
Engine vibration, Accident occurring 5 January 2004 near Munich Airport involving a Fokker F28 Mk0070 (Fokker 70)

Micro-summary: Severe #1 engine vibrations on this F.28 dictate an emergency landing.

Event Date: 2004-01-05 at 0816 (local=UTC+1)

Investigative Body: Federal Bureau of Aircraft Accidents Investigation (BFU), Germany

Investigative Body's Web Site: <http://www.bfu-web.de/>

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Investigation Report

AX001-0/04
November 2005

Identification

Kind of occurrence: Accident
Date: 5 January 2004
Location: near Munich Airport
Type of aircraft: Transport Category Airplane
Manufacturer / Model: Fokker Aircraft B.V. / F28 MK0070
(Fokker 70)
Injuries to persons: Three minor injuries
Damage to aircraft: Aircraft severely damaged
Other damage: Field damage
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The investigation has been conducted in compliance with the Law relating to the Investigation into Accidents and Incidents Associated with the Operation of Civil Aircraft (Flugunfall-Untersuchungsgesetz - FIUUG) dated 26. August 1998.

According to the Law, the sole objective of the investigation shall be the prevention of future accidents and incidents. It is not the purpose of this activity to apportion blame or liability or to establish claims.

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Abbreviations

AFM	Airplane Flight Manual
AGL	Above Ground Level
AIRMET	Information concerning enroute weather phenomena which may affect the safety of low-level operations
ANU	Aircraft Nose up
AOM	Airplane Operating Manual
AP	Autopilot
ATC	Air Traffic Control

C	Celsius
cm	Centimetre
CVR	Cockpit-Voice-Recorder

DME	Distance Measuring Equipment
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EGT	Exhaust Gas Temperature
EPR	Engine Pressure Ratio

FDR	Flight-Data-Recorder
FL	Flight Level
ft	Feet
ft/m	Feet/Minute
FWC	Flight Warning Computer

G	9,81 m/s ²
GAMET	Area forecast for low-level flights
GPWS	Ground Proximity Warning System
GS	Glide Slope

HP	High Pressure
hPa	Hectopascals
hrs	Hours
Hz	Hertz

IP	Intermediate Pressure
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions

kt	Knot
----	------

L	Left
LH	Left Hand
LOC	Localizer

m	Meter
MFDS	Multifunctional Display System
mH	Megahertz
mm	Millimetre
MODSOV	Modulating and Shut-off Valve
MSL	Mean Sea Level

N1 / N2	Speed of engine shafts
NM	Nautical Mile = 1,852 Kilometre

OAT	Outside-Air-Temperature
OGV	Outlet guide vanes

QNH	Altimeter pressure setting to indicate elevation above mean sea level
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PIC	Pilot-in-command
P/N	Part Number

R	Right
RH	Right Hand
RPM	Rounds Per Minute
RT	Room Temperature

s	Seconds
SB	Service Bulletin
SCT	Scattered
SEI	Stand-by Engine Indicator
SIGMET	Information concerning enroute weather phenomena which may affect the safety of aircraft operations
S/N	Serial Number
SPECI	Aviation selected special weather report

t	Ton
TAT	Total-Air-Temperature

VOR	VHF omni-directional radio range
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Synopsis

On 5 January 2004 at 07:27 hrs¹ a Fokker 70 certificated in Austria departed from Vienna with four crew members and 28 passengers aboard for a scheduled flight to Munich. It had been an uneventful flight until the airplane was transferred to the air traffic control unit Munich. Suddenly, at FL 90, heavy vibrations on the RH engine were indicated during the approach to airport Munich. When additionally unusual noises were coming from the rear of the airplane, the crew declared an emergency due to severe engine problems and requested to be cleared for an immediate landing.

Thus the airplane was immediately cleared for a descent to 3,500 ft and by means of several heading instructions guided to a short approach of approximately 8 NM to the instrument landing system of runway 26L. Because the airplane could not maintain the glide slope it touched down at 08:16:35 hrs approximately 2.5 NM short of the beginning of the runway on a snow covered field with the landing gears partially extended. After a sliding distance of 220 m, the airplane came to rest lying on its severely damaged fuselage. All occupants were able to leave the airplane without assistance.

The accident was due to the following immediate causes:

- After a prolonged time under moderate icing conditions and low engine thrust, ice developed on the rotors of the low pressure compressors of both engines.
- The bonded joints of the ice impact panels on both engines failed due to strains caused by ice-induced vibrations of the engines and by ice which had shedded from the rotors of the low pressure compressor.
- The loose ice impact panels became trapped in front of the outlet guide vanes of the low pressure compressor and affected the airflow in the by-pass duct in such a way that the engines now only produced low thrust.
- The runway was no longer within reach of the aircraft as the loss of thrust on both engines had not triggered any warnings and was not indicated until the necessary demand of thrust at an altitude of 3,500 ft.
- Due to its nature the terrain within reach was not suited for the landing of a transport airplane.

The emergency landing of the aircraft was reported to the German Federal Bureau of Aircraft Accidents Investigation at 08:25 hrs. The German Federal Bureau of Aircraft Accidents Investigation immediately initiated an investigation. On the day of the occurrence, staff members of the Dutch Transport Safety Board and the Austrian Air Accident Investigation Branch and representatives of the operator concerned, of the type certificate holder of the aircraft and of the type certificate holder of the engine arrived at the accident site.

The following investigation groups were established: Meteorology, air navigation services, flight operations, airplane (engine, systems). In accordance with ICAO Annex 13, accredited representatives of the State of registry, the State of the operator and the State of manufacture of the airplane as well as advisers for the Fokker 70 and the Rolls-Royce TAY-620-15 engine participated in the investigation.

¹ Unless otherwise specified, all times are indicated in local time (UTC + 1h)

1. Factual information

1.1 History of the flight

The aircraft had departed at 07:27 hrs from Vienna for a scheduled flight to Munich. Four crew members and 28 passengers were aboard the airplane. According to crew statements, the flight from Vienna was uneventful until the transfer to the air traffic control unit Munich.

When passing Salzburg VOR the crew contacted Munich Radar. When at 07:54 hrs the airplane had been taken over and identified by the air traffic control unit the crew was informed of the approach route NAPSA 26, the prospective runway and the kind of approach (see attachment 1). Afterwards the crew was instructed to descend to FL 100 and to reduce speed to 220 kt. The approach to Munich was initiated under visual meteorological conditions. The landing was to be made with the flaps set to 42°.

The ice detection system was triggered during descent to FL 100. Engine and airframe anti-icing systems were switched on simultaneously (see attachment 2). FL 100 was reached at 07:59:58 hrs. The pilots stated that they encountered icing conditions when the airplane entered the clouds. At FL 100 ice is reported to have formed at the windscreen edges. The inspection of the black stripes on the wings showed no ice accretion. Vibrations on the RH engine increased temporarily after a flight time of six minutes at FL 100. While the crew checked the fuel quantity on the multifunction display because of the traffic density they noticed vibrations in the upper green range of the display.

As the airplane was approximately 12.5 NM south of Munich airport, the crew was instructed to descend to FL 90 and to change heading to 020°. Heavy vibrations on the RH engine occurred during descent. According to crew statements, the airbrakes were extended in order to increase thrust setting on the engines without increase in airspeed. Immediately afterwards the warning VIB HIGH ENG2 was triggered at FL 90. The actions of the Abnormal Procedure Vibration High checklist indicated on the multifunctional display were carried out. However, the RH engine was not shut down for lack of other failure indications. Afterwards no more problems for the RH engine were indicated.

Simultaneously with the strong vibrations on the RH engine, vibrations and noises from the rear cabin area were heard in the cockpit. FDR data showed that at 08:08:14 hrs the EPR of the LH engine dropped from 1.5 to 1.1 and stayed at about 1.0 after that (see attachment 3). In the cockpit heavy vibrations had been noticed also and a rattling noise had been heard. But the vibrations were not displayed on the multifunctional display as originating from the engines. At 08:08:22 hrs, the PIC declared an emergency because of severe engine problems and requested an immediate landing. The situation prompted the PIC to make an announcement to the passengers.

The airplane was immediately cleared to descend to 5,000 ft based on a QNH of 1,017 hPa and to change to a heading of 080°. The crew requested an approach as short as possible. FDR data showed that at 08:08:40 hrs, while leaving FL 90, the EPR of the RH engine dropped also from 1.4 to 1.0 within the next four minutes; this EPR reduction was incremental and occurred independent of the thrust setting (see attachment 4). At 7,000 ft the air brakes were extended for a short time and engine thrust increased. During the descent to 5,000 ft the airplane was transferred to Munich Director. After 08:12:45 hrs when the airplane had reached approximately 5,000 ft the EPR of the RH engine retained values of about 1.0 also.

Munich Director immediately issued a clearance to further descend to 3,500 ft. The air brakes were extended again for a period of 44 seconds. Thereby the airspeed was reduced to approximately 170 kt. With the landing gears extended and the flaps set to 15°, the airspeed was about 150 kt. The airplane was guided to the landing course of the ILS 26L approximately 8 NM in front of the threshold. During the short ILS approach to runway 26L no warnings or messages were active. At approximately 4,000 ft flaps were extended to 25°. After the airplane had descended in landing configuration to the cleared altitude of 3,500 ft and horizontal flight had been established, the crew noticed that by pushing the thrust levers forward, the EPR on both engines did not increase to the required value.

The speeds N1 and N2 and the exhaust gas temperatures (EGT) of both engines increased, the EPRs, however, remained at values of around 1.0. After the message of the crew that they were just approaching the ILS (... coming established ILS ...) the flight was transferred to Munich Tower. Airspeed decreased to approximately 115 kt. The autopilot was immediately switched off, the airplane again established in descent, the flaps reset to 15° and the landing gears retracted (see attachment 7). Airspeed increased to approximately 135 kt. The flaps were again set to 25°.

The airplane received clearance to land. At 08:16:10 hrs the controller informed the crew that the Fokker was approximately 500 ft below the glide path. At this time the height measured by the radio altimeter was 500 ft AGL. At the same time the GPWS generated the audible warnings "Too low" and "Gear". The crew informed the controller that the runway could not be reached and that the landing would take place approximately 4 NM short of the runway (...We will not make it...to the runway...we are touching down probable 4 Miles before the field ...).

From approximately 400 ft AGL downwards the airplane was clear of clouds. The landing gear selector lever was set to "LG Down" 13 seconds prior to ground contact. The PIC informed the cabin crew of the imminent emergency landing through the repeated exclamation "Brace for impact" 5 seconds prior to touch down. At 08:16:35 hrs, the airplane touched down on a snow-covered field approximately 2.5 NM short of the runway with landing gears partly extended and came to rest severely damaged lying on the fuselage after a sliding distance of 220 m (see attachment 7). All occupants left the airplane without assistance via the forward passenger door exit.

1.2 Injuries to persons

Injuries	Crew	Passengers	Total in the aircraft	Others
Fatal	--	--	--	--
Serious	--	--	--	--
Minor	--	3	3	--
None	4	25	29	--
Total	4	28	32	--

1.3 Damage to aircraft

The airplane was severely damaged.

1.4 Other damage

Field damage was caused.

1.5 Personnel information

Pilot-in-command (PIC)

Age and sex:	32 years / male
Kind of license:	Airline transport pilot license (ATPL)
Ratings/authorizations:	Rating as a pilot-in-command of <ul style="list-style-type: none">• single- and multi-engine landplanes up to 5,700 kg maximum mass type rating as a pilot-in-command of <ul style="list-style-type: none">• Fokker 70/100 Instructor rating for airline transport pilots, visual night flying and flights under IFR.
Medical fitness:	Fit, without restrictions
Total flight experience:	7,320 hours, of which 4,577 hours on the Fokker 70
Flight time the day before:	8 hours
Rest time prior to the start of duty:	16 hours
Flight time prior to the accident:	2 hours
Pilot flying:	PIC

Copilot:

Age and sex:	30 years / male
Kind of license:	Commercial pilot license (CPL)
Ratings/authorizations:	Rating as a pilot-in-command of <ul style="list-style-type: none">• single- and multi-engine landplanes up to 5,700 kg maximum mass Type rating as a copilot of <ul style="list-style-type: none">• Fokker 70/100
Medical fitness:	Fit, without restrictions
Total flight experience:	1,465 hours:, of which 1,379 hours on the Fokker 70
Flight time the day before:	7 hours
Rest time prior to the start of duty:	16 hours
Flight time prior to the accident:	2 hours

1.6 Aircraft information

The Fokker F28 Mk0070 (Fokker 70) is a short and medium range twinjet transport category airplane with a seating capacity of 70 passengers. The engines of the low wing monoplane are mounted to either side of the fuselage behind the wings. The airplane has a wingspan of 28.08 m and a fuselage length of 30.91 m (see attachment 6). The maximum take-off mass is 38 t. According to the manual, the best glide ratio (both engines flame out) of the Fokker 70 is 1:12 (1,000 ft/2 NM, drift down speed).

At the time of the accident the aircraft, S/N 11559, year of manufacture 1995, had accumulated 19,304 hours total operating hours and had completed 14,334 flight cycles. On 23 December 2003 an A-check and a B-check had been performed in the scope of continuous inspection. The last service action was a 65-hours-check on 29 December 2003.

1.6.1 Engines

The airplane was equipped with two Rolls-Royce TAY 620-15 turbo fan engines. These two-shaft engines have a by-pass ratio of 3:1. After the air flows through the low pressure compressor, 75 % will pass by the core engine and only the remaining 25% are available for the IP and HP compressors and the combustion process (see attachment 8).

Ice impact panels are bonded into the intake of the engine casing between the low pressure compressor rotor and the outlet guide vanes. They protect the engine casing from damages caused by ice separating from the rotor of the low pressure compressor. The design of the ice impact panels had been modified by the manufacturer in 1994. The modifications are described in the service bulletin (SB) 72-1326.

The engine pressure ratio (EPR) is the parameter to measure engine thrust. It is the ratio between the pressure in the by-pass duct and the pitot total pressure. The EPR indication for the Multifunctional Control Display Unit (MFDU) in the cockpit is calculated by the EPR system. Each engine has its own independent EPR system.

A Failure Mode Effect Analysis (FMEA) was conducted in 1987 in the scope of design and registration of the engine. It was examined which effects a detachment of ice impact trays might have on the engine's operability. At this time the ice impact panels consisted of six honeycomb segments. A total of 36 trays were bonded to them. The FMEA concluded that a detachment of trays will most likely not lead to a blockage of the by-pass duct.

The same FMEA also examined detachment or break up of honeycomb lining (acoustic panels). In this context the analysis concluded that the fan blades could be damaged, the fan OGV's could possibly be blocked, the low pressure compressor might surge and N1 might increase. It was assumed that the failure would be indicated in the cockpit by a reduced EPR and a rise in N1 and vibration level. The effects of both failures were classified as minor.

1.6.2 Systems

Engine vibration indication system

The engine vibration indication system shows the level of out-of-balance force for both rotor shafts. Severe out-of-balance forces indicate irregularities within the engine. Each engine has its own system. The systems consist of the vibration transducer and the vibration signal conditioner. The vibration signal conditioner receives signals from the vibration transducer, the N1 and N2 RPM indicators and the Centralized Fault Display Unit, calculates the corresponding

value to be indicated and transmits it to the Multifunctional Control Display Unit. The system displays only such vibrations which can be associated to speeds N1 and N2 of the respective engine.

Engine bleed-air system

The engine bleed air system supplies several systems with pressurized air at an modulated temperature and a defined pressure when airframe or engine anti-icing is on. In flight the system is supplied by both engines. For this purpose air is taken from the 7th and/or 12th stage of the engine high pressure compressor.

Anti-icing system

Slats, stabilizer and engine inlet cowls are thermal anti-iced using hot air (250°C) from the engines bleed-air supply systems. The anti-icing systems are controlled from the anti-icing control panel in the cockpit.

Engine anti-icing system

The engine anti-icing system uses hot engine bleed-air to give protection from ice (either ice built-up or by melting existing ice) on the engine intake. Fan blades and spinner are not heatable. Ice formation can lead to a rise in engine vibration. Normally such ice formation sheds itself (ice shedding) independently and vibration decreases again.

As a support for the ice shedding the thrust lever is pulled back into idle, is held there and after five seconds set to 85% N1. Thereby the auto throttle system has to be shut down. The thrust levers can be put back into the original position if, with this procedure, the vibration has decreased or disappeared.

Airframe anti-icing system

The airframe anti-icing system uses hot engine bleed-air to warm up the leading edges of the wings and the stabilizers in order to prevent ice formation or to melt existing ice. The system consists of a modulating and shut-off valve (MODSOV), two high-flow pressure switches, one low-flow pressure switch, the Piccolo Tubes and the supply lines.

The modulating and shut off valve modulates the anti-ice airflow to the Piccolo Tubes in the wing leading edges and keeps it at a constant pressure. The two high-flow pressure switches measure the pressure in the supply lines of the RH and LH Piccolo Tubes in the wings. The low-flow pressure switch measures the pressure in the supply line to the Piccolo Tubes in the left wing. The Piccolo Tubes let the anti-icing air go into the wing leading edges. Each has three rows of air-spray holes. The air goes overboard through slots in the bottom of the wing leading edge.

Ice detection system

The crew has several options to determine ice formation on the airplane. On the one hand, black stripes are attached to the upper surface of both wing tips, assisting the crew in visually determining the icing condition of the wings. On the other hand, there is an electric ice detection system. The main component of the system is the ice detection probe mounted to the outside of the airplane. Detected icing triggers corresponding alerts in the cockpit.

The ice detection probe is mounted on the right bottom side of the forward fuselage below the cockpit. It vibrates at a preset ultrasonic frequency. In case of ice formation on the ice detection

probe, the frequency will decrease. This change is measured. If the actual frequency is below or above certain limits, the ice detection probe will send a signal to the airplane warning system. The ice detection probe has an installed permanent self-test circuit. If an error is detected, a signal will be sent to the flight warning system.

When the system is switched on, the ice detection probe will activate the power-on-test. If this test has satisfactorily been passed, the ice detection probe will change to the sensing mode. The ice detection probe will work in the sensing mode as long as the ice formation measured is below 0.5 mm. Once the above-mentioned value is reached, the system will change into detection mode. In the detection mode the heating will be switched on to melt the ice on the ice detection probe and for a period of 60 s a signal will be sent to the flight warning system. In case of severe icing, the signal will remain active until ice formation on the ice detection probe is approximately 0.5 mm again.

Flight warning system

In case that during flight the flight warning computer (FWC) reports severe errors within the on-board systems or dangerous flight conditions, the aircraft manufacturer recommends to comply to the approved emergency procedures defined in part 3 of the Airplane Flight Manual (AFM). One part of this procedure is directly displayed in the multifunction display. Other reports of the FWC generate acoustic signals only.

1.6.3 Procedures

Maintenance procedures

a) Engine manufacturer service bulletin (SB) implementation

With the SB 72-1326 dimensions and design of the ice impact panels were modified. Originally the ice impact panels consisted of six honeycomb segments with a total of 36 trays bonded to it. The new design consisted of six foam segments wrapped with glass fibre. The SB was issued by the engine manufacturer to be complied with optionally, as in the past there had been cases in which individual trays of the ice impact panels had detached. This often happened in connection with the fan blades of the low pressure compressor rotor rubbing against the ice impact panels. The forward edge of the new ice impact panels was now 7.6 mm further behind the fan blade tips. At the time of the accident the SB edition dated 16 January 1998 was effective. The SB did not contain details on the accomplishment of the work but a reference to the repair instruction HRS3491 of the engine manufacturer.

This repair instruction contained 23 work steps. Some of these work steps were only intended for certain designs of non-modified fan cases. For twelve work steps reference was made to further partial steps in other documents. In some of these partial steps reference was made to still other documents (see attachment 16). In work step 23 APPLY ADHESIVE, for instance, relating to the preparation of the adhesive, reference was made to another work step in the Overhaul Process Manual. In this work step reference was in turn made to a further work step. The latter in turn contained a reference that the specifications given by the manufacturer were to be adhered to unless the Overhaul Process Manual contained other provisions for individual items.

Work step 16 CHECK CLEANLINESS contained a reference to a non-existent work step. According to the statement of the editor this was an editorial error. Work step 12 REMOVE THE EXISTING ADHESIVE - REMOVE ALL TRACES OF ADHESIVE DOWN TO BARE MATERIAL was only intended for certain part numbers of the fan cases. For the RH engine of the accident

airplane this was not the case. For more detailed information about the degreasing of the components, the repair instruction HRS3491 contains several references to the OVERHAUL PROCESS 101 and 102. It was not defined which of the numerous procedures described in both documents was to be applied.

Most of the required consumable materials were only listed under a general designation and a company internal number (e.g. Omat 5/7 GARNET PAPER). Thus, the exact material could only be found in the Overhaul Materials Manual (here: 80 grit garnet paper). According to the repair procedure various adhesives were acceptable for bonding the panels in place. Also, the retention of the components while curing was not mandatorily required.

b) Information of the adhesive manufacturer

The adhesive Hysol® EA 934 NA is manufactured by Loctite Corporation, Bay Point, CA 94565-0031, USA (now Henkel Corporation). The technical data sheet (rev. 1/01) includes the following information about the processing of this adhesive (excerpt):

- The temperature of the components to be mixed should be close to 25°C.
- The surfaces to be bonded should be clean, dry and properly prepared.
- The parts to be bonded should be held in place until the adhesive is set. Handling strength of the adhesive will be obtained after 8 hrs at 25°C. Afterwards the fixing or the pressure used during curing may be removed.
- At a temperature of 25°C normal performance of the adhesive is achieved after a curing time of 5 to 7 days.

The adhesive manufacturer also gives general information about the surface preparation of the parts to be bonded. These basically include:

- For proper surface preparation all grease, oil or foreign particles are to be removed from the surfaces to be bonded.
- Degreasing of metallic surfaces should be performed by means of a rag soaked with trichloroethane, which is to be renewed sufficiently frequently.
- The surface may also be prepared by abrading with medium grit garnet paper. Abrasion should always be followed by a removal (degreasing) of contaminants and loose particles.

Flight operational procedures

For icing conditions and engine vibration the following procedures are defined in the Fokker Airplane Flight Manual (AFM) of the Fokker 70 (excerpt):

NORMAL PROCEDURES - OPERATION IN ICING CONDITIONS

5.05.01 Page 4: ENGINE ANTI-ICING

When icing conditions exist or are anticipated during ground or flight operation or after an ICING alert via MFDS:

ENGINE ANTI-ICING.....ON

After ICING alert ...

NOTE: 2. Increases in engine vibration levels in flight above the alert level may develop in icing conditions. The fan should normally shed the ice and vibration will reduce. To assist in shedding the ice, if sustained vibration is indicated and operational circumstances permit, quickly retard one thrust lever at a time to idle for 5 seconds and then advance the thrust lever momentarily to 85 per cent N1, thereafter restore to the required thrust setting

ABNORMAL PROCEDURE - ENGINE

4.13.01 Page 5: VIBRATION HIGH

VIB.....ALTN

- If alert persists:

THRUST LEVER.....RETARD

- If vibration is accompanied by other failure indications:

FUEL LEVER.....SHUT

SINGLE-ENGINE-PROCEDURE.....APPLY

For icing conditions and engine vibration the following procedures are defined in the operator's Airplane Operating Manual (AOM) for the Fokker 70 (excerpt):

SYSTEM OPERATION – ICE AND RAIN PROTECTION

5.08.01 Page 1: ENGINE ANTI-ICING – See section Engine

WING AND TAIL ANTI-ICING

The wing and tail anti-icing systems must be selected on when icing conditions exist or when icing is observed (See chapter ...)

SYSTEM OPERATION ENGINE - NORMAL PROCEDURES

5.14.01 Page 4: ENGINE ANTI-ICING

Engine anti-icing must be on during all ground – and flight operations when icing conditions exist or are anticipated.

In icing conditions ...

5.14.01 Page 4: ENGINE VIBRATION

Momentary increase in vibration noted during acceleration und deceleration may be disregarded. In icing conditions increases in vibration level may occur. Normally the fan will shed the ice and vibration will reduce. To assist in shedding ice in case of sustained high vibration level, one thrust lever at a time may be quickly retarded, held there for 5 seconds, and then advance momentarily to 85 % N1

FLIGHT PROCEDURES - FLYING IN ADVERSE CONDITIONS

COLD WEATHER OPERATION

7.03.03 Page 5: Climb-Cruise-Descent

- Engine anti-icing may be activated when icing conditions exist and following an “ICING” alert at MFDS
- An increase in engine vibration level may be observed during icing conditions. The fan should normally shed any ice formation and the vibration should diminish. To assist in ice shedding (and operational circumstances permitting) disconnect ATS, quickly retard one thrust lever at a time to idle. Hold it there for 5 seconds and then advance the thrust lever momentarily to 85 per cent N1. This procedure will eliminate or reduce the vibration, and the thrust levers may be re-adjusted to their original positions
- Wing and tail anti-icing systems should be activated when icing is observed ...

1.7 Meteorological information

According to information provided by Austrocontrol, the crew had the weather information for the region EUR (Europe) (in effect at 7:00 hrs UTC), 60 – 75 minutes prior to the planned flight from Vienna to Munich, available for self-briefing: wind and temperature forecast charts for FL 50 up to FL 390, the significant weather chart (SWC) and a compilation of weather reports and warnings (AIRMET and SIGMET).

In the SWC of the region EUR (in effect at 7:00 hrs UTC), compact clouds with moderate icing conditions (MOD ICE) below FL 140 were forecast for the area between Vienna and Munich. Additionally moderate turbulence was forecast below FL 160.

The area weather forecast (GAMET) in effect between 04:00 hrs and 10:00 hrs UTC issued by Deutscher Wetterdienst (German Meteorological Services) for the flight information region (FIR) Munich stated moderate icing conditions (MOD ICE) below FL 90. Except for this particular warning in the GAMET no other warnings (SIGMET) were existent at the time of the accident.

At 07:55 hrs a Special Meteorological Aeronautical Report (SPECI) was issued for the approach to Munich. This report included the following weather information:

Wind direction 260°, wind velocity 16 kt, surface visibility 2,500 m with light snow fall, base of lowest clouds (FEW) 300 ft AGL with scattered clouds (SCT) at 1,100 ft; Broken clouds (BKN) in 2,000 ft; outside air temperature on the ground -0°C, dew point -2°C; Atmospheric pressure (QNH) 1,017 hPa. Landing weather forecast (TREND) for the subsequent two hours was temporary (TEMPO) horizontal ground visibility of 4,000 m, snowfall and a drop of the cloud base (5-7/8) to 1,000 ft.

According to the expert opinion of the Deutscher Wetterdienst, the existing data resulted in the following meteorological conditions in the area east of Munich Airport:

At the time of the accident, there was light to moderate snowfall, surface wind direction was 260° to 280°, average wind velocity was between 13 and 18 kt. Surface wind was gusty with speed peaks between 20 and 25 knots. Even wind speed peaks of 30 kt could not be safely excluded. At the site of the accident, there were temporary flurries of snow brought about by the strong ground wind.

At the time of the accident, the base of the lowest clouds (1/8 to 3/8 stratus) was most probably at 300 ft AGL. Above the stratus clouds there were 4/8 to 6/8 stratocumulus clouds with a base between 1,000 ft and 1,500 ft AGL. Above 2,000 ft up to 2,500 ft AGL there was another stratocumulus cloud layer covering 7/8 to 8/8.

Cloud ceiling was most probably between FL 100 and FL 120. Above FL 180 there were, at least locally, still high clouds. It is to be assumed that in the area below FL 120 moderate icing conditions and in connection with weak convection currents and higher liquid water contents sporadically moderate to heavy icing conditions existed.

1.8 Aids to navigation

The airplane was equipped with an inertial navigation system. The airplane was assigned the approach procedure NAPSA 26 TRANSITION, which is a radio navigation approach procedure. In addition, the following equipment was available for the approach to runway 26L of Munich Airport:

- instrument landing system with a localizer course of 262° and a glide slope of 3.0°, an outer marker at 5.1 NM DME and a middle marker at 1.7 NM DME.
- distance measuring equipment on 108.60 MHz

The final approach fix for an ILS approach is at an altitude of 5,000 ft MSL and at 12 NM DME. The evaluation of the ILS monitor values and a ground survey were satisfactory.

1.9 Radio communications

Radio communications were held in English. For the investigation, a transcription of all radio communications and the original tape recordings were available.

Due to snow removal on the northern runway, air traffic approaching Munich and subsequent radio communications focused on the southern runway which was in use. At 08:08:22 hrs the crew declared an emergency by transmitting MAYDAY and reported severe engine problems. At the request of the crew, the controller immediately guided the airplane to a short approach issuing further headings and descent clearances and observing the actual traffic situation. He informed his supervisor who alerted the responsible services. The flight time left until the estimated landing was approximately eight minutes. Radio communications continued to be held on the general frequency used by the entire air traffic. Until the forced landing the crew had to change frequency twice.

Four minutes after declaring an emergency, the crew reported that after the landing they would not need any assistance: "And for your information, we do not need any assistance on guard it seems to be severe icing on the engines and we can vacate the runway on our own".

1.10 Aerodrome information

Munich Airport is located 28.5 km (15.4 NM) north-east of Munich city at an elevation of 1,487 ft MSL. It is an airport controlled by the DFS Deutsche Flugsicherung GmbH (German Air Navigation Services) with two parallel runways of 4,000 m length and 60 m width each. The bearing of the runways is 082° and 262°, respectively. The lateral distance between the runways is 2,280 m. The elevation of the runway threshold 26L is 1,470 ft MSL.

During the period between 07:45 hrs and 08:10 hrs the northern runway was closed for the purpose of snow removal. During this period the whole air traffic was handled on the southern runway.

1.11 Flight Data Recordings

Radar data

The three-dimensional movement of the airplane was monitored by ATC radar and displayed as target symbols on the controller work station monitors (see attachment 1). The radar data were recorded and available for evaluation. The last recording was made when the airplane was already on the ground.

Flight data recorder

The airplane was equipped with a Flight-Data-Recorder L-3com (Loral) F1000, P/N S800-3000-00, S/N 00463 (solid state recorder). It recorded values of 379 parameters over a period of 43 hours and 33 minutes. Optically as well as electrically, the recorder was in good order and condition. The FDR was secured and read out at the flight data recorder laboratory of the German Federal Bureau of Aircraft Accidents Investigation using the Loral ground support station 2 (GS/2). The data necessary for the assessment of this accident were selected and plotted as a function of time.

The FDR had stored 22 flights. According to the recordings, relevant for this flight, the approach to Munich was initiated at 07:42:30 hrs from FL 280. During the descent to FL 100, the recording of vertical and lateral accelerations showed a superimposed vibration at 07:56:40 hrs. From this moment on vertical accelerations varied between 0.9 g and 1.2 g and lateral accelerations between +0.05 g and -0.05 g. At 07:57:41 hrs simultaneously with the release of the ice warning the engine and airframe anti-icing systems were switched on (see attachment 2).

When reaching FL 100 the pitch angle of the airplane increased by 2°. N1 of both engines increased by approximately 10 % and the air speed of 220 kt indicated by the controller was obtained. At FL 100 short-term vibrations on the RH engine with an intensity of 0.5 inches/s occurred. During the descent to FL 90, which took 80 s, vibrations of the same intensity occurred again on the RH engine. At 08:07:14 hrs at FL 90, vibrations on the RH engine increased to 1.2 inches/s triggering the vibration warning.

At 08:08:14 hrs the EPR-reading of the LH engine dropped from 1.5 to 1.1 (see attachment 3). Four minutes later, at 08:12:45 hrs, the EPR of the RH engine also remained at values around 1.0 even with N1 increased (see attachment 4). At this time the airplane had descended to an altitude of approximately 5,000 ft. FDR data show that N1, N2 and EGT engine parameters did not correspond anymore to the engine thrust commands.

The recording of the course of the flight below 5,000 ft (see attachment 5) shows that the airplane reached the glide path with an airspeed of 160 kt at about 4,000 ft and continued the descent to an altitude of 3,500 ft. Landing gears were extended and the flaps had a position of 15°. When the airplane had descended below the glide path the flaps were extended to 25° and the pitch angle was continuously increased to 9°. Airspeed decreased to 115 kt and the airplane approached the glide path from below.

Before the glide path was reached again, pitch angle was decreased, landing gears were retracted again and the flaps set to 15°. Airspeed increased to approximately 135 kt. The flaps were again set to 25°. Only a few seconds prior to the forced landing the extension of the landing gears was initiated once again. When the airplane touched down at 08:16:35 hrs with an airspeed of approximately 110 kt and a pitch angle of approximately 10°, the nose landing gear was in the extended and locked position, whereas the main landing gears were in an intermediate position.

Initial ground contact occurred with a rate of descent of approximately 1.000 ft/min. Vertical acceleration was +1.2 g. Immediately after touch down the pitch angle decreased from 11° to 0° within two seconds and a short-term vertical acceleration of +2.6 g was recorded. During the movement on the ground vertical acceleration was between +1.4 g and -0.4g. Deceleration averaged 0.7 g during the sliding phase.

Cockpit voice recorder

The airplane was equipped with a cockpit voice recorder L-3com (Loral) A200S, P/N S200-00 12-00, S/N 00443 (solid state recorder). At intervals of 30 minutes, the CVR recorded simultaneously 4 channels. Optically and electrically, the recorder was in good order and condition. The CVR was secured and read out at the flight data recorder laboratory of the German Federal Bureau of Aircraft Accidents Investigation.

The recordings were analysed using the audio processing programme Soundforge. The recording made via the cockpit microphone was difficult to understand because of noise and other ambient noise. Using filters, several files were created. These files were subject to improvement of intelligibility and optimisation of surrounding noise. Representatives of the Austrian investigation authority and the operator concerned participated in preparing the transcription.

In addition to the conversations between the pilots, the CVR also recorded radio communications and cockpit ambient noises. At 08:07:14 hrs, a short humming noise, which reoccurred at 08:07:31 hrs, was recorded. At 08:08:10 hrs, the CVR recorded a clattering noise and the co-pilot asked for the causes of this noise. After the declaration of an emergency at 08:08:22 hrs the flight attendant notified the flight crew at 08:08:48 hrs of a clattering noise in the cabin ("... there is a super rumble on the left ...").

In order to analysis the recorded humming noises, sonograms were created using the unfiltered cockpit microphone channel recording of the relevant time frame. These sonograms showed that the humming noise had a frequency of 80-100 Hz.

1.12 Wreckage and impact information

1.12.1 Accident site

The airplane had come to rest on a field east of Munich Airport, 2.5 NM short of the threshold of runway 26L on the extended centre line. The field's surface was frozen. The elevation was 1,472 ft MSL. The airplane's longitudinal axis was oriented to the south-west (240°). A uniform skid mark approximately 3 m wide and 10 to 50 cm deep led from the position of the aircraft toward 068°. At 110 m from the aircraft the mark bent toward 085° and ended after another 110 m (see attachment 7).

The airplane lay on its fuselage. The nose landing gear which had been torn off lay at a distance of approximately 120 m from the airplane in the skid mark described above. The nose landing gear doors were damaged. The main landing gear was retracted but not locked. The main landing gear doors had been torn off. The flaps were extended in a position between 25° and 40°. The flaps on the left-hand side were damaged. The inner flap on the right-hand side was slightly bent and the outer flap was undamaged. The wing fuselage transition fairing was severely damaged on both sides. The ailerons were in neutral position, the rudder was slightly deflected to the right and the elevator was deflected downward. The horizontal stabilizer trim was set to -4.5° (ANU).

On both engine fan casings all six ice impact panels had detached. Almost all of the loose panels were lying crossways in front of the outlet guide vanes of the low pressure compressor (see attachments 9-12). They matched the version described in the SB 72-1326 of January 1998 consisting of six segments made of glass-fibre reinforced foam. Further mechanical damage on the engines was not found.

The landing gear lever in the cockpit was in the LG DOWN position, the flap lever was in the position "42". Both thrust levers of the engines were in the fully forward position (full thrust). The fuel valves were in the closed position. The fire handles of the engines were pulled and turned. The fire switch of the auxiliary power unit was pushed and the parking brake set. The wing and tail anti-icing systems as well as both engine anti-icing systems were switched on. The automatic circuit breaker landing light 1 was opened. All the other automatic circuit breakers were closed. Rudder trim was neutral; aileron trim was in the position 0.5 units left. The engine vibration switch was in the ALTERNATE position. The standby engine indicator (SEI) was off.

Measurements of the fuel quantity in the tanks using the electronic measurement and indication system and the dip sticks resulted in a total of 2.4 t of kerosene, respectively. The fuel quality was satisfactory.

1.12.2 Findings on the aircraft

Systems and components

The engine anti-icing system was checked at the accident site using a ground power unit and an air starter. Malfunctions were not found.

The modulating and shut-off valve of the airframe anti-icing system was checked on a test bench. Malfunctions were not found.

The ice detection probe was checked on a test bench. This check revealed that the basic oscillation frequency was 39,935.773 Hz and thus was not within the prescribed frequency range of 39,975 to 40,025 Hz. The sensing probe had a dark colour and was bent forward by approximately 2°.

Engines

The engines were examined at the manufacturer. All fuel and oil filters and the magnetic chip detectors were removed and visually inspected. The fan blades of the low-pressure compressor were removed and an ultrasonic inspection was performed. Furthermore, a boroscope inspection of the engines was performed. The fan cases were removed and replaced by new ones. Neither the checks nor the subsequent test runs revealed any malfunctions of the engines.

The fan case of the LH engine (S/N 17116) had been modified in July 2001 pursuant to SB 72-1326 in one of the organisations of the engine manufacturer in Great Britain. Since this modification the engine had been in service for 5,823 hours and 4,221 cycles. According to the technical report of the manufacturer ice impact damage in the area of the acoustic liner had not been found. The bonding surfaces of the ice impact panels in the fan case did not show any residual adhesives. The surface was very smooth. A few brown patches on the steel surface of the fan case were found. At the lowest point there was a semicircular dark patch. The metal surface of the case behind the ice impact panels showed some smear markings. The bonding surface of the ice impact panels was almost completely covered with adhesive. The surface of the adhesive was very smooth. On three panels, clearly defined areas with brown discoloured adhesive were found.

The fan case of the RH engine (S/N 17103) had been modified in August 1999 pursuant to SB 72-1326 by an organisation in the USA. Since this modification the engine had been in service for 9,224 hours and 7,825 cycles. According to the technical report of the manufacturer ice impact damage in the area of the acoustic liners were not found. The bonding surfaces of the ice impact panels in the fan case showed adhesive residues in a few locations. The steel surface was very smooth and showed marks produced by a rotating abrasive wheel in some places. Some isolated brown patches were found on the steel surface of the fan case. The bonding surfaces of the panels were very smooth without any residual adhesives.

The panels of the LH engine were generally more heavily fragmented than those from the RH engine. Most of the fragments were still present and could be assigned to their original positions. The panels did not show any damage caused by foreign objects.

1.13 Medical and pathological information

Medical examinations were not performed.

1.14 Fire

There was no evidence of fire in flight or after the impact.

1.15 Survival aspects

At 08:09:31 hrs Munich tower gave the alert. The fire brigade (south) and additional rescue forces took up their positions in staff rooms alongside runway 26L. After the crew had, at 08:16:15 hrs, announced a forced landing outside the airport, the tower gave a new alert "accident outside the airport".

The operation centre of the fire brigade had listened in on the message of the crew via radio and had already instructed the rescue services to leave the airport area to the east. The rescue services initially looked for the accident site in the vicinity of the extended centre line of runway 26R. The airport's rescue operation centre relied on a report they had received. In cooperation with the crew of the airplane, the tower then directed the rescue services via radio to the accident site, where they arrived at 08:34 hrs.

During the forced landing outside the airport, the occupants were exposed to the vertical accelerations of the touch down and to the forces produced by the deceleration of the airframe in the subsequent sliding phase. The occupants had fastened their seat belts but were not prepared for a forced landing. Three occupants suffered minor injuries. All occupants were able to leave the airplane without assistance via the forward passenger door exit. On two seats the pads of the armrests separated during the deceleration on the ground.

1.16 Tests and research

Tests concerning mechanical stress

Due to the accident, Rolls Royce Germany charged the Institute for Lightweight Engineering and Polymer Technology (Institut für Leichtbau und Kunststofftechnik) of the Technical University of Dresden to conduct investigations on bonded joints between steel and glass-fibre reinforced plastics. Strength characteristics were analysed against different adhesives, different preparation variants and varying environmental conditions.

The prepared samples were to comply with the procedural regulations during manufacture and maintenance. For the preparation of the surfaces additional explanations by Rolls Royce Germany were required. The bonded joints of the samples were made using the adhesives which were approved for the bonding of the ice impact panels as a whole. With tensile tests vertically to the bonding surface (pull-off tests) the highest forces were determined for epoxy film adhesives. Tensile tests in bonding direction showed that this adhesive had the highest tensile strength. This adhesive is exclusively used during manufacture.

With peeling loads applied to the bonded joints (peel drum tests) the highest forces were obtained with polysulfide adhesives exclusively used in maintenance. The epoxy paste adhesive which had been used to bond the ice impact panels into the engines showed varying forces. With this adhesive only a fractional part of the strength of the polysulfide adhesive was obtained and at low temperatures strength values were extremely low. The results of the peel drum tests are shown in attachment 13.

Dynamic load tests

By order of the German Federal Bureau of Aircraft Accidents Investigation, dynamic tests with the adhesive used to bond in the ice impact panels and with the ice impact panels of the accident airplane were performed by the Fraunhofer Society for the Advancement of Applied Research (Fraunhofer Gesellschaft zur Förderung angewandter Forschung e.V.) in Bremen with the following results and evaluations:

A comparison revealed that the residual adhesive on the ice impact panels had cured and was identical with the epoxy paste adhesive Hysol EA 934NA which had been made available by Rolls Royce Germany as a test sample.

Vibration stress of the fully cured adhesive and the ice impact panels with the frequencies which had occurred in flight did not result in significant changes of the storage modulus of the adhesive. According to the explanations of the Fraunhofer Society for the Advancement of Applied Research in Bremen the frequency is not the cause for the failure of the bonding of the ice impact panels. For the most part, the ice impact panels showed signs of loss of adhesion between the bonding surfaces of the engine and the adhesive, indicating errors in the preparation of the bonding surfaces.

In the processing instruction for the bonding of the ice impact panels neither the cleaning procedure to be applied nor the cleaning or degreasing agent to be used is identified. Different places of the instruction mention that special tools are not required. According to the processing instructions of the adhesive manufacturer and the basic principles of bonding practice it is considered essential that the parts to be joined remain fixed until reaching handling strength (8 hrs at 25°C).

A procedure written for field application would clearly define the preparation procedure for the surfaces to be bonded including the materials to be used and the bonding procedure proper in accordance with the adhesive manufacturer's instructions. Numerous cross-references in the actual written procedure suggest that the latter is difficult to work with.

1.17 Organizations and their procedures

For in-flight emergencies the following procedures are established in the Manual of Operations for the Air Traffic Control Services (BA-FVK) of the DFS Deutsche Flugsicherung GmbH (excerpt):

- 600 Emergency procedures
- 611 General
 - 611.1 The various circumstances surrounding each emergency situation preclude the establishment of exact and detailed procedures to be followed. Therefore, the procedures outlined hereunder are intended to serve as a general guide to ATS personnel. ATS units shall maintain close and complete coordination among each other, and personnel shall use their best judgment in handling emergency situations.
 - 611.2 Take all possible measures without delay to assist an aircraft which is known to be in an emergency situation.
- 612 Responsibility
 - 612.1 The responsibility to initiate emergency procedures rests basically with the ATC unit in whose area of responsibility the emergency occurs or which first received news of the emergency.
 - 612.2 In case of an air accident or if an emergency landing is anticipated at or near the aerodrome, first of all alert the local rescue units (fire brigade, ambulance, etc.) in accordance with local procedures.
- 641 Use of communication facilities
 - 641.2 In case of an emergency, decide whether the aircraft is to remain on the frequency or whether it should change to another frequency. If necessary, instruct all other aircraft to change to another frequency.

Note: Frequency changes of aircraft in emergency shall be limited to the absolute necessary.
 - 641.21 Inform other units as appropriate, ...
 - 641.22 Handle distress communication on the emergency frequency in order to avoid repeated frequency changes, particularly if transfer of traffic to another ATC unit is to be expected.
 - 641.441 Impose silence on stations interfering with the distress communication. Address such instruction to ALL STATIONS or to a particular station, according to circumstances.
- 840 Special Procedures
 - 841 Distress Traffic
 - 841.3 The station in distress or controlling the distress traffic may impose silence on all or on certain radio stations interfering with the distress traffic with the instruction STOP TRANSMITTING MAYDAY.

According to the statement of the DFS Deutsche Flugsicherung GmbH setting up an additional frequency requires an additional work station which is to be occupied with an available controller. This controller would have to familiarize himself with the emergency and the current

traffic situation prior to assuming an active role in the control of the aircraft. It takes some 8 to 10 minutes to do this.

The pilot flying the aircraft at the time of the occurrence stated that the navigational assistance provided by the air navigation service was appropriate to the situation. The copilot, who performed radio communications, stated that it would have been more convenient and would have increased capacity if radio communications with other aircraft had been tuned out, frequency changes had not been necessary and the information given had been minimized.

1.18 Additional information

During the investigation, the German Federal Bureau of Aircraft Accidents Investigation was informed by the engine type certificate holder about other occurrences where parts or whole trays of the ice impact panels of the former design had detached. All these reports only concerned one engine of the respective airplane. The occurrences were caused by foreign object impacts (bird strikes, ice ingestion). Very often the engines concerned had to be shut down because of heavy vibrations. None of the occurrences led to loss of thrust of the respective engine because with the former design the trays of the ice impact panels were small enough to not damage the engine.

The aircraft type certificate holder had issued a bulletin right after the accident and based on this bulletin the Italian civil aviation authority informed the German civil aviation authority responsible for type support of the Rolls-Royce TAY 620-15 engine on 9 January 2005 about an engine failure during the flight of a Fokker 100. According to documentation of the engine type certificate holder this particular incident occurred on 21 October 2003. The airplane was on a flight from Palermo to Venice and cleared for FL 250. During climb the engine anti-icing system was engaged and the airframe anti-icing system was switched on prior to entering icing conditions. After approximately 15 min in icing conditions (engines and wing/tail anti-ice on) thrust of the RH engine decreased and was not adjustable after that. Except for a temporary increase in turbine gas temperature (TGT) into the yellow range of the indication there were no further indications about the emerged engine failure.

The crew diverted to Rome. The engine concerned (S/N 17004) was inspected and all six ice impact panels were found lying across the outlet guide vanes of the engine. A maintenance check after a stall including a boroscope inspection was conducted and did not produce any insights. An ultrasonic inspection of the fan blades did not show any results either. The FDR could not be read out because of a tape defect. The engine fan case was modified in August 2000 according to SB 72-1326. Since then the engine had been in service for 6,748 hours and 5,994 cycles. The other engine of the airplane had been fitted with the older version of ice impact panels.

1.19 Useful or effective investigation techniques

Not applicable

2. Analysis

2.1 Flight operations

Crew

Both pilots held valid licences and ratings required to conduct the flight. In view of their total flight time and flight time on the type they were to be considered experienced pilots. Documents provided by the operator show that both pilots had satisfactorily passed their check flights. The PIC also held an instructor rating for airline transport pilots and therefore especially familiar with emergency procedures.

Operating procedures

Simultaneously with the icing alert the crew switched the engine anti-icing and airframe anti-icing systems on. This shows that the crew had already recognised the icing conditions and anticipated the indication. This action complies with the procedures established in the operator's Fokker 70 AOM. The AOM's special edition for the Fokker 70 developed by the aircraft manufacturer on behalf of the operator deviates in some passages from the Airplane Flight Manual (AFM). According to the AFM this action should have taken place prior to or while entering clouds based on total air temperature (TAT).

The AFM contains a list of conditions under which the engine anti-icing system is normally to be switched on during flights in icing conditions. It is supplemented by a reference to an important procedure (Note 2: SHEDDING PROCEDURE). This reference relates to the condition ABNORMAL PROCEDURES – ENGINE, see Chapter 4.13.01, without this condition being mentioned there. The AOM's special edition refers to procedures for the operation of the airplane under icing conditions in different places and in various ways. In chapter 5.14.01 Engine Anti-Icing the multifunctional display system (MFDS) is not mentioned as an OR condition. On the other hand, the MFDS is mentioned in chapter 7.03.03 as an AND condition and in both chapters the wording selected is different: must be on / may be activated. This leads to unclarity in the implementation of these procedures and should, therefore, be corrected, even though it did not play any role in the subsequent events of this particular case.

Conduct of flight

The crew attributed the increased vibrations indicated for the RH engine, after reduction of airspeed and entering clouds (icing conditions) in FL 100, to ice formation on the fan. The crew did not request an ATC clearance to leave FL 100 or 90 as they obviously expected an imminent clearance for descent. The result was that the airplane flew, for some time (approximately 6 minutes), with reduced engine thrust under moderate icing conditions which, in all likelihood, led to icing of the fan blades of both engines.

The crew stated that the vibrations were most intense in flight idle. Therefore, the PIC operated the speed brakes which led, by engaged auto throttle, to an RPM increase of the engines. The effect of this action comes very close to the effect of the procedure described in the AFM, Chapter Normal Procedures – Operation in Icing Conditions under Note 2 Ice-Shedding Procedure. When an engine vibration high alert for the RH engine was generated, the crew started to perform the pertinent checklist. In accordance with the checklist, the engine was not shut down because no additional malfunctions occurred after thrust reduction. This checklist did not refer to the ice shedding procedure.

Until then, the LH engine showed no unusually high vibrations. The PIC was prompted to declare an emergency and request a short approach by a noise clearly audible in the cockpit but indefinable by the crew. Later, the cabin crew described the noise as "super rumble" on the left-hand side.

During the whole descent from FL 90 to 3,500 ft the engines were running smoothly in a low thrust range and all engine indications were in the normal range. The crew could not recognise the reduced performance of the two engines. Thus the PIC did not hesitate to operate the airbrakes for some time, in order to reduce the airspeed to such a degree that the flaps could be extended. Once flaps and landing gears were extended it became apparent that the engines developed insufficient thrust. There was no malfunction indication at that time because in the flight warning computer monitoring of the N1 to EPR ratio is not intended. EPR indications showed, however, that despite an RPM increase the engines developed insufficient thrust.

The 3° glide slope of the ILS could not be reached because the airspeed in horizontal flight decreased more and more and it became necessary to descent again in order to maintain a safe airspeed. Landing gears and flaps were retracted again in order to reduce drag. Without engine thrust the aircraft could not reach the glide path. Even if it had reached the glide path it could not have maintained it because it has a glide angle of approximately 5° (1,000 ft/2NM), only.

In this situation the crew held the airplane in a stable and controllable flight condition. At 2,000 ft AGL (3,500 ft MSL) it was not possible any more to increase the airspeed to the airplane's optimum glide speed. With the airspeed close to the stall speed, the constant rate of descent was approximately 800 ft/min. With this low airspeed it was not possible to significantly reduce the rate of descent.

Except for the severe damage to the wing fuselage transition fairing on both sides, the airplane fuselage did not show any further deformed areas. This shows that the damage to the airplane was not due to the impact load but to the characteristics of the ground. The switch settings found in the cockpit basically corresponded to the condition one would find after completion of the Ground Emergency Checklist.

Aids to navigation

All airborne and ground aids to navigation were available. As the airplane was guided to the final approach using radar vectors, only the ILS was used for navigation.

Weather/icing conditions

As part of the pre-flight briefing, the crew were given documents specifically compiled by the airline for the intended flight. According to the Euro Significant Weather chart (EUR SWC) the area between Vienna and Munich was expected to have moderate icing (MOD ICE) below FL 140 and moderate turbulence below FL 160. For the most part the weather forecast was correct.

There were no indications for the existence of moderate to severe icing, which the expert opinion of the Deutscher Wetterdienst considered to be sporadically possible under certain circumstances.

Radio communications

Following the declaration of an emergency on frequency 120.77 MHz, radio communications between the air navigation service and the airplane initially continued on this frequency. The workload for the crew, which was already high at the time, was still further increased by the air navigation service requesting information about the number of passengers and dangerous goods aboard and transmitting information about the weather and the runway condition. Repeated frequency changes and listening in on radio communications of other airplanes demanded the crew's attention also. This could have been avoided, if the airplane had received a separate frequency right after declaring the emergency.

Air traffic control

When the crew declared the emergency at 08:08:22 hrs and reported severe engine problems, the controller granted the airplane priority over the other incoming traffic on the express request of the crew. He guided the airplane with headings and descent clearances to a short approach under consideration of the current air traffic situation. With it, the controller responded to the PIC's express request and was in accordance with the provisions under no. 611.2 of the Manual of Operations for the Air Traffic Control Services (BA-FVK) which states that "All possible measures to assist an aircraft which is known to be in an emergency situation shall be taken without delay."

For this direct approach, the controller had to change the approach sequence and delay the landing of nine other aircraft and/or assign holding patterns to them, since the northern runway was closed. The supervisor was informed and the emergency and the modified approach sequence were coordinated with the adjacent control sectors. This meant that further approaches had to be delayed and start up clearances and departures had to be deferred as well, as it was not predictable whether the runway would be blocked after the landing and how the situation would develop.

During his hearing the co-pilot stated that it would have been more convenient and would have increased capacities if radio communications of other aircraft had been suppressed, which was factually justified. Because of organisational reasons, use of a separate radio frequency was not possible. The provisions in the BA-FVK, no. 611.2 do not arrange for the use of a separate frequency but put the handling of emergencies largely into the hands of the controller.

2.2 Aircraft

Maintenance

Besides the loose ice impact panels, the investigations conducted on the aircraft and its components did not reveal any indication of other technical deficiencies related to the accident. The maintenance records of the operator did not indicate any possible deficiencies either.

The investigation of the ice impact panels and the associated bonding surfaces on the engines clearly showed an adhesion failure. This means that neither the adhesive nor the materials to be bonded failed but that the bonding between the adhesive and the materials was insufficient. In this case the reason for it could only be an insufficient preparation of the bonding surfaces.

The smooth surfaces on the fractured surface of the LH engine's fan case and of the adhesive on the panels prove that the fan case was not prepared correctly prior to the application of the adhesive. The brown discolorations on the bonding surfaces of the fan case and on the surface of the adhesive indicate that the bonded joint had separated some time ago and that ingress of moisture had taken place.

The smooth surfaces and only slight abrasive marks of the fan case of the RH engine prove that the surface of the case was not sufficiently prepared for the bonding. As the panels did not show any abrasive marks and only very few traces of the adhesive it is to be assumed that the panels had been used without any preparation.

The repair instruction HRS3491 of the engine manufacturer describes all essential steps for the modification of the ice impact panels on the engine cases. Due to the great number of references to other documents, however, the instruction is almost unusable in practice. For the preparation of bonding surfaces of fan cases the work step "REMOVE ALL TRACES OF ADHESIVE DOWN TO BARE MATERIAL" would have been necessary for all kinds of engine cases. That this error had not been noticed and that the unclear points within the cross-references had not been corrected since the issuance of the instruction in 1998 show that in practice the instruction had not been used as a work basis. It is obvious that in this respect the manufacturer's quality assurance system did not work.

The instructions of the adhesive manufacturer and the repair instruction of the engine manufacturer differ in several points. Whereas the engine manufacturer permits different options and agents to degrease the bonding surfaces, the adhesive manufacturer recommends trichlorethane. The general reference in the repair instruction to all degreasing methods basically allowed by the engine manufacturer does not ensure a constant and sufficient quality of work. For this purpose it would be necessary to limit the choice of degreasing methods to a small number and to specify them in detail. In view of the working instruction which is not usable in practice and the poor strength of the bonded joints found later on, it is quite probable that the bonding surfaces on both engines had not been degreased as necessary.

The adhesive manufacturer recommends abrading the bonding surfaces with medium grit garnet paper. The instruction of the engine manufacturer demands polishing of the bonding surfaces (... POLISH REPAIR AREA). For this purpose a garnet paper with an internal number (Omat 5/97) is indicated. This is an 80 grit garnet paper which cannot be used to polish this kind of surface; it will just abrade it. The contradiction within this work step will normally not be noticed as the grit of the garnet paper can only be determined with the help of another document.

Since the fan cases and the panels already have very smooth surfaces, the person doing the work cannot fathom the meaning of the work step "polishing". The purpose of the work step, i.e. abrading the surface to obtain better adherence of the adhesive, is not mentioned. In practice this obviously had the effect that this work step was not carried out as neither on the panels nor on the fan case clear and even traces left by 80 grit garnet paper could be found.

The description of the processing of the adhesive given in the repair instruction of the engine manufacturer is not coherent. On one hand, it includes detailed instructions on the other hand general references to the instructions of the adhesive manufacturer are made. The repair instruction indicates a minimum curing time of one hour and a minimum curing temperature of 12°C. Those values, however, do not correlate with each other. Only by using a table, which is also referred to, it becomes clear that with a temperature of 12°C curing takes 168 hours. A curing temperature of 60°C is necessary in order to reduce curing time to one hour.

Whereas the adhesive manufacturer prescribes fixing of the components during the curing process, the repair instruction leaves this to the discretion of the person doing the work. Due to the form of the components sufficient fixing would be possible only by means of special tools. According to the documents of the engine manufacturer such tools, however, are not necessary for this kind of work and thus are not available.

The discrepancies concerning the curing temperature and duration as well as the contradiction relating to the necessary fixing of the components show clearly that the repair instruction does not meet the requirements for a process description to achieve a high-quality and constant work result. These two items primarily influence the strength of the adhesive and not the adhesive qualities on the contact surfaces. In the present case an adhesive failure due to the poor preparation of the contact surfaces had occurred before a cohesive failure could occur. Thus these items of the procedural instruction should be revised.

Based on the residual adhesive found on the bonding surfaces of the ice impact panels of both engines it could be determined that the cured epoxy adhesive was very inelastic. Deformation of the separated ice impact panels led to further flaking of the residual adhesive and to cracking of the adhesive film. This explains why in the RH engine no residual adhesive was found. The determined brown discolorations on the fan case can be attributed to water embedding. Freezing water pushes the ice impact panels away from the bonding surfaces and generates a peeling load of the bonded joints. Such a peeling load is also to be expected with a deformation of the fan case.

Mechanical load tests have shown that for the strain on bonded joints caused by peeling loads a polysulfide adhesive is better suited than an epoxy adhesive. Additionally, there were considerable differences in strength between the "film" and the "paste". Since epoxy paste adhesive has shown unacceptable strength with low temperatures it follows that this adhesive is not suited for this application.

Systems

The ground test of the engine anti-icing system did not show any defects and the investigation of the components of the airframe anti-icing system did not reveal any malfunctions either. Therefore, it may be assumed that these systems had been available during the flight and had functioned properly.

The ice detection probe of the ice detection system had passed the functioning tests provided by the manufacturer. The sensing probe, however, was slightly bent. Because of the bent probe the base frequency of the ice detection probe was too low. This in turn caused the probe to respond too early. Thus it is quite probable that a warning signal was transmitted to the warning system when ice thickness was still well below 0.5 mm.

Normally, the heating of the probe is switched on when ice formation on the probe is approximately 0.5 mm. If the heating is turned on with ice formation below 0.5 mm the developing heat cannot dissipate and leads eventually to a discolouration of the surface.

The dark discolouration of the probe is a further indication of too early a response of the ice detection probe. This in turn means that if the system did not respond during descent from FL 280 to FL 100, surely there were no critical icing conditions.

Attachment 2 shows that from 08:06 hrs on the ice warning switched off several times for periods of up to 2 minutes. This suggests that, from this time on, the aircraft was subject to light icing conditions, at the most.

Engines

The investigation of the engines did not reveal any reasons for the unbalance of the RH engine which was recorded at 08:07 hrs by the FDR (see attachment 4). Since the airplane was under icing conditions at the time it may be regarded as certain that this unbalance had been caused

by uneven ice formation on the rotor of the low pressure compressor. The unbalance reached its maximum at 08:07:19 hrs. Approximately 100 s later, the unbalance had decreased again to normal values. The unbalance did not significantly increase again. It may be assumed that during this period the ice separated from the rotor of the RH engine.

The recorded parameters of the LH engine do not show any unusually high unbalance for the whole flight. Therefore, ice formation on this engine cannot be documented. As both engines had been subjected to the same environmental conditions and had been operated with almost the same thrust settings until 08:07 hrs, it may be assumed that ice had formed on this engine as well. It could not be determined when the ice separated from the rotor.

The sudden drop of the EPR to N1 ratio of the low pressure compressor rotor of the LH engine recorded by the FDR at 08:08:14 hrs is the result of a stall on the rotor of the low pressure compressor. The only possible reason for the stall is the obstruction of the by-pass caused by the loose ice impact panels which were lying in front of the outlet guide vanes.

The CVR recorded a clattering noise at 08:10:10 hrs. It is quite possible that the recorded noise and the "super rumble in the rear left" reported 30 s later by the flight attendant were identical. It is also possible that the noise was caused by loose ice impact panels which briefly spun around the engine. It is to be assumed that all ice impact panels of this engine had separated from their installation positions at the same time.

On the RH engine, the EPR to N1 ratio of the low pressure compressor rotor was decreasing over a period of several minutes. This can only be explained by a slowly progressing obstruction of the by-pass caused by loose ice impact panels and the related disturbance of the air flow on the rotor of the low pressure compressor.

From 08:13 hrs on, neither of the two engines reached an EPR of more than 1.2 independent of the position of the thrust levers and the speeds of the low pressure rotors. This means that the thrust then produced by both engines was in the range of idle thrust, only.

The FMEA valid at the time of commission of the engine type TAY 620-15 concerned the former version of ice impact panels. This FMEA assumes that a complete detachment of honeycomb panels will be indicated in the cockpit by reduced EPR and increased N1 and vibration values. Even this assumption did not take into account that changes in indicated values occur only if the engine runs in certain performance levels. The accident has shown that such failures remain undetected as long as the engine runs with low thrust settings.

Since an engine FMEA of more recent date was not submitted it may be safely assumed that the 1994 ice impact panel modification was not reason for amending the risk assessment. This assessment was subject to further assumptions. It did not take into account that the use of an epoxy paste adhesive would result in lower strengths of the bonded joints, that for the intended use a polysulfide adhesive would be better suited, that the repair procedure was suited to a very limited extend for the bonding of the modified ice impact panels and that work errors during the make of the bonded joints will affect all not just one ice impact panel in the engine. Engine failure would be avoidable during detachment of the ice impact panels if the ice impact panels would break into smaller pieces.

Under the condition that an engine failure occurs based on deficiencies of an individual piece it is correct to regard such an event as "marginal" in case of multi-engined aircraft. Product safety of the airplane was not yet affected under these conditions. This did not change until a deficiency occurred which was not limited to an individual piece of the engine type. Double

engine failure had become more probable through a maintenance deficiency and it became a reality as the described circumstances show. Differences in how damage progressed are attributable to the degree of deterioration the bonded joints of the two engines had suffered before.

Crashworthiness

FDR data showed that the vertical acceleration during the forced landing of the airplane was not unusually high. The contact of the main landing gears, which were just extending, with the surface of the field caused a sudden pitching movement of the fuselage due to the high positive pitch and the deceleration. Therefore touch down of the nose gear was harder than normal (whiplash effect).

The acceleration of +2.6 g resulting from the ground contact of the airplane structure was effective only for a split second. This acceleration did not cause injuries to the occupants. Due to the unevenness of the terrain and the deceleration of the fuselage, which stressed the airplane structure, three occupants suffered minor injuries and several armrests were damaged. As no further damage to the cabin, the seats and the seat belts had occurred, a deficiency of the armrests concerned (deficiencies of individual pieces) is to be assumed. Maintenance personnel stated that frequently armrests had to be replaced.

3. Conclusions

3.1 Findings

- Both pilots held the necessary licenses and ratings required for the conduct of the flight. Due to their total flight experience and their flight experience on the type, the pilots were to be considered experienced and qualified.
- The airplane was properly certificated and maintained in accordance with existing regulations and approved procedures.
- For the flight, moderate icing from the ground up to FL 140 and moderate turbulence up to FL 160 had been forecast. This weather forecast was available to the crew a sufficient period of time prior to the flight. For the most part, the weather forecast was correct.
- In-flight system deficiencies or malfunctions had not been reported by the pilots and according to the recordings of the FDR had not occurred.
- The assigned approach procedure in connection with a high volume of traffic on the one remaining runway (south) led to a prolonged duration of flight in the assigned altitude.
- The long flight duration in moderate icing in connection with low engine thrust contributed to the ice formation on the rotors of the low pressure compressors.
- There were discrepancies between the AFM of the aircraft and the AOM of the operator concerning the use of the engine and airframe anti-icing systems. These discrepancies had no influence on the accident.
- The vibrations on the RH engine and heavy vibrations and noises in the rear area of the airplane were to be attributed to ice formation on the fan. It is to be assumed that ice had formed on the fan blades of both engines and that it had separated from them during this period.
- The bonded joints of the ice impact panels of both engine cases failed within short intervals because the bonding between adhesive and the materials had peeled away in some places.
- Improper preparation of the bonding surfaces, ingress of moisture and poor elasticity of the adhesive caused the bonded joints of the ice impact panels to progressively fail over an extended period of time.
- The instruction of the engine manufacturer for the bonding of the ice impact panels was difficult to accomplish and unclear concerning the preparation of the bonding surfaces. In the instruction it was not mentioned that a clamping device for contact pressure and fixation of the ice impact panels following the bonding process was required.
- The loose ice impact panels became trapped in front of the outlet guide vanes of the low pressure compressor and affected the airflow in the by-pass in such a way that the engines only produced little thrust. During the FMEA this possible failure and its consequences had insufficiently been taken into consideration.
- Declaring an emergency and requesting immediate landing and an approach as short as possible were comprehensible requests by the crew considering the information on the engine condition available to them at the time.
- During descent to the final approach altitude thrust of both engines had to be held at a performance level where the disturbed connection between N1 and EPR could not be noticeable on the EPR-display.

- When thrust was required to reach the glide slope at 3,500 ft, the EPR-indication showed that no effective thrust was produced so that the airplane could not reach the runway any more.
- Due to its nature the field in front of the runway was not suited for the landing of a transport airplane.

3.2 Causes

The accident was due to the following immediate causes:

- After a prolonged time under moderate icing conditions and low engine thrust, ice developed on the rotors of the low pressure compressors of both engines.
- The bonded joints of the ice impact panels on both engines failed due to strains caused by ice-induced vibrations of the engines and by ice which had detached from the rotors of the low pressure compressor.
- The loose ice impact panels became trapped in front of the outlet guide vanes of the low pressure compressor and affected the airflow in the by-pass duct in such a way that the engines only produced low thrust.
- The runway was no longer within reach of the aircraft because the loss of thrust on both engines had not triggered any warnings and was not indicated until the necessary demand of thrust at an altitude of 3,500 ft.
- Due to its nature the terrain within reach was not suited for the landing of a transport airplane.

The accident was due to the following systematic causes:

- A high volume of traffic led to a prolonged flight duration in the assigned altitude and with the assigned air speed. During the conduct of the flight the forecast icing conditions were not taken into account.
- The bonded joints of the ice impact panels of the engine cases failed within short intervals due to strains caused by ice formation, since the bonding surfaces had not been prepared properly. In some areas, the bonding between adhesive and the materials had peeled away.
- The instruction for the modification of the ice impact panels was partly unclear and included deficiencies which adversely affected the durability of the bonded joints of the ice impact panels and increased the development of working errors and qualitative defects.
- In the scope of manufacture and maintenance the quality assurance system failed to identify that the epoxy paste adhesive to be used was not fully suited for the specified repair procedure and that the procedural instructions did not fully meet the specified expectations.
- The conducted FMEA during commission of the engine type and the design changes of the ice impact panels did not take into account a possible detachment and its consequences.
- The concept of the automatic monitoring system of the aircraft did not consider this particular kind of engine malfunction (change of the N1 to EPR ratio).

4. Safety recommendations

As a result of the forced landing the Luftfahrt-Bundesamt (LBA) responsible for the type support of the Rolls Royce TAY 620-15 engine issued on 16 January 2004 the Airworthiness Directive D-2004-055 requiring visual inspections of the ice impact panels of all affected engine versions. According to information provided by the engine manufacturer approximately 30% of the ice impact panels were replaced in the scope of these inspections.

During the ongoing investigation the findings on the aircraft prompted the German Federal Bureau of Aircraft Accidents Investigation to issue the following safety recommendations:

Recommendation no. 02/2004

The Luftfahrt-Bundesamt responsible for the type support of the Rolls Royce TAY 620-15 engine should ensure by suitable actions that the engine manufacturer install the ice impact panels in such a way that even with a complete or a partial failure of the component or its attachment an engine failure or a considerable thrust reduction is precluded.

Recommendation no. 20/2004

Until comprehensive product safety is restored, the Luftfahrt-Bundesamt responsible for the type support of the Rolls Royce TAY 620-15 engine should allow flight operations with airplanes on which the engine types concerned are installed only if on at least one engine of each airplane affected the ice impact panels have been bonded with polysulfide adhesive during manufacture or repair procedure.

With the airworthiness directive D-2004-313 the service bulletin TAY 72-1638 became mandatory. In the SB the engine manufacturer had recommended that before 1 March 2005 the ice impact panels on at least one engine of each airplane affected must be bonded with polysulfide.

After the conclusion of the investigation, the German Federal Bureau of Aircraft Accidents Investigation has issued the following safety recommendations:

Recommendation no. 09/2005

The Luftfahrt-Bundesamt responsible for the type support of the Rolls Royce TAY 620-15 engine should check:

- if the engine manufacturer eliminated the errors and deficiencies, as revealed by the investigation, in the manufacturer's instructions for the implementation of the ice impact panel modification;
- if the deficiencies found in the manufacturer's instructions are attributable to fundamental deficiencies of the engine manufacturer's quality assurance system.

Recommendation no. 10/2005

The aircraft type certificate holder for the Fokker 70/100 should bring the Aircraft Operating Manual (FOM/AOM) in agreement with the Airplane Flight Manual regarding mandatory requirements especially procedures for flight under icing conditions. Unmistakable AFM requirements should be adopted in the AOM unchanged. The issues (AOM – Special Edition) prepared and delivered on behalf of the aircraft's operator should also be changed.

The respective regulatory authorities have received copies of these safety recommendations with the recommendation to oversee the changes.

Braunschweig, November 2005

German Federal Bureau of Aircraft Accidents Investigation

pp

K. Büttner

Investigator in charge

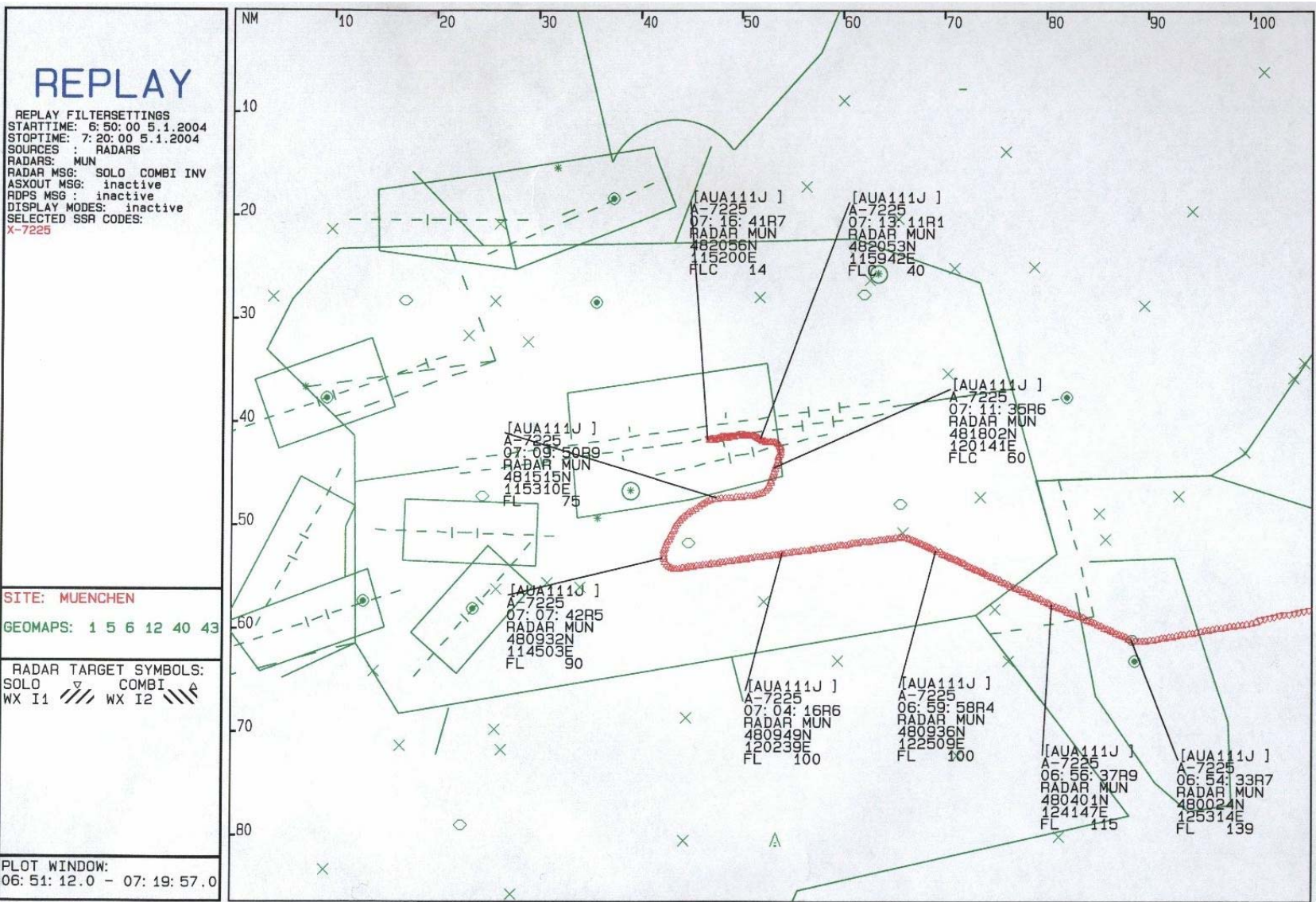
The following staff members of the German Federal Bureau of Aircraft Accidents Investigation have contributed to the investigation:

Field Investigation	U. Berndt, T. Kostrzewa, F. Kühne
Air Traffic Control	H. Peters
Weather	E. Krupper
Flight Data Recordings	U. Pitz, D. Ritschel, A. Thiel
Flight Operations	E. Krupper, L. Müller, A. Wilke
Aircraft Systems	T. Kostrzewa

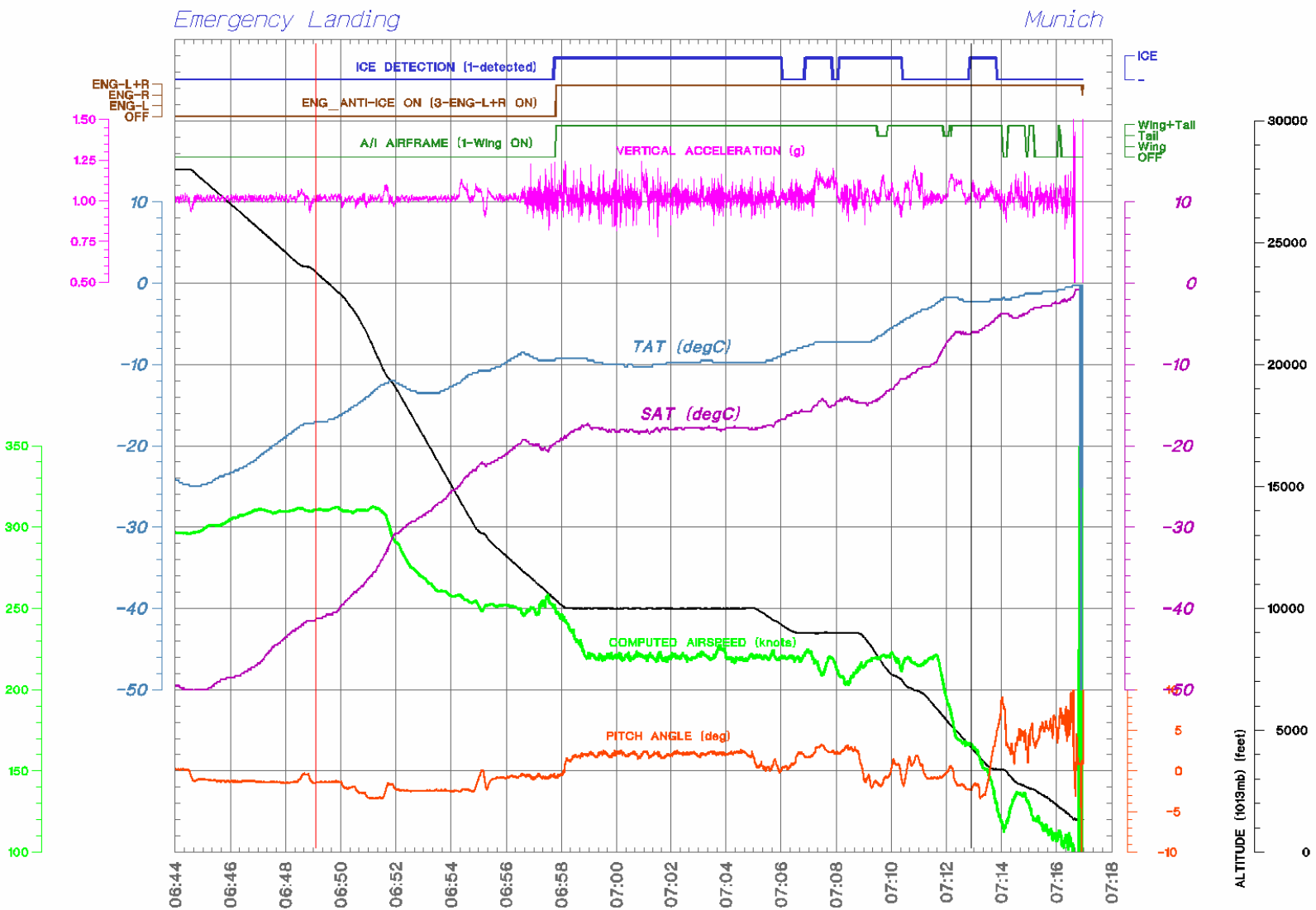
5. Attachments:

- Attachment 1 Approach to Munich
- Attachment 2 Approach profile
- Attachment 3 Changes on the LH engine at 08:08:14 hrs
- Attachment 4 Changes on the RH engine at 08:08:40 hrs
- Attachment 5 Forced landing
- Attachment 6 Three view drawing Fokker 70
- Attachment 7 Accident Site
- Attachment 8 Rolls Royce TAY 620-15 engine
- Attachment 9 Loose ice impact panels in the LH engine intake
- Attachment 10 All loose ice impact panels of the LH engine
- Attachment 11 Loose ice impact panels in the RH engine intake
- Attachment 12 All loose ice impact panels of the RH engine
- Attachment 13 Peel drum test results
- Attachment 14 Cross-references in the repair instruction

Attachment 1: Approach to Munich (times indicated in UTC)



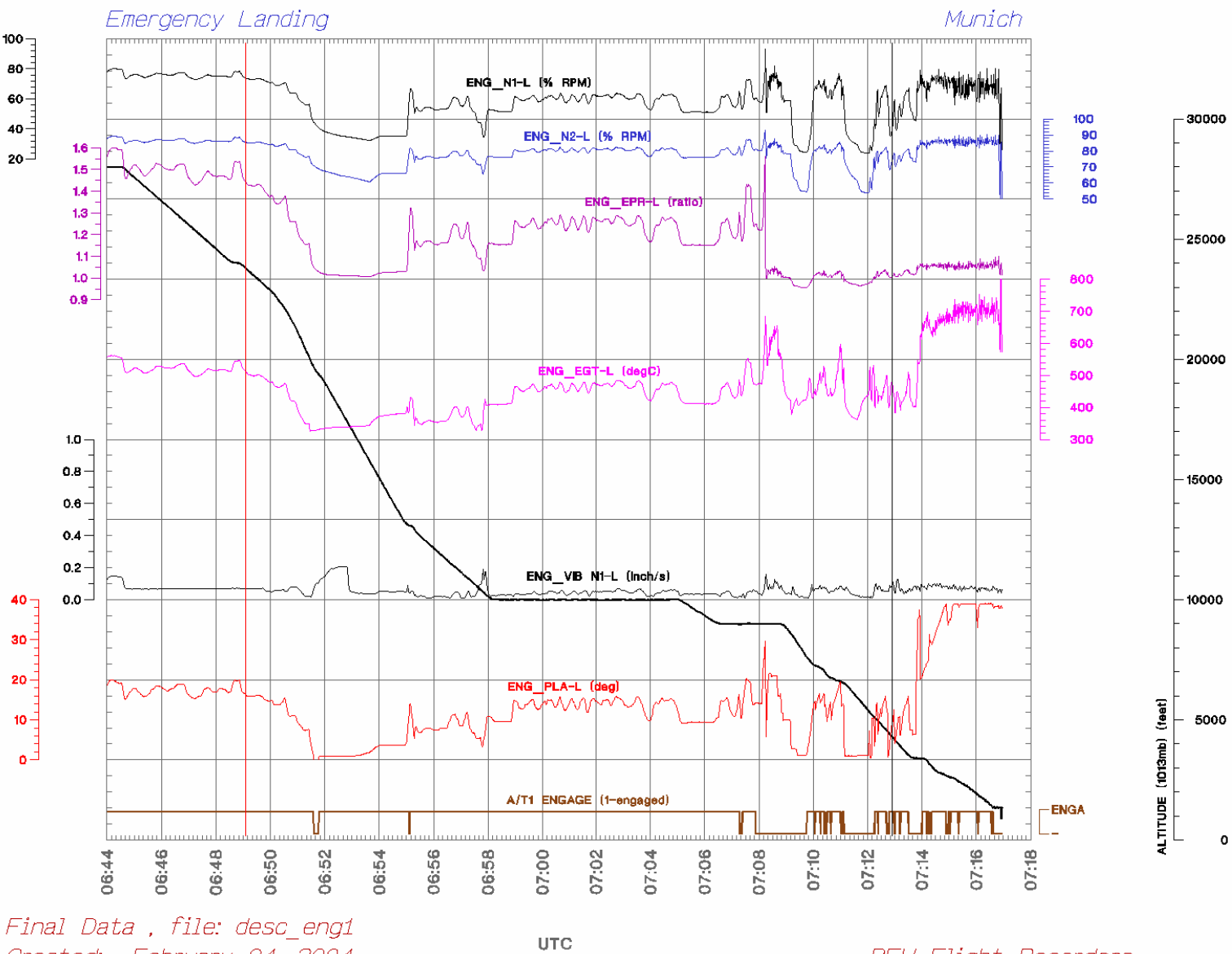
Attachment 2: Approach profile (times indicated in UTC)



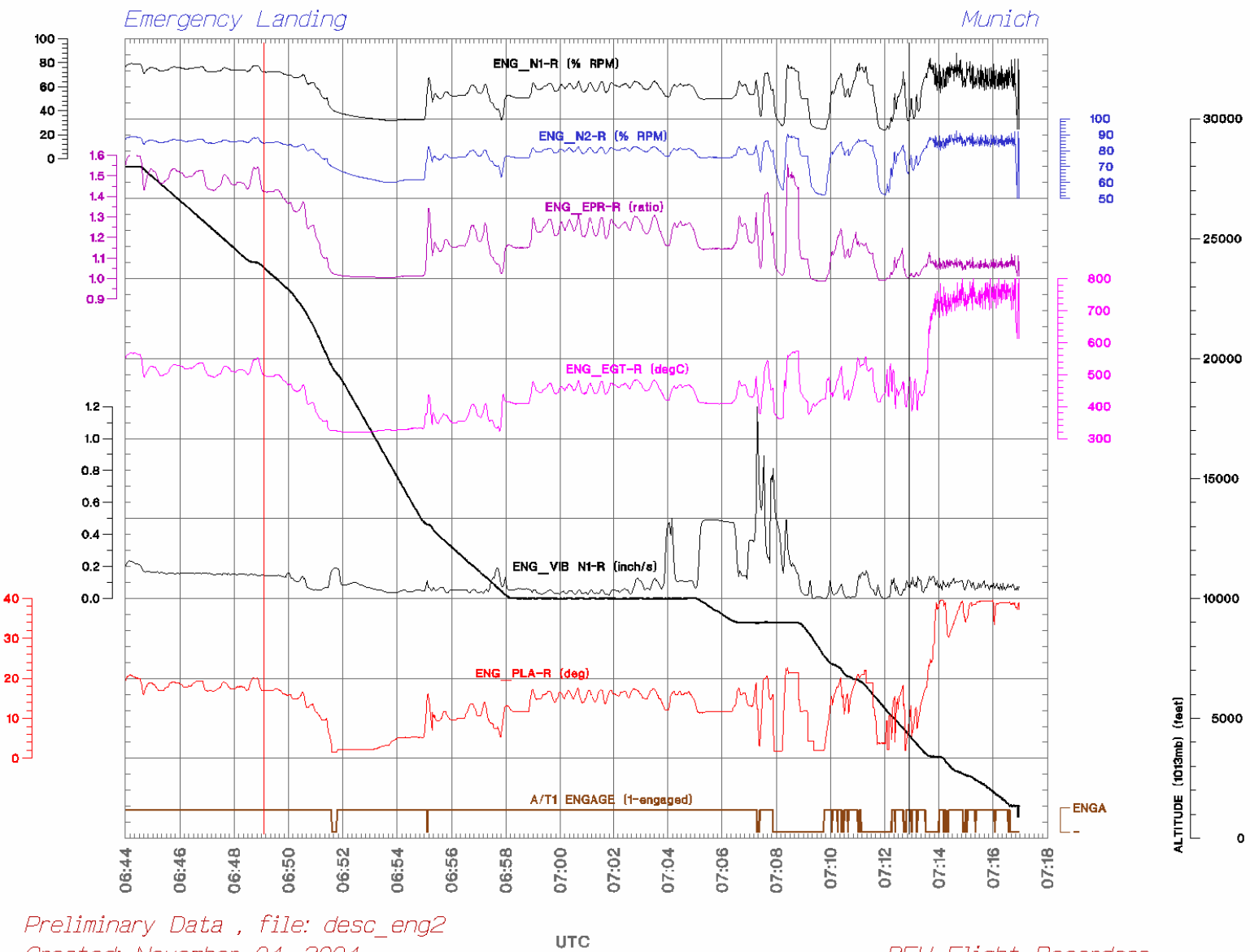
Final Data file: desc_flight1
Created: February 06, 2004

BFU Flight Recorders

Attachment 3: Changes on the LH engine at 08:08:14 hrs (07:08:14 UTC)



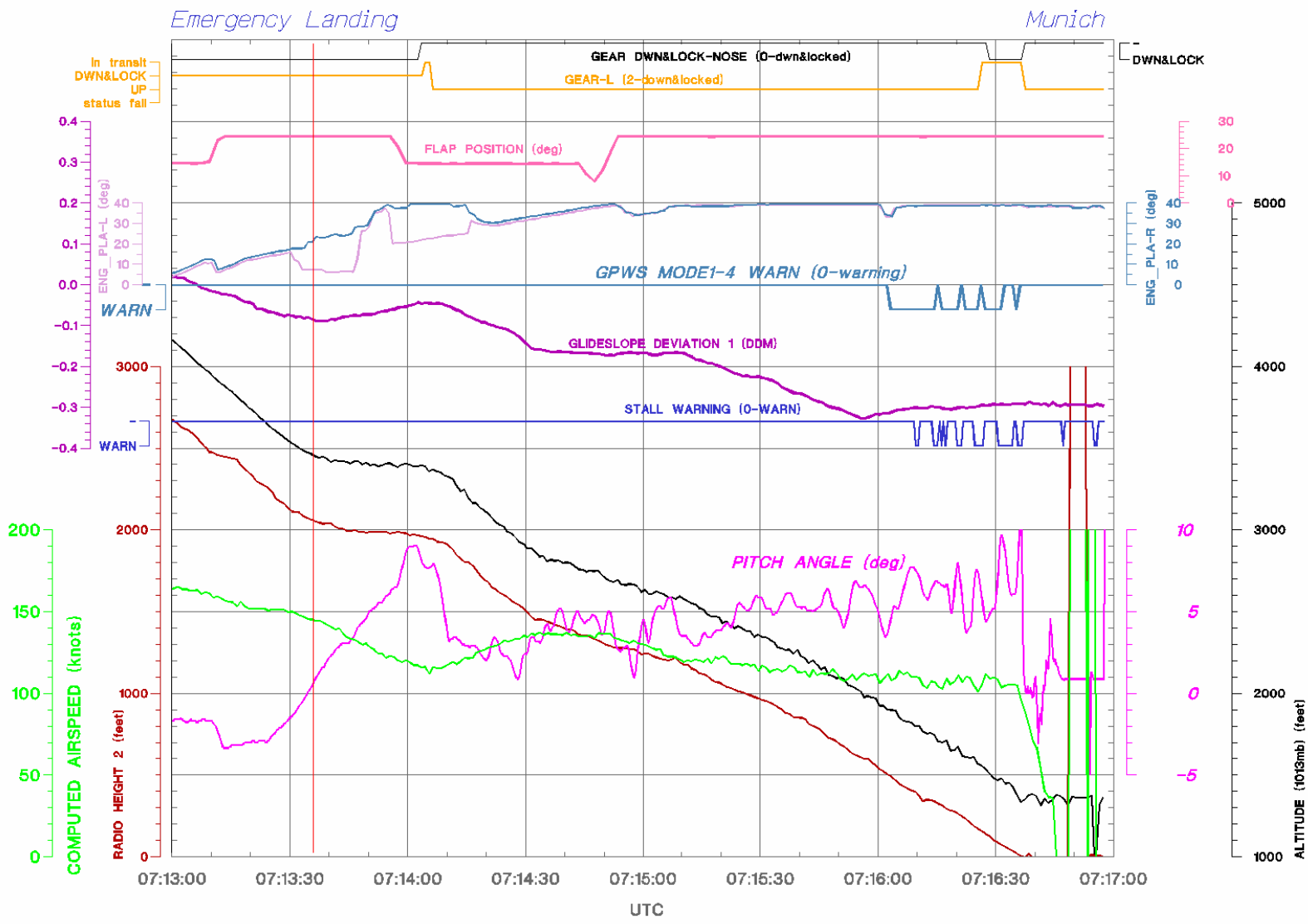
Attachment 4: Changes on the RH engine from 08:08:40 hrs (07:08:40 UTC)



Preliminary Data , file: desc_eng2
Created: November 04, 2004

BFU Flight Recorders

Attachment 5: Forced landing (times indicated in UTC)



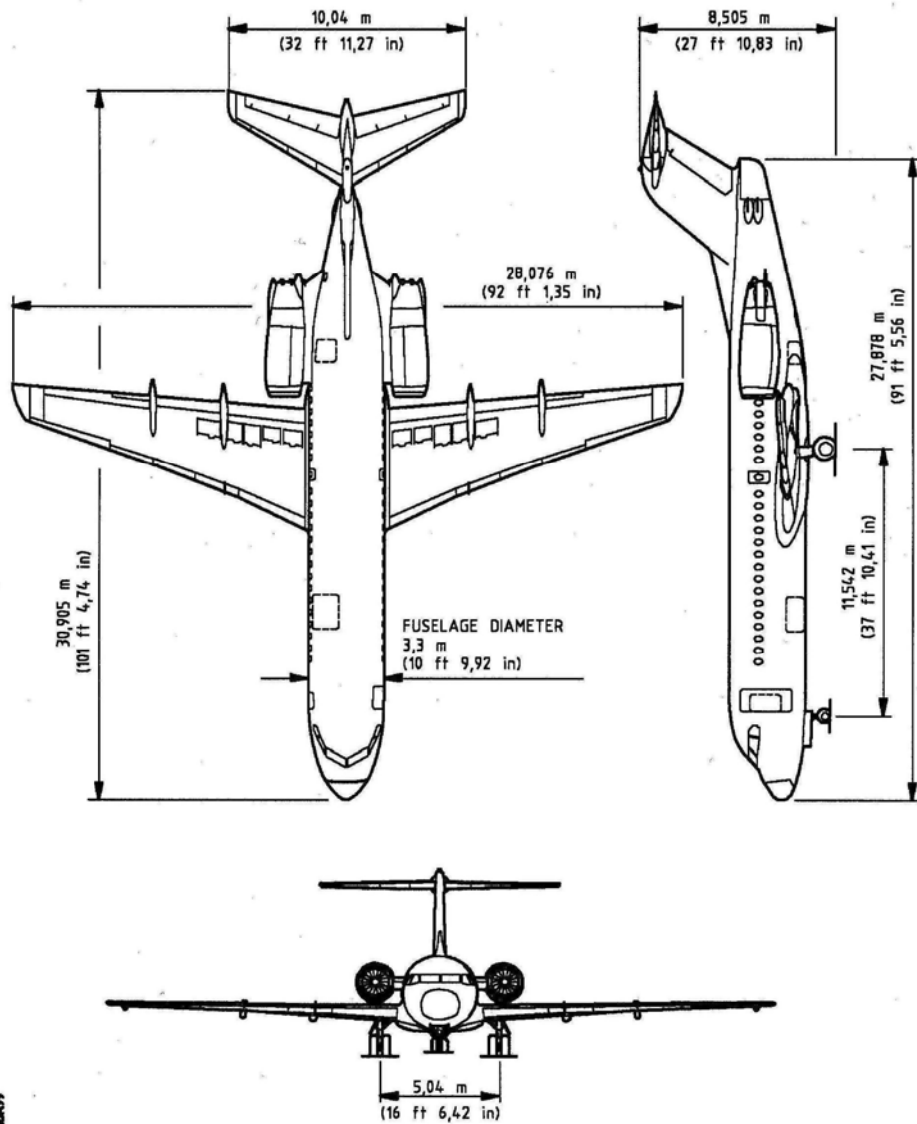
Final Data , file: touchdown2
Created: July 25, 2005

BFU Flight Recorders

Attachment 6: Three view drawing of the Fokker 70



Fokker 70
MAINTENANCE MANUAL



External Dimensions - Aircraft in Static Position
Fig. 06-10-00-990-010-A03

ILL. EFFECTIVITY: ALL

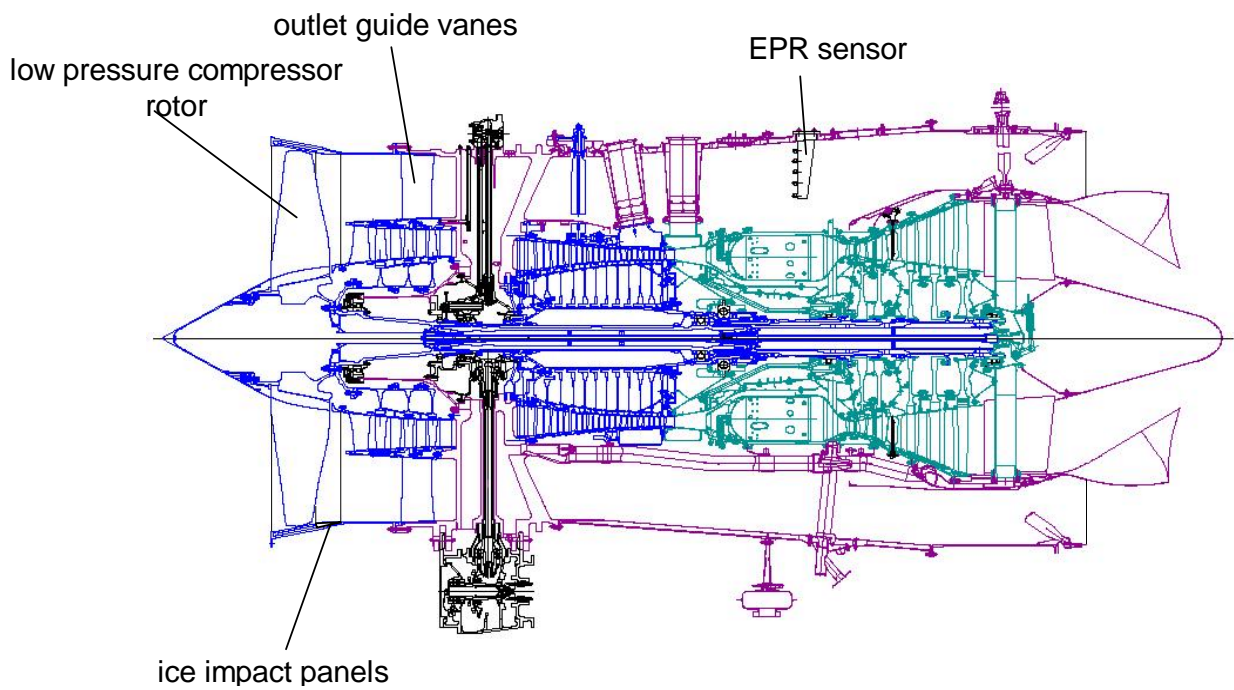
627 **06-10-00**
COMPONENT INFORMATION-1-A

ZZ2-810-A
Page 004
Dec 01/95

Attachment 7: Accident site



Attachment 8: Rolls Royce TAY 620-15 engine



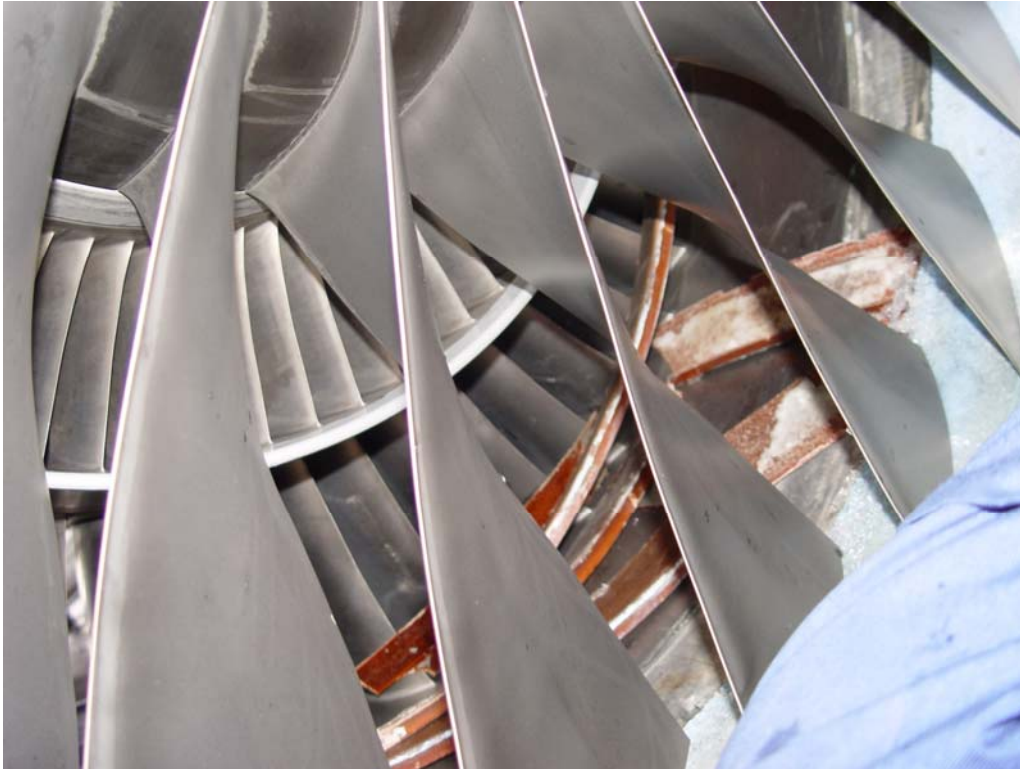
Attachment 9: Loose ice impact panels in the LH engine intake



Attachment 10: All loose ice impact panels of the LH engine



Attachment 11: Loose ice impact panels in the RH engine intake

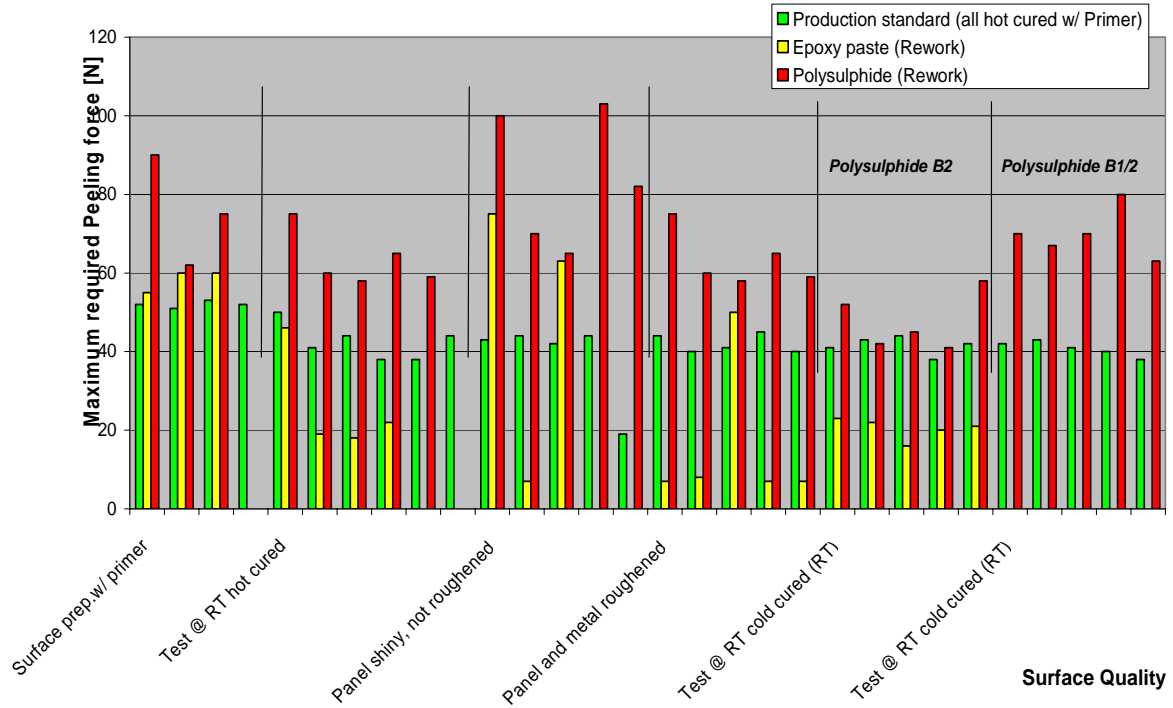


Attachment 12: All loose ice impact panels of the RH engine

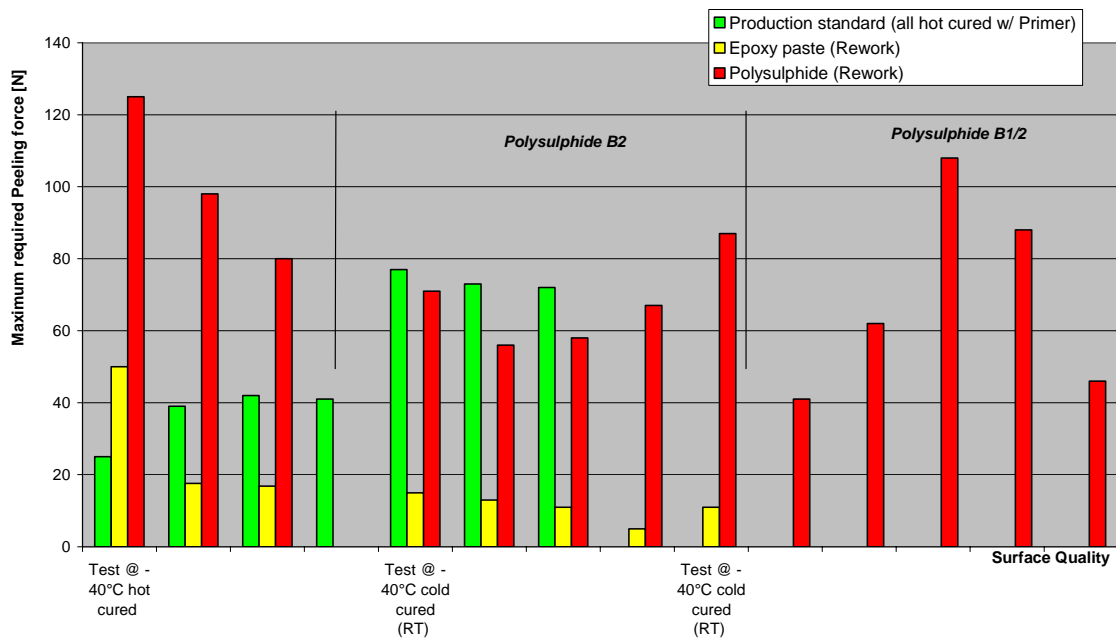


Attachment 13: Peel drum test results

Bonding Strength Test - Peel drum Test Results - Test @ RT



Bonding Strength Test - Peel drum Test Results - Test @ RT



Attachment 14: Cross-references in the repair instruction

SB 72-1326

1.H. Special tools not required

2.A. Rework case in accordance with HRS3491

HRS3491

4. Special Tools: None

10. Assy A only: Remove honeycomb to the level of existing adhesive

11. Assy C only: Remove panel to the level of existing adhesive

12. Assy C only: Remove existing adhesive, use OMat 5/118 or 5/119, remove all traces of adhesive down to the bare metal

14. Clean and polish repair area

Degrease repair area. Refer to 70-00-00-300-707, ST 70-00-00-360-707-001

70-00-00-300-707, ST 70-00-00-360-707-001, prepare stainless steel parts

B. Degrease in accordance with 70-00-00-100-101 or 70-00-00-100-102

70-00-00-100-101

11. Cold liquid degrease, Method 1

A. Apply solvent

swab with lint free cloth

Allow the parts to dry

70-00-00-100-102

5. For local washing parts (to remove grease): ST 70-00-00-110-102-002

ST 70-00-00-110-102-002

7.B. Apply cleaner by swab or brush soaked in cleaning solution made up in ST 70-00-00-180-102-001

C. Allow the parts to stand up for 15 min.

D. Swab wash the parts with clean water to remove the chemicals

F. Dry the parts

Hand abrade, use OMat 5/97 or 5/98

15. Degrease repair area. Refer to 70-00-00-100-101 or 70-00-00-100-102
70-00-00-100-101
70-00-00-100-102
16. Check cleanliness, refer to 70-00-00-300-707, ST 70-00-00-300-707-001
70-00-00-300-707, ST 70-00-00-300-707-001
?
18. Degrease repair area. Refer to 70-00-00-100-101 or 70-00-00-100-102
70-00-00-100-101
70-00-00-100-102
20. Clean and polish panel
Degrease repair area
refer to 70-00-00-300-707, ST 70-00-00-360-707-001
70-00-00-300-707, ST 70-00-00-360-707-001, prepare stainless steel parts
B. Degrease in accordance with 70-00-00-100-101 or 70-00-00-100-102
70-00-00-100-101
70-00-00-100-102
Hand abrade the repair area, use OMat 5/97 or 5/98 garnet paper
21. Degrease the panels. Refer to 70-00-00-100-101 or 70-00-00-100-102
70-00-00-100-101
70-00-00-100-102
22. Check cleanliness of the panels, refer to 70-00-00-300-707, ST 70-00-00-300-707-001
70-00-00-300-707, ST 70-00-00-300-707-001
?
23. Apply Adhesive
Prepare adhesive in accordance with 70-00-00-300-707, ST 70-00-00-360-707-015
70-00-00-300-707, ST 70-00-00-360-707-015
B.(2) Refer to ST 70-00-00-860-707-054 for instructions on the mixing
ST 70-00-00-860-707-054

- A.(1) Refer to manufacturer's data, unless otherwise specified in this document, for the following:

Mixing ratio, temp. range for application, pot life/gel time, cure cycle

70-00-00-300-707, ST 70-00-00-360-707-015

- B.(3) Weigh out 100 parts of grey paste (Part A) and 33 parts of amber liquid (Part B) and mix thoroughly.

The working life is approximately one hour at 22°C

Apply a thin layer of epoxy

Use OMat 8/52 adhesive

25. Fit the panels

Ensure the panels are fitted to the rear of case

Ensure the panels fit flush with all adjacent aerodynamic surfaces

If necessary locally clamp panels

26. Cure adhesive

refer to 70-00-00-300-707, ST 70-00-00-360-707-015

70-00-00-300-707, ST 70-00-00-360-707-015

- C.(3) For time and temperature see Fig. 70-00-00-860-707-002

Min time 1hr, min temp. 12° C

Monitor temp.

Where available use heat blanket and vacuum bag