



# In-flight engine failure – Christmas Island

## 19 October 2009

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- safety data recording, analysis and research
- fostering safety awareness, knowledge and action.

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### Abstract

On 19 October 2009, a British Aerospace Avro-RJ70 aircraft sustained an in-flight engine failure shortly after taking off from Christmas Island.

The investigation found that the number-2 engine failed due to severe overheating damage to the high-pressure turbine section components. The overheating was most likely related to a defective fuel injector nozzle that exposed the turbine nozzle guide vanes and blades to a sustained over-temperature condition and cumulative thermal damage. Although the engine's operating performance and condition was being monitored as part of the operator's Engine Condition and Trend Monitoring (ECTM) program, no significant indications of the impending failure were detected in the lead up to the failure.

The flight crew reported that while responding to the engine failure they were unable to extend the fire lever in order to operate the engine's fire suppression system. The operator subsequently inspected the system, but could not duplicate the problem.

The ATSB did not identify any safety issues as a result of its investigation that required safety action to be taken.

### FACTUAL INFORMATION

#### History of the flight

On 19 October 2009, a British Aerospace Avro-RJ70 aircraft, registered VH-NJT, was being operated on a scheduled passenger flight from Christmas Island to Cocos Island. On board the

aircraft were 51 passengers and seven crew. At around 1607 local time<sup>1</sup>, the aircraft commenced the take-off roll on runway 18 at Christmas Island Aerodrome. The copilot was the handling pilot and the pilot in command (PIC) was monitoring and performing non-flying duties. Due to the length of the sector, the crew was also augmented by a relief pilot.

While climbing through 3,200 ft above mean sea level (AMSL), the flight crew heard a loud bang from the left side of the aircraft. The sudden noise was accompanied by airframe vibrations, fluctuations of the number-2 engine turbine gas temperature and a rapid reduction in the high-pressure compressor speed (%N2). Immediately following the event, the PIC took control of the aircraft as the handling pilot and the crew actioned the checklist items from the quick reference handbook<sup>2</sup>. The number-2 engine was subsequently shut down and the climb continued.

The flight crew elected to discontinue the flight and return to Christmas Island. While informing the cabin crew of that decision, the flight crew were advised that several passengers had observed a long tail of flame from the exhaust cone of the number-2 engine.

1 The 24-hour clock is used in this report to describe the local time of day, Christmas Island Time (CXT), as particular events occurred. Christmas Island Time was Coordinated Universal Time (UTC) +7 hours.

2 Quick reference handbook (QRH), one volume containing a subset of important information for easy and quick reference, such as during emergencies. The QRH was the primary reference for flight crews when abnormal conditions developed.

The relief pilot, who had been seated in the passenger cabin, entered the flight deck and confirmed to the flight crew that the exhaust flame from the number-2 engine had now extinguished. The PIC reported that to make full use of crew resources, it was decided that the relief pilot would assume non-flying duties from the copilot's position. After repositioning to the jump seat, the copilot advised air traffic control of the crew's intention to return the aircraft to Christmas Island.

During the subsequent turn-back and descent, the PIC repositioned the aircraft to the north of the island in preparation for a straight-in approach to runway 18. The aircraft landed without further incident and there were no injuries.

#### *Other information – engine fire protection*

Following the incident, the flight crew reported to the Australian Transport Safety Bureau (ATSB) that they were unable to discharge the number-2 engine fire suppression system. Discharging the fire system was one of the required procedural actions in response to the engine failure. The crew reported that they were only able to extend the fire handle<sup>3</sup> approximately ½ cm, and on release, the lever retracted from the apparent tension in the cable. Although considerable effort was reportedly applied by the crew, the fire handle could not be extended. The PIC reported having experience in the use of the handle in both aircraft and simulator environments, and as such, believed that the difficulties encountered were indicative of a mechanical problem with the system.

### **Damage to the aircraft**

After receiving advice of the occurrence, the operator dispatched maintenance personnel to Christmas Island to inspect the aircraft. The inspection revealed severe internal damage to the low and high-pressure turbines of the number-2 engine. The damage to the engine was completely contained and there was no other damage to the aircraft.

The operator's maintenance personnel also carried out a functional check and examination of the aircraft's fire suppression system; initially at Christmas Island, and subsequently after the return flight back to Perth. It was reported to the ATSB that no anomalies were found with the operation of the system, including the extension of the number-2 engine fire lever.

### **Aircraft information**

The Avro-RJ70 aircraft, serial number E1228, was manufactured in 1993 by British Aerospace (BAe) of the United Kingdom (UK) (Figure 1). The RJ70 was originally developed from the BAe 146-100 aircraft platform. Both types shared a virtually identical configuration; however, the RJ70 was fitted with higher power engines and digital avionics.

**Figure 1: Photograph<sup>4</sup> of VH-NJT showing the engine configuration**



### **Pilot information**

Both the PIC and copilot had considerable experience flying the BAe 146 aircraft. At the time of the occurrence, the copilot was undergoing line training and had recently gained his RJ70 endorsement. A summary of the crew's experience is contained in Table 1.

The relief pilot was a current training captain and had considerable experience flying both the BAe 146 and RJ70 aircraft types. He held a valid and current endorsement as copilot for the aircraft type.

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3 When the fire handle is actuated, various engine systems are isolated and the engine bay fire extinguishers are discharged.

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4 Photograph courtesy of Mr I Maiden.

**Table 1: Operating crew experience**

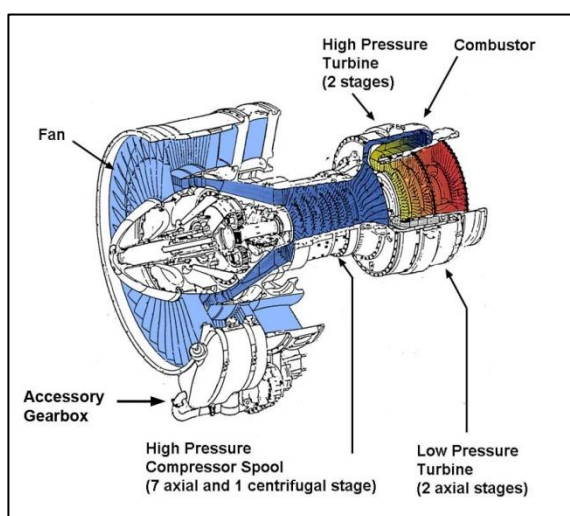
	Avro-RJ70	BAe 146
Copilot	22 hrs	4,868 hrs
PIC	1,223 hrs	6,516 hrs
Relief pilot	9,054 hrs (combined total for the RJ70 and BAe 146)	

## Engine information

The failed number-2 engine was a Honeywell model LF507-1F high bypass-ratio turbofan (SN 7266). The LF507 engine design was modelled on the ALF502 engines fitted to BAe 146 aircraft. However, the LF507 was uniquely equipped with a FADEC<sup>5</sup> fuel management system. The engine comprised four modules (Figure 2):

- front fan module driven by a two-stage low-pressure turbine (LPT)
- gas producer module containing a seven-stage high-pressure compressor (HPC) a single-stage centrifugal compressor, and a two-stage high-pressure turbine (HPT)
- combustor turbine module comprising an annular reverse-flow combustion chamber and a two-stage LPT
- accessory gearbox module.

**Figure 2: Cutaway of the Honeywell LF507 engine**



Maintenance documentation supplied by the operator showed that the engine had been

installed on the aircraft for the entirety of its service life. At the time of the occurrence, the engine had completed 24,796.4 hours total time in service (TTIS) and 13,422 cycles since new (CSN). Since its last overhaul, the engine had operated for 6,927.6 hours and 3,710 cycles.

The maintenance documentation showed that on five occasions during the month leading up to the occurrence (approximately 181 hours of operation), flight crews had reported difficulty in starting the number-2 engine for the first flight of the day. Numerous components were replaced as part of the troubleshooting efforts to correct the starting issue. Component replacements included the flow divider, fuel solenoid valve and multiple replacements of the 'A' ignition system igniters. The last corrective action aimed at addressing the starting problem was the replacement of the fuel manifolds, which was completed three flights, (4.2 hours of operation) before the engine failure. A summary of the number-2 engine's maintenance history is listed in Table 2.

## Recorded information

Upon return to Australia, the aircraft's flight data recorder (FDR) was removed and downloaded by the operator's personnel. The data was provided to the ATSB for analysis. The FDR monitored and recorded only a limited number of engine-related parameters: fan speed (%N1)<sup>6</sup>, vibration levels, low oil pressure indication and power lever angle.

The FDR information indicated that at around 1607, the aircraft commenced the take-off roll from runway 18. The engine failure occurred approximately 2 minutes after takeoff, at an airspeed of 142 kts, as the aircraft climbed through 3,200 ft AMSL. The engine failure was revealed in the recorded data as a rapid decay in fan speed (%N1), immediately followed by an elevated spike in vibration and a low oil pressure warning. At no stage during the flight did the number-2 engine fire detection circuit trigger. About 1 minute after the engine failure and with the aircraft still climbing, the number-2 engine power lever angle was reduced.

At an altitude of about 4,600 ft AMSL, the flight crew initiated the descent and return to the

<sup>5</sup> Full Authority Digital Electronic Control.

<sup>6</sup> %N1 refers to the engine fan speed as a percentage of a rated RPM.

aerodrome, and at 1626, the aircraft touched down on runway 18, after a total flight time of 18 minutes. A plot of the recorded data is presented at Appendix A of this report.

**Table 2: Summary of number-2 engine (SN 7266) operational reports and relevant service history**

Date and hours since overhaul	Engine issue and maintenance completed
29 Jan 2006 0.0 hrs	Engine overhauled and refitted to RJ-70 aircraft VH-NJT
1 Sep 2009 6,746.6 hrs	<i>Pilot report</i> - engine slow to light <i>Maintenance action</i> - fuel filter inspected and flow divider replaced
22 Sep 2009 6,799.4 hrs	<i>Pilot report</i> - engine slow to light <i>Maintenance action</i> - 'A' system ignition igniter replaced
23 Sep 2009 6,809.1 hrs	<i>Pilot report</i> - engine slow to light <i>Maintenance action</i> - fuel solenoid valve replaced
28 Sep 2009 6,829.8 hrs	<i>Pilot report</i> - engine slow to light <i>Maintenance action</i> - 'A' system ignition igniter replaced
30 Sep 2009 6,843.9 hrs	<i>Pilot report</i> - engine slow to light <i>Maintenance action</i> – engine successfully started
13 Oct 2009 6,896.4 hrs	<i>Pilot report</i> - Nil start for number-two engine
18 Oct 2009 6,923.4 hrs	<i>Maintenance action</i> - Fuel manifold assembly replaced
19 Oct 2009 6,927.6 hrs	Engine failure - Christmas Island

#### *Trend monitoring*

The aircraft operator had been monitoring the performance of the engines using an engine condition trend monitoring (ECTM) program. An ECTM program is an engine health monitoring system, with the capacity to provide timely warnings to an operator of any trends in the measured engine parameters<sup>7</sup> that might be precursors to a loss of engine performance, or to an engine failure. The data was manually recorded by the flight crew once the aircraft was

stabilised at the required in-flight condition. It was subsequently collated and supplied to the engine manufacturer's designated analysis centre.

The number-2 engine's ECTM data leading up to the failure was provided to the ATSB and an analysis of that data did not show any unusual trend changes prior to the incident. No deviation in the measured parameters that would indicate a developing problem with the number-2 engine was observed when comparing %N2 against TGT, fuel flow and %N1.

## Examination of the number-two engine

### *Engine disassembly and examination*

The damaged engine was sent from Perth to the engine manufacturer's facilities at Luton in the UK. An accredited representative<sup>8</sup> from the UK Air Accidents Investigation Branch (AAIB) oversaw the inspection and disassembly on behalf of the ATSB. The manufacturer subsequently provided a report to the ATSB with the following observations.

### *Lubrication*

The lubrication system and magnetic chip detector were drained and inspected. No evidence of contamination or overheating of the engine oil was found.

### *High-pressure compressor and combustor (HPC)*

Inspection of the HPC revealed no evidence of foreign object damage or contaminant ingestion. The combustion liner was generally in good condition, although the swirler assembly<sup>9</sup> at the 6 o'clock position was slightly burnt and displayed an uneven wear pattern, consistent with it having rubbed on the corresponding fuel nozzle. There was no abnormal carbon accumulation or evidence of fuel streaking in the combustion liner.

<sup>7</sup> Measured parameters for LF507-1F ECTM analysis were: turbine gas temperature (TGT), compressor turbine speed (%N2), fan speed (%N1) and fuel flow.

<sup>8</sup> An accredited representative as defined in ICAO Annex 13 is a person designated by a State, on the basis of his or her qualifications, for the purpose of participating in an investigation conducted by another State.

<sup>9</sup> The swirler assembly facilitates mixing of air and fuel within the engine prior to combustion.

### *High-pressure turbine (HPT)*

Disassembly of the HPT section found that the stage-1 nozzle guide vanes were in relatively good condition, with the notable exception of the complete burn-through of three vanes and the inner shroud at the 6 o'clock position (Figure 3). The leading edges of all stage-1 turbine blades showed evidence of heat damage and erosion (Figure 4).

All of the stage-2 turbine blade tips had fractured unevenly along their span. The blade stub fracture surfaces were obscured by molten metal deposits and showed no evidence of solid object impact (Figure 5). The stage-2 turbine damage was consistent with blade separation from exposure to engine operating temperatures above the melting temperature of the blade material. A stage-2 nozzle guide vane was also completely burnt through at the 6 o'clock position, in a similar manner to the stage-1 nozzle (Figures 6 and 7).

### *Low pressure turbine (LPT)*

Disassembly of the LPT section revealed that all of the stage-3 and -4 low pressure turbine blades had separated at the mid-span position, with heavy impact damage and metallization<sup>10</sup> present (Figure 8).

### *Fuel system -injector nozzles and manifolds*

The in-line fuel filter was found heavily contaminated with very fine debris. Chemical analysis indicated that the debris was an aluminium-rich product, with minor amounts of sulphur and oxygen - similar to corrosion product. The main fuel filter was clean, as was the downstream inlet screen to the fuel flow divider.

On the basis of the low time between the replacement of the fuel manifolds/nozzles and the engine failure, together with the heat damaged condition of the power turbine, the AAIB quarantined the fuel manifolds and injector nozzles for further testing and examination. Testing of all 28 nozzles from both manifolds did not reveal any undesirable nozzle spray pattern or fuel flow characteristics. All the nozzles were

reportedly clean and free from deposits (Figures 9 and 10). Examination and testing of the previously-fitted fuel injector nozzles/manifolds was not possible, as they had already been overhauled by the time the request was made.

### *Fuel system - FADEC*

The engine's full-authority digital engine control system (FADEC) was comprised of two modules; the electronic control unit (ECU) and a hydro-mechanical assembly (HMA). The FADEC system was designed to automatically control the engine throughout its full range of operation.

At the request of the ATSB, the HMA was sent to the unit's manufacturer for a functional check. During that process, the main metering valve (MMV) potentiometer was identified supplying deviating feedback signals – a malfunction reported by the engine manufacturer that could potentially induce excessive fuelling and high turbine gas temperatures.

### *Engine accessories*

Also noted in the manufacturer's teardown report was that the 'A' system ignition igniter harness failed when electrically tested – a possible factor contributing to the reported difficulty starting the number-2 engine in the preceding months.

**Figure 3: Stage-1 nozzle guide vanes showing burn through at the 6 o'clock position**



<sup>10</sup> An effect from high temperature exposure where a metallic coating is formed when alloy turbine components melt and then deposit onto other parts of the engine.

Figure 4: Stage-1 HPT with leading edge vane erosion and melting



Figure 7: Close-up of burn through of stage-2 HPT nozzle guide vane



Figure 5: Stage-2 HPT blade separation



Figure 8: Thermal damage and metallization of the stage-3 LPT showing blade tip separation



Figure 6: Severe heat damage to the stage-1 and -2 HPT, showing burn through of a stage-2 nozzle guide vane at the 6 o'clock position (arrowed)



Figure 9: View of the fuel manifold at the 6 o'clock position



**Figure 10:** Close view of an injector nozzle from the 6 o'clock position with no blockages evident



### Aircraft fire protection system

The aircraft was equipped with a fire warning and suppression system. Two independent, electrically-operated fire extinguishers were fitted in the nose cowling of each engine and were able to be discharged by pilot manipulation of a fire handle. Manipulation of the handle also isolated relevant engine-mounted components associated with fuel, hydraulics, bleed air and electrical systems.

The fire handle was located on the flight deck overhead panel. Its manipulation followed three distinct phases, as follows (see also Figures 11 and 12):

1. When pulled out to the initial stop, a microswitch activates the ENG FIRE HANDLE annunciator on the Master Warning System (MWS) panel.
2. After rotating the handle slightly, the fire handle is further withdrawn to its limit of travel. During this phase, in addition to electrically-isolating engine mounted components, the handle operates a system of pulleys and cables that mechanically closes the engine's low-pressure fuel valve.
3. Subsequent turning of the fire handle to the left or right through 90 degrees will then discharge either the number-1 or -2 extinguisher (respectively) into the forward engine bay.

The aircraft operator indicated that engine fire protection systems on its aircraft are functionally tested by maintenance personnel on a 15-month

periodic basis. The cable and pulley mechanism that is connected to the fire handle is also lubricated at that time.

### Crew training - fire system

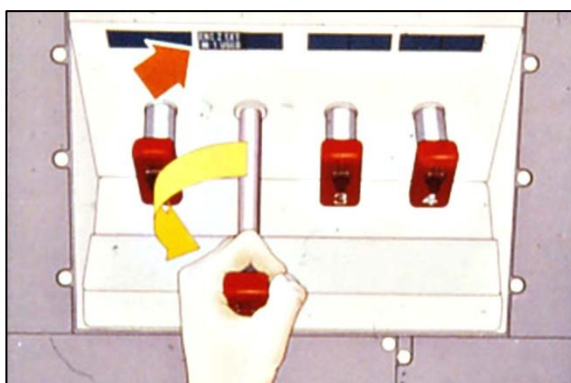
Instruction, familiarisation and experience using the engine fire protection system is provided to flight crews through flight simulator training, during which they are exposed to normal, abnormal and emergency situations and procedures. To maintain currency, company pilots complete recurrent training in the simulator every 6 months. That training included manipulation of the fire handle in response to simulated engine fire conditions. While the fire handle in the simulator is not connected to a cable or mechanical linkage, the handle was designed to be manipulated in the same manner as an actual RJ70 aircraft. The fire handle in the training simulator may become worn through constant use, and consequently over time require less force during operation in order to extend and rotate the fire handle beyond the initial detent.

**Figure 11:** Illustration<sup>11</sup> of the overhead fire panel within the flight deck



<sup>11</sup> Image source - Ansett Flight Simulator Centre training notes.

Figure 12: Illustration<sup>12</sup> showing actuation of a fire handle



Note: rotating the handle left or right will discharge either the number-1 or -2 fire extinguisher.

### Other events

The LF507/ALF502 engine type has a known history of issues relating to the fuel manifolds. Industry reporting to the Australian Civil Aviation Safety Authority (CASA) indicated that there were 11 instances between 1998 and 2009 where the fuel manifolds had either leaked or had cracked. There was one report of an engine fire from fuel manifold leakage.

In 2004, the engine manufacturer published a service bulletin<sup>13</sup> that was initially prompted by an engine fire attributed to a loose fuel nozzle that leaked during operation. In 2006, the engine manufacturer released another service bulletin<sup>14</sup> that provided further advice for inspecting the manifolds for evidence of fuel leakage. These service bulletins were embedded in the operator's maintenance program.

12 Image source - Ansett Flight Simulator Centre training notes.

13 Honeywell Service Bulletin ALF/LF 72-1094, 'Engine - combustor section - introduce improved fuel nozzle, part no. 2-310-213-01, and fuel manifold assembly, part no. 2-163-620-39/-40/-41/-42', dated 30 April 2004.

14 Honeywell Service Bulletin ALF/LF A72-1098, 'Engine - combustor section - visual inspection of fuel manifold assembly, part no. 2-163-620-39/-40/-41/-42', dated 22 May 2006.

## ANALYSIS

### Occurrence flight

After takeoff from Christmas Island and while climbing through 3,200 ft above mean sea level (AMSL), the number-2 engine of an Avro-RJ70 aircraft (VH-NJT) failed and was shut down, necessitating a return to the departure aerodrome. The crew reported no prior indications of problems or potential issues with the powerplant. This was also reflected in the recorded data for the incident flight. The crew were first alerted to an issue by a loud bang from the left side of the aircraft, which was followed almost immediately by airframe vibration and a reduction in power from the number-2 engine.

The PIC's decision to assume the handling pilot's role and to continue climbing the aircraft until completing the emergency and non-normal checklist was considered to be an appropriate use of crew resources, as was the decision to reposition the relief pilot (who had previously been seated in the passenger cabin) into the copilot's seat. Those decisions ensured that the highest level of pilot experience was maintained at the controls of the aircraft for the remainder of the flight.

### Activation of the fire suppression system

Immediately after the engine failure, the crew attempted to activate the number-2 engine fire suppression system. All attempts were unsuccessful despite considerable physical effort being applied to the fire handle.

Flight crew practical experience in the use of the fire suppression system was generally gained through simulator training. It has been noted that the fire handle in the training simulator may become worn through constant use, and consequently over time require less force to extend and rotate the handle beyond the initial detent. This was in contrast to the fire handle on the flight deck of the RJ70 aircraft, which was rarely manipulated and was connected to a cable and pulley mechanism. The force required to pull the fire handle to the first stop in the aircraft may well have been significantly greater than what was typically experienced in the simulator.

While it is possible that the lack of fidelity in the simulator training had not adequately prepared the crew for the force necessary to activate the

fire suppression system, the description of the crew's difficulties and their efforts to activate the lever, together with their reported experience in using the aircraft fire suppression system on previous occasions, led to the conclusion that the problem was most likely the result of an intermittent or transient mechanical issue with the actuation mechanism, that only became apparent during the incident flight.

The operator informed the Australian Transport Safety Bureau (ATSB) that the reported fire handle defect could not be duplicated on the ground. The system was found to be fully functional after being inspected and tested by their maintenance personnel. As such, the ATSB investigation was unable to fully reconcile the flight crew's difficulties in actuating the number-2 engine fire lever with subsequent examination of the operation of the lever.

### Engine failure

From the evidence established during the investigation, it was apparent that the number-2 engine failed due to severe heating and destruction of the internal turbine components. The stage-1 turbine blades had sustained severe heat and erosion damage, but no impact damage. All of the rotating turbine blades and the stationary vanes downstream of the stage-2 nozzle guide vane displayed the effects of sustained high temperature exposure and related mechanical impact damage. Liberation of the stage-2 turbine blades would have produced an out of balance condition within the engine, leading to vibratory forces that allowed the rotating components to collide with the engine's stationary assemblies.

A large flame that passengers reported extending from the engine exhaust was most likely the result of uncontrolled fuel combustion, stemming from the internal turbine failure events.

Based on the localised heat damage to the stage-1 and -2 nozzle guide vanes, it is probable that a defective injector nozzle allowed incomplete combustion of the fuel prior to entering the turbine section. The engine manufacturer considered it unlikely that such an event would have left any evidence, such as carbon deposits in the combustion liner, but would have caused considerable damage to the turbine section.

### Engine fuel system

Leading up to the failure, the engine had proven difficult to start on a number of occasions. All of the diagnostic efforts were directed at troubleshooting a problem with the engine's fuel system. The engine failed only 4 hours after the fuel manifolds were replaced as part of the maintenance action aimed at addressing the starting problems. After the failure, the replacement nozzles were tested and did not reveal any undesirable atomisation patterns or fuel flow characteristics. As such, it was most likely that the previously-installed fuel manifolds had been producing defective fuel injection patterns in the area associated with the 6 o'clock position, and that during a period of operation leading up to the failure, the injectors had exposed the turbine nozzle guide vanes and blades to a sustained over-temperature condition. Furthermore, it is possible that in the month leading up to the engine failure, the multiple difficult starting events had also contributed to the heat damage sustained by the hot section components<sup>15</sup>.

It was noted in the manufacturer's teardown report that the 'A' system ignition harness was faulty when tested. The ignition harness was responsible for conducting high voltage to the igniters during engine start-up. Any breakdown of the harness may have contributed to the period of difficult starting.

The engine manufacturer also reported that when tested, the main metering valve potentiometer from the HMA within the FADEC system was supplying deviating feedback signals. Although this may have induced excessive fuelling, it is unlikely that such a malfunction contributed to the engine failure due to the very localised heat damage to the nozzle guide vanes.

Despite evidence to suggest that the engine damage had probably developed in the month leading up to the failure, the ATSB investigation could not discount the possibility of the damage occurring in the 4 hours of engine operation immediately after the injector fuel manifolds were replaced. Despite the replacement injector

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<sup>15</sup> Heat damage can be produced by excessive fuel and insufficient air flow during engine start-up procedures i.e. hot starting.

nozzles passing the acceptance testing, a transient blockage from carbon or other detritus material may have affected the injector spray patterns. The engine's in line fuel filter was found heavily contaminated with fine particles of corrosion product. It is possible that not all of the corrosion product was captured by the in-line filter, and that some may have accumulated downstream, producing undesirable injector nozzle spray patterns and anomalous fuel atomisation behaviour.

### Engine trend monitoring

The operator's ECTM analysis provided no indicators of pre-existing engine damage in the interval leading up to the occurrence. Had the damage occurred in the period associated with the starting difficulties, it is possible that localised damage may not have been detected as a shift in the monitored engine parameters (TGT, %N1, %N2 and fuel flow).

ECTM techniques are predicated on the fact that general physical turbine degradation or damage results in inefficiencies and consequent measurable parameter shifts (an increase in %N2, TGT and fuel flow) for a given power setting. It is possible that the localised nature of the developing damage may not have had sufficient overall influence on the operation of the engine to be detected by the ECTM program.

### FINDINGS

From the evidence available, the following findings are made with respect to the in-flight engine failure involving a British Aerospace Avro-RJ70 aircraft, registered VH-NJT, and should not be read as apportioning blame or liability to any particular organisation or individual.

### Contributing safety factors

- The number-2 engine failed as a result of severe localised overheating and burn-through of the stage-1 nozzle guide vanes, and the subsequent destruction of the downstream turbine components.
- Damage to the stage-1 nozzle guide vanes was probably related to pre-existing and undetected defective fuel injector nozzle/s.

### Other safety factors

- During the immediate response to the engine failure, the flight crew were unable to activate the number-2 engine fire suppression system.
- The engine condition trend monitoring program did not provide forewarning of the turbine system damage that eventually led to the engine failure, most likely as a result of the localised nature of the developing damage.

### SAFETY ACTION

No safety issues requiring action were identified as a result of this investigation. Relevant organisations may, however, proactively initiate safety action in order to reduce their safety risk. The following proactive safety action in response to this incident has been undertaken.

### The aircraft operator

The operator advised the ATSB that in response to the reported inability to activate the aircraft's number-2 engine fire suppression system, an immediate functional check of the aircraft fire system was performed by the operator's maintenance personnel. Although there was no fault found in that initial inspection, as a precaution, the operator subsequently conducted a more detailed inspection of the aircraft in order to identify any potential issues. The ATSB was advised that both inspections did not reveal any pre-existing fault or condition that could have contributed to the flight crew's difficulties with the fire suppression system.

### SOURCES AND SUBMISSIONS

#### Sources of Information

The main sources of information for the investigation included:

- the aircraft operator
- the flight crew
- the engine manufacturer.

#### Submissions

Under Part 4, Division 2 (Investigation Reports), Section 26 of the Transport Safety Investigation Act 2003, the ATSB may provide a draft report, on a confidential basis, to any person whom the

ATSB considers appropriate. Section 26 (1) (a) of the Act allows a person receiving a draft report to make submissions to the ATSB about the draft report.

A draft of this report was provided to the aircraft operator, the flight crew, the engine and aircraft manufacturers, the United Kingdom (UK) Air Accidents Investigation Branch (AAIB), and the Australian Civil Aviation Safety Authority (CASA). The submissions were reviewed and where considered appropriate, the text of the report was amended accordingly.

APPENDIX A: Graphical representation of flight data recorder (FDR) data from the occurrence flight

