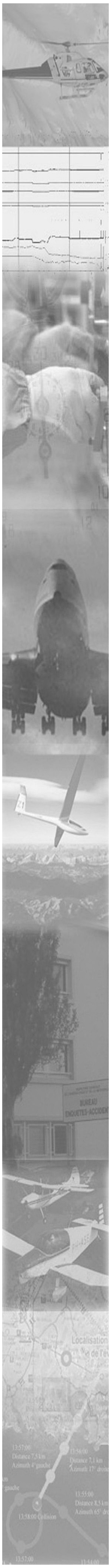
MINISTERE DE L'EQUIPEMENT DES TRANSPORTS ET DU LOGEMENT - INSPECTION GENERALE DE L'AVIATION CIVILE ET DE LA METEOROLOGIE - FRANCE



BEA

Accident on 25 July 2000 at “La Patte d’Oie” in Gonesse (95) to the Concorde registered F-BTSC operated by Air France

Interim report (10/07/2001)

f-sc000725ae2

FOREWORD

This document updates the progress made on the technical investigation as of 10 July 2001, adding to the preliminary report and the interim report already published. Only updated and new paragraphs are included and their numbering is consistent with those of the previous reports.

The investigation is continuing, research has not yet been completed and some elements may be further modified. Only when all of the work is completed will it be possible to draw conclusions on the circumstances and causes of the accident.

In accordance with Annex 13 of the Convention on International Civil Aviation, with EC directive 94/56 and with Law N°99-243 of 29 March 1999, the analysis of the accident and the conclusions and safety recommendations contained in this report are intended neither to apportion blame, nor to assess individual or collective responsibility. The sole objective is to draw lessons from this occurrence which may help to prevent future accidents or incidents.

SPECIAL FOREWORD TO ENGLISH EDITION

This report *has* been translated and published by the Bureau Enquêtes-Accidents to make its reading easier for English-speaking people. As accurate as the translation may be, the original text in French is the work of reference.

Table of Contents

Glossary

ADP	Aéroports de Paris (Paris Airports Authority)
AJ	Adjustable Jet
BAE	British Aerospace
BEA	Bureau Enquêtes-Accidents
CAA	Civil Aviation Authority (UK)
CAM	Cockpit Area Microphone
CC	Cabin Crew
CEAT	Toulouse Aeronautical Test Centre
CG	Centre of Gravity
CVR	Cockpit Voice Recorder
EADS	European Aeronautic Defense and Space
FC	Flight Crew
FDAU	Flight Data Acquisition Unit
FDR	Flight Data Recorder
FE	Flight Engineer
FF	Fuel Flow
FO	First Officer
FOD	Foreign Object Damage
ft	Feet
GPWS	Ground Proximity Warning System
HP	High Pressure
kt	Knots
LP	Low Pressure
MTOW	Maximum Take Off Weight
N1	Low Pressure Turbine Rotation Speed
N2	High Pressure Turbine Rotation Speed
NTSB	National Transportation Safety Board
P/N	Part Number
P7	Jet Exhaust Pressure
PF	Pilot Flying
PFCU	Power Flight Control Unit
Psi	Pounds per Square Inch
QNH	Altimeter setting to obtain Aerodrome Elevation when on the Ground
TCU	Throttle Control Unit
TRE	Type Rating Examiner
UTC	Universal Time Co-ordinated
VR	Rotation speed

SYNOPSIS

Date and time
Tuesday 25 July 2000 at 14 h 44[(1)]

Aircraft
Concorde
registered F-BTSC

Site of accident
La Patte d'Oie in Gonesse (95)

Owner
Air France

Type of flight
Charter flight
Flight AFR 4590

Operator
Air France

Persons on board
Flight Crew: 3
Cabin Crew: 6
Passengers: 100

Summary

During takeoff from runway 26 right at Roissy Charles de Gaulle Airport, shortly before rotation, the front right tyre (tyre n° 2) of the left landing gear ran over a strip of metal which had fallen off of another aircraft and was damaged. Debris was thrown against the wing structure leading to a rupture of tank 5. A major fire, fuelled by the leak, broke out under the left wing. Problems appeared shortly afterwards on engine 2 and for a brief period on engine 1. The aircraft took off but was able neither to climb nor accelerate. The crew noticed that the landing gear would not retract. At a speed of 200 kt and a radio altitude of 200 ft, the aircraft flew for about one minute. Engine 1 then lost power, the angle of attack and bank increased sharply. The thrust on engines 3 and 4 fell suddenly. The aircraft crashed onto a hotel.

Consequences

	People			Equipment
	Killed	Injured	Uninjured	
Crew	9	-	-	Destroyed
Passengers	100	-	-	
Third parties	4	6	-	

[1] Except where otherwise noted, the times shown in this report are expressed in Universal Time Co-ordinated (UTC). Two hours should be added to obtain the legal time applicable in France on the day of the occurrence.

UPDATE ON THE INVESTIGATION

After the publication of the preliminary report on 31 August 2000 and of the interim report on 15 December 2000, the investigation has continued, following up the four main subject areas:

- wreckage,
- conduct of flight and aircraft performance,
- previous events, certification and regulations,
- technical research,

in close co-operation with the representatives of the investigative organisations and companies concerned, and in co-ordination with those responsible for the judicial investigation.

The technical investigators held a working meeting with the representatives of Continental Airlines at the headquarters of the NTSB in Washington. They have completed their work on the wreckage, in particular on the left side of the aircraft (dry bay, wing, landing gear well). Examinations of the engines, the pieces of tank 5 and the landing gear, carried out within the context of the judicial investigation, and subject to the corresponding procedural constraints, have been completed. Examinations of the tyre debris and the FE panel, carried out in the same context, are continuing. The technical investigators have requested supplementary examinations of pieces of tank 5. The technical investigators have, with Goodyear, carried out taxi tests of a tyre over a metallic strip similar to the one found on the runway after the accident.

Work on the causes of the destruction of tank 5 and on the ignition and development of the fire have continued. This is not yet complete.

The Commission of Inquiry has held three further meetings in the course of which they have been informed of the progress of the investigation and have discussed and approved the draft of the second interim report. Several of its members have participated in the BEA's work.

At this stage of the investigation, nothing has been brought to light that contradicts the following general scenario:

The Concorde taking off from runway 26R at a speed of 175 kt ran over a strip of metal from a DC 10 that had taken off a few minutes before. This strip cut the tyre on wheel n° 2 of the left main landing gear. One or more pieces of the tyre were thrown against the underside of the wing at the level of tank 5. This led to the rupture of the tank as part of a process, currently under study, which appears to associate the deformation of the tank wall and the propagation of the shock wave through the kerosene. A significant leak resulted from this. The escaping kerosene was swirled around in the turbulence around the landing gear and caught fire. The causes of the combustion are still being researched. Engines 1 and 2 then encountered severe problems through the hot gases caused by the combustion of the kerosene. The aircraft took off with a very large stabilised flame that caused structural damage throughout the flight. The engine 2 fire alarm came on, and the crew carried out the engine fire procedure. Engine 1 recovered an almost normal level of thrust. The aircraft was flying at low speed and remained at a low altitude. The crew noticed that the landing gear would not retract, apparently because of a malfunction of the left door, the latter being due to damage caused either by impacts resulting from the tyre's destruction, or by the flames. The crew mentioned a possible landing at Le Bourget aerodrome. The loss of power on engine 1 occurred a few seconds later because of the ingestion of a mixture of hot gases/kerosene and internal damage caused by the previous ingestion of structural debris. Aircraft angle of attack and bank then increased sharply; control of the aircraft was lost as a result of a combination of thrust asymmetry, profound thrust-drag imbalance and, perhaps to structural damage caused by fire. The thrust of engines 3 and 4 fell suddenly, apparently due to a voluntary reduction associated with airflow distortion. The aircraft crashed.

6 - AIRCRAFT INFORMATION

6.2 Landing Gear

6.2.1 General

The Concorde has a nose gear, an auxiliary gear situated at the rear of the fuselage and two main landing gears, each with a bogie with four wheels. The bogies are equipped with a system that detects under-inflation of a tyre and transmits a visual signal to the cockpit. This system lights two red TYRE warning lights on each of the pilots' instrument panels and lights a WHEEL warning light on the right pilot instrument panel above the landing gear control lever. An amber TYRE warning light also lights up on the engineer's panel.

This detection system is inhibited when the speed of the front wheels is less than 10 kt or when their direction is over three degrees and none of the thrust levers is in full forward position. The red TYRE warning lights are inhibited when the indicated airspeed is above 135 kt.

The detection system is self-monitoring. Lighting of a yellow SYSTEM warning light situated on the engineer's panel (next to the amber TYRE lamp) indicates that the self-monitoring mode has detected a fault in the under-pressure detection system.

6.2.2 Landing Gear Retraction

Landing gear retraction is electrically controlled by a lever situated on the pilot's instrument panel (three-position lever: up, neutral, down). It is activated by hydraulic pressure from the Green system. There is no emergency system for gear retraction; the Yellow hydraulic system is only used for extension, in case of failure of the Green system.

The landing gear control lever can only be moved from the "down" position to the "up" position on condition that electrical power is supplied to it, which requires that the left landing gear shock absorber be uncompressed. The retraction sequence then begins, the "doors" warning lights illuminate and remain lit all the time the doors are opening.

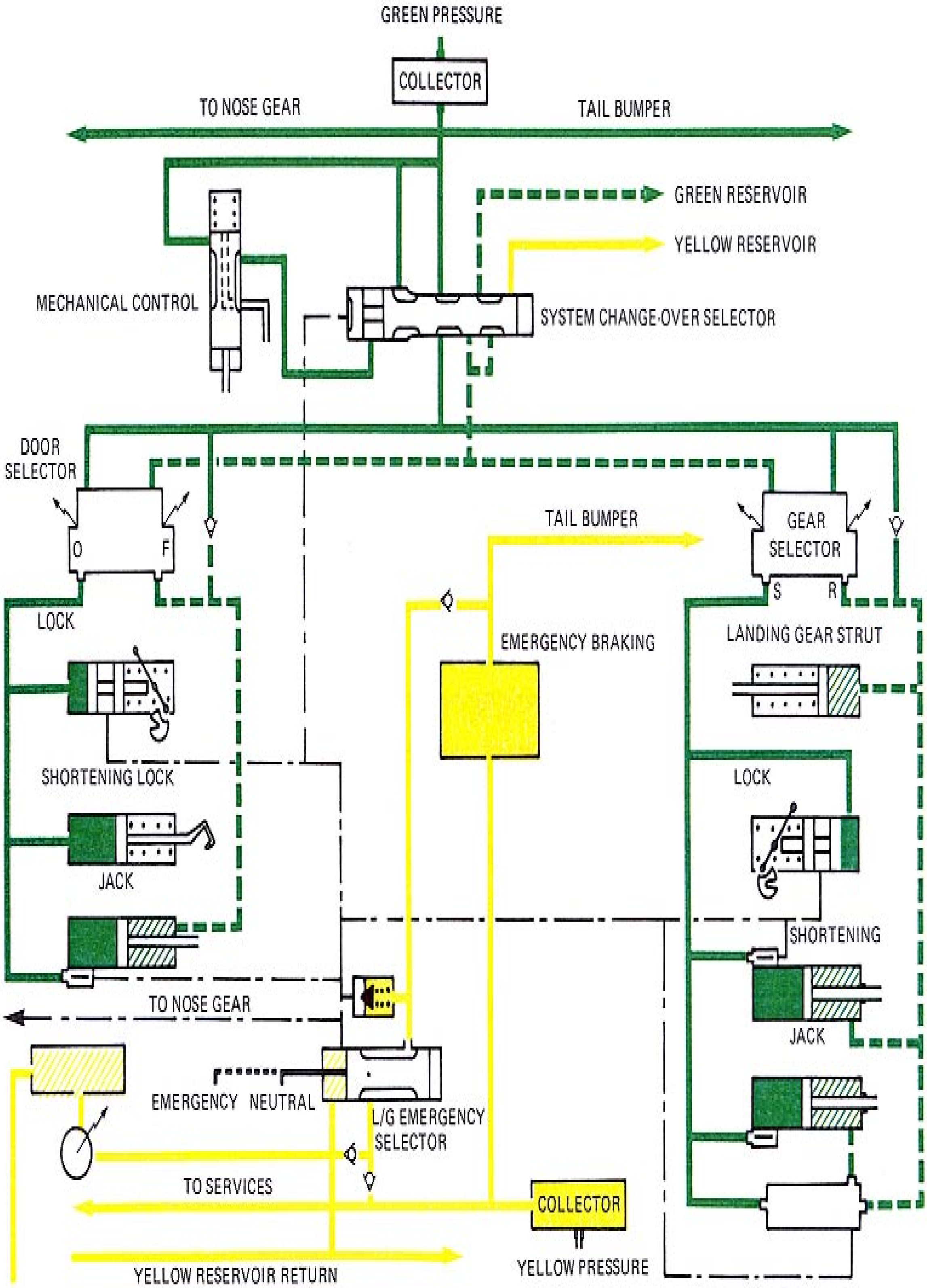


Figure 1: Hydraulic systems for landing gear operation

The “up” position initiates gear door opening, the doors being kept open by hydraulic pressure throughout the retraction sequence. The wheels are automatically braked. When all of the doors are seen to be open[2], the following conditions are checked:

perpendicularity of the bogies[3],
nose gear centring [4].

When these conditions are met, the hydraulic pressure is distributed towards the landing gear locks and the retraction jacks[5] then the landing gear actuating cylinder.

During retraction of the main landing gear, the shock absorbers are retracted into the gear strut to allow it to be stowed in the landing gear well. When the gear is locked in the up position, door closing is ordered. The gear selector is then placed in “neutral” position to cut off electrical and hydraulic power.

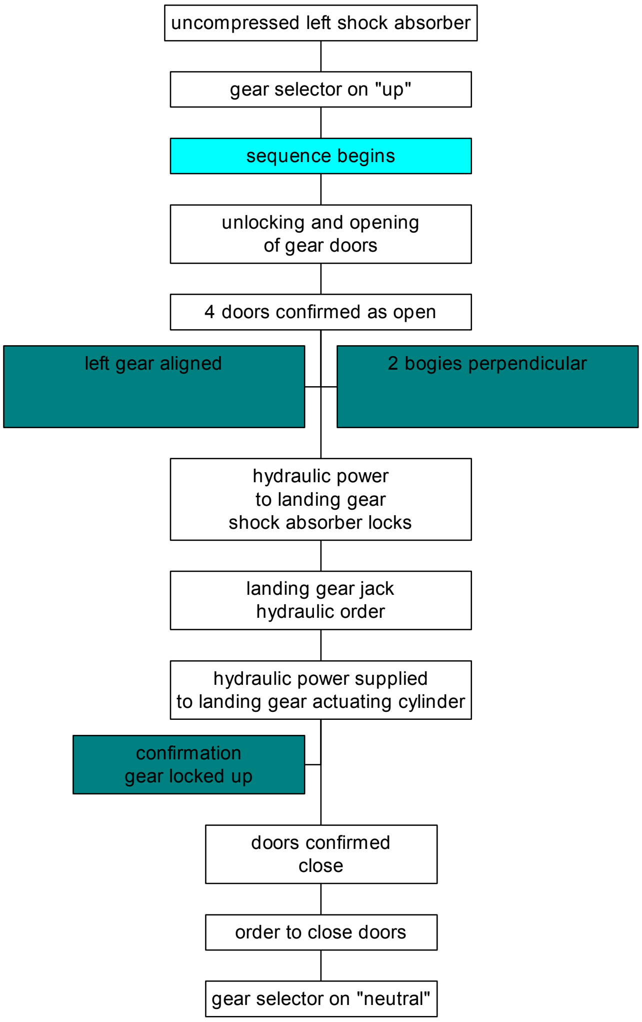


Figure 2: Gear retraction cycle

Note: a complete gear retraction sequence lasts about twelve seconds, divided in the following way: two for door opening, eight for gear retraction, eight for door closing.

6.4 Engines

6.4.4 Fire Protection

The fire detection system consists of two loops designed so as to detect:

- a fire around the engine

and/or

- a torch flame type fire around the combustion chamber.

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[2] If one of the «door open» sensors is destroyed, the information transmitted is «the door is not open» and the gear retraction sequence cannot begin.

[3] The perpendicularity is ensured by two independent pneumatic cylinders filled with nitrogen.

[4] This centring, which is purely mechanical, is performed by a finger-cam assembly.

[5] Gear retraction continues even if the retraction jack is defective.

Each loop includes in series a sensing assembly around the forward part of the reactor, a sensing device around the rear part (these two devices are calibrated for an air temperature above 600 °C) and an intermediate sensing device around the combustion chamber.

The two loops must detect the fault simultaneously to set off the ENGINE FIRE warning. This results in a red flashing warning light lighting up on the fire handle of the engine in question, accompanied by an aural alarm (chime), then by a gong and the illumination of the corresponding red ENGINE warning light on the Main Warning System.

Actuating the fire handle leads to closure of:

- the air conditioning bleed valve,
- the hydraulic shut-off valves,
- the HP and LP fuel valves,
- the reheat fuel valves,
- the secondary air flap,
- the auxiliary nacelle ventilation flap.

The dual head extinguishers are activated by two push buttons (two strikes) located behind each fire handle.

Note: the red warning light in the Main Warning System is also associated with alarms for low oil pressure, engine TCA overheat, and detection of liquid in the dry bays.

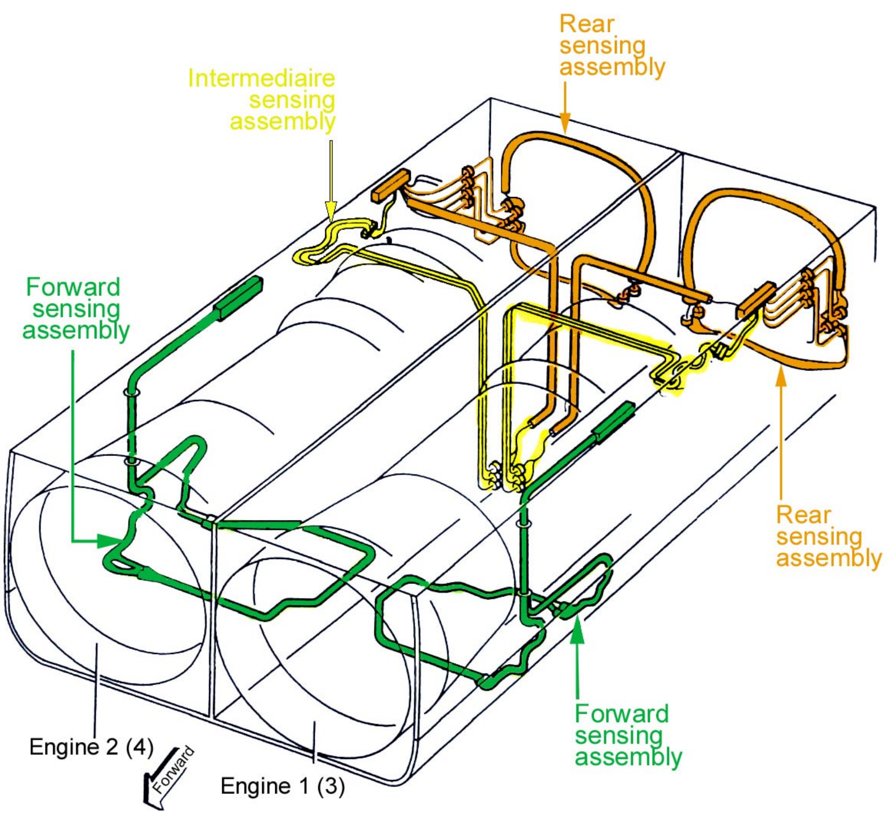

Figure 3: Diagram of the Fire Detection System (each sensing device integrates the two detection loops)

6.7 Aircraft systems

6.7.1 Flight Controls

There are three groups of flight controls, related to the rudder[(6)], inner elevons and the median and outer elevons.

The rudders are hydraulically activated by twin spool power flight control units (PFCU), each of the spools being supplied by the main Blue and Green hydraulic systems, the Yellow system providing backup to either of the other two systems. Each PFCU is controlled by an electrical system (Blue and Green respectively). The Blue system is active in normal operation, the Green system replaces it in case of failure. The PFCU's switch over to mechanical in case of failure of the Green system. Switching of the control systems is managed by Blue or Green comparators, which control PFCU slaving and by the static logic monitor which generates switching.

The electrical control and slave feedback systems for the various groups are independent. However, power to the PFCU synchros is common to the three flight control groups.

6.7.2 Air Conditioning

The air conditioning system consists of four independent groups that receive air at high pressure bled from the engines and condition it by cooling, reheating and desiccation. This air is then used to pressurise the aircraft and ventilate certain equipment.

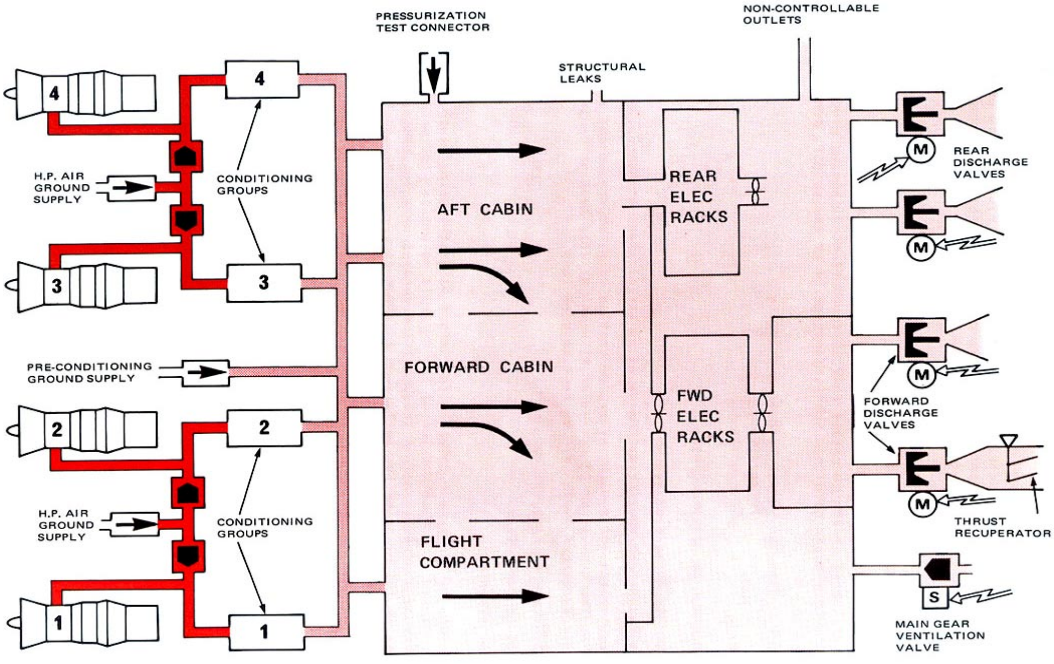

Figure 4: Diagram of the Fire Detection System (each sensing device integrates the two detection loops)

[6] There are two integral rudders.

Each group is supplied by the last stage of the engine HP compressor through a dual bleed and pressure limitation valve. The numbers of the groups are the same as for the engines.

The four bleeds are directed towards a collector. When all of the groups are operating, group 1 supplies the flight compartment, group 2 the forward cabin, and groups 3 and 4 the aft cabin. In case of an engine failure, the collector shares the air between the different areas.

Each group is protected against over-pressure, abnormal increases in temperature or the presence of smoke. When smoke is detected (detector situated at the collector entry) the “SMOKE” warning light lights up on the control panel and the group valve is automatically shut.

11 - FLIGHT RECORDERS

11.2 Cockpit Voice Recorder

11.2.1 CVR Readout

The Fairchild A-100 type CVR is a four-track magnetic tape recorder. The theoretical bandwidth is between 150 Hz and 5 kHz, though it is possible to obtain information up to 8 kHz if the information has a lot of energy.

The four tracks contain recordings of:

- radio communications on tracks 1 and 4,
- communications with the cabin crew on track 1,
- communications with the ground engineer on tracks 1, 2 and 4,
- the CAM on track 3.

The CAM is located in the middle of the upper instrument panel in the cockpit. The control box for test, erase and listening functions is located at the foot of the Flight Engineer’s station. This box includes a microphone that is not connected to the CVR.

11.2.1.1 Time-base

After opening, the tape was read out on a read-out device whose recording function was inhibited and which was equipped with two CVR heads in order to obtain optimum quality.

The recording speed of the tape was adjusted to the speed of the recording. For this, the interference created by the aircraft’s on-board power supply was used (400 Hz). On a real-time spectral representation of the signal, it corresponds to an energy peak of 400 Hz whose exact frequency varies according to the readout speed. This is thus adjusted so that the energy peak is precisely at a 400 Hz value.

However, the value of the frequency of the on-board power supply can fluctuate slightly around 400 Hz during the various phases of flight. For better accuracy, the audio recording was synchronised with the parameter recording.

This synchronisation was carried out mainly by studying the radio communications. In fact, a discreet recorded every second on the FDR changes condition (0 to 1) during a communication. As the speed of the CVR recording influences the length of the communication, the recorders can be synchronised precisely by ensuring that the beginning of the communication recorded on the CVR corresponds to the variation of 0 to1 of the discreet on the FDR, and that the end of the communication corresponds to its return to 0.

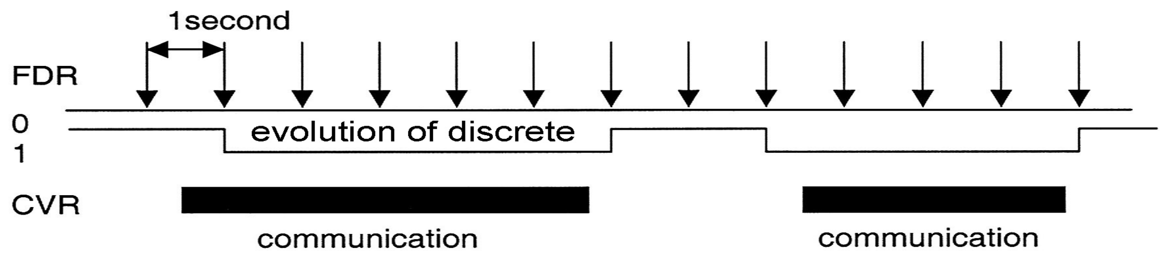

Figure 5: Synchronisation

Finally, the time-base used by the control tower, when validated, was used for the CVR transcript. To this end, the transcript of the radio communications recorded by the CVR was compared with the one made from the tower recording. It should be noted that problems were encountered when determining this time-base: because of a technical problem, the UTC time on each of the tower's two recorders was slightly different.

11.2.1.2 Software Used

a) At the time of the first readout of the recording, a digital copy was made using Samplitude software. This software permits signal visualisation of all four tracks with resolution up to sample level. In addition, it has highly developed filtering capacity to improve the intelligibility of speech. Nevertheless, since the filtering technique can induce phase rotations, all of the spectral analysis was carried out on an unfiltered signal.

Work was carried out on the four tracks simultaneously, which allowed synchronisation of events present on different tracks. The signals were deliberately under-sampled at 44.1 kHz so as not to lose information during copying.

An archive corresponding to a raw copy with no filtering was then made on a compact disc. It includes four files to .wav standard and files specific to the software allowing them to be read out.

b) Three different representations of the signal were studied with Xwaves spectral analysis software. This approach was confirmed with the head of the Air Accidents Investigation Branch (AAIB) flight recorder division, who was present during the last series of tests. By common agreement, the time-frequency representation appeared to be the most useful. The three representations are as follows:

- Temporal representation, commonly used by linguists. Time is on the x-axis and amplitude on the y-axis. This representation is difficult to use in fact, taking into account the presence of a strong background noise and the strong and random signals to be handled.

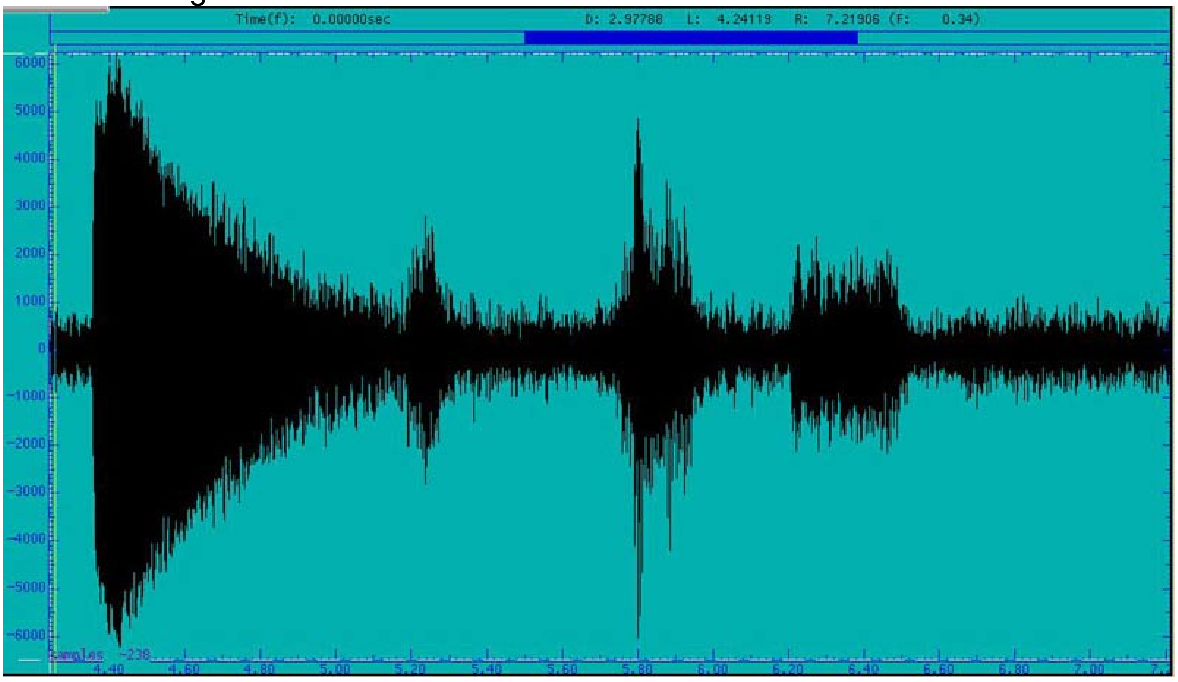

Figure 6: Temporal representation

- The time-frequency representation, where the time is on the x-axis, the frequency on the y-axis and energy in a third dimension represented by the colour. The colour varies from dark blue to white, passing through red and yellow, the white representing the highest levels of energy.

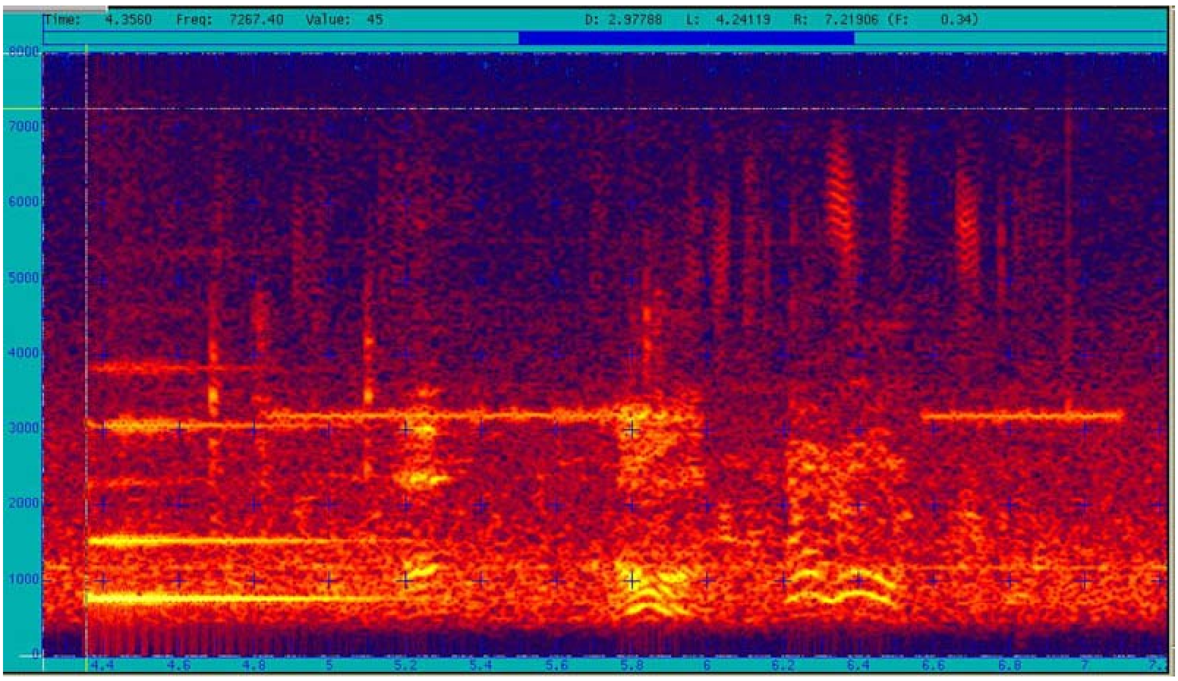

Figure 7: Time-frequency representation

- Frequential representation where the frequency is on the x-axis and energy on the y-axis. This representation makes it possible to know the division of energy in relation to frequency at any given moment of time. It gives a cross-section of the signal in the time-frequency domain.

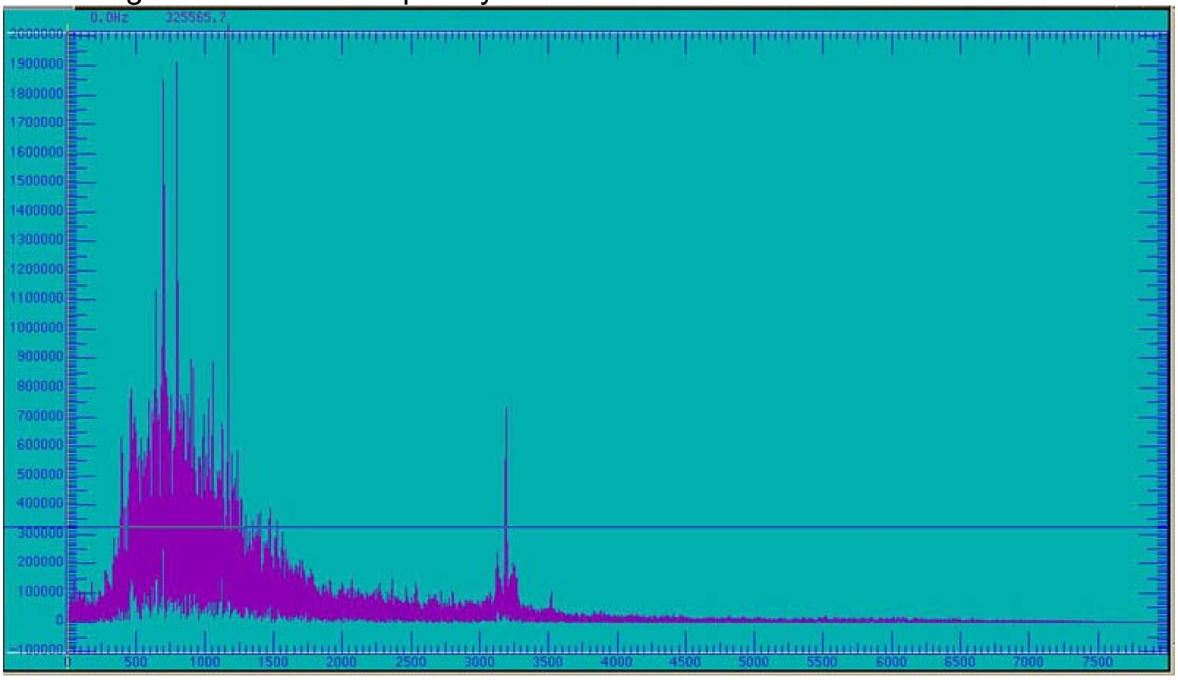

Figure 8: Frequential representation

11.2.2 Transcript of the Recording

The method used to transcribe the recording consisted of faithfully reproducing, almost phonetically, what was heard, without interpretation or extrapolation. However, knowledge of procedures and technical terms currently in use is sometimes very helpful for the comprehension of certain words or parts of words. This was why several aircrew who knew the voices of the crew, the background noise of a Concorde cockpit and the various alarms joined in with this work. In addition, filtering adapted to the flight segment allowing reduction of the parasite background noise was used to improve the intelligibility of the recording.

The beginning of the recording was at 14 h 12 min 23 s. Item 17 on the checklist, “cockpit check” was under way. This was followed by the “pre-start-up” checklist, engine starting, the “post start-up”, “taxi” and “pre-takeoff” check lists. The definitive transcript of the last five minutes of the recording, beginning with the “takeoff briefing” from the “taxi” checklist, is included in appendix 2.

Of the whole thirty minutes on the CVR, the following elements are of note [(7)]:

14 h 13 min 13 s, FE “so total fuel gauge I’ve got ninety-six four with ninety-six three for ninety-five on board”.

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[7] NB: the numbers (❶, etc.) refer to the points on the trajectory included in the preliminary report (see § 9.1 and appendix 5).

14 h 13 min 46 s, FO *“fire protection”*, FE *“tested”.*

14 h 14 min 04 s, FO “ZFWZFCG”, FE “so I’ve got ninety-one nine and fifty-two two”.

14 h 14 min 17 s, Captain “the speed index so V1 a hundred and fifty, VR one hundred and ninety-eight, V2 two hundred and twenty two hundred and forty two hundred and eighty it’s displayed on the left”.

14 h 14 min 28 s, FO “trim”, Captain “it’s thirteen degrees”.

14 h 14 min 53 s, Captain “next the control lever is at fourteen and you’ll have N2 of ninety-seven and a bit”, FE “ninety-seven”.

14 h 22 min 22 s, Captain “ok we’re going to do one hundred eighty-five one hundred that’s to say we’ll be at the… structural limit”, “structural err fifty-four per cent balance (*) see”.

14 h 37 min 51 s, FO “hey, you’ve got the indicators going into Green all the time…”.

14 h 38 min 55 s, FE “you’re right, we’ll stay in Yell… in Green”.

14 h 38 min 59 s, FO “we’ll stay in Green, eh”.

14 h 39 min 04 s, Captain “so the takeoff is… at maximum takeoff weight one hundred eighty tons one hundred which means four reheats with a minimum failure N2 of ninety-eight”, “Between zero and one hundred knots I stop for any aural warning the tyre flash”, “tyre flash and failure callout from you right”, “Between one hundred knots and V1 I ignore the gong I stop for an engine fire a tyre flash and the failure callout”, “after V1 we continue on the SID we just talked about we land back on runway twenty-six right”.

14 h 40 min 19 s, Captain “How much fuel have we used?”, FE “We’ve got eight hundred kilos there”.

14 h 41 min 09 s, FE “Brake temperatures checked one hundred fifty…”. The Captain asks “Is it hotter on the left or the right there?”. The FE answers “it’s about the same”.

14 h 42 min 31 s, Captain *“top”.*

❶ 14 h 42 min 54.6 s, FO *“one hundred knots”.*

14 h 42 min 57 s, FE “*four greens”.*

❷ 14 h 43 min 03.7 s, FO *“V1”*.

14 h 43 min 10 1 s, noise followed, from 14 h 43 min 11 s to 14 h 43 min 13.8 s, by a change in the background noise. In the same time period the FO announces

“watch out”.

❸ 14 h 43 min 13.4 s, message from the controller indicating flames at the rear and readback by the FO.

14 h 43 min 16.4 s, FE *“(stop)”.*

14 h 43 min 20.4 s, FE “Failure eng… failure engine two”.

❹ 14 h 43 min 22.8 s, fire alarm.

14 h 43 min 24.8 s, FE *“shut down engine two”.*

14 h 43 min 25.8 s, Captain *“engine fire procedure”* and in the following second the noise of a selector and fire alarm stops.

14 h 43 min 27.2 s, FO “watch the airspeed the airspeed the airspeed”.

14 h 43 min 29.3 s, fire handle pulled.

❺ 14 h 43 min 30 s, Captain *“gear on retract”*. In the course of the following eight seconds the crew mention the landing gear several times.

14 h 43 min 42.3 s, second fire alarm.

14 h 43 min 45.6 s, FO *“(I’m trying)”,* FE “*I’m firing it”.*

14 h 43 min 46.3 s, Captain “(are you) shutting down engine two there”.

14 h 43 min 48.2 s, FE *“I’ve shut it down”*.

14 h 43 min 49.9 s, FO *“the airspeed”*.

❻ 14 h 43 min 56.7 s, FO “the gear isn’t retracting”.

14 h 43 min 58.6 s, third fire alarm.

Between 14 h 43 min 59 s and 14 h 44 min 03 s, three GPWS warnings are heard and at the same the FO announces *“the airspeed”.*

❼ 14 h 44 min 14.6 s, FO “Le Bourget Le Bourget” then a few seconds later ❽ “negative we’re trying Le Bourget”.

14 h 44 min 31.6 s, end of the recording.

Note: some words in the flight part of the recording, “stop” for example, were doubtful. These portions of the recording were sent to the CNRS linguistics laboratory in Aix-en-Provence. The work on signal filtering and phoneme analysis carried out by the researchers at the lab did not clear up the doubts.

11.2.3 Identification of the Alarms and Noises

In order to determine the origin of the alarms and selector noises heard and to obtain information on the revolving parts of the engines from the recording, a series of measurements were performed on the ground on an Air France Concorde.

11.2.3 1 Procedure

a) Identification of the noise of a selector is based on the comparison of its spectral representation with that of the sound of a known selector. The characteristic elements compared are the duration of the signal, the distribution of the energy in relation to the frequency and the cadence. Certain selector movements imply the generation of several energy peaks. Thus, it is sometimes necessary to move the selector from its initial position, actuate it then release it: the cadence is the time between these peaks.

   For example, in figure 9 below the cadence is of 170 ms, the duration of the first noise is 30 ms, that of the second 40 ms. The spectre located on the left side shows an energy peak around 2,900 Hz which corresponds to release of the selector.

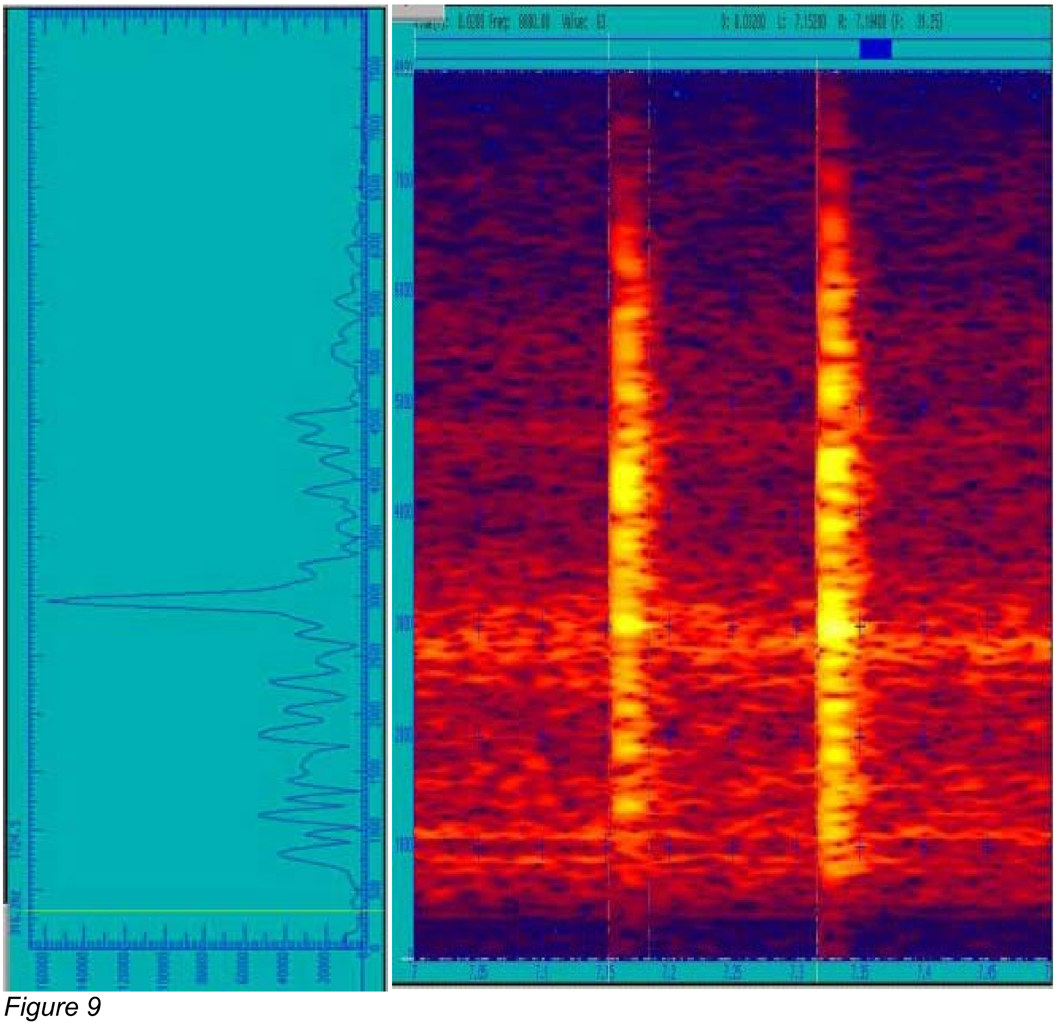


Figure 9

b) It is difficult to compare selector noises if the background noise is not itself comparable. This consistency is even more necessary when the automatic amplification control function attenuates high amplitude recordings in order to avoid saturation of the signal. Thus, the presence of the 400 Hz and its high energy harmonics can alter the signal to be analysed or hide the energy peaks at certain frequencies.

Figure 10 below shows the time-frequency representation of the noise produced by the movement of an identical selector, on the left on a Concorde with a high level of parasites and on the right on F-BTSC.

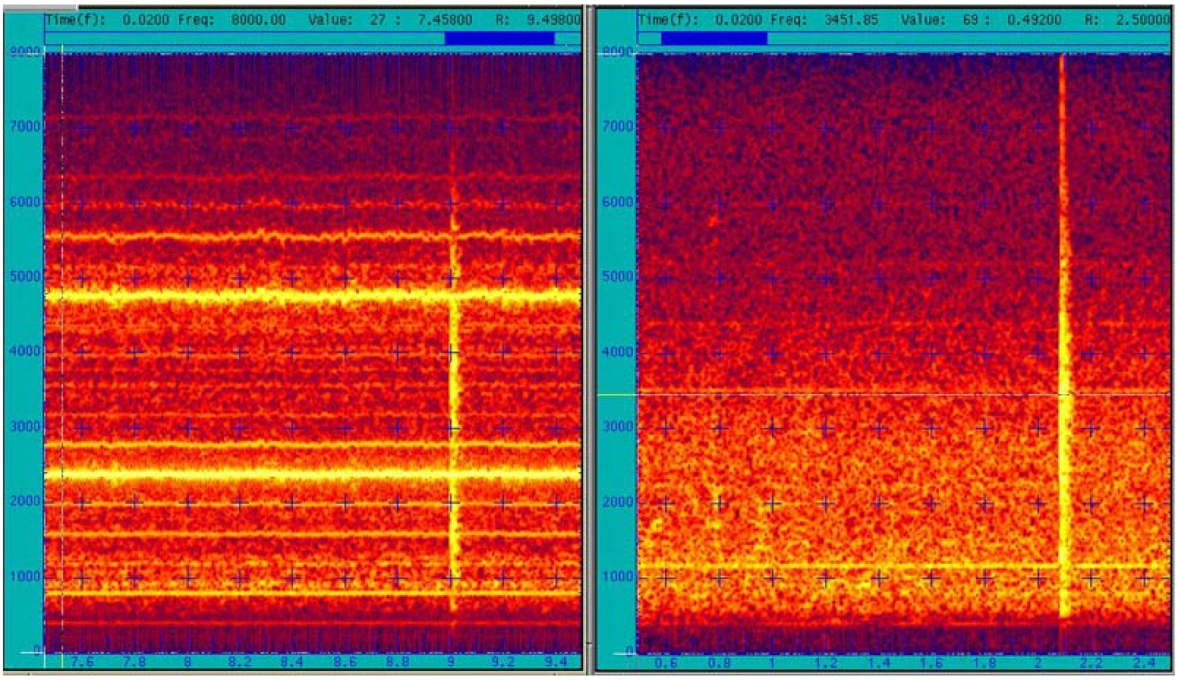


Figure 10

The recording method makes it impossible to reason in absolute values, expressed for example in dB. The terms relative amplitude and non-dimensional energy can be used.

Furthermore, it was necessary to find a test aircraft with background noise similar to that on the accident aircraft.

Equally, the movements of the selectors were performed with and without the fire alarm on. The presence of the fire alarm also meant the person actuating the selectors was under stress.

c) There can be other limitations to the identification of selector, such as:

- The way the selector is moved. The same person may move a selector in several ways. One of the aims of the tests was thus to find a common point in the spectral representations of the movements of the same selector actuated in different ways. In order to validate this common point, several people also actuated the selectors.

- A response in a different frequency for selectors which were notionally identical, as exists in the case of engines, for example. The spectral representations of the movement of each of these selectors were compared to evaluate this parameter.

Engine operation does not, however, have a significant effect on the background noise, as shown by the recordings below (figure 11); the first with engines shut down (left) and the second in flight (right).

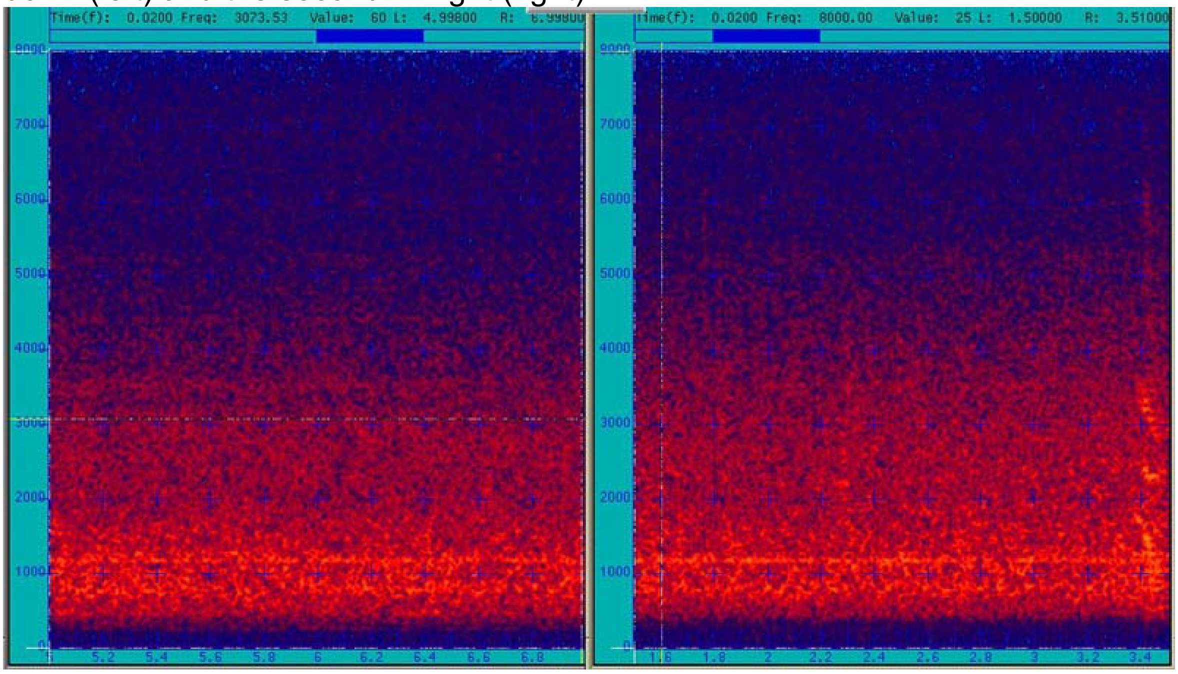


Figure 11

This explains why the analyses did not demonstrate the frequencies related to the behaviour of the engines during spool up or in flight. Equally, the noises specific to taxiing are not perceptible.

d) One factor to be taken into account but which is not quantifiable is human feeling. In reality, the best receivers and filters remain the human ear and brain. They are capable of integrating aspects of spectral representation and thus have the feeling of resemblance even if analysis makes it impossible to get complete similitude.

e) Finally, the range of hypotheses can be reduced thanks to exchanges between crew members. Some selector noises are expected when the pilots carry out a specific procedure.

11.2.3.2 Supplementary Research

11.2.3.2.1 Recordings in flight

To complete the work on measurements, CVR recordings on takeoff were used, even though such recordings are difficult to find since they are normally wiped out after thirty minutes of a normal flight.

The following flights are considered:

- Takeoff of F-BVFC from New York on 14 June 1979,
- Takeoff of F-BVFC from New York, during the ferry flight on 21 September 2000. During this flight, a copy of the CVR was made using the control recording output on the control box. As a result, all four tracks of the CVR are mixed on the copy.

Note: a recording by hand microphone on a normal recorder would not be usable, the measurement system not taking into accounts the structural transmissions.

These recordings did not bring to light any additional information, taking into account the differences in the background noise and the small number of selector movements during these takeoffs.

11.2.3.2.2 400 Hz demodulation

Some vibrations of an aircraft's structure can propagate to the CVR and leave a trace through a modulation of the 400 Hz. Analysis of this frequency then allows for identification of a transitory characteristic and, consequently, knowing the moment when the phenomenon causing the vibration occurred. The following figures were obtained in this way during series of explosive tests on a jumbo jet aircraft on the ground. The time is on the x-axis and the non-dimensional energy on the y-axis.

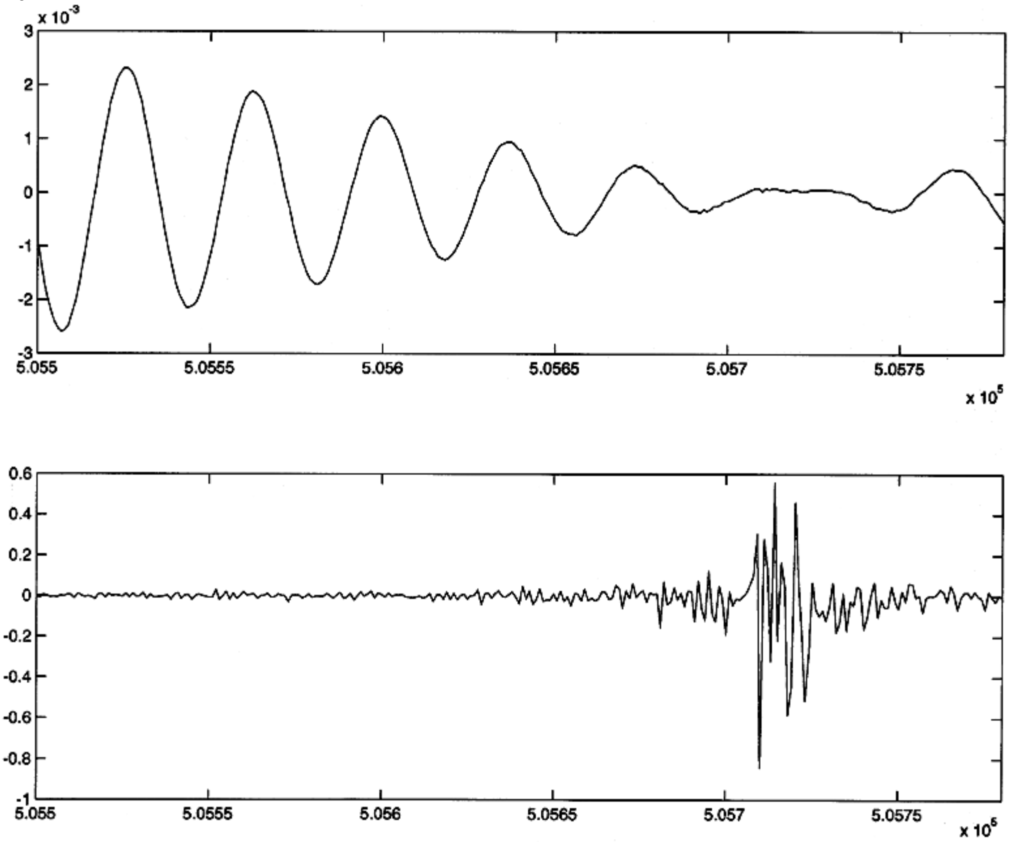


Figure 12

In collaboration with a specialist from the University of Southampton *Institute of Sound and Vibration Research*, research into possible tyre explosion or debris impacts on the structure was carried out using F-BTSC's CVR recording.

This study, carried out using Matlab software did not produce any usable results. It is likely that the possible vibrations were not of sufficient amplitude to register on the signal recorded.

11.2.3.3 Research Results

The detailed results of the research undertaken are given in appendix 1. To summarise, the following facts were deduced from analysis of the recorded noises:

- the selector noise at 14 h 42 min 30.4 s is the click of the thrust levers brought to their stop.
- the selector noise at 14 h 43 min 21.3 s is the movement of the TCU selector that switches from "main" to "alternate".
- the alarm that appears and disappears several times from 14 h 43 min 22.8 s is the engine fire alarm.
- the selector noise at 14 h 43 min 26.2 s corresponds to a reduction on a thrust lever or cutting a HP fuel cock.
- the selector noise at 14 h 43 min 27.5 s corresponds to movement of the electric pitch trim actuators.
- the selector noise at 14 h 43 min 29.3 s corresponds to the pulling of a fire handle.
- the alarm at 14 h 43 min 32.6 s is the forward toilet smoke detection; the cockpit door is open.
- the selector noise at 14 h 43 min 44.7 s is similar to firing the extinguisher with the first shot pushbutton.
- two or three noises between 14 h 44 min 24 s and 14 h 44 min 27 s appear to correspond to a reduction on a thrust lever or shutting a HP fuel cock.

Note: movements of the landing gear control lever are not detected, as is confirmed by the ground recordings.

12 - WRECKAGE AND IMPACT INFORMATION

12.4 Work on the Wreckage

12.4.1 Reconstruction of the Wing and Examination of the Debris

Following a first phase focused on the lower wing around the gear well, a second reconstruction phase centred on the parts of the wing between spars 46 and 72 and between ribs 21 left and right took place from 1 October 2000 to 31 January 2001. This operation was undertaken with the active collaboration of experts from the manufacturers EADS and BAE System, from Air France and from British Airways.

The parts found at the accident site were sorted according to geometrical criteria, so as to create groups of pieces before identifying and positioning them. The pieces of the wing were laid flat on two areas representing the upper and lower wing surfaces. The condition of the wreckage did not, however, allow much useful information to be gleaned for the investigation.

Note: the presence of asbestos released when the accident occurred caused some difficulties, mainly as a result of the need to install special equipment.

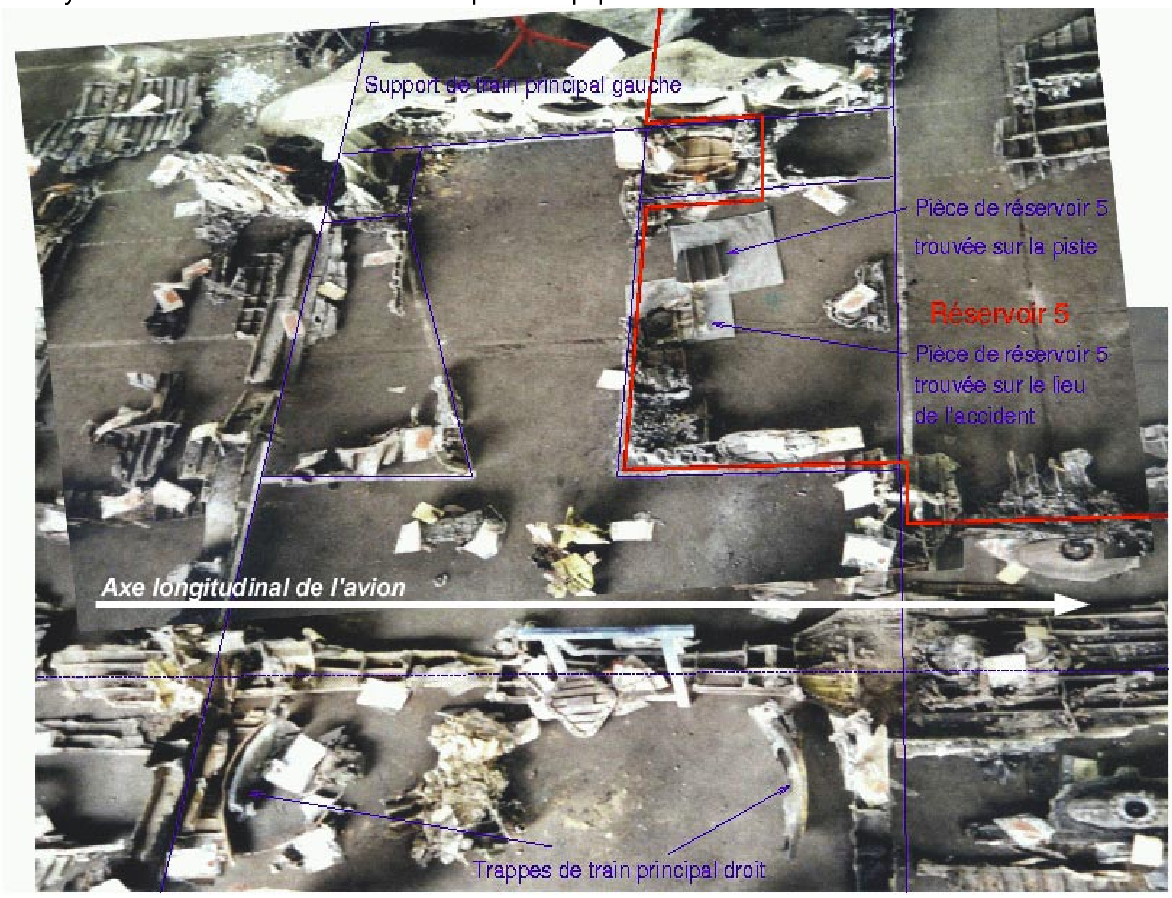


Figure 13: View of the wing reconstruction in the hangar

12.4.1.1 Upper Wing

It was impossible to reconstruct the surfaces located near the landing gear well, nor the majority of the right wing.

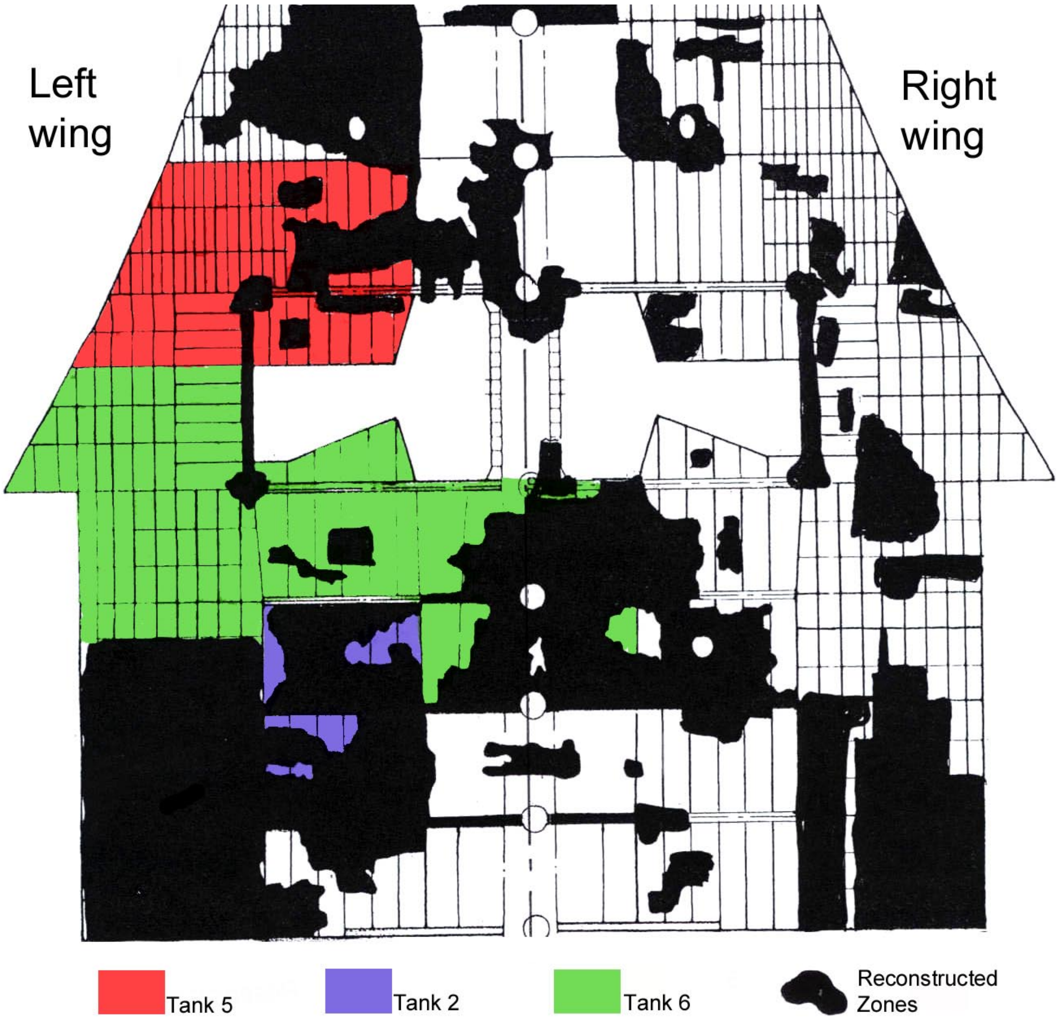


Figure 14: Computerised representation of the upper wing

12.4.1.2 Lower Wing

Almost nothing from tank 5 was recovered. Only one part of the edge of the landing gear well and two sensor locations were still visible near the location of the piece found on the runway.

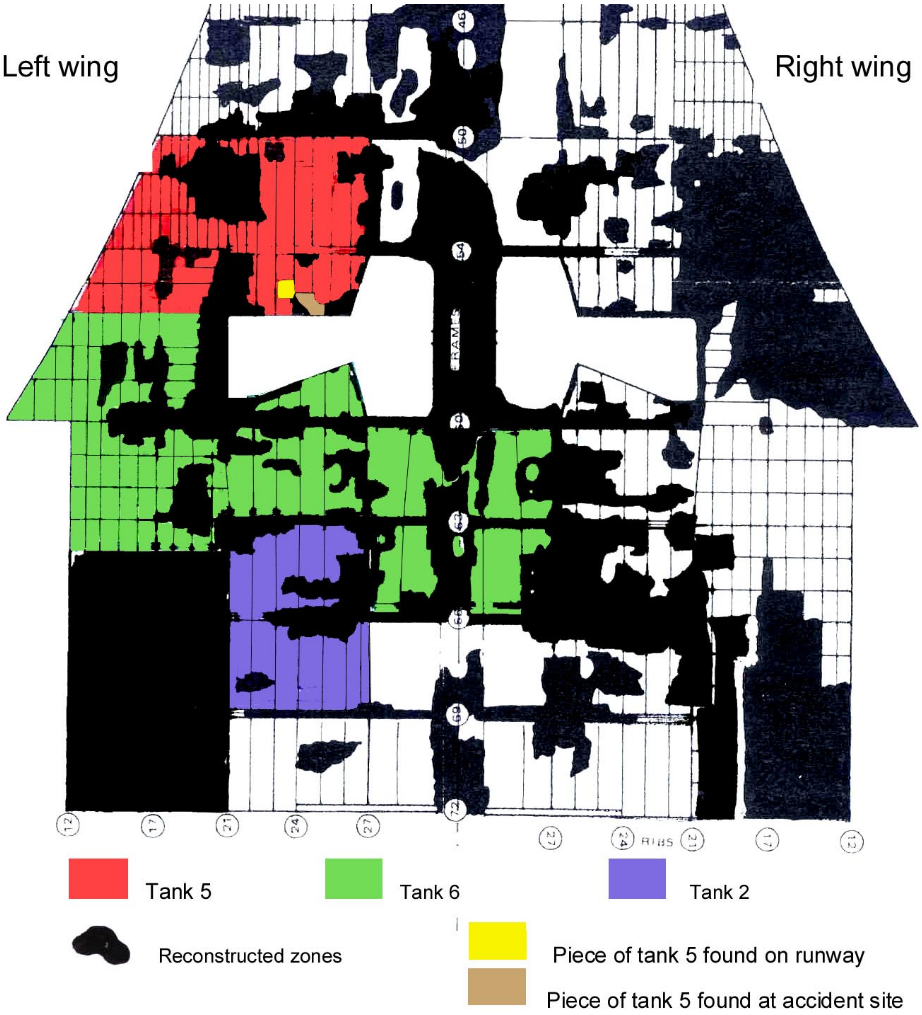


Figure 15: Computerised representation of the lower wing

12.4.2 Aft part of Fuselage

One part of the vertical partition separating tank 11 from the tail was identified. The piping from the Jettison system pass through this partition in order to reach the tail cone where the fuel dump vents are located. The part of this partition on the tank 11 side showed no traces of fire or meltdown. The face located on the cone side did, however, bear marks of soot and combustion. This is consistent with the parts of the cone found melted under the flight path. It is concluded from this that the fire spread to the tail cone via the auxiliary gear door.

12.4.3 Examination of the Seats

The seats in the cockpit were examined. Their position is consistent with the normal position for takeoff, in particular for the FE who had his seat in the forward position. The FE positions himself between the Captain and the FO for takeoff (and for landing), facing the centre instrument panel. From this position he cannot actuate some selectors on the FE instrument panel located laterally at the rear of the cockpit. Apart from the takeoff and landing phases, he sits facing the FE panel.

Note: none of the normal or emergency procedures requires movement of the selectors on the FE instrument panel during takeoff or landing.

12.4.4 Examination of the Dry Bays

12.4.4.1 Description

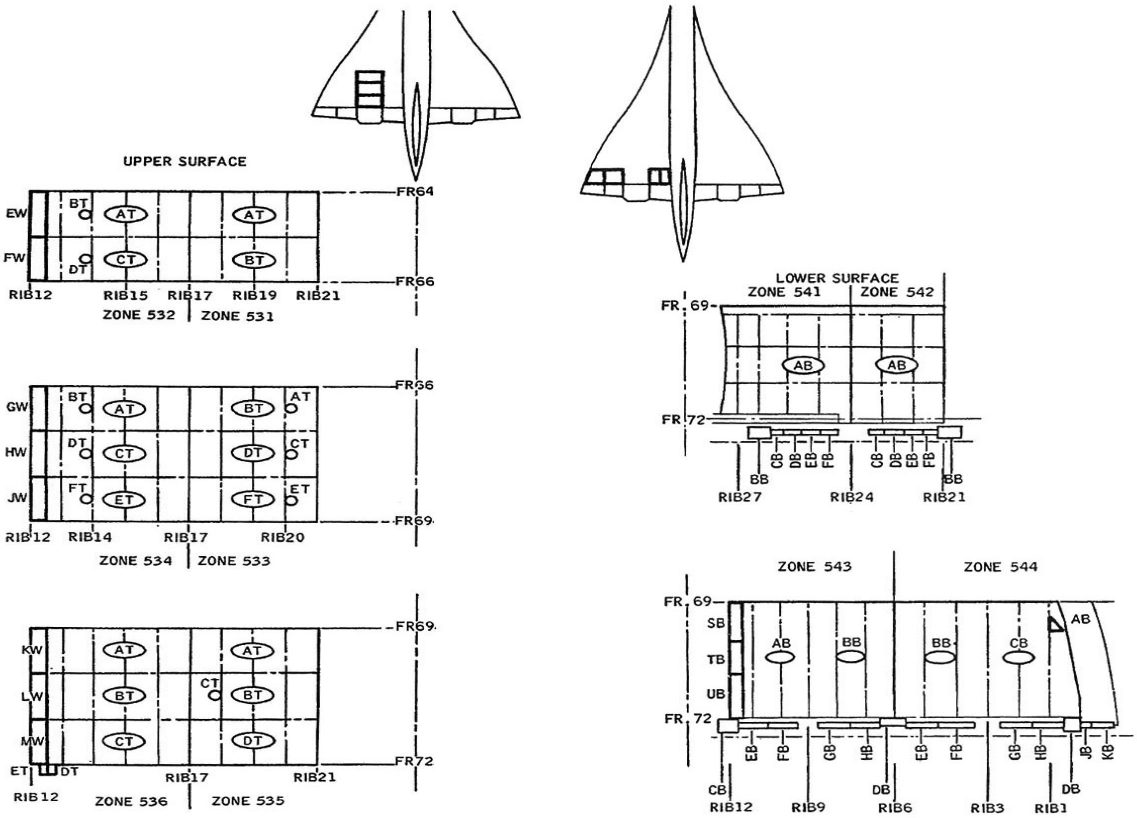


Figure 16: Dry bays

Above each engine compartment there is an area called the dry bay. This area is divided into two parts:

- the forward part, defined by spars 64 and 66 and ribs 12 and 21. The fuel supply lines coming from the feeder tanks as well as, for each engine, a hydraulic/fuel heat exchanger,

- the aft part, between spars 66 and 72 and ribs 12 and 21. This area communicates between spars 69 and 72 and the area stretching from the wing root zone to the wing tip. A fuel/air heat exchanger installed in line with a cold air unit turbine is installed in this area for each engine.

Each dry bay is separated from the engine nacelles by a heat shield. The stainless steel honeycomb structure of the engine cowlings also prevents the wing structure being destroyed in case of an engine fire.

12.4.4.2 Examination

The dry bay located above engines 1 and 2 was examined by the technical investigators and their advisors. At the time of impact, it was broken off between ribs 12 and 21. All of the lateral partitions were destroyed. The heat shield was generally intact except for an indentation on impact at the level of the engine 2 nacelle.

12.4.4.2.1 Forward Part

Door 531BT was still attached to the upper surface of the bay. Door 532CT was found melted into its housing. These two doors provide access to the forward part of the dry bay. This bore no signs of overpressure, there were no traces of flames inside and the partition separating them from the aft part was generally intact. Only the tank 2 LP fuel supply valves were found there.

12.4.4.2.2 Aft Part

Eight doors located on the upper surface and providing access to the aft part of the dry bay were found under the path of the aircraft on the runway centreline extension. None of the doors bore any traces of fire. Two of the doors were equipped with an overpressure valve which opens at a pressure estimated at 200 mbar. The two valves were closed and door 535AT was bulged out as a result of overpressure directed from the inside to the outside. The valve opening rods had buckled under the effect of the distortion, which shows that the valves had no time to open. Lower surface door 541AB, which communicates with the aft part of the dry bay, was also found in the runway extension area. The section of the wing surrounding this door was found at the crash site. Both parts bore traces of soot clearly indicating the passage of the flame over the lower surface of the wing.

The air ducts located between the air/fuel heat exchanger and the engine 2 CAU were intact, except for a broken sensor and an air vent apparently ripped off on impact. Around engine 1, the air ducts located between the air/fuel heat exchanger and the CAU were separated in both the longitudinal and latitudinal axes. The rest of the ducts showed no anomalies.

Examinations showed that the aft part of the dry bay as well as the communicating areas suffered a very violent overpressure after takeoff, leaving no time for the overpressure valves to open. The door latches broke off as a result of this overpressure. The manufacturer estimates that a pressure of about 450 mbar on a door could lead to the rupture of the most loaded axis. Combustion of an air/kerosene mixture in the enclosed space of the dry bay could generate an overpressure which could reach a few bars in a few tenths of a second (stoechiometric mixture). Transition from combustion to detonation (propagation of a wave of combustion at supersonic speed) can generate a shock wave equivalent to pressure rise of several dozen bars.

12.4.5 Structural Resistance to Flames

Concorde's specifications show a rapid deterioration with temperature of the mechanical characteristics of the alloy used for the majority of its structure. At around 300 °C, these characteristics are already six times lower than at normal temperature.

Digital modelling was performed by EADS at the request of the investigators to study the influence of temperature on the parts of the structure exposed to the flame, as well as on the lower wing skin at tanks 2 and 6.

The case studied is based on a fire attached to the main landing gear well and a flame with a temperature of 1,100 °C located between the fuselage and the nacelle. The effects taken into account are those of convection and radiation exchange between the flame and the structure. Under these conditions, in seventy-five seconds, the time the structure was exposed to the flame in flight:

- the average temperature of the lower surface of tanks 2 and 6 is nearly 300 °C,
- the average temperature of the fuel contained in tank 2 reaches 25 °C while that in 6, less exposed to the flame, is about 20 °C,
- the average temperature of the structural parts other than the tanks, taking into account neither the radiation nor the internal convection of those parts not containing fuel, reaches around 650 °C.

Note: the results of this study are average values. The projections of melted aluminium noted on the parts found under the aircraft's flight path show that, locally, higher temperatures were quickly reached (the melting point of aluminium is 660 °C). Some essential components such as the inner elevons directly exposed to the flame suffered very significant damage (note that a piece of elevon was found on the runway centreline extension).

16 - TESTS AND RESEARCH

16.1 Preparation of Flights at Air France

16.1.1 General Organisation

Note: this chapter is included in the Preliminary report numbered 16.1.

16.1.2 Preparation of Flight AFR 4590

16.1.2.1 Flight Planning

The preparation of flight AFR 4590 began at 09 h 12. The dispatcher's work screen indicated QFU 27. In addition, the non-availability of thrust reverser 2 led to a reduction of 2.5% in the maximum weight in operation.

Based on data on the wind (a twelve kt headwind), the QNH (low, 1008 hPa), the temperature (higher than the norm) and the usable length of the runway, the dispatcher calculated the maximum weight as 177,930 kg. However, flight preparation showed a takeoff weight of 184,800 kg with the one hundred passengers checked in.

At about 09 h 30, the dispatcher informed the duty officer of the weight problem, without however specifying the QFU used for the calculation. The duty officer first thought of using another aircraft, then tried to resolve the technical problem with the reverser and finally thought of loading the baggage onto another flight.

On his side, the dispatcher studied two hypotheses for routes (one direct and one with an optional technical stop) and loading so that the flight could take place in terms of its weight.

A little before 10 h 00, the crew called the dispatcher who informed them of the problem. The crew informed him that they had asked for the replacement of the failed pneumatic motor on reverser 2, asked him to file a direct ATC flight plan and told him that they were going to take over the flight preparation themselves.

Note: work had been under way on runway 27 for three weeks. The instructions to assist flight preparation stated that they should “favour (runway 27) for Concorde, because of noise pollution”, runway 26 being used only “exceptionally”. However, information relating to the runway configurations, in particular runway length, was available.

The meteorological data used by the dispatcher were not archived. No directives instructed him to do so. The preparation undertaken by the crew was not archived either. The technical investigators therefore redid the calculations with the flight dispatcher, using the meteorological data of the day of the accident, runway 26 right and without the technical restriction due to the reverser. In these conditions, the estimated takeoff weight come out at 184,802 kg for a MTOW of 185,070 kg.

16.1.2.2 Flight Departure

It was impossible to discover whether the crew took possession of the flight dossier, even though it had become redundant. The load sheet, including the fuel loading sheet and the Captain’s signature, was not found.

16.1.2.3 The Runway

The flight being delayed, its handling began at 11 h 00 and finished at 14 h 45. All aspects of the flight preparation were dealt with by at least one agent.

The baggage loading plan was not signed by agent C2 since the bags indicated as red by the baggage reconciliation system (BRS) had been taken on board (see § 16.2). The authorisation to load was given by the aircraft manager and the aircraft service technician signed the final loading plan without which the load sheet could not be established.

16.1.2.4 Traffic

Note: the following is based on the loading log, that’s to say the list of actions performed by the aircraft manager on his screen and copies of screen printouts.

The aircraft manager began preparing the flight (D1) at 11 h 13. At 11 h 34 the one hundred passengers and seventy-nine items of baggage had been checked in. Since the baggage represented a total weight of 1,651 kg and the loading had not yet been completed, he estimated the final weight of the baggage at 1,700 kg. It should be noted that the screen showed an average weight per bag of 20.9 kg.

The aircraft manager entered the total fuel weight and the taxi fuel weight of 95.0 and 1.9 tons at 11 h 55, of 95.5 and 2 tons at 12 h 14, of 95.4 and 2.1 tons at 12 h 15 finally of 95.4 and 2 tons at 12 h 16.

16.6 Metallic Strip found on the Runway

The metallic strip found on the runway after the accident appeared to be an aviation part that did not belong to the Concorde. A search was therefore undertaken to identify the aircraft from which the part had fallen. This search was focused on the aircraft that had taken off from the same runway after 13 h 00. In addition, research on several types of aircraft showed that the part could be a wear strip from a CF6-50 engine fan reverser cowl.

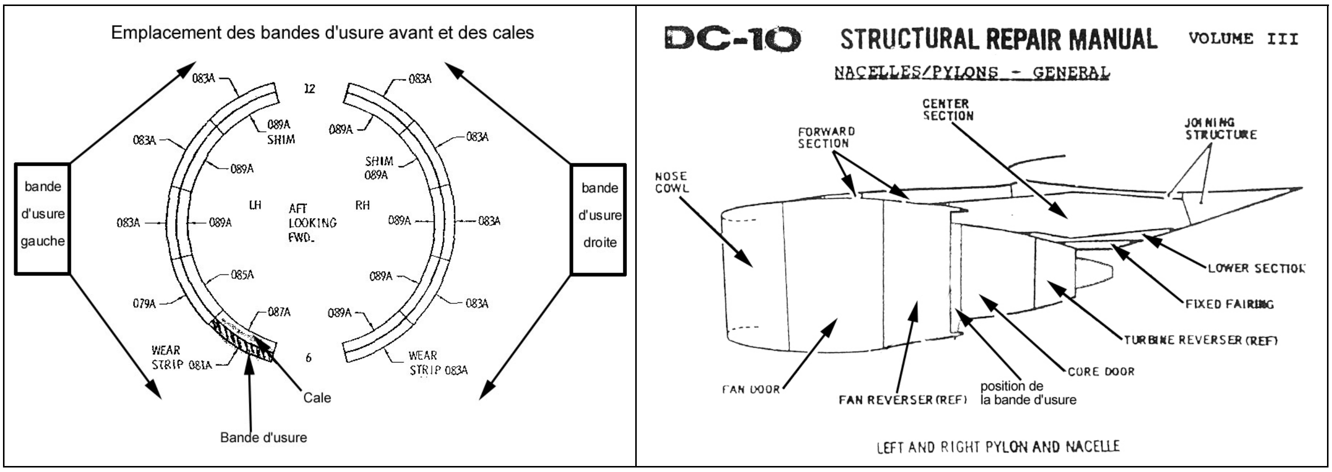


Figure 17: Diagram showing the positions of the wear strips

The DC 10 registered N 13067, operated by Continental Airlines, had taken off five minutes before the Concorde to undertake Paris-Newark flight COA 55. Since this aircraft, seen briefly at Paris Charles de Gaulle on 30 August 2000, could be the aircraft which had lost the part, a technical investigator assisted by the Accredited Representative of the NTSB and by FAA specialists visited its base at Houston to examine it in the presence of representatives of the operator.

Note: only one aircraft, an Air France Boeing 747, had taken off between the DC 10 and the Concorde.

16.6.1 Observations on N 13067

The following observations were made on the aircraft's right engine (engine 3):

a) Fan reverser aft support

- the lower left wear strip, about forty-four centimetres long, was missing. When closed, the forward part of the core door usually rests on the wear strip,
- the support was painted with green epoxy primer,
- in the position where the missing part would be, the support was covered in red type RTV 106 mastic
- there was no trace of RTV 106 on the other parts of the support,
- there was no trace of RTV 106 on the wear strips which are in place,
- there were numerous paint runs on the support and on the wear strips and the paint partially overlapped onto the fan reverser cowl,
- in the position of the missing part, the support still possessed several rivets,
- the support was drilled with thirty-seven holes, of which some had gaps between them that were less than twice the diameter of the holes.

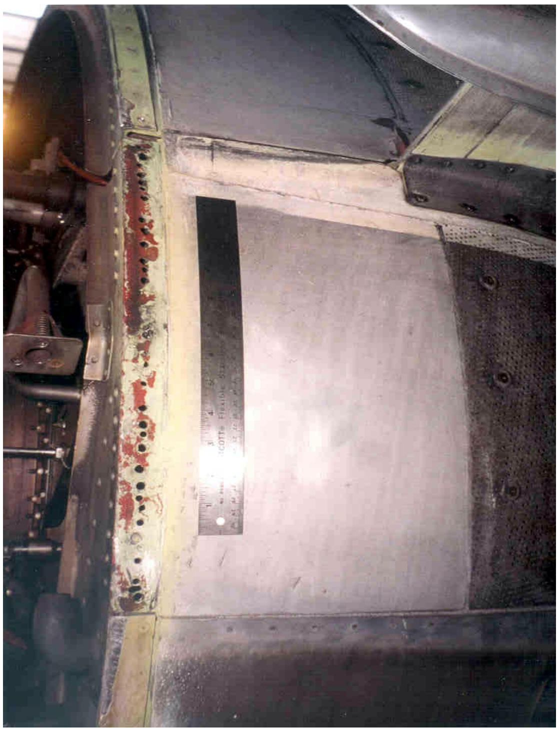


Figure 18

Figure 19

b) Wear strips

- the right wear strips appeared to be original parts made of stainless steel (angled section at the tip),
- the left wear strips had been replaced, and did not appear to be original parts,
- spacing between rivets on the wear strips in place and their alignment appeared to be correct,

- the level of wear on the strip adjacent to the missing strip had clearly exceeded the tolerances accepted by the manufacturer.

Figure 20

c) Lower right wear strip

- a rivet was missing on the strip, which was deformed and there was play of six millimetres in relation to the support,
- the rivet at the end was broken off, the part remaining on the support prevented the strip from sticking to the support, which prevented correct closure of the door,
- in comparison with an original part, this strip was too long.

d) Left fan door

- from the exterior, there was no apparent anomaly,
- inside, deep wear marks were observed, in particular on the part which usually rests on the strips,
- to the right of the bearing point of the strip adjacent to the missing strip, severe wear of around two millimetres was observable on the cowl,

e) Fan and reverser assembly closed

- When closed, the fan/reverser cowl assembly made it practically impossible to note the absence of the lower strip.

Some photographs were taken and some samples of materials (mastic and paint) were taken. A rivet was also removed from one of the remaining strips. At the request of the investigators the engine fan and reverser cowls were removed and stored by Continental Airlines.

16.6.2 Manufacturer's Documentation

16.6.2.1 Disassembly and Repair of Wear Strips

The manufacturer's documentation specifies the conditions for disassembly and repair of the wear strips. Instruction sheet 78-32-03 (disassembly and repair) of the Aircraft Maintenance Manual indicates, on pages 901 to 905, the equipment and materials to use and what to do. The sheet specifies that no special tools are required. This operation is classified as a minor repair (that's to say one which does not imply the replacement or repair of structural elements) and requires no particular inspection after completion.

The wear strip is made of stainless steel 0.055 inch (1.40 mm) thick and one inch wide. The sheet specifies that this strip can be manufactured in the workshop from stainless steel, the dimensions then being 0.055 inch (1.40 mm) thick and 1.395 inch (35.43 mm) without the angled section.

It is specified that a template must be made in order to use the existing holes in the support and to drill the new wear strip with the correct dimensions. The rivet holes must have dimensions between 3.63 and 3.73 millimetres.

Delaminated shims are inserted between the wear strip and the support in order to ensure that the diameter of the cowl support is 72.18 inches ± 0.09 inch. The wear tolerance of the wear strip is 0.030 inch.

Note: it appears that checking this diameter is difficult to undertake using the method recommended by the manufacturer. Consequently, either repairers do not insert the shims, which leaves too much play between the forward and aft cowls, or the shims are inserted in a uniform manner under all the wear strips, the lower strip then being easily removable with a screw so as to remove its shim if it's not possible to close the door.

Assembly procedures for reverser cowls have evolved with time. Some wear strips machined with holes could not be adjusted to fit existing supports. The manufacturer therefore published Service Bulletin 78-206 on 7 July 1983 that details the procedure to follow to drill new holes on the support.

This service bulletin recommends filling the existing holes with an EA 934 NA epoxy adhesive, then drilling new holes using the wear strip as a template. A footnote specifies that it is unnecessary to fill in the old holes if they do not interfere with those of the wear strip. To install wear strips that have not been pre-drilled, (which is the case of wear strips made in the workshop) the service bulletin refers back to the procedure, which implies the use of a template to drill the holes.

The maintenance procedure states in a note that alternative solutions can be used for the tools, equipment and consumables recommended. The manufacturer told investigators that this note would not apply to the wear strip which, even when it was made in a workshop, had to be made of stainless steel to be in compliance with the requirements of the maintenance manual.

16.6.2.2 Space between the Core Door and the Fan Reverser Cowl

The play between the core door and the fan reverser cowl must be between 0.030 inche (0.7 mm) and 0.5 inche (12.7 mm) as shown hereafter:

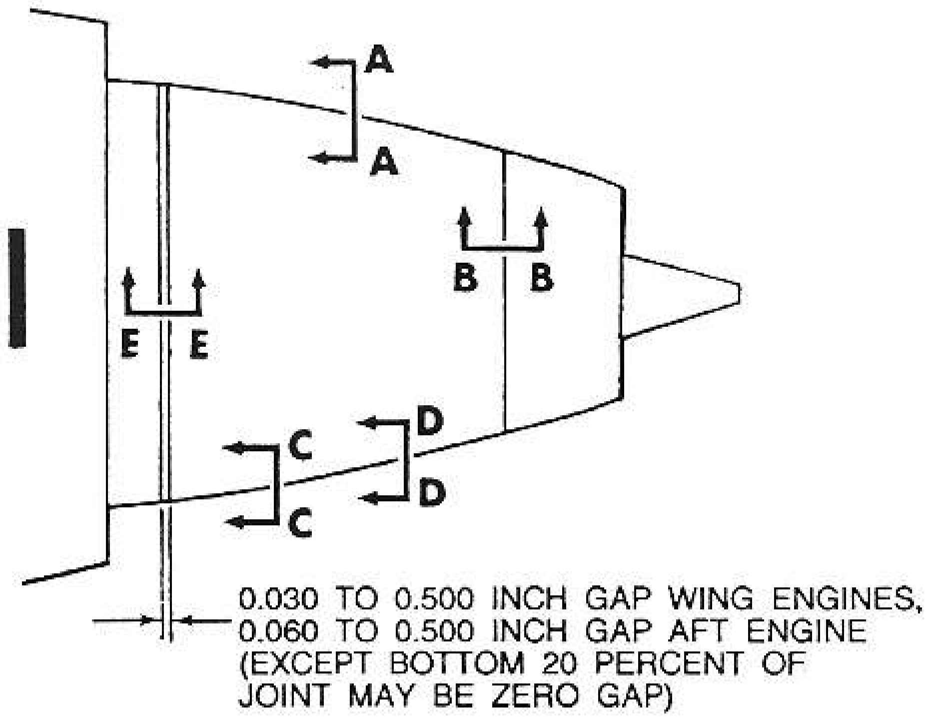


Figure 21: Play between the core door and the fan reverser cowl

During the investigation, it was noticeable on various aircraft that the play measured with engines stopped could exceed these values without touching the width of the wear strip. However, with the engine running, particularly when under takeoff thrust, the pressure inside the cowls is very high. Their deformation may then allow loss of a wear strip no longer attached to its support.

16.6.3 Maintenance on N 13067

N 13067's maintenance documents show that the left wear strips on engine 3 were replaced at Tel Aviv, by Israel Aircraft Industries, during the C check completed on 11 June 2000.

Further work was carried out at Houston on this engine's reverser cowl on 9 July. The mechanical report states that the lower left wear strip was changed during the job. The technician who completed this report stated that he had noticed a twisted wear strip that was sticking out of the cowl. The job was performed specifically to replace it.

The absence of the wear strip is not easy to notice when the cowl doors are closed. Between 9 July and 3 September 2000, the cowl doors on engine 3 were opened at least once (25 August). No maintenance documents refer to the wear strips during this period.

16.6.4 Examination of the Wear Strip

The wear strip found on the runway was subjected to laboratory examination:

- The strip was 435 mm long, 29 to 34 mm wide and about 1.4 mm thick. It was made of a type TA6V alloy composed of titanium (89.67%), aluminium (7.03%), vanadium (2.28%) and iron (1.02%). It was covered on one side in green primer paint of an epoxy bisphenol A resin containing elements of silicate and pigments of strontium chromate. The other side was covered in red silicon mastic for high temperatures. The rivets, of Cherry Max type, were made of an aluminium alloy bush – magnesium A-G5 or 5056 - and a steel stem with an alloy of chrome-nickel-molybdenum covered with a layer of cadmium.

- The strip possessed twelve drill holes with random spacing, some off centre with the longitudinal axis.

- The presence of circular indentations on the mastic side bears witness that the part opposite it possessed extra drill holes. Seventeen hole marks were counted in addition to the twelve holes drilled in the strip.

- Black marks were noted on the outer side of the strip and black elastomer debris was found jammed in one of the rivets. The spectra of these marks and deposits are similar to the Concorde tyre.

16.6.5 Examination of Samples taken from N 13067

The samples taken during the examination of N 13067 in Houston were examined in the lab:

- The primer paint from the cowl is similar to the residues of paint taken from the mastic on the strip.

- The red mastic sampled from the cowl in the area of the missing piece is a silicon mastic of the same type as that present on the strip.

- The rivet taken from another strip, of Cherry Max type, is made up of an alloy aluminium–magnesium A-G5 bush and a steel stem with lightly alloyed 40NVD 2 type alloy (AISI 8740 steel). The material the stem is made of is slightly different from that of the rivets in the strip.

16.6.6 Analysis of the Photos of the Cowl on N 13067

The photos of the engine cowl taken during examination of N 13067 were compared with the metallic strip:

- The unoccupied part of the joint on the cowl closing area has comparable dimensions to those of the strip.

- The cowl has thirty-seven drill holes of the same diameter as those of the strip; they correspond to the drill holes and circular marks visible on its mastic-coated side.

- Eight rivets are in place, in holes which do not correspond to those on the strip and which appear to result from a previous installation.

- There is a relation between the torn and unstuck zones on the mastic present on the strip and on the engine cowl.

In conclusion, investigation and examinations carried out show a clear relation between the metallic strip and the joint area on the cowl of engine 3 on N 13067.

Note: the findings reported in paragraphs 16.6.4, 16.6.5 and 16.6.6 were made at the Saclay Engine Test Centre.

16.6.7 Tyre destruction Mechanism

Test were carried out in the United States in a Goodyear technical centre to reproduce the conditions leading to damage to a tyre from a curved metallic strip with comparable dimensions to the one found on the runway.

Two Concorde tyres were used for these tests. One of the strips used was made of titanium, the others made of a stainless steel whose mechanical resistance characteristics are similar to titanium.

The tyres were installed on the side of a trolley towed by a truck. The load spread out on the trolley allowed each tyre to bear a load of about twenty-five tons, equivalent to that on each main landing gear tyre on Concorde. Taking into account the test equipment and the load, the speed of the truck was around 10 km/h.

Figure 22: Tyre Test Installation

During the tests:

- an initial positioning of the strip, done with the titanium strip, resulted in its being flattened by the tyre,

- in a second position, the strip remained stable on its cutting side and the tyre was cut into,

- the tyre cut went right through its thickness, practically all across the width of the area in contact with the ground and in accordance with the shape of the strip,


Figure 23


Figure 24

- this cut continued onto the tyre shoulders and sidewalls through a static rupture in the direction of the reinforcing material of the tyre body,

- the static ripping spread as far as the tyre beads, in other words slightly more deeply than the ripping noted on the remains of tyre n° 2 on Concorde.

Extension of the lines from the ripping demonstrates that the piece that could be released was comparable to the piece of tyre found after the accident near to the strip.

16.9 Engines

16.9.1 Observations on the Engines

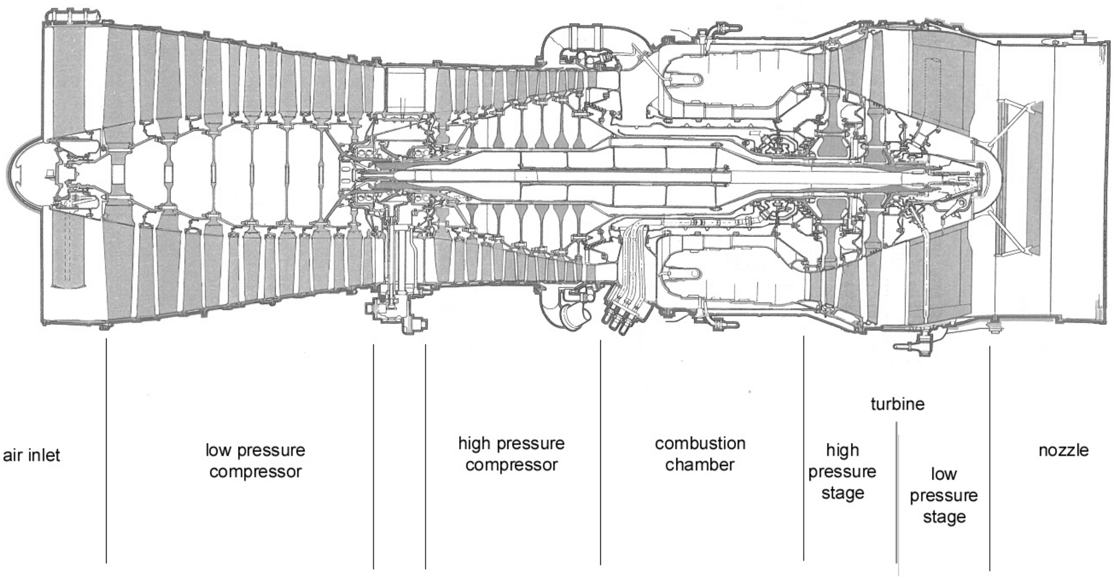


Figure 25: Olympus 593 – Cross Section of Airflow

16.9.1.1 Disassembly of Engines 1 and 2

The technical investigators made observations on engines 1 and 2 during disassembly.

Note: the engines, as well as disassembled inner parts, were washed in order to eliminate all possible traces of asbestos.

16.9.1.1.1 Engine 1

- LP compressor module

Ten blades from the n° 1 stage of the LP compressor showed hard impacts with material pick-up. In particular, blade 6 showed metal pick-up that appears to result from impact with a small piece of metal. Impacts with loss of material were noted on the tops of the leading and trailing edges of the n° 1 and 2 rotor stages. These result from plastic distortion of the blades and untwisting towards the blade tips, with clashing [(8)] on the stators of stages n° 1 and 2.

Stage n° 4 of the compressor showed blade deflection in the opposite direction to that of rotation in the lower sector and to a lesser degree in the upper sector. This distortion corresponds to the crushing of the casing at the time of impact with the ground.

On the upper half of the compressor discs, traces of overheating after impact are noticeable, related to prolonged exposure to temperature. The lower part of these discs is blackened with a soot deposit.

Taking into account the slight deflection of the blades, it appears that the LP compressor was turning slowly at the time of impact with the ground.

- HP compressor module

The HP compressor module shows marks of ingestion of hard bodies. The blades from stages 1 to 7 show significant impact marks.

- Combustion chamber

The combustion chamber showed no damage or oxidation related to any particular thermal constraints. Deposits of magnetic and non-magnetic materials were found there.

- Turbine

Small debris, traces of metallisation and impact are visible on the HP and LP turbine disc blades.

16.9.1.1.2 Engine 2

- LP compressor module

Three blades of stage n°1 of the LP compressor showed soft body impacts. No trace of metallisation, ingestion or damage related to hard bodies was noted. Distortion on the lower part corresponds to the crushing of the casing on impact.

- HP compressor module

The rotors of stages n° 1, 2, and 3 of the HP compressor showed distortion of the lower part due to the impact. The n° 1 stator stage showed no impact marks. Some vanes on the stage 2 stator were bent. From stage 3 on, clashing related

[8] Interaction of the rotor blades and stator vanes.

damage to the stators and rotors is noticeable. The module showed no marks of secondary impact.

- Combustion chamber

The combustion chamber showed no damage or oxidation related to any particular thermal constraints. Small debris was found there during disassembly.

- Turbine

The LP and HP turbine stages showed no marks of damage due to a foreign object. Overall, the turbine had suffered no distortion, apart from the part that had struck the ground. The turbine showed no signs of rotation on impact with the ground.

16.9.1.2 Examination of Engines 3 and 4

Visual examinations of engines 3 and 4 were performed so as to determine their level of external damage. An intrascope examination of the airflow was also performed on both engines in order to determine their internal condition.

16.9.1.2.1 Engine 3

- External examination of the engine

Engine 3 showed signs of overheating on its lower sector due to the fire on the ground. Its general appearance was comparable to that of engines 1 and 2.

The impact with the ground caused generalised distortion of the casings, more serious than that noted on engines 1 and 2. The LP compressor casing was completely flattened. The deflection distortion of the blades on the first stages of this module indicate that its rotation was blocked in less than one revolution.

The ends of the flange on the aft part of the LP compressor casing were forced several centimetres apart. The HP and LP turbines and their nozzles were seriously damaged on impact under a high vertical load. The violence of the shock contributed to the sudden halt to rotation of the LP body.

The left accessory gearbox remained in place with all of the parts of the fuel circuit, severely damaged by the impact. Observation of the FCU showed that the throttle valve was set at sixteen degrees, a position close to idle.

- Intrascope examination

The intrascope examination of the LP compressor showed more significant damage on this engine than on engine 1. The stator vanes on the first four stages that could be inspected were very severely damages and for the most part torn off their inner attachment points. In the most distorted sectors, some rotor blades showed pick-up on their leading edges, similar to the clashing observed on the engine 1 LP compressor.

Examination of the HP compressor in the only sector visible through the stator access points, situated at 11 o'clock on a generator, showed that the blades from all of the stages were bent and more or less entangled with the stator vanes. This damage appeared more significant than that observed in this area on the same components on engine 1. The blade airfoils showed no impacts such as those affecting the HP compressor on engine 1.

16.9.1.2.2 Engine 4

- External examination of the engine

The external aspect of engine 4 is similar to that of engine 3.

Forward, the LP compressor casing is flattened and the air inlet vanes have been torn off. The twist distortion of the first stages of the compressor probably resulted from more rotation on impact than that of engine 3. The ends of the flange on the aft part of the LP compressor casing were forced several centimetres apart. The HP and LP turbines and their nozzles were seriously damaged on impact under a high vertical load.

The left accessory gearbox remained in place with all of the parts of the fuel circuit, severely damaged by the impact. Observation of the FCU showed that the throttle valve was set at fourteen degrees, a position close to idle.

- Intrascope examination

The intrascope examination of the LP compressor showed more significant damage on this engine than on engine 1. The blades on the four compressor stages showed pick-up or clashing in their leading edges, as well as the beginnings of shearing on the trailing edge. There were no impact marks on the airfoils examined.

The blades on all stages of the HP compressor were deflected and entangled with the stator vanes. The pick-up and tears on the airfoils examined on a very limited angular sector were more significant than those observed on the same parts of engine 3. However, they showed no impacts such as those affecting the HP compressor on engine 1.

16.9.1.3 Laboratory Research

Research was carried out in a laboratory on the parts of engines 1 and 2, which seemed to possess marks of foreign object damage (FOD). Analysis was performed on deposits sampled from the engines in order to determine their nature and their possible origin.

Note: the marks and deposits associated with operation of the engines may have been altered by the debris and various elements coming from the environment of the accident site.

16.9.1.3.1 Engine 1

The marks found on blade 6 of the first stage of the LP compressor, as well as on blades 13 and 14, were caused by a piece of stainless steel.

The soot deposits and the compressor disc colouring indicate that they were subject to thermal constraints whose distribution was not uniform. Considering these colourings, the estimated temperature was around 550 °C to 600 °C.

The highest temperatures affected the upper inner parts of the airflow. This tends to show that this was a consequence of the fire on the ground and the chimney effect produced in the airflow.

Traces of aluminium alloy coming from the airframe were identified inn the samples analysed. It was impossible to determine the origin of other elements identified, such as cadmium, tungsten or cobalt.

Antimony was found on numerous impact marks. Antimony is used in certain paints designed to be subjected to thermal constraints, but also in most fire extinguisher products. This element is also used in the vulcanisation of rubber, though not in the manufacture of Concorde tyres, as analyses confirmed.

Other elements such as sulphur, zinc and some traces of iron were identified. These elements, used in the manufacture of tyres, were not however present in sufficient quantities to be able to assert that tyre debris had been ingested. In addition, in the hypothetical case of tyre debris ingestion, it is normal not to find carboniferous residues, carbon not leaving any residues with temperatures over 500 °C.

Finally, several fragments of glass fibre material were identified among the debris found in the combustion chamber.

According to the studies carried out in the United Kingdom, the marks of clashing observed on the blades of the LP compressor could result from ingestion of soft bodies such as tyre debris (as in the Washington accident), from massive ingestion of fuel, or even from water deflector debris.

16.9.1.3.2 Engine 2

Although numerous particles of lead were found around the impact points, the analyses could not determine the nature of the bodies involved in the soft body impacts found on three first stage rotor blades in the LP compressor.

Only two neighbouring blades (blades 6 and 7) of the third stage LP compressor sustained hard body shocks on their leading edges. Analysis showed that an iron-based body was the origin of one of them. Some traces of antimony and zinc were also found, without it being possible to associate them with the iron-based body.

A fragment of glass fibre was found, its structure being identical to that of the fragments found in engine 1.

Two adjacent blades from the LP compressor first stage and fifteen blades from the HP compressor third stage showed some loss of material on their airfoil, just under the peak. This resulted from an overload sustained on impact with the ground. This observation is confirmed, both through an examination of the fracture topography (9^{th} blade in particular) which shows the same blue colouring as the blade leading edge, and through the fragments resulting from these fractures, which remained in the vicinity of the HP compressor. This tends to show that it was the ground fire and not ingestion of hot gases that caused this colouring.

The soot deposits and the colouring of the discs on the different stages of the LP compressor indicate that they sustained thermal constraints. These overheating marks seem more uniformly distributed than on engine 1. Their examination shows that the thermal constraints were lower than those born by engine 1 and that they occurred during prolonged exposure to high temperature, with the engine stopped.

As for engine 1, it is likely that after the impact with the ground, the fire neutralised certain clues. In the present case, no traces of hot gas ingestion were found.

16.9.1.3.3 Examination of the HP fuel cock selectors

There are four selectors (one per engine) situated on the upper centre panel. They are used in the normal engine shutdown procedure and cut the supply of fuel.

The four fuel HP cock selectors found in the wreckage were examined in the workshop. The mechanical position of the selectors as well as electrical tests on the contacts indicated that the four selectors were in the OPEN position.

Note: this statement leads to the conclusion that the sound recorded at 14 h 43 min 26.2 s cannot be the result of a cut-off of the HP cock and that it is therefore a movement of the throttle control lever.

16.9.2 Tyre Debris Ingestion during Operation

Six cases of tyre bursts leading to a loss of thrust during takeoff have been reported. Tyre debris had entered the engines, affecting the performance of nine engines in total.

Date	Registration	Engine affected	N2 Drop	Loss of thrust
14 June 1979	F-BVFC	2	1%	9%
21 July 1979	F-BVFD	2	*	14%
23 September 1979	F-BVFB	3	3%	12%
6 October 1979	G-BOAA	3 4	0.3% 0%	1% 0%
19 February 1981	F-BTSD	1 2	2% 0%	9.5% 0%
14 December 1981	G-BOAC	1 2	3% 18%	0% 5%

***** Due to parameter sampling every four seconds, the very brief fall in N2 has not been quantified.

16.9.3 Data Readout

This paragraph presents a synthesis of the engine parameters and the CVR recording, consistent with the observations made during disassembly of the engines. You are reminded that these parameters are recorded every four seconds. The following elements come from extensive analysis of the available data. Times were calculated with a precision of a tenth of a second.

Among the recorded parameters, there is a calibration error of about 2.3% on the N1 for engines 1, 2 and 4 (for example, for a real value of 100%, the recorded value is 97.7%) and of 7% for engine 3, of the order of 1.7% on N2 at high rpm (for example, for a real value of 103%, the recorded value is 101.3%), of the order of 20 °C for the Tj parameter (for example, for a real value of 750 °C, the recorded value is 730 °C), of a few hundred kilos on the Fuel Flow at low rpm (for example, for a real value of 400 kg/h, the recorded value is 0).

Powering up of engines and their behaviour during the initial phase of takeoff, up until 14 h 43 min 11 s, is normal on all four engines with a longitudinal acceleration (Nx) of 0.268 gramme.

Time	Engine 1	Engine 2	Engine 3	Engine 4
14 h 43 min 11.7 s and 14 h 43 min 12.3 s	The parameters are normal.			
14 h 43 min 12.7 s and 14 h 43 min 13.3 s		The Tj, P7, N1, N2, Aj show deviations.		
14 h 43 min 12.0 s and 14 h 43 min 13.0 s	Surge.	Surge.		
14 h 43 min 13.0 s	The Nx is recorded at its minimal value of 0.133 g.			
14 h 43 min 12.1s to 14 h 43 min 14.1 s	The GO LIGHT lamps go out.			
14 h 43 min 15.7 s and 14 h 43 min 16.3 s	Confirmation of the surge. The thrust is equal to about 75% of the nominal thrust.			
14 h 43 min 16.1 s and 14 h 43 min 18.1 s	The GO LIGHT lamp lights up.			
14 h 43 min 16.7 s and 14 h 43 min 17.3 s		Thrust is hardly above the level corresponding to idle (about 3% of nominal thrust).		
14 h 43 min 18.1 s and 14 h 43 min 20.0 s	The GO LIGHT lamp goes out[9].		The GO LIGHT lamps go out[9].	
14 h 43 min 19.7 s and 14 h 43 min 20.3 s	Thrust is equal to about 80% of nominal thrust.			
14 h 43 min 20.7 s and 14 h 43 min 21.3 s		The engine is in recovery phase. Thrust is equal to about 15% of nominal thrust.		
14 h 43 min 20.9 s and 14 h 43 min 21.9 s	Surge.	Surge.		
14 h 43 min 22.8 s		The fire alarm sounds.		
14 h 43 min 23.7 s	Thrust is close to idle and equal to about 4% of nominal thrust.			
from 14 h 43 min 24.7 s to 14 h 43min 25.3 s		Thrust is equal to about 12% of nominal thrust.		
14 h 43 min 24.8 s		The FE “shut down engine 2”.		

[9] This is a normal consequence of the uncompressed state of the left main landing gear shock absorber. The lag which appears on the data recorder results from sampling over four second periods.

Time	Engine 1	Engine 2	Engine 3	Engine 4
14 h 43 min 25.8 s		The Captain calls for “engine fire procedure”.		
14 h 43 min 26.2 s		The thrust lever is moved to its stop in idle position.		
14 h 43 min 27.7 s and 14 h 43 min 28.4 s	N2 passes below 58% and thrust is equal to about 45% of nominal thrust.			
14 h 43 min 28.7 s and 14 h 43 min 29.3 s		N1 and N2 have a curve, which is typical of an engine running down normally. The fire handle is pulled.		
14 h 43 min 28.3 s			The parameters show behaviour consistent with a switch from TAKE OFF to CONTINGENCY. The fuel flow, primary nozzle and P7 pressure are consistent with reheat operating on these engines.	
14 h 43 min 35.5 s	The engine is operating in CONTINGENCY mode, although the P7 indicates a shortage of thrust of about 5%.			
14 h 43 min 42.3 s		A second fire alarm and the associated gong are heard.		
14 h 43 min 58.6 s		The fire alarm an associated gong sound for the third time although the alarm had stopped four seconds before. The alarm continues until the end of the recording.		
14 h 43 min 59.5 s and 14 h 44 min 11.5 s	Fuel Flow and P7 show signs of fluctuation. The engine is in underspeed and suffers a final surge.			
14 h 44 min 24.7 s to 14 h 44 min 27.0 s			Probable reduction of the thrust levers by the crew.	
14 h 44 min 25.5 s and 14 h 44 min 26.5 s			Surge due to distortion of the airflow in the air inlets.	

16.9.4 Engine Operation

16.9.4.1 Engine 1

The first loss of thrust was caused by a surge. The parameters show that it occurred a short time after the tyre destruction, between FDR times 97602.8 (14 h 43 min 12.3 s) and 97603.4 (14 h 43 min 13 s). The disassembly of the engine brought to light the ingestion of foreign bodies probably linked to the explosion of the tyre, apparently the cause of the surge. However, since the surge on this engine happened practically at the same time as that on engine 2, it is also possible that the cause was the same for both engines, that's to say related to ingestion of hot gases.

The second loss of thrust was caused by a further surge that happened when the aircraft angle of attack was 13°. The loss of thrust (the remaining thrust is comparable to that of an engine at idle) was much greater than the loss of thrust recorded during previous ingestion of tyre debris. This surge could only have been caused by the ingestion of a kerosene/hot gas mixture, facilitated by the change in the aircraft's attitude.

After the second surge, the engine returned to almost normal operation in CONTINGENCY mode commanded by the fuel regulation system. A thrust deficit of around 5% is, however, recorded. This loss of thrust was probably due to the mechanical damage the compressors suffered as a result of ingestion of debris caused by the destruction of the tyre. The ingestion of hot gases and/or fuel-air mixture is unlikely considering the subsequent stability of the parameters.

The engine then operated in a stable manner for twenty-two seconds. Then the Fuel Flow parameter is disturbed due to the ingestion of kerosene by the main or auxiliary air intakes, causing regulatory action to occur.

Fifteen seconds after the fluctuations in the fuel flow, the engine surged again and decelerated rapidly. According to Rolls Royce, analysis of the parameters shows that the engine suffered a final severe surge due to probable ingestion of debris such as pieces of aluminium or glass fibre or honeycomb structures belonging to the aircraft structure. The surge might also have come from ingestion of a large quantity of fuel. It was responsible for serious damage (clashing) which was observed on the LP compressor when the engine was disassembled.

16.9.4.2 Engine 2

The loss of thrust was caused by a surge that occurred at practically the same time as that on engine 1. The thrust then available is comparable to that of an engine at idle. It has been established through witness testimony and marks noted on the runway that the fire was burning before the engine surge. What's more, the facts noted during disassembly, as well as experience acquired in service, show that the internal damage to the engine before the impact was not sufficient to cause a surge. The only mechanism consistent with a surge leading to a great loss of thrust is ingestion of hot gases.

Between times 97611.2 (14 h 43 min 20.7 s) and 97611.8 (14 h 43 min 21.3 s), the parameters show the engine recovering. The acceleration value is consistent with the thrust equivalent to that delivered by three engines and is explicable as the consequence of an increase in thrust from engines 1 and 2. A short time later, the longitudinal acceleration fell again as well as the engine 2 parameters. This is the result of a second surge probably caused by ingestion of hot gases and/or a fuel-air mixture through the auxiliary air intake that opened again since the aircraft had started to accelerate again.

Engine fire alarm actuation and the very low values on the parameters led the crew to shut down the engine after the Captain called for the engine fire procedure. In fact, the movement of the throttle control lever to its idle stop is heard and, a short time later, pulling of the fire handle. In addition the deceleration of the engine, established from the recorded parameters, is consistent with a commanded engine shut down.

16.9.4.3 Engines 3 and 4

Engines 3 and 4 operated normally until 14 h 44 min 17.5 s (14 h 44 min 18.5 s, taking into account the sampling rate of the recording.). Fuel flow is recorded as decreasing from 14 h 44 min 21.5 s (22.5 s). The same is true for the P7 parameters at 14 h 44 min 25.5 s (26.5 s). The engine parameters show a rapid decrease at 14 h 44 min 29.5 s (30.5 s). Certain sounds recorded on the CVR between 14 h 44 min 24 s and 14 h 44 min 27 s probably correspond to the idle stop position of the throttle control lever. However, the loss of thrust is too sudden to be only the result of a reduction in the power. A surge due to distortion of the airflow because of roll and the high angle of attack of the aircraft at that moment in the flight also contributed.

All of the internal damage noted resulted from the impact with the ground.

16.9.4.4 Conclusion

The observations and examinations carried out on the four engines brought to light no malfunction of any of their basic equipment or components, or any indication of any behaviour outside of the certificated norms. None of them showed any signs of overheat or overspeed prior to the impact with the ground. The behaviour not commanded by the crew resulted from abnormal outside factors such as the ingestion of soft and hard bodies, hot gases and fuel.

16.10 Origin of the Non-retraction of the Landing Gear

The CVR recording shows that the crew noticed the non-retraction of the landing gear at 14 h 43 min 56.7. Eleven seconds pass between the presumed beginning of the manoeuvre (announcement saying *“I’m trying”)* and the announcement *“the gear isn’t retracting”*.

Examination of the wreckage did not bring to light the cause of this malfunction, the few facts established not really being usable:

- the landing gear selector was found between the “down” and “neutral” positions, outside of the detent but under the mechanical guard,

- the locking catch on the left main landing gear door was open. Nothing can, however, be concluded from this, since during an emergency gear extension, door opening is ensured by means of rods linked to the structure. These rods may have been activated at the time of the impact,

- the retraction lock on the right main landing gear shock absorber was blocked. This lock is only released when the initial conditions are met (door confirmed open, nose gear straight and bogies perpendicular).

Observation of the movements of the door actuators found at the crash site was not relevant either. The left gear door actuator is in fact a double-effect model without a mechanical lock, hydraulic pressure alone maintaining it in position. During the impact, the destruction of the hydraulic pipes caused a loss of hydraulic pressure. The pistons could thus move freely in the body of the actuator.

It is therefore necessary to conduct a systematic analysis of the possible causes of the non-retraction of the landing gear, based on the description of the system in 6.2.2.

A precondition to gear retraction is the movement of the control lever towards the “up” position. None of the crew’s reactions leads to the supposition that the lever had not been moved or that it was blocked.

A malfunction in the door opening cannot, however, be excluded, whether it be as a result of an incorrect indication or a mechanical blockage leading to the non-opening or partial opening of a door.

If there was no door-opening problem, the sequence continued with a check on the position of the nose gear and the bogies. Nothing indicates any suspicion of a failure in the mechanical nose gear alignment system during takeoff, and main gear perpendicularity is recorded at that time on the FDR.

Having reached this stage, the conditions are met to supply hydraulic power to the landing gear actuating cylinders.

After opening of the doors, the landing gear elements operate independently. If a partial hydraulic failure, linked to a rupture of a pipe in the Green hydraulic system, had then occurred, only the landing gear located on the side of the rupture would have been affected.

No mention was, however, made by the crew of any asymmetry in the landing gear display and no remarks were made on a partial retraction of the gear.

In addition, total loss of the Green hydraulic system would have caused a gong to sound via a PFCU fault. No such gong was recorded on the CVR. Furthermore, this failure would have led, at the same time, to a switch to mechanical by the rudder (see § 16.11). This switch occurred, however, almost five seconds after the announcement that the gear was not retracting.

In conclusion, taking into account the examination of the failure, only a partial opening of the door can explain the non-retraction of the landing gear. It was probably the left landing gear door, the only one located in a part of the aircraft which could have suffered damage linked to the destruction of the tyre and to the fire.

16.11 Rudder Switch to Mechanical

The CVR recording shows that at the beginning of the flight, because of a failure in the Blue electrical system, the crew decided to leave with the rudders on the Green system. During the flight, at 14 h 44 min 01 s, about half a minute before the impact, the rudder switched to the mechanical system. Three hypotheses can in theory explain this switch:

- Loss of the green hydraulic system

In accordance with the flight control system logic (see § 6.7.1), the loss of the Green hydraulic system leads to a switch of the rudders to mechanical mode. However, the loss of a hydraulic system would generate a gong that was not identified during analysis of the CVR. Although it cannot be excluded, such a cause of failure is thus unlikely.

Note: according to this hypothesis the movement of the emergency hydraulic selector “from Yellow to Green” then the use of the reset button makes it possible to regain the Green system.

- Detection of a Failure

Possible detection by the computers of a servo failure on the Green electrical system of one of the rudder PFCU’s (false or real alarm) leads to a switch to mechanical mode for the rudders. Since nothing connects the appearance of such a fault to the damage caused by the chain of events linked to the accident at that time, such a cause of failure is also unlikely.

- Loss of Green hydraulic system

Power supply to the Green electrical system of the inner elevon PFCU’s, located in the filed of the flame, could have been damaged. This power supply being common to the three control surface groups, the Green electrical system would then have been lost to all of the PFCU’s.

However, since at the time of the event the “inner” and “outer and median” elevon PFCU’s were working normally on the Blue electrical, only the rudder PFCU’s could be directly affected by the loss of the Green electrical system, which explains why only the rudder switched to mechanical mode.

16.12 Alarms

16.12.1 Toilet Smoke Alarm

A toilet smoke detection alarm was recorded at 14 h 43 min 32.6 s. Since the air conditioning in the toilets comes from the forward cabin, this alarm can be explained by passage into the conditioning circuit of a combustible mixture ingested by engine 2, which had just stopped, or by engine 1 (see § 6.7.2).

It is also possible that it was a false alarm. Although this type of event is not in fact usually followed up, several people told investigators that false toilet smoke alarms were not unusual on the Concorde.

16.12.2 Engine Fire Alarm

The engine fire alarm was noted three times during the flight. Three potential causes were identified:

- The flame[10] established under the lower wing surface heated up the forward (aluminium) and aft (titanium) cowlings enough for the temperature to reach the initiation threshold (600 °C). According to a BEA study, the alarm originated in the intermediate assembly.

Note: the external fire could set off this alarm through the titanium aft cowling and melt the aluminium forward cowling in a time of between six and thirteen seconds.

- The fuel ingested by the ventilation doors located at the junction between the nacelle and the wing ignited on contact with the hot sections of the engine. In this case there would be an alarm on the aft assembly. When the fire handle is pulled, a valve closes the air bleed at the level of the last stage of the compressor.

- The fuel entering through the lower ventilation scoops ignites on contact with the hot sections of the engine.

The first alarm, recorded at 14 h 43 min 22.8 s, eleven seconds after the beginning of the external fire, stopped after four seconds. It may have been caused by the temperature of the intermediate or aft assemblies exceeding the threshold value until the modification in airflow due to the aircraft taking off made it drop temporarily below this threshold. A transitory flame could also have been the cause of the alarm.

The second alarm was heard sixteen seconds after the first stopped. A fire

[10] Estimated temperatures: convection about 1,000 °C; radiation about 1,500 °C.

extinguisher being fired by the FE, leading to cooling of the assemblies, explains why it stopped for four seconds. Then, since the cause external to the engine continued, the temperature of the assemblies went past the initiation threshold and the alarm was reactivated, from that moment until the end of the flight.

17- INFORMATION ON ORGANISATIONS AND MANAGEMENT

17.1 Concorde Operations at Air France

17.1.1 Flight Crew

At the time of the accident, the Concorde division contained around thirty people and possessed six aircraft. In comparison, the Airbus division contains more than a thousand flight crew, of whom about one hundred are instructors and possesses more than a hundred aircraft.

The management is organised in the following way:

- a head of division, Captain, flight crew executive and Concorde type rating examiner (TRE),
- a flight safety officer, Captain, flight crew executive,
- a ground attaché,
- a Captain, Concorde TRE who supervises two other Concorde TRE's,
- a technical attaché, FE,
- an FE executive who supervises two Concorde FE instructors and the FE technical attaché.

Although not included in the organisation chart, a FO also participates in instruction tasks. The other members of the division are Captains, First officers and Flight Engineers.

Unlike in other divisions, the head of the division deals with all line release of captains. The aircrew have a special status in their professional context.

The division has an average age higher than in other divisions. The Concorde type rating is on a voluntary basis and based on service time, and the aircrew who join are generally highly experienced.

According to persons interviewed in the course of the investigation, the limited size of the division had a rather favourable effect on relations within the crews and with the hierarchy.

17.1.2 Cabin Crew

Unlike the flight crew, the cabin crew attached to Concorde operations also flew on other long-haul aircraft. However, the normal and maximum working hours, limitations regarding flights, stopovers and post-flight rest times were all subject to specific arrangements outside of the normal work contract.

17.1.3 Maintenance

Concorde maintenance is the responsibility of a joint A310/Concorde department attached to the Long-Haul Operations Directorate within the Air France Maintenance Directorate. The A310/Concorde department is organised in specific control units for Concorde (general overhaul, technical) and Airbus (technical) and in common control units (production, logistics). Management, human relations, human factors and a secretariat are placed under the direct control of the head of department.

The A310/Concorde Production control unit carries out inspections and maintenance operations up to the C check.

17.2 Airworthiness Oversight by the Certification Authorities

The Concorde was the first aircraft to be developed under international co-operation and, quite exceptionally, a parallel process of primary certification was conducted in the two partner countries. Concorde thus possesses two type certificates, which means that from a purely regulatory perspective, the aircraft flying the French flag and those flying the British flag correspond to two different models. However, in practice, the DGAC and the CAA jointly manage oversight over airworthiness issues. These two authorities have each designated a Project Certification Manager who has a team of specialists.

Oversight over airworthiness issues is organised around an annual meeting called the Airworthiness Review Meeting (ARM) with the representatives of the two manufacturers, EADS and British Aerospace. Meetings are also organised when in-service problems affect airworthiness, in order to decide on steps to be taken.

Feedback is ensured by the operators who transmit any incidents recorded to the manufacturers. The latter present a monthly report to the two authorities.

Note: significant events, accidents or serious incidents, are also notified directly to the investigatory bodies.

Airworthiness of the Olympus engines is subject to specific oversight, which is also carried out jointly by the DGAC and the CAA. Twice-yearly meetings take place with Rolls Royce and SNECMA, the engine manufacturers, during which cases of in-flight shutdowns and acceleration-stops are analysed. In 1998, a complete review of the safety of the engines was carried out in the context of continuing long-term operation of supersonic aircraft.

18.2 Absence of the Spacer on the left main Landing Gear

Examination of the landing gear (see first interim report 12.3.5) revealed the absence of the central spacer from the left main landing gear, this spacer not having been re-installed during the “A01” check carried out from 17 to 21 July 2000. It was thus appropriate to study the circumstances of this omission and any possible contribution to the accident on 25 July.

With reference to the latter:

- a thorough examination of the left main gear bogie and tyres was carried out at the aeronautical test centre (CEAT) in Toulouse within the framework of the judicial investigation,
- a study was requested from Messier-Dowty, the designer of the landing gear,
- the ground trajectories of the aircraft on 25 July and on its previous flights were studied.

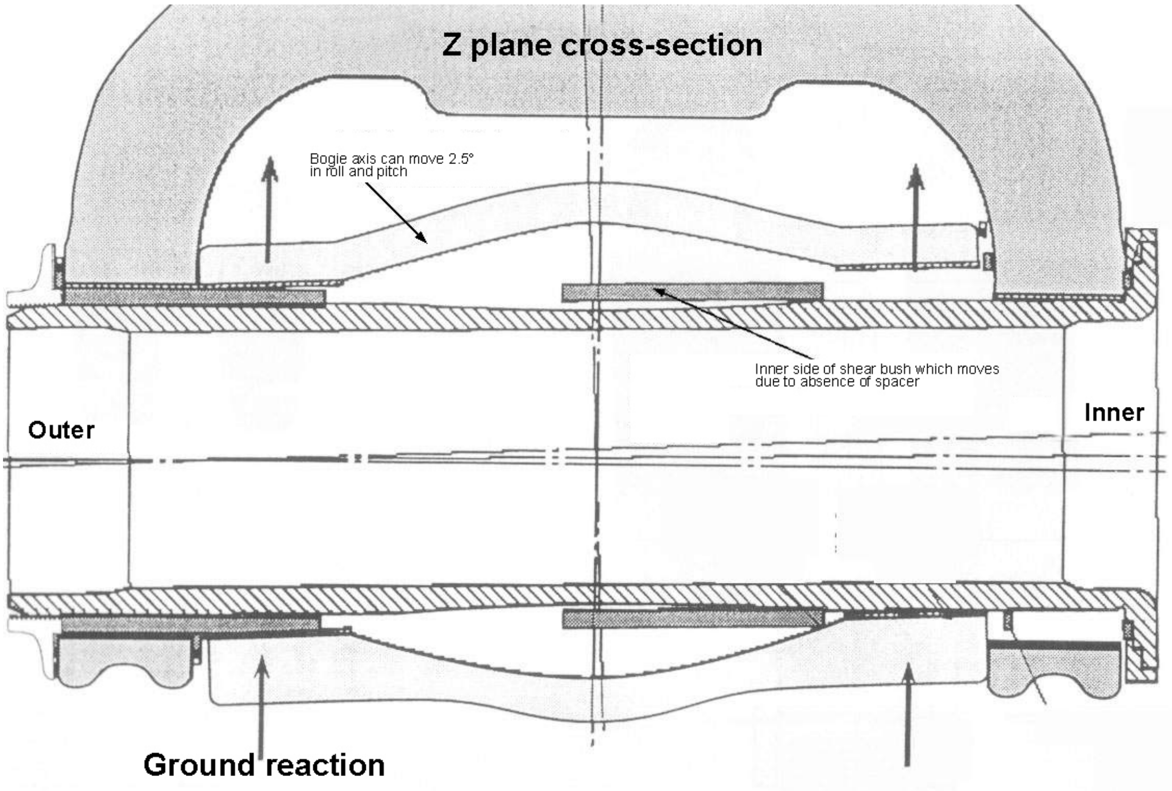


Figure 26 : Landing gear without spacer

18.2.1 Maintenance Operations

During the "A01" check, the replacement of the bogie on the left main landing gear was carried out on the 18 and 19 July by the personnel in the Air France A310/Concorde Production control unit.

It should be noted that this was the first time that a change of bogie had been undertaken on Concorde at Air France.

18.2.1.1 Documentation

The Concorde Maintenance Manual (Chapter 32-11-28) used by the maintenance personnel details the conditions for removal and re-installation of a bogie. This document specifies simultaneous removal of the main axle, the two shear bolts and the spacer, with the aid of a special extractor.

This extractor is referenced as P/N 253300/78 in the Concorde Maintenance Manual and in the Concorde Illustrated Tool and Equipment Manual (Chapter 32-11-00). It is known in the Air France tool reference system under the code C32-048.

For the re-installation of the main axle, it is specified that the two shear bushes and the spacer recovered from the removed bogie be installed, then this assembly is to be installed through the bogie and the shock absorber with the aid of a guide.

Note: it appears that Concorde is the only aircraft whose bogies are designed with shear bushes and a spacer.

18.2.1.2 Work performed

The replacement of the bogie was carried out in the course of two shifts. The first shift (A shift) undertook removal of the bogie on 17 July from 06 h 00 to 18 h 00. The second (B shift) undertook the reinstallation of the bogie from 17 July 18 h 00 to 18 July 06 h 00. The personnel concerned possessed the requisite qualifications and authorisations.

Note: Each shift worked for 12-hours. This choice, made with the agreement of the interested parties, was intended to avoid having to pass on multiple instructions. It is in compliance with the regulations relating to ground personnel.

During removal of the bogie, the extractor tool was not used. Only the bushes were extracted after removal of the axle. The spacer remained on the bogie. Because they were using the tool reference in their working document, the Aircraft Maintenance Manuel (AMM), the personnel did not find the extractor in the store. A check carried out after the discovery of the anomaly on 23 October 2000 confirmed, however, the presence of two extractors.

During reinstallation, the shear bushes were positioned directly in their receptacle on the drum, before the axle was reinstalled. This made it impossible to detect the absence of the spacer on the new bogie.

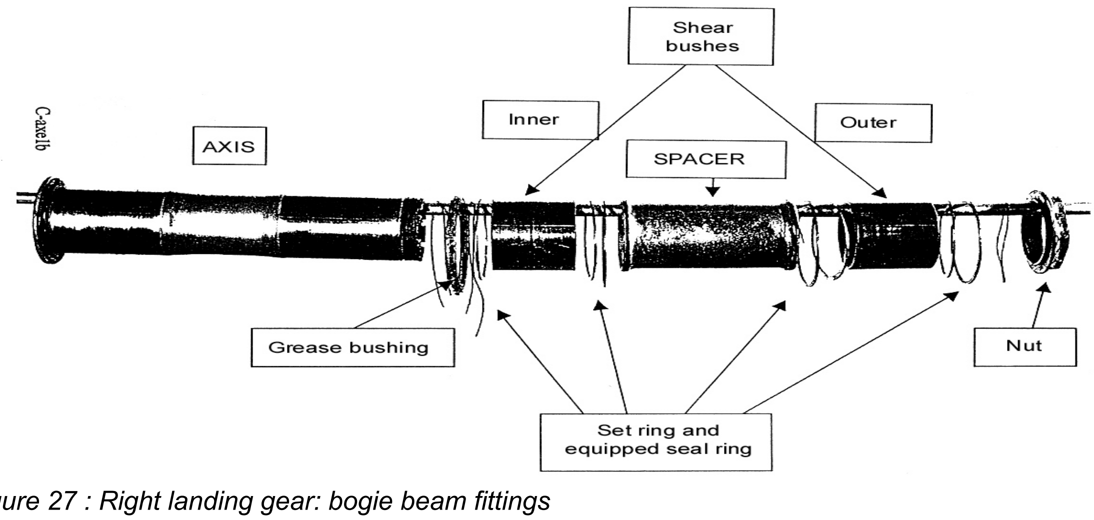


Figure 27 : Right landing gear: bogie beam fittings

The checks and tests carried out before reintroduction into service brought no anomalies to light. These included manoeuvring the landing gear so as to extend and retract it. It should however be noted that, since the landing gear is not in contact with the ground, any possible alignment problems would not be noticeable.

18.2.2 Examination of the Bogie

When the bogie was disassembled in the workshop, no traces of debris from the spacer or traces of melted metal were found. Since this tube-shaped part could not come off the axle completely, the above evidence confirms that it was not present on the aircraft before the accident. It was also noted that the inner shear bush had escaped from its housing.

The condition of the various pieces (shear bushes, bronze bearings, seals) show that the inner shear bush had moved from its position progressively during the last few flights. The marks indicate that the mechanism was operational although the shear bush was no longer in its position on the bronze bearings of the shock absorber and bogie.

The exact chronology of this displacement is, however, difficult to determine since the bush was not new and certainly bore marks related to its previous usage. The only marks observed on the mechanical parts correspond to movements in the vertical plane alone or to normal oscillations of the bogie.

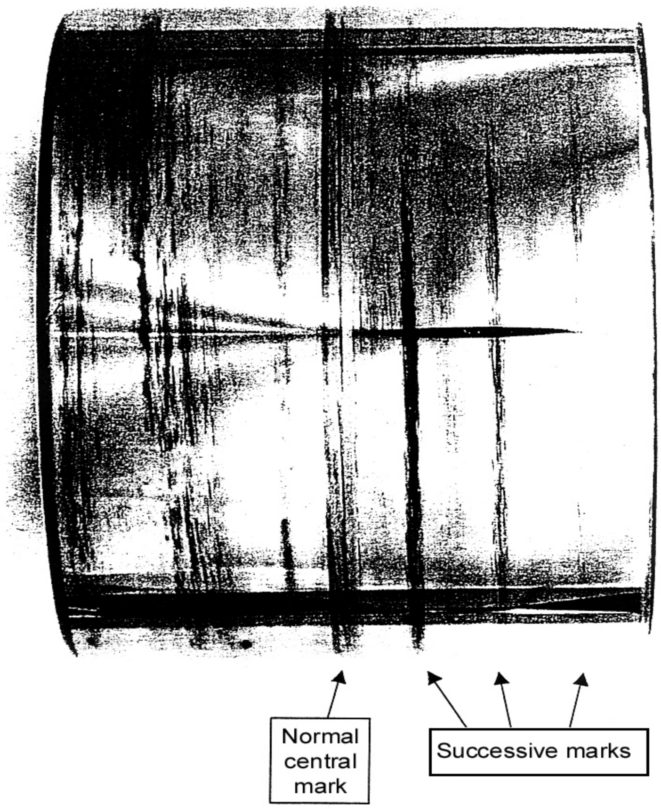


Figure 28: Left landing gear: inner shear bush

18.2.3 Possible consequences on the Landing Gear of the absence of the Spacer

18.2.3.1 Mechanical Aspect

A geometrical calculation demonstrates that in case of complete slippage of the shear bush, the end of the landing gear shaft can move within the inner bearing of the slide rod to the extent of the play created by the absence of the shear bush, that is to say 7.25 mm at the radius.

The bogie beam can move by the same amount in relation to the axis of the shaft, disregarding the residual guidance provided by the outer shear bush.

Maximum displacement of the geometrical axis of the bogie beam results from the combination of the two movements described above, which corresponds to 14.5 mm at the radius, thus a cone angle at the apex of 5°, the tip of the cone being located at the centre of the outer bearing.

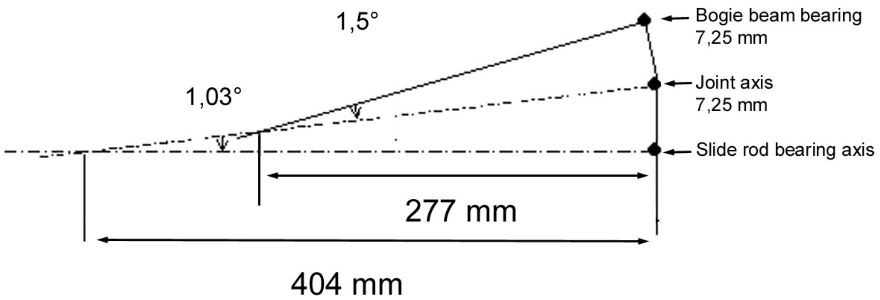


Figure 29: Effect of the absence of the shear bush on bogie geometry

18.2.3.2 Effects on the electrical Wiring and Pipes

An examination was undertaken to determine what might be the consequences of displacement of the axle on the shoulder side in the slide rod bearing. This displacement results in a relative movement between the attachment points of the wires and the pipes on the slide rod on one side and on the bogie on the other.

The electrical wires are long enough to take up a displacement of 20 mm, which protects them in the configuration studied.

The pipes attached to the rotating joint are not designed to take up such a displacement, but it is conceivable that their deformation might not necessarily lead to a complete rupture, taking into account their shape. Such a rupture would in any case only lead to a loss of braking.

18.2.3.3 Displacement of the Bogie

- Mechanical effects

Vertical displacement is viewed as part of normal operations as far as the equipment is concerned (bogie oscillations) and thus has no effect.

A displacement in the horizontal plane is, on the other hand, abnormal. It requires predominance of horizontal loads over vertical loads, which is not the case during the takeoff phase.

- Dynamic behaviour

When the four tyres are correctly inflated, the vertical load transmitted by the bogie beam takes the axle to its upper stop on the bronze bearing of the fork on the slide rod (shock absorber). This generates a camber angle of around 2.5°. The load applied on the two outer tyres (n°1 and 5) is then increased by around 20% whilst the load applied on the two inner tyres (n° 2 and 6) being diminished by the same amount.

After the burst of tyre n°2, the load that it was bearing was redistributed between the outer tyres. Consequently, a new equilibrium was generated around its axle on the outer shear bush. The camber angle was then practically zero.

It is also necessary to consider the possible effect of sideslip. The complete displacement of the shear bush can in fact engender lateral loads as a result of the appearance of a sideslip angle. Studies show that for sideslip angles of less than 5°, the self-aligning moment that appears tends to pull the wheel back towards the running axis.

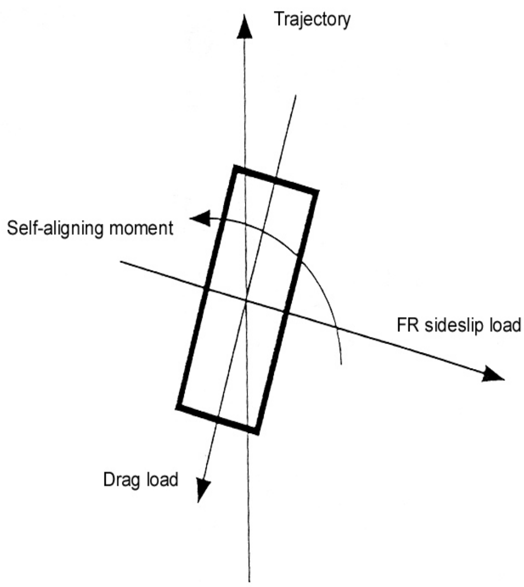


Figure 30: Typical behaviour of tyre under sideslip

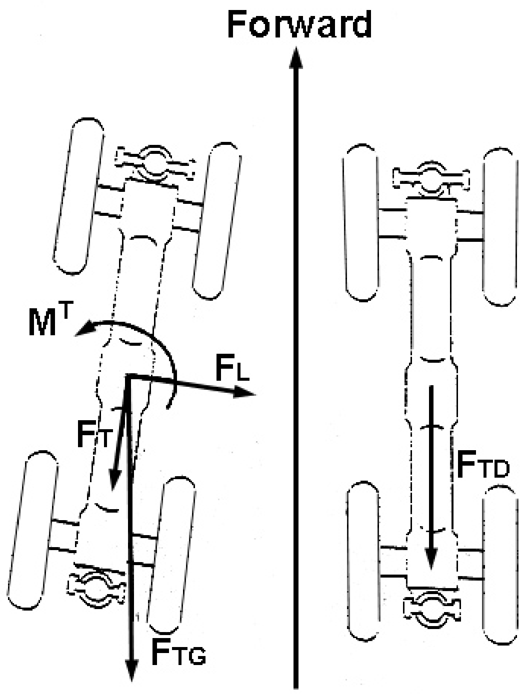


Figure 31: Sideslip forces

Overall, the balance of forces at the centre of the bogie would result in self-aligning moment and two loads whose resultant is increased drag, that is to say a tendency to make the aircraft veer to the left. The level of this drag would be at most around 1,000 daN, very low in relation to the thrust of the engines. The influence of possible sideslip on the trajectory is thus very low or negligible.

18.2.4 Examination of the Tyres

Workshop examination of tyres n° 5 and 6 did not bring to light any evidence of deterioration. In addition, examination of the wheels, bearings and brakes on wheels n° 1, 2, 5 and 6 showed that these parts were in normal condition.

18.2.5 Study of the Beginning of the Flight

In theory, the absence of the spacer could have instigated an asymmetrical trajectory, tyre overheating and slower acceleration than normal. Study of the marks on the runway as well as calculations of the trajectory and acceleration made on the basis of the data from the flight recorders entirely contradict this hypothesis:

- After taxiing to the runway, when the crew were performing the pre-flight checklist and in accordance with it, the crew called out the temperature of the brakes. The temperature was 150° (the temperature must exceed 220° for there to be an alarm). In addition, it was the same for the left and right landing gear bogies. Thus, the temperature of the brakes was in no way abnormal.

- During the takeoff run, the aircraft would have a tendency to deviate to the left if the left main landing gear had induced parasite drag. However, its trajectory is rectilinear before the loss of thrust on engines 1 and 2 and there are no observable inputs to the right on the rudder. On the contrary, some slight inputs to the left are even observable before V1.

- The acceleration recorded by the flight data recorder is 0.268 g, which is the normal value for the Concorde when it is at its maximum weight. Furthermore, 34 seconds after the beginning of the takeoff run, the aircraft had rolled 1,200 metres and reached a speed of 151 kt. With a weight of 185 tons and with conditions as on that day, the Concorde rolls 1,150 metres and reaches a speed of 150 kt in 33 seconds. Aircraft performance was thus strictly in accordance with the design values up until the damage to tyre n° 2 by the metallic strip. Furthermore, takeoff performance on the flights that preceded the accident (but after the bogie replacement work) was in accordance with published norms. There is no significant difference compared to takeoff performance on other Concordes.

- Up until the time the aircraft ran over the metallic strip, no remarks or reactions by the crew indicate any abnormal aircraft behaviour.

- The first tyre marks recorded on the runway after the accident are those of the tyre on wheel n° 2 after damage by the metallic strip.

In addition, a change in bogie perpendicularity might have occurred, preventing gear retraction. As shown in paragraph 16.10, this did not happen.

*   *
*

In conclusion, nothing in the body of research undertaken indicates that the absence of the spacer contributed in any way to the accident on 25 July 2000.

18.3 Prevention of Debris-related Risks on the Movement Area

18.3.1 Current Regulations in France

After the Concorde accident, a review of instructions related to runway inspections at French aerodromes was carried out by the DGAC. This showed that in the absence of national regulations, the ICAO norms and recommendations are generally followed. According to the aerodrome, inspections of the movement area are carried out by various organisations: the runway operations office, the Rescue and Fire Fighting Service (RFFS), the BRIA, the operator. It depends mainly on the terms of the operating contract in force.

The DGAC is currently preparing a draft regulation and an operations manual concerning runway inspections, based on and extending the ICAO's recommendations. A manual on preventing the presence of debris on the movement area is also being prepared.

18.3.2 Prevention of debris-related Risks at Paris Charles de Gaulle

18.3.2.1 Manoeuvring Area

Safety on the manoeuvring area (runways and taxiways) is the responsibility of the ADP aerial operations division. Apart from checks in case of discovery of debris, the internal regulations specify three daily inspections. Before the accident on 25 July 2000, the real average was two inspections a day, since when it has become three. Sweeping is carried out by agents from the ADP equipment division, under a protocol with the ADP aerial operations division.

Discoveries of debris on the manoeuvring area are reported in the runway operations office duty officer's operations log. Determining the origin of the debris does not systematically lead to an internal investigation. According to the type and size of the object, the BEA is informed, and the pilot or the operator of the aircraft that may have lost the object is alerted.

The instruction lists which are the basis of follow-up for safety on the platform do not contain any data relating to debris. Since May 2001, the presence of debris on the movement area is subject to statistical analysis.

A working group on prevention and safety/feedback was set up in 1999. It is mainly concerned with air traffic aspects but should help identify and analyse events that precede accidents.

Note: a similar working group was created in Nice in 2001.

18.3.2.2 The Apron

Prevention of debris on the apron (access and parking areas) is covered by the policy on safety on the apron, which is the responsibility of the ADP operations division. This policy has two parts: one regulatory and the other relating to partnerships.

The regulations for operation of the movement area (that's to say the manoeuvring area and the apron) requires "maintaining the movement area in good condition". It applies to all users of the platform and any breaking of the regulations results in a summons. Application of the regulations is ensured by agents of the state (DGAC and GTA) with assistance from sworn agents from ADP, the safety inspectors on the movement areas.

In parallel, the partnership element in the safety policy for the apron is organised around two organisations:

- a co-ordination body, the "Area Safety Commission". It includes the representatives of the airport, the airlines, the assistance and service providers on the apron and various public services. The commission meets three times a year. This body co-ordinates and makes proposals,

- an association governed by the 1901 law, the "Area Safety Charter" created in 1994. Several airlines, ADP and service providers are members. This association makes comments and takes action. Thus, a seminar was held in 2000 on the problem of safety on movement areas. The association also publishes a quarterly bulletin "Safety Info". The association meets frequently and the members are in weekly contact. Nevertheless, ADP's representatives regret that too few airlines participate,

there are also some training and information events, mainly:

- poster campaigns on specific themes,

- a training project for persons working on the movement area, in co-ordination with their employers,

- an occasional publication "Safety Flash".

Cleaning of the apron is handled by the Equipment Division. Collection of debris is sub-contracted. Both operations are carried out in a preventative and curative manner. In addition, a contract for cleaning small debris calls for the service provider to work on the verges and green spaces bordering the apron.

There is no qualitative or quantitative follow-up system for the presence of debris on the apron.

18.3.3 Situation Abroad

18.3.3.1 Canada

18.3.3.1.1 History

In 1974, the Canadian civil aviation authorities, in co-operation with the national airlines, formed a "national committee on prevention of debris-related risks". This committee was wound up in 1985.

Management of the main Canadian aerodromes is currently franchised to non-government bodies. The operators of these aerodromes must possess an aerodrome certificate issued by Transport Canada and are subject to the regulations in CAR Part III, Aerodromes and Airports.

18.3.3.1.2 Regulations

The regulations concerning prevention of debris-related risks are included in CAR 302 "Airports".

Paragraph 302.07, on the operator's obligations, specifies that the latter must comply with the published norms and recommendations. The latter require a daily infrastructure inspection. Paragraph 302.07 imposes an additional runway inspection in certain cases (accident or incident, works or potentially dangerous conditions).

Paragraph 302.08 states that the operator must publish an operations manual approved by Transport Canada. This manual must describe safety measures, amongst other things. Although the regulations do not specifically require a programme for prevention of debris-related risks, approval of the operations manual implies the description of such a programme in practice.

18.3.3.1.3 Technical documentation

In 1976, a "Manual for Prevention of Foreign Object Damage" was published by the authorities, which at that time managed the aerodromes. This manual, revised in 1983, contains technical instructions for the prevention of debris-related risks. Although it does not have the power of law, this manual is still the reference document for aerodrome operators.

18.3.3.1.4 Oversight

In the context of oversight of aerodrome certification, Transport Canada conducts an annual inspection of aerodromes in the course of which an inspection of the movement area is carried out.

18.3.3.1.5 Training

Since the privatisation of the aerodromes, Transport Canada no longer takes care of training related to airports.

18.3.3.1.6 Example: Vancouver International Airport

Vancouver International Airport has three runways and 370,000 movements per year. There are three infrastructure inspections per day.

The airport is an active participant in the NAFPI (USA). It has an active programme for prevention of debris-related risks based on:

- the active participation of all of the participants working on the airport's movement area,
- the co-ordination of actions on the prevention of debris-related risks by an airport Safety representative,
- training for those who work on the movement area,
- information campaigns (posters, thematic presentations, good conduct prize).

A commission on debris-related risks meets once a quarter. Originally it met once a month, which proved demotivating for the participants. This commission is presided over by a safety representative and groups together the companies working on the movement area. Participation is voluntary.

A symposium was organised in 1996 with the participation of several Canadian airports and industry representatives.

18.3.3.2 United States

18.3.3.2.1 Background

All aerodromes where aircraft with more than thirty seats are operated must hold an operations certificate issued by the FAA under chapter 14 of the CFR, Part 139. To obtain this the operator must publish an aerodrome certification manual containing procedures and plans in accordance with Part 139. The FAA Airport Certification and Safety Inspectors (ACSI's) carry out annual inspections and oversight inspections of certified aerodromes.

18.3.3.2.2 Regulations

Control of debris on aerodromes is covered by sub-section D Operations, of Part 139.

Paragraphs 139.305 and 139.307 specify that debris of all kinds must be removed immediately from paved and unpaved areas of aerodromes.

Paragraph 139.327 (Self-inspection program) requires that the aerodrome manual describe when and how runway inspections are to be conducted, including extra or special inspections (following an accident or incident, in case of works or specific meteorological conditions).

Inspection reports must be archived for at least six months.

18.3.3.2.3 Advisory Circular

To assist the airport authorities to comply with the regulatory requirements, the FAA published Advisory Circular n° 150/5380-5B *"debris-related risks".*

This circular recommends the establishment of a programme for the prevention of debris-related risks. This puts the accent on the need for co-operation between all of the partners at the airport and on the importance of training and the involvement of all those working on the platform. It recommends a review of the causes and factors contributing to the presence of debris before the development of the programme for prevention of debris-related risks.

The circular also recommends the setting up of a committee for prevention of debris-related risks, grouping together the representatives of all of the organisations working on the movement area.

It suggests several solutions (areas dedicated to collected debris, equipment for cleaning the movement area) and refers to documents and reports by Aerospace FOD Prevention Inc. (NAFPI, non-profit-making association of professionals).

18.3.3.2.4 Training

The FAA, in co-operation with the American Association of Airport Executives (AAAE), has set up three or four day training programmes called *airport operation and safety schools*. Debris-related risks are presented by different participants in the field of aviation such as pilots, aircraft manufacturers and airport operators.

18.3.3.2.5 Example of Atlanta Hartsfield International Airport

Atlanta Hartsfield International Airport has four runways and a million aircraft movements a year. There is one infrastructure inspection per day.

The airport has an active programme for prevention of debris-related risks based on:

- the active participation of all of the participants working on the airport's movement area,
- the co-ordination of actions on the prevention of debris-related risks by an airport "Operations" agent,
- training for those who work on the movement area,
- information campaigns for personnel (posters, participation in infrastructure inspections).

A safety commission meets once a month. Questions on debris-related risks are systematically included on the agenda.

A specific commission on debris-related risks met in April 2001 in order to take action in advance of risks related to the work on the aerodrome extension.

18.3.3.2.6 Example of Washington National Airport

Washington National international airport has three runways. There is one infrastructure inspection per day.

The airport has an active programme for prevention of debris-related risks based on:

- the active co-operation of all of the participants working on the airport's movement area,
- surveillance by the aerodrome maintenance and operations personnel and by the various participants at the airport,
- the co-ordination of actions on the prevention of debris-related risks by an airport "Operations" agent,
- training for those who work on the movement area.

There is no specialised commission. There used to be one but the limited number of events and the experience acquired did not justify its continuation. It will be re-established if the circumstances warrant it.

Note: various items of equipment and materials (sweepers, receptacles for debris, magnetic bars) are used in the context of prevention of debris-related risks.

18.3.3.3 Holland

The Dutch civil aviation authorities apply ICAO Annexe 14. There are no specific national regulations relating to the inspection of the movement areas nor, more generally, on the prevention of debris-related risks.

Example of Amsterdam Schiphol Airport:

- In 1995, a pilot safety group was set up at Schiphol and an airport safety management system (ASMS) was created. The Dutch civil aviation authorities approved this system in 1998. The existence of such a system is not yet a requirement.

- In 1997, the integrated safety management system (ISMS) was set up. The ISMS brings together the airport authority, the air traffic control authority, and various airlines and companies working at the aerodrome. Co-operation between all those working on the movement area is ensured through participation in working groups.

- The safety rules are defined in the airport manual (Airside Regulation and Rules) and airport officers are responsible for ensuring their application.

- A runway inspection is performed three times a day. Additional inspections are carried out if the runway remains inactive for more than twenty minutes.

- The whole movement area is swept regularly and receptacles for debris are placed at different places on the apron.

- Discoveries of debris are recorded in the database on incidents and accidents on the movement area. The type of debris, the time and place of discovery are noted.

- An information campaign aimed at prevention of debris-related risks is conducted each year. Rewards are given to companies and persons who contribute to prevention.

- The level of awareness of persons working on the movement area is measured via questionnaires and their training includes a section on debris-related risks.

18.3.3.4 United Kingdom

- National context

The FAA requires that aerodromes, through the certification process, supply details on their inspection policies for movement areas, including on additional inspections following any incident which might lead to the presence of debris in a critical area. The CAA does not define the frequency of inspections nor their objective.

The CAA encourages aerodromes to adopt a policy and safety management system, although this is not a regulatory requirement. The Civil Aviation Publication 642 of March 1995 offers guidance on the setting up of a system of safety management.

The safety management systems developed up to now include all aspects of airport operations, including prevention of debris-related risks. Those responsible for the aerodrome define the policy and procedures that must be applied by persons working on the movement area. This results in training programmes, information programmes, safety committees and certain sanctions.

All of the large aerodromes have a programme for permanent sweeping and publish their policy on prevention of debris-related risks in their aerodrome manual and/or in instructions. Most of the aerodromes supply a brochure entitled the "Apron Safety Code".

- Other regulations and publications

The United Kingdom has set up a system of mandatory notification for events and any damage caused to an aircraft by debris is usually reported through this system. Aerodromes must supply their comments on events that concern them and specify what steps have been taken to avoid any future repetition.

In December 2000, the CAA sent a note to aerodromes to stress the dangers of damage caused to tyres by debris. This note reiterates the requirements in terms of inspections and invites aerodromes to verify their procedures in this area.

The CAA also publishes a guide on works on aerodromes, which sets out steps to eliminate debris or to prevent it from reaching the movement area.

List of appendices

Analysis of alarms and noises recorded on the CVR

1 Alarms

- Toilet smoke

Tests confirmed that the alarm heard at 14 h 43 min 32.6 s was in fact a toilet smoke detection alarm. This alarm can be recorded by the CVR when the cockpit door is open.

- Fire alarm

The bell heard three times after14 h 43 min 22.8 s was identified as a fire alarm. This alarm, well known to aircrew, also includes a gong.

- Gongs

14 h 43 min 23.5 s: this gong, which appears 0.7 s after the first ring of the bell, is part of the aural fire alarm.

14 h 43 min 28.2 s: this gong corresponds to the automatic switching of the electric pitch trim actuators.

14 h 43 min 37 s: this gong is probably related to the engine 2 alarm following the drop in oil pressure due to engine 2 shutdown. On the FDR the engine warning parameter appears again.

14 h 43 min 43 s: this gong, which appears 0.7 s after the first ring of the bell, is part of the aural fire alarm.

14 h 43 min 59.4 s: this gong, which appears 0.7 s after the first ring of the bell, is part of the aural fire alarm.

14 h 44 min 26.6 s: no explanation found.

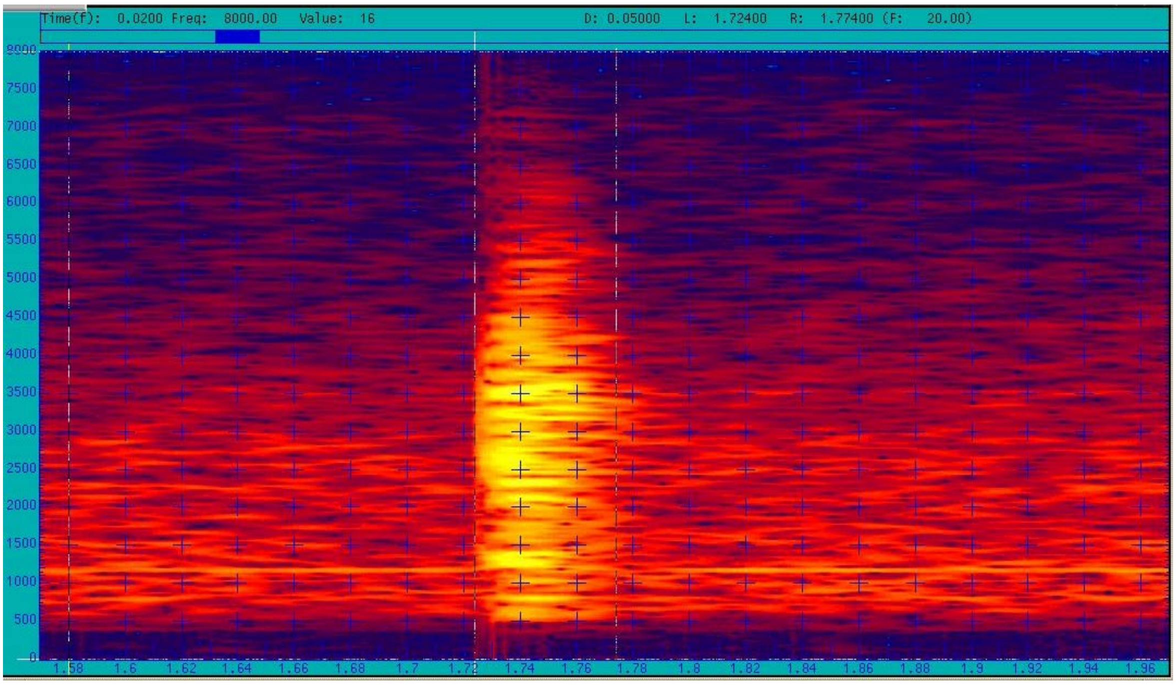
14 h 44 min 27 s: no explanation found.

Note: two gongs generated by two different systems but separated by less than twenty milliseconds cannot be distinguished by spectral analysis.

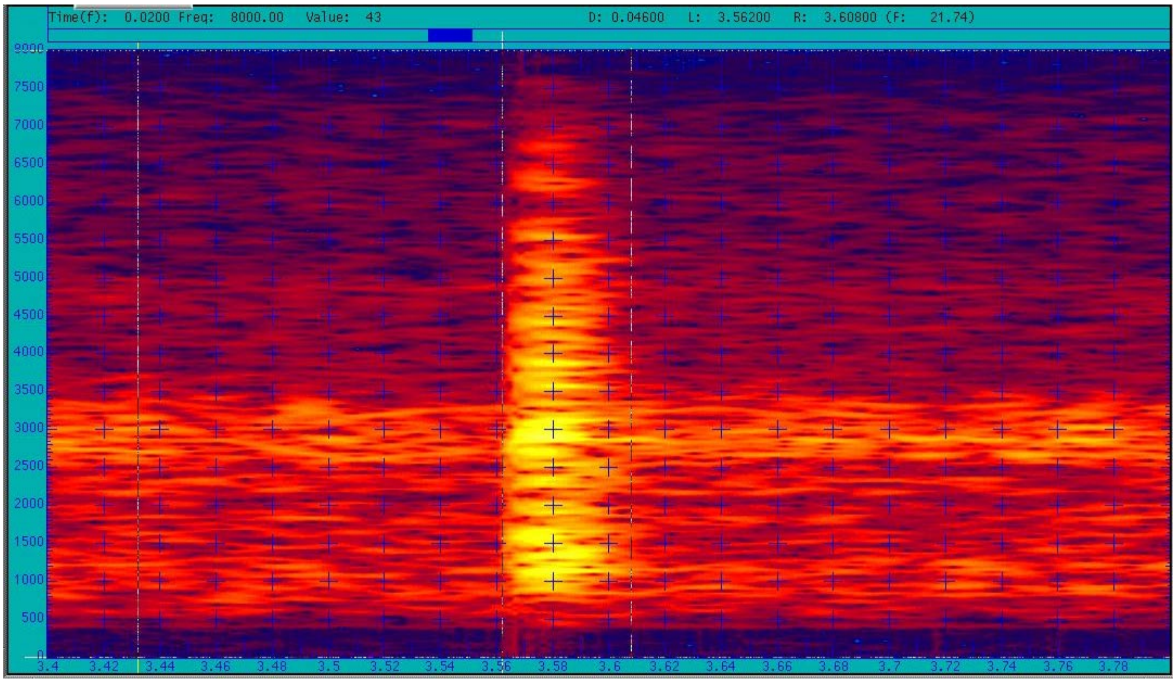
2 Noises

- Noise at 14 h 42 min 30.4 s

This noise is identified as the “clicking” of the thrust levers. The normal procedure, during power up, is to advance the levers to their stop. This interpretation is consistent with the results from the FDR. The comparison of the time-frequency representations recorded on F-BTSC and of that recorded on F-BTSD are shown hereafter.



Noise on F-BTSC



Clicking of thrust levers during power up on F-BTSD

- Change in background noise at 14 h 42 min 31.3 s

After the clicking of the thrust levers, there is an increase in the noise from the air conditioning, associated with the increase in engine noise. It is not possible to determine the rotation speed of the rotating parts of the engine.

- Noise of selector at 14 h 42 min 47.5 s

When passing through sixty knots. The “engine 4 take off N1 limiter” changes position automatically. Synchronisation with the FDR confirms this selector movement since the aircraft was passing through sixty knots when this noise was made.

- Noise at 14 h 42 min 55.1 s

The origin of this noise was not identified.

- Noise at 14 h 43 min 10.1 s

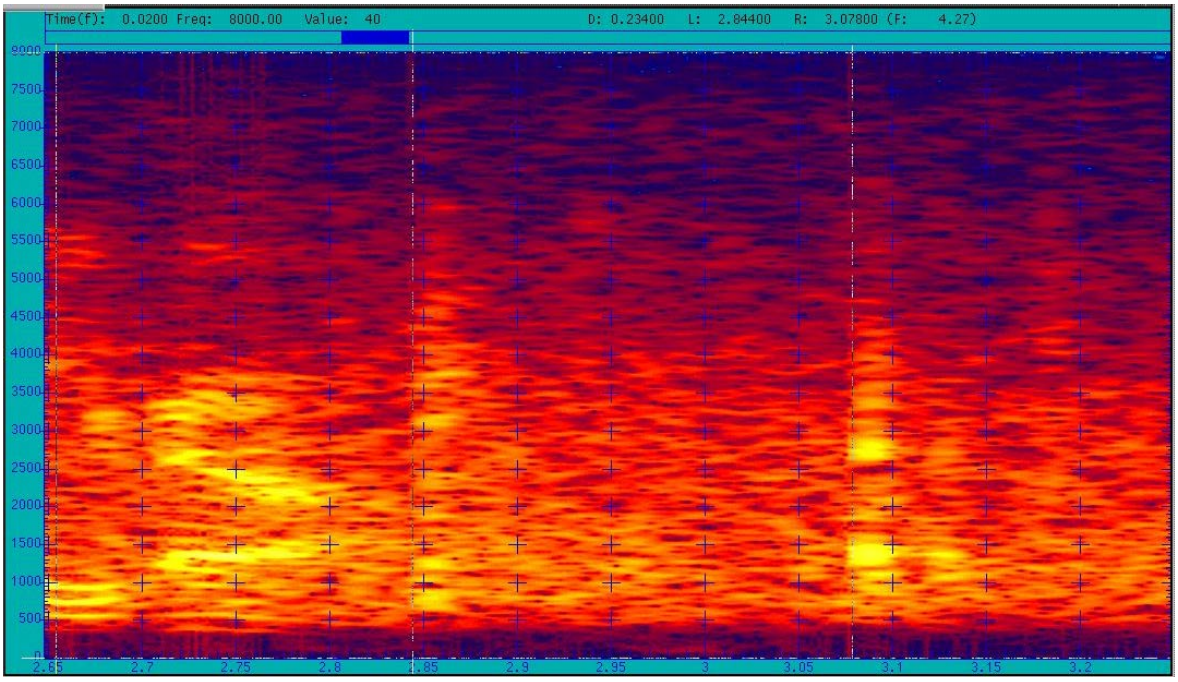
The origin of this noise was not identified. It is followed by a change in the background noise which couldn't be interpreted either.

- Noise at 14 h 43 min 16.1 s

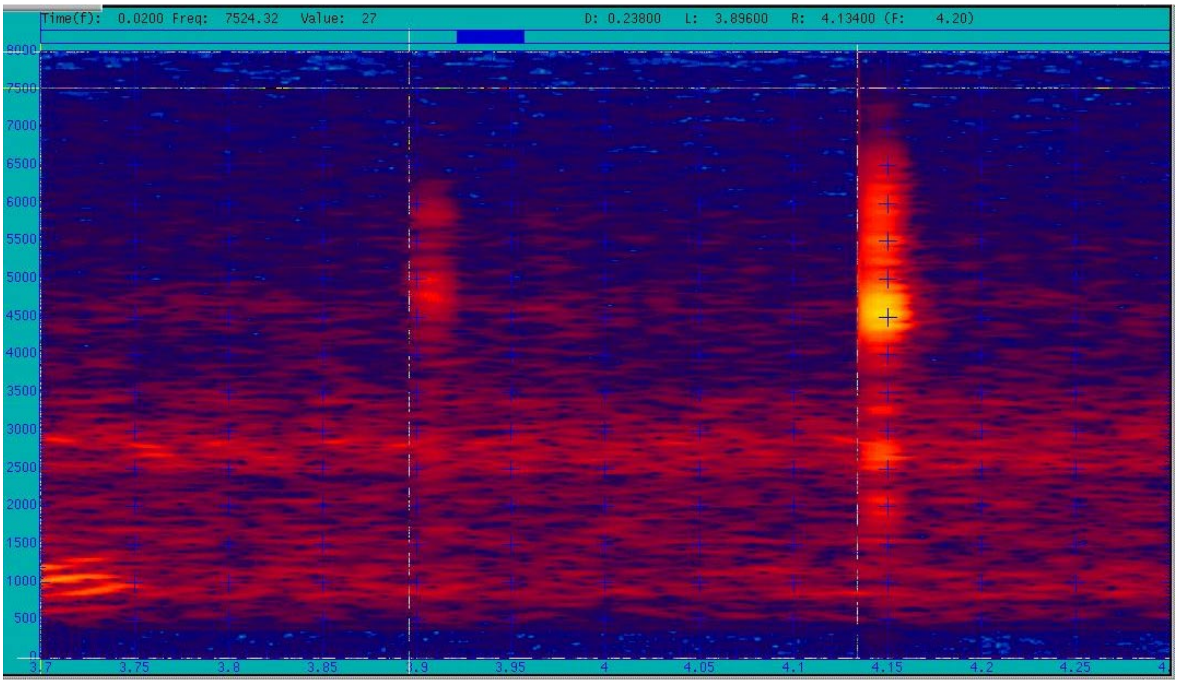
The origin of this noise was not identified.

- Noise of selector at 14 h 43 min 21.3 s

The rate and auditory perception, as well as application of procedures, enabled this noise to be identified as being that of the movement of the TCU selector from “main” to “alternate”. The time-frequency analyses of the noise on F-BTSC and on F-BTSD are shown hereafter.



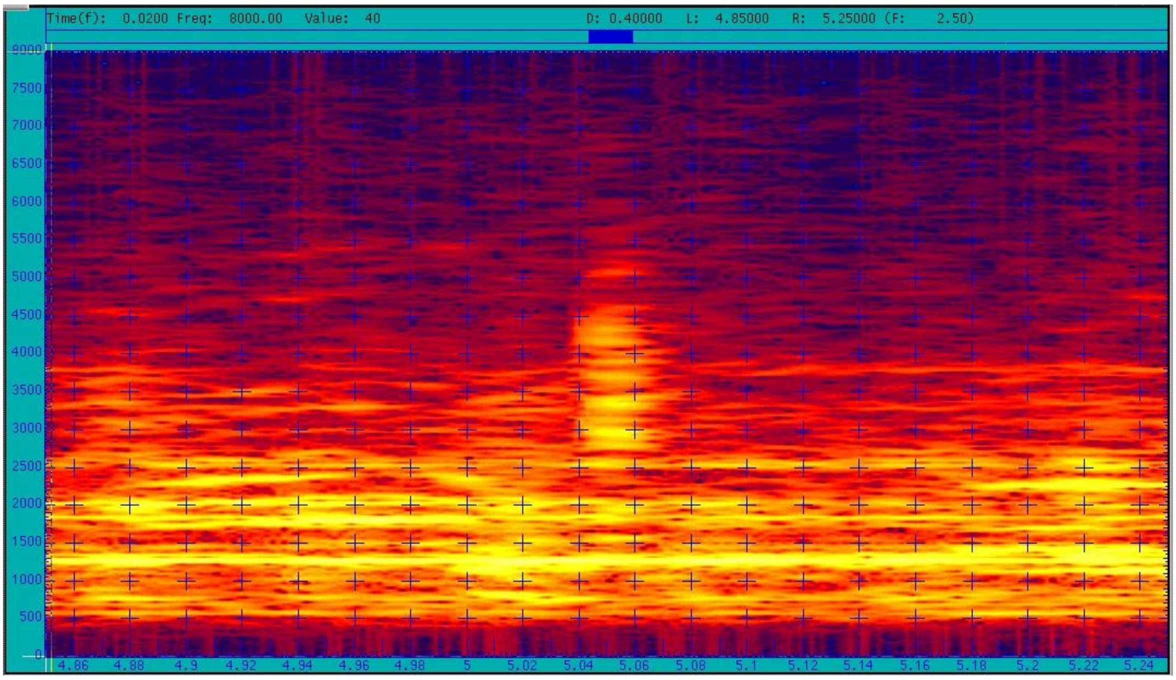
Noise of selector on F-BTSC (234 ms)



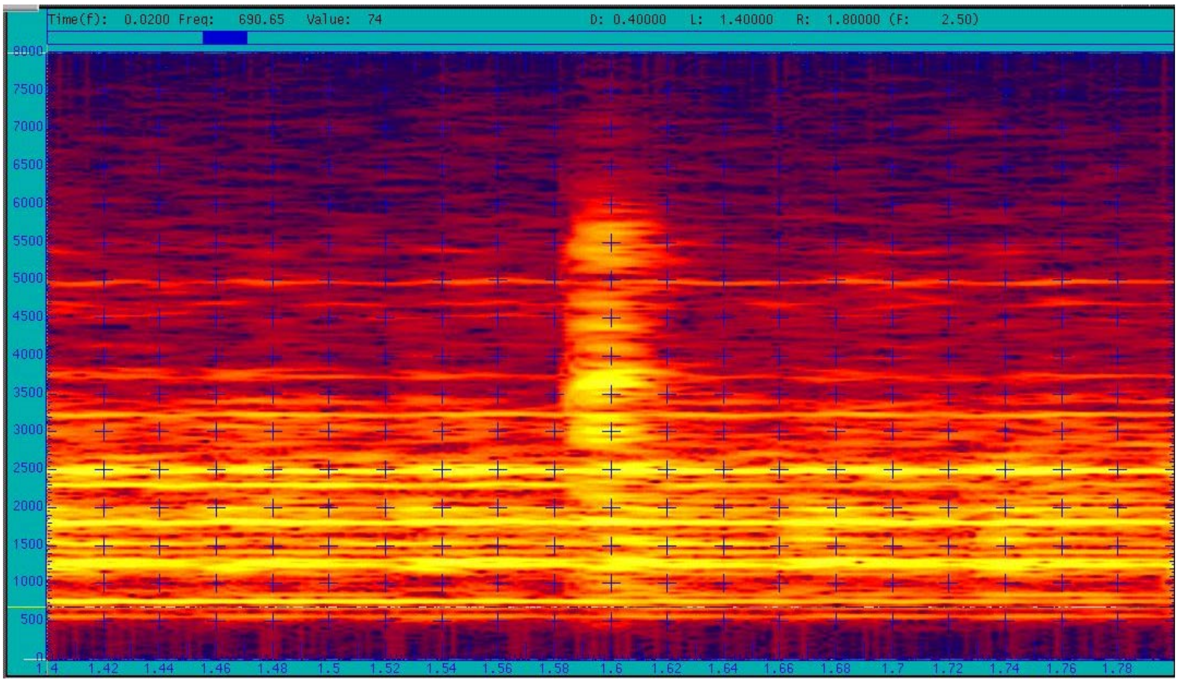
Noise of selector on F-BTSD (238 ms)

- Noise of selector at 14 h 43 min 26.2 s

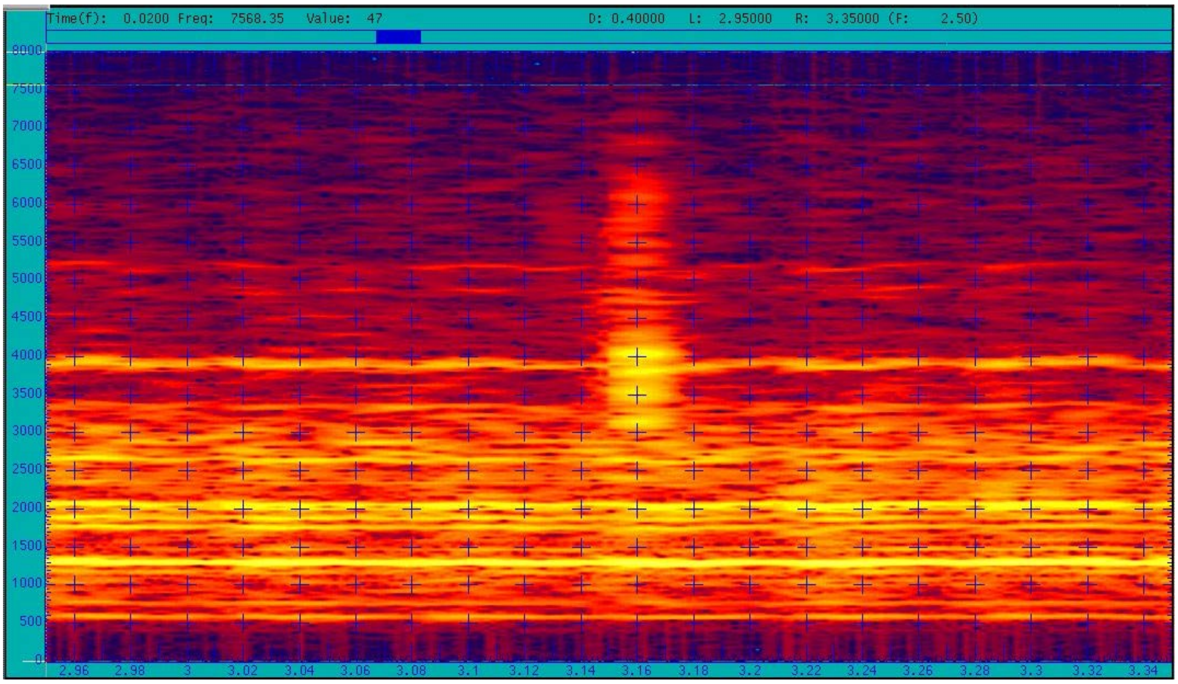
On the FDR a decrease in engine speed is noted after this selector noise. There were four hypotheses to explain this decrease in speed. The first was independent of crew action in the cockpit, the three others were respectively an action on the thrust lever, a cut through movement of the HP fuel cock or a de-selection of auto-thrust. The spectral representation is very close to that of a thrust lever reduction or a HP fuel cock shutoff, though it is impossible to distinguish between them. The time-frequency analyses of the noise on F-BTSC and on F-BTSD are shown hereafter.



Noise of selector on F-BTSC



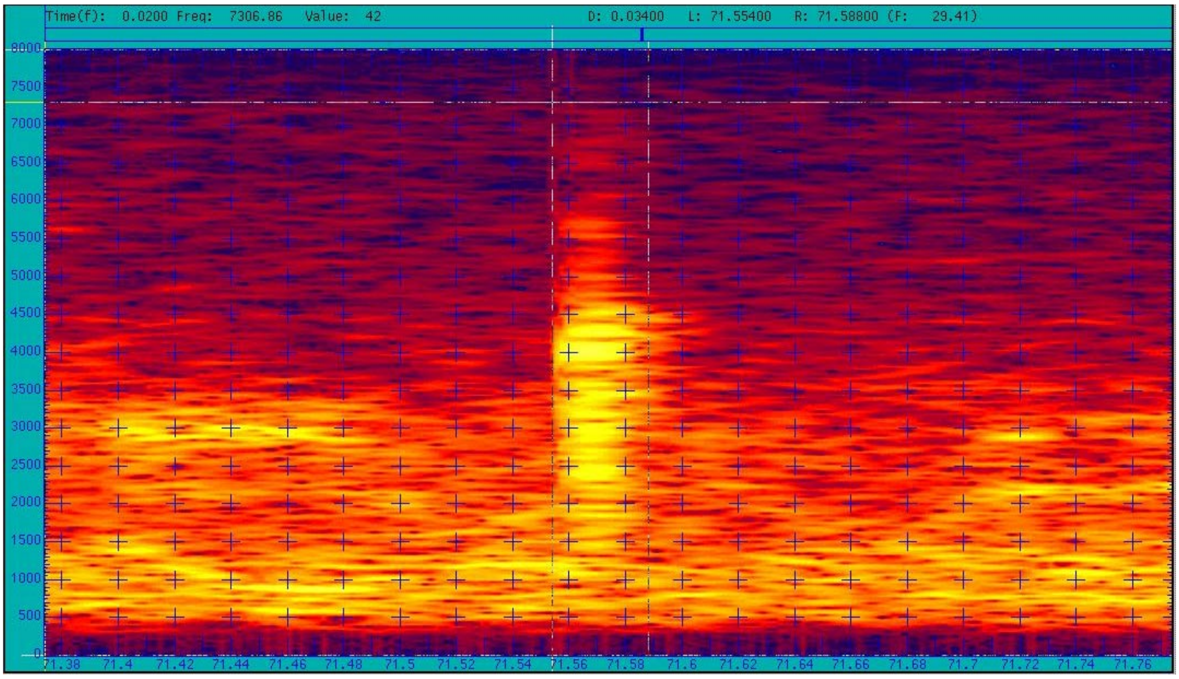
Movement of the lever towards idle position on F-BTSD



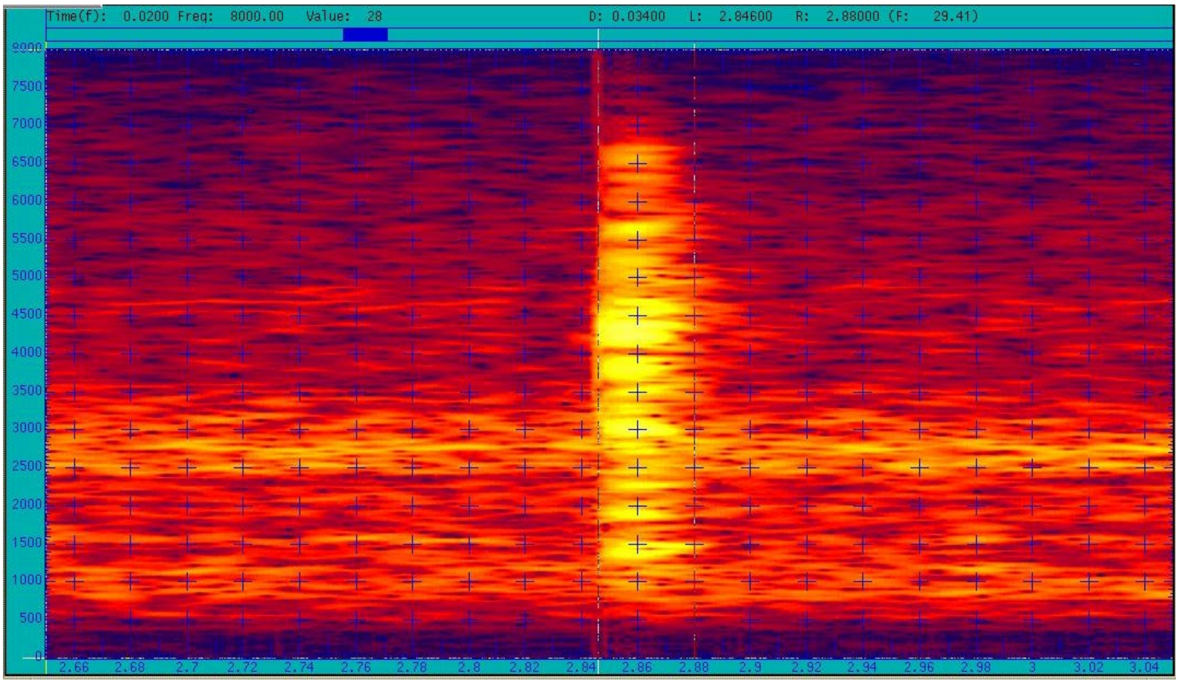
HP fuel cock shutoff on F-BTSD

- Noise of selector at 14 h 43 min 27.5 s

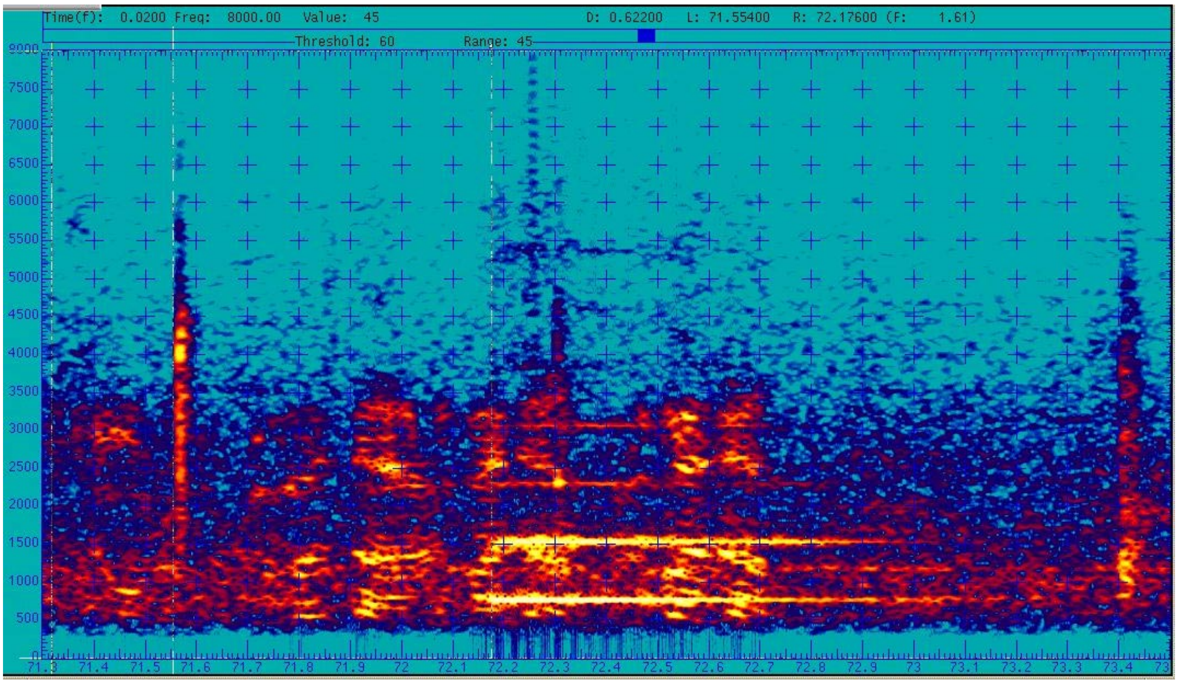
Several elements enabled identification of the electric pitch trim actuators: energy peaks at approximately frequencies, the duration of the signal and the time between the selector noise and the appearance of the gong 0.7 to 0.8 s later. The time-frequency analyses of the noise on F-BTSC and on F-BTSD are shown hereafter.



Noise on F-BTSC



Movement of the electric pitch trim actuators on F-BTSD



Distance between the selector noise and the appearance of the sound of the gong.

- Noise of selector at 14 h 43 min 29.3 s

The spectral representation closest to this noise corresponds to pulling the fire handle. The noise at 14 h 43 min 44.7 s confirms this action.

- Noise at 14 h 43 min 37.3 s

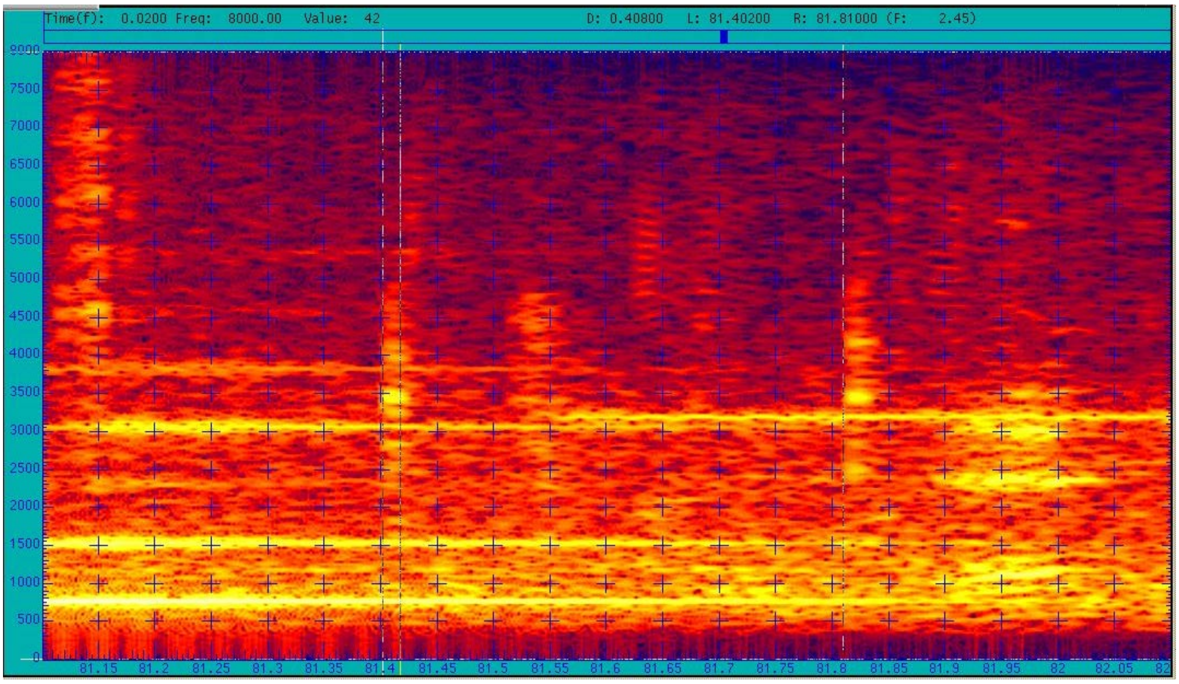
The origin of this noise was not identified.

- Noise at 14 h 43 min 38.4 s

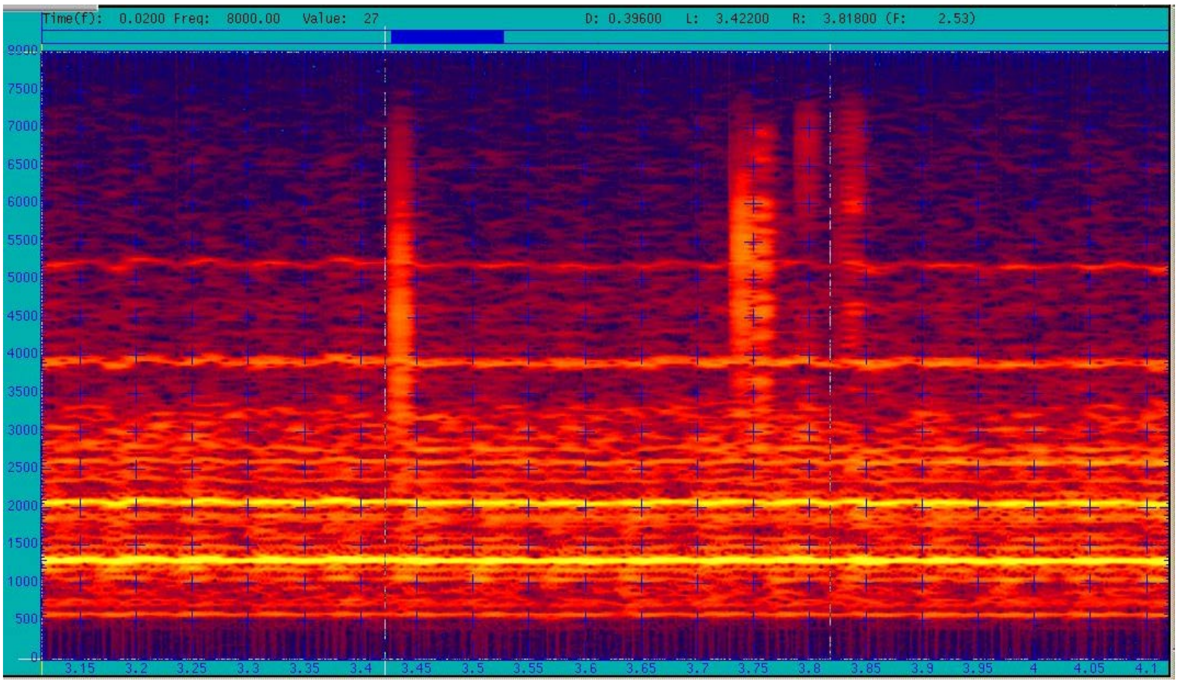
The origin of this noise was not identified.

- Noise of selector at 14 h 43 min 44.7 s

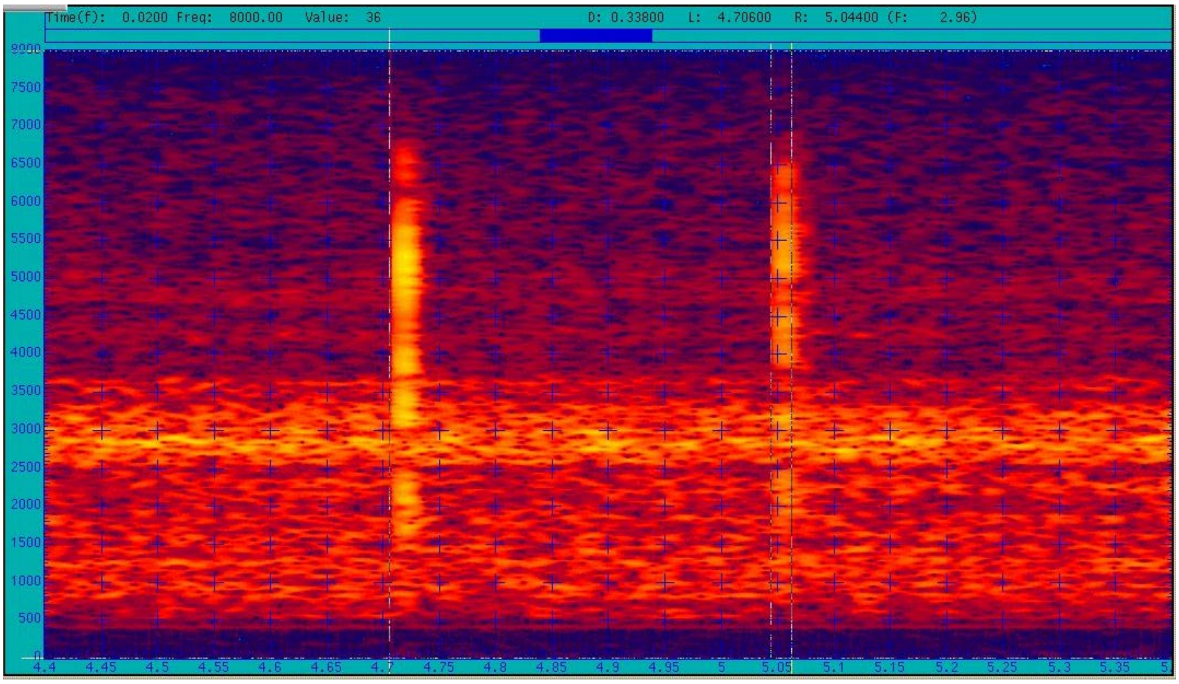
This noise is similar to activation of the “first shot” pushbutton which corresponds to the firing of the extinguishers in the engines. This action can only be taken if the fire handle has been pulled. The rate between the two energy peaks which make up this noise is characteristic of action on this button or, more exactly, of the destruction of the glass which covers this button. In the three time-frequency analyses that are shown hereafter, this time is between 0.35 and 0.4 s.



Noise on F-BTSC (408 ms)



First shot activated on F-BTSD with fire alarm (396 ms)



First shot activated on F-BTSD without fire alarm (338 ms)

- Noise at 14 h 43 min 53.0 s

The origin of this noise was not identified.

- Noise at 14 h 44 min 10.5 s

The origin of this noise was not identified.

- Noises of selectors between 14 h 44 min 24 s and 14 h 44 min 27.5 s

Six selector movement noises are perceptible. None could be identified. However, two or three appear to be movements of engine thrust levers or HP fuel cock cut-offs.

CVR TRANSCRIPT

FOREWORD

The following is a transcript of elements which were comprehensible, at the time of the preparation of the present report, on the cockpit voice recorder. This transcript contains conversations between crew members, radiotelephone messages between the crew and Air Traffic Control services and various noises corresponding, for example, to the use of controls or to the alarms.

The reader's attention is drawn to the fact that the recording and transcription of the CVR are only a partial reflection of events and of the atmosphere in the cockpit. equently, the utmost care is required in the interpretation of this document.

The voices of the crew are heard through the cockpit area microphone. They are placed in separate columns for reasons of clarity. One column is reserved for other voices, noises and alarms, which are also heard through the cockpit area microphone.

GLOSSARY

UTC Time	The transcript of the preliminary report was timed in 25ths of a second. For easier reading, the data is now presented in tenths of a second format
FDR Time	Generated time recorded by the FDR in seconds and tenths of a second
CAM	Cockpit area microphone
Ctl	Air Traffic Control centre on the frequency in use
FC	Fire Chief
CC	Cabin crew
SV	Aircraft computer-generated voice
➪	Communications to ATC, from the ground and by the CC on the intercom
?	Speaker not identified
( )	Words or groups of words in brackets are doubtful
(*)	Words or groups of words not understood

CVR UTC TIME	FDR TIME	CAPTAIN	FIRST OFFICER	FLIGHT ENGINEER	COCKPIT AREA MICROPHONE	VHF INTERPHONE PA	OBSERVATIONS AND ALARM NOISES
14 h 12 min 23 s	BEGINNING OF RECORDING						
14 h 39 min 04 s		so the takeoff is … at maximum takeoff weight one hundred eighty-five tons one hundred which means four reheats with a minimum failure N2 of ninety-eight					
39 min 21 s 39 min 25 s		between zero and one hundred knots I stop for any aural warning the tyre flash				(Ctl) Air France four five nine O contact the Tower on one hundred twenty decimal nine	
39 min 29 s			➪ one hundred twenty-nine four five nine O good afternoon				
39 min 35 s		tyre flash and failure callout from you right					
39 min 38 s		between one hundred knots and V1 I ignore the gong I stop for an engine fire a tyre flash and the failure callout					
39 min 45 s				yes			
39 min 46 s		after V1 we continue on the SID we just talked about we land back on runway twenty-six right					
39 min 51 s		and the quick reference handbook is ready for an overweight landing					
39 min 56 s						(Ctl) Air France four five nine O hello	
39 min 58 s			➪ hello threshold twenty-six right four five nine O				

CVR UTC TIME	FDR TIME	CAPTAIN	FIRST OFFICER	FLIGHT ENGINEER	COCKPIT AREA MICROPHONE	VHF INTERPHONE PA	OBSERVATIONS AND ALARM NOISES
14 h 40 min 01 s						(Ctl) (*) four five nine O line up on runway twenty-six right	
40 min 04 s			➪ we line up and hold on twenty-six right four five nine O				
40 min 07 s		ready in the back?					
40 min 10 s			let’s go				
40 min 11 s		➪ CC prepare for takeoff					
40 min 16 s		pre-takeoff check-list					
40 min 19 s		how much fuel have we used?					
40 min 23 s				we’ve got eight hundred kilos there			
40 min 24 s		eight hundred kilos?					
40 min 28 s		right	no difference on the second segment				
40 min 31 s		we haven’t left yet, have we (*)					
40 min 35 s		err brakes one hundred degrees					
40 min 37 s				before takeoff takeoff monitor			
40 min 39 s			armed				
40 min 40 s		armed					
40 min 41 s 40 min 43 s 40 min 44 s				the parameters for take... takeoff parameters	 (CC) cabin ready		
40 min 45 s		well they’re confirmed, nothing has changed					
40 min 47 s				noise reduction parameters confirmed engine rating light on take-off			
40 min 55 s				N1 limiter four ninety eight eighty idle on high			
14 h 41 min 00 s				central alarm system			
41 min 01 s 41 min 02 s 41 min 03 s		 recall inhibit				(Ctl) Air France four five nine O so I will call you back as soon as it’s free in front	

CVR UTC TIME	FDR TIME	CAPTAIN	FIRST OFFICER	FLIGHT ENGINEER	COCKPIT AREA MICROPHONE	VHF INTERPHONE PA	OBSERVATIONS AND ALARM NOISES
41 min 04 s			➪ holding position four five nine O				
41 min 05 s				the transponder			
41 min 08 s				I'min putting it on			
41 min 09 s				brake temperatures checked one hundred fifty the CG is at fifty …. four two			
41 min 17 s				reheat four whites de-icing			
41 min 19 s		okay					
41 min 20 s		is it hotter on the left or the right there?					
41 min 28 s				it's about the same you know			
41 min 30 s			what's the max?				
41 min 32 s				there we're at one hundred fifty			
41 min 33 s			yeah it goes up fast on this taxiway we'll have to watch out				
41 min 45 s 41 min 47 s		so um depart on the centreline to one hundred	on the centreline level one hundred				
41 min 55 s				CG fifty-four			
14 h 42 min 08 s				(*)			
42 min 17 s	97547.5					(Ctl) Air France four five nine O runway twenty-six right wind zero ninety eight knots cleared for takeoff	
42 min 21.6 s 42 min 23.3 s	97552.1 97553.7		➪ Four five nine O takeoff twenty-six right		Noise of selector		
42 min 24.8 s	97555.3	is everybody ready					
42 min 25.8 s	97556.3		yes				
42 min 26 s	97556.5			yes			
42 min 26.6 s	97557.1	to one hundred V1 one hundred fifty					
42 min 28.8 s	97559.3	(*)					
42 min 30.4 s	97560.9				Noise of selector		Clicking of thrust levers
42 min 31 s	97561.5	top					

CVR UTC TIME	FDR TIME	CAPTAIN	FIRST OFFICER	FLIGHT ENGINEER	COCKPIT AREA MICROPHONE	VHF INTERPHONE PA	OBSERVATIONS AND ALARM NOISES
42 min 31.3 s	97561.8				Change in background noise		Increase in the airflow in the air conditioning and an increase in engine speed
42 min 35.3 s	97565.8					(?) go Christian	
42 min 37.4 s	97567.9					Two transmission clicks	
42 min 43.3 s	97573.8			we have four reheats			
42 min 47.5 s	97578				Noise of selector		Movement of automatic selector on passing 60 kt
42 min 54.6 s	97585.1		one hundred knots				
42 min 55.1 s	97585.5				Noise		
42 min 55.5 s	97586	checked					
42 min 57 s	97587.5			four greens			
14 h 43 min 03.7 s	97594.2		V 1				
43 min 10.1 s	97600.6				Noise		
43 min 11 s 43 min 11.9 s	97601.5 97602.4	 (*)			Change in background noise		
43 min 13 s	97603.5		watch out				
43 min 13.4 s 43 min 13.8 s 43 min 16.1 s 43 min 16.4 s	97603.9 97604.3 97606.6 97606.9			(stop)	End of change in background noise Noise of selector	(Ctl) Concorde zero... four five nine O you have flames (*) you have flames behind you	(?) (*) right SIMULTANEOUS BROADCASTS
43 min 18.8 s	97609.3		➪ Roger				
43 min 20.4 s	97610.9			failure eng… failure engine two			
43 min 21.3 s	97611.8				2 selector noises		TCU passing from main to alternate
43 min 22.8 s	97613.3				Bell		Fire alarm
						(?) it's really burning eh	
43 min 23.5 s	97614				Gong		
43 min 24.8 s	97615.3			shut down engine two			
43 min 25.8 s	97616.3	engine fire procedure					
43 min 26.2 s	97616.7				Noise of selector		Thrust lever reduction or HP shutoff
43 min 26.8 s	97617.3				End of bell		
43 min 27.2 s 43 min 27.5 s 43 min 28.2 s	97617.7 97617.9 97618.7		watch the airspeed the airspeed the airspeed		Noise of selector Gong		Automatic trim selector
43 min 28.7 s 43 min 29.3 s 43 min 30 s	97619.2 97619.8 97620.5	gear on retract			Noise of selector	(?) it's really burning and I'min not sure it's coming from the engines	Fire handle being pulled
43 min 31.6 s 43 min 32 s 43 min 32.6 s	97622.1 97622.5 97623.1			the gear	Alarm	(Ctl) four five nine O you have strong flames behind you	Toilet smoke detection
43 min 34.5 s	97624.5					Beginning of reception of a Middle Marker	

CVR UTC TIME	FDR TIME	CAPTAIN	FIRST OFFICER	FLIGHT ENGINEER	COCKPIT AREA MICROPHONE	VHF INTERPHONE PA	OBSERVATIONS AND ALARM NOISES
43 min 34.7 s	97625.2		➪ yes roger				
43 min 35.5 s	97626			the gear (Jean)			
43 min 37 s	97627.5				Gong		
43 min 37.3 s 43 min 37.7 s 43 min 38.4 s	97627.8 97628.2 97628.9		 no	 gear	Noise Noise	(Ctl) so do as you wish you have priority for a return to the field	
43 min 39 s	97629.5	(gear) retract					
43 min 41.2 s	97631.7		➪ roger				
43 min 42.3 s	97632.8				Bell		Fire alarm
43 min 43 s	97633.5				Gong		
43 min 44.7 s	97635.2				3 selector noises		
43 min 45.6 s	97636.1		(I'min trying)	I'min firing it			
43 min 46.3 s	97636.8	(are you) shutting down engine two there			End of smoke detection alarm		
43 min 4.28 s	97638.7			I've shut it down			
43 min 49.3 s	97639.8					End of reception of Middle Marker	
43 min 49.9 s	97640.4		the airspeed				
43 min 53 s	97643.5				Noise		
43 min 54.8 s	97645.3				End of bell		
43 min 56.7 s	97647.2		the gear isn't retracting				
43 min 58.6 s	97649.1				Bell		Fire alarm
43 min 59.1 s	97649.6				(SV) whoop whoop pull up		GPWS warning
43 min 59.4 s	97649.9				Gong		
14 h 44 min 00.6 s	97651.1				(SV) whoop whoop pull up		GPWS warning
44 min 00.7 s	97651.2		the airspeed				
44 min 02 s	97652.5				(VS) whoop whoop pull up		GPWS warning
44 min 03 s	97653.5					(FSL) De Gaulle tower from fire service leader	
44 min 05.2 s	97655.7					(Ctl) fire service leader err... the Concorde I don't know his intentions get into position near the southern double runway	
44 min 10.5 s	97661				Noise of selector		
44 min 12 s	97662.5	(*)					
44 min 13.2 s 44 min 14.6 s 44 min 16.5 s	97663.7 97665.1 97666.7	 (too late)	 Le Bourget Le Bourget			(FSL) De Gaulle tower from fire service leader authorisation to enter twenty-six right	
44 min 18.1 s 44 min 19.8 s	97668.6 97670.3	 (no time no)				(Ctl) Fire service leader correction the Concorde is returning on runway zero nine in the opposite direction	

CVR UTC TIME	FDR TIME	CAPTAIN	FIRST OFFICER	FLIGHT ENGINEER	COCKPIT AREA MICROPHONE	VHF INTERPHONE PA	OBSERVATIONS AND ALARM NOISES
44 min 22.8 s	97673.2		➪ negative we're trying for Le Bourget				
44 min 24.7 s	97675.2				Noise of selector		
44 min 25.1 s	97675.6				Noise of selector		
44 min 25.4 s	97675.9				Noise of selector		
44 min 26.2 s	97676.7				Noise of selector		
44 min 26.4 s 44 min 26.6 s 44 min 27 s	97676.9 97677.1 97677.5		(no)		Gong Gong and noise of selector	(FSL) De Gaulle tower from fire service leader can you give me the situation of the Concorde now	
44 min 27.5 s	97678				Noise of selector and beginning of movement of objects in cockpit		
44 min 29 s	97679.5	(*)					Noises of effort
44 min 30 s	97680.5	(*)					
44 min 30.7 s	97681.2	(*)					
14 h 44 min 31.6 s	97682.1	END OF RECORDING					