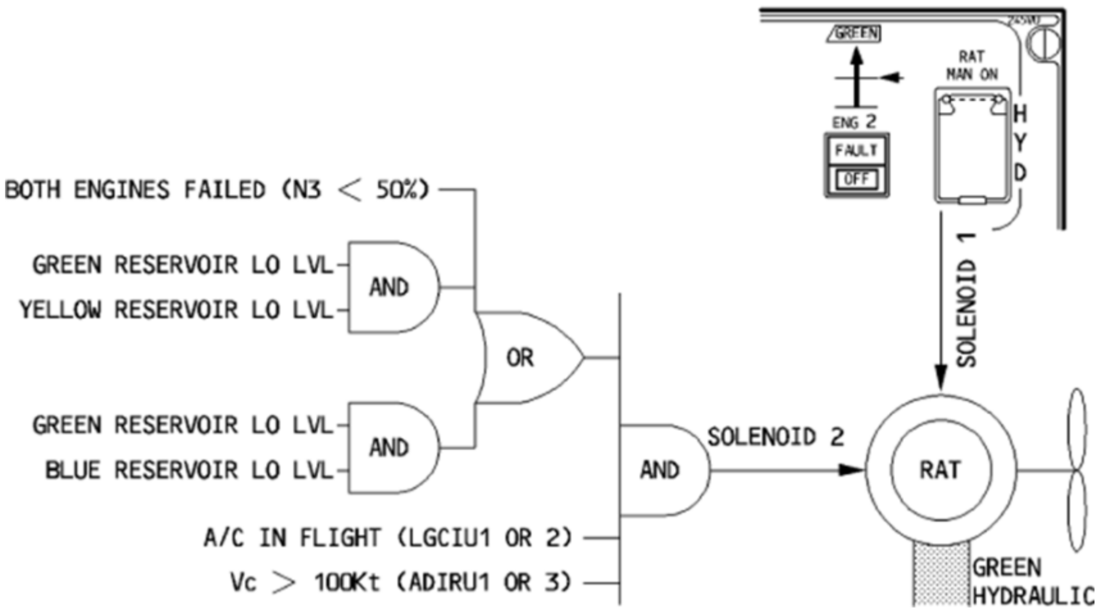

Fig. 4: Ram Air Turbine System Overview Source: Airbus

With a guarded switch, the RAT can be deployed manually at any time. An ECAM advisory will prompt the flight crew to do so when appropriate. Precondition for the manual extension of the RAT:

- Quantity of the green hydraulic system is at least 8 l.
- The electrical pumps are switched off.
- The mechanical pumps are switched off.

The respective FCOM procedures are described in the Appendix.

According to the aircraft manufacturer, there is no separate stand pipe installed in the reservoir of the RAT.

The hydraulic page of the ECAM indicates the individual fill quantities of the reservoir of each hydraulic system, among other things. The reservoir of the green hydraulic system has a maximum quantity of 47 l. The indication MAX FILL appears at 38 l. The normal quantity is depicted with a green band between 32 l and 38 l. At a quantity of 17 l, the green band changes to an amber one. The low-level warning occurs at 8 l. The quantities of the two other hydraulic systems deviate from this (Fig. 5).

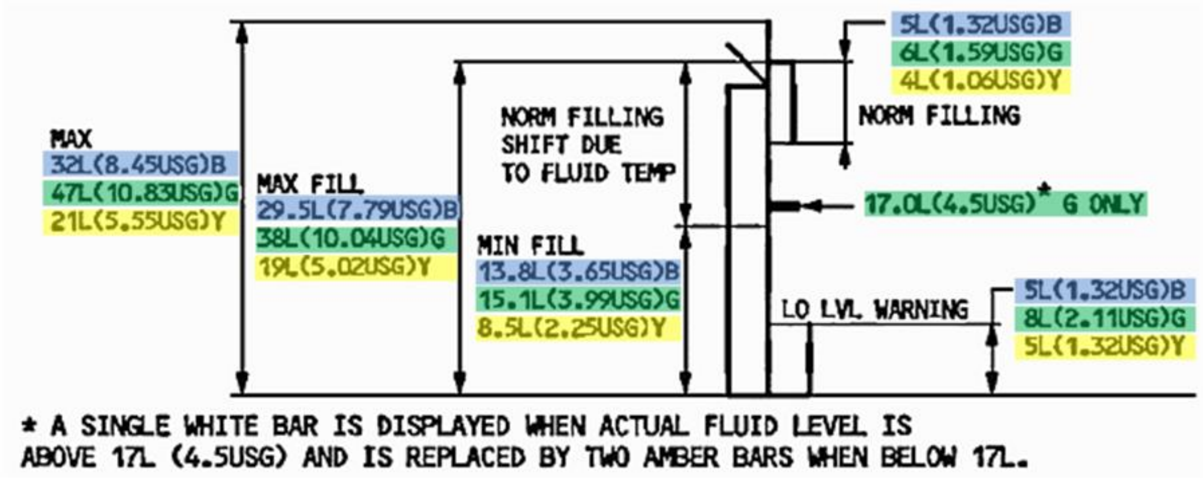

Fig. 5: Quantity indication of the hydraulic systems. Source: Airbus

The electrical pump of the blue system is only intended for ground operation. It provides services during maintenance work. In-flight operation is not permitted because it only has about 18% of the flow rate of the EDP. Otherwise this could result in unequal movement of the control surfaces (flight control jerk).

1.6.2.2 Fire Shut Off Valve

The Fire Shut Off Valve (FSOV) is installed in the pylon. In the FCOM the function is described as follows:

FIRE SHUTOFF VALVES

Applicable to: [redacted]

A fire shutoff valve is positioned upstream of each engine driven pump. The flight crew can close the valve by pushing the FIRE pushbutton.
Both engine green hydraulic fire shut-off valves are automatically closed by the HSMU, in the event of green reservoir low level. In case of a further blue or yellow reservoir low level, the green fire shut-off valves remain closed, enabling the green system to be restored by using the RAT. The flight crew cannot re-open the fire shut-off valves in flight, once they have been automatically closed.

Fig. 6: Description of the FSOV, excerpt from the FCOM (DSC-29-10-20 P 3/8) Source: Operator

The aircraft manufacturer had given the following supplemental information on the function of the FSOV:

> *In case of green hydraulic reservoir low level, detected by the low level switch FIN 10JS1 (less than 8 litres) and confirmed by the quantity transmitter FIN 9JS1 information (less than 10 litres) for 100 ms, the FSOVs close automatically.*
>
> *The Automatic closure of the FSOV is aiming to preserve a sufficient quantity of Green system fluid for eventual Ram Air Turbine operation and to address a certification case of engine burst.*

Under certain circumstances, the FSOV is re-opened again by the HSMU. The aircraft manufacturer stated the following, which provides additional details on the system logics:

> *HSMU (Hydraulic System Monitoring Unit) includes a specific logic that automatically re-opens of the G Hyd Sys FSOV and allows saving both green EDPs in case of single green hydraulic reservoir low level.*
>
> *During the next 150 seconds, if the Blue and Yellow hydraulic reservoir are considered normal (no low level condition), the green hydraulic system FSOVs are reopened by HSMU to prevent EDP damage by cavitation.*

1.6.3 Engine

The Pratt & Whitney PW4168A engine is a model of the PW4000-100 family. It is a two-shaft turbofan engine with a fan diameter of 2,540 mm (100 inch). It is equipped with a 5-stage Low Pressure Compressor (LPC), an 11-stage High Pressure Compressor (HPC), an annular combustor, a 2-stage High Pressure Turbine (HPT) and a 5-stage Low Pressure Turbine (LPT). The 4th LPT stage consists of 44 vane clusters with 3 blades each. The LPT drives the LPC and fan.

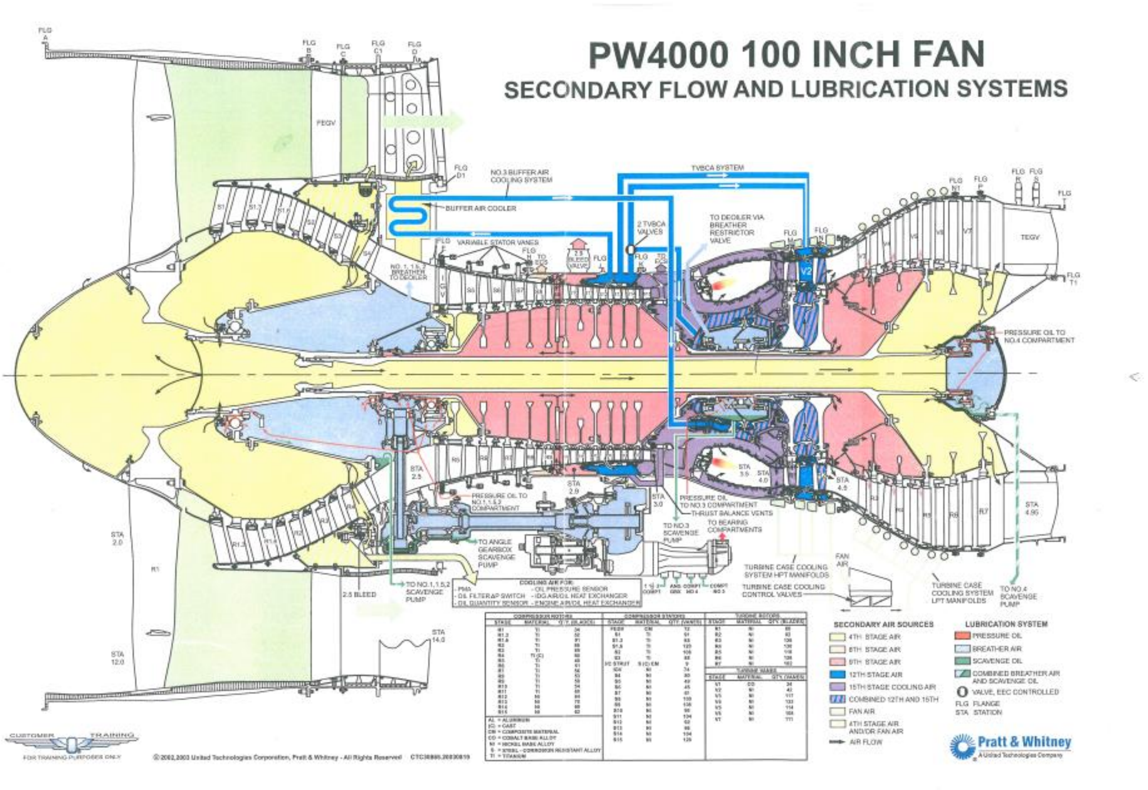

Fig. 7: Section drawing of the PW4000 Source: Pratt & Whitney

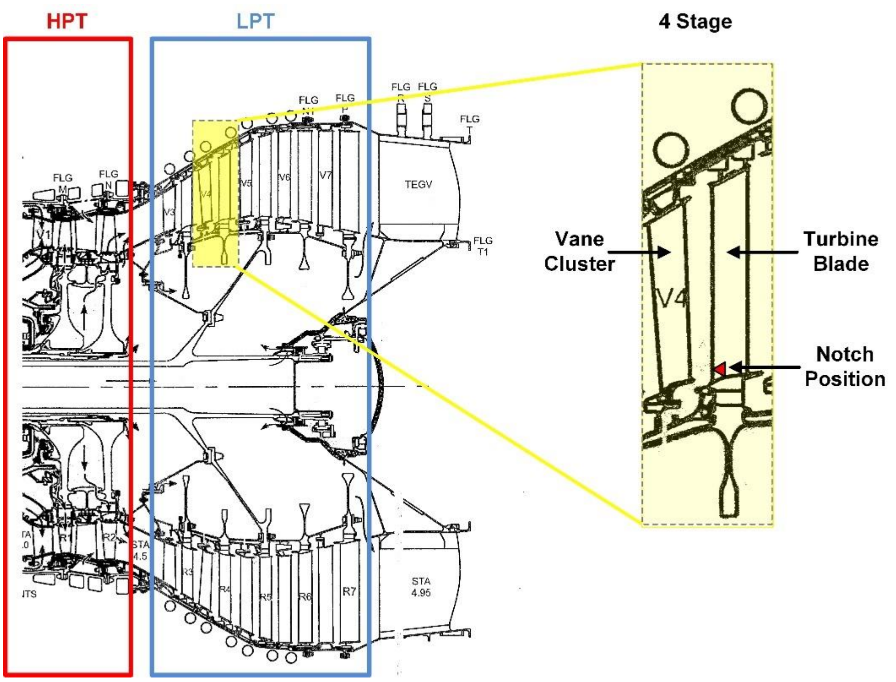

Fig. 8: Section drawing of the PW4000 turbine including depiction of the 4th turbine stage

Source: Pratt & Whitney, adaptation BFU

The Federal Aviation Administration (FAA) had issued the engine type certification data sheet E36NE.

According to the engine manufacturer, engine failure occurred prior to December 2012 involving the similar engine model PW4000-94 which was caused by failure of the vane cluster. The reason was a wrong geometry (non-uniform gusset fillet) caused by a faulty casting procedure. The Service Bulletin SB PW4ENG 72-804 was issued which intended replacement of the faulty components in the PW4000-94 engine models. In addition, the number of possible repairs of the vane clusters was limited.

On 7 November 2012 the FAA AD 14-09-2012 (2012-NE-02AD) came into force. It intended replacement of the vane clusters of the 4th stage of the LPT on the PW4000-94 and -100 models. The vane clusters with the Casting Integral Marking[13] 51N554 AT 1447 1S2 C3A, which were installed in the engine involved, were not addressed.

Up until December 2012, there were no engine failures involving the PW4000-100 model which were caused by vane cluster failures of the 4th stage of the LPT.

The Pratt & Whitney Service Bulletin (SB) PW4G-100-72-251 dated 28 October 2014 described the replacement of the PW4000-100 engine models vane clusters. The reason was a wrong geometry (non-uniform gusset fillet) caused by a faulty casting procedure for some vane clusters manufactured between February 1992 and June 2010. The vane cluster in the engine involved had the Casting Integral Marking 51N554 AT 1447 1S2 C3A which were included in the SB mentioned above.

The Full Authority Digital Engine Control (FADEC) regulates the engine thrust with two modes. In normal operation the FADEC regulates the engine so that a certain Engine Pressure Ratio[14] (EPR-mode) is maintained. As an alternative, the engine can also be regulated in the N1-mode, where the RPM of the LPC/LPT shaft is the reference figure for the engine thrust.

If the engine cannot be operated in the EPR mode, the ECAM indicates the information ENG1(2) EPR MODE FAULT. Once the FADEC has determined that the engine can once again be operated in the EPR mode, the ECAM indicates EPR MODE RECOVERABLE. By deactivating the N1 mode in the cockpit the EPR mode is activated again.

[13] Describes the production batch of the casting

[14] The engine pressure ratio is created by the pressure behind the turbine and the inlet pressure in front of the fan.

The aircraft manufacturer Airbus recommends that in case of engine damage:

> *In order to ensure the highest level of systems redundancy and of recovery when possible, the Airbus philosophy is to maintain the engine operative as long as it is globally safe to do so. The ECAM and the operational procedures support this objective.*

1.6.4 Electronic Centralized Aircraft Monitoring

The Electronic Centralized Aircraft Monitoring (ECAM) is a system which registers certain parameters and errors of the systems and engines and indicates them on two displays in the cockpit (Engine Warning Display (E/WD) and System Display (SD)). In addition, to a certain extent correction measures are also indicated for the pilots. Inputs are made on the ECAM control panel. The colour of the indicated error or information depends on importance and urgency.

Red: The failure or the configuration of the aircraft requires immediate action.

Amber: The crew must know the failure and/or configuration but no immediate action is required.

Green: Normal operation

White: Information regarding the performance of procedures.

Blue: Procedures to be performed or limitations

Purple: Special information regarding a certain equipment or situation.

The warnings are categorised in three levels depending on their importance and urgency. The warning with the higher priority is listed on top. The same is true for the corrective measure.

Failure Level	Priority	Colour Coding	Aural Warning	Recommended Crew Action
Level 3	Safety	Red	Continuous Repetitive Chime	Immediate
Level 2	Abnormal	Amber	Single Chime	Awareness, then action
Level 1	Degradation	Amber	None	Awareness, then monitoring

Tab. 6: Depiction of the ECAM warnings

At individual flight phases, certain warnings are suppressed.

Level 3 failures are also indicated by the Master Warning Light and level 2 failures by the Caution Light. The System Synoptic Page of the SD can depict up to 12 systems.

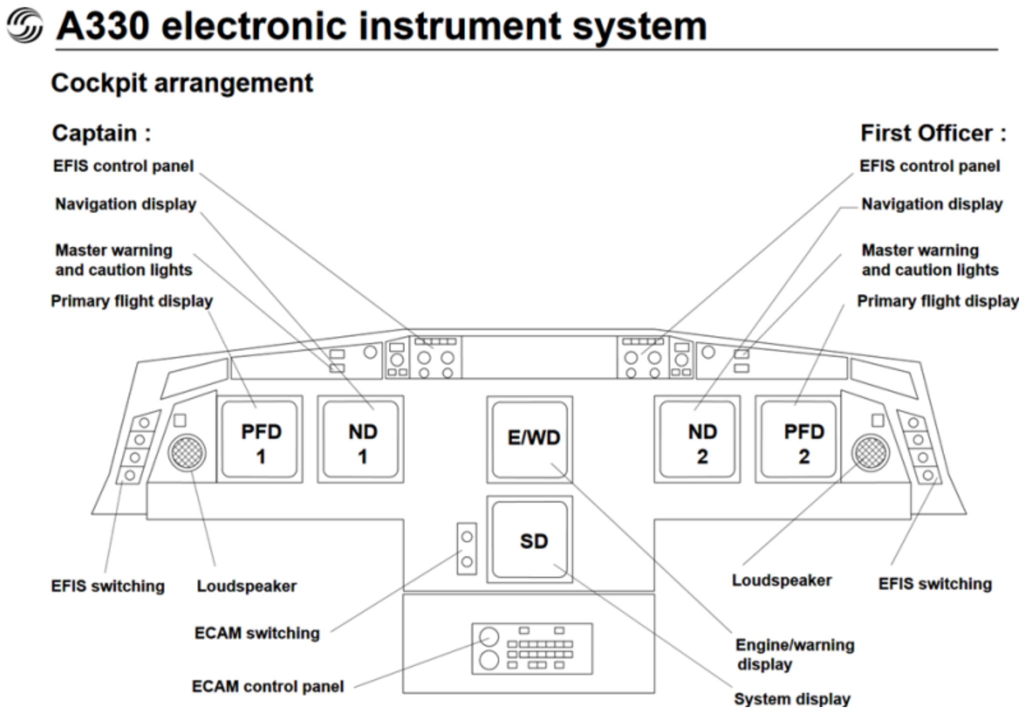

Fig. 9: Cockpit Arrangement A330 Overview Source: Airbus

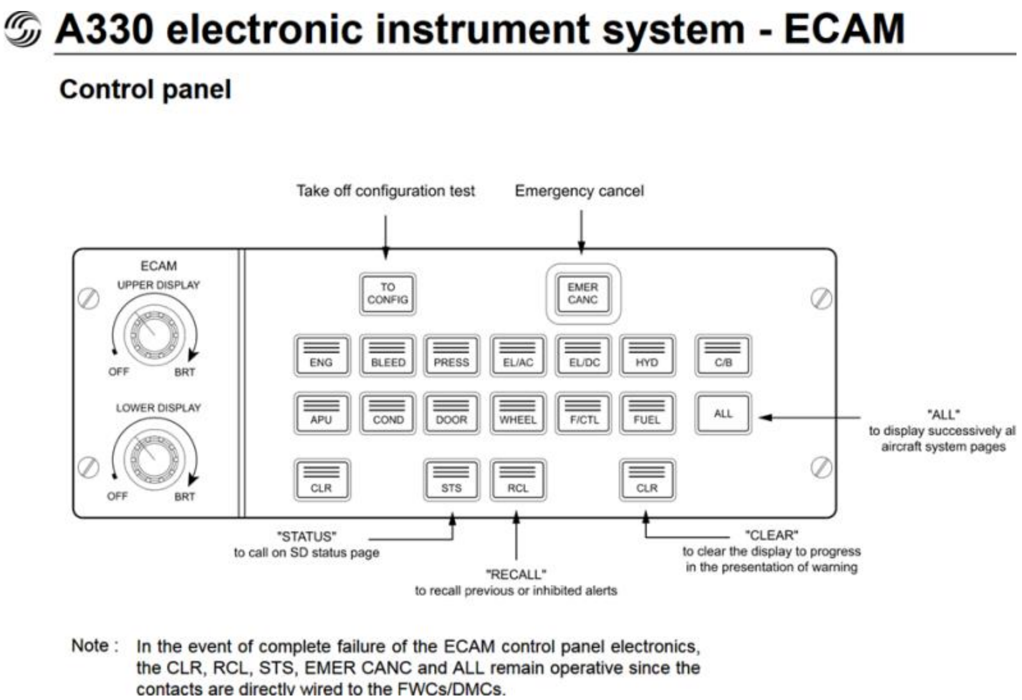

Fig. 10: ECAM Control Panel Source: Airbus

The E/WD has four displays. On them the most important engine parameter, the fuel quantity, slats and flaps positions and up to seven lines of text information are depicted. If there is more information an arrow at the lower end of the text appears. Seize of the arrow is independent of the amount of invisible information.

On the SD information concerning the three hydraulic systems, among other things, can be called up and are shown as schematic. The hydraulic pressure is listed in the upper subsection as number and the unit “psi”. Quantity is depicted as graph without the exact value.

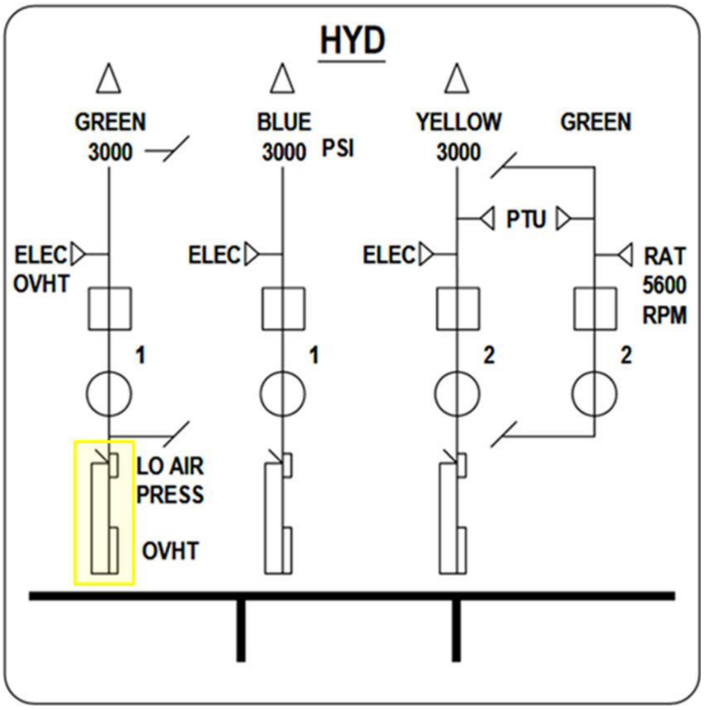

Fig. 11: Hydraulic system page, the included yellow box shows the indication of the quantity.

Source: Airbus, adaptation BFU

The Status Page of the SD displays the condition of the aircraft after a failure has occurred. This page is divided in two columns. The left depicts the status of individual systems including further action instructions. The right lists the failed systems.

The following procedures result in the ECAM command to shut off the engine:

- ENGINE STALL
- ENGINE FIRE
- ENG FAIL (trigger when the engine is spooling down sub idle while M/L is still ON).

On the ECAM the instruction to push the Engine Fire push button (ENG FIRE P/B-SW) occurs if:

- A fire was detected
- There is engine failure with substantial engine damage

These two cases were also described in the FCOM, Chapter Abnormal and Emergency Procedure, Item ENG1(2) FIRE (IN FLIGHT) and ENG1(2) FAIL.

The (ENG FIRE P/B-SW) simultaneously

- silences the aural fire warning
- arms the fire extinguisher squibs
- closes the low-pressure fuel valve
- closes the hydraulic fire shut-off valve
- closes the engine bleed valve
- closes the pack flow control valve
- cuts off the FADEC power supply
- deactivates the Integrated Drive Generator (IDG).

1.6.5 Braking System

The main landing gear is equipped with brakes which are operated by two independent systems. In normal operation, the green hydraulic system supplies the brakes. The blue hydraulic system supplies the alternate system. In cases where pressure generation of the blue system fails, it can be supplied by a hydraulic accumulator. The accumulator can supply at least seven full brake applications. The Brake Triple Indicator indicates brake pressure.

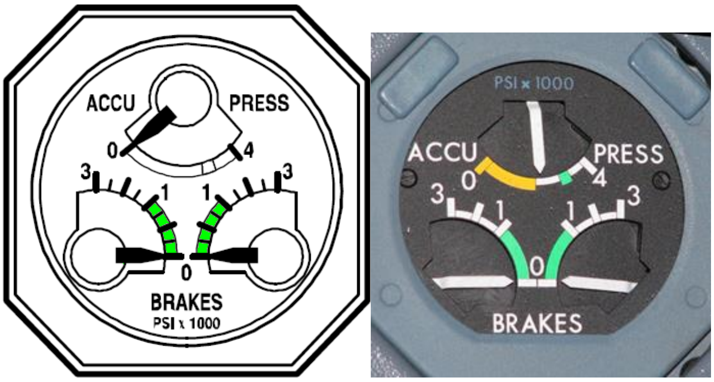

Fig. 12: Brake Triple Indicator with green marking up to 1,000 psi Source: FCOM, adaptation BFU

The FCOM Chapter Abnormal and Emergency Procedures, Landing Gear (PRO-ABN-32) described in the checklist LOSS OF BRAKING the actuation of the brakes using the alternate system.

BRAKE PEDALS	PRESS
Apply brakes with care, since initial pedal force or displacement produces more braking action in alternate mode than in normal mode.	
MAX BRK PR	1000 PSI
Monitor brake pressure on the BRAKES PRESS indicator. Limit brake pressure to approximately 1 000 PSI and, at low ground speed, adjust brake pressure as required.	

Fig. 13: Abnormal and Emergency Procedures/Hydraulic Source: FCOM

1.6.6 Controls

In normal operation, control of the aircraft generally occurs in Normal Law. In this case the aircraft has the following protections:

- *3 Axis control*
- *Flight envelope protection*
- *Maneuver load alleviation*

Depending on failures which may impair controls there are three more laws:

- *Alternate Law (ALT 1 or ALT 2)*
- *Direct Law*
- *Mechanical*

Several protections available during Normal Law are then disabled.

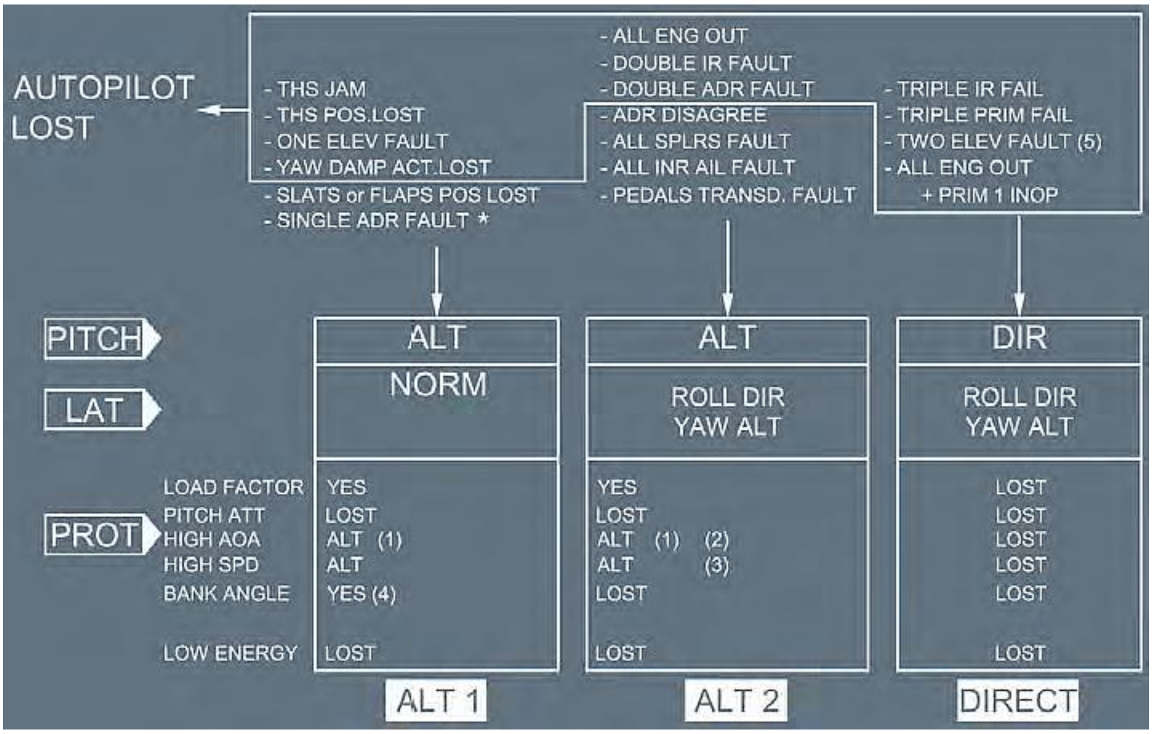

Fig. 14: Depiction of the protections which are disabled in Alternate Law and Direct Law. Source: Operator

Lift control at the wing occurs via flaps, slats and the deflection of the aileron. Selection occurs via a lever with 5 positions (0 to 3 and FULL). The configuration of the individual controls depends on the airspeed. The actual configuration (config) is indicated on the ECAM.

1.6.7 Information in the Quick Reference Handbook and the Flight Crew Operating Manual

The FCOM Chapter PRO-ABN-70 listed the following items for shutting off an engine (Appendix):

- ENG 1(2) EGT Overlimit
- ENG 1(2) N1/N2 Overlimit
- ENG 1(2) FAIL

The Quick Reference Handbook (QRH) Chapter ABN-70 described six cases which are connected with an engine failure.

ABN-70 Engines

■ ENG ALL ENG FLAMEOUT - FUEL REMAINING ■..........70.01
■ ENG ALL ENG FLAMEOUT - NO FUEL REMAINING ■.... 70.02
ENG RELIGHT (IN FLIGHT)..70.03
ENG 1(2) STALL...70.04
ENG TAILPIPE FIRE..70.05
HIGH ENGINE VIBRATION..70.06

Fig. 15: Chapter ABN-70 Engines of the QRH Source: Airbus

Chapter ABN-29 described three failure cases which are connected with the hydraulic systems.

ABN-29 Hydraulic

HYD B+Y SYS LO PR Summary.. 29.01
HYD G+B SYS LO PR Summary..29.02
HYD G+Y SYS LO PR Summary..29.03

Fig. 16: Chapter ABN-29 Hydraulic of the QRH Source: Airbus

1.6.8 Maintenance of the left engine

According to the maintenance documentation, on 15 March 2011 the left engine was subject to repairs. At the time, the engine had an operating time of 36,955 hours (TSN) and 6,156 cycles (CSN). According to the operator, at the time of the serious incident the engine had a total operating time of 45,221 hours (TSN) and 7,228 cycles (CSN).

On 12 November 2008 during maintenance action, new vane cluster of the 4th stage (Part Number 52N774-01) were installed in the engine with the serial number 733 525.

At the time of the serious incident, they had a total operating time of 17,286 hours and 2,206 cycles (total). Until the serious incident, the vane clusters had not been subject to repairs.

1.7 Meteorological Information

At the time of the occurrence it was dark. According to the aviation routine weather report (METAR) of Phuket Airport, of 1330 UTC (2030 hrs, local) the following weather conditions prevailed:

Wind: 080°/03 kt

Visibility:	8,000 m
Clouds:	1/8 – 2/8 at 2,000 ft, 3/8 - 4/8 at 12,000 ft,
	5/8 - 7/8 at 30,000 ft[15]
Temperature:	26°C
Dewpoint:	24°C
Air Pressure:	1,009 hPa

No significant change within the next two hours.

1.8 Aids to Navigation

A non-precision RNAV (GPS) approach includes several waypoints identified by GPS coordinates and altitudes. The approach to runway 09 was conducted using the approach chart LIDO[16]-RNAV (GNSS) 09.

In the vicinity of the airport, three holding procedures were available:

1. PUT VOR: Minimum holding altitude was 2,500 ft AMSL with an inbound course of 267° and right-hand turns. The holding point was defined by the 267° radial of PUT VOR with a distance of 6.9 NM.
2. LAZIO: Minimum holding altitude was 3,000 ft AMSL with an inbound course of 114° and left-hand turns. The holding point was defined by GPS coordinates.
3. ROMAA: Minimum holding altitude was 3,000 ft AMSL with an inbound course of 033° and right-hand turns. The holding point was defined by GPS coordinates.

[15] AGL

[16] Registered trademark of Lufthansa Systems GmbH & Co. KG Marketing & Communications

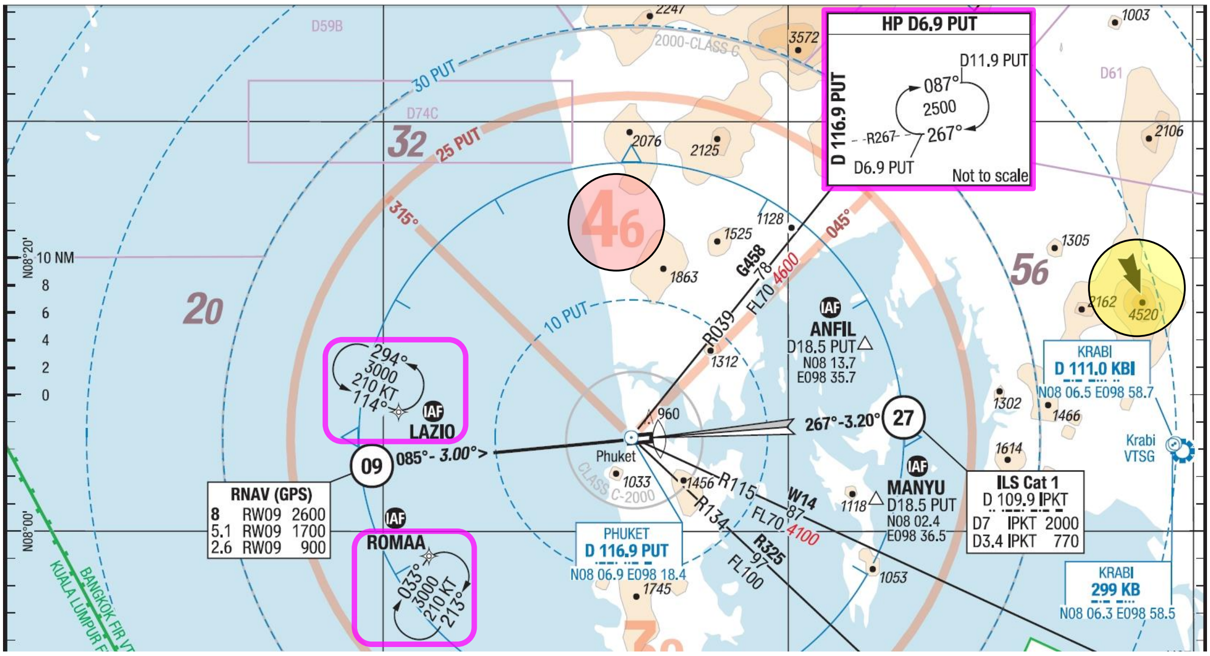

Fig. 17: Airport Facility Chart, 27 January 2011

Purple boxes: Holding Procedures

Red circle: Highest MSA, yellow circle: Highest obstacle on the chart Source: LIDO, adaptation BFU

1.9 Radio Communications

Radio communications with the responsible air traffic control were held in English. The CVR recordings were used to examine radio communications.

After engine damage occurred, radio communications included a total of 31 contacts between flight crew and the air traffic control unit. During 15 of these radio contacts, the flight crew was interrupted by the completion of ECAM actions or the conduct of the flight. Other aircraft had been on the same frequency for the entire time and contacted the air traffic control unit a total of 13 times.

1.10 Aerodrome Information

Phuket Airport, Thailand, (VSTP) is an international airport. Airport elevation is 82 ft AMSL. It had one runway in the directions 085°/265° (Marking 09/27). It was 3,000 m long and 45 m wide. For runway 09 there was no approach lighting system available. High Intensity Lights with a distance of 60 m each were installed in the area of the touch-down zone. As optical references, Precision Approach Path Indicators (PAPI) were located right and left of the runway. The 2 PAPI had a glideslope of 3.0°. Figures 13 and 14 were taken from the LIDO AGC 3-20, January 2011.

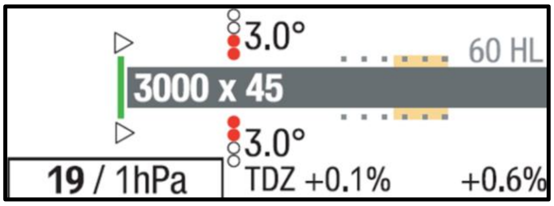

Fig. 18: Runway information, 27 November 2011 Source: LIDO

The aerodrome chart showed the vertical cross section including the different runway profiles.

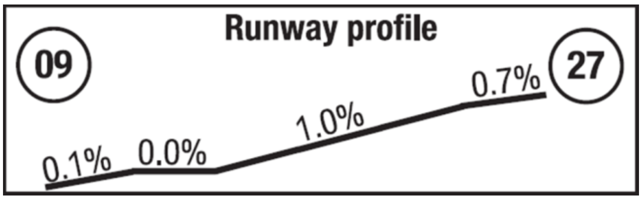

Fig. 19: Runway profile, 27 November 2011 Source: LIDO

1.11 Flight Recorders

Manufacturer FDR	L-3COM
Model	FA 2100
Part Number	2100-4043-02
Serial Number	447401

Tab. 7: FDR information

Manufacturer CVR	Fairchild
Model	A200S
Part Number	S200-0012-00
Serial Number	1908

Tab. 8: CVR information

The BFU seized the two recorders, both were undamaged. The BFU avionics laboratory was able to read out the data.

A Handheld Multi Purpose Interface of Flight Data System was used to download the FDR data.

The LORAL Digital Audio Playback Unit and the software Sonic Foundry Audio Vegas 2.0a were used to download the CVR data. The quality of the CVR recording was good. Excerpts from the CVR recording are part of the Appendices and do not contain any personal and/or incomplete remarks.

The relative times of the CVR were synchronised with the aircraft times the FDR had recorded. Synchronisation points were the initial FDR recording of a warning at 1354:12 UTC and the first recording of the Continuous Repetitive Chime on the CVR (both after the engine damage).

The following graph shows the FDR parameters which are relevant for a stabilized approach.

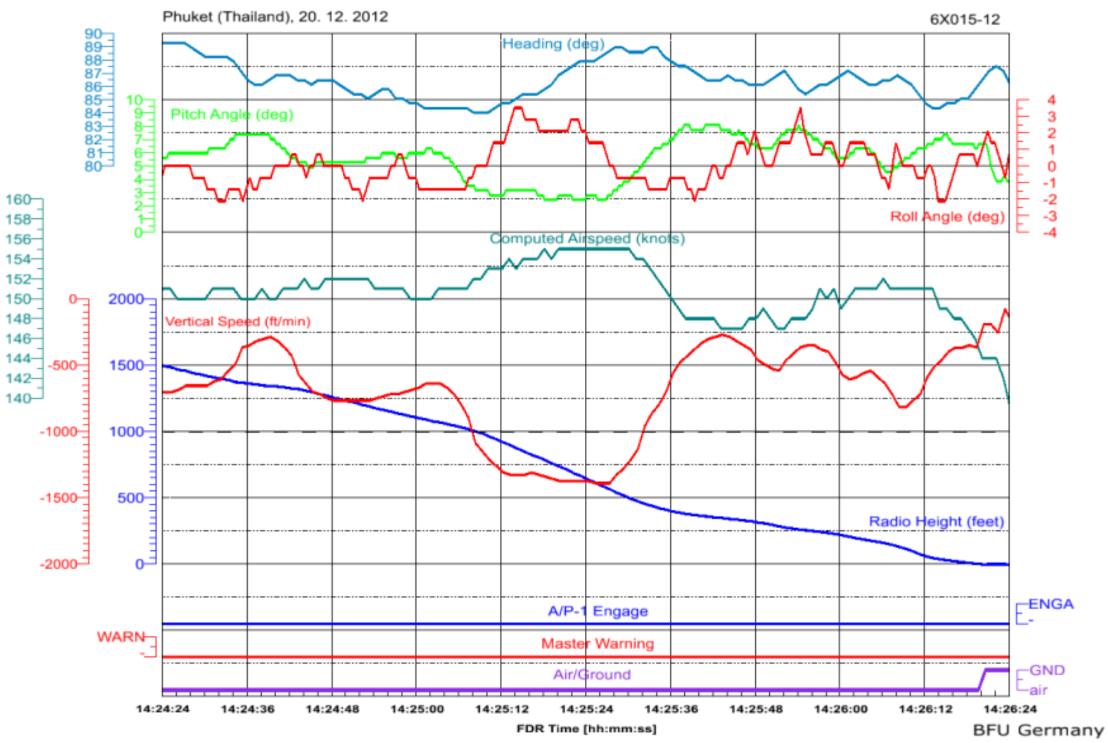

Fig. 20: FDR parameters: approach and landing Source: BFU

The following table shows, among other things, the extreme parameter values of the FDR which are relevant for the evaluation of the criteria for a stabilized approach (see 1.17.2)

	Altitude between 1,000 and 200 ft	at 1,000 ft	at 500 ft
Airspeed [Computed Airspeed]	147 to 155	152	155
vertical Speed [ft/min]	-272 to -1,392	-1,152	-1,216
Roll Angle [°]	-2 to +4	0	-1
max. Pitch Angle [°]	2 to 8	4	4

Tab. 9: Parameters for the evaluation of the criteria for a stabilized approach at different altitudes[17]

The CVR recording shows the following radio communications ratio with the air traffic control unit between the engine damage and the landing.

	PIC	Co-pilot
PIC is PF	8	35
Co-pilot is PF	5	1

Tab. 10: Radio communications ratio of PIC and co-pilot

1.12 Wreckage and Impact Information

1.12.1 Accident Site[18]

After the landing, it was determined that parts of the left engine's low pressure turbine exited the engine housing and entered the engine nacelle. The right translating sleeve reverser of this engine showed several impacts. Neither the cowling nor the translating sleeve reverser had been punctured.

The maintenance organisation stated that after the damage the green hydraulic system was filled with approximately 38 to 40 l hydraulic fluid. The other systems (blue and yellow) did not require any filling. In the area of the Case Drain Line of the mechanical

[17] Radio Altitude

[18] The following information is based on the documentation of the maintenance organisation.

pump of the green hydraulic system a line link was loose (Link between line IPC Item -180 and Union -230).

It was determined that five wheels of the main landing gear were flat and the fuselage showed several impacts and dents.

1.12.2 Engine Examination

The left engine was examined at SR Technics, Zurich, Switzerland, in the presence of the NTSB, the engine manufacturer Pratt & Whitney and the BFU, among others. Further investigations were conducted at Pratt & Whitney.

General

The fan, the compressor and the combustion chamber showed wear marks consistent with the operating time of the engine. The blades of the High Pressure Turbine (HPT) did not show any damage. The outer diameter of the LPT drive shaft showed a rub mark which corresponded with a rub mark at the inner diameter of the HPT drive shaft.

The 3rd turbine stage did not show any apparent damage. Starting with the 4th LPT stage all subsequent rotors and guide vanes showed damage to various degrees. Except for two vane clusters of the 4th stage, all other vane clusters of this stage were inside the housing. All blades of the 4th stage were fractured close to the blade root platform.

All turbine blades of the 5th, 6th and 7th stages were torn off. The fracture surfaces were irregular and grainy. The vane clusters Nos. 2, 3, and 13 of the 5th stage were missing. Other vane clusters of this stage were no longer engaged in the housing or no longer in their original positions and showed damage. The vane clusters of the 6th and 7th stages showed similar damage. The turbine discs were not damaged.

The LPT front case showed three holes and three splits in the plane of the 4th turbine stage; the largest was 425 mm long and 45 mm wide. In the plane of the 4th and 5th turbine stages were numerous outward bulges but none in the plane of the adjacent 3rd and 6th stages. The aft LPT housing showed two holes but no outward bulges.

The outer case of the exhaust pipe showed several dents but no holes. The EGT probes showed impact marks. Wall thickness of the LPT housing was consistent with the part requirements. Micro structure and hardness were consistent with the specifications of the material used.

The right thrust reverser showed a multitude of impacts. There were 46 impact marks which penetrated the sealant and insulation ablative material. The underlying composite structure was damaged at 12 places. The outer structure was not damaged.

4th LPT stage:

Except for the vane clusters Nos. 2 and 3[19] all others of this stage were within the housing. One vane cluster was found at the bottom of the LPT housing next to other debris. During the investigation, this vane cluster was named “A” because it was not possible to allocate it unambiguously to position 2 or 3. The other missing vane cluster was not found.

Fig. 21: View of the 4th guide vane stage. The yellow marking shows the position of the two missing vane cluster

Source: BFU

The vane clusters Nos. 1, 4, to 38, 43 and 44 were engaged in the housing. The vane clusters Nos. 39, and 42 were not engaged in the housing. At the inner end they were displaced forward. The vane clusters Nos. 41 and 42 showed circumferential rub marks on their inner platform rear face. The trailing edge of the inner ends of the airfoils on vane cluster No. 42 also showed rub marks. The 4th rotor stage had a notch rubbed in on the leading edge of the blades in the transition area of the platform (Fig. 8 and Fig. 22).

All turbine blades of the 4th stage were fractured close to the blade root platform (about 7 mm above the platform). Nine 4th stage LPT blades showed signs of fatigue failures

[19] The vane clusters were numbered circumferentially beginning at the upper end of the turbine (12 o’clock position). The 4th Guide vane stage had 44 vane clusters.

which began in the vicinity of the leading edges and progressed to overload fracture. The fracture surfaces of the remaining blades showed signs of forced ruptures.

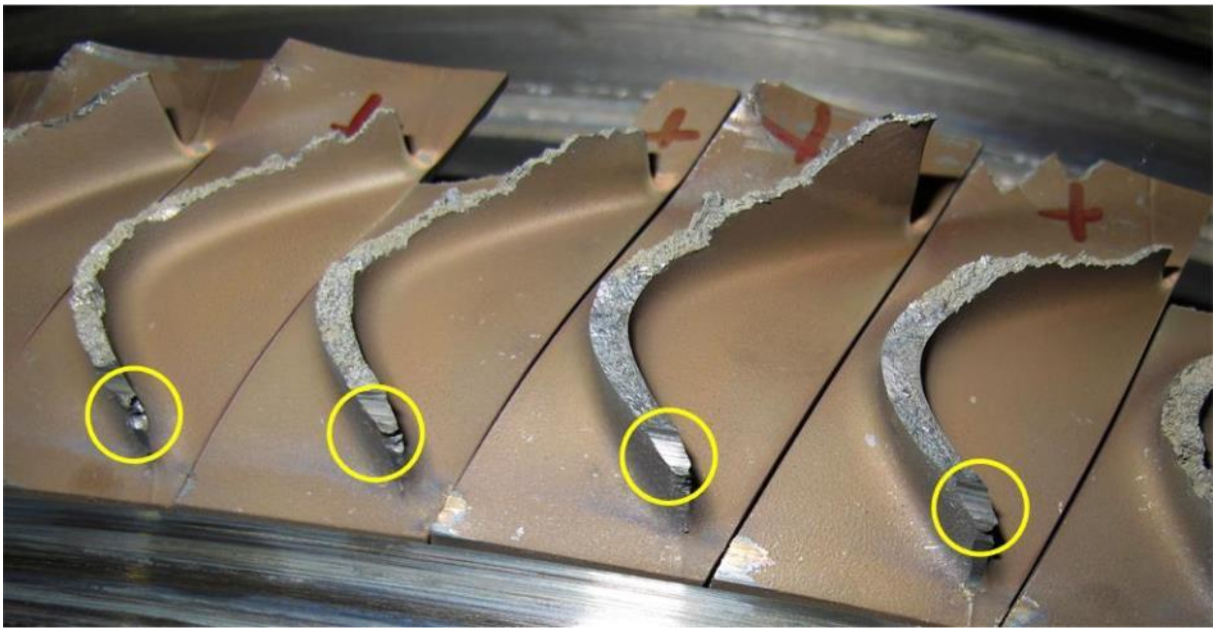

Fig. 22: Turbine stage #4 (rotor) with rubbed in notch Source: Pratt & Whitney

The visual inspection of all vane clusters revealed a small recessed area at Gusset 1[20], apparently a result of the casting process. The break edges of the gusset 1 (vane cluster No. 4) measured 0.0508 mm (0.002 in.) According to the manufacturer's requirements a radius of 0.0762 to 0.381 mm (0.003 – 0.015 in) was required. The radii at the end face of gusset 1 on cluster "A" measured between approximately 1.6002 mm (0.063 in) and up to 0.6604 mm (0.026 in).

[20] Numbering from the pressure to the suction side

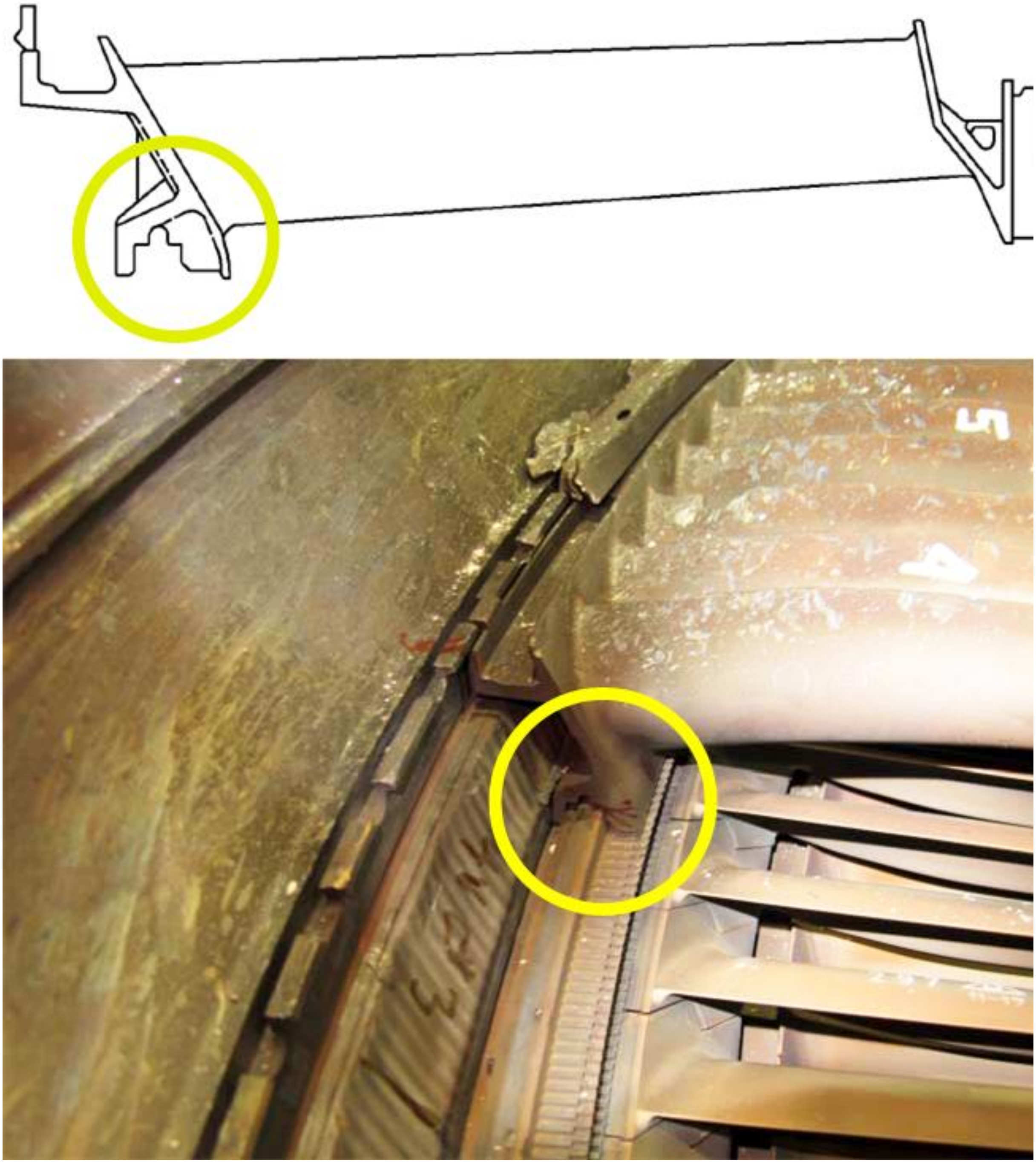

Fig. 23: Vane Cluster # 4, principle drawing and close up, yellow circle shows an outside diameter gusset

Source: Pratt & Whitney, adaptation BFU

Five vane clusters showed visible cracks: No. 44 and "A" (each at gusset 1), No. 4 (at gussets 1, 3 and 4), and Nos. 14 and 19 (very small cracks at gusset 1). The fracture surface of vane cluster 4 (gusset 4) showed characteristics of forced rupture, whereas vane cluster "A" (gusset 1) showed signs of fatigue fracture.

Fig. 24: Vane cluster No. 4 including numbering of the gussets Source: SR Technics, adaptation BFU

All remaining 43 vane clusters of the 4th LPT stage were subject to Fluorescent Penetrant Inspection (FPI). All examined clusters showed cracks indications mainly in the four gussets of the clusters. Double and multiple crack indications were also documented.

The vane clusters showed the Part No. PN 52N774-01A and the Casting Integral Marking 51N554 AT 1447-1-S2C3A.

1.12.3 Pylon

The left pylon was examined at Airbus. The following was determined:

- The pylon was measured and showed no deviations
- There were cracks in the front fairing at Panel 451 CL
- Fatigue fracture at the Hydraulic Line Bracket F29030080
- Gap under heads of screws: 3.5 mm (Report TD-29 AIB-0001))
- Twists on coupling nuts on pipes

- Cracks at panel sheets and missing riveting

Due to the holes in the engine housing and the resulting heat, it could not be evaluated if material damage which might have affected the pylon's strength had occurred. Therefore, the pylon was replaced.

1.13 Medical and Pathological Information

Not applicable

1.14 Fire

There were no indications of fire. The FDR did not record any fire warning at the left engine.

1.15 Survival Aspects

Not applicable

1.16 Tests and Research

On 26 February 2014, the occurrence flight was re-enacted at a certified level-D simulator. The aim was to determine the indications in the aircraft during the occurrence.

The Technical Pilot and the Flight Safety Operator of the operator conducted the flights. The limitations the simulator presented in regard to the correct reproduction of the occurrence flight were analysed beforehand and restricted as much as possible by appropriate programming. The main difference was the failure - low pressure in the blue hydraulic system - connected with the indication HYD G+B SYS LO PR. This failure occurred in the simulator earlier than during the occurrence flight.

The indications of the ECAM on the E/WD and the SD were of primary interest. These should give information regarding the indication of the failure, the action instructions and the behaviour of a flight crew concerning the completion of necessary abnormal procedures. The course of the flight, lateral as well as vertical, was not decisive for this experimental set-up.

During the first simulator flight, the flight crew performed the actions the way they had been carried out during the occurrence flight.

Another simulator flight was conducted, where the ECAM actions were completed consequently. The simulator crew shut off the 2 hydraulic pumps of the green hydraulic system after the HYD G SYS LEAK indication had appeared, contrary to the occurrence flight. The most important finding of the second flight was that after the HYD G+B SYS LO PR warning the instruction CONSIDER RAT MAN USE appeared on the ECAM. The use of the RAT resulted in the green hydraulic system remaining operative including essential functions such as controls and slats. The PF stated that the aircraft had been much easier to control during the second flight.

1.17. Organisational and Management Information

1.17.1 Safety Management System of the Operator

1.17.1.1 General Information

The operator stated that the Safety Management System (SMS) was essentially based on the following sources of information:

- Flight Data Monitoring (FDM)
- On-line reporting and paper reporting
- Alternative Training and Qualification Program (ATQP)[21]
- Information from other departments (maintenance, ground OPS, flight OPS)
- External sources (airport reports, ATC, etc.)

The analyses were presented in different publications and statistics which were made available to the personnel. In addition, Safety Action Group Meetings were held monthly and consisted of the safety officer of each department.

[21] At the time of the occurrence ATQP had not been implemented

Agenda	Distribution	Interval
Flight Data Monitoring Deficiency Report (FDMDR)	CAMO, Fleet Management, Avionics Department	weekly
Flight Safety Statistics Boeing / A320 / A330 Fleet	Flight Crews	monthly
Flight Safety Status Report (FSSR)	O, OY, OF, Fleet Management, OF-OT, OM-OI	monthly
Cabin Safety Status Report (CSSR)	O, OY, OF, Fleet Management, OF-OT, OM-OI, OX-OK, MCT, MCST	quarterly
Safety Status Report (SSR)	O, OY, Safety Representatives of related Areas	quarterly
Flight Safety Info (FSI)	Flight Crews	at least annually
Cabin Safety Info (CSI)	Cabin Crews	at least annually
Flight Safety Assessment Report (ABF-SAR)	OF, Fleet Management, OF-OT, related Flight Crew, ABFS intranet, OI if necessary	as required
Cabin Safety Assessment Report (ABC-SAR)	OF, OX-OK, OF-OT, related Flight Crew, related Cabin Crew, ABFS intranet, OI if necessary	as required
Flight Safety Investigation Report (ABF-SIR)	OF, Fleet Management, OF-OT, related Flight Crew, ABFS intranet, OI if necessary, FOCA, BFU	as required
SIRA Documentation	Safety Management, related nominated person, OY, others as required	as required
Flight Safety Bulletin	Flight Crews, Cabin Crews	as required
Cabin Safety Bulletin	Cabin Crews	as required
Safety Bulletin	related Department	as required
Safety Presentation	Departments within [redacted] group, Partner Airlines, working Groups, Authorities	as required
Training Documentation	Participants of Safety Training	as required
Cabin Safety Quick Reporting Guide	Cabin Crews	as required
3D Flight Animation	Flight Crews, Fleet Management	as required
Feedback regarding significant Flights	Flight Crews	as required

Fig. 25: Overview flight safety products of the operator Source: Operator

1.17.1.2 Analysis of Flight Data at the Operator

The data of all flight operations were regularly analysed (FDM). Every 60 days the data was anonymised. By Flight Data Review Request, each flight crew could review their own data. If slight to moderate deviations from the Standard Operating Procedures (SOP) were determined, the flight crews received a letter to raise their awareness. If moderate to severe occurrences (High Risk Classifications) occurred, a hearing was conducted. Evidence-based campaigns were derived from the analysis of the FDM data. If SOP deviations (operational deficits) occurred, the Safety Action Group passed the information on to the training department.

The Line Operations Safety Audit (LOSA) is an analysis procedure for aviation which provides airlines with an appropriate tool to optimise air transport safety with the collection of safety-relevant data during normal operations. Since 2007, LOSA checks were conducted during Quality Inspection Flights, which are different from the Line Checks.

1.17.1.3 Flight Crew Training and Checks

The operator stated that the evaluation of the simulator training was performed as follows:

> *After the simulator training the simulator instructor confirmes the performance of the individual training items and flight manoeuvres. Training items which the pilot did not handle satisfactorily could be repeated. If the repeat training is again no satisfactorily the instructor can mark the training item on the form as "Fail" or "Not Pass". In closing, pilot and simulator instructor discuss the completed training.*

The item Crew Resource Management of the simulator check evaluation sheet was not individually assessed. The operator did not intend it. The instructor, however, had the option to make positive and negative entries in the remark field. The operator realised this deficit and established the Alternative Training and Qualification Program (ATQP) with the following aim (Operational Manual Part D):

> *The objective of ATQP is to improve the training and qualification standards of flight crews. ATQP is founded on the principle of evidence based training. Through collection and statistical analysis of training and checking information, areas requiring improvements can be identified and trained.*

The performance of the flight crews was evaluated by the trainer/examiner and recorded electronically. The operator stated that this evaluation could be used for the debriefing after a simulator session and for statistical analyses. It was also possible to search for focal issues in order to improve the training (similar to FDM). It would also be possible to improve standardisation of the trainers/examiners. At the time of the occurrence and due to the short time in service, among other things, this system did not yet have the ability to identify flight crew or individual crew members who in flight and under stress would be less able to cope with complex situations than they have shown in the simulator.

According to the operator, deviation from the defined standard had not been discernible in the two pilots involved.

1.17.1.4 Simulator Training

Already in 2012, the operator implemented Evidence Based Simulator Training (EBT) in accordance with the recommendation of ICAO DOC 9995.

It had the aim to improve the mental capacity of pilots in different areas such as decision making, communication or situational awareness. It is based on the training of standardised actions during normal situations up to complex scenarios with multiple errors. The pilots are placed in a practical environment in combination with a complex simulated failure scenario. The main attention is focused not only on the completion of ECAM and QRH procedures but on the situational awareness and the decision-making process of the pilots.

The operator had developed different simulator training scenarios for the Line Oriented Flight Training (LOFT). One LOFT scenario covered different technical topics such as hydraulic systems, air conditioning, aircraft electronics. Every six months the simulator program was adapted and the main focal issues changed. The technical focal issues had to be repeated within a three-year cycle. Prior to the occurrence, engine failures shortly before or after take-off were trained in LOFT scenarios, but not ones at high altitudes. After the occurrence, the operator included engine failure at high altitudes in their planning. Since 2013, the operator had implemented EBT in their LOFT simulator trainings. The Operational Manual Part D described the implementation of the LOFT training.

According to the operator, there was an annual failure rate of about 5% during simulator checks.

1.17.1.5 Just Culture

The operator had stipulated the following in regard to Just Culture (excerpt):

> *1. [operator] is committed to the safest possible flight operating standards. To achieve this, it is imperative to have an atmosphere of trust in which people are encouraged and feel responsible to provide all essential safety-related information, which will be used to improve safety, but in which they also understand that a line must be drawn between acceptable and unacceptable behaviour.*
>
> *2. [operator] fully supports the principal of Just Culture. The objective of our Just Culture policy is to foster an environment whereby employees and related contractors are empowered to report any safety risk without fear of retribution, in the clear understanding that the Company accepts that errors and lapses of*

judgement may occur and that staff, in the course of their normal, expected duties, do not intentionally commit such errors.

3. Employees who make honest mistakes or misjudgements will not incur punitive action – provided that they report such incidents in a proper, timely fashion, and cooperate with any subsequent investigation. The only exceptions to this general non-punitive policy are where the actions or omissions involve negligence, reckless disregard or a failure to report safety incidents or risk exposures. An employee who acts irresponsibly in one of these ways is potentially exposed to disciplinary action. An employee compliance with reporting requirements will be a factor to be weighed favourably in the Company's decision making in such circumstances.

The operator stated that due to the transparent procedure (Just Culture) the number of reports increased significantly.

1.17.2 Criteria for a Stabilized Approach

The FCOM Chapter FCB12, of April 2011, Intermediate/Final Approach, General stipulated a list of criteria which a flight crew had to ensure during approach prior to reaching an altitude of 1,000 ft AGL. The aim of these stabilized approach criteria was to establish early landing configuration at completion of the landing checklist.

The following paragraph describes the criteria for a stabilized approach. It is an excerpt of the FCOM, Chapter Procedures Normal Operation – Standard Operation (PRO-NOR-SOP-18) P 4/10, of 16 August 2012 of the operator.

GENERAL

The objective is to be stabilized on the final descent path at VAPP in the landing configuration, at 1 000 ft above airfield elevation (in instrument conditions, or at 500 ft above airfield elevation in visual conditions, after continuous deceleration on the glide slope).

- *To be stabilized, all of the following conditions must be achieved prior to, or upon reaching this stabilization height:*
- *The aircraft is on the correct lateral and vertical flight path*
- *The aircraft is in the desired landing configuration*
- *The thrust is stabilized, usually above idle, to maintain the target approach speed along the desired glide path*

- *No excessive flight parameter deviation.*

If the aircraft is not stabilized on the approach path in landing configuration, at 1 000 ft above airfield elevation in instrument conditions, or at 500 ft above airfield elevation in visual conditions, or as restricted by Operator policy/regulations, the flight crew must initiate a go-around, unless they think that only small corrections are necessary to rectify minor deviations from stabilized conditions due, amongst others, to external perturbations.

The operator had specified in the FCOM Chapter Procedures Normal Operation – Standard Operating Procedures (PRO-NOR-SOP-19) the following standard call outs for the PNF during a non-precision approach. If the values below were exceeded, the PNF should use the respective standard call outs in order to advise the PF so that he could initiate corrective actions.

PNF calls out:

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

- "SINK RATE", when V/S is greater than – 1 000 ft/min

- "BANK", when the bank angle goes above 7 °

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

- "COURSE", when the course deviation is greater than ½ dot or 2.5 °(VOR), or 5 °(ADF).

- "_ FT HIGH (LOW)" at altitude checkpoints.

Following PNF flight parameter exceedance callout, the suitable PF response will be:

- Acknowledge the PNF callout, for proper crew coordination purposes

- Take immediate corrective action to control the exceeded parameter back into the defined stabilized conditions

- Assess whether stabilized conditions will be recovered early enough prior to landing, otherwise initiate a go-around."

1.17.3 Calculation of the Actual Landing Distance and Speed

The calculation of the Actual Landing Distance (ALD) was carried out using an Electronic Flight Bag (EFB). It is a computer with stored documents and on which calculations for the conduct of the flight can be performed.

The calculation of the ALD is based on factors which may influence the landing distance. This also includes component and system failures. The EFB software which was used during the occurrence did not allow multiple inputs of theses failures. For the calculation of the ALD for Phuket Airport only the actual landing mass, the wind and the engine failure could be considered. The factors: incomplete slat/flap positions, the hydraulic system failure and the resulting use of the alternate braking system just with the hydraulic accumulator, remained unconsidered. After the occurrence, the EFB software was updated by the aircraft manufacturer which created the option that multiple factors for the calculation of the ALD could be entered.

Shortly after the engine damage, the flight crew had calculated the ALD using the EFB and selected single-engine operation, the actual landing mass and auto brake, initially with auto brake low and later with medium. An ALD of 2,270 m and of 2,986 m, respectively, was determined. There was no calculation that included the system failures which had occurred later.

According to the table in the QRH Chapter In-Flight Performance, Operating Speed of 8 August 2012, V_{LS} for Config 2 Position was 150 kt[22]. This resulted in a V_{APP} for the approach of 165 kt.

1.17.4 Electronic Centralized Aircraft Monitoring

So-called ECAM actions are indicated on the ECAM and are procedures which flight crews have to carry out. Interruptions, continuations and completion of these procedures should be conducted using the standard call outs specified in the FCOM Normal Procedures (Stop ECAM, Continue ECAM, ECAM completed).

1.17.5 Flight Crew Task Sharing

The FCOM Chapter PRO-ABN-01 Abnormal and Emergency Procedures described the following:

> *When the flight crew performs procedures, the flight crew uses the “READ” and “DO” principle (oral reading).*
>
> ***TASKSHARING***
>
> *The general tasksharing shown below applies to all procedures.*
>
> *The pilot's flying remains the pilot flying throughout the procedure.*
>
> *The Pilot Flying (PF), is responsible for the:*

[22] All speeds are calibrated airspeed unless stated otherwise.

- Thrust levers

- Control of flight path and airspeed

- Aircraft configuration (request configuration change)

- Navigation

- Communications.

The Pilot Not Flying (PNF), is responsible for:

- Monitoring and reading aloud the ECAM and checklists

- Performing required actions, or actions requested by the PF, if applicable

- Using the engine master switches, reset buttons, IR[23] and guarded switches, with PF's confirmation.

1.17.6 Checks and Briefings

In accordance with the FCOM Chapter PRO-NOR-SOP, Standard Operating Procedures, during descent an approach briefing has to be conducted. During the approach and prior to landing, the approach checklist and the landing checkklist, respectively, have to be completed. The CVR recording shows that neither the briefing nor the completion of the checklists was performed.

1.17.7 Medical Requirements

At the time of the occurrence, the issuance of medical certificates and the entry of restrictions therein took place in Germany in accordance with the requirements of „Bekanntmachung der Bestimmungen über die Anforderungen an die Tauglichkeit des Luftfahrtpersonals“ (Declaration of the regulations concerning the requirements of the fitness to fly of flight crews) pursuant to JAR-FCL 3. Based on these, the Aero-Medical Examiners (AME), Aero-Medical Center (AMC) and the Aero-Medical Section (AMS) of the Luftfahrt-Bundesamt (LBA, German civil aviation authority) were qualified to make decision as to the fitness to fly. The issuance of medical certificates in medically complex cases and the entry and deletion of certain high-level restrictions, e.g. “OCL”, was made by the Referat L5 (department) of the LBA. This department had the supervisory control of the AMEs, AMCs and the medical certificates[24] they issued.

[23] Inertial Reference

[24] Regulation (EU) No. 1178/2011 and the corresponding document „Acceptable Means of Compliance and Guidance Material to Part-MED“ came into force in Germany on 8 April 2013.

1.18 Additional Information

1.18.1 Report of the Flight Crew

The PIC stated immediately after the occurrence and again about fice weeks later during an interview with the operator's Flight Safety Department and the BFU, respectively, that he had tried to re-establish autothrust function as fast as possible so that the aircraft could fly "automatically" again and "wir Kapazitäten frei haben (we had free capacities)". According to his statement, ECAM had required a reset of the EPR mode. The respective push buttons on the overhead panel had to be pushed. The localisation of these push buttons had required time since they are rarely used.

He also stated that he had been worried about the unclear ALD and therefore wanted to touch-down at the beginning of the runway.

The co-pilot stated during these interviews that during the Mayday calls to the air traffic control unit he had informed them about an engine fire, among other things. He had done this in order to get a higher priority.

Both assessed their team work during the occurrence as positive.

At a later stage, the PIC reported that all his actions were taken according to a plan, based on the consideration of various options. This essentially concerned not switching off the pumps and the selection of the landing site.

> *If one system has already failed, it makes no sense to switch off a second system according to ECAM, even though it would still be usable for some time. With "follow ECAM" we would have led ourselves into the "single hydraulic" situation.*

The information on the ECAM had played a minor role for him.

> *Working through the lines in the standard way (reading, thinking, "checked") would inevitably have meant a […] flight time extension of at least half an hour - adding the constant interruptions caused by "Stop ECAM, Continue ECAM, Clear ECAM". We simply didn't have that time with an emptying system that was still needed. Strict adherence to the listed but questionable ECAM procedures was counterproductive in this phase. It was never planned to do completely without ECAM information and information was demonstrably retrieved at all times. Especially under "Systems Lost" it became clear that the ECAM "regime" was no longer the criterion for action up to the touchdown point.*

He described his consideration between the option to drive the slats/flaps and the selection of the landing airport.

The critical factor was to determine how severe the leakage rate in the main system was. If the slats could not be extended, the runway in Phuket would be too short. If ECAM had been followed and the hydraulic pumps of the main system had been switched off, Phuket as the "nearest suitable airport" would have been "switched off" at the same time. Because ECAM would have indicated "No Slats" and thus kicked Phuket out of the circle of the "next suitable". I considered it justifiable not to shut down the pumps and to strictly observe the leakage in order to maintain the physical rationale for an approach to Phuket.

1.18.2 Decision Model

In order to find solutions to a problem and perform safe and structured actions, one of the models used in aviation is FORDEC. It is the abbreviation of a decision model which includes actions that are described as follows: Facts, Options, Risks and Benefits, Decision, Execution, Check.

1.18.3 Crew Resource Management

The aim of flight crew team work is to act so that an error of one flight crew member is noticed by the other and corrective action can be initiated (e.g. by bringing it up).

The BFU commissioned an expert to assess the actions of the flight crew with regard to Crew Resource Management (CRM) on the basis of the CVR recordings considering the different flight phases (Appendix 9).

The positive and the negative actions were counted on the basis of the following parameters:

Communication	**Leadership and Teamwork**
achieve a positive first impression	take the lead of the crew as commander
encourage open and honest communication	establish goals, control outcome and correct
listen actively	consider condition of others
consider suggestions	take initiative
share information	support others
assure reception	seek ideas and views from others
assure understanding	propose alternative ideas if appropriate
announce ambiguities and uncertainties	present own point of view
clearly state plans and intentions	provide appropriate feedback
speak frankly about problems within the crew	address and manage conflicts
	achieve rational climate
Workload Management	avoid intimidation
prioritize operational tasks	accept appropriate criticism

distribute tasks appropriately	persist until corrective action is taken
use external and internal resources	avoid competition between crew members
plan ahead	
allocate time to task appropriately	**Additional**
avoid haste	plans ahead
aim to minimize negative effects of stress	briefs all items
aim to minimize negative effects of error	establish gates
	crosscheck FMA
Situation Awareness and Decision Making	read ECAM thoroughly
act with respect to time available	read C/L complete
avoid distractions	keep a system overview
anticipate and recognize factors affecting your operation	distance / time to field
evaluate facts	terrain awareness
monitor execution	correct fuel awareness
FORDEC	

Tab. 11: Parameters for the assessment of the CRM

The flight crew actions were also assessed in accordance with LOSA and documented in a Crew Performance Marker Worksheet (Appendix 10).

1.18.4 SaMSys Study

In connection with the implementation of the Safety Management System (SMS), the Deutsche Lufthansa AG has conducted simulator studies concerning risks during flight operations and the behaviour of flight crews in complex failure scenarios (SaMSys Study). The findings should result in conclusions for their own safety work. The SaMSys-II study examined handling of complex abnormal flight situations during simulator flights.

In detail, the following factors were examined: Technical problems (TEC), human errors (HUM), operational deficits/problems (OPS) and social deficits in team work (SOC). The study showed that the combination of these factors increases the appearance probability of a safety critical event. Especially the combinations HUM+SOC with OPS or TEC problems constituted the largest part of causes for safety critical events.

The study showed that 30% of flight crews solved their tasks very well, whereas 60% solved their problems with difficulties and errors.

At 10% of the flights, the flight crews acted in a way that an accident occurred. It was observed that the communications of the PM (wrong or missing remarks) and counterproductive inputs contributed significantly to the development of an accident.

1.18.5 Other Occurrence

The BFU received information concerning another occurrence that combined an engine failure and the loss of the green hydraulics circuit from an operator (Report on the bird strike of the PH-AOB, an Airbus A330-200, at Entebbe International Airport on 10 October, 2010. Report 1011.10).

As a result of this investigation the following suggestions were addressed to Airbus, among other things:

> *It is recommended [25] that Airbus reconsiders the system logic that re-opens the green hydraulic fire shutoff valves 150 s after automatic closure, when a green reservoir low level is sensed in combination with an engine failure.*

Note: Airbus stated that “such a logic was not considered effective on subject fleet due to the system architecture. However, the logic was enhanced on the next products thanks to the new architectures” (see 1.18.9).

> *It is recommended to include a non-annunciated procedure in the A330 QRH that calls for the engine to be shut down and the fire p/b to be pressed in the event that severe engine damage exists in the absence of engine related ECAM cautions or warnings.*

Note: Airbus stated “Airbus is not in a position to develop a procedure requesting to press the engine fire pushbutton based on flight crew assessment only, without any ECAM alert. The adverse effect of such a procedure would be to increase the risk of unduly pressing the fire pushbutton, thus preventing the flight crew from restarting the engine if necessary for safety purpose.”

1.18.6 Description of the Medical Limitations and Restrictions

The EASA Acceptable Means of Compliance and Guidance Material to Part-MED1, Initial issue 15 December 2011, described the medical limitations and restrictions as follows:

> *[…]*

[25] This report was issued by the operator but not by a SIA. Therefore, the rules for issuing safety recommendations in accordance with ICAO Annex 13 or EU Regulation No. 996/2010 were not applicable.

OML Valid only as or with qualified co-pilot
This applies to crew members who do not meet the medical requirements for single crew operations, but are fit for multi-crew operations. Applicable to class 1 medical certificates only.

OCL Valid only as co-pilot
This limitation is a further extension of the OML limitation and is applied when, for some well defined medical reason, the pilot is assessed as safe to operate in a co-pilot role but not in command. Applicable to class 1 medical certificates only.

OSL Valid only with safety pilot and in aircraft with dual controls
The safety pilot is qualified as PIC on the class/type of aircraft and rated for the flight conditions. He/she occupies a control seat, is aware of the type(s) of possible incapacity that the pilot whose medical certificate has been issued with this limitation may suffer and is prepared to take over the aircraft controls during flight. Applicable to class 2 and LAPL medical certificates only.

[…]

1.18.7 ICAO Requirements for Air Navigation Service Providers

The ICAO Air Traffic Management, Doc 4444, Chapter 15 published recommendations for Air Traffic Services (ATS) during an emergency.

[…]

15.1.1.2 When an emergency is declared by an aircraft, the ATS unit should take appropriate and relevant action as follows:

………

e) obtain from the operator or the flight crew such of the following information as may be relevant: number of persons on board, amount of fuel remaining, possible presence of hazardous materials and the nature thereof; and

……….

15.1.1.3 Changes of radio frequency and SSR code should be avoided if possible and should normally be made only when or if an improved service can be provided to the aircraft concerned.

………

Note. — Requests to the flight crew for the information contained in 15.1.1.2 e) will be made only if the information is not available from the operator or from other sources and will be limited to essential information.

[…]

1.18.8 Investigation

On 20 December 2012, the BFU was informed by the operator that an event had occurred. As State of Occurrence of the event, Thailand decided not to investigate it and, according to ICAO Annex 13, delegated the investigation to the BFU as the investigation authority of the State or Registry of the aircraft. On 3 January 2013, the BFU began investigations and notified the States of Manufacture of the Aircraft and of the Engines, BEA and NTSB, respectively. They subsequently nominated accredited representatives and designated technical advisors of the aircraft and engine manufacturers, Airbus and Pratt&Whitney.

1.18.9 Information of the Aircraft Manufacturer

During the investigation, the aircraft manufacturer Airbus stated the following in regard to the incident:

[…] Airbus confirms the applicability of the alerts triggered during the incident and of the associated abnormal procedures. From a safety point of view and in absence of any major engine fault, keeping the engine operative till the ENG 1 EGT OVERLIMIT and not pushing the ENG FIRE P/B-SW when shutting it down was the best option.

[…]

Airbus philosophy

In order to ensure the highest level of systems redundancy and of recovery when possible, the Airbus philosophy is to maintain the engine operative as long as it is globally safe to do so. The ECAM and the operational procedures support this objective.

The flight crew always keep the possibility to decide otherwise and switch the engine off and push the ENG FIRE P/B-SW. Such flight crew judgement should result from a safety risk analysis that evaluates the pros, the cons, and the reversible and irreversible consequences for the rest of the flight.

BFU was informed that this information will not supersede the Airbus Operational Philosophy as documented in the Flight Crew Training Manual (FCTM) (Appendix 12).

Airbus assessed the climb performance if a go-around should be necessary:

> *The aircraft was configured as close as possible to MSN 288 in terms of weight and CG, configuration CONF 3 (24°/22° instead of 21°/22°), gear down, G+B failed, sea level. A go-around was performed when reaching 100ft AGL. 50ft to 60ft were lost in the go-around before the aircraft achieved positive climb. The climb rate was about 400-500ft/min when stabilised after the go-around.*

Airbus provided information about the design of the "High Leak Logic" on A330neo.

"High Leak Logic" in addition to the same protections as A330ceo:

- *impact on the green EDP's HP, case drain or suction line of the failed engine (within the UERF[26] risk zone) is detected and isolated quickly so that the system remains functional from the opposite (unaffected) engine's EDP*
- *impact is determined by pressure loss on the EDP's delivery and case drain lines (via pressure switches) and the corresponding green FSOV is closed quickly **
- *this function use additional input parameters to prevent inadvertent / false triggering (OR impact), hence it is realized by an additional wiring/relay circuit, which isn't practicable to retrofit post aircraft production (i.e. A330ceo)*

** Note: Control is dedicated to an individual FSOV, independent from the FIRE P/B.*

1.19. Useful or Effective Investigation Techniques

Not applicable

[26] UERF: Uncontained Engine Rotor Failure

2. Analysis

2.1 General

The BFU intended to determine the circumstances of the engine damage and the extent of the damage which had been caused by liberated engine parts. The BFU assessed that given the fact that two hydraulic systems had failed the requirements for a Serious Incident were met.

2.2. Course of the Flight

2.2.1 Left Engine Damage

The flight crew noticed the engine damage because of the sounds and vibrations, the warnings and the ECAM information. The thrust lever of the left engine was pulled back. Because engine thrust was reduced, the EGT and N2 threshold values were no longer exceeded and the vibration level decreased. The engine operated in N1 mode. It can be assumed that in this phase no further engine damage occurred.

Even though the PIC assumed “severe” engine damage and wanted to shut off the engine, the flight crew followed the ECAM actions because they quickly wanted to regain a high degree of automatic flight[27]. When FADEC recovered the capability to operate in EPR mode, the ECAM action ENG EPR MODE RECOVERABLE was triggered. When the crew selected the N1 mode off, the FADEC resumed the operation in EPR mode.

After the EPR mode had been re-established, the FADEC aimed at thrust increase (defined by a certain EPR value). Due to the mechanical damage at the LPT, the engine was not able to attain the commanded EPR level. Even though the thrust lever was in the IDLE position, the threshold value (EGT) was repeatedly exceeded. This resulted in engine shut-down by the flight crew.

According to the procedures in the FCOM Abnormal and Emergency Procedures, PRO-ABN-70 Powerplant:

- ENG 1(2) EGT OVERLIMIT
- ENG 1(2) N1/N2 OVERLIMIT

[27] Because autothrust had been shut off, engine thrust had to be set manually.

the engine has to be shut down if the parameters cannot be met. These procedures were available to the flight crew.

The FDR data showed that operation in N1 mode was possible without EGT/N2 exceedance, whereas this was not possible in EPR mode. Therefore, with this damage, the attempt to operate the engine in EPR mode again could not be successful and ultimately resulted in the shut-down, as it was stipulated in the above-mentioned procedures.

Airbus issued the Flight Operations Briefing Note (Handling Engine Malfunctions)[28] to give flight crews indications for the further use of engines.

The decision to shut off the engine or operate it in Flight Idle is the first essential decision for the further course for the flight. Had the engine been operated in Flight Idle, auxiliary units such as the hydraulic pumps of the green and blue hydraulic systems would have remained powered. If the blue system had remained powered and therefore fully functional, the later problems would have been significantly minimised (Chapter 2.3.3). On the other hand, engine shut-off was a safe option to prevent further damage. It cannot be assessed if continued operation of the engine would have been possible without increasing the damage significantly. After the engine was shut off, it was possible to eliminate further damage of the engine and the thermal load of the pylon.

The flight crew decided at their own discretion to shut off the engine. This had the effect that the engine was not available as energy source for the hydraulic pump of the blue hydraulic system and that the green hydraulic system still continued to run empty.[29]

The PIC's decision to shut down the engine is understandable based on the observations. The procedures ENG 1(2) EGT OVERLIMIT and ENG 1(2) N1/N2 OVERLIMIT confirm these actions.

2.2.2 Double Hydraulic System Failure

After the left engine was shut down, pressure in the blue hydraulic system was maintained for about 20 min. Due to configuring the aircraft for the approach and the related decrease of airspeed, the blue hydraulic system no longer supplied any

[28] At a later date, the FOBN was adopted into the FCTM

[29] In this case the flight crew could not yet recognise that the Green Hydraulic System was leaking and the engine cowling had been punctured.

pressure because of lack of windmilling (decreasing RPM of the N2 rotor). It was not possible to anticipate the leakage of the green hydraulic system.

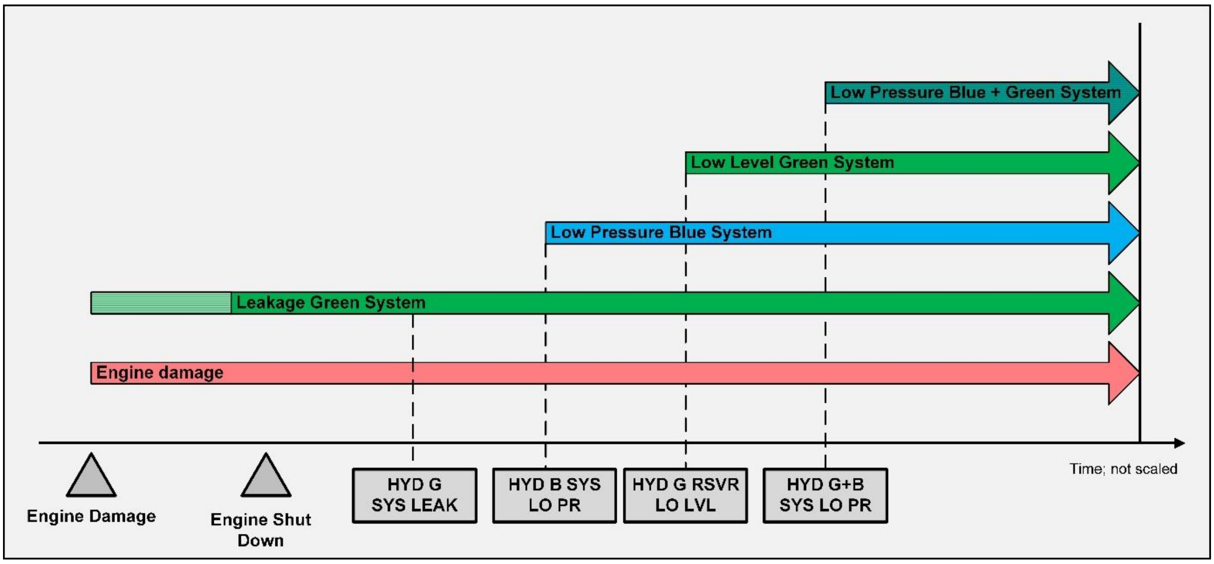

Fig. 26: Schematic sequence of events, which resulted in double hydraulic system failure
The boxes correspond with the ECAM indications. The green-white dashed line depicts a phase where it is unknown whether leakage had already occurred. Green and blue and green-blue dashed lines, respectively, correspond with the depicted hydraulic systems. Source: BFU

The completion of the ECAM actions is of particular importance. The flight crew was made aware of the leakage of the green hydraulic system for the first time by the warning HYD G SYS LEAK.

Fig. 27: ECAM HYD, G SYS LEAK Source: BFU (Simulator)

In particular, the co-pilot had difficulties to understand the meaning of the instruction LEAK RATE MONITOR. This is apparent by the CVR recording where the flight crew talks about values of “3,050”, then “3,000” and finally “2,901” (without any units). The co-pilot’s comment “Ja, die decreased (Yes, it decreased). Also wir haben jetzt dreitausend, die bleibt eigentlich so (now we have 3,000 it actually stays the same, now)" is contradictory and shows that the flight crew had not assessed the available information correctly. It is obvious that the hydraulic pressure was interpreted as Leak Rate.

At the hydraulic page, only the reservoir and the hydraulic pressure were indicated, but not the leak rate.

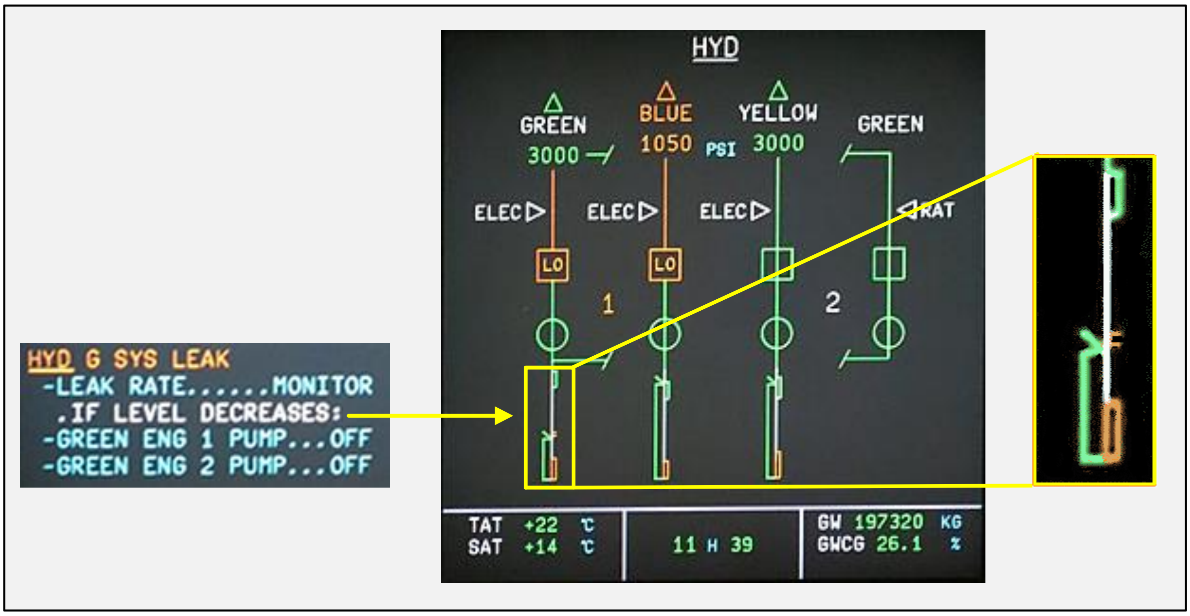

Fig. 28: Indication of the hydraulic levels

Left: ECAM action on the E/WD (excerpt)

Centre: indication of the hydraulic system page on the SD

Right: indication of the fill quantity on the hydraulic system page

The BFU added the yellow markings　　　　Source: BFU

The first ECAM line (LEAK RATE MONITOR) of the procedure HYD G SYS LEAK refers to a physical unit which is not displayed or available. This may have drawn attention to the pressure indication rather than the level indicator, where more suitable information would have been available. Apparently, it was "easier" for them to recognise the hydraulic pressure of 3,000 psi than to deduce the hydraulic system leakage from the symbolised indication of the reservoir. For example, the indication LEVEL MONITOR would have drawn the flight crew's attention to the indication of the fill quantity and forced an assessment.

However, the second line IF LEVEL DECREASES leads to the level indicator. The level indicator was well below the normal level (41 l vs. 17 l). The significant low level should have resulted in the observation of the level indicator. Moreover, the quantity indicator becomes amber when the warning level is triggered.

Determining the Leak Rate would require several minutes. The flight crew would have to wait for this process to end to ensure the correct completion of ECAM actions. It is not conceivable that during this period no (other) interruptions occur. According to the statements made in Chapter 2.4.5 a comparatively long work step and the subsequent high number of expected interruptions is extremely error prone. Since such ECAM actions only appear during technical failures and normally require the completion of abnormal procedures, the contradictory indication increases the workload of the flight crew.

This had the effect that the ECAM action LEAK RATE MONITOR was not completed and the hydraulic pumps of the green hydraulic system's engines were not switched off.[30] During leakage in the pressure pipe, switching off the pump would have resulted in decrease or termination of the leakage. In this case switching off the pump would not have changed anything in regard to the leakage, because in the Case Drain Line is always a volume flow, according to the manufacturer.

Due to the decrease in airspeed and the resulting reduction of the left engine RPM the pressure in the blue hydraulic system dropped. This triggered the Blue System Low Pressure warning. After the landing gear had been extended, more hydraulic fluid flowed from the reservoir. This triggered the warning HYD G+B SYS LO PR at 1421:42 UTC. The loss of the pressure of the green hydraulic system was a result of the closure of FSOV 1 and 2. At that time, the aircraft had only the yellow hydraulic system available. The functions of the green and blue hydraulic systems depicted in Fig. 3 were no longer available. The aircraft was operated in Alternate Law and the landing gear could no longer be retracted.

2.2.3 Approach and Landing

During the approach, the flight crew had difficulty to determine the landing distance considering the failures and special circumstances. These were:

- Up until that time they had used little fuel which meant the maximum allowable landing mass was exceeded.

[30] The still existing hydraulic pressure of the green hydraulic system was possible because of the still operating pumps.

- Engine failure and therefore a higher V_{REF}[31].
- Failure of the green and blue hydraulic systems and therefore incomplete slats and flaps positions (Config 3).
- Failure of the green hydraulic system and therefore failure of the normal braking system including anti-skid function.
- Failure of the blue hydraulic system and therefore operation of the alternate braking system with just the hydraulic accumulator.

The flight crew had calculated the ALD prior to the hydraulic systems failures. They had considered the actual landing mass and the engine failure. The software of the EFB then in use would not have allowed a calculation using all the factors. Therefore, the flight crew could not calculate the precise ALD. However, they did not even try. Hence, they could not conclusively assess whether Phuket Airport was suitable.

The approach speed was not determined. This important flight parameter should imperatively have been determined considering the landing mass, the single-engine operation and the slat/flap positions (Config). Based on the data available, the BFU calculated the approach speed V_{APP} as follows:

Landing mass:	200 t
Flap/Slat Position:	Config 2[32]
Wind correction:	5 kt

The V_{LS} for Config 2 position was 150 kt. The V_{APP} of the actual configuration was 165 kt. In fact, approach speed was between 147 kt and 155 kt, which means in a range requiring correction. During final approach between 1,000 ft AGL and 200 ft AGL maximum allowable vertical rate of descent (1,000 ft/min) was exceeded. In this flight phase, the criteria for a stabilized approach were no longer met. Despite these difficulties in meeting the parameters, the flight crew was able to land the aircraft in the Touchdown Zone.

In some cases, a go-around could be required. Due to the single-engine condition and the non-reversible aircraft configuration (flaps, slats and landing gear), resulting in a limited climb performance, such a manoeuvre could only have been performed with

[31] The VREF of an aircraft is increased in single-engine operation because of the asymmetrical thrust speed has to be increased.

[32] For the approach, the flight crew had put the flap lever in Config 3. The slats did not drive to the selected Config 3 (Target: 24°, is: 22°). Because of this Config 2 was chosen for the calculation of V_{APP}.

significantly reduced safety margins. In addition to the low climb performance, the environmental conditions (darkness, obstacles) and the earlier work load of the flight crew would have made the go-around more difficult.

During the approach the autopilot disengaged. Hence, the co-pilot (PF) had to control the aircraft manually. Aggravating circumstances were that only the control surfaces powered by the remaining yellow hydraulic system were available. The aircraft was operated in Alternate Law. Some protections were no longer available.
In this phase, the PIC repeatedly made clear remarks to fly lower. The simultaneous sidestick inputs triggered the Dual Input warning. The statement of the PIC that he had been concerned about the unclear ALD and that he therefore wanted to touch down rather very early and to lower the nose gear quickly to the ground after landing does not justify the temporary interference. According to his estimation, the co-pilot did not realise this as he expected so that he made inputs at his sidestick. Neither the aircraft manufacturer nor the operator allows dual sidestick inputs. By summation of the control inputs the control surfaces by trend were controlled as the PIC wanted. Since the aircraft no longer reacted as the co-pilot expected, for a short time the inputs at the sidesticks contradicted each other completely. The dual input of the PIC represents a severe interference of the co-pilot's control of the aircraft.
Neither the normal anti-skid system nor the alternate anti-skid system was available. The co-pilot faced the difficulty to decelerate the aircraft with the alternate braking system. Only the capacity of the alternate braking system's accumulator was available. A brake pressure of maximal 1,000 psi had to be maintained. Adherence to such a pressure with the small manometer at the co-pilot's side is difficult. The brake pressure data the FDR had recorded shows that this was not successful. Since the ECAM actions had not been read it is also possible that excessive braking application resulted from lack of awareness of the braking system limitation.

Considering that several factors extended the landing distance and that the flight crew did not have a clear ALD, excessive application of the brake by the co-pilot is understandable.

In addition, the following factors made the landing difficult:

- The approach was conducted as GPS non-precision approach (GNSS). This required the flight crew's increased attention concerning actions in the cockpit. In general, approaches are flown using the instrument landing system.
- The approach was flown from the west above the ocean to runway 09 which was not equipped with approach lighting. The only optical support was the PAPI.

- The landing was conducted with a landing mass allowed for emergencies; it was about 16 t and therefore above the maximum allowable landing mass of the manufacturer.

The approach presented an extremely high work load for the flight crew. In addition to the task required of a normal landing, there were the technical limitations and the respective actions.

In order to gain some time for necessary actions it was decided to fly a “holding”. This was a correct decision. Once the hydraulic system failures occurred the flight crew, especially the PIC, had the wish to land as fast as possible and be safely on the ground (at 14:15:40 UTC „ok dann müssen wir […] landen jetzt (ok, then we have to land now)“; at 14:16:16 UTC „request approach“). Then the “holding” was changed to a Racetrack Approach Procedure with subsequent landing. The resulting pressure of time increased the work load during approach and landing. In general, during this occurrence there was no pressure of time, because compared to landings at aerodromes of destination there was enough fuel. Workload Management also means to choose the right moment for an approach. ECAM processing should be completed thoroughly and calmly.

The SaMSys conducted in 2015 showed that only about 30% of flight crews are capable to solve time complex abnormal situations during approach satisfactorily. Hence, the behaviour of this flight crew is not unusual.

2.3. Aircraft Damage

2.3.1 General

The examination of the left pylon determined a range of damage. It is highly likely that the majority of the damage were connected to the engine damage and the resulting increased vibrations. The assessment of the fatigue failure at the hydraulic line bracket was of particular interest. If it had fractured prior to the engine damage, the free oscillating line could have facilitated the loosening of the pump drain line. Due to the missing information as to the beginning of the fatigue failure, it was not possible to express an opinion. The same is true for the other damage of the pylon.

It has to be assumed that the landing gear wheels were damage during their blockage.

2.3.2 Engine

The damage the investigation revealed allows the conclusion that the point of origin was the 4th LPT guide vane stage. This is proved by the fact that the blades of the 3rd LPT stage were present, whereas the blades of the 4th stage had been torn off. The same is true for the damage at the LPT front case which also starts behind the 3rd stage.

The indications of high cycle fatigue found at nine rotor blades of the 4th LPT stage can be explained by the rubbed in notches on the blades' leading edges. These are the results of contact with the vane clusters of the 4th stage which were lying upstream of these blades. It is highly likely that the rubbed in notches resulted in fatigue fracture at one blade which in turn caused more damage at neighbouring blades and on all following LPT stages.

The rubbed in notches at the leading edges of the blades of the 4th LPT stage corresponded in regard to their positions and extent with the damage at the trailing edge of the inner sealing ring of the vane cluster. Because there were no indications that the rotor had changed position, it has to be assumed that non-rotating parts, in this case the vane clusters, changed positions. The structure failure of the vane cluster gussets has to be viewed as cause of the change of position. The flawed geometry originating in the production process of the vane cluster gussets resulted in cracks and ultimately in structure failure. During previous maintenance actions all 44 vane clusters were replaced by new ones. They had been manufactured prior to 2010. Therefore, it has to be assumed that the missing vane cluster A also featured the flawed geometry.

The engine manufacturer was aware of the flawed geometry of the vane clusters of the 4th LPT stage due to failures of the similar model PW4000-94. The reason for their flawed geometry was also a flawed casting procedure. Had the actions then initiated been applied to vane clusters with the Casting Integral Marking 51N554AT 1447 1S2C3A earlier replacement on engines of the PW4000-100 models would have been the result. The corrective measures initiated in September 2010 could not become effective since the LPT of the engine involved had been repaired already in December 2008.

The Service Bulletin PW4G-100-72-251 also addressed the vane clusters with the Casting Integral Marking 51N554AT 1447 1S2C3A, which were installed in the engine involved. However, this Service Bulletin was not published until 28 October 2014.

Hence, the corrective measure to remove the vane clusters with the flawed geometry was initiated.

Even though vane cluster debris was pushed through the turbine housing, the BFU did not classify this occurrence as Uncontained Engine Failure[33], which would have required the liberation of parts with high kinetic energy. This was not the case here.

2.3.3 Hydraulic System

The BFU is of the opinion that the leakage of the green hydraulic system at the drain line of the left EDP was caused by increased vibrations during the engine damage. It is unlikely that two failures of this type (engine damage and leakage) occur simultaneously and independent of each other. The chronological consideration of the warnings of the reservoir's fill quantity does not allow drawing an unambiguous conclusion as to when the leakage started and if the drainage was linear.

Indication	Time [hh:mm]	Quantity [l]	Flow [l/min]
None	1354	38[34]	
HYD G SYS LEAK	1415	17	1.0
HYD G RSVR LO LVL	1420	8	1.8

Tab. 12: Calculation of the leakage

It cannot be deduced unambiguously if the leakage was caused immediately during the engine failure in combination with the temporary but very high vibration level or during the continued engine operation until it was shut off.

The leakage on the Case Drain Line could only have been isolated if the FSOV would have been closed after the engine was shut off. This is only the case for a leakage at this area of the hydraulic system. Closing the FSOV would not have had an effect with a leakage at any other location. Even after the indication HYD G SYS LEAK, a flight crew had no way to find the exact location of the leakage. Thus, it would be difficult to independently develop a strategy for action.

[33] Uncontained failure of a turbine engine is any failure which results in the escape of rotor fragments from the engine or APU that could result in a hazard. Rotor failures which are of concern are those where released fragments have sufficient energy to create a hazard to the airplane. Source: FAA AC 20-I28A

[34] Assumptive fill quantity at the time of engine damage

The BFU assessed whether and under which conditions, the redundancy of the complete hydraulic system (Green, Blue and Yellow) could have been improved (Fig. 29).

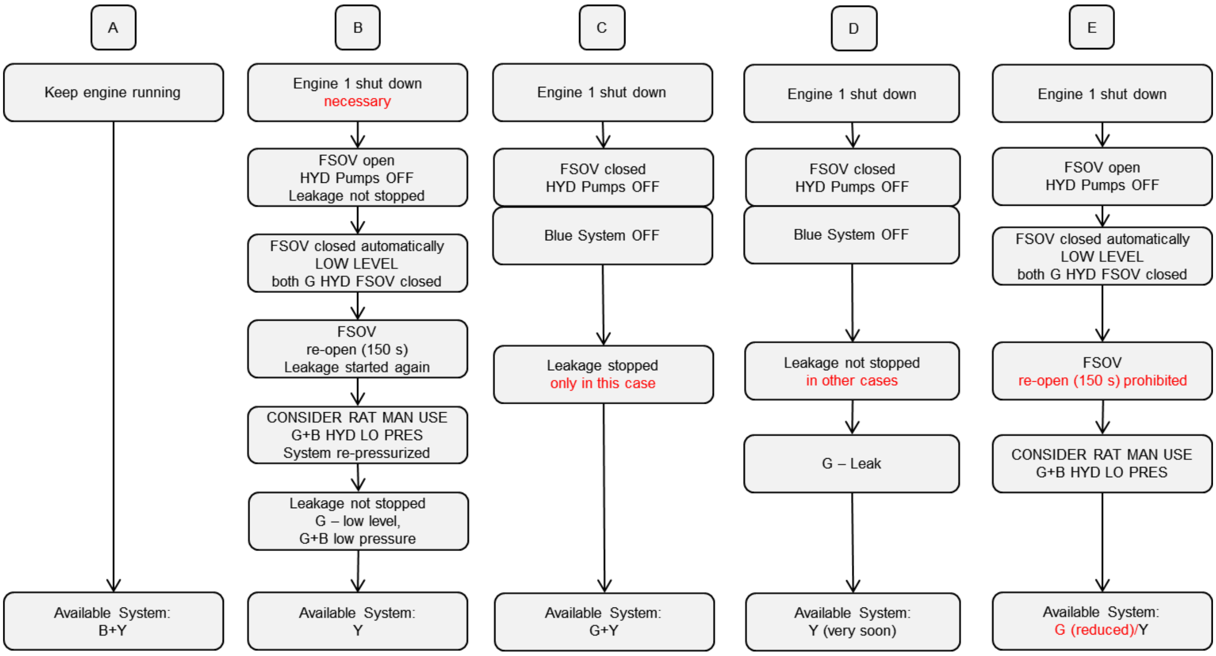

Fig. 29: Scenarios for possible actions and their consequences during this occurrence Source: BFU

Description:

A: The engine continues running. If it can be operated until the end of the flight, two fully functional hydraulic systems are available. As the worst-case scenario, the engine has to be shut off at a later time. Subsequently, scenarios B, C or D have to be applied.

B: After the engine is shut off, the FSOV remains open. The green hydraulic system runs empty. When airspeed is decreased, at an unpredictable time pressure at the blue hydraulic system becomes low. Only the yellow hydraulic system is available for landing.

C: After the engine is shut off, the FSOV is closed. Pressure in the blue hydraulic system decreases immediately and irreversibly. At the same time the leakage in the green hydraulic system is stopped. This is only true for any leakage in the Case Drain Line and low leakages in other lines. The green (driven by the other engine) and the yellow hydraulic systems are available for landing.

D: After the engine is shut off, the FSOV is closed. Pressure in the blue hydraulic system decreases immediately and irreversibly. The leakage in the green hydraulic system cannot be stopped because it is in a section that cannot be isolated by the FSOV. Only the yellow hydraulic system is available for landing.

E After the engine is shut off, the FSOV is closed. For landing, the yellow hydraulic system is available. In addition, with the extension of the RAT it would have been possible to still operate some functions of the green hydraulic system with the remaining fluid. Especially the controls operated by this system and the autopilot would have been available.

Precondition would be that the HSMU does not open the FSOV again (a design change would be required).

Analysis of the Scenarios:

Scenario A would result in two hydraulic systems being available for landing (B HYD+G HYD. It shows which grave consequences the unnecessary shut-off of an engine can have. If an engine shut-down is inevitable (immediately or at a later stage), scenarios B to D have to be considered.

The essential difference with regard to the availability of hydraulic systems is the closing of the FSOV. Keeping it open allows the operation of the blue hydraulic system, but there is no option to stop the leakage in the green hydraulic system. Even if the FSOV is closed automatically (after LOW LEVEL detection), the automatic re-opening of the FSOV after 150s prevents a steady closure (Scenario B).

If the FIRE P/B switch of the left engine would have been activated[35] and the FSOV had closed, the leakage of the green hydraulic system would have been stopped (Scenario C). This is only true for this specific case where the leak was located in the Case Drain Line of the EDP. If the leakage had occurred at another position, it could not have been stopped like this (Scenario D). In both scenarios, the blue hydraulic system becomes inoperative immediately and irreversibly. The decision to use the FIRE P/B requires knowledge of the location of the leakage. To consciously choose one of these variants requires information about the damage and intensive troubleshooting, which is not possible for a flight crew in this situation. However,

[35] According to the procedure ENG 1(2) FAIL in combination with the condition IF DAMAGE

Scenario C represents the best redundancy of the hydraulic systems for this particular case.

Contrary to the ENG 1(2) FAIL procedure, the ENG 1(2) SHUT DOWN procedure does not provide for any FIRE P/B activation.

The prevention of the automatic re-opening of the FSOV after 150 s would at least allow the use of the green hydraulic system driven by the RAT (Scenario E). This would require a design change of the HSMU as it was suggested in the report concerning the occurrence involving PH-AOB in 2010.

A separate automatically closing FSOV, as it was introduced in the design of A330 NEO, would allow the shutting off of individual hydraulic systems.

Due to the complexity of the scenario and the limited options to identify the location of the leakage and stopping it, the degradation of the green hydraulic system (G HYD) was almost unavoidable. Therefore, the status of the hydraulic systems was as follows:

- Blue: intact, but not operational when speed decreases
- Green: damaged, temporary operation due to the leakage, time remaining is unknown
- Yellow: intact, no limitation

Shutting down the two G-HYD pumps (engine), in accordance with the ECAM procedure, would not have stopped the hydraulic leakage, but would have immediately stopped the operation of the green hydraulic system. To achieve optimal use of the remaining green hydraulic system fluid, the intermitted activation of the EDPs would have been reasonable[36].

2.4 Flight Crew Actions

2.4.1 Situational Awareness

The situational awareness of the pilots was limited. Their system knowledge was not retrievable in a way that they could correctly assess the damage of the aircraft. The limited ability to handle the situation compliant with the rules shows that they could react to the technical failures only to some extent and step by step were “getting behind the aircraft”.

[36] A reduced outlet pressure results in a reduced case flow

The CVR recording shows that the flight crew could not assess the extent of the engine damage and the consequences of its shut-down to the hydraulic systems. The flight crew did not address the pressure drop in the blue hydraulic system and was surprised when the corresponding ECAM action was indicated. After the ECAM warning HYD G SYS LEAK appeared, the Leak Rate was not monitored. The flight crew's recorded remarks "ja wir könnten das saven (yes we could safe this)" and "Triebwerk ist ja eh abgestellt (engine is shut off anyway)" indicate weak situational awareness.

Until the landing, the flight crew was unclear if and which systems were available, especially if and which brakes would function. This is recognisable by the very unclear remarks concerning the technical condition of the aircraft: "da ist irgendwas mit der wing (there is something with the wing)", "wir haben keine Bremsen mehr (we have no brakes any more)", "ich weiß nicht, was mit den Bremsen ist (I have no idea about the brakes)", "electric hydraulic wheel ist weg (it says electric hydraulic wheel is lost)", "spoilers armed, do not use spoilers - ich weiß es nicht (I do not know)", "also wir haben noch accu brakes, wahrscheinlich nur noch (we still have accu brakes, probably only)" (Appendix 2).

The plan the PIC presented afterwards to intentionally not switch off the hydraulic pumps, to strictly observe the leak rate, to drive the slats/flaps quickly and, depending on their position attained, to maintain Phuket as the "next suitable" airport, could not be gathered from the CVR recordings. He did not communicate his plan to the co-pilot.

Regardless of the limitations during the calculation of the ALD, they were not aware of the ALD and the landing and braking methods required by the system failures. The flight crew was only aware that their safety margin was narrow: "Es muss passen (it has to fit)" and "Lieber drei rote als drei weiße (rather 3 red than 3 white)".

2.4.2 Application of and Adherence to Procedures

Actions after the Engine Damage

The flight crew identified the engine damage immediately as "Engine Failure" and the PIC made a corresponding call-out. The left engine was correctly identified as cause and its thrust reduced.

Without further analysis of the engine damage, completion of the ECAM actions and confirmation from the PIC, the co-pilot made the decision for the Mayday call and the return to Phuket.

After the engine parameters had once again exceeded the limits, the PIC decided to shut off the engine without further communication with the co-pilot. Considering the consequences of this decision this communication should have taken place.

ECAM

During the damage on the engine and the hydraulic systems, the ECAM indicated the procedures required to be completed. In accordance with the FCOM, the flight crew would have had to complete and confirm them with respective call outs.

Immediately after the engine damage, the flight crew carried out these instructions. Typical of this phase was that the completion was interrupted repeatedly, the ECAM actions were not implemented right away and the interruptions and the completion, respectively, were not confirmed with the stipulated call-outs „Stop ECAM“, „Continue ECAM“ and „ECAM Completed“.

As the flight progressed, the ECAM instructions were no longer fully executed when failure messages occurred. For example, after the ECAM warning HYD G SYS LEAK the corresponding ECAM procedure was begun. The call-out stipulated in the FCOM was not made. Between 1415:20 UTC and 1416:13 UTC and then later between 1417:23 and 1417:40 UTC, individual steps of the ECAM action were carried out. This resulted in the fact that the not completed ECAM action to shut off the hydraulic pumps remained unnoticed (Chapter 2.2.2). The completion of the ECAM action was interrupted by the approach planning and the transition of control. The PIC's statements show that he attached very little importance to ECAM in this phase.

After the HYD G SYS LEAK and HYD G+B LO PR indications, no other ECAM actions were carried out any more.

The correct handling of the ECAM actions was repeatedly disregarded and finally stopped.

During the completion of complex abnormal/emergency procedures it is very difficult to recognise an erroneous ECAM completion or to reverse it due to doubts or start from the beginning. The SaMSys Study showed that none of the 120 pilots repeated the ECAM action or began again from the start due to doubts or working errors. Accurate ECAM completion must have the highest priority.

Other Procedures

Other procedures (not ECAM) were not completed or not carried out at all:

- During the completion of abnormal and emergency procedures the FCOM required the PF to conduct radio communications. This assignment of tasks was not adhered to. Radio communications were conducted by the PF and the PNF.
- The landing checklist, the approach briefing and the missed approach briefing were not completed and conducted, respectively.
- The cabin crew was not informed of the risks during the impending landing.
- The PIC interfered several times with the flight controls (dual input).

The incomplete or faulty execution of procedures began immediately after the engine damage and broke down after the technical problems with the hydraulic systems occurred.

FORDEC

Regardless of the ECAM actions, it was the flight crew's responsibility to analyse the situation continuously and take necessary actions. The FORDEC procedure was only applied at 1411:57 UTC by the co-pilot and then ended with the remark: „Viel zu sagen, (a lot to say) ne?". This occurred even though at the time they had no final clarity about the ALD. In Fig. 30 the pink triangle is the moment of the decision-making process FORDEC, which lasted a total of nine seconds between engine damage and landing. At different times, the application of the FORDEC procedure would have been reasonable.

Assessment of the engine damage

- Choice of aerodrome of destination given the landing mass and the landing distance available.
- Assessment of the engine damage considering continuous operation or shut-off.
- Elimination of an erroneous assessment of the engine damage (the co-pilot had mentioned engine fire several times).

Planning the landing (prior to the hydraulic system failure).

- Calculation of the ALD.
- Go-around capability and go-around procedure considering the overweight landing and the single-engine operation.

Planning the landing (after the hydraulic system failure).

- Estimation of the ALD considering the available configuration and the alternate braking system.
- Re-assessment of the go-around capability considering the available configuration, the limited option of the remaining yellow hydraulic system and the extended landing gear (retraction impossible).
- Possible alternatives to handle the hydraulic failure were not discussed, e.g. use of RAT or a possibly necessary emergency extension of the landing gear.

Especially in phases where specified procedures (e.g. engine shut-off procedure, ALD calculation, dual hydraulic failure) cannot clearly be transferred to the existing situation, the use of an analytical decision-making tool such as FORDEC could have resulted in the structural identification and handling of the problem. The consistent application of the FORDEC procedure would have increased the likelihood that the flight crew returns to a course of action that is faithful to the procedure.

FORDEC is based on analytical decisions and not on recognition-primed decisions. The decisions of this flight crew were mainly recognition-primed decisions; a structural consideration process is rarely found in the recorded communication.

The SaMSys Study showed that regardless of experience and training level, two thirds of the pilots stated during the subsequent de-briefing that they had applied FORDEC. During the occurrence, FORDEC was only expressed but the procedure not really applied. The FORDEC procedure was later only used to justify the previously made decisions. In practice, this trained procedure is often not used during complex system failures.[37] It is possible that FORDEC is degraded to the justification of previously intuitively made recognition-primed decisions if the procedure is applied several minutes after certain actions were completed (ECAM, QRH).

Air Traffic Control Unit

After the thrust lever of the left engine was set to Flight Idle, the co-pilot suggested to make a Mayday call and return to Phuket Airport. It is necessary and understandable to inform the air traffic control unit immediately about the emergency and the deviation from the planed flight path. However, at the time (13 s after the engine damage), the pilots had not shared any information concerning the technical condition of the engine or the subsequent flight plan. Hence, the co-pilot informed the air traffic control unit during the Mayday call that there was an engine fire, among other things. This was

[37] Drees, Müller, Schmidt-Moll (2017). Risk analysis of the EASA minimum fuel requirements considering the ACARE-defined safety target. In *Journal of Air Transport Management* 65: Page 1- 10.

repeated three times in different forms. Even though he later stated that he had only done it to receive higher priority from the air traffic control unit, he conveyed a wrong situation.

Seven radio contacts followed between flight crew and air traffic control unit lasting 1:07 min in total. The communication with the air traffic control unit concerned clearances of altitudes, runway directions and the wind situation. Even though this information was important, in this phase radio communications had taken on an importance which was not appropriate to the situation. There was constant alternation between completion of the engine problem, communication with the air traffic control unit, the navigation and conduct of the flight. The BFU is of the opinion that after the Mayday call the flight crew should have made a consequent announcement to the air traffic control unit that unnecessary and interrupting communications are to be postponed to a later time. This happened only once (1400:34 UTC „stand by").

During this phase, the flight crew and the air traffic control unit repeatedly reopened communications which interrupted the continuous completion of the necessary actions after the engine damage. In general, during an emergency radio communications play a minor role. Hence, the sequence: Aviate, Navigate, Communicate.

2.4.3 Non-technical Skills

Crew Resource Management

The analysis of the communication (Appendix 9) shows that "negative" CRM events predominate already in the phase immediately after the engine damage. Once the hydraulic failure occurred, the number of these events increased. From this time on the communication was mainly one-sided, from the co-pilot to the PIC.

With the worsening technical condition of the aircraft mutual support decreased. At the end of the approach, basic actions such as the approach briefing and the completion of the landing check list dropped away. Only after the runway was in sight the "positive" actions increased again.

What also stood out was that the remarks the PIC made were not suited to give precise information for the co-pilot:

- "Da ist irgendwas mit der wing (there is something with the wing)"
- "ich weiß nicht, was mit den Bremsen ist (I have no idea about the brakes)"
- "Also, wir können, müssen möglicherweise, uns auf (we can, must possibly), spoilers armed, do not use spoilers, ich weiß es nicht (I do not know)."

These statements did not contribute positively to solving the technical problems.

The immediate decision to turn around, the aspiration to establish landing configuration as soon as possible and the resurgence of the communication once the runway was in sight, shows the PIC's intention to land as quickly as possible. This aspiration shaped his actions and pushed known and trained procedures and behaviour in the background.

The assessment of crew performance according to LOSA/Crew Performance Marker Worksheet (Appendix 10) showed the weakness of this flight crew in regard to planning, execution and control of actions as well as with the PIC's role as leader:

- Weak leadership of the PIC
- The co-pilot was therefore required to take over leadership
- Unclear role distribution PF-PNF
- Structured decision-making processes were not promoted

Contrary to this analysis, the crew members evaluated their cooperation as good. The BFU cannot assess how these two crew members would have acted during a flight without any problems or stress level. During this flight, the stress level was so high that constructive team work was significantly impaired.

The characteristics, commonly known as NOTCHES (non-technical skills), are part of the CRM training.

Interruptions and Workload Management

Between the engine damage and the landing, the flight lasted 34:32 minutes and was interrupted[38] 147 times by which the thought processes and actions of the flight crew were disrupted. This means about every 14 seconds an interruption occurred. Either one pilot interrupted the other (62%) or the air traffic control unit triggered the interruption. If the interruptions are added which the flight crew caused themselves by contacting the air traffic control unit which then also called back, 85% of all interruptions were caused by the flight crew.

The actions which had to be performed during this occurrence can be divided into four essential working areas:

1. Decision making

[38] An interruption is defined as pausing an action or thought for a short time only to take it up again later

2. ECAM and QRH completion

3. Cockpit communication

4. Communications with the air traffic control unit

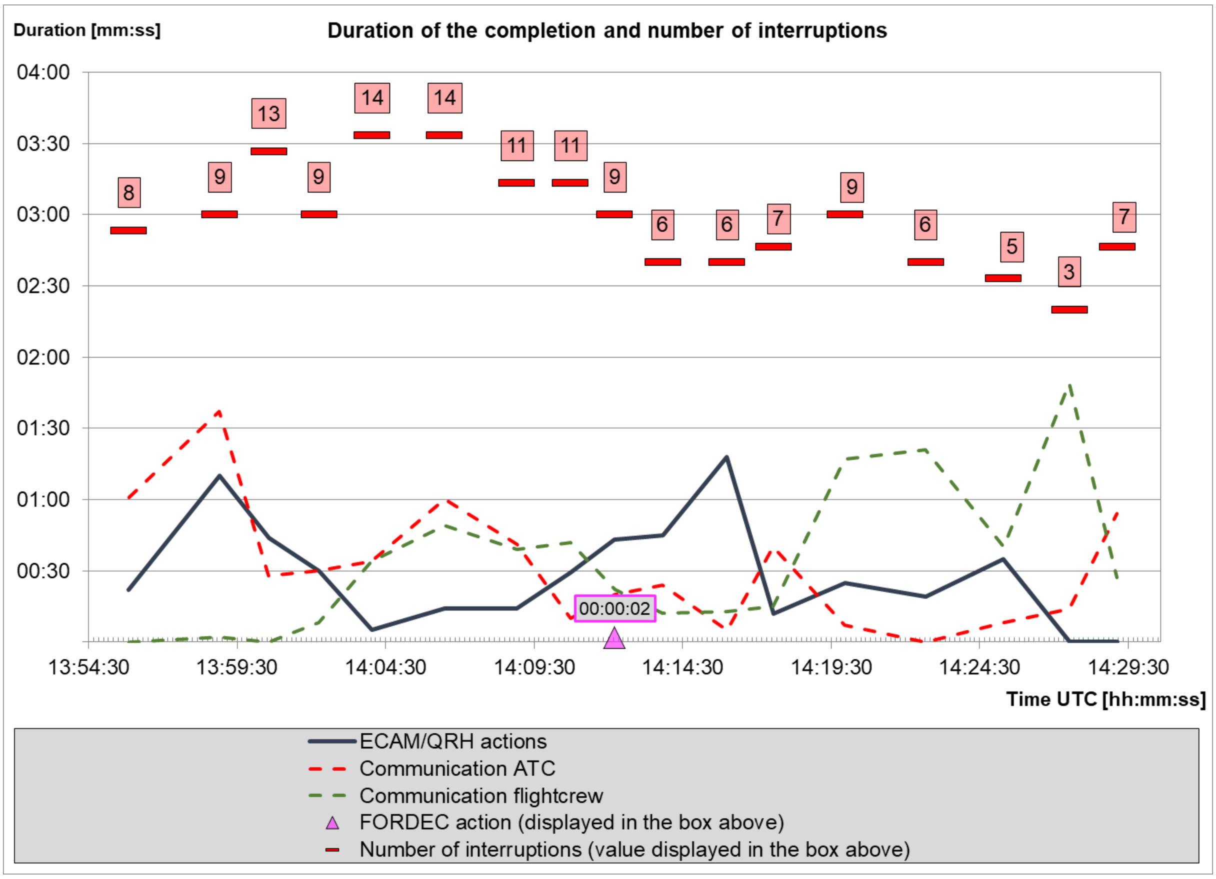

Fig. 30: Duration of the completion and number of interruptions Source: BFU

Between the engine failure and shutting the engine off, the actions of the flight crew are characterised by processed ECAM actions and communication with air traffic control. Between 1410:45 UTC and 1417:30 UTC ECAM/status actions are once again processed, communication with the air traffic control unit takes place at the same time. It shows that all important situations during the flight were interrupted numerous times.

At 1415:14 UTC the ECAM action LEAK RATE – MONITOR appears which is not unambiguous concerning the required action. Immediately afterwards 4 interruptions occur which last up to 25 seconds.

Time	CM1	CM2	Radio	Interruption [s]
14:15:16	hydraulic system G leak….ne ey ([not really])	wat denn (what)?		
14:15:20		green system leak, ja alles klar (yes okay) [*], monitor if level decreases, read [*], wie sieht's denn aus (what does it say)?		
14:15:30		dreitausendfünfzig, dreitausendfünfzig ja (3,050, 3,050, yes)?		
14:15:32	det stimmt ja gar nich, ja ist gut, es wird weniger ja (that's not true, yes okay, it is decreasing, yes)			16
14:15:40	ok dann müssen wir lan, landen, landen jetzt (then we must lan, land, land now)			02
14:15:42		ok, land ASAP in amber [*], kurz (short), target speed VLS in the final stages at [*], reverse thrust use max available after nose wheel touchdown, brakes apply as [*] as necessary und (and)		14
14:15:57	we're commencing approach			03
14:16:00		ja, max vertical speed at touchdown dreihundertsechzig Fuß pro Minute (360 ft/min), ich leg das mal eben weg, und, äh sollen wir pack two auch ausmachen (I will delay this and shall we turn off pack 2)?		10
14:16:09	ne komm jetzt, vergess pack (okay, forget the pack), Hydraulik G, G ist jetzt angesagt (is now relevant)			
14:16:13		alles klar (okay), leak rate monitor ham wir gemacht (we did perform)		07
14:16:16	request approach			
14:16:18		[call sign], we are ready for approach, we are now flying downwind		
14:16:25			[call sign] roger, cleared direct to intermediate fix, descend two-thousand-six-hundred feet, cleared RNAV zero niner approach	
14:16:33		cleared RNAV approach, runway zero niner, cleared direct to the intermediate fix [call sign]		25
14:16:41	gibst du mir, äh gibst du den approach jetzt rein (do you give me the approach in now [will you insert approach for me, now])?			
14:16:44		der approach ist drin ja (yes, the approach is inserted yes)		
14:16:45	ja (yes)?			
14:16:46		ja der approach ist drin (yes the approach is in)		05
14:16:47	wo, wo äh, gut jetzt fliegen wir nach LAZIO oder wohin (where, where, we fly to LAZIO now or whereto)?			
14:16:51		nein, nach, …, nicht zu (no to. …, not to) [*] Phuket whiskey		
14:16:55	hat, hat [*], ja okay der ist da (has has yes okay it is there)			11
14:16:58			[call sign] two zero miles from touchdown, is it ok for descent?	
14:17:04		was hat er gesagt (what did he say)?		
14:17:07	say again			
14:17:08			[*] two zero miles [*] touchdown, is it ok for descent?	
14:17:13	roger we're descending now out of five-thousand [*] after this we turn äh [*] we turn left onto the final			
14:17:20			[call sign] roger	25
14:17:23	hydraulic leak rate monitor			
14:17:25		ja die (yes it) decreased, also wir haben jetzt dreitausend, die bleibt eigentlich so, ne (now we have 3,000 it actually stays the same)?		
14:17:28	ja (yes), green engine one pump off			
14:17:31		green engine two pump off		
14:17:34	ja wir könnten das saven, dann, ne (yes, we could save this then)?			
14:17:35		ja (yes)		
14:17:36	aber die Rate ist eigentlich noch (but the rate is actually still)			
14:17:38		die bleibt (it stays the same), ne?		17
14:17:39	ja, wat was (yes, what)			
14:17:40		Triebwerk, Triebwerk ist ja eh abgestellt (engine, engine is shut off anyway)		02
14:17:42	ja also pass auf (yes, listen), you have control?			
14:17:44		I have control		04
14:17:45		dann mach mal hier (then perform here) clear hydraulic		
14:17:48	clear			09
14:17:54		so, fühlst du dich jetzt gut (so, do you feel okay now)?		01
14:17:55	[*] mit der Hydraulik macht mir jetzt Sorgen (I am actually worried about the hydraulic)			02
14:17:57		ok, one-thousand to go		
14:18:01	ok, wir gehen dann runter auf dreitausend ja (we go down to 3,000, yes)?			
14:18:04		checked, we have seven-hundred to go		
14:18:05	und der approach fängt in zweitausendsechshundert an (and the approach starts at 2,600)			11
14:18:08		ja (yes)		
14:18:13	speed			15
14:18:28		so, approach phase aktiviert (active)		
14:18:29	ja (yes)			06
14:18:36	hydraulic ist neunundzwanzig null eins (is 29 0 1)			
14:18:43	Ja (yes)			
14:18:45		system		
14:18:47		ja, aus bitte (yes, out [disangage] please)		12
14:18:48	so wir haben, wir können (so we have, we can)			
14:18:52		Ja (yes) [*]		
14:18:54	ja ist doch jetzt aus Junge (Come on, it is off now, boy)	[*]		32
14:19:07	ok commencing approach			

Fig. 31: Interruptions after the ECCAM action LEAK RATE – MONITOR. Each is depicted by a black horizontal line. The Hydraulic ECAM actions are highlighted in red. Source: BFU

This sequence clearly illustrates the negative effect of interruptions and shows the importance of Workload Management during an in-flight emergency.

In practice it is common that tasks cannot be performed purely sequentially and one after the other. They inevitably have to be performed simultaneously and by turns. Research was able to determine the error frequency due to interruptions. An interruption of work of only three seconds doubles the number of mistakes. If work is interrupted by five seconds, error rate is tripled.[39]

Error rate caused by interruptions and the subsequent risk is also a significant risk during all flight phases, even on the ground during turn-around.[40] Interruptions have a causal connection to the error rate but also to the experienced work load.[41] Good Workload Management has to consider which tasks are high-risk and must not be interrupted. During the completion of important ECAM actions a flight crew should avoid interruptions as much as possible and prevent outer distractions.[42]

2.5 Qualification and Training of the Flight Crew

2.5.1 Qualification of the Pilot in Command

The PIC held an Airline Transport Pilot License with the rating as PIC including instrument rating for A330. His medical certificate with the limitation OCL authorised him to fly as co-pilot only. He was, therefore, not authorised to fly as PIC.

The information of the AME and the AMC support the statement of the PIC that the entry was an error. It is likely that the entries OSL and OCL were confused. The BFU is, therefore, of the opinion that the limitation OCL was not justified by medical findings. Hence, during this occurrence it did not influence the PIC's capability to act.

The limitation OCL which was entered twice in the medical certificate did not have any consequences at the operator as to the deployment of the PIC. The BFU is of the opinion that this fact shows that oversight of the fitness to fly was not reliably performed at the operator.

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[39] (Altmann, Trafton, Hambrick (2013). Momentary interruptions can derail the train of thought. In Journal of experimental psychology. 2014, Vol. 143, No.1, S. 215-226).

[40] (Gontar, Schneider, Schmidt-Moll, Bengler (2017). Hate to interrupt, but…. Analyzing turn-arounds from a cockpit perspective. In *Cognition, technology and work*. London)

[41] Kim, Parameshwara, Guo and Pasupathy (2018). The impact of interrupting nurses on mental workload in emergency departments. In *International Journal of human-computer interaction*.

[42] Loukopoulos LD, Dismukes RK, Barshi I (2009) The multitasking myth: handling complexity in real-world operations. Ashgate Publishing Ltd, Farnham

During the flight the PIC had handed over control of the aircraft to the co-pilot. He justified this with the remark that he had not conducted a landing in eight weeks. Here, the PIC had correctly estimated his flying skills and drawn the right conclusion. In this case, it would have been wrong to insist to control the aircraft.

2.5.2 Training and Checks

The analysis of the training documentation of both pilots showed no indications that they experienced difficulties during training sessions and the stipulated checks. The documentation, however, also shows that the checks were passed with “Standard”. In some individually assessed training parts the pilots received “Above Standard”. The simulator instructor did not include an individual evaluation in the simulator check evaluation sheets. Therefore, the documentation does not allow drawing any conclusion as to the flight crew’s skills in regard to difficult situations, decision making and most of all CRM. All checks should include assessment of the CRM behaviour which allows a conclusion as to the tendencies in the behaviour of individual pilots.

The training content of the previous years did not include any situation similar to the occurrence flight. Engine failures were trained but only shortly before or after take-off and never at high altitudes. Engine failure during take-off is preceded by a respective briefing which defines the subsequent course of the flight. The course of the flight during engine failure at high altitudes is full of variants. That means correct decision making is very important.

Since the training program is defined bi-annually, training content is known and the flight crews are aware of the requirements and not surprised. This would be required, however, in order to create stress situations for flight crews similar to real ones.

The BFU is of the opinion that the training should include unexpected multi-failure scenarios (“Train the unexpected”).

2.5.3 The Operator’s Safety Management System

The operator assessed flight data. The Safety Management System allowed the anonymised analysis of flights and flight phases. Focal points for further flight safety activities could be deduced from this. Only gross errors allowed the retracement of individual flight crews. This system was not designed to allow the identification of flight crews which had difficulties handling complex situations. Even if the supervision of FDM data were personalised, deficits would only attract attention if a complex event took place and the result were visible in the data.

At a later date, the operator implemented Just Culture. This system is based on voluntary reports. The operator also included events in their safety assessment which the persons involved reported because they were so exceptional. This system was suitable to improve the safety culture of the operator.

2.6 Actions of the Air Traffic Control Unit

Immediately after the Mayday call, the air traffic control unit began to coordinate the flight path with the flight crew and requested information. This communication took place in a situation where the flight crew had to conduct tasks to control the engine and the hydraulic systems. It is understandable that the air traffic control unit asked for this information but at this time it had no priority. The flight crew could have and should have discontinued the communication in order to not be interrupted all the time. It is likely that due to the wrong information “engine fire” by the co-pilot, the air traffic control unit was additionally motivated in their activities.

Since interruptions are linked with errors it is important to limit communications with an air traffic control unit to a minimum so that the workload of a flight crew is not increased further. The number of calls has to be as low as necessary and as coherent as possible. In this case, the aircraft had departed Phuket only minutes earlier and information regarding endurance and persons on board would have been available at the airport.

In addition, during an emergency all other aircraft on the same frequency should receive another. Or the aircraft involved should receive their “own”. This would ensure that the aircraft involved would be on a “quiet” frequency. The flight crew’s necessary willingness to listen for their own callsign among the many requires considerable attention. This binds resources which are needed to complete other procedures. As far as possible, frequency change should be avoided.

ICAO Doc 4444, Air Traffic Management, Chapter 15 included the items mentioned above and should be applied by air navigation service providers. It would help to reduce the workload of flight crews during emergencies and reduce error-prone interruptions and distractions.

2.7 Summary

The Serious Incident was caused by the engine damage and the resulting creeping leakage of the green hydraulic system. Two hydraulic systems failed, even though continuous operation of one of these two systems would have been technically possible in this particular case. The safety of the landing including a possibly necessary go-around was reduced due to the limited performance of the aircraft.

Repeated interruptions of the flight crew's actions resulted in procedures not being properly implemented and constructive workload management not being performed. The actions of the flight crew, especially the deviation from procedures, prevented them from obtaining overview and subsequent control of events.

The flight crew's CRM did not result in the recognition of the deficits and therefore they were not remedied.

At the final stage of the flight, the flight crew was no longer in full control of the situation. In combination with the degraded aircraft performance this resulted in a higher probability of an accident.

The combination of technical problems (TEC), human factors (HUM) and deficits in teamwork (SOC) is not limited to this occurrence. It is characteristic for incidents and accidents in transport aviation and was confirmed by a study.

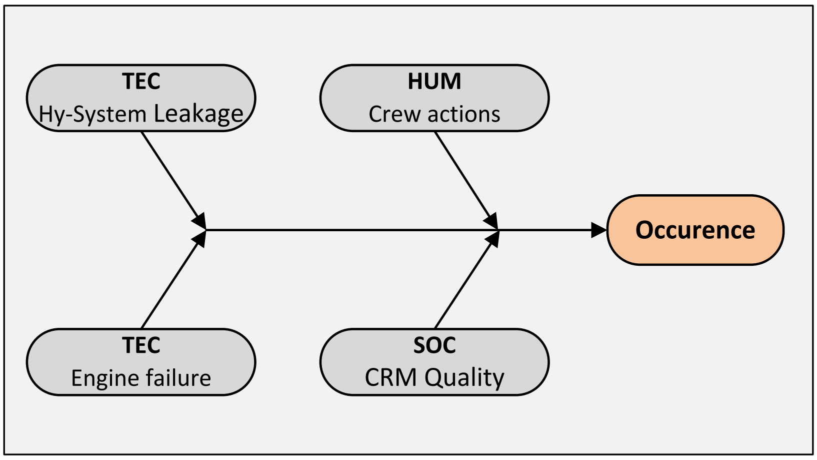

Fig. 32: Depiction of the concurrence of different influencing factors during an incident Source: BFU

Even though the flight crew met the training requirements and the operator had established a SMS, with the existing means, a multi-failure scenario could not be managed on an acceptable level.

3. Conclusions

3.1 Findings

Flight Crew:

- The PIC held a valid licence. The medical certificate did not authorise him to fly as PIC. The restrictions recorded on the medical certificate were erroneous.
- The co-pilot held a valid licence and a valid medical certificate.
- Both pilots had passed their simulator checks of the last three years.

Aircraft:

- The aircraft had a valid airworthiness certificate.
- The engine damage was caused by failure of the vane cluster of the 4th LPT stage.
- The failure of the vane clusters was caused by deviation of the component geometry which was the result of flawed casting moulds.
- Similar deviations of other vane cluster batches had previously caused engine failures.
- The actions the manufacturer had introduced should prevent more vane cluster failures.
- The ECAM actions would not have resulted in engine shut-down. According to the FCOM procedures EGT OVERLIMIT the engine should be shut down in this case.
- Due to the vibrations during the engine damage, it is likely that the Case Drain Line of the mechanical hydraulic pump of the green hydraulic system was loosened.
- In case of a leakage at the Case Drain Line of the EDP, the leakage of the Green Hydraulic System could have been stopped if the FSOV would have been closed.
- The technical features in the aircraft did not allow the location of this leakage to be determined. Therefore, ECAM action and procedures in the FCOM/QRH to stop the leakage were not suitable for this particular case.
- The green hydraulic system failed because a leak occurred, causing the level in the reservoir to become low.

- Due to the complexity of the scenario and the limited options to identify the location of the leakage and stopping it, the degradation of the green hydraulic system was almost unavoidable.
- The blue hydraulic system failed because the EDP was no longer driven after the engine was shut down and the windmilling decreased.
- Due to the green and blue hydraulic systems failures, parts of the control surfaces were no longer actuated, the autopilot had disengaged, the braking system partially failed, reverting to alternate braking without antiskid, and the slats did not drive to the intended final position.
- For deceleration of the aircraft on the runway only the alternate braking system powered by the hydraulic accumulator was available.
- The ECAM action (LEAK RATE - MONITOR) required the flight crew to determine the extent of the leakage even though this numerical value is not depicted. The leak rate could be estimated by the level indicator reading.

Flight Crew Actions:

- The flight crew did not carry out the procedures as described in the FCOM.
- The ECAM actions were either not completed at all or only partially.
- The landing checklist was not completed.
- An effective FORDEC procedure was not peformed.
- The flight crew did not correctly recognise the loss of hydraulic fluid of the green hydraulic system. Therefore, the required actions were not completed.
- Insufficient communication resulted in ineffective solutions of problems.
- The flight crew was not able to gain a thorough overview over the technical problems.

Conduct of the flight / flight operations:

- The meteorological conditions had no influence on the course of events.
- A go-around would have been possible only with a limited climb performance, due to single-engine operation and the unchangeable configuration of the aircraft (landing gear, slats, flaps).
- The software of the EFB did not allow calculation of the ALD considering the single-engine operation and the overweight landing.

Operator:

- The operator did not perform individual-related supervision of the FDM results.
- The operator did not systematically supervise the fitness to fly of the flying personnel.

3.2 Causes

Immediate Cause:

This Serious Incident was caused by a leak in the green hydraulic system following an engine failure in a location, where the available information and the associated procedure would not have been suitable to stop the leakage and thus maintain the functionality of this hydraulic system for the remainder of the flight.

The Serious Incident was also caused by the limited capability of the flight crew to assess the developing situation and manage it.

Systemic Cause:

The Serious Incident was caused by the fact, that the established procedures to ensure flight safety, especially the existing SMS and the training syllabus of the operator, were not adequate to prepare the flight crew for this multi-failure scenario.

4. Safety Message

The following safety messages can be deduced from the investigation:

1. The training of flight crews in regard to unexpected complex situations should include interruptions by third parties (e.g. ATC).
2. The assessment of simulator checkflights should be designed in a way that Crew Resource Management (CRM) of the pilots during unexpected complex situations is assessed at length.
3. Air Traffic Services (ATS) should ensure that the number of calls to flight crews made by Air Traffic Control (ATC) is as limited and as coherent as possible. The Air Traffic Management, Doc 4444, Chapter 15 of the International Civil Aviation Organisation (ICAO) should be considered.
4. Air Traffic Services (ATS) should ensure that an aircraft involved in an emergency should receive another (“own”) frequency, if an improved service

can be provided to the aircraft concerned. The Air Traffic Management Doc 4444, Chapter 15 of the International Civil Aviation Organisation (ICAO) should be considered.

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Braunschweig	1 August 2023

5. Appendices

Appendix 1: FDR Graphs of the Course of the Flight

Appendix 2: CVR Transcript of the Flight (after engine damage)

Appendix 3: Times of all Radio Contacts with the Air traffic Control Unit

Appendix 4: Photographs of the engine damage

Appendix 5: Photographs of the damage of the cowling and at the pylon

Appendix 6: Engine Damage Procedures / Descriptions in the QRH and FCOM

Appendix 7: FCOM procedure during hydraulic pressure loss in the green and blue hydraulic system

Appendix 8: QRH Procedure Overweight Landing

Appendix 9: CRM Assessment

Appendix 10: Assessment of the Flight Crew Actions in Accordance with LOSA

Appendix 11: Excerpt Airbus Flight Operations Briefing Notes

Appendix 12: Extract from the FCTM

Appendix 13: ECAM Actions

Appendix 1: FDR Graphs of the Course of the Flight

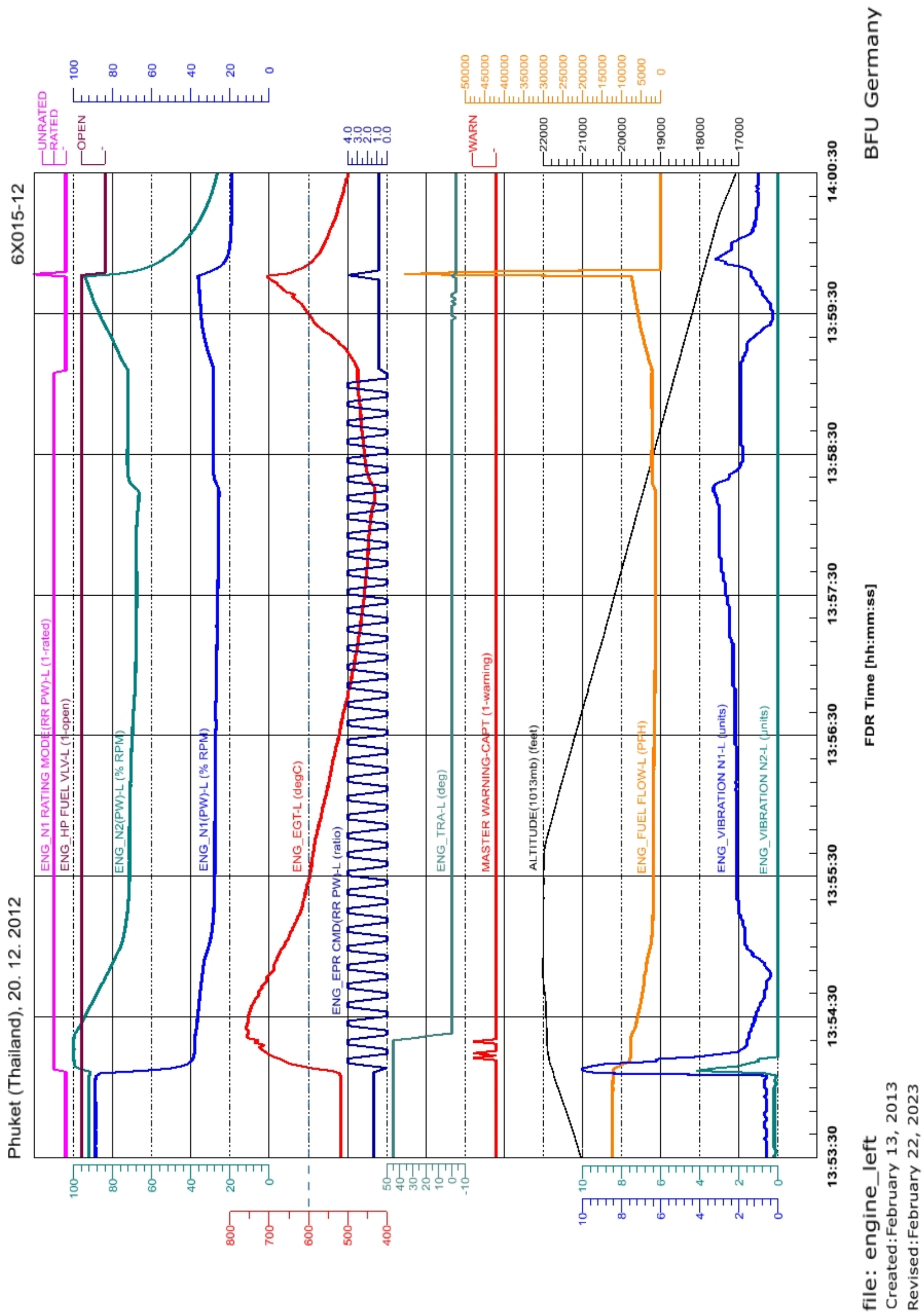

Fig. 33: FDR data of the engine damage Source: BFU

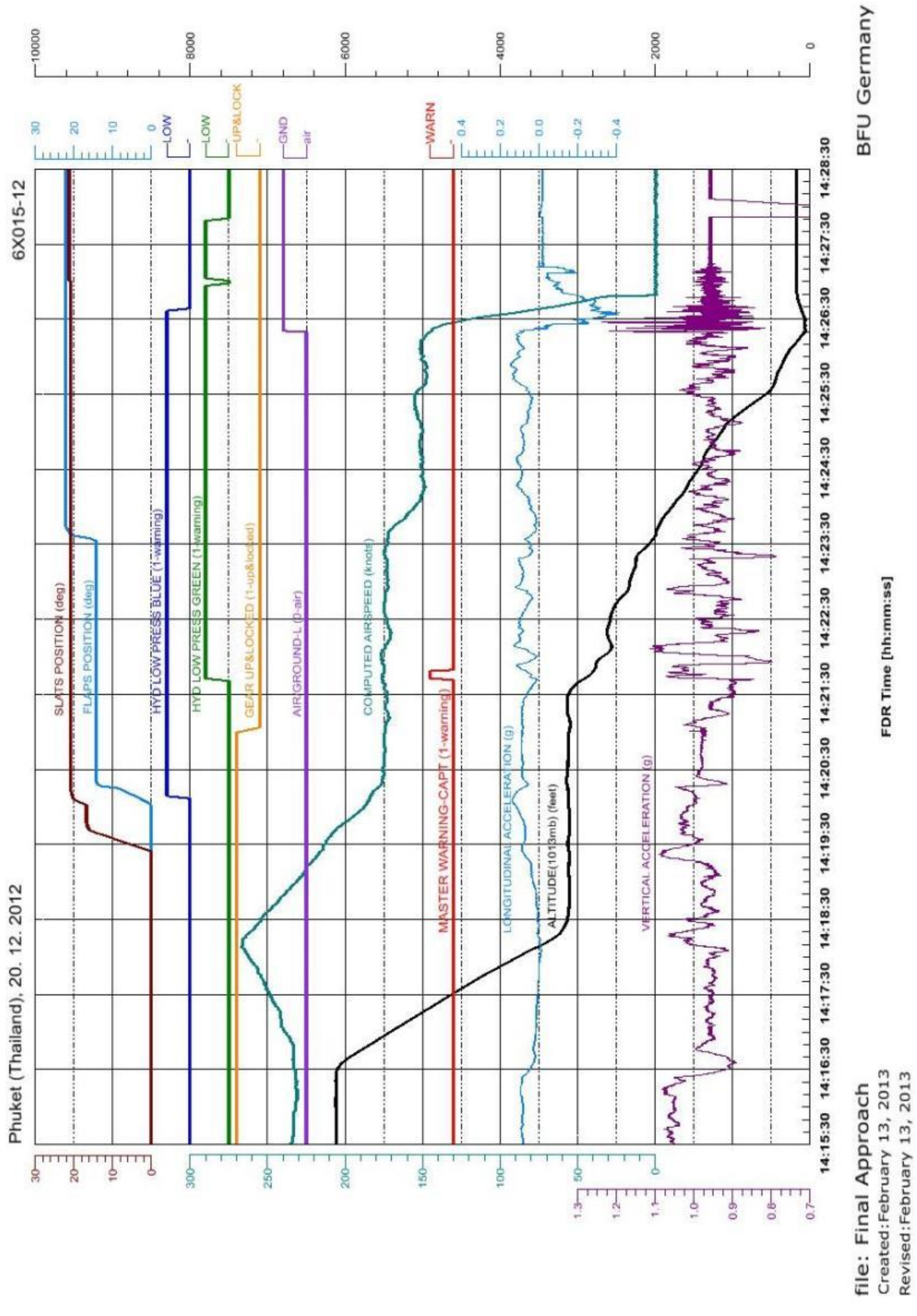

Fig. 34: FDR data of the landing approach Source: BFU

Appendix 2: CVR Transcript of the Flight (after engine damage)[43]

Time (UTC) [hh:mm:ss]	CM1	CM2	Radio
13:54:13	engine failure		
13:54:15		engine one EGT overlimit	
13:54:17	ja (yes)		
13:54:20		N-two overlimit	
13:54:22		number one confirmed	
13:54:23	ja (yes)		
13:54:24		number one	
13:54:26		zieh ihn raus (pull it out *[reduce it]*)	
13:54:32		ich mach (I do) Mayday, Mayday, Mayday, ne *[ok]*?	
13:54:33	ja (yes)		
13:54:36		zurück nach Phuket (return to Phuket), ne?	
13:54:37	ja (yes)		
13:54:38		Lumpur Lumpur [call sign] Mayday Mayday Mayday, we have engine fire, request to return to Phuket	
13:54:52			say again
13:54:52	hey		
13:54:53		Lumpur Control [call sign] Mayday Mayday Mayday request to return to Phuket we have engine fire	
13:55:00			[call sign] [*]
13:55:09			[call sign] report your level now
13:55:01		level two two zero	
13:55:13			say again
13:55:15	two two zero request right turn to Phuket		
13:55:17		request right turn to Phuket [call sign] requesting right turn to Phuket Mayday Mayday Mayday	
13:55:23			[call sign] approved ah right ah turn to papa uniform tango
13:55:28		right turn to papa uniform tango [call sign] and…	
13:55:31	request descent		
13:55:32		requesting descent and please inform Phuket airport	
13:55:36			[call sign] copied
13:55:39		okay	
13:55:40	[*] continue ECAM		
13:55:43		autoflight autothrust off	

[43] [*] = Unintelligible word(s)
Additional statements in italics in square brackets express translation that are necessary for understanding, but do not correspond with a literal translation.

Time (UTC) [hh:mm:ss]	CM1	CM2	Radio
13:55:44	ja (yes)		
13:55:45		clear autoflight	
13:55:46	ja (yes)		
13:55:47		engine one, EPR mode fault engine N-one mode on	
13:55:51	ja (yes)		
13:55:52	mach mal (make *[put in]*) direct papa uniform tango		(ATC with other aircraft)
13:56:00	descending level one-hundred		
13:56:04		descending level one-hundred is [*] confirmed	
13:56:06			[*] four two five ah
13:56:10		go ahead for [call sign]	
13:56:11			now?
13:56:13		go ahead for [call sign]	
13:56:15			[*] [call sign] level now?
13:56:17		we are descending to level one-hundred	
13:56:20			[call sign] ah copied
13:56:28		victor tango sierra papa	
13:56:32		ich mach auf (I will open)	
13:56:35		wir gehen wieder zurück (we are going back)	
13:56:37		ja (yes)	
13:56:38			[call sign] from Phuket, ah you are cleared to descend to flight level one three zero
13:56:43		cleared to descend flight level one three zero [call sign]	
13:56:54		engine one	
13:56:56	ja (yes) continue ECAM		
13:57:05	so**,** nav to papa uniform tango, ja (yes)?		
13:57:07		ja (yes)	
13:57:32			[call sign] contact Bangkok Control on one two five decimal seven
13:57:37		one two five decimal seven [call sign]	
13:57:45	machen (make *[perform]*) engine, engine one EPR mode fault		
13:57:50		ja ich tue jetzt (yes I am doing now *[performing]*) engine one, N-one mode	
13:57:54	ja, ich weiß..[*]…damit ich den, damit ich die äh autothrust nicht anmach (yes I know in order not to turn on autothrust)	ich weiß (I know)	
13:58:12		is guarded	
13:58:34			

Time (UTC) [hh:mm:ss]	CM1	CM2	Radio
13:58:36		engine one N-one mode on	
13:58:40			
13:58:45		ich mach (I make *[switch]*) engine [*] one anti-ice on	
13:58:47	ist an (is on)		
13:58:48		ist an (is on)?	
13:58:49	ne engine [*] anti-ice on, ja mach an (yes put it on)		
13:58:54		EPR mode recoverable sagt er jetzt (he says now)	
13:58:56	ja [*] was macht jetzt die die engine (what does the engine do now)? [*], die einser (the one)		
13:59:02	ham wir auto (do we have auto)		
13:59:02		mach mal auto (make *[engage auto]*)	
13:59:04	engine one		
13:59:05		ja (yes)	
13:59:05	engine one N-one mode off bitte (please)		
13:59:12		EPR mode ist wieder da (is back again)	
13:59:19		Bangkok Control Bangkok Control [call sign]	
13:59:22			[call sign] Bangkok Control radar contact request endurance expect a landing on runway rnav runway zero niner
13:59:33	no, ah what is the wind?		
13:59:35			
13:59:36		please confirm the wind [call sign]	
13:59:38	ok engine shut		
13:59:39			[call sign] nine four correction [call sign] cleared direct
13:59:44	mach die engine aus (shut down the engine)		
13:59:46			to intermediate fix runway zero niner
13:59:47	engine number one off		
13:59:49		number one confirmed	
13:59:49	ja (yes)		
13:59:51			expect RNAV landing on RNAV runway zero nine
13:59:55		roger expecting runway [*] runway zero nine	
14:00:00		ok land ASAP in amber ham wir jetzt (we have now)	
14:00:03		engine one shutdown	
14:00:04	ja (yes) APU, APU an (on)	engine start switches	(ATC with other aircraft)

Time (UTC) [hh:mm:ss]	CM1	CM2	Radio
14:00:08		fuel imbalance monitored	(ATC with other aircraft)
14:00:09		TCAS mode selector auf (to) TA	(ATC with other aircraft)
14:00:18		ich schreib kurz (I quickly write down) fuel imbalance auf	(ATC with other aircraft)
14:00:23		sechzehn drei, sechzehn drei ist kein [*], wir sind gleich unten (16 3, 16 3 is no, we are down soon)	
14:00:27	ich hör dich jetzt nicht (I can't hear you right now)		
14:00:28			[call sign] request endu, endurance and ah soul on board
14:00:33	seven hours		
14:00:34		yepp (yes) seven hours endurance [call sign], stand by	
14:00:39		so abnormal bleed configuration, cross bleed open	
14:00:41	ja (yes)		
14:00:42		und (and) pack one off, air pack one is off	
14:00:47		start the APU	
14:00:49		so land asap, wir haben die (we have the) electrical page	
14:00:51	ja (yes)		
14:00:52		äh, air conditioning ist gleich an beziehungsweise [*] APU ist gleich an (is on soon respectively APU is available soon)	
14:00:55	ja (yes)		
14:00:56		momentan (right now) no supplied by APU, clear ELEC?	
14:01:00	so		
14:01:00		so status, for landing use flap three	
14:01:05	äh ham wir ja nicht (we do not have) CAT three, ach so (ah yes), flaps three		
14:01:08		flaps three genau (exactly)	
14:01:09	ja (yes)		
14:01:09		ich geb den (I'll set) RNAV approach runway zero nine ein	
14:01:12	ja (yes)		
14:01:15			[call sign] could you, can you tell me your endurance and ah soul on board?
14:01:25		dreihundert (300)	
14:01:25	let äh		

Time (UTC) [hh:mm:ss]	CM1	CM2	Radio
14:01:26		we have three-hundred souls on board endurance seven hours [call sign]	
14:01:31			confirm four hour and tree zero four soul on board?
14:01:35	ja (yes)		
14:01:36		affirm	
14:01:37			copy
14:01:38		*private remark*	
14:01:40		so	
14:01:43		[*] at chart zero nine RNAV, zack	
14:02:01			[call sign-incomplete]
14:02:07			[call sign], you ah require any special assistance?
14:02:15	fire brigade	[call sign] we, we need äh the fire brigade at the runway we've shut down the engine, we don't know if there is still any if we still have any fire outside and we need the fire brigade on ground and äh please inform our operations	
14:02:31			roger [call sign]
14:02:34		so	
14:02:36		autoflight autothrust limited	
14:02:37	ja (yes)		
14:02:37		thrustlever MCT	
14:02:40		one-thousand to go	(ATC with other aircraft)
14:02:51	so jetzt setz mich mal rein, was hat die für nen Wind gehabt (now put me in *[inform me]*, what wind did she have)?		
14:02:55		ich hab noch keinen (I still do not have any)	
14:02:55	dann frag mal welchen Wind Phuket hat (the ask which wind Phuket has)		(ATC with other aircraft)
14:02:59		ja (yes)	
14:03:06	so altimeters		
14:03:10		altimeters tausendneun (1009) [*]	
14:03:10			[call sign] contact Phuket Approach one two four seven
14:03:16		twenty four seven [call sign]	
14:03:18			Bye, bye
14:03:20			(ATC with other aircraft)
14:03:27	ok jetzt mach (do now)		
14:03:28		Phuket Approach [call sign], äh maintaining one three-thousand	

Time (UTC) [hh:mm:ss]	CM1	CM2	Radio
14:03:32			[call sign] radar identified direct to intermediate fix runway zero nine QNH one zero zero nine expect an RNAV approach for runway zero nine
14:03:39	also ich sag gleich was, ich hab jetzt nur [*] keine Zeit (I am going to say something soon I just do not have time now)		
14:03:43	No	expect RNAV approach runway zero nine, and äh please confirm the wind	
14:03:47			Ah, surface wind now zero seven zero degree at three knots
14:03:52		zero seven zero with three knots, thank you and please confirm fire brigade is at the runway	
14:03:58	pass auf (listen)		
14:03:59			affirm
14:04:00	ok pass auf (listen)		
14:04:01		ok go ahead	
14:04:02	dann äh gib, mir mal, wir müssen erst mal die runway length berechnen, ob wir mit zweihundert Tonnen, sagen wir mal hundertachtundneunzig Tonnen da rein können (give me, we must calculate the runway length, if we can go in there with 200 t, let's say 198 t)		
14:04:11		ja (yes)	
14:04:12		overweight landing ham wir bestimmt (we certainly have)	
14:04:14	ja (yes)		
14:04:21		pass mal auf (listen)*quiet)*	
14:04:28			[call sign], continue descent to ah altitude
14:04:36	to what?		
14:04:38		please confirm altitude	
14:04:39			three-thousand feet
14:04:41		continue descent to three-thousand feet [call sign]	
14:04:43	äh that is below, that is below, äh we like to go to five-thousand first		
14:04:49		äh, we are descending initially five-thousand feet [call sign]	

Time (UTC) [hh:mm:ss]	CM1	CM2	Radio
14:04:52			roger approved initially five-thousand feet and cleared direct to join final approach course for runway zero nine
14:05:01	ja, we have to, we have to, we need some more time to calculate		
14:05:05		ah cleared to descend then cleared for the approach and we need, äh at least five more minutes	
14:05:14	ja, dann müssen wir nen holding fliegen (yes, then we have to fly a holding)		
14:05:16		ja klar (yes clear)	
14:05:16	pass auf, dann bin ich mal eben bei den Paxen, geht das (listen, I am going to the paxes *[I make the announcement to the paxes]*, is that okay)?		
14:05:18		ja geht (yes, it works)	
14:05:19	wir haben autothrust an, gehen runter auf fünftausend, ja (we have autothrust on, go down *[descent]* to 5,000, yes)?		
14:05:21		ja, ja ja (yes)	
14:05:23		passt jetzt alles (everything fits now)	
14:05:24	off ATC		
14:05:25		on	
14:05:29	(makes PA)		[call sign], which engine
14:05:37	(makes PA)	we shut down engine number one we don't have [*] fire, we just shut it down, but äh for safety reasons we need the fire brigade	
14:05:57			[call sign] roger
14:06:29	so jetzt, wat hast du da jetzt drin? den approach (so now, what did you select now? the approach)?		
14:06:34		das ist der (it is the) approach, RNAV approach runway zero nine ist drin (selected)	
14:06:36	ja (yes)		
14:06:37		landing config drei ist schon mal (3 is already) selected	
14:06:40	haste hier auch schon gemacht (have you already done it here, too)? Ne, ne (no, no)?		
14:06:43	Du (you)?		

Time (UTC) [hh:mm:ss]	CM1	CM2	Radio
14:06:44		[*] noch machen, ne da hab ich noch gar nichts gemacht (still have to do, no, there, I have not done anything yet)	
14:06:46	wo ist denn flaps drei, wo steht denn dat (where is flaps three, where is it written)?		
14:06:48		landing flap three	
14:06:49	mode		
14:06:50		Da (there)	
14:06:52	flap	[*]	
14:06:54		So, inflight *(quiet)*	
14:07:29			[call sign] position tree zero miles west of the airport, confirm landing [*]
14:07:38	ja, die sind dabei (yes, they are there)		
14:07:39	Ah, we cannot say if we can land [*]. Maybe we need, äh we need a three-sixty, but we tell you later, we first, äh proceed, äh to, äh to papa uniform tango, maintaining five-thousand feet		
14:07:53			roger approved
14:08:00	ey		
14:08:01		ja (yes)	
14:08:03	ground proximity [*]		
14:08:04		warning system off	
14:08:05	is dat de (is it)? [*]		
14:08:07			[call sign], do you accept ah fuel dumping for, ah, [*] of the airport?
14:08:15	äh, say again please		
14:08:17		fuel dumping können wir gar nicht (we cannot)	ah do you want to fuel dumping?
14:08:21	no we are not able to dump fuel but maybe we need to loose some fuel, we are on [*] calculation and äh we tell you later		
14:08:29			roger
14:08:42	was rechnest du (what are you calculating)?		
14:08:43		die landing distance rechne ich gerade (I am calculating the landing distance)	
14:08:55			[call sign], Phuket approach maintain five-thousand until Phuket VOR, then join circuit for landing
14:09:06	Ja, we maintain five-thousand as a minimum and		

Time (UTC) [hh:mm:ss]	CM1	CM2	Radio
	then, we do, äh a holding pattern over, äh papa uniform tango until we finish with our procedures		
14:09:17			roger
14:09:19		Also, runway length available ist dreitausend Meter (is 3,000 m)	
14:09:22	ja (yes)		
14:09:24		Klappen drei (flaps 3)	
14:09:24	ja (yes)		
14:09:25		weight limitation, wir haben ne (we have an) overweight landing	
14:09:27	ja (yes)		
14:09:28		landing distance zweitausendsechshundert Meter (2,600 m)	
14:09:30	ja (yes)		
14:09:30		ja (yes)	
14:09:31		eins Komma fünf, der Faktor (1 point 5 is the factor) factored landing distance ist zweitausendneunhundertsechsundachtzig Meter (is 2,986 m)	
14:09:35	watt zweitausendneunhundert… (what? 2,900)		
14:09:36		Neunhundertsechsundachtzig (986)	
14:09:38	factored landing distance?		
14:09:41		stop margin vierzehn Meter (14 m), go around gradient ist äh vier komma vier sieben Prozent (is 4 point 47 percent)	
14:09:52	ground proximity warning off, is datt denn jetzt wieder (now is this again)?, system off		
14:10:01	gib mal nen holding ein über, über, ähm, und check mal eben die, äh die altitude, die wir da haben dürfen (enter holding above, above and check the altitude which we are allowed to have)		
14:10:15		holding ist drin (holding is inserted)	
14:10:21	vier sechs ist Minimum äh (4 6 is minimum)?		
14:10:23		ja (yes)	

Time (UTC) [hh:mm:ss]	CM1	CM2	Radio
14:10:28		über Phuket, äh, Phuket hat jetzt kein holding veröffentlicht hier (above Phuket, Phuket has no published holding)	
14:10:31	na wir fahren einfach da rein (we simply go in there)		
14:10:32		ja genau (yes exactly)	
14:10:34	pass auf, jetzt muss ich noch eins wissen, ich muss wissen, ob wir auf der safe side sind was die minimum safe ist fünftausend, ja ne (listen, I now have to know one thing, I have to know if we are on the safe side concerning the minimum safe, it is 5,000 yes)?		
14:10:43		ja (yes)	
14:10:47	ja (yes)	ja gut wenn du jetzt mal rechnest tausend Fuß drüber ja (yes if you calculate now 1,000 ft higher, yes)? Sind fünf sechs, müssten wir eigentlich sechstausend maintainen (are 5 6, we should actually maintain 6,000)	
14:10:53	ok maintain six-thousand		
14:10:55		[call sign] maintaining six-thousand feet	
14:11:00			roger maintain six-thousand feet approved
14:11:04		ok	
14:10:37			[call sign] advise, when ready for commencing approach for landing
14:11:09	we will enter holding		
14:11:10		we will enter the holding, we will enter the holding over Phuket, I call you when in the holding	
14:11:14			ok
14:11:15		ok äh Status ja (status yes)? Approach [*] for landing use flap three habe ich schon eingestellt und (I have selected already) fuel imbalance monitor	
14:11:21		[*] noch mal eben drauf, wir haben jetzt eine imbalance von vierhundert Kilo, da passt noch was (just on top we have 400 kg imbalance now, so, there is still space)	(ATC with other aircraft)
14:11:27	ja (yes)		

Time (UTC) [hh:mm:ss]	CM1	CM2	Radio
14:11:29		und Status noch mal, INOP ist (and status once again INOP is) reverser one, captain TAT, engine one bleed pack one, alles auf der linken Seite, ich mach mal die bleed an (everything on the left side, I will switch on bleed)	
14:11:44	ja (yes)		
14:11:48		[*] Status ist komplett (is completed) confirm clear	
14:11:53	clear		
14:11:57		okay, FORDEC	
14:11:59	ok		
14:11:59		[*] viel zu, zu sagen (a lot to say), ne?	
14:12:01	pass auf, ähm ich habe seit acht Wochen keine Landung mehr gemacht, fühlst du dich in der Lage (listen, I have not made any landing within the last 8 weeks, do you feel up to it)?		
14:12:06		ja, ja auf jeden Fall kann ich machen (yes, yes, in any case, I can do it)	
14:12:07	ok dann, äh dann, äh ich, ich assistiere dabei (ok then, then I will assist)		
14:12:11		Yes	
14:12:12	Ja (yes)		
14:12:13	ich, ich mach dat jetzt einfach, das ist nonstandard, aber ich muss es tun, jetzt, es ist einfach, du, du hast mehr Erfahrung, Flugerfahrung, jetzt also denk dran, wir haben extrem knappe margin, mit wie, mit welchen brakes hast du gerechnet (I, I am going to simply do this now, it is non-standard, but I just have to do it now, you, you have more experience, flying experience, so remember we have an extremely narrow margin with, how, with which brakes *[settings]* did you calculate)?		
14:12:24	bei dem bei der (by the) landing distance		
14:12:31		[*] go around gradient äh [*] three landing technique [*]	

Time (UTC) [hh:mm:ss]	CM1	CM2	Radio
		braking mode habe ich low gerechnet (I calculated for low)	
14:12:45	ja (yes) medium	[*]	
14:12:50		müssen wir gleich die overweight landing ähh Checkliste noch machen (then we still have to perform the overweight landing checklist)	
14:12:53	ja (yes)		
14:12:53		jetzt ist die landing distance neunzehn sechsundsechzig und factored ist zwotausendzwohundertsiebzig (now the landing distance is 19 26 and factored is 2,670)	
14:12:57	ja, guck mal, da haben wir achthundert Meter zurück [*] ja (look, there we have 800 m back)		
14:13:00		ham wir da kein Problem (we do not have a problem)	
14:13:01	ja hast du mit zwohundert Tonnen gerechnet (yes did you calculate with 200 t)?		
14:13:03		ja (yes)	
14:13:04	ja (yes)		
14:13:04		ja, gut dann (yes good then)	
14:13:05	ja, ist ok (yes, it is ok)		
14:13:08		[*] fuel balance noch loswerden ja (still to get rid of)	
14:13:12	ja (yes)	du hast den Passagieren Bescheid gesagt (you informed the passengers), runway zero nine ist drin (is inserted)	
14:13:19	and, äh Phuket, äh we are approaching, äh papa uniform tango, after this we turn left maintaining six-thousand, ähm for a kind of holding pattern, maybe we can start our approach out of the holding pattern		
14:13:34			roger [call sign] approved that request, advise again when ready for commence approach
14:13:43	roger, call you when ready commencing approach, until then, we will stay at six-thousand in the hold		
14:13:49		so, Feuer haben wir ja jetzt nicht ja (we do not now have fire yes)	

Time (UTC) [hh:mm:ss]	CM1	CM2	Radio
14:13:51	ne (no=		
14:13:52		overweight landing check [*] mal raus (out)	
14:13:53	ja, bitte ja (yes please yes)		
14:14:07		*private Äußerung (private remark)*	
14:14:15		Ok, ich les mal vor ja (I am going to read it aloud, yes)?	
14:14:17	ja (yes)		
14:14:17		automatic landing is certified up to the max landing weight	
14:14:21	ja können wir ja nicht machen, vergiss es (yes we cannot do that, forget it)		
14:14:23		ja (yes)	
14:14:24	ja (yes)		
14:14:25		autoland, depending on situation, [*], Jeppesen, consider landing configuration as required, required ist Klappen 3 (is flaps 3)	
14:14:32	Ja, entering hold left turn		
14:14:39		[call sign] is entering holding over Phuket and turning left	
14:14:45			roger
14:14:47		den on (this on)	
14:14:51		use ECAM flap setting if required for abnormal operation, in all other cases full is preferred for max ops, machen wir nicht (we will not do that), in all cases landing configuration, landing distance check, die ham wir schon gecheckt (we already checked it), pack one and two off [*], APU supplied by APU	
14:15:16	hydraulic system G leak….ne ey (*[not really]*)	wat denn (what)?	
14:15:20		green system leak, ja alles klar (yes okay) [*], monitor if level decreases, read [*], wie sieht's denn aus (what does it say)?	
14:15:30		dreitausendfünfzig, dreitausendfünfzig ja (3,050, 3,050, yes)?	
14:15:32	det stimmt ja gar nich, ja ist gut, es wird weniger ja (that's not true, yes okay, it is decreasing, yes)		
14:15:40	ok dann müssen wir lan, landen, landen jetzt (then we must lan, land, land now)		

Time (UTC) [hh:mm:ss]	CM1	CM2	Radio
14:15:42		ok, land ASAP in amber [*], kurz (short), target speed V_{LS} in the final stages at [*], reverse thrust use max available after nose wheel touchdown, brakes apply as [*] as necessary und (and)	
14:15:57	we're commencing approach		
14:16:00		ja, max vertical speed at touchdown dreihundertsechzig Fuß pro Minute (360 ft/min), ich leg das mal eben weg, und, äh sollen wir pack two auch ausmachen (I will put it away *[do it later]* and shall we turn off pack 2)?	
14:16:09	ne komm jetzt, vergess pack (okay, forget the pack), Hydraulik G, G ist jetzt angesagt (is now relevant)		
14:16:13		alles klar (okay), leak rate monitor ham wir gemacht (we did perform)	
14:16:16	request approach		
14:16:18		[call sign], we are ready for approach, we are now flying downwind	
14:16:25			[call sign] roger, cleared direct to intermediate fix, descend two-thousand-six-hundred feet, cleared RNAV zero niner approach
14:16:33		cleared RNAV approach, runway zero niner, cleared direct to the intermediate fix [call sign]	
14:16:41	gibst du mir, äh gibst du den approach jetzt rein (do you give me the approach in now *[will you insert approach for me, now]*)?		
14:16:44		der approach ist drin ja (yes, the approach is inserted yes)	
14:16:45	ja (yes)?		
14:16:46		ja der approach ist drin (yes the approach is in)	
14:16:47	wo, wo äh, gut jetzt fliegen wir nach LAZIO oder wohin (where, where, we fly to LAZIO now or whereto)?		
14:16:51		nein, nach, …, nicht zu (no to. …, not to) [*] Phuket whiskey	
14:16:55	hat, hat [*], ja okay der ist da (has has yes okay it is there)		

Time (UTC) [hh:mm:ss]	CM1	CM2	Radio
14:16:58			[call sign] two zero miles from touchdown, is it ok for descent?
14:17:04		was hat er gesagt (what did he say)?	
14:17:07	say again		
14:17:08			[*] two zero miles [*] touchdown, is it ok for descent?
14:17:13	roger we're descending now out of five-thousand [*] after this we turn äh [*] we turn left onto the final		
14:17:20			[call sign] roger
14:17:23	hydraulic leak rate monitor		
14:17:25		ja die (yes it) decreased, also wir haben jetzt dreitausend, die bleibt eigentlich so, (now we have 3,000 it actually stays the same), ne?	
14:17:28	ja (yes), green engine one pump off		
14:17:31		green engine two pump off	
14:17:34	ja wir könnten das saven, dann, ne (yes, we could save this then)?		
14:17:35		ja (yes)	
14:17:36	aber die Rate ist eigentlich noch (but the rate is actually still)		
14:17:38		die bleibt (it stays the same), ne?	
14:17:39	ja, wat was (yes, what)		
14:17:40		Triebwerk, Triebwerk ist ja eh abgestellt (engine, engine is shut off anyway)	
14:17:42	ja also pass auf (yes, listen), you have control?		
14:17:44		I have control	
14:17:45		dann mach mal hier (then perform here) clear hydraulic	
14:17:48	clear		
14:17:54		so, fühlst du dich jetzt gut (so, do you feel okay now)?	
14:17:55	[*] mit der Hydraulik macht mir jetzt Sorgen (I am actually worried about the hydraulic)		
14:17:57		ok, one-thousand to go	
14:18:01	ok, wir gehen dann runter auf dreitausend ja (we go down to 3,000, yes)?		
14:18:04		checked, we have seven-hundred to go	

Time (UTC) [hh:mm:ss]	CM1	CM2	Radio
14:18:05	und der approach fängt in zweitausendsechshundert an (and the approach starts at 2,600)		
14:18:08		ja (yes)	
14:18:13	speed		
14:18:28		so, approach phase aktiviert (active)	
14:18:29	ja (yes)		
14:18:36	hydraulic ist neunundzwanzig null eins (is 29 0 1)		
14:18:43	Ja (yes)		
14:18:45		system	
14:18:47		ja, aus bitte (yes, out *[disangage]* please)	
14:18:48	so wir haben, wir können (so we have, we can)		
14:18:52		Ja (yes) [*]	
14:18:54	ja ist doch jetzt aus Junge (Come on, it is off now, boy)	[*]	
14:19:07	ok commencing approach		
14:19:11		ready for left turn	
14:19:12		turning left	
14:19:14	and [call sign], turning left onto hotel kilo tango whiskey india		
14:19:21			[call sign] roger
14:19:25		flaps one	
14:19:31		[PIC's name], alles ok bei dir (everything okay with you)?	
14:19:31	ja (yes)		
14:19:44		danke (thank you)	
14:19:51		so ich flieg dann manuell (I will fly manually), autothrust on und dann am Boden (and later on ground) max reverse	
14:19:58	so, da kam jetzt flaps two fault auch noch (so, in addition, we got flaps 2 fault now)		
14:20:02	sollen wir flaps two machen (shall we set flaps 2)?		
14:20:04		[*] flaps two [*]	
14:20:06	was wir haben haben wir (what we have we have *[done is done]*)		
14:20:13			
14:20:14		blue system low pressure, ist klar (is clear *[that is expected]*) [*]	
14:20:28	was dat denn jetzt (what's that now)?		

Time (UTC) [hh:mm:ss]	CM1	CM2	Radio
14:20:36	da ist irgendwas mit der wing du (there is something with the wing)		
14:20:38		bitte (please *[say again]*)	
14:20:38	da ist irgendwas mit der wing (there is something with the wing)		
14:20:55	wir haben aber Klappen zwei und wollen wir, wollen wir gear rausmachen (we have flaps 2 and do we want to extend the gear)?		
14:21:00		Ok, gear down	
14:21:08		green reservoir low level	
14:21:12	taking action		
14:21:18	three greens		
14:21:19		bitte (please *[say again]*)	
14:21:20	three greens		
14:21:21	zwei auf, jetzt auf zweitausend sechshundert, ja (2, now to 2,600, yes)?		
14:21:23		ja (yes)	
14:21:33	so [*] äh		
14:21:34		ECAM action	
14:21:35	eh, hydraulic G re, reservoir low, green, wo isser (where is it)?		
14:21:39		green electric pump	
14:21:41	ja (yes)		
14:21:46		confirmed	
14:21:49	autopilot off	äh	
14:21:50		Autopilot, I have control	
14:21:53	Ja (yes)		
14:21:54		der Autopilot rausgefallen (the autopilot disengaged)	
14:22:03	Zweitausendsechshundert (2,600)?		
14:22:07	da hinten ist der airport (over there is the airport)		
14:22:08		ja (yes)	
14:22:12	so		
14:22:16	und wir machen den (and we perform the), äh final approach, haste drin (you have inserted)?		
14:22:19		ist drin (is inserted)	
14:22:20	dann müssen wir hier noch machen, ja (then we still have to perform this here, yes)		
14:22:23	final track ist		
14:22:24	null acht fünf (085)		

Time (UTC) [hh:mm:ss]	CM1	CM2	Radio
14:22:26	kommt er (does he come *[is it alive]*)		
14:22:36	wir haben keine Bremsen mehr (we have no brakes any more)		
14:22:40	ich muss das mal eben äh lesen (I just have to read this)		
14:22:43		ja (yes)	
14:23:15	speedbrake, do not use		
14:23:17		ok	
14:23:21	electric hydraulic wheel ist weg sagt er (it says electric hydraulic wheel is lost)		
14:23:25			[call sign], seven mile from touchdown, wind zero five zero degree, two knots runway zero niner, cleared to land
14:23:28		flaps three	
14:23:33	cleared to land		
14:23:34	wir haben jetzt Klappen zwei ich versuch nochmal drei zu machen ja (we now have flaps 2, I am trying to make 3 again, yes)?		
14:23:38		Ja (yes)	
14:23:39	kommt noch (still to come)		
14:23:48	so, [*] sie sind drauf, ich weiß nicht, was mit den Bremsen ist, ne (so, they are on, I have no idea about the brakes)		
14:23:52	also, wir können, müssen möglicherweise, äh uns auf (we can, must possibly), spoilers armed, do not use spoilers, ich weiß es nicht (I do not know)		
14:24:15	so, Lampen an (lights on), landing signs on, landing gear down, flaps, landing light		
14:24:21		so, und gleich noch die (and soon the) overweight landing [*] ne	
14:24:23	ja (yes)		
14:24:23		final phase of approach und äh	
14:24:27	was kommt noch (what else)?		
14:24:27		max, maximum dreihundertsechzig Fuß pro Minute (360 ft/min)	

Time (UTC) [hh:mm:ss]	CM1	CM2	Radio
14:24:30	ja, ja dat ist jetzt egal (yes, it doesn’t matter now)		
14:24:37	also, wir haben noch (we still have) äh accu brakes, wahrscheinlich nur noch ne (probably only)		
14:24:40		ja (yes)	
14:24:55	es muss passen ne (it has to fit)		
14:24:56		ja (yes)	
14:24:57	also, äh lieber drei rote als drei weiße (rather 3 red than 3 white)		
14:25:04	So, das wäre jetzt neunhundert Fuß, müssten wir jetzt haben, bist nen bisschen zu hoch, du bist ja noch schnell, nich, wir haben äh zehn Knoten Gegenwind, einhundertachtundvierzig groundspeed (so now, it should be 900 ft, we should have now, you are a bit too high, you are still fast, we have 10 kt headwind, 148 ground speed)		
14:25:16	continue, ja (yes)		
14:25:18	biste gut drauf (are you in a good mood)?		
14:25:19		bin gut drauf (I am in a good mood)	
14:25:23		flight directors off	
14:25:24	ja (yes)		
14:25:30	vierzehnhundert Sinkrate vierzehnhundert Sinkrate reduzieren, reduzierst du (1400 rate of descent, 1400 rate of descent, reduce, do you reduce)?		(ATC with other aircraft)
14:25:34		ja (yes)	
14:25:36	gut (good)		(ATC with other aircraft)
14:25:38	level off		
14:25:40	so und jetzt (and now)		
14:25:41	[*] wind kommt leicht von links (wind will be slightly from the left)		
14:25:43	gear is down three green		(ATC with other aircraft)
14:25:46	jetzt wieder, jetzt wieder runter, ja, noch nicht ganz (now again, now again, down, yes, not quite)		
14:25:55	die andere, nicht [*], muss weiß sein, eine muss weiß		

Time (UTC) [hh:mm:ss]	CM1	CM2	Radio
	sein (the other one, not, has to be white, one has to be white)		
14:25:59	ja, fünfhundert Fuß Sinkrate jetzt (yes, 500 ft rate of descent now)		(ATC with other aircraft)
14:26:08	runter jetzt, runter, runter, runter (down now, down, down, down)		
14:26:10	ja (yes)		
14:26:12	siebenhundert Sinkrate, achthundert (700 sinkrate, 800)		
14:26:15	bis zwanzig Grad, runter runter (until 20 degrees, down down)		
14:26:17		ich muss reduzieren (I have to reduce)	
14:26:18	runter (down)		
14:26:20	ganz runter (all the way down)		
14:26:20	runter (down)		
14:26:17	runter (down)		
14:26:24	ja (yes)		
14:26:27	ja (yes)		
14:26:46	so		
14:26:53	attention crew on station		
14:27:00		Reifen dürfte Platt sein (tires will be deflated)	
14:27:06	reverser, reverser		
14:27:08		unlocked	
14:27:09	ja (yes)		
14:27:11	Bremse (brake)		
14:27:13		[*]	
14:27:15		parking brake, you have control	
14:27:17	ja, was ham wir jetzt (what do we have now)?		
14:27:18		[*] low pressure engine two, minor fault [*]	[call sign] contact tower one one eight decimal one, good day
14:27:26	Ja, runway is blocked		
14:27:29		[call sign] stopping on the runway, runway is blocked	
14:27:31	äh, tower, äh, tower runway is blocked now by us, we have a flat tire and äh fire brigade should come immediately to the aircraft		
14:27:39			[call sign, roger fire brigade is on the way, contact tower on one one eight decimal one for more information

Time (UTC) [hh:mm:ss]	CM1	CM2	Radio
14:27:48		over to eighteen one [*] [call sign]	
14:27:51	äh, ich mach die engine aus, ja (I will shut off the engine, okay)?		
14:27:52		alles klar (okay)	
14:27:53	wir haben ja APU an (we have the APU running)		
14:27:56		engine two minor fault, reverser one minor fault [*]	
14:28:04	and tower what does the, äh what does the fire brigade say about any fire on the aircraft?		
14:28:10		[*]	
14:28:11			[call sign] negative
14:28:14	no fire on the aircraft, ok		
14:28:17			affirm
14:28:19	(makes PA announcement)		
14:28:31		ja das kommt von den Reifen, wir haben (yes this comes from the tires, we have) [*]	
14:28:37		äh, engine one reverser minor fault, clear engine one?	
14:28:40	vergiss es (forget it), clear engine one		
14:28:44			[call sign], fire brigade reports flat tire and hot brake, negative fire
14:28:51	we have flat tire, we cannot leave the runway		
14:28:53		and we are, we have a flat tire, we are unable to leave the runway	
14:28:58	buses and stairs		
14:28:59			[call sign] we understand
14:29:01	buses and stairs		
14:29:01		we need buses and stairs at the aircraft	
14:29:05			ok
14:29:08	normal operation, normal operation		

Appendix 3: Times of all Radio Contacts with the Air traffic Control Unit

The note (as disruption) marks the initiated interruptions of the conduct of the flight by the air traffic control unit

1) 13:54:38 UTC
2) 13:55:09 UTC
3) 13:56:15 UTC
4) 13:56:38 UTC
5) 13:57:32 UTC as interruption
6) 13:59:22 UTC
7) 13:59:39 UTC as interruption
8) 13:59:51 UTC as interruption
9) 14:00:28 UTC as interruption
10) 14:01:15 UTC as interruption
11) 14:01:31 UTC as interruption
12) 14:02:07 UTC as interruption
13) 13:03:10 UTC as interruption
14) 14:03:32 UTC
15) 14:03:47 UTC
16) 14:04:28 UTC
17) 14:04:52 UTC
18) 14:05:29 UTC as interruption
19) 14:07:29 UTC as interruption
20) 14:07:53 UTC as interruption
21) 14:08:07 UTC
22) 14:08:21 UTC
23) 14:08:55 UTC as interruption
24) 14:11:00 UTC
25) 14:10:37 UTC as interruption
26) 14:13:34 UTC
27) 14:14:45 UTC
28) 14:16:25 UTC
29) 14:16:58 UTC as interruption
30) 14:19:21 UTC
31) 14:23:25 UTC as interruption

Appendix 4: Photographs of the engine damage

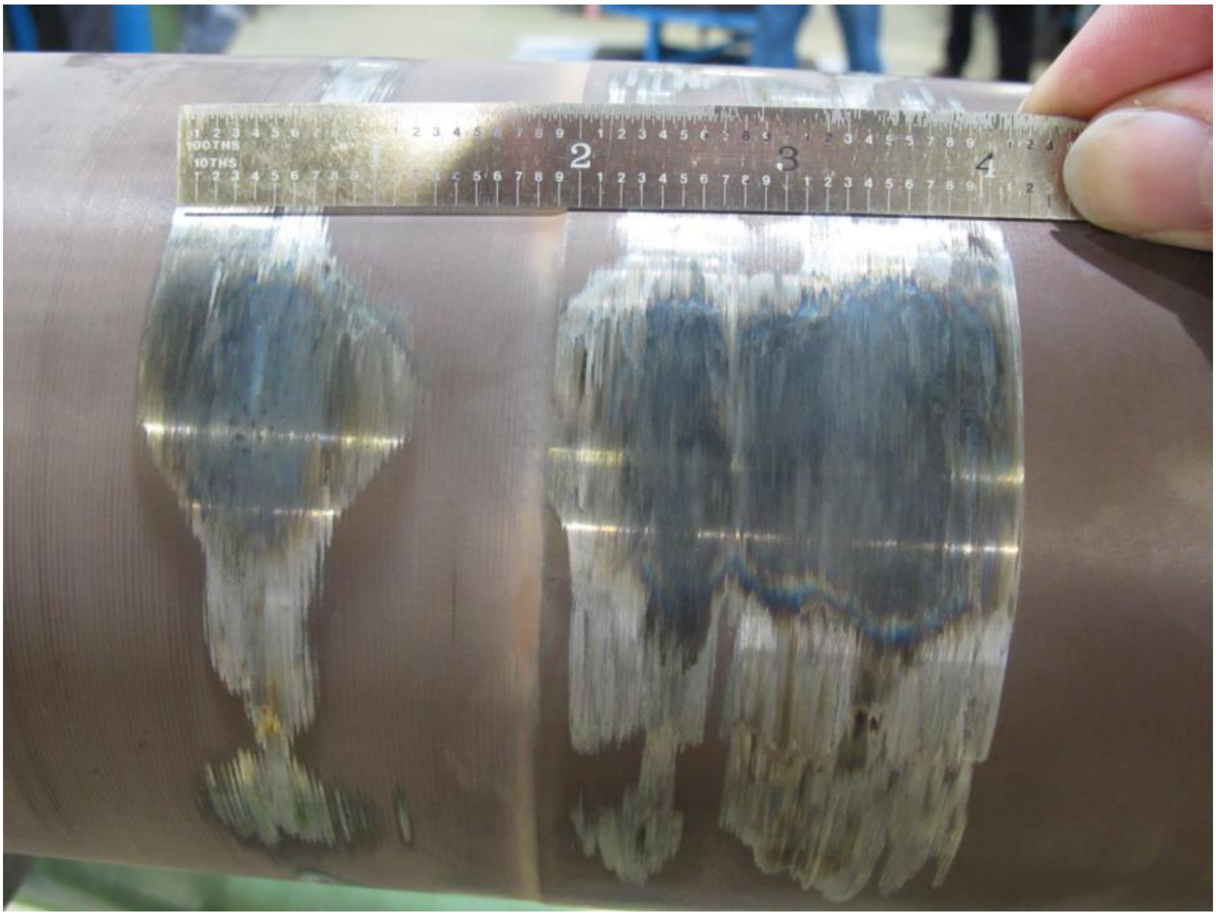

Fig. 35: Rub marks at the LPT shaft, measuring tape: inch. Source: Pratt & Whitney

Fig. 36: Damaged LPT housing, white markings mark the position circumference (footnote 19)
yellow measuring tape: inch. White measuring tape: cm Source: Pratt & Whitney

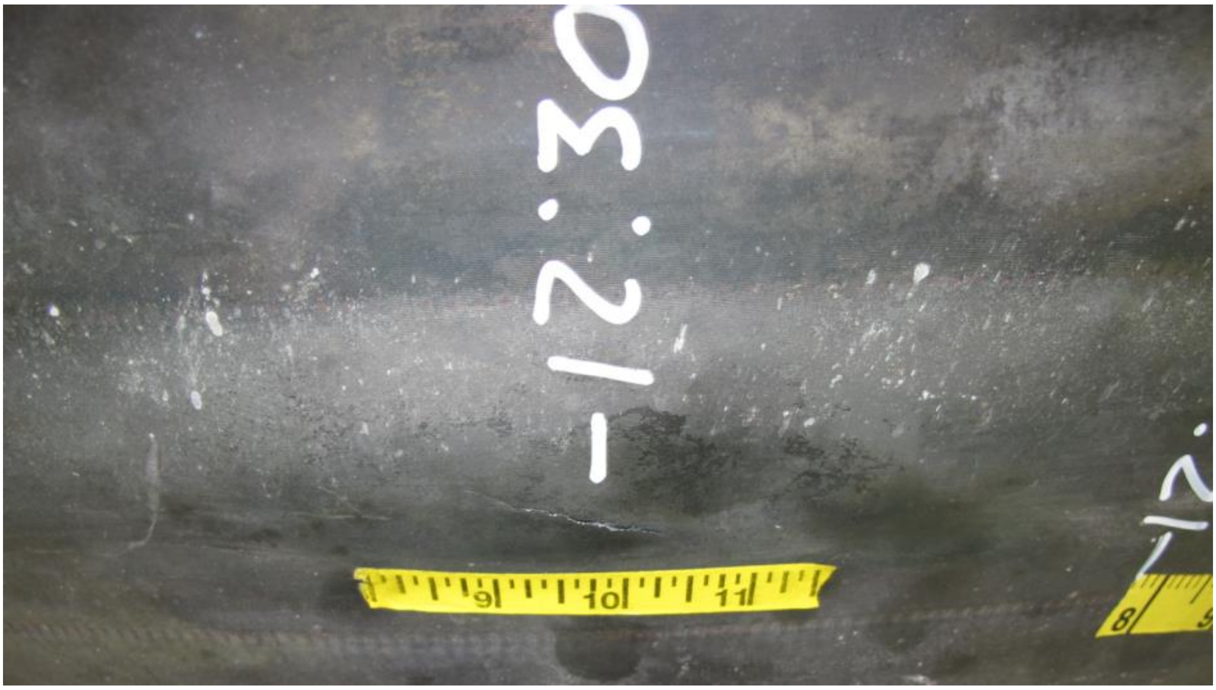

Fig. 37: Damaged LPT housing at 1230 position (footnote 1919) Source: Pratt & Whitney

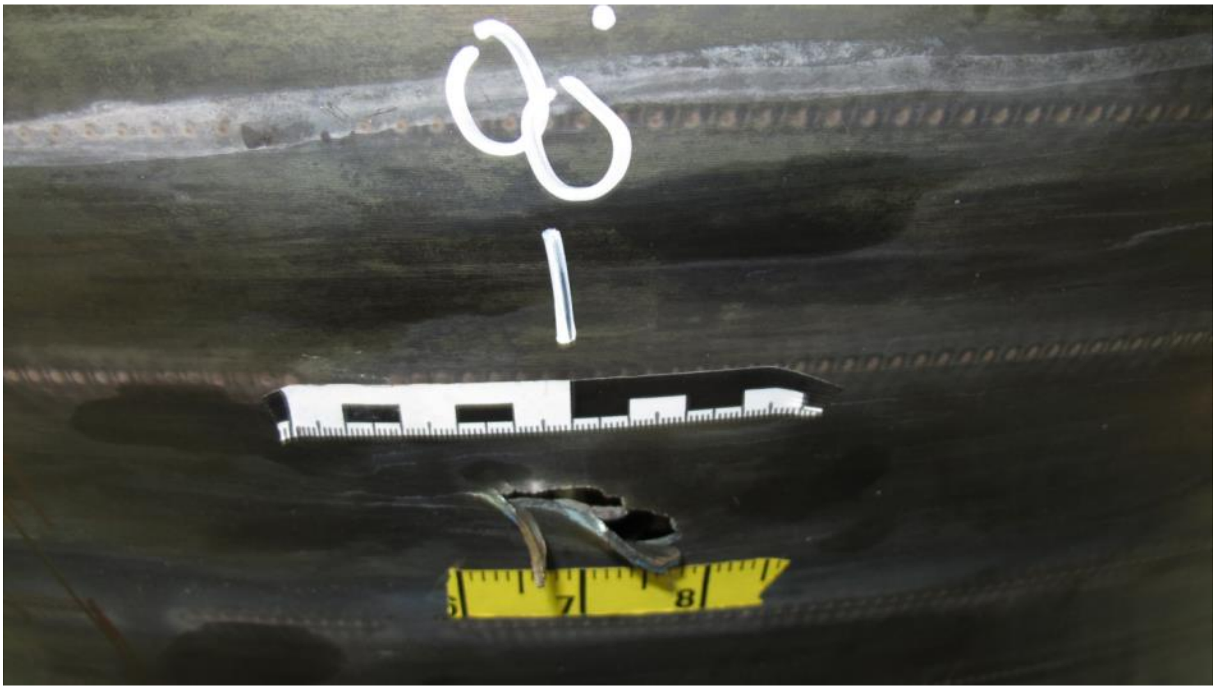

Fig. 38: Damaged LPT housing at 0830 position (footnote 19)

Yellow measuring tape: inch. White measuring tape: cm Source: Pratt & Whitney

Appendix 5: Photographs of the damage of the cowling and at the pylon

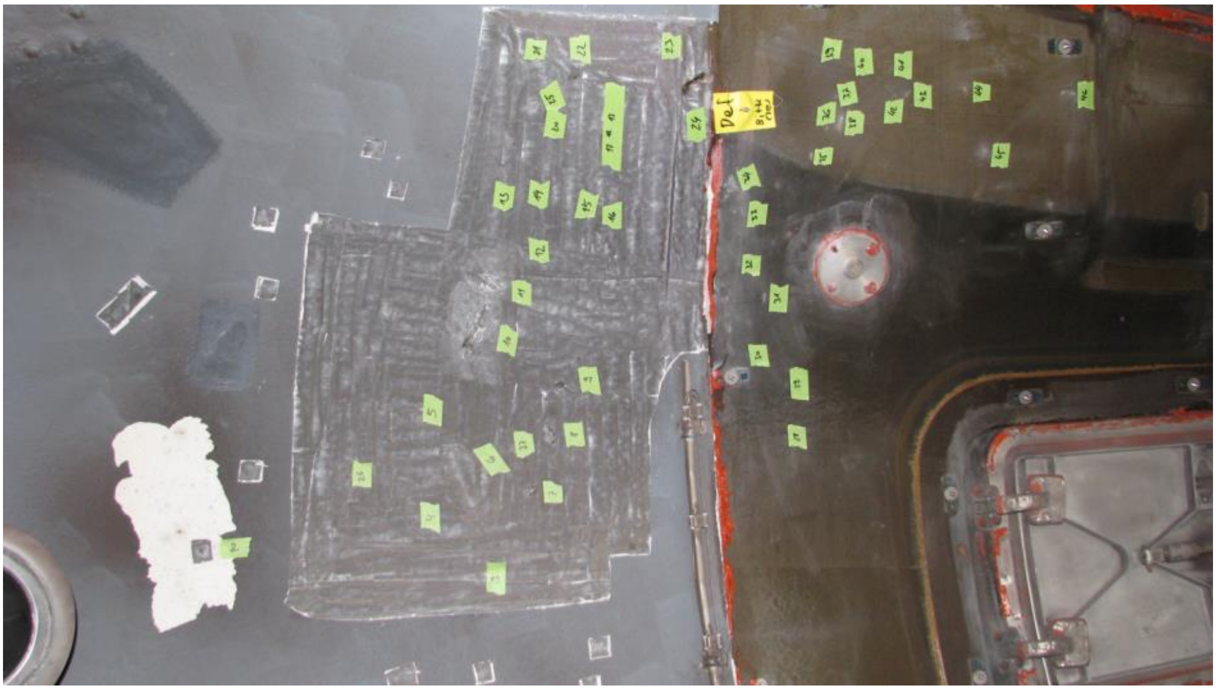

Fig. 39: Damage of the right thrust reverser door Source: BFU

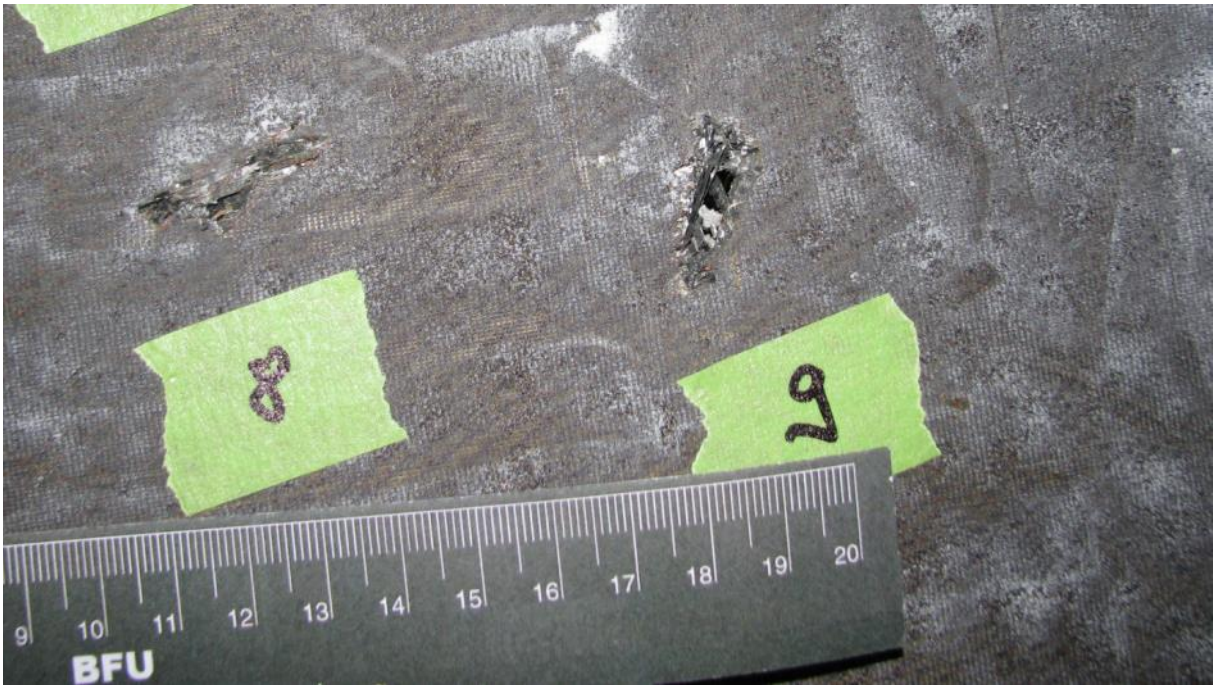

Fig. 40: Details of the damage of the right thrust reverser door Source: BFU

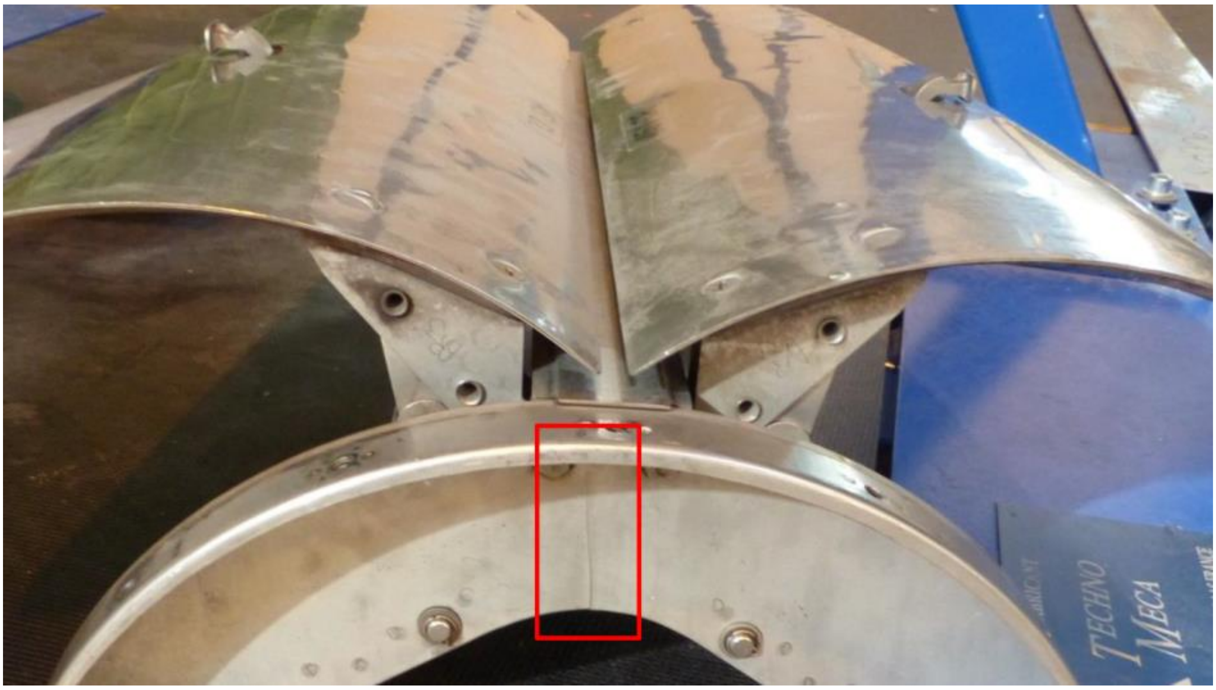

Fig. 41: Crack at the front fairing (Panel 451), red mark shows the position of the crack

Source: Airbus, adaptation BFU

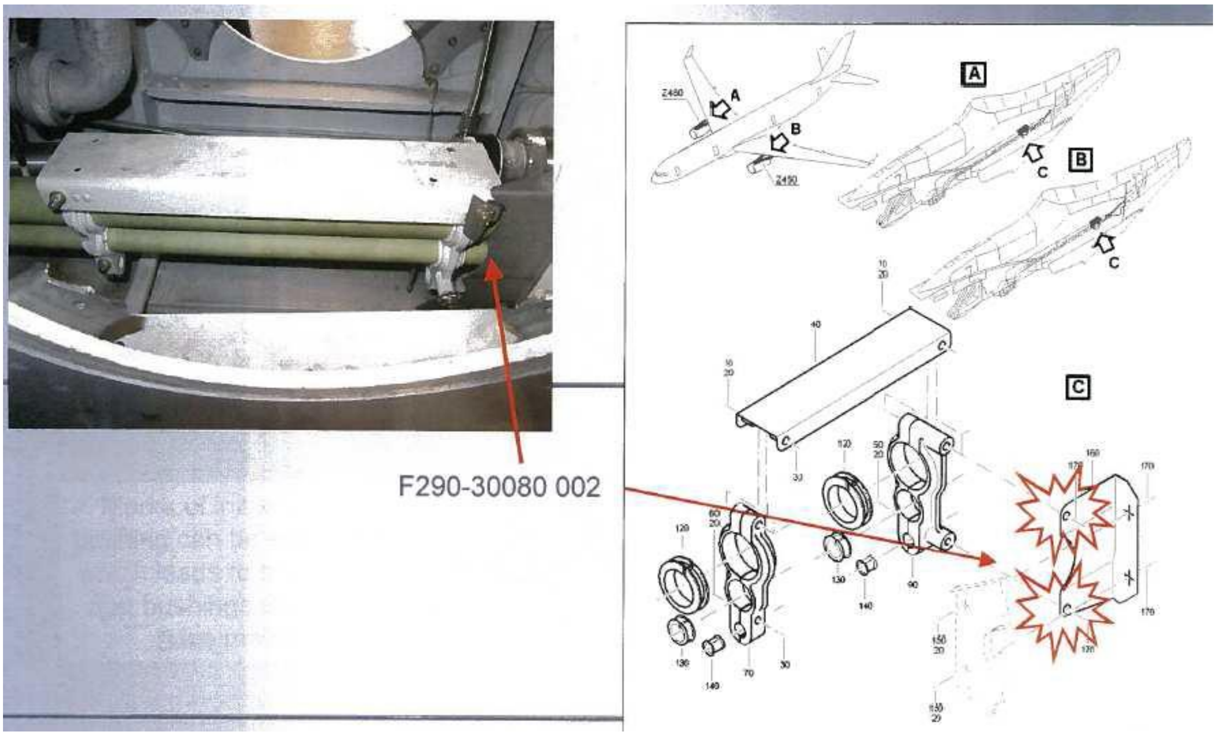

Fig. 42: Fatigue fracture at the Hydraulic Line Bracket F29030080 Source: Airbus

Fig. 43: Fatigue fracture at the Hydraulic Line Bracket F29030080, in detail Source: Airbus

Appendix 6: Engine Damage Procedures / Descriptions in the QRH and FCOM

A330 QUICK REFERENCE HAND BOOK	ABNORMAL AND EMERGENCY PROCEDURES	70.04 17 JUL 12

ENG 1(2) STALL

A stall may be indicated by varying degrees of abnormal engine noises, accompanied by flame from the engine exhaust (and possibly from engine inlet in severe cases), fluctuating performance parameters, sluggish or no thrust lever response, high EGT and/or a rapid EGT rise when thrust lever is advanced. Engine stalls must be reported for maintenance action.

■ **Stall is detected by the FADEC:**

■ **In flight:**

FUEL ADJUSTED

Fuel/Air ratio is automatically decreased until the stall disappears.

THR LEVER 1(2) .... IDLE
ENG 1(2) PARAMETERS .... CHECK

● **IF ABNORMAL:**

ENG MASTER 1(2) .... OFF

■ **On ground:**

THR LEVER 1(2) .... IDLE
ENG MASTER 1(2) .... OFF

■ **If the crew detects a stall before the ECAM activation:**

The following non ECAM procedure may be applied:

THR LEVER 1(2) .... IDLE
ENG PARAMETERS 1(2) .... CHECK

Note: *If parameter trend toward normal and no redline exceedence exists, monitor the parameters.*

■ **If abnormal parameters persist above redline:**

ENG MASTER 1(2) .... OFF

ASSOCIATED PROCEDURES

ENG 1(2)
SHUT DOWN

Apply ENG SHUT DOWN procedure.
Engine restart at crew discretion.

■ **If normal parameters:**

ENG A ICE 1(2) .... ON
WING A ICE .... ON

Operation of the engine and wing anti ice will increase the stall margin but EGT will increase accordingly.

THR LEVER 1(2) .... SLOWLY ADVANCE

● **If stall does not reoccur:**

Continue engine operation.

Fig. 44: ENG 1(2) STALL, QRH ABN-70 Source: Operator

ENG 1(2) EGT OVERLIMIT

Applicable to: ALL

- **Maximum pointer indications:**

L2 EGT above 600 °C or above 620 °C at takeoff power.

L1 THR LEVER (AFFECTED ENGINE)........ BELOW LIMIT

L2 *If unable to maintain **EGT** within limits, shut down affected engine. If conditions do not permit engine shutdown, land as soon as possible using the minimum thrust required to sustain safe flight.*
Normal operation may be resumed to next landing.
Report in maintenance logbook.

Fig. 45: ENG 1(2) EGT OVERLIMIT, FCOM Chapter PRO-ABN-70 Source: Operator

ENG 1(2) N1/N2 OVERLIMIT

Applicable to: ALL

- **Maximum pointer indications:**

L2 N1 above 100 %
N2 above 100 %

L1 THR LEVER (AFFECTED ENGINE)........ BELOW LIMIT

L2 *Normal operation may be resumed to next landing.*
If unable to maintain N1 or N2 within limits, shut down the affected engine. If conditions do not permit engine shutdown, land as soon as possible using the minimum thrust required to sustain safe flight.
Report in maintenance logbook.

L1 - **Maximum pointer indications:**

L2 N1 above 106 %
N2 above 106 %

L1 THR LEVER (OF AFFECTED ENGINE)........ IDLE
ENG MASTER (AFFECTED ENGINE)........ OFF

L2 *If conditions do not permit engine shutdown land as soon as possible using the minimum thrust required to sustain safe flight.*

L12

ASSOCIATED PROCEDURES

ENG 1(2) SHUT DOWN

Refer to PRO-ABN-70-B ENG 1(2) SHUT DOWN

Fig. 46: ENG 1(2) N1/N2 OVERLIMIT, FCOM Chapter PRO-ABN-70 Source: Operator, adaptation BFU

A330 FLIGHT CREW OPERATING MANUAL	PROCEDURES ABNORMAL AND EMERGENCY PROCEDURES POWERPLANT

ENG 1(2) FAIL

Applicable to: ALL

An engine flame-out may be recognized by a rapid decrease in EGT, N2, FF, followed by a decrease in N1.

Engine damage may be accompanied by:
- Explosions
- Significant increase in aircraft vibrations and/or buffeting
- Repeated, or uncontrollable engine stalls
- Associated abnormal indications, such as hydraulic fluid loss, no N2 indication.

■ **Before takeoff, or after landing:**

THR LEVER (AFFECTED ENGINE)........ IDLE
ENG MASTER (AFFECTED ENGINE)........ OFF

■ **IF DAMAGE:**

ENG FIRE P/B-SW (AFFECTED ENGINE)........ PUSH
AGENT 1........ DISCH
L + R INR TK SPLIT........ ON

■ **IF NO DAMAGE:**

ENG (AFFECTED) RELIGHT........ CONSIDER

ASSOCIATED PROCEDURES

ENG 1(2) SHUT DOWN

Apply the ENG SHUT DOWN procedure (Refer to PRO-ABN-70-B ENG 1(2) SHUT DOWN), if damage, or if engine relight is unsuccessful.

● **In flight:**

ENG START SEL........ IGN

Selection of continuous ignition confirms the FADEC's immediate relight attempt. It also protects the remaining engine.

THR LEVER (AFFECTED ENGINE)........ IDLE

Note: *In the case of GPWS (EGPWS) alerts, reduce speed with care below VLS with the flaps extended (at light weights VMC may be reached before α max), when applying the GPWS (EGPWS) procedure.*

Continued on the following page

BER A330 FLEET — PRO-ABN-70 P 9/90
FCOM — M → — 17 JUL 12

Fig. 47: ENG 1(2) FAIL Checklist, FCOM PRO-ABN-70 — Source: Operator

A330 FLIGHT CREW OPERATING MANUAL	PROCEDURES ABNORMAL AND EMERGENCY PROCEDURES POWERPLANT

ENG 1(2) FAIL (Cont'd)

L1 ● **IF NO ENG RELIGHT AFTER 30 S:**
ENG MASTER (AFFECTED ENGINE)....OFF

■ **IF DAMAGE:**
ENG FIRE P/B-SW (AFFECTED ENGINE)....PUSH

L2 *If the ENG FIRE pb-sw is pushed, the FADEC is no longer supplied.*

L1 AGENT 1 AFTER 10 S....DISCH
L+R INR TK SPLIT....ON

L2 *Note: If no fuel leak is evident, set both INR TK SPLIT pb-sw back to the normal position.*

L1 ■ **IF NO DAMAGE:**
ENG (AFFECTED) RELIGHT....CONSIDER

L2 *Apply the ENG RELIGHT (in flight) procedure (Refer to PRO-ABN-70 ENG RELIGHT (In Flight)).*

L12

ASSOCIATED PROCEDURES

ENG 1(2) SHUT DOWN

Apply the ENG SHUT DOWN procedure (Refer to PRO-ABN-70-B ENG 1(2) SHUT DOWN), if damage, or if engine relight is unsuccessful.
If high engine vibrations occur and continue after engine shutdown, reduce airspeed and descend to a safe altitude.
Attempt to define, and use, a practical airspeed and altitude for minimum vibrations. For performance reasons, the landing is in CONF 3. CONF 3 should be selected, as the landing configuration, on the MCDU.

ENG 1(2) FUEL FILTER CLOG

Applicable to: ALL

L2 Crew awareness.

Maintenance action is due.

BER A330 FLEET		PRO-ABN-70 P 10/90
FCOM	← M to N	17 JUL 12

Fig. 48: ENG 1(2) FAIL Checklist, FCOM PRO-ABN-70 Source: Operator

Appendix 7: FCOM procedure during hydraulic pressure loss in the green and blue hydraulic system

HYD G + B SYS LO PR

Applicable to: MSN 0288-0493

Ident.: PRO-ABN-29-T-00011374.0003001 / 04 MAR 13

LAND ASAP

RAT..MAN ON

"RAT MAN ON" is only triggered, in case of a G + B hydraulic system low level.

CONSIDER RAT MAN USE

"CONSIDER RAT MAN USE" is not triggered in case of green reservoir overheat, or a green hydraulic system low level.

Note: To extend the RAT, the flight crew must press the RAT MAN ON pb located on the Hydraulic overhead panel.
With the RAT extended, the green system is recovered. This permits slat extension recovery. However, green pressure will be lost when the speed drops below 140 kt.
At a time, the red " G + B SYS LO PR" warning will be triggered again, and antiskid will be lost. To anticipate the lost of antiskid, the ECAM "HYD B RSVR LO AIR PR/OVHT/LO LVL" procedure requests to select it OFF. With the RAT extended, fuel consumption increases by approximately 1 %.

MIN RAT SPEED..140 KT

Note: The "MIN RAT SPEED .... 140 kt" action line is displayed if the "RAT .... MAN ON" action line or the "CONSIDER RAT MAN USE" action line is displayed.

AFFECTED PUMPS...OFF

SPD BRK..DO NOT USE

Due to the loss of one elevator.

MANEUVER WITH CARE

To avoid high hydraulic demand on the remaining system.

Note: As a general rule, do not manually select a HYD ELEC PUMP ON, except temporarily, to retract the spoilers if they remain out after a hydraulic failure.

ASSOCIATED PROCEDURES

F/CTL ALTN LAW
(PROT LOST)
MAX SPEED..330/.82

Continued on the following page

A330 FLIGHT CREW OPERATING MANUAL	PROCEDURES ABNORMAL AND EMERGENCY PROCEDURES HYDRAULIC

HYD G + B SYS LO PR (Cont'd)

SECONDARY FAILURES

*WHEEL
*F/CTL

Continued on the following page

airberlin group A330 FLIGHT CREW OPERATING MANUAL	PROCEDURES ABNORMAL AND EMERGENCY PROCEDURES HYDRAULIC

<u>HYD</u> G + B SYS LO PR (Cont'd)

L12

STATUS

SPD BRK .... DO NOT USE
MAX SPEED.. 330/0.82
MIN RAT SPEED (IF RAT EXTENDED)...................... 140 KT
MANEUVER WITH CARE
MAX BRK PR.. 1 000 PSI

<u>APPR PROC</u>

- **If system lost by RSVR LO AIR PR:**
  AFFECTED ENG PUMP...................................... ON
- **If system lost by RSVR OVHT:**
  - **IF GREEN OVHT OUT:**
    GREEN ENG 1 + 2 PUMPS.......................... ON
  - **IF BLUE OVHT OUT:**
    BLUE ENG 1 PUMP...................................... ON
- **If HYD not recovered:**
  GPWS FLAP MODE (IF S < 2)......................... OFF
  S/F JAMMED PROC...................................... APPLY
  FOR LDG (IF S < 2)..............................USE FLAP 2
  This line is replaced by "FOR LDG: USE FLAP 2" when CONF 2 is selected, as a reminder.
  FOR LDG (IF S ≥ 2)..............................USE FLAP 3
  This line is replaced by "FOR LDG: USE FLAP 3" when CONF 3 is selected, as a reminder.
  - **FOR L/G GRVTY EXTN:**
    MAX SPEED..200 KT
    LDG GRVTY EXTN.................................DOWN
  - **WHEN L/G DOWNLOCKED:**
    L/G LEVER...DOWN
    APPR SPD (IF S ≥ 1)......................VLS + 10 KT

<u>INOP SYS</u>

F/CTL PROT
G + B HYD
ANTI SKID
L/G RETRACT
AP 1 + 2
SLATS
L ELEV
MOST SPLRS
REV 1 (PW/RR Eng)
L + R INR AIL
N/W STRG
AUTO BRK
NORM BRK
ALTN BRK
YAW DAMPER 1
CAT 2

Continued on the following page

airberlin group A330 FLIGHT CREW OPERATING MANUAL	PROCEDURES ABNORMAL AND EMERGENCY PROCEDURES HYDRAULIC

HYD G + B SYS LO PR (Cont'd)

Approach speed must be increased, due to the loss of one elevator.

LDG DIST PROC.......................................APPLY

ALTN LAW: PROT LOST
CONSIDER RAT MAN USE
See (1)
BRK B ACCU PR ONLY
See (2)
INCREASED FUEL CONSUMP
See (3)
FLAPS SLOW
See (4)

(1) *"CONSIDER RAT MAN USE" is not triggered in case of a green reservoir overheat, a green hydraulic system low level.*
(2) *7 full brake applications are available.*
(3) *Disregard FMS fuel predictions and Refer to QRH/FPE-FPF Fuel Penalty Factors Tables in order to find the applicable Fuel Penalty Factor.*
(4) *Note: Following a blue hydraulic system failure, the parking brake may be inoperative due to blue accumulator low pressure.*

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FCOM — ← R — 17 JUL 12

Fig. 49: HYD G+B SYS LO PR Checkliste, FCOM PRO-ABN-29 Source: Operator

Appendix 8: QRH Procedure Overweight Landing

airberlin group A330 QUICK REFERENCE HAND BOOK	ABNORMAL AND EMERGENCY PROCEDURES	80.06 05 SEP 12

OVERWEIGHT LANDING

Automatic landing is certified up to the Maximum Landing Weight (MLW). Autoland flight tests have, however, been successful up to 229 t.
Depending on the situation (e.g. emergency or other) and provided that the runway is approved for automatic landing, the flight crew can decide to perform an autoland up to 229 t.

JETTISON ....CONSIDER
LDG CONF..AS REQUIRED

Use the ECAM flap setting, if required for abnormal operations.
In all other cases:
- *FULL is preferred for optimized landing performance*
- *If the aircraft weight is above the maximum weight for go-around (given in the table below), use FLAP 3 for landing.*

In all cases, if the landing configuration is different from FLAP FULL, use 1 + F for go-around.

LDG DIST..CHECK
PACK 1 and 2..OFF or supplied by APU

Selecting packs OFF (or supplied from APU) will increase the maximum thrust available from the engines, in the event of a go-around.

- **In the final stages of approach**

TARGET SPEED..VLS

Reduce speed to reach VLS at runway threshold.
Touch down as smoothly as possible (Maximum V/S at touchdown 360 ft/min).

- **At main landing gear touchdown**

REVERSE THRUST..USE MAX AVAILABLE

- **After nosewheel touchdown**

BRAKES..APPLY AS NECESSARY

Maximum braking may be used after nosewheel touchdown. But, if landing distance permits, delay or reduce braking to take full benefit of the available runway length.

- **Landing complete**

BRAKE FANS ....ON if available

Be prepared for tire deflation, if temperatures exceed 800 °C.

MAXIMUM WEIGHT FOR GO AROUND IN CONF 3 (1000 KG)								
OAT (°C)	AIRPORT ELEVATION (FT)							
	0	2 000	4 000	6 000	8 000	10 000	12 000	14 000
10	239	231	219	205	191	175	160	147
15	239	231	219	205	190	173	158	145
20	239	231	219	203	187	171	155	142
25	239	231	216	200	183	166	152	140
30	237	225	211	193	176	161	148	
35	230	219	201	185	170			
40	222	208	191	176				
45	211	195	181					
50	196	181						
55								

Fig. 50: QRH procedure overweight landing Source: operator

Appendix 9: CRM Assessment

The expert came to the following conclusion:[44]

Each of the parameters was classified as positive (productive) and as negative (counterproductive). It should be noted, that these observations describe certain behaviours but do not assess them. Friendly agreement is as much a behaviour as severe wrong factual information. Both appear only once in the statistics. The option to assess observed behaviour was deliberately dispensed with because analysis is only relevant in comparison with similar flights, e.g. simulator studies with fixed scenarios during several flights.

This resulted in the following chart:

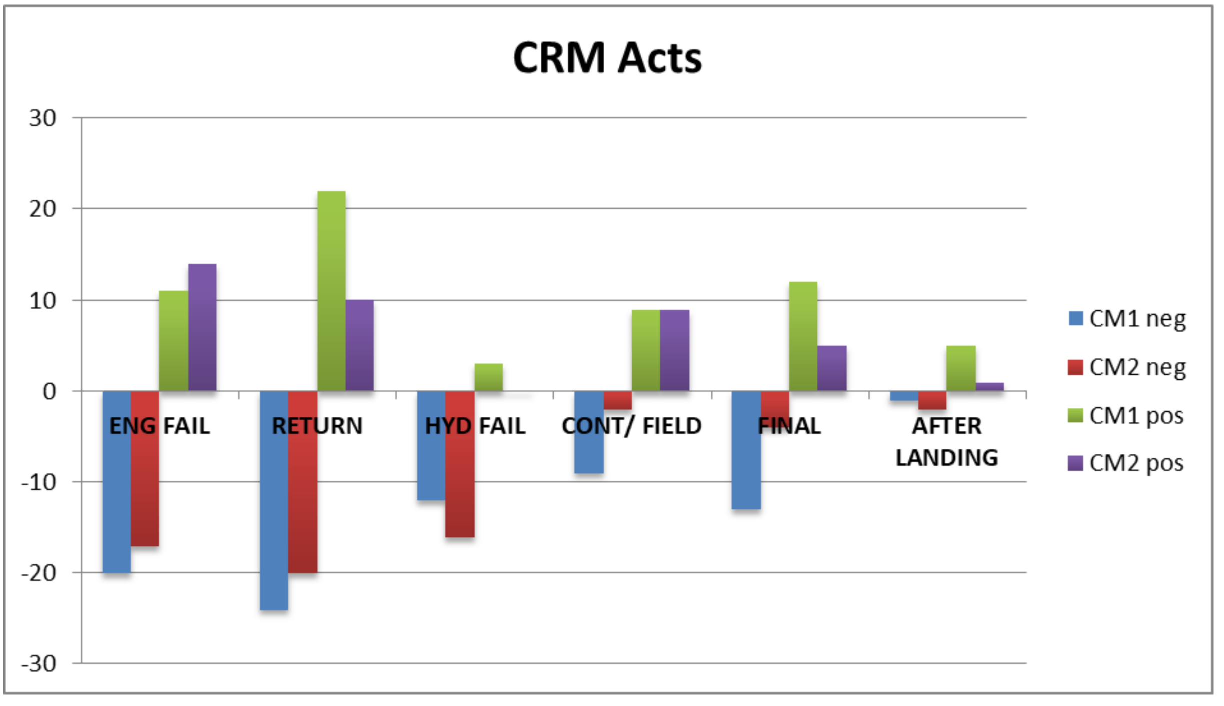

Fig. 51: Assessment of CRM actions during individual flight segments Source: Expert

At the beginning of the scenario some aspects of CRM can still be observed. The number of "negative" CRM events scotched every "positive" input.

[44] In the expert opinion, the PIC is called CM1 and the co-pilot CM2.

The number of observed CRM relevant behaviour decreases with the progress of the flight. The more dramatic the condition of the aircraft became the less support through CRM occurred.

By adding the number of CRM events, the image is as follows:

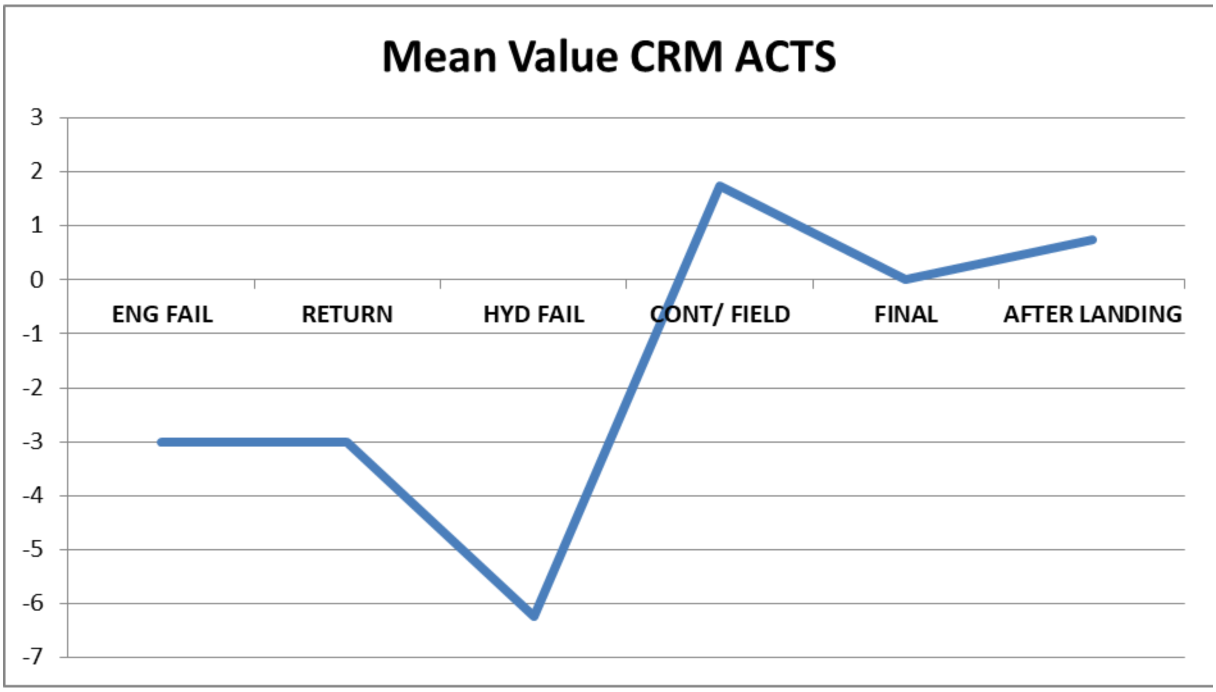

Fig. 52: Mean value of CRM actions during individual flight segments Source: Expert

Once the HYDRAULIK LEAK failure occurs, CRM collapses.

Only as "field in sight" occurs, the mind quiets and the positive events prevail, but in extremely small numbers. The main part of the positive events is found in the remarks about the flight path from CM1 to CM2 as CM1 tried to "runtersprechen (talk-down)" his colleague. The relief to have the runway in sight can be seen in the diagram.

The dual input event which occurred later was not counted as CRM action. By counting these two parts (talk-down and dual input), on average the statistics remain significantly below zero.

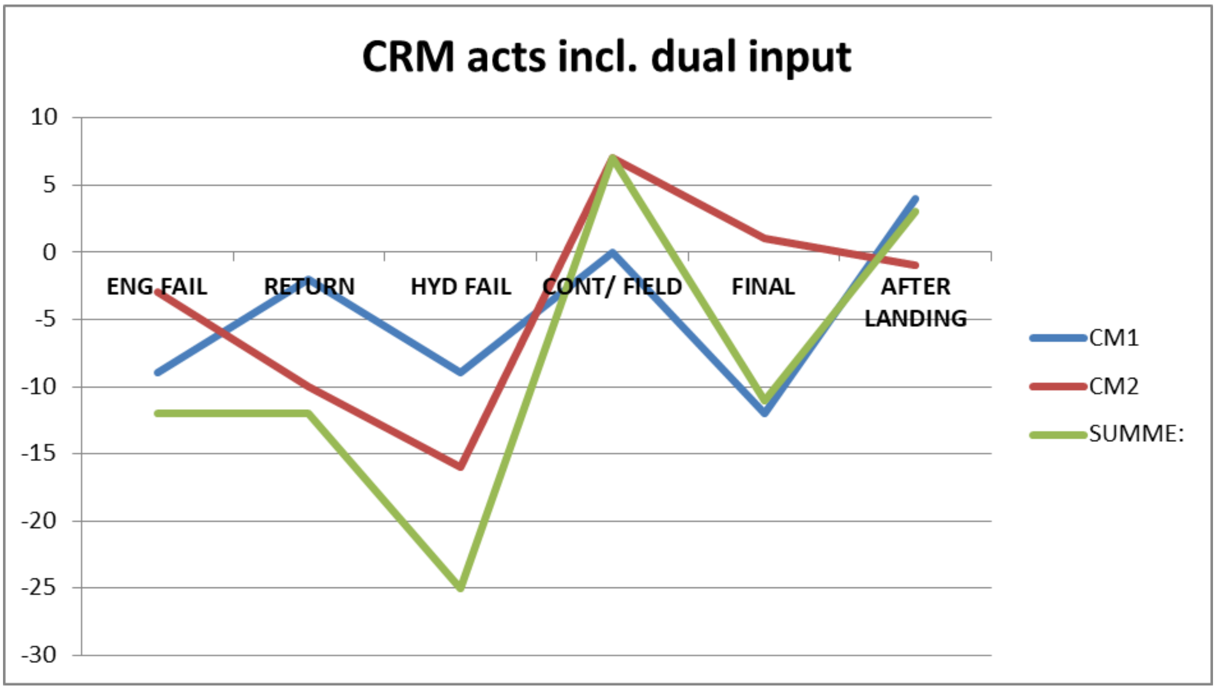

Fig. 53: Sum of CRM actions during individual flight segments, extended Source: Expert

Of interest is the verbal communication of the flight crew. Especially during the beginning of the scenario it stands out that CM1 very often answers with a monosyllable "Ja (Yes)". There is almost no initiative by CM1.

He says 43 times "Ja" including commenting the scarcely read ECAM actions.

The main communications direction is from the right to the left, CM2 to CM1:

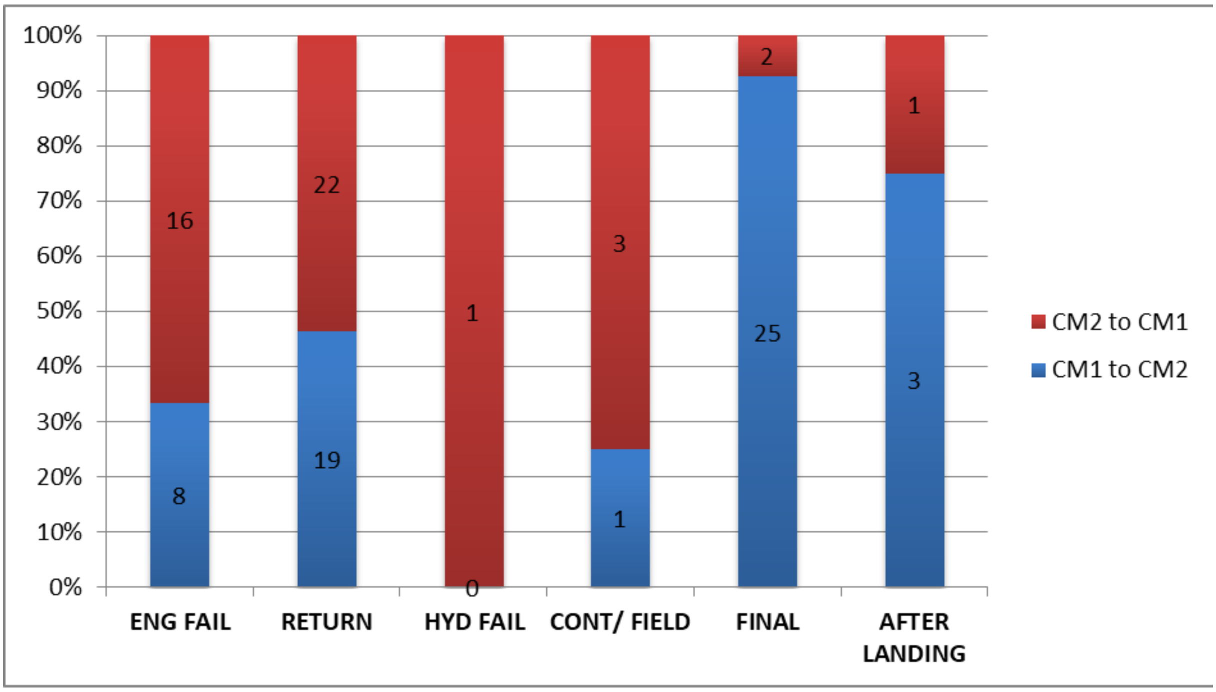

Fig. 54: Ratio of the communications between PIC and co-pilot Source: Expert

During final approach, as CM1 talks the PF down, the communications direction turns around:

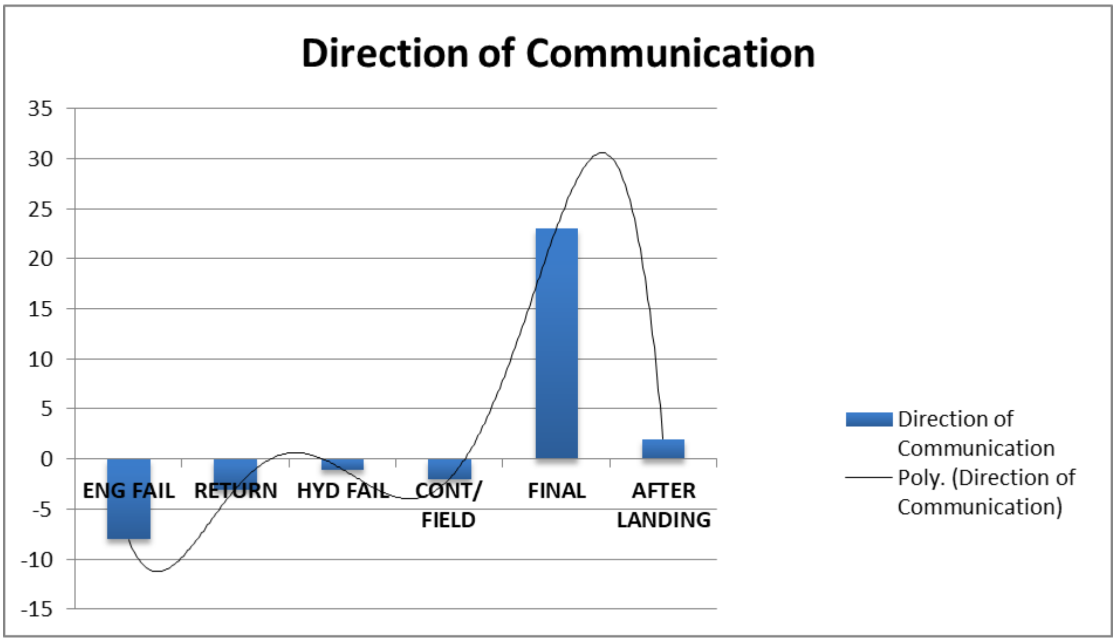

Fig. 55 Communication between PIC and co-pilot Source: Expert

positive values = communication from CM1 to CM2

negative values = communication from CM2 to CM1

After landing, the flight crew once again acts relatively correctly and in accordance with SOPs. One can observe the release of the tension:

While CM2 concentrates on “minor faults”, CM1 analyses the fire situation with ATC he confirms once again “no fire". Here, CM1 correctly takes care of important things. CRM actions and communications go back to neutral values.

Appendix 10: Assessment of the Flight Crew Actions in Accordance with LOSA

Part of the LOSA questionnaire (Crew Performance Marker Worksheet, Ref.: FAA AC 120-90 Appendix 3, ICAO Doc 9803 AN/761) was applied to assess the crew performance also during abnormal operation. This procedure was applied during scientific studies (e.g. SaMSys).

PLANNING BEHAVIORAL MARKERS

1. Briefing:

1.1. The required briefing was interactive and operationally thorough

1.1.1 The required briefing was interactive and operationally thorough

Briefings could not be observed. There was no briefing, stating the plans how to return. There was no briefing for the contingency. There was no approach-briefing. There was no missed approach briefing. There was no cabin briefing.

2. Plans stated

2.1. Operational plans and decisions were communicated and acknowledged

2.1.1 Shared understanding about plans — “Everybody on the same page”

There was no obvious plan except the will to return asap, which was forced by CM2.

3. Workload Assignment

3.1. Roles and responsibilities were defined for normal and non-normal situations

3.1.1 Workload assignments were communicated and acknowledged

Standard PF / PNF roles were used. Sometimes those roles were mixed up.

4. Contingency Management

4.1. Crew members developed effective strategies to manage threats to safety

4.1.1 Threats and their consequences were anticipated

4.1.2 Used all available resources to manage threat

Not even standard strategies were used. Checklists were not used. FORDEC was not used. Briefings were not used.

EXECUTION BEHAVIORAL MARKERS

1. Monitor / Crosscheck

1.1. Crew members actively monitored and cross-checked systems and other crew members

1.1.1 Aircraft position, settings, and crew actions were verified

Monitoring was rudimentary. Indications were misinterpreted or ignored.

2. Workload Management

2.1. Operational tasks were prioritized and properly managed to handle primary flight duties

2.1.1 Avoided task fixation

CM2 got sometimes stuck fixated to a checklist, while a more important ECAM was up. CM2 fixated to max. 360 ft/min upon landing, causing CM1 dual input.

2.1.2 Did not allow work overload

Work overload was dominant throughout the flight.

3. Vigilance
3.1. Crew members remained alert of the environment and position of the aircraft
3.1.1 Crew members maintained situational awareness
Position was monitored, but flight-plan often not known by CM1. Navigation was not optimized in terms of time. There was no plan for a go around.

4. Automation Management
4.1. Automation was properly managed to balance situational and/or workload requirements
4.1.1.1. Automation setup was briefed to other members
4.1.1.2. Effective recovery techniques from automation anomalies
Recovery from A/THR failure took long, but worked. It was not clear why the A/P had disconnected with the dual hydraulic failure. FD was on, however not used in vertical mode during final approach.

REVIEW / MODIFY BEHAVIORAL MARKERS
1. Evaluation of plans
1.1. Existing plans were reviewed and modified when necessary
1.1.1 Crew decisions and actions were openly analyzed to make sure the existing plan was the best plan
There was no real plan – rather an execution driven by the circumstances.

2. Inquiry
2.1. Crew members asked questions to investigate and/or clarify current plans of action
2.1.1 Crew members not afraid to express a lack of knowledge - “Nothing taken for granted” attitude
There were no questions asked except rhetorically. Questions, respective not knowing, was expressed by CM1. This sometimes resulted in wrong information.

3. Assertiveness
3.1. Crew members stated critical information and/or solutions with appropriate persistence
3.2. Crew members spoke up without hesitation
CM2 spoke up without hesitation and often with no respect to operational tasks, which should have been prioritized. CM1 spoke up very seldom and was driven by CM2 most of the time.

OVERALL BEHAVIORAL MARKERS
1. Communication Environment
1.1. Environment for open communication was established and maintained
1.1.1 Good cross talk
1.1.2. flow of information was fluid, clear, and direct
Communication was basically open. Standard phrases where seldom used. SOP wording was seldom to be heard. A great part of Communication was unidirectional from CM2 to CM1. Basic english was not very good in ATC communication on both, crew and ATC side. Cabin Crew was not briefed. No remaining flighttime, nature of the contingency, etc. was given. A PA was spoken by CM1, but no specific crew info given.

2. Leadership
2.1. Captain showed leadership and coordinated flight deck activities
2.1.1. in command, decisive, and encouraged crew participation

Except shifting the PF-function to CM2, CM1 showed only small amounts of leadership. He did not insist in reading checklists correct, nor in correct wordings for SOPs, nor in execution of ECAM actions and STATUS items. CM1 seemed „introverted“.

Appendix 11: Excerpt Airbus Flight Operations Briefing Notes

Handling Engine Malfunctions

If not sure which Engine is malfunctioning, keep-it running

Several accidents or incidents have been caused by a rushed decision to shutdown an engine, due to the inability to correctly assess which engine was malfunctioning.

If the analysis of the instruments is not enough, the crew should smoothly move the thrust levers and check the proper variation of the engine parameters.

If possible, keep the Engine running

In-service experience shows that, when the flight crew notices a drift of the engine parameters (EGT, vibrations, advisory level, etc...), they often decide to perform a preventive engine shutdown.

However, unless a procedure requires an engine shutdown, it is usually preferable to keep the engine running.

Even at idle, the engine:

- Provides electric, hydraulic and bleed power redundancy
- Produces less drag than a windmilling engine.

An ECAM advisory (if applicable) is an indication that a parameter is still in its normal range but is drifting away. It is meant for crew awareness (attention getter) and monitoring. The guidelines associated to the advisory conditions are provided in the FCOM/QRH. Consequently, except for engine vibrations, no action should be taken based only on the advisory.

Fig. 56: Airbus Flight Operations Briefing Notes Source: Airbus

Appendix 12: Extract from the FCTM

Procedures are performed using the "READ & DO" principle (except MEMORY items or OEB immediate actions):

- ECAM procedures, are triggered automatically in response to an abnormal behavior of the systems monitored by the Flight Warning System (FWS);
- QRH procedures, are applied by the flight crew in response to an abnormal event detected by any flight crewmember;
- OEB procedures, are triggered in some situations.

In most situations, the following sequence is the basic one that should be applied by the flight crew. However, this sequence may not cover all operational situations. Therefore, in all cases, the flight crew should exercise their judgment and adapt the sequence of actions to the real conditions. In the case of abnormal or emergency situations, the flight crew should apply the procedures in the following sequence, as appropriate:

- MEMORY ITEMS or OEB immediate actions;
- OEB;
- ECAM;
- QRH.

When an abnormal situation is detected by the flight crew, the first priority of the flight crew is to maintain a safe flight path before the flight crew performs any READ & DO actions. When the flight crew performs a “READ & DO" ECAM/QRH/OEB procedure, they must:

- Correctly read and apply the ECAM/QRH/OEB actions
- Appropriately share tasks
- Carefully monitor and crosscheck.

However, in some time critical situations, the flight crew has no time to refer to the ECAM/QRH/OEB procedure. Therefore, the flight crew must know, and strictly apply by memory, items referred to as MEMORY ITEMS or OEB immediate actions.

Appendix 13: ECAM Actions

E/WD : FAILURE TITLE conditions	AURAL WARNING	MASTER LIGHT	SD PAGE CALLED	LOCAL WARNINGS	FLT PHASE INHIB
B + Y SYS LO PR or G + B SYS LO PR or G + Y SYS LO PR System pressure ≤ 1 450 PSI Reset, if pressure ≥ 1 750 PSI	CRC	MASTER WARN			4, 5
G (Y)(B) RSVR LO AIR PR Reservoir air pressure ≤ 22 PSI Reset, if air pressure ≥ 25 PSI					3, 4, 5, 7, 8
G (Y)(B) RSVR OVHT Fluid temperature ≥ 95 °C					
G (Y)(B) RSVR LO LVL Fluid quantity : < 8 l (2.11 US Gal)(Green) < 5 l (1.32 US Gal)(Blue-Yellow)				FAULT lt on associated pump(s) pb	4, 5, 7, 8
G ENG 1(2) PUMP LO PR, or G ENG 1 + 2 PUMP LO PR, or B ENG 1 PUMP LO PR, or Y ENG 2 PUMP LO PR, or Engine pump pressure ≤ 1 450 PSI	SINGLE CHIME	MASTER CAUT	HYD		3 See *, 4, 5, 7, 8 * only for G ENG 1 (2)
G (Y)(B) ELEC PUMP FAULT Elec pump LO PR or ovht					3, 4, 5, 7, 8
G (B)(Y) SYS LO PR System pressure ≤ 1 450 PSI Reset, if pressure ≥ 1 750 PSI					
RAT FAULT RAT not fully stowed and not running, or stowing pressure applied.	NIL	NIL			3, 4, 5, 6, 7, 8
MONITORING FAULT HSMU not racked.			NIL	NIL	3, 4, 5, 7, 8
G RSVR UNDERFILLED On ground reservoir quantity < 17 l, if temperature > 0 °C or RSVR QTY < quantity function of temperature	SC	MC	HYD		3, 4, 5, 6, 7, 8
G SYS LEAK In flight only.					1 to 5 7 to 10

Fig. 57: ECAM actions of the hydraulic system Source: Operator

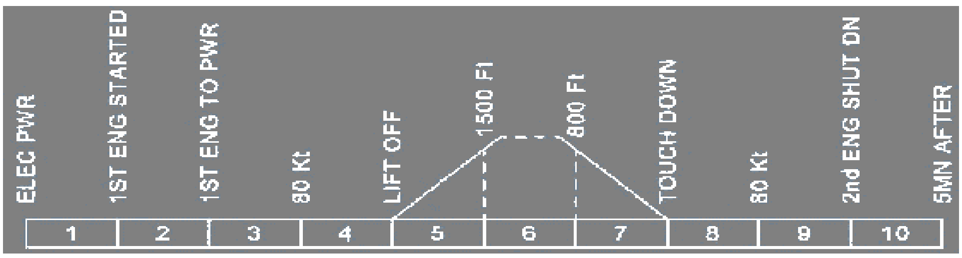

Fig. 58: ECAM Indication in different flight phases Source: Operator