REPORT IN-045/2006

DATA SUMMARY

LOCATION

Date and time	**Thursday, 27 July 2006; 22:15 local time**
Site	**29.8 NM east of Barcelona Airport, FL 235**

AIRCRAFT

Registration	**EC-IJF**
Type and model	**BOMBARDIER CRJ200 CL-600-2B19**
Operator	**Air Nostrum LAM**

Engines

Type and model	**GENERAL ELECTRIC CF34-3B1**
Number	**2**

CREW

	Pilot in command	Copilot
Age	**36 years old**	**29 years old**
Licence	**ATPL**	**CPL**
Total flight hours	**5,100 h**	**Not available**
Flight hours on the type	**3,950 h**	**1,714 h**

INJURIES

INJURIES	Fatal	Serious	Minor/None
Crew			**4**
Passengers			**44**
Third persons			

DAMAGE

Aircraft	**Heavy damage to left engine**
Third parties	**None**

FLIGHT DATA

Operation	**Commercial air transport – Scheduled – International – Passenger**
Phase of flight	**En route – Climb**

REPORT

Date of approval	**7 October 2010**

1. FACTUAL INFORMATION

1.1. History of the flight

On 27 July 2006, aircraft EC-IJF, callsign AN8174, was operating out of Barcelona airport en route to Basel. For the cockpit crew, consisting of the captain and copilot, it was the first flight of the day. For the two members of the cabin crew, who were attending to the 44 passengers onboard, it was the second flight after two hours of activity. The aircraft had started its operation at 07:37, the incident flight being the eighth and last of the day.

The aircraft took off normally at 22:01:22 from runway 25R. Six minutes later they were cleared by ATC to deviate from instrument departure DALIN 1D to fly around a storm area. Fourteen minutes into the flight, at 22:15:43, in an area without any weather problems, there was a loud bang followed by strong jolts. The aircraft was 29.8 NM east of Barcelona airport flying over the Mediterranean Sea. The airplane was climbing through 23,515 ft. Its speed was 248 kt and its heading 060°.

The following warnings were immediately received: left engine reverser unlocked, smoke in the lavatory, left engine low oil pressure and, seven seconds after the bang, fire in the left engine. The crew combated the emergency by entering the engine fire procedure. As recorded on the CVR, the engine was shut down off 16 seconds after the fire warning was received and the first fire extinguishing bottle was discharged after 71 seconds. Since the fire warning did not clear, they discharged the second bottle, which also failed to extinguish the fire. They declared an emergency to ATC and decided to return to Barcelona airport. While flying toward the field on a heading of 250°, the crew executed a 360° turn to lose altitude and start the final approach. The cabin crew prepared the passengers for an emergency landing with a possible evacuation on the runway.

At 22:25:30, with the aircraft on short final and after 9 minutes and 40 seconds, the left engine fire warning cleared. The aircraft landed with a single engine on runway 25R and came to a stop on exit taxiway GA at 22:29:27.

The cockpit crew ordered an evacuation at 22:29:44 out the right side using the front and rear doors. The firefighting service, which had been alerted, was present during the evacuation and applied firefighting foam as a precaution, though at that time they did not notice any flames or smoke coming from the engine.

All 48 people onboard were uninjured. The aircraft suffered significant damage, but only to the left engine.

1.2. Damage to aircraft

The damage to the aircraft was confined strictly to the left engine. A cursory glance revealed that a fan blade and the upper and lower access cowls had detached, as well

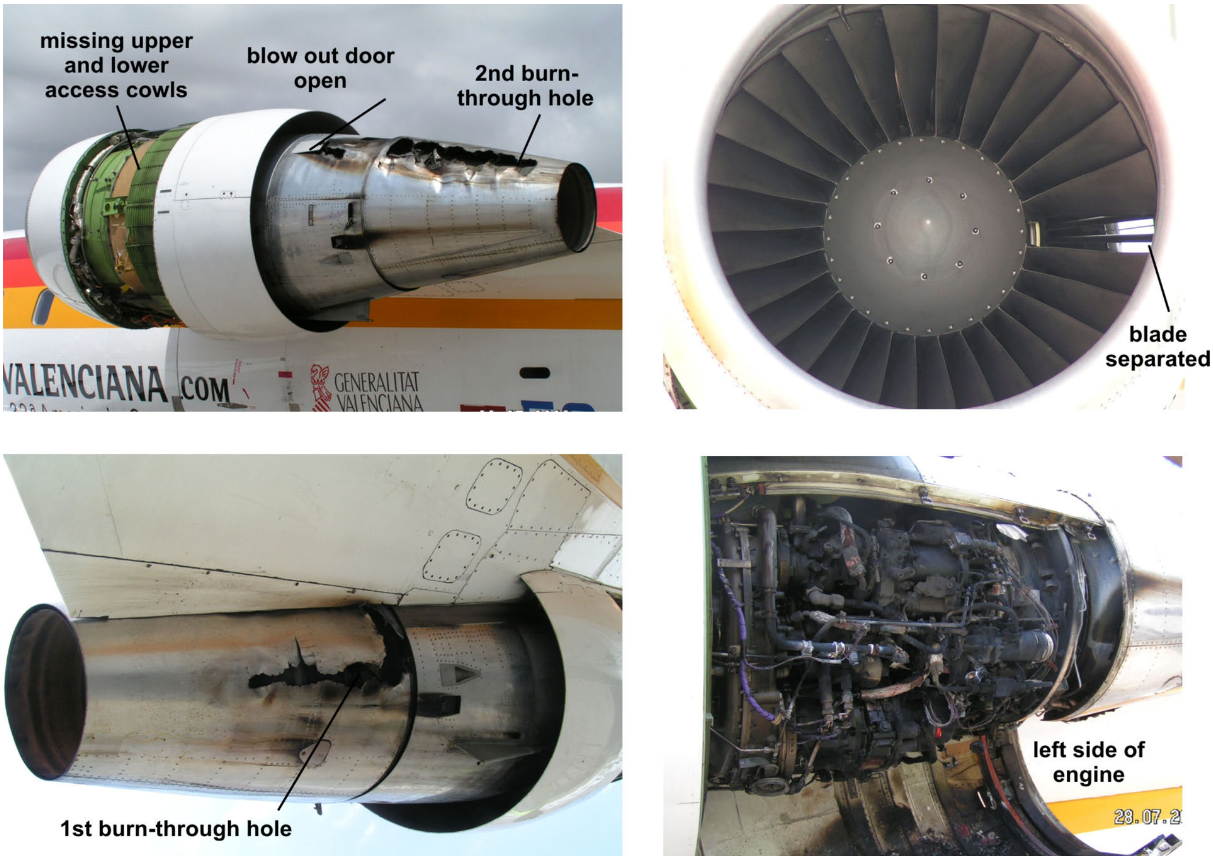

Figure 1. Left engine of aircraft EC-IJF after the incident

as areas where an intense fire had burned through. There was no damage to the rest of the aircraft.

1.3. Personnel information

1.3.1. *Information about the captain*

The captain, 36 years of age, had an airline transport pilot license and CRJ-100 and instrument ratings, all valid and in force at the time of the incident.

He had been working for Air Nostrum since the year 2000. He had a total of 5,100 flight hours and had flown 3,950 h on the CRJ, 2,300 as a copilot. As captain he had accumulated 1,650 h since August 2004. In the 24 hours prior to the incident he had a total of 3:20 h of flight activity. The incident flight was his first flight of the day. He was seated in the LH seat.

As part of the initial and ongoing training he had received since joining the company, he had taken an initial and four refresher courses on cockpit resource management (CRM), the last of these on 1 June 2006, two months before the incident.

1.3.2. *Information about the copilot*

The copilot, 29 years of age, had a commercial pilot license and valid and in force CRJ-100 and instrument ratings at the time of the incident.

He had been working for Air Nostrum since 2004 and had accumulated 1,714 h, all as a CRJ copilot. Like the captain, he had a total of 3:20 h of flight activity in the 24 hours prior to the incident. The incident flight was the first of the day. He was seated in the RH seat and was the pilot flying at the time of the incident.

As part of the initial and ongoing training he had received since joining the company, he had taken an initial and two refresher courses on cockpit resource management (CRM), the last of these on 26 April 2006, three months before the incident.

1.3.3. *Previous flights of captain and copilot as a crew*

Since the time when the copilot joined the company two years before, the two had flown together prior to the incident flight on 24, 25 and 26 July 2006 and on 8 July 2005.

1.3.4. *Information about cabin crew*

The two flight attendants had valid and in force licenses and medical certificates on the date of the event. The purser was 27 years old and had 1,536 h at the company. The second attendant was 23 years old and had accumulated 91 hours. Their flight activity on that day had begun when they took over as the cabin crew on aircraft EC-IJF at Bologna airport (Italy) on the flight prior to the incident. They had been working for just over two hours.

1.4. Aircraft information

1.4.1. *General*

The BOMBARDIER CANADAIR CL-600-2B19 CRJ-200 is a twin-engine jet with a capacity for 50 passengers and is intended for use in regional and short-range flights. Its maximum takeoff weight is 23,133 kg.

The incident aircraft, S/N 7705, had been manufactured in 2002 and delivered to Air Nostrum in November 2002. On the date of the incident it had all the authorizations, certificates and insurance required for the conduct of public passenger transport operations.

1.4.2. *Status of aircraft and maintenance*

The aircraft was factory equipped with two General Electric GE CF34-3B1 engines, S/N GE-E-873549 (left engine) and GE-E-873548 (right engine).

At the time of the incident both engines had accumulated a total of 10,896 h (TSN) and 8,899 cycles (CSN). The left engine was manufactured in June 2002 and installed on the incident aircraft S/N 7705 EC-IJF in September 2002, prior to aircraft delivery by Bombardier to Air Nostrum in November 2002.

As for maintenance, on 15 August 2003 the main fuel control (MFC) on the left engine was replaced in conformance with General Electric service bulletin 73-034, which was issued on February 10, 2003. The same action was carried out on the right engine half a year later, on 4 January 2004. In the time since this replacement, the left engine had operated for 8,601 h and 7,064 cycles. There were no maintenance entries in the engine log book related to the fan blades.

1.4.3. *General Electric GE CF34-3B1 engine*

The CF34-3B1 is a dual shaft turbofan engine with a high bypass ratio.

In the low pressure (LP) shaft, the single-stage fan is driven by the four-stage low pressure turbine (LPT). The fan consists of a wheel of 28 blades joined to a disk. Each blade is made of a single piece of forged titanium weighing some 1.2 kg. 100% N1 is equivalent to 7,400 RPM. The high pressure (HP) shaft consists of a 14-stage compressor and a high pressure turbine (HPT) with two stages. Its nominal RPM value at 100% N2 is 17,820. Both shafts rotate clockwise as seen from the exhaust end. The location of the engine components is generally expressed in terms of a hypothetical clock face as seen from behind. The main fuel control (MFC) is thus at the 8 o’clock position, on the left side.

Six of the 14 HP compressor stages feature a variable geometry (VG) system that modifies the position of the stator vanes by means of two actuators that rely on hydraulic force provided by the fuel.

The lubrication system for the seven bearings that support the two engine shafts contains a maximum of seven liters of oil.

The fan discharge airflow can be reversed via blocker doors that deploy in the fan discharge duct when the fan reverser translating cowl moves aft.

The accessory gearbox (AGB) is located ahead of the accessory compartment and has three attachment points, at 3:00, 6:00 and 9:00. These points are frangible so as to protect the AGB casings. There is a secondary attachment that limits the movement of the box as a whole should the main attachments fail. The main fuel pump (MFP) and main fuel control (MFC) is attached at the base of the AGB.

1.4.4. *Engine cowls and fairings*

The engine is shrouded in various cowls and fairings that provide it with a tapered aerodynamic surface. The casings, cowls and fairings create annular compartments around the engine within which flows a stream of air to provide cooling and to vent possible inflammable vapors. For ease of cooling the core cavity is divided into 2 zones (forward compartment or zone A and aft compartment or zone B) by a radial fireshield, located just aft of the high pressure turbine. The air supply for the forward compartment enters through 31 holes and exits through 4 holes. The air supply for the aft compartment enters through 4 holes. By way of reference to the descriptions provided in this report, we note the following components:

- Upper and lower access cowl.
- Translating cowl.
- Upper and lower core cowl. These are hinged and latched so as to provide access to accessories and other engine components. These cowls are supported and closed atop a firewall that isolates the accessory compartment area from the exhaust and low pressure turbine. At the 11:00 position there is a blow out door that releases pressure to the outside in the event of an excessive pressure rise.
- Exhaust nozzle fairing.

1.4.5. *Fire protection systems*

The aircraft has a fire detection and extinguishing system that responds to engine fire or overheat conditions.

There are two engine detection zones: the core or the compartment under the engine cowls (which triggers an ENG FIRE message on EICAS) and the area under the exhaust pipe fairings (which triggers a JET PIPE OVHT message on EICAS). Each of these zones is equipped with two detection loops to ensure system redundancy. When a fire or overheat condition is detected in the engine core, a visual ENG FIRE warning is generated on EICAS, the ENG FIRE PUSH button illuminates and the fire bell sounds.

The suppression system consists of two bottles that can be discharged into either engine. The discharge first requires pressing the ENGINE FIRE PUSH button in the cockpit, which closes the shutoff valve, SOV, and then the BOTTLE ARMED PUSH TO

DISCH. The system is designed to combat a confined fire detected within the engine nacelle's compartments.

In the lavatory there is a smoke detector that, if triggered, turns on the SMOKE TOILET caution.

1.4.6. *Fuel system*

The fuel system on this aircraft allows cutting off the fuel supply from the tanks, located in the wings, to the engines at two points. The first is in the center box at the outlet of the tanks and relies on two SOVs (shutoff valves), one for each engine; the second is in the main fuel control (MFC), located in the engine. The manufacturer estimates that there is a maximum of 4.06 liters of fuel between these two cutoff points.

If the ENG FIRE PUSH button is pressed in the cockpit, the fuel SOV for that side closes, the BOTTLE ARMED PUSH TO DISCH button illuminates and the ENG SOV CLSD message appears on EICAS. In addition, if the thrust lever is retarded in the cockpit to the cutoff position, the main fuel control will close.

1.4.7. *EICAS warnings*

The aircraft is equipped with a central advisory system, which is a part of EICAS (Engine Indicating and Crew Alerting System), and that generates visual and aural messages to notify the crew of conditions, alerts, cautions and warnings associated with aircraft systems. Depending on the nature of the problem, only visual warnings, or visual and aural signals, may be generated.

According to information in the maintenance manual, the way the messages recorded on the flight of EC-IJF are displayed on EICAS is as follows:

- Fire in engine core: warning advisory that displays the words L ENG FIRE in red on the EICAS screen. At the same time the master warning red pushbutton flashes and a triple chime sounds, followed by the fire bell.
- Low oil pressure: warning notification that displays the words L ENG OIL PRESS in red on the EICAS screen. At the same time the master warning red pushbutton flashes and a triple chime sounds, followed by the synthetic voice "ENGINE OIL".
- Reverser unlocked: caution notification that displays the words L REV UNLOCKED in amber on the EICAS screen. At the same time the master caution amber pushbutton flashes and a single chime sounds.
- Smoke in lavatory: caution notification that displays the words SMOKE TOILET in amber on the EICAS screen. At the same time the master caution amber pushbutton flashes and a simple chime sounds, followed by the synthetic voice "SMOKE".

1.4.8. *EGPWS "TOO LOW TERRAIN" warning*

The CRJ-200 has a ground proximity warning system (EGPWS) that monitors the flight status of the aircraft with relation to the terrain and alerts the crew if necessary. One of this system's modes of operation, mode 4B, was activated while aircraft EC-IJF was on approach, generating the "TOO LOW TERRAIN" warning. This aural notification is triggered when the gear is down, the flaps are not in a landing configuration and the aircraft crosses a linear boundary defined between 1,000 and 245 ft at a speed in excess of 159 kt. This warning can be cleared in the cockpit by pressing the FLAP OVRD button.

1.5. Flight recorder and ATC information

The data from the flight data recorder (DFDR, FA2100, P/N 2100-4343-00 and S/N 000188834), the cockpit voice recorder (CVR, FA2100, P/N 2100-1020-00 and S/N 000187083) and the communications with ATC services allowed investigators to reconstruct the sequence of events that occurred on the flight. The data correlation between the DFDR, CVR and ATC shows an average delay of seven seconds in the time references provided by ATC with respect to those of the DFDR. The time references used in this section correspond to the local time as recorded by ATC.

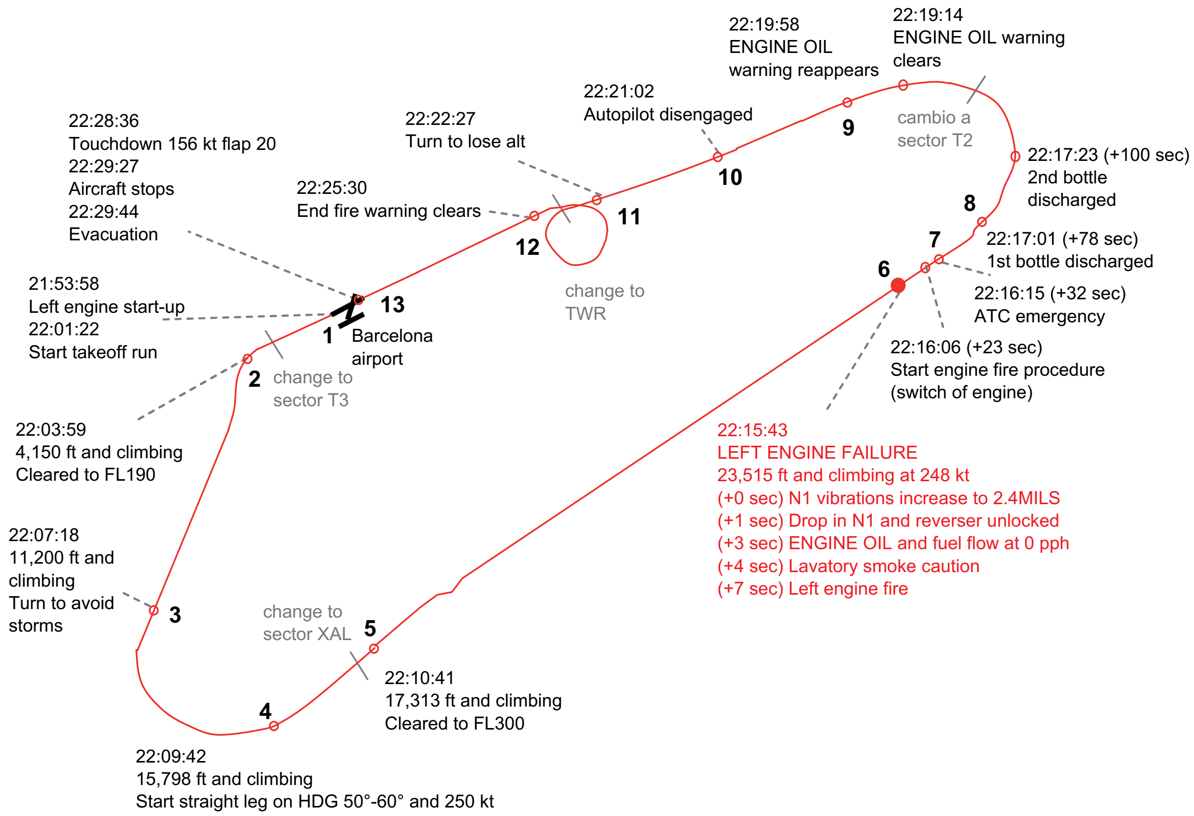

Figure 2. Complete flight path

The flight lasted a total of 36 minutes from the initial engine startup to shutdown. Figures 2 and 3 show the complete flight of aircraft EC-IJF. The first 22 minutes (points 1 to 5 in Figures 2 and 3) transpired without incident and with the engines working normally. The aircraft climbed, requested a turn to avoid an area of storms and continued climbing on a course of 50°-60° and an average GS of 250 kt (segment 5-6 in Figures 2 and 3).

At 22:15:43, with the aircraft at an altitude of 23515 ft, at 248 kt and climbing, the left engine failed (point 6 in Figures 2 to 5). At that instant the left engine N1 RPMs indicated 93.2% and the ITT temperature was 780 °C. On takeoff, at sea level and with takeoff thrust, the N1 RPMs were 87.6% and the ITT temperature was 790 °C. The recorders show the following after the failure:

- Left engine N1 vibrations at 2.4 mils and vertical acceleration at –1.32g.
- At t = +1 second the left engine reverser unlocked and N1 started to fall.
- At t = +3 seconds the left engine low oil pressure was received and the fuel flow to the left engine dropped to zero.
- At t = +4 seconds lavatory smoke caution activated.
- At t = +7 seconds left engine fire warning activated.

Figures 4 and 5 show the progression of the engine failure parameters for one and two minutes, respectively.

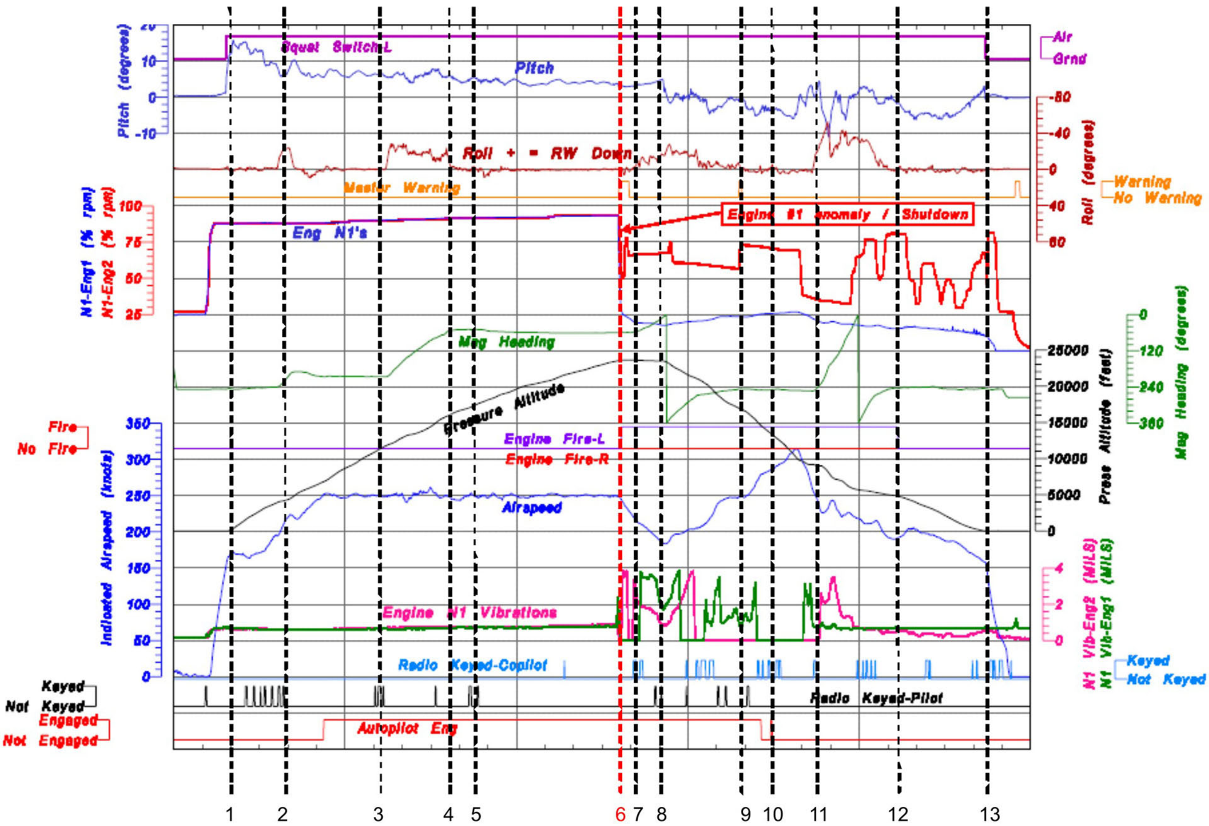

Figure 3. Complete flight: flight parameters, fire, N1 and N1 vibration advisories and autopilot setting

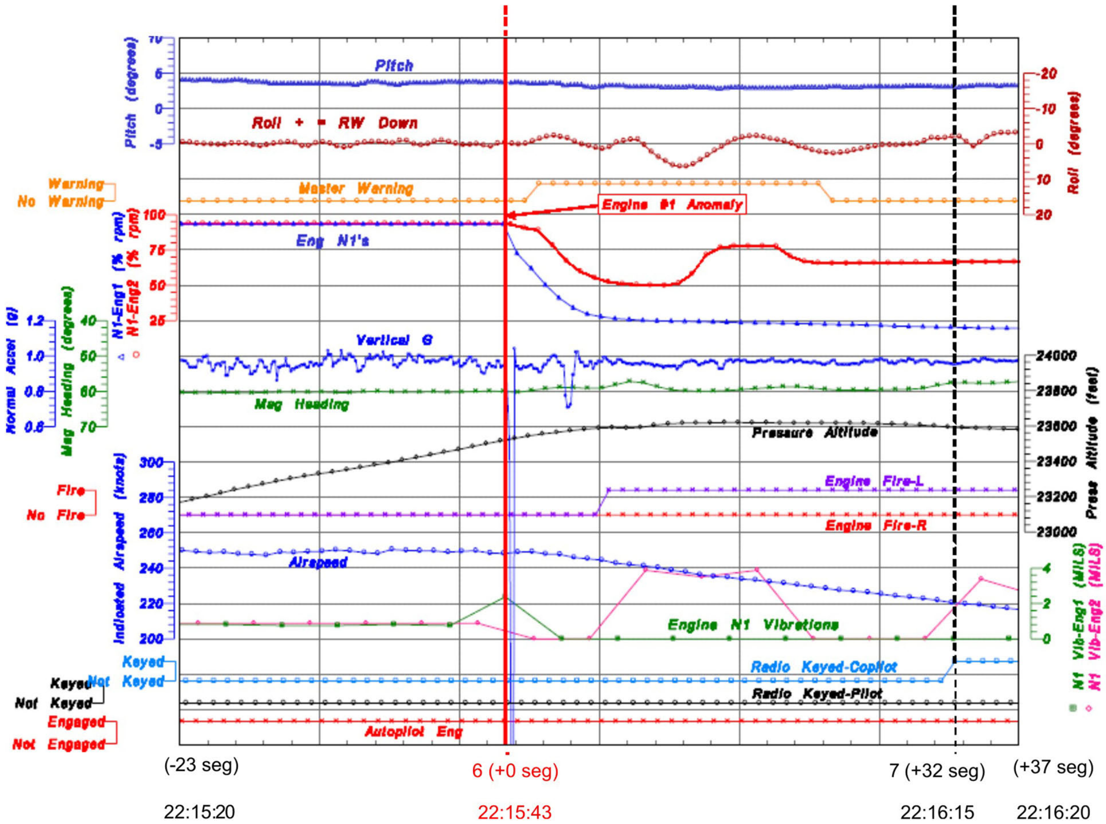

Figure 4. Engine parameters during failure: 1 minute

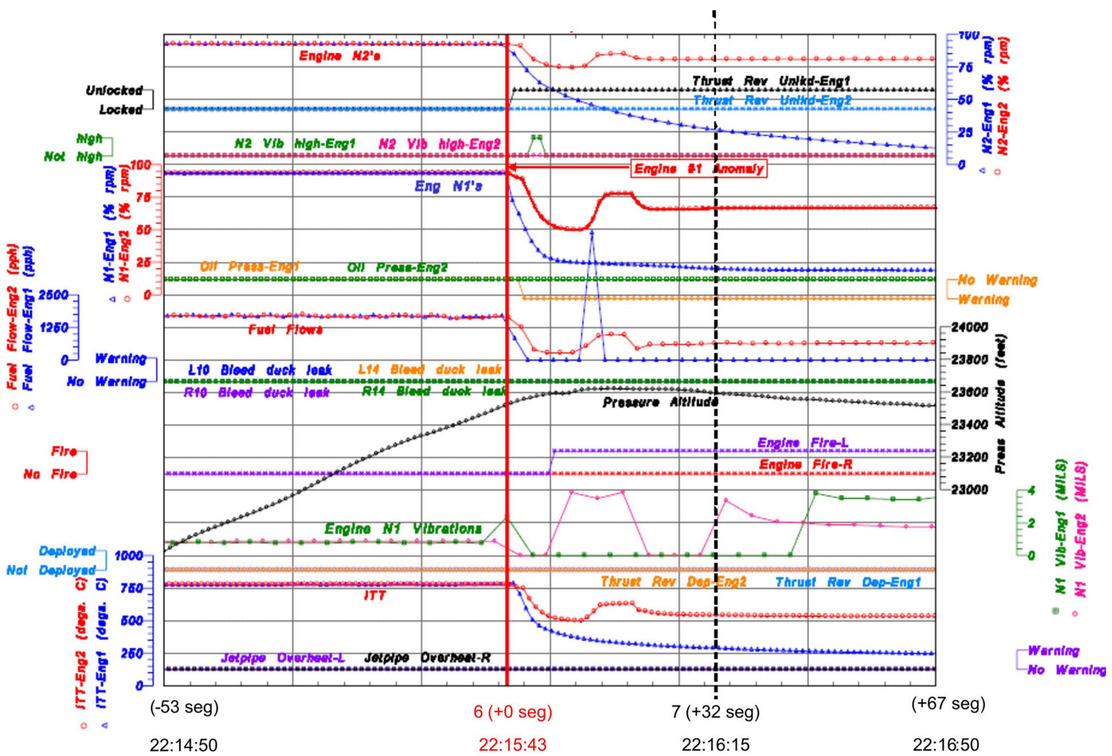

Figure 5. Engine parameters during failure: 2 minutes

Within 16 seconds of the fire warning (23 seconds after the failure of the engine), the crew started the engine fire procedure by confirming the engine to be cut off. At the 32-second mark, the ATC was notified of the emergency (point 7 in Figures 2 to 5). Seventy-one seconds after the fire warning the first bottle was discharged (point 8 in Figures 2 and 3) and 22 seconds later (at T = 93 seconds) the second bottle.

The return trajectory to Barcelona took place with the left engine fire warning lit (cleared after 9 minutes and 40 seconds), the left reverser unlocked caution lit (did not clear for remainder of flight) and left engine low oil pressure warning (cleared and then re-activated for remainder of flight).

On the captain's initiative, the autopilot was disengaged at 13583 ft at 22:21:02 (point 10 in Figures 2 and 3). Shortly thereafter the aircraft was at 314 kt and N1 was at 30% (between points 10 and 11 in Figures 2 and 3). One minute before the fire warning extinguished the copilot said "left engine shutoff valve close" following a caution warning.

Five "TOO LOW TERRAIN" warnings were received between 172 and 63 ft. The aircraft touched down at 22:28:36 at 156 kt with 20° flaps. The right reverser was used as requested by the captain. At 22:29:27 the aircraft was stopped on rapid exit taxiway GA, the right engine was stopped and at 22:29:44 the evacuation started. The evacuation had been anticipated and reported to ATC and to the cabin crew, who prepared the cabin and passengers for it.

Table 1 shows a transcript of the communications between the crew from the appearance of the engine failure until the completion of the fire procedure. All of the warnings previously described were heard during the first 23 seconds, along with the identification of the reverser failure by the copilot, who was the pilot flying. There is no record of any verbal communication from the captain on the CVR until the start of the fire procedure.

The CVR reveals the constant monitoring by the copilot of altitude, speed, landing field position and distance to clouds throughout the return flight to Barcelona.

The communications with ATC indicate that priority was given to the aircraft for landing at Barcelona. The instructions given by sector T2 were long (one of them lasted 14 seconds) and referenced VOR-DME maneuvers. These instructions involving VOR-DME maneuvers coincided with the reappearance in the cockpit of the low oil pressure warning (point 9 in Figures 2 and 3).

<table>
<tr><th>Time after failure</th><th colspan="3">Content</th><th>Origin/ function</th></tr>
<tr><td>+0 sec
(6 Figure 2)</td><td></td><td rowspan="4">NOISE</td><td></td><td></td></tr>
<tr><td>+1 sec</td><td></td><td rowspan="3">SINGLE CHIME
TRIPLE CHIME</td><td></td></tr>
<tr><td>+2 sec</td><td>The reverser, the reverser, the reverser.</td><td>COP/PF</td></tr>
<tr><td>+3 sec</td><td></td><td></td></tr>
<tr><td>+4 sec</td><td></td><td>«SMOKE»</td><td></td><td></td></tr>
<tr><td>+6 sec</td><td>The reverser, the reverser, the reverser, the reverser.</td><td>«SMOKE»</td><td></td><td>COP/PF</td></tr>
<tr><td>+7 sec</td><td></td><td rowspan="8">FIRE BELL</td><td></td><td></td></tr>
<tr><td>+8 sec</td><td></td><td>TRIPLE CHIME</td><td></td></tr>
<tr><td>+10 sec</td><td>The reverser.</td><td rowspan="6">«ENGINE OIL»
«ENGINE OIL»
«ENGINE OIL»
«ENGINE OIL»
«ENGINE OIL»
«ENGINE OIL»
«ENGINE OIL»</td><td>COP/PF</td></tr>
<tr><td>+12 sec</td><td></td><td></td></tr>
<tr><td>+15 sec</td><td>OK, OK, OK, airplane.</td><td>COP/PF</td></tr>
<tr><td>+18 sec</td><td>OK, OK, OK, it’s alright.</td><td>COP/PF</td></tr>
<tr><td>+19 sec</td><td>No, no, don’t touch that, don’t touch that.</td><td>COP/PF</td></tr>
<tr><td>+22 sec</td><td></td><td></td></tr>
<tr><td rowspan="4">+23 sec</td><td colspan="3">Sorry, sorry confirm cutting right engine?</td><td>COP/PF</td></tr>
<tr><td colspan="3">Cut it.</td><td>CTE/PNF</td></tr>
<tr><td colspan="3">The right one ¿ok?</td><td>COP/PF</td></tr>
<tr><td colspan="3">Cut it, cut it.</td><td>CTE/PNF</td></tr>
<tr><td>+32 sec
(7 Figure 2)</td><td colspan="3">Barcelona AN8174 declaring an emergency, we need to return to the field immediately, we’ve had a left engine failure.</td><td>COP/PF</td></tr>
<tr><td>+40 sec</td><td colspan="3">Are you flying or what?</td><td>COP/PF</td></tr>
<tr><td>+40 sec</td><td colspan="3">8174 copy, ¿why? How do you wish to return to the field?</td><td>ATC</td></tr>
<tr><td>+46 sec</td><td colspan="3">Well, the most direct path, please, AN vector we’ve had an engine failure.</td><td>COP/PF</td></tr>
<tr><td rowspan="2">+50 sec</td><td colspan="3">Confirmed.</td><td>CTE/PNF</td></tr>
<tr><td colspan="3">Confirmed.</td><td>COP/PF</td></tr>
<tr><td>+53 sec</td><td colspan="3">OK left confirmed. Can you confirm?</td><td>COP/PF</td></tr>
<tr><td rowspan="4">+56 sec</td><td colspan="3">(unintelligible) Engine FIRE.</td><td>COP/PF</td></tr>
<tr><td colspan="3">OK?</td><td>COP/PF</td></tr>
<tr><td colspan="3">Talk to them</td><td>COP/PF</td></tr>
<tr><td colspan="3">Or Gerona.</td><td>COP/PF</td></tr>
<tr><td rowspan="4">+73 sec</td><td colspan="3">I have the controls.</td><td>CTE/PF</td></tr>
<tr><td colspan="3">8174 if you can to your left on course 330.</td><td>ATC</td></tr>
<tr><td colspan="3">OK talk to them.</td><td>COP/PNF</td></tr>
<tr><td colspan="3">To the left heading 330 AN 8174.</td><td>CTE/PF</td></tr>
<tr><td rowspan="2">+78 sec
(8 Figure 2)</td><td colspan="3">Discharging the bottle, ok? Discharging the bottle.</td><td>COP/PNF</td></tr>
<tr><td colspan="3">8174 cleared to flight level 140, correction 160.</td><td>ATC</td></tr>
<tr><td rowspan="2">+87 sec</td><td colspan="3">The engine is cut. Flue flow is at zero. To 160 ok.</td><td>COP/PNF</td></tr>
<tr><td colspan="3">To 160 AN 8174. OK, it was an emergency, lowering nose to 140.</td><td>CTE/PF</td></tr>
<tr><td rowspan="2">+100 sec</td><td colspan="3">Discharging the other bottle, ok?</td><td>COP/PNF</td></tr>
<tr><td colspan="3">OK, is it out?</td><td>CTE/PF</td></tr>
</table>

Table 1. Cockpit communications: onset of failure and fire procedure

1.6. Investigation of engine

After the incident it was noted that a fan blade had become detached. The separation was contained and the remains of the blade were found embedded in the fan containment ring. The upper and lower access cowls were lost in flight and not recovered.

There was extensive fire damage to the accessory compartment, especially to the left side in the vicinity of the fuel pump and main fuel control. The fuel, oil and electric lines were all damaged by the fire.

The aft Variable Geometry (VG) head line which connects the MFC to the actuator head tube was found detached from its elbow fitting at the MFC. The elbow fitting at the MFC was positioned outward towards the 9:00 o'clock position versus the proper installation position towards the 6:00 position downward position. Fuel was still observed dripping from the elbow fitting at the MFC.

The left hand (9:00 position) fusible mount bolt was sheared and had decoupled per the design intent, leaving the AGB supported on the left hand side by the secondary restraint cable. The right hand (3:00 position) mount attachment bolts had backed out of their front frame inserts, leaving the mount pad pulled away from the front frame by about 1/8 of an inch. The 6 o'clock fusible mount bolt did not separate or decouple. There was also cracking on the forward surface of the AGB near the 6:00 position mount. Oily deposits were observed on the compressor case above this AGB crack, but there was no evidence of thermal damage or fire in this general area forward of the AGB.

The air starter valve and inlet duct were separated from the starter, which was still attached to the accessory gear box.

Play/movement was found within the throttle control system. Total system looseness was ±1.3 degrees at the MFC lever. Of the three screws which attached the throttle gearbox to its support bracket, the top screw was found missing, the lower left hand screw was found loose but installed and the lower right hand screw was installed and secured.

All 84 bolts securing the aft flange of the turbine transition case to the forward flange of the low pressure turbine (LPT) case were separated, with most of them being found lying in the bottom of the core cowl. Metallurgical examination confirmed that the bolts separated in shear. No evidence of fatigue was found. Microstructure and hardness confirmed that the bolts were typical of Inco 718 material.

Fire damage on the exhaust nozzle fairing indicates that the LPT stator case rotated from its original location at the time of the fan blade separation. The rotation was the result of separation of all 84 HPT transition case to LPT stator case flange bolts. The LPT stator case did rotate a second time to its final position later in the fire event from evidence of a second separate area of fire damage to the exhaust nozzle fairing. The LPT stator rotated in the counter clockwise direction based on the positioning of the "C" sump service lines. Sometime later in the fire event, the LPT stator case rotated an additional 180 degrees.

The four ventilation exit ports located in the upper and lower core cowls showed thermal distress originating from the interior or engine side. The most extensive damage (in terms of missing and melted material) was the exit port located at the 8:00 position in the lower core cowl. From 8:00 to 10:00, the nacelle fire seal was observed to be thermally damaged with pieces of seal missing. The lower core cowl has a forward compartment drain and was observed to be still wetted with fuel. There are two additional forward compartment drain holes located aft of the above drain. These two drains are located at 6:00 at the lowest position in the lower core cowl and were found oily and sooted.

The exhaust nozzle, except for some discoloration, and the low pressure turbine were undamaged.

The ENG FIRE PUSH button was confirmed to have been pressed and that both extinguishing bottles had discharged.

1.6.1. *Fan blade separation*

The blade that detached from the left engine of aircraft EC-IJF was identified as the eleventh of a total of 28 that comprise the fan assembly. The blade, P/N 6018T30P14, is a component with a lifetime limited to 18,000 cycles (CSN). The one that failed, S/N MAE35246, was manufactured by Teleflex (Mexico) in June 2002 and installed new on the engine, meaning it had the same number of cycles (8,899 CSN) as the engine at the time of the incident. Along with Teleflex, there are three other blade manufacturers for the GE CF34-1 and CF34-3 engines. Of this engine's 28 blades, 26 were made by Teleflex and two by another supplier.

The blade detached due to a break in the tangs used to attach it to the fan disk (Figure 6) caused by a dwell-time fatigue crack. The point of origin was found in the middle tang, from where it propagated by dwell-time fatigue. The forward and aft tangs also showed fractures resulting from stress overload. The main section of the fractured pin, which was removed from where it had become embedded in the fan containment ring, had shear fractured and showed no signs of fatigue or of material defects.

The metallurgical and fractographic analyses revealed the presence of metallographic defects in the drilled surfaces on the middle tang and in the forging of the piece that reduced its dwell time fatigue-resistance properties. Specifically, extensive bands of

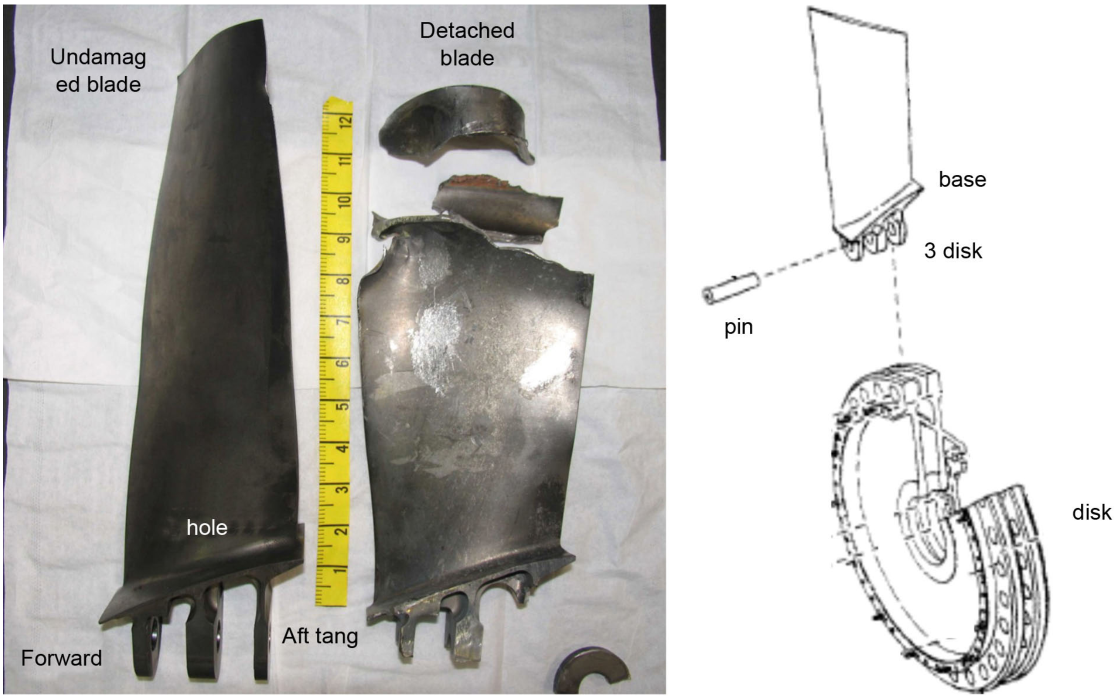

Figure 6. Detached number 11 blade

"aligned alpha colonies[1]" were observed, the grains of which were unfavorably oriented relative to the primary loading direction. In the separated blade, the presence of these colonies had given rise to the incubation of fatigue cracks. The composition of the material from which the blade had been manufactured conformed to design specifications and did not exhibit oxygen or nitrogen enrichment.

In general, the blades are manufactured from titanium laminate bars or billet with a diameter of between 2 and 3.5 inches. While reviewing the blade manufacturing processes of General Electric's four suppliers, it was noted that Teleflex utilized a larger diameter billet, higher forging temperatures (up to 37.7° C than the other manufacturers) and that the chemical composition of the material had the highest levels of aluminum content.

Detecting which blades might have be affected requires cutting the blades through destructive testing.

Also detected in the same crack initiation area was the presence of a layer where the grain was deformed and which General Electric attributed to the use of improperly

[1] At low temperatures, titanium exhibits a compact hexagonal close packed crystalline structure called alpha or alpha phase. Depending on the thermal and mechanical alloy manufacturing method, the orientation of the alpha grains can be more or less random. When the alpha grains in a region are similarly oriented, this region is known as the alpha colony. The size and alignment of the colonies are very important because they affect the material's characteristics in such a way that the smaller and less aligned the colonies, the better the material's resistance to dwell-time fatigue cracking. The fabrication process is what determines the size of these colonies.

sharpened tools. It was noted that the processes for machining and reaming the tang holes did not specify the periodicity with which the tools used in this task were to be replaced.

1.6.2. *Detachment of the VG head line*

The variable geometry head line is a flexible fuel hose that is attached to the main fuel control (MFC) through a rigid elbow. This elbow was improperly installed; it should have been in a top down configuration and yet it was found oriented radially toward the outside of the engine. The diagrams in the maintenance manuals and IPC show an outline of this hose in its proper theoretical position, although nothing is specified in this respect in the associated texts.

As for the attachments of the line in its path along the side of the engine, it was noted that a clamp was missing. The CF45-3B IPC SEI 779 Rev 35 and the CF34-3B1 IPC SEI 775 Rev 39 show a cushion clamp on the aft actuator head line hose assembly. This is not consistent with CF34-3B/B1 engine drawing 6089T11, which does not call out a clamp at this location. The error was the result of a copy from the CF34-1A/-3A/-3A2 IPC and was corrected as a result of this finding.

It was also noted that the elbow fitting was tightly installed into the MFC housing, which indicates that it was installed in that exact position and did not move as a result of the event. No other defects were found, such as marks, flattening or kinks in the elbow itself indicative of tension from the hose. The flexible hose also showed no signs of having been subjected to tension, twisting or flexing.

Tests were conducted by General Electric at Smith Tubular Systems facilities in an effort to reproduce the conditions that caused the head line to detach. The hose was placed under mechanical stress and over-pressurized from the inside with fuel. The stress tests were not conclusive in revealing what caused the hose to fail. The hoses were capable of absorbing significant stress without breaking or leaking, but these stress tests were static and may not have accurately duplicated the shock loading of the event. That an internal overpressure from fuel caused the detachment was ruled out since the normal operating pressure is far below what it can withstand. The hose pressure test is a static test. General Electric maintains that the most probable cause of the failure of the line was a shock impact load that ripped the hose and its collar from the elbow, damaging only the internal Teflon tubing, which started the fire.

The conclusion of the NTSB materials laboratory is that the hose detached from the elbow under the effect of an existing fire, the heat from which caused the internal Teflon liner or the collar to weaken, thus allowing it to separate under minimal loading.

1.7. Organizational and management information

1.7.1. *Engine fire procedure*

The Aircraft Flight Manual includes a procedure to be used in the event of an in-flight engine fire. The procedure includes six memory items for the crew, to be executed immediately while at a sufficient altitude. A seventh and final item in the procedure ties in with the "In-Flight Engine Shutdown" procedure (included in Appendix II). The in-flight engine shutdown procedure in the event of an engine failure ends by directing the crew to the "Single-Engine Approach and Landing" procedure (included in Appendix II).

L or R ENG FIRE or Severe Engine Damage (In Flight)

At a safe altitude, affected engine:

(1) Thrust lever .... Confirm and IDLE
(2) Thrust lever .... Confirm and SHUT OFF
(3) ENG FIRE PUSH switch .... Confirm and select
(4) FUEL BOOST PUMP switch .... Confirm and off

After 10 seconds and fire warning persists:

(5) Affected engine BOTTLE switch .... Select, to discharge

After another 30 seconds and fire warning still persists:

(6) Other engine BOTTLE switch .... Select, to discharge

(7) Single Engine Procedures In-Flight Engine Shutdown .... Accomplish

The purpose of executing this procedure is to stop the flow of fuel from the engine to the fuel nozzles and to stop the flow of fuel to the engine and, if necessary, to discharge the extinguishing agent to the engine core cowl forward compartment (zone A). The cutoff of fuel is achieved in two ways: first, by acting on the main fuel control (MFC) via the thrust lever; and secondly, by closing the supply lines from the tanks to the engine. The thrust lever that is actuated by the crew is connected by cables to the thrust lever transmission gearbox, which is located above the engine and connected to the MFC with a rod. The adjustment between these components for the idle, maximum thrust, reverse thrust and fuel cutoff functions allows the movement of the thrust lever in the cockpit to the SHUT OFF position (step 2 in the procedure) to be transmitted to the main fuel control, which then inhibits the supply of fuel to the injectors. The second way to cut off the engine's fuel supply is with the SOVs. These are located in the center box between the wings and interrupt the flow of fuel from the tanks before the inlet to the engine. These valves are controlled from the cockpit through the ENGINE FIRE PUSH button (step 3 in the procedure).

1.7.2. *Guidelines for action in emergency situations*

The airline's Pilot Reference Handbook (PRH) defines, among other things, the following general guidelines for action in abnormal and emergency situations (Chapter 2.2.A and 2.2.D):

- After an in-flight engine failure, the pilot flying (PF) must focus on flying the aircraft and handling communications, while the pilot not flying (PNF) must execute the emergency lists.
- The nature of the failure must be clearly identified by either pilot.
- The steps to be taken in executing the procedure start with the memory items, which must be performed immediately without resorting to the reading of any checklists. The abnormal or emergency checklists in the quick reference handbook are executed next. Last are the normal checklists.
- Crosschecks are essential, as is strict discipline and coordination between the crew.

The autopilot must be engaged as soon as possible whenever above 600 feet AGL.

ATC services must be notified of the urgency situation as specified in the Air Traffic Regulations (Sections 10.5.3.1.1, 10.5.3.1.2 and 10.5.3.2.1.1) via the use of the term "mayday", preferably repeated three times at the start of the transmission.

1.8. Additional information

1.8.1. *Statements*

In his statement the pilot noted that when they took over the aircraft from the previous crew, with which they interacted personally, the previous crew did not report any technical problems. After takeoff, the first 15 minutes transpired normally. They were in stable atmospheric conditions without any turbulence and the autopilot was engaged, selected to the copilot's side. Then, without any warning, there was a loud bang, accompanied by strong and rhythmic vibrations. Immediately afterward the reverser unlocked caution and left engine fire warning illuminated. Both pilot and copilot were not absolutely sure about the position of the left engine power lever in the IDLE position and did not recall if they moved the power lever from IDLE to SHUTOFF. With regard to the reverser warning, he did not notice any yawing motion, and therefore did not believe that the reverser had actually deployed. They focused on the fire warning and discharged the bottles. The fire warning did not clear, however, and remained lit until seconds before landing. In a subsequent statement, the captain clarified that when the fire warning appeared, he placed his hand on the right engine throttle lever to protect it and prevent any possible actions involving the "good" engine.

When the emergency occurred, the copilot was the pilot flying but he decided to take control of the aircraft and disengage the autopilot. The weather on the return course to Barcelona was good and they had the airport lights in sight. They did not attempt to re-start the engine.

After landing, and in light of the fact that the engine fire warning had cleared, he decided not to stop the airplane on the runway and to evacuate on taxiway GA. The airport fire brigade was already waiting for them and when he exited the aircraft they were applying firefighting foam to the engine.

The copilot's interview and statement did not provide any further data. Both the captain and the copilot agreed that the ATC instructions did not comply with their requests for vectors; on the contrary, they were long and referenced standard maneuvers.

1.8.2. *Similar cases of fan blade separation*

This event was the first in-service fan blade separation experienced by a CF34-1/-3 engine. A second contained fan blade separation event occurred on 24 may 2007. The failed blade had 4717 cycles and 5845 hours and was manufactured by Teleflex and part of the suspect group identified by GE. The aircraft, registration N933EV, was operated by Atlantic Southeast Airlines and was flying from Syracuse to Atlanta at 23000 ft when the crew heard a loud bang and felt uncontrollable vibrations in the right engine. They shut down the engine and declared an emergency. A single engine landing was accomplish without incident. No injuries were reported. The blade separation was contained and did not result in a fire. The upper and lower core cowls detached and the LPT case-to-TTC flange had separated.

1.8.3. *Recommendations issued by the NTSB*

As a consequence of the investigations into the incidents involving aircraft EC-IJF and N933EV, the United States accident investigation agency, the National Transportation Safety Board (NTSB), issued seven safety recommendations on 5 March 2008 (Appendix I).

The United States civil aviation authority FAA (Federal Aviation Authority) issued the Airworthiness Directives 2009-24-11 and 2010-01-04 in order to inspect the fan blade abradable rub strip on certain engines for wear, the fan blades on certain engines for cracks, and the aft actuator head hose fitting for correct position, and if necessary repositioning on engines CF34-1A, CF34-3A and CF34-3B.

Based on the their own internal investigation and as a result of the inspections conducted on their suppliers, General Electric adopted measures intended to reduce the aluminum content of the material used to manufacture the blades and to control the wear and replacement of the tools used to machine the tangs that attach the blade to the fan disk.

2. ANALYSIS

While in flight en route to Basel, and after 22 minutes of operation and 14 minutes of flight, the left CF34-3B1 engine on aircraft EC-IJF experienced a general sudden and unexpected failure. A fan blade separated, which caused the detachment and rotation of the LPT module, among other damage. The resulting engine fire was not contained by the cowls and fairings and burned for 9 minutes and 40 seconds in flight until the warning cleared three minutes before landing.

2.1. Technical aspects of left engine failure

2.1.1. *Description of probable failure mechanism*

The following probable fracture sequence has been established for the engine:

- Onset of failure:
  - Fracture of blade.
  - Vibrations that affected the fan cowls and unlocked the reverser (+1 second).
- Immediately following the fault:
  - Fracture of 84 bolts and first rotation of LPT module and associated elements. Failure of oil lines.
  - Damage to AGB and loose of throttle gearbox attachment screws tot support bracket.
  - Loss of oil (+3 seconds).
- Fire (+7 seconds) and failure of the VG head line.
- Second rotation of LPT module.

Occurrence of failure

The general engine failure initiated with the separation of the number 11 fan blade due to a dwell-fatigue fatigue crack. This blade separation resulted in a significant fan mass imbalance which resulted in high fan (N1) vibrations.

These fan vibrations caused the detachment of the upper and lower access cowls and the triggering of the fan reverser unluck and deploy microswitches. Within a second an EICAS message appeared warning of the unlocked reverser, though at no time did it actually deploy (the airplane did not yaw or give any warnings that the reverser had deployed). It is possible that the engine vibrations were transmitted to the airplane cabin and affected the lavatory smoke detector, triggering the alarm, and to the accelerometers in the wheel well, which registered –1.32 g.

Immediately after the failure

The loss of low pressure shaft RPMs, with the high pressure shaft maintaining its inertia, led to the stall of the compressor and the loss of flow in the LPT. The increased pressure forward of the guide vanes in the first stage of the LPT shattered the engine, breaking the 84 bolts on the transition case flange in reaction to the instantaneous stoppage of the fan at the moment the blade separated. The LPT rotor turns inside the LP stators, which are joined to the LPT box, the exhaust nozzle and its fairing. That is why once the attaching bolts broke, in reaction to the gasses that were flowing through the LP rotor, the LPT box and the exhaust nozzle and rotating some 30° counter-clockwise. This turn caused the failure of the oil line that supplied bearings six and seven.

The accessory box was also affected by the vibrations produced by the fan failure. Its supports suffered structural damage, oil leaked through a crack that formed and the entire box shifted from its position. The high fan imbalance and the AGB movement were also factors in the looseness observed in the throttle system. The observed loosenes in the throttle gearbox system could have altered the position of the throttle stops and affected the ability to cut the fuel flow to the engine.

The loss of oil through the failure of the accessory box and the separation of the supply lines to bearings six and seven triggered the low oil pressure warning in the cockpit within three seconds.

Fire and failure of VG head line

After the failure of the accessory box and the first rotation of the LPT module, a fire ignited in the forward compartment of the engine core. This fire triggered a fire warning seven seconds after the separation of the blade. The fire was most intense in the left side of the engine, between 6:00 and 8:00. It was not possible to accurately determine where the fire originated due to the extent of the damage resulting from a burn time in excess of nine minutes.

Once the fire started, the compartment’s internal pressure increased to the point that the blow out door opened. The fire breached the fire seal and passed to the aft compartment, which led to the initial perforation of the exhaust nozzle fairing (Figure 1).

One of the factors influencing the fire is related to the fact that the VG head line detached from the main fuel control, spilling fuel onto the main fire area. There are varying opinions as to whether the detachment of this line caused the fire or merely exacerbated an already existing fire.

It is General Electric's opinion that the separation of the VG head line hose from its fitting initiated the fire, and resulted from a sudden pull on the hose when the MFC moved following the shift of the AGB. The different installation position of the elbow and the lack of an attachment flange caused a reduction in the design clearance of the hose. No signs were found, however, of damage from mechanical stresses either on the hose or on the elbow indicative of a possible initial stress failure of the hose, except for some references to the effects of a shock impact load different from those that might be expected from the application of a static load.

The damage to the internal Teflon liner or to the hose collar resulted from the overheating of the hose. This indicates that the detachment of the VG head line took place after the fire broke out, contributing to the fire but not igniting it. In this sense, the flow of cooling air inside the compartment dragged the flames aft, meaning the fire must have been fed from an area that was forward of and below that which contained the VG head line elbow.

In summary, the most likely cause for the detachment of the VG head line is considered to be overheating from an existing fire that started and spread in seven seconds and whose point of origin is unknown. The improperly assembled elbow and VG head line can be ruled out as having caused the detachment of said line.

Second rotation of LPT module

Lastly, there was a second 180° counter-clockwise rotation of the LPT module and of the exhaust nozzle fairing, which accounts for the position in which they were found after the incident. This second rotation, like the first, resulted as a reaction of the turn of the LPT rotor and probably happened when the engine increased their rpm once the autopilot was disengaged (N1 near 30% and a speed of 314 kt) with the aircraft in a nose down attitude some seven minutes after the failure. When this rotation took place the fire was still burning in the aft engine compartment. It was then that the fire burned through the exhaust nozzle fairing again, this time through the blow out door (Figure 1).

2.1.2. *Identification of fire*

This fire was notable, in addition to its intensity, for its long duration (9 minutes and 40 seconds). The records show that a large part of the oil system, which contained six or seven liters, spilled in less than three seconds, and that the fire was burning within seven seconds, giving rise to temperatures that triggered the fire alarms.

For the fire to ignite there had to be air, combustible material and an ignition source. The air source was initially the cooling air in the engine compartment, and the combustible material was the spilled oil and kerosene. The cracks that probably appeared in the engine from the start of the incident led to leaks of combustible material that built up on the cowls and fairings and which were prevented from draining to the outside by the rotation of the LP module. The ignition would have resulted from the contact with the hot surfaces (250 °C or higher) of the box in the combustion area or, alternatively, by contact of the atomized kerosene mist with hot gasses outside the exhaust nozzle.

Once the fire started, the measures used to combat it as specified in the engine fire procedure were not effective, since it continued to burn for over nine minutes. As revealed by the CVR, 16 seconds after the fire alarm was received (23 seconds after the engine failure), the engine was stopped. The FDR did not reveal any changes to the fuel flow, since it was negligible just three seconds after the separation of the blade, meaning there is no other means of verifying that the engine was in fact stopped. The crew statement does not permit to assure that the fuel flow to the engine was stopped from the beginning due to the fact that they did not remember to retard the power lever to the SHUTOFF position. At engine idle, the fuel flow is so low that fuel flow transmitter cannot record the value and shows 0 pph, so the crew may have seen the fuel flow at 0 and thought the engine lever was in shutoff detent. The structural damage that was present from the start affected the integrity of the throttle gearbox, so that despite the fact that the engine was stopped in the cockpit, this action may not have been transmitted to the engine. At the 43-, 46- and 49-second marks following the fire alarm, conversations can be heard in the cockpit referring to items (3) and (4) of the procedure, but which cannot be fully confirmed. The next action intended to fight the fire and that should have ensured the fuel supply was cut off was at the 71 second mark (78 since the failure), and involved the discharging of the first bottle, which requires that the SOV in the wings be closed. This means a period of between 16 and 71 seconds following the fire alarm elapsed without any actions being taken to ensure there was no fuel supply to the engine. It has to be note that the copilot informed about the SOV closed one minute before the end of the fire warning, more than 9 minutes later from the beginning and from the discharge of the fire extinguish agent, action that closes the SOV.

In addition to the breaches made by the fire and the structural damage to the engine, it is considered a delay in stopping the fuel supply to the engine by the crew that kept the fire burning until three minutes prior to landing.

2.1.3. *Analysis of material failures and recommendations issued*

Fan blade separation. This is a fault that is envisioned when certifying the engine and which, according to regulations, must be contained, as happened in this case, by the engine fairings and cowls. The investigation by General Electric has shown the effect of a specific manufacturer's production process on the decreased dwell-time fatigue resistance properties of a certain percentage of blades.

Since detecting the blades affected by these manufacturing defects requires the performance of destructive testing, the NTSB issued two safety recommendations (A-08-04 and A-08-05) intended to improve the safe operation.

Damage affecting the integrity of the throttle lever. There is the possibility that the throttle lever in the cockpit may have been ineffective in stopping the flow of fuel to the engine due to the additional clearance gained by the throttle gearbox. This failure would result in an extended period during which the fuel was able to leak. The NTSB has already issued recommendations A-08-03 and A-08-09 to address this.

Damage to the attachment and integrity of the AGB. The frangibility of the AGB retaining screws is a design feature, so the fracture of one and the partial failure of another is not a cause for concern in and of itself. However, the secondary retention did not prevent the box casing from cracking, which allowed for the loss of oil that would eventually catch on fire.

Failure of a variable geometry system fuel hose. The most likely reason for the failure of this line was the progressive weakening of the line by the fire that had broken out in the aft engine compartment. As a result of the investigation, mistakes were found in the assembly instructions for said line and which are addressed in NTSB recommendations A-08-07 and A-08-08.

In-flight detachment and loss of fan cowls. Since the engine failure took place over the Mediterranean, the fall of two large sections of the cowls did not have any safety consequences. While it is true that had this occurred over populated areas the repercussions could have been more serious, the risk to people outside the aircraft is minimal.

Failure to extinguish fire. Though the flames were not contained by the engine cowls, they did not affect the engine pylons or the airframe. The discharge of two extinguishing bottles did not manage to quench the fire that had broken out in the engine's accessory compartment. In this case, with both fuel and oil leaks and large holes opened in the cowls by the fire itself, the dispersion of the fire fighting agents made it impossible to contain the fire.

Unlocked reverser. The left reverser unlocked caution was due to the damage caused to the system microswitches by the detachment of the fan cowls.

Alarms and warnings. Numerous aural and luminous warnings were received by the crew over the course of the emergency. Those involving the unlocked reverser, the low oil pressure and the engine fire were an accurate representation of what was happening to the left engine. The lavatory smoke warning was the only that did not reflect reality.

2.2. Aspects related to the cockpit crew

The situation faced by the crew was made more complex by the accumulation and persistence of cockpit warnings. In seven seconds, and without any prior signs, they received warnings involving the reverser, oil and fire in the left engine, a fire that burned for over nine minutes while in flight. The actions explained below notwithstanding, the emergencies were handled adequately and without any consequences to the passengers.

In the first 22 seconds a series of superimposed warnings was received. The copilot is heard identifying the reverser failure and telling the captain not to touch the right engine throttle, as clarified in later statements. The captain, despite not making any comments at the onset of the emergency, was taking measures to protect the "good" engine. This initiative of safeguarding the throttle with the hand can be considered as a good preventive measure, though the fact that it is not mentioned in any of the operator's guidelines disconcerted the copilot who, on the contrary, thought he was going to cut it.

Immediately after silencing the warnings, the copilot initiated the fire procedure, which he then executed. Twenty-three seconds had elapsed since the general failure and 16 since the fire warning. While there was no verbal identification of the nature of the emergency nor of the procedure that was to be started, both the captain's and the copilot's priorities and assessments of the emergencies were proper, and despite a series of erroneous confirmations about which engine to cut, the actions taken involved the correct engine.

The copilot, at the controls at the time, in addition to initiating the emergency procedure also handled ATC communications. This initial task overload led to a change in functions during the emergency procedure as the role of pilot flying was transferred to the captain. During the flight another transfer of functions would take place involving communications, which went from the captain to the copilot on several occasions. Keeping in mind the distribution of tasks specified by the company for this type of situation, the copilot should have focused on flying and handling communications while the captain combated the emergency.

Disengaging the autopilot is not considered suitable practice in these situations. On the contrary, a reliance on automation, such as the autopilot, is recommended in emergencies.

The appearance of the "TOO LOW TERRAIN" warnings indicate that item (5) of the single-engine landing procedure was not executed. Visibility conditions were good, as a result of which neither pilot took any actions or made any comments. Under less favorable conditions, this warning would have resulted in an unnecessary missed approach maneuver.

Of lesser importance is the fact that in notifying of the emergency, the term "mayday" was not used as specified in the Air Traffic Regulations. In this case it was of no consequence since they were given priority to land, but in other circumstances, such as those involving foreign airports or crews or with more traffic, the priority required by their situation may not have been clear to other aircraft. The decision to return to Barcelona is considered correct given the proximity (it was the closest airport, though not by much) and the means and capabilities available at that airport with respect to the rest.

The coordination and information provided to the flight attendants and ATC regarding the evacuation was complete and precise and emphasized the side to be used in the evacuation.

The incident flight was the first flight of the day, meaning fatigue is not considered as a factor in assessing the cockpit crew's actions.

2.3. Aspects related to ATC services

When the engine failure occurred, the aircraft communicated its emergency situation to ATC on the frequency it was currently assigned.

ATC was fast and efficient in providing and confirming the return course that took the aircraft directly to Barcelona airport on a long direct approach. It also cleared the approach path of other traffic, granting absolute priority to the aircraft in distress. From the crew's point of view, however, with the aircraft at too high an altitude and with procedures to perform, the ATC instructions referencing VOR-DME maneuvers were occasionally too long (up to 14 seconds) and contributed to the agitation of the crew, which had requested vectors. In these situations, the cockpit workload requires short and concise control instructions.

The mobilization of emergency services at Barcelona airport was properly coordinated by ATC. There were no delays in responding to the scene once the aircraft landed.

3. CONCLUSIONS

3.1. Findings

- The aircraft was properly and in force licensed and certified to fly.
- Fourteen minutes after taking off from Barcelona, the number 11 fan blade in the left engine separated.

- There was an in-flight fire that, despite the discharging of the two extinguishing bottles, lasted for 9 minutes and 40 seconds, and persisted until three minutes prior to landing.
- The fire started in the engine accessory compartment and burned through the fire seal and into the aft compartment under the exhaust nozzle fairing.
- The flames burned two large holes into the exhaust nozzle fairing, damaged the fire seal and burned through parts of the upper engine cowl.
- The fire did not spread to other parts of the airplane.
- The weather was not a factor in the incident.

Engine

- The blade separated due to a reduction in the dwell-time fatigue resistance properties of the middle tang that is used to hold the pin that attaches the blade to the fan disk.
- The reduction in the dwell-time fatigue resistance properties was due to the presence of unfavorably oriented aligned alpha colonies in the titanium structure and from which the crack propagated in low-cycle fatigue.
- The separated blade was contained by the fan containmen ring. The resulted high fan imbalance resulted in several secondary events:

  — Shear separation of the 84 bolts in the HPT transition to LPT stator case flanges.
  — Rotation and separation of the LPT module and all its associated components.
  — Separation of the VG head line from its MFC end fitting.
  — Detachment and cracking of the accessory gearbox.
  — Excessive throttle system looseness.
  — Detachment and loss of the fan access cowls.
  — Unlocking of the fan reverser transcowl.

- Although not casual in the failure an error was discovered in the assembly of the rigid elbow that joins the flexible VG head line to the main fuel control (MFC). This error revealed several inconsistencies in the documentation for installing this piece.

Crew

- All of the crew members were properly and in force certified and licensed.
- The captain and copilot had flown the three days prior to the incident. This was their first flight of that day.
- The cockpit warnings were properly and quickly assessed and prioritized.
- The in-flight engine fire procedure was started 16 seconds after the fire warning was received. The first extinguishing bottle was discharged after 71 seconds.
- The distribution of tasks between the crew members during the emergency was not consistent with the operator’s operational criteria.
- An uneventful single-engine landing was made on runway 25R at Barcelona.
- The airplane was evacuated on rapid exit taxiway GA without incident.

ATC

- ATC deviated traffic ahead of and behind EC-IJF so as to give it landing priority.
- The fire fighting service was alerted and was on hand ready to aid in the evacuation.

3.2. Causes

The failure of the left engine on aircraft EC-IJF was caused by the separation of one of the fan blades resulting from dwell-time fatigue cracks that initiated from areas of aligned alpha colonies in the titanium microstructure that resulted from the blade manufacturing process.

4. SAFETY RECOMMENDATIONS

As a consequence of the investigations into the incidents involving aircraft EC-IJF and N933EV, NTSB, issued seven safety recommendations regarding technical aspects identified. The recommendations of this report only concern the operational aspects of the incident.

The situation confronted by the crew of aircraft EC-IJF was made critical by the practically simultaneous appearance of cockpit warnings and the presence of an unextinguished fire in the left engine that persisted for 9 minutes and 40 seconds. Although the emergency was satisfactorily resolved, an analysis of the crew's actions revealed some aspects involving crew resource management that warrant the issuance of a safety recommendation.

REC 03/10. It is recommended that Air Nostrum reinforce its technical crew training in the following areas:

- Leadership and techniques for deliberate decision-making in abnormal and emergency situations.
- Crew task distribution in abnormal and emergency situations.
- Standards and procedures for fault identification, notification and prioritization in abnormal and emergency situations.
- Strict compliance with procedures in abnormal and emergency situations so as to avoid inducing uncertainty in other crew members.
- The appropriate use of automation in every situation.
- The use of standard terminology in abnormal and emergency situations.

APPENDIX I
NTSB Recommendations to the U.S. Federal Aviation Administration and Transport Canada

The National Transportation Safety Board recommends that Transport Canada (http://ntsb.gov/Recs/letters/2008/A08_3.pdf):

> Require Bombardier to redesign the retention feature of the Canadair Regional Jet-100/-200 aircraft engine throttle gearbox to ensure that it can withstand the loads generated by a fan blade separation or similar event (A-08-03).

The National Transportation Safety Board recommends that the Federal Aviation administration (http://ntsb.gov//Recs/letters/2008/A08_4_9.pdf):

> Require GE Aviation to define a reasonable maximum cycle limit below 4,717 cycles since new for Teleflex-manufactured CF34-1/-3 fan blades, considering the two failures and available data, and require that the blades be removed from service before that limit is exceeded (A-08-04).
>
> Require GE Aviation to include dwell time fatigue testing in the CF34-1/-3 fan blade manufacturing process requirements to verify that any modified manufacturing process adequately reduces the possibility of the presence of aligned alpha colonies in the finished part (A-08-05).
>
> Require GE Aviation to make modifications to the CF34-1/-3 engine design and ensure that an engine unbalance event will not cause the engine to catch fire (A-08-06).
>
> Require GE Aviation to revise the CF34-1/-3 engine manual so that it clearly specifies the aft actuator rod[2] hose elbow orientation and the requirement for adequate slack in the hose (A-08-07).
>
> Require a one-time inspection of the aft actuator rod[3] hoses installed on all CF34-1/–3 engines to ensure hose integrity during an unbalance event (A-08-08).
>
> Require that all operators of Bombardier Canadair Regional Jet-100/-200 aircraft incorporate Bombardier's redesign of the engine throttle gearbox retention as recommended in Safety Recommendation A-08-03 (A-08-09).

[2] Due to a publishing error, the text in the recommendation makes reference to the *rod hose* when it should read *head hose*.

APPENDIX II
Procedures for in-flight engine shutdown and single-engine approach and landing

IN-FLIGHT ENGINE SHUTDOWN

Accomplish an engine shutdown only when flight conditions permit:

(1) Affected thrust lever .... Confirm and IDLE
(2) Affected thrust lever .... Confirm and SHUT OFF
(3) 14th STAGE ISOL switch .... OPEN

If engine shutdown was not due to a hydraulic system high temperature condition:

(4) Affected HYDRAULIC B pump .... on
- If left engine shut down .... HYDRAULIC 1 switch ON
- If right engine shut down .... HYDRAULIC 2 switch ON

(5) Affected FUEL, BOOST PUMP switch .... Confirm and off
(6) ANTI-ICE, LH or RH COWL switch .... Affected side OFF
(7) APU (if available) (30,000 feet and below) .... Start
(8) APU GEN switch .... ON
(10) Fuel system .... Check
Crossflow .... AUTO
Quantity/Balance .... CHECK

Engine damage is suspected/intentional shutdown:

(11) Land at the nearest suitable airport
(12) Single Engine Approach and Landing procedure ... Accomplish

SINGLE ENGINE APPROACH AND LANDING

(1) APU (if available) (30,000 feet and below) .... Start
(2) APU GEN switch .... ON

Below 15,000 feet:

(3) L and R PACKS .... ON
(4) Go-around thrust reference .... Set

Airplanes with the EGPWS installed

(5) GRND PROX, FLAP switch .... OVRD

Approach and landing:

(6) Approach and landing flaps 20
(7) Final approach speed .... Not less than $V_{ref\ (flaps\ 45°)}$ + 12 KIAS
(8) Actual landing distance .... Increase by a factor of 1.25 (25%) for a flaps 20° landing without the use of reverse thrust

CAUTION

If required, use remaining thrust reverser carefully upon landing