Aircraft Type and Registration:	Airbus Industrie A320-211, D-AIPK
No & Type of Engines:	2 CFM56-5-A1 turbofan engines
Year of Manufacture:	1990
Date & Time (UTC):	13 December 1992 at 1730 hrs
Location:	Approximately 5 nm west of London Heathrow Airport
Type of Flight:	Public Transport
Persons on Board:	Crew - 6 Passengers - 107
Injuries:	Crew - None Passengers - None
Nature of Damage:	Substantial heating damage to the No 2 air turbine starter and the wiring to the Engine Control Unit (ECU)
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	51 years
Commander's Flying Experience:	10,000 + hours (of which 1,700 were on type) Last 90 days - 200 hours Last 28 days - 60 hours
Information Source:	AAIB Field Investigation

History of the flight

The aircraft and crew had operated the scheduled service from Dusseldorf to London Heathrow, landing at 1410 hrs. The return flight to Dusseldorf was scheduled to depart at 1505 hrs. At 1515 hrs, during the pushback and whilst starting the No 1 engine, the No 1 air turbine starter failed and the aircraft had to return to the stand for rectification. A replacement air turbine starter was fitted and rectification completed by 1705 hrs. At 1713 hrs the aircraft was pushed back again from stand F6 and, after a normal start, taxied for departure from Runway 27L.

At 1720 hrs the aircraft was cleared for take off to route via the Brookmans Park VOR. The weather at the time was wind 250°/12 kt, visibility 30 km, cloud 4 octas at 1,800 feet, 7 octas at 2,200 feet, temperature 10°C, dew point 7°C with a QNH of 1018 mb.

At 1722 hrs, whilst climbing through 4,000 feet, the No 2 engine wound down to idle power, the master caution illuminated and several Electronic Centralised Aircraft Monitoring (ECAM) warning messages appeared. The commander states that he disconnected the autothrust system and exercised the No 2 thrust lever but this had no effect on the engine, which remained at idle power. Two circuit breakers (A3: IGN SYS A and A5: FADEC A and EIU 2) on the overhead panel were also found to have tripped and these could not be reset by the crew.

The aircraft was levelled at 5,000 feet and the crew requested a priority return to Heathrow but did not declare an emergency.

ATC vectored the aircraft for an ILS approach on Runway 27R and at 1734 hrs the aircraft landed without further incident. Although no emergency had been declared by the crew, ATC alerted the airport fire vehicles and brought them to full emergency status prior to the landing. The fire vehicles escorted the aircraft to its parking gate and remained in attendance until the engine cowlings had been opened and the engine examined. Although there had been no fire or overheat warnings on the flight deck the air turbine starter, engine cowling and wiring to the Engine Control Unit (ECU), part of the Full Authority Digital Engine Control (FADEC) system, were found to have suffered extensively from heat damage.

Recorded data

Two accident recorders were fitted to the aircraft, a Cockpit Voice Recorder (CVR) and a Digital Flight Data Recorder (DFDR). The 30 minutes duration CVR was not removed from the aircraft since the airborne part of the recording had been overwritten due to the amount of time the aircraft had spent on the ground with power on the electrical systems. Data recorded in the non volatile memory within the No 2 engine's ECU and the ECAM post flight report were made available by the aircraft's operator.

Digital Flight Data Recorder

The DFDR, which had a duration of 25 hours and recorded 80 analogue parameters and 150 discretes (on/off indications), was removed from the aircraft and replayed on the AAIB's replay facilities.

At 1515 hrs the No 2 engine was started successfully, an attempt was then made to start the No 1 engine. The start valve was opened 10 times over a 9 minute period, however, the N2 value did not change from 0%. At the end of the seventh start attempt the No 2 engine was shut down.

A subset of the DFDR data is presented in Figure 1 covering the period from the successful start of both engines, through the take off, landing and finally taxi. The timescale is in minutes referenced to an artificial datum. UTC, as obtained from the aircraft system is also indicated.

The figure shows data for eight parameters, Nos 1 and 2 engine throttle lever angles (TLA), commanded N1 (N1T), actual N1 (N1), the No 2 engine's ECU channel in control and the aircraft's altitude referenced to a pressure of 1013 mb. The commanded N1 is a parameter generated inside the ECU in response to demands placed on the engine from sources which include the throttle lever angles, the autoflight system's autothrust requirements and bleed air requirements.

After the replacement of the No 1 engine starter, the No 1 engine was started at 1714 hrs followed by the No 2 engine at 1715 hrs. The aircraft took off at 1720:55 and climbed normally.

At 1722:36, as the aircraft was passing through an altitude of 4,500 feet, the No 2 engine reduced power over a 15 second period from an N1 value of 91% to a value of 27%. The value recorded for the No 2 throttle lever angle did not change during this event. Prior to the event the No 2 engine's ECU had been using its internal channel B, within 3 seconds of the event the ECU had changed to channel A.

The recorded values for the No 1 engine N1, commanded N1 and throttle lever angle did not vary significantly from before the event until 35 seconds after it.

At 35 seconds after the event both throttle levers were reduced to 6°, the No 1 engine throttle lever was then increased to a value of 20°, however, no change in the No 2 engine throttle lever is recorded. Throughout the rest of the flight non transient values of between 0° and 5° are recorded for the No 2 engine throttle lever with 1 second transient values of 8°, 5° and 13°.

After the event, steady values of No 2 engine N1 matched the commanded N1 values to within 1%, with the exception of a 5 second period, shown at 15 minutes 40 seconds in Figure 1, when a commanded N1 reduction to 22% (N1T) was answered by a rise in engine N1 to 37%.

At 3 minutes 10 seconds after the event the No 2 engine's ECU reverted to using channel B. Coincident with this change of channel was the loss on the DFDR of the No 2 engine's N2 signal. At 1734 hrs the aircraft landed successfully using reverse thrust on the No 1 engine during the landing run. Following a taxi to the stand both engines were shut down at 1741 hrs.

Whilst the aircraft's engines were running there were no recorded indications of fire, thrust reversers unlocked or thrust reversers deployed.

Post Flight Report

The post flight report (PFR) is a printout of warnings displayed on the pilot's ECAM display and of failure messages logged by the centralised fault display interface unit (CFDIU). The PFR was obtained by the maintenance crew after the aircraft had docked at the terminal. Information contained within the report has a timing resolution of 1 minute.

At 1722 hrs the PFR indicates that there was a reverser fault within the No 2 engine FADEC and that the autoflight system autothrust was deactivated. Also indicated are reverser deploy and stow switch faults and a break in the feedback loop of the autoflight system. From 1723 until 1726 hrs there follows a series of indications of sensor failures and finally at 1730 and 1731 hrs indications of the failure of the engine interface unit (EIU) which feeds data to and from the ECU.

Engine control unit

The ECU contains two channels, channel A and channel B, each capable of controlling the engine in the event of the degradation of the other channel. The functioning of each channel is monitored within the unit and any faults detected in a channel are stored in that channel's volatile memory along with general housekeeping data. When the aircraft lands and its speed drops below 80 kt, the data is transferred into non volatile memory (NVM). The NVM will store up to the last 12 major faults occurring on each channel, each fault is time tagged with a resolution of one minute. During the engine inspection at the operator's facility, following the incident, the ECU was removed and examined. The NVM was interrogated and a printout was obtained detailing the data stored within.

The examination revealed that the unit had been subjected to external heating which had scorched the front panel severely, scorched, oxidised and bent connector pins and melted the rubber connector inserts. Temperature logging stickers within the unit indicated that the channel A area of the box had reached 121°C and the channel B area 93°C.

NVM interrogation revealed that no NVM data was stored describing faults on channel A connected with the incident. Circuit breaker 49VUA5 tripped during the flight removing the 28V supply to the EIU and the ECU. Failure of the EIU was indicated in the PFR at 1730 hrs and also in the channel B NVM data at 1730 hrs. Loss of power and data informing the ECU of the aircraft's speed may have led to the loss of fault data on channel A. The loss of the EIU stopped further error indications relating to this engine from appearing on the cockpit displays and removed the ability to restart the No 2 engine in the event of it stopping.

Twelve major faults were stored for channel B, all were connected with the incident, fault indications started at 1725 and finished at 1730 hrs. Faults occurring before these, such as the thrust reverser fault indicated on the PFR at 1722 hrs, were lost since only 12 faults can be stored. Eight sensor faults were stored indicating the loss of temperature, pressure and position sensors, the 4 other faults stored were power and control faults.

A thrust reverser deploy/stow switch signal fault was stored at 1725 hrs. Also stored at 1725 hrs were indications that the ECU was over temperature and that proper control of its cooling air supply had been lost. At 1730 hrs the ECU stored a fault indication that one of its 115V supplies had failed, this supply is protected by circuit breaker 49VUA3 and is one of three supplies for the igniters on both engines.

Technical examination

Figure 2 shows the cowlings on the right-hand side of the No 2 engine after D-AIPK's return to Heathrow. From the heavy streaking emerging from every aperture aft of the fan case front face, it was apparent that there had been extensive combustion within the engine compartment in flight. Figure 3 is a closer photograph of the lower portion of this engine compartment with the cowling door open, showing the starter air duct, the position of the air turbine starter, the ECU and the electrical harnesses connected to the ECU. In this design, all the ECU's electrical signalling connections are mounted on this lower face of the ECU box. Not visible in these photographs is the extensive heat damage to the inside face of the cowling door close to the air turbine starter and the ECU electrical harnesses.

It was immediately apparent that the source of the heating in the No 2 engine compartment had been the air turbine starter, which is attached to the aft face of the engine accessory gearbox and which, during engine starting, drives this gearbox and thus the engine's HP shaft. The system design is that the start valve stays open until the HP shaft reaches 50% N2, at which point the air start valve closes and the air turbine starter disengages. This air turbine starter (s/n 25176) had suffered massive overheating and so, as an initial step, the operation of the start valve was examined; it is the start valve which admits air from the aircraft's pneumatic system to operate the air turbine starter, which is purely mechanical and has no electrical connections. The system was functioned with the APU running and the start valve was found to operate normally; when removed, the valve body and mechanism were found to be undamaged.

A BITE (Built-In Test Equipment) check of the engine fire warning system was satisfactory and showed that the system was intact and functional on both engines. Visual inspection confirmed the integrity of the fire detection loops.

Subsequent examinations

The two air turbine starters were later disassembled and examined at the operator's maintenance facility. The starter (s/n 25306) which had failed in the afternoon of the 13th while installed on engine No 1, had not suffered from heat damage and the output shaft was found to have failed at its shear neck. When the pawl-and-ratchet clutch was examined, it was found that slivers were missing from the ends of all three pawls. According to the manufacturer's representative the indications were, therefore, that this starter had suffered a 'high speed running engagement' but that the failure had been 'benign' in that none of the fractured pieces of pawl were substantial enough to jam the clutch mechanism. Given the automated nature of the A320 engine start sequence, such a 'high speed running engagement' is generally attributed to fluctuating pneumatic duct pressure, leading to disengagement and subsequent heavy re-engagement of the clutch pawls. The aircraft's APU was replaced on 23 December 1992 in order to cure a history of producing unstable duct pressure which had started in October 1992.

The air turbine starter (s/n 25176) from the No 2 engine, by contrast, showed evidence of massive overheating and the loss of all lubricating oil. This had resulted in the release of the steel turbine wheel from its bearings and this wheel had then advanced into its air inlet plenum, demolishing the stator assembly, which is made of aluminium alloy. The overheating had occurred due to the loss of one complete pawl from the pawl-and-ratchet clutch and this pawl, found in two main pieces, had jammed the clutch mechanism. Thus, following the closure of the start valve at 50% N2, the starter's epicyclic train and turbine wheel had continued to be back-driven by the engine gearbox, generating large amounts of heat, until the failure of the turbine bearings and the release of the turbine wheel. The timing of the ECAM messages and the streaking on the nacelle demonstrate that this occurred while the aircraft was in flight.

The thrust reverser portion of the engine wiring harness was examined by the manufacturer of the engine nacelle. This showed that heat damage to the harness in proximity to the ECU had resulted in a number of electrical 'shorts'; the wire manufacturer assessed that this pyrolysis of the insulation would require localised temperatures of at least 750°F (399°C).

The airframe manufacturer considers that, of the multiple electrical 'shorts', the most likely to have resulted in the No 2 ECU reducing engine thrust to idle was one involving position signalling from the thrust reverser system. The absence of a fire warning would be attributable to neither zonal nor local temperature being high enough within the engine compartment for the fire detection loop to be triggered.

Corrective action

In October 1989, a similar incident occured to another A320, G-BUSC. In this incident, there had been a pawl failure similar to that in D-AIPK, also leading to overheating of the air turbine starter, although with less internal damage within the starter than was the case in D-AIPK. The same phenomenon of physical damage to the ECU electrical harnesses was noted, again to a lesser extent than in D-AIPK.

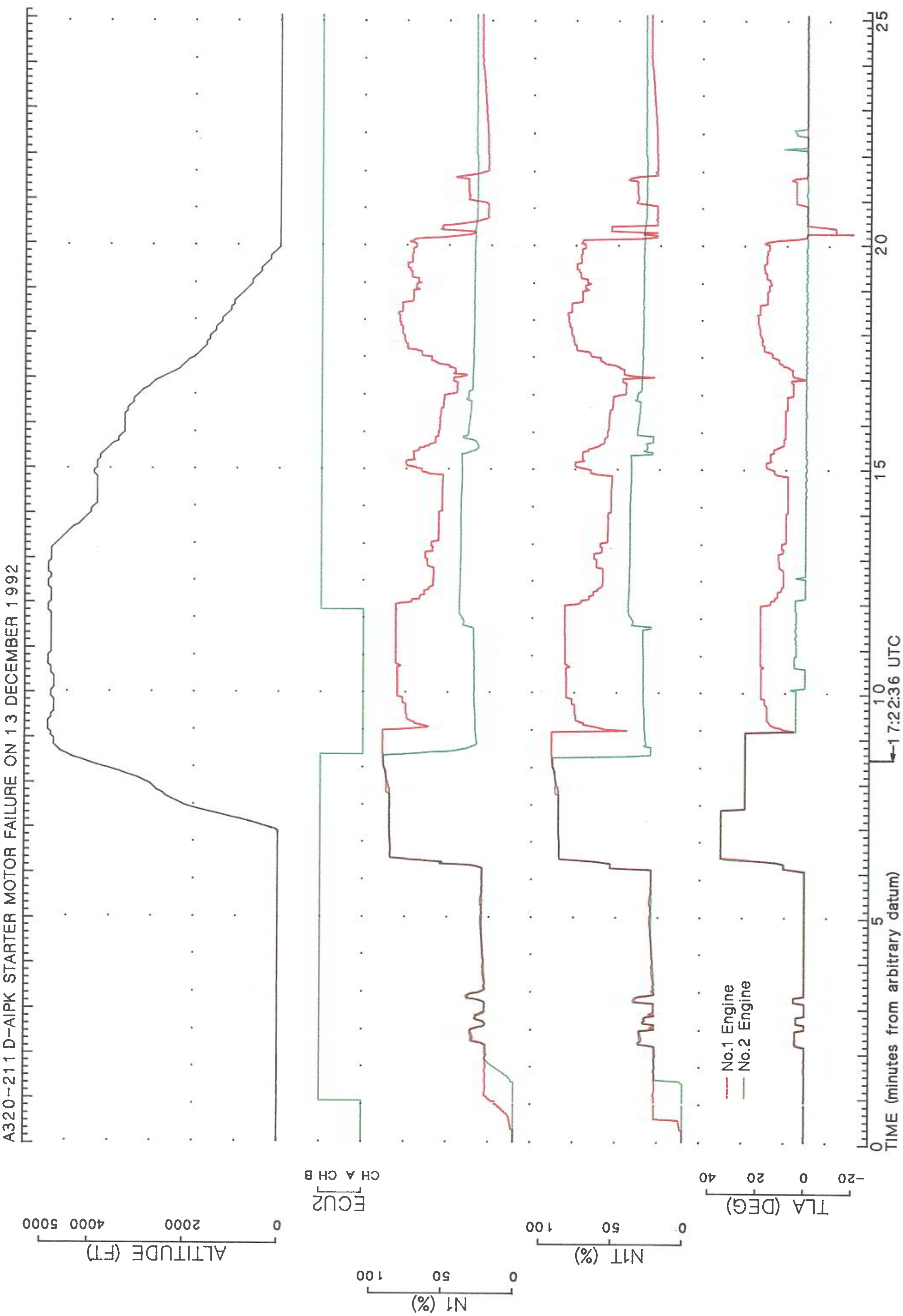
In July 1991 the engine manufacturer introduced Service Bulletin, CFM SB 80-003, which provided for rework of the air turbine starter. This rework involved the addition of a retaining plate to the pawl-and-ratchet clutch so that, if a pawl were released, such as in a 'high-speed running engagement', it could not move into a position in which it would jam the clutch mechanism. At the time of the incident to D-AIPK, the air turbine starter (s/n 25176) on the No 2 engine had not been reworked. The manufacturer of the starter indicates that, to date, the Service Bulletin has been effective in eliminating this particular 'jamming' mode of failure. According to the starter manufacturer, as of June 1993, of the 650 starters supplied approximately 200 were believed to have had the Service Bulletin incorporated.

Given the success record of the Service Bulletin modification, the potential serious consequences of a turbine starter overheat and the vulnerability of the ECU the AAIB has made two Safety Recommendations:-

93-62 It is recommended that the CAA liaise with the DGAC in order to confer mandatory status on the Service Bulletin, CFM SB 80-003, which provides for rework of the air turbine starter on CFM56-5 engines. (Issued 23 November 1993)

93-63 It is recommended that the CAA liaise with the DGAC and review, for the CFM56-5 engine design, the protection from fire and overheat afforded to the Engine Control Unit (ECU) and the associated wiring harnesses. (Issued 23 November 1993)

Figure 1


A320-211 D-AIPK STARTER MOTOR FAILURE ON 13 DECEMBER 1992
ALTITUDE (FT)
0
2000
4000 5000
ECU2
CH A CH B
N1 (%)
0
50
100
N1T (%)
0
50
100
TLA (DEG)
-20
0
20
40
No.1 Engine
No.2 Engine
TIME (minutes from arbitrary datum)
0
5
10
15
20
25
17:22:36 UTC

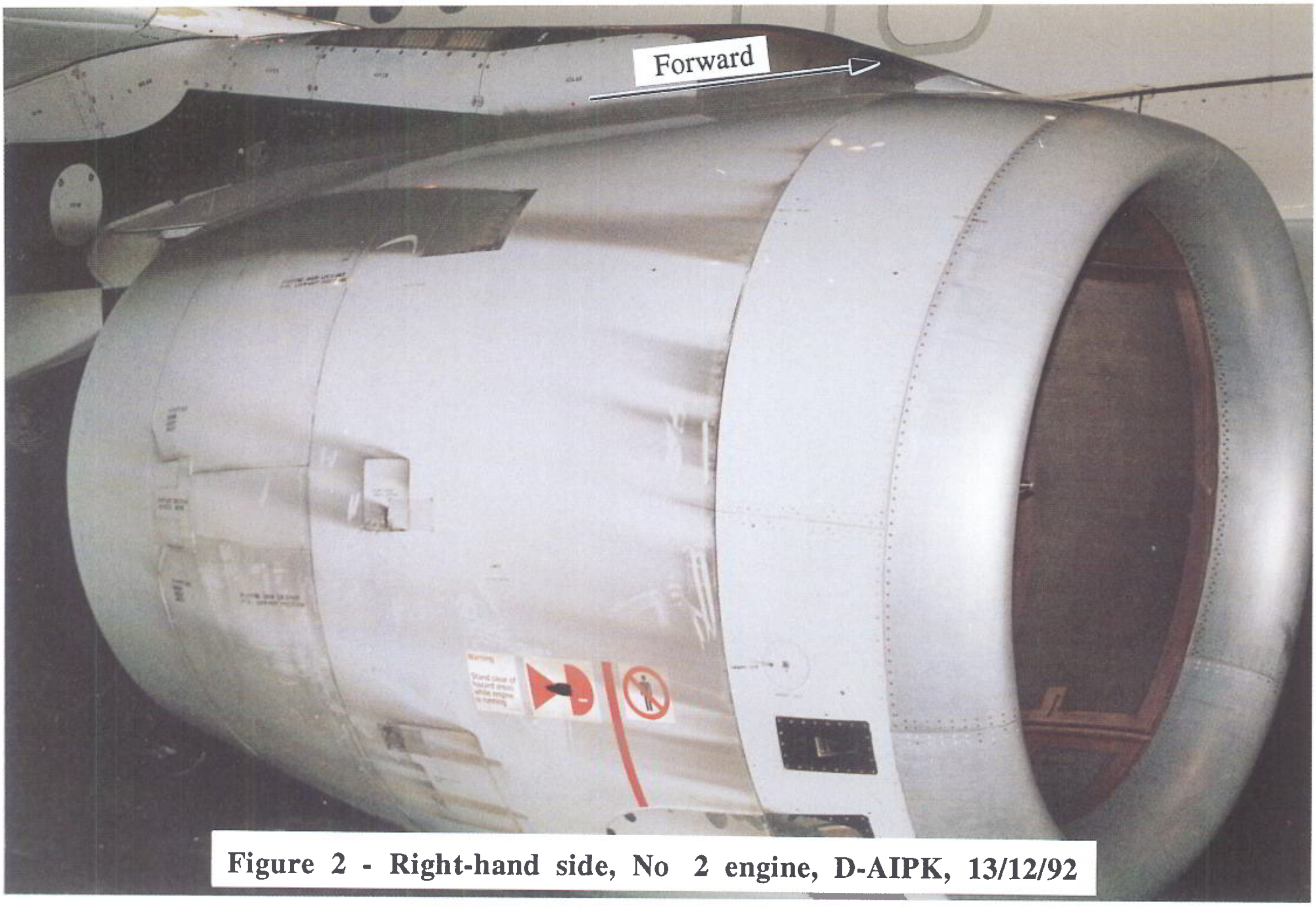


Figure 2 - Right-hand side, No 2 engine, D-AIPK, 13/12/92

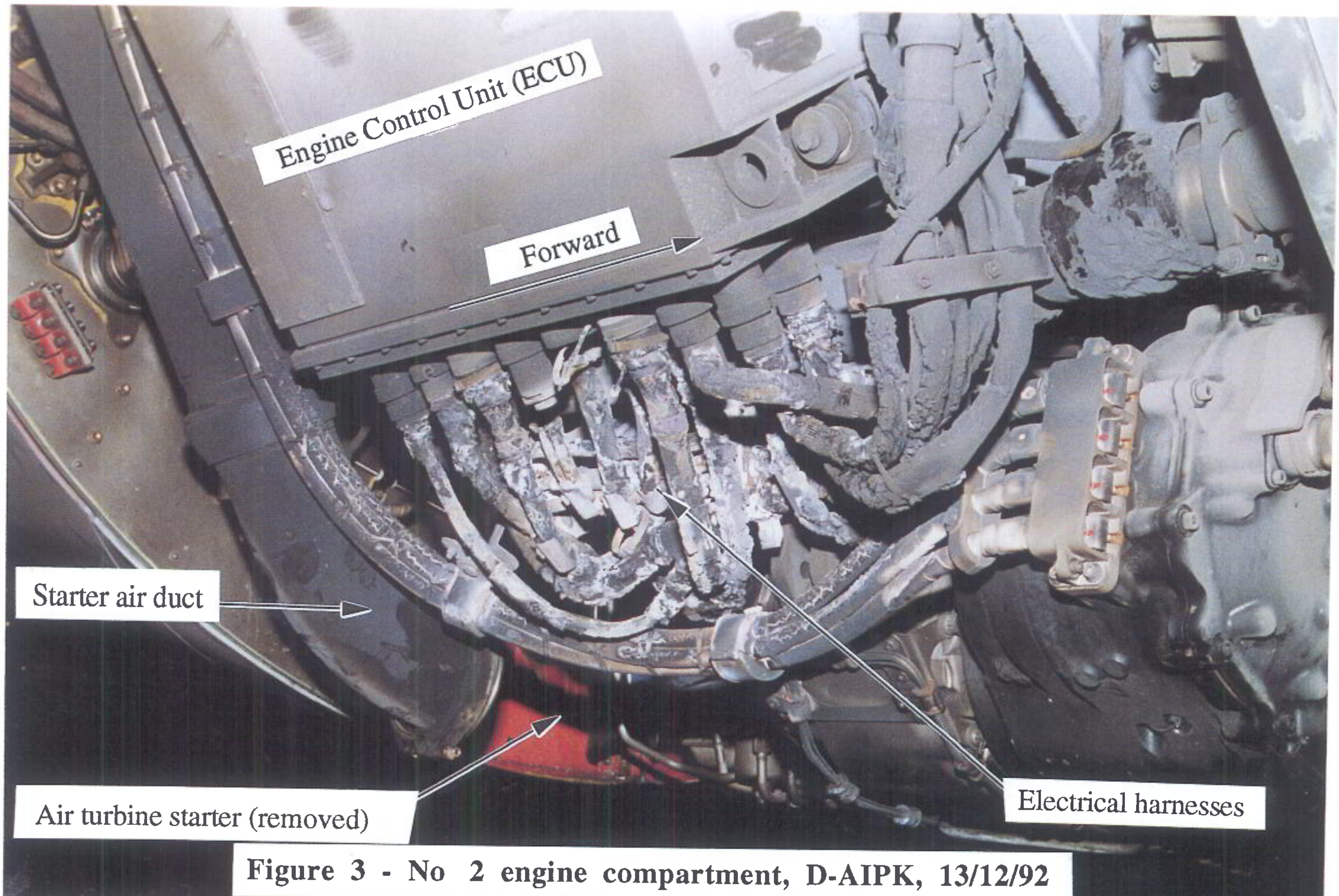


Figure 3 - No 2 engine compartment, D-AIPK, 13/12/92