



Australian Government

Australian Transport Safety Bureau

ATSB TRANSPORT SAFETY REPORT

Aviation Occurrence Investigation – AO-2007-052

Final

Uncontained Engine Starter Failure

General Electric CF6-80E1-A3

Darwin Aerodrome

24 October 2007

VH-QPE

Airbus A330-300



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Postal address: PO Box 967, Civic Square ACT 2608
Office location: 62 Northbourne Avenue, Canberra City, Australian Capital Territory
Telephone: 1800 020 616; from overseas + 61 2 6257 4150
Accident and incident notification: 1800 011 034 (24 hours)
Facsimile: 02 6247 3117; from overseas + 61 2 6247 3117
E-mail: atsbinfo@atsb.gov.au
Internet: www.atsb.gov.au

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Abstract

On 24 October 2007 at Darwin aerodrome, an Airbus A330-300, registered VH-QPE, made two unsuccessful attempts to start the right engine. Subsequent inspection of the engine revealed an uncontained failure of the starter turbine and secondary damage to the integrated drive generator.

The starter was returned to the manufacturer to conduct a failure investigation. The investigation revealed damage consistent with ‘crash engagement’ of the starter resulting in failure of the overrunning bearing. The blades were designed to separate from the turbine disc in this event, however, the starter failed to contain the cut-off blades as designed. The manufacturer proposed corrective actions to prevent further occurrences.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

The Australian Transport Safety Bureau (ATSB) is an operationally independent multi-modal bureau within the Australian Government Department of Infrastructure, Transport, Regional Development and Local Government. ATSB investigations are independent of regulatory, operator or other external organisations.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to fare-paying passenger operations.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and Regulations and, where applicable, relevant international agreements.

Purpose of safety investigations

The object of a safety investigation is to enhance safety. To reduce safety-related risk, ATSB investigations determine and communicate the safety factors related to the transport safety matter being investigated.

It is not the object of an investigation to determine blame or liability. However, an investigation report must include factual material of sufficient weight to support the analysis and findings. At all times the ATSB endeavours to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why, in a fair and unbiased manner.

Developing safety action

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. The ATSB prefers to encourage the relevant organisation(s) to proactively initiate safety action rather than release formal recommendations. However, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation, a recommendation may be issued either during or at the end of an investigation.

The ATSB has decided that when safety recommendations are issued, they will focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on the method of corrective action. As with equivalent overseas organisations, the ATSB has no power to implement its recommendations. It is a matter for the body to which an ATSB recommendation is directed (for example the relevant regulator in consultation with industry) to assess the costs and benefits of any particular means of addressing a safety issue.

About ATSB investigation reports: How investigation reports are organised and definitions of terms used in ATSB reports, such as safety factor, contributing safety factor and safety issue, are provided on the ATSB web site www.atsb.gov.au.

FACTUAL INFORMATION

Background

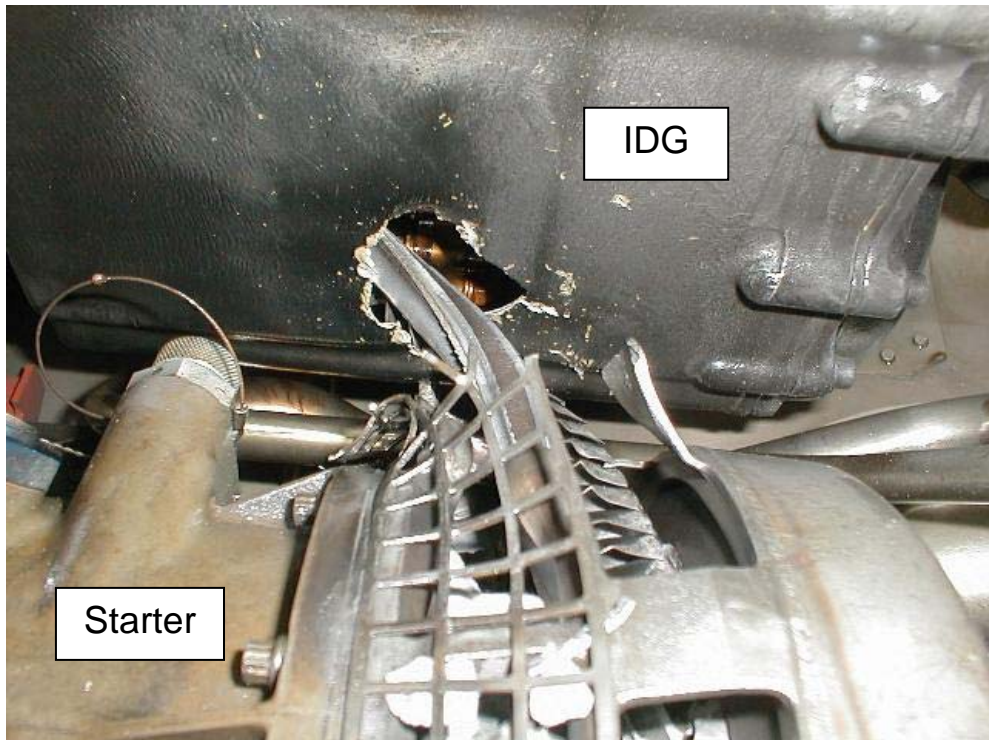
On 24 October 2007 at Darwin aerodrome, an Airbus A330-300, registered VH-QPE, made two unsuccessful attempts to start the right engine. A review of the quick access recorder (QAR) data indicated that the first automatic start attempt lasted 1 minute 10 seconds and resulted in an engine start fault and no N2 rotation¹.

The second attempt was a manual start lasting 6 minutes, at which time smoke and sparks were observed from under the engine cowls. Subsequent inspection of the engine revealed an uncontained failure of the starter turbine and secondary damage to the integrated drive generator (IDG) (Figure 1).

The aircraft was fitted with two General Electric CF6-80E1-A3 turbofan engines. The starter, part number 3505468-4, was reported to have been in service for 14,988 flight hours and 2,428 cycles.

The starter was returned to the manufacturer to conduct a failure investigation.

Figure 1. Uncontained starter failure and associated IDG damage



¹ N2 refers to the rotational speed of the high pressure compressor in a gas turbine engine.

Starter location

The starter, part number 3505468-4, was mounted in the CF6-80E1-A3 turbofan engine as shown in Figure 2. Immediately adjacent to the starter was the IDG and oil and fuel lines, shown in more detail in Figure 3. The accessory gearbox containing the starter was separated from the hot section of the turbine by a heat shield.

Figure 2: Starter installed

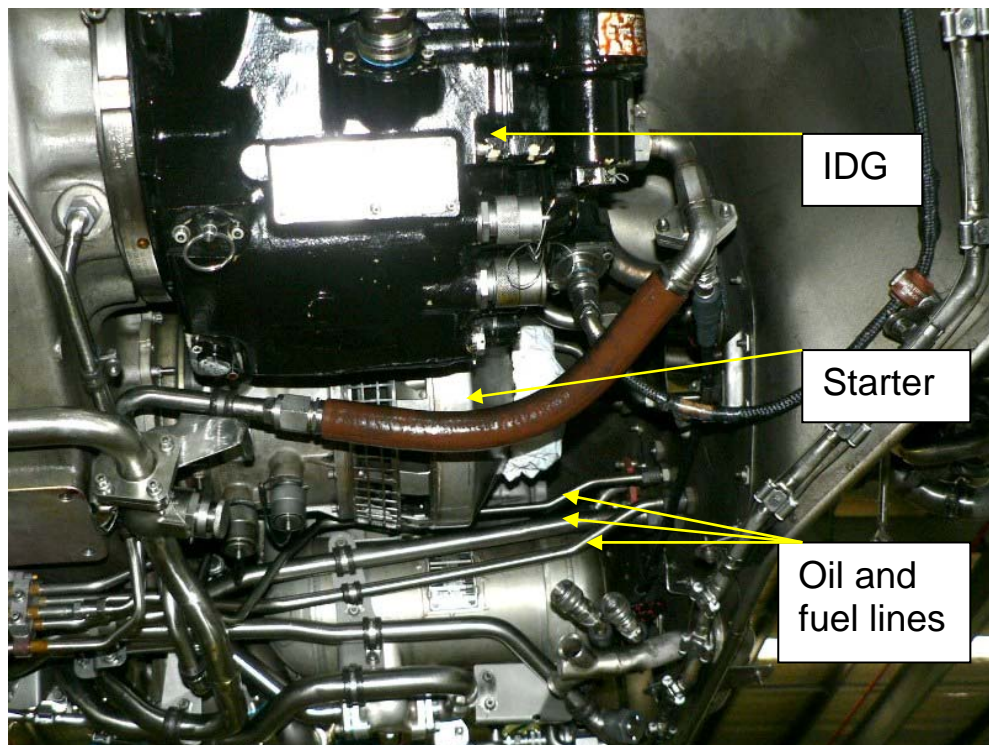


Figure 3: Starter and adjacent oil and fuel lines



Air turbine starters

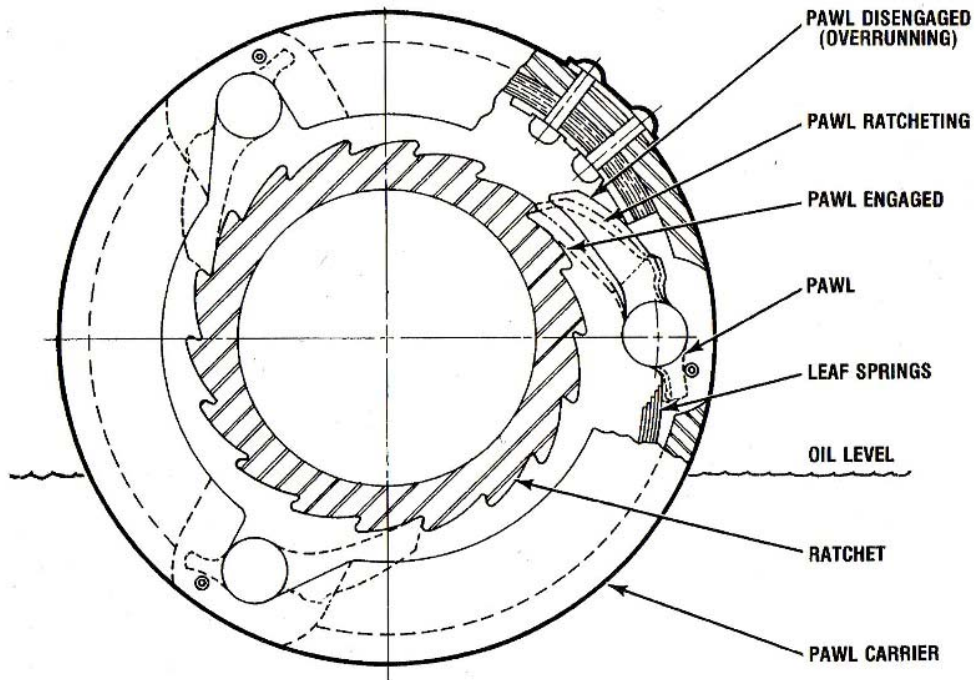
The propulsion starting system utilises pressurised air to drive an air turbine starter at high speed. The starter drives the engine high pressure rotor through a reduction gear and the engine accessory drive system. The air required to drive the starter comes from one of the following three sources:

- The aircraft APU
- Another aircraft engine
- A ground power unit

The air supply is controlled by a starter air valve (SAV), which is pneumatically operated and electrically controlled.

The high-speed, low-torque from the starter is converted to a lower-speed, high-torque via reduction gearing. The engagement mechanism for the drive shaft of the 3505468-4 starter consisted of a ratchet and pawl type clutch (Figure 4), such that at low engine speeds, the pawl springs force the pawls to engage with the ratchet on the drive shaft. When the engine speed exceeds that of the drive hub, the pawls act as fly weights and become completely withdrawn from the drive hub.

Figure 4. Example of a pawl clutch assembly



Manufacturer's investigation findings

The starter manufacturer's internal investigation report of the uncontained starter failure, found that the damage sustained by the starter components was consistent with a crash engagement. Crash engagements are described in the report as follows:

Crash engagements can occur when during a start cycle the pneumatic supply to the starter is temporarily interrupted (this could be caused by commanding other pneumatic devices "on" during a start cycle, or from pneumatic power supply irregularities). The interruption would allow the clutch to disengage. When the power is re-applied the starter will accelerate to free-run speed, while the clutch will always rotate with engine starter pad speed. As the engine decelerates the clutch will eventually try to re-engage, crashing into the high-speed ratchet of the free-running starter.

Crash engagements result in significant damage to the clutch and can also damage the overrunning bearing and lead to further starter damage. The likely failure scenario proposed by the manufacturer is described below and illustrated by Figure 5:

At some time the starter was subjected to a crash engagement. The impact may have forced skidding in the overrunning bearing as well as a large over turning moment. As more starts were being performed, and during each subsequent engine run, the overrunning bearing further deteriorated. The clutch shaft begins to wobble. The bearing eventually fails completely, allowing the output shaft to move further out of position. The pawls can now contact the ratchet, eventually wearing away most of the ratchet teeth. During a subsequent start attempt the pawls then fail to engage because the ratchet teeth have become too worn. The starter then goes to free-run speed. The turbine bearings fail, allowing the turbine to move axially into the starter. The cutter pins begin to cut off the turbine blades. The blades eventually separate from the turbine disc, hit only the edge of the containment ring, and exit from the starter, causing IDG damage. The starter no longer drives/assists the engine, and a no-start occurs.

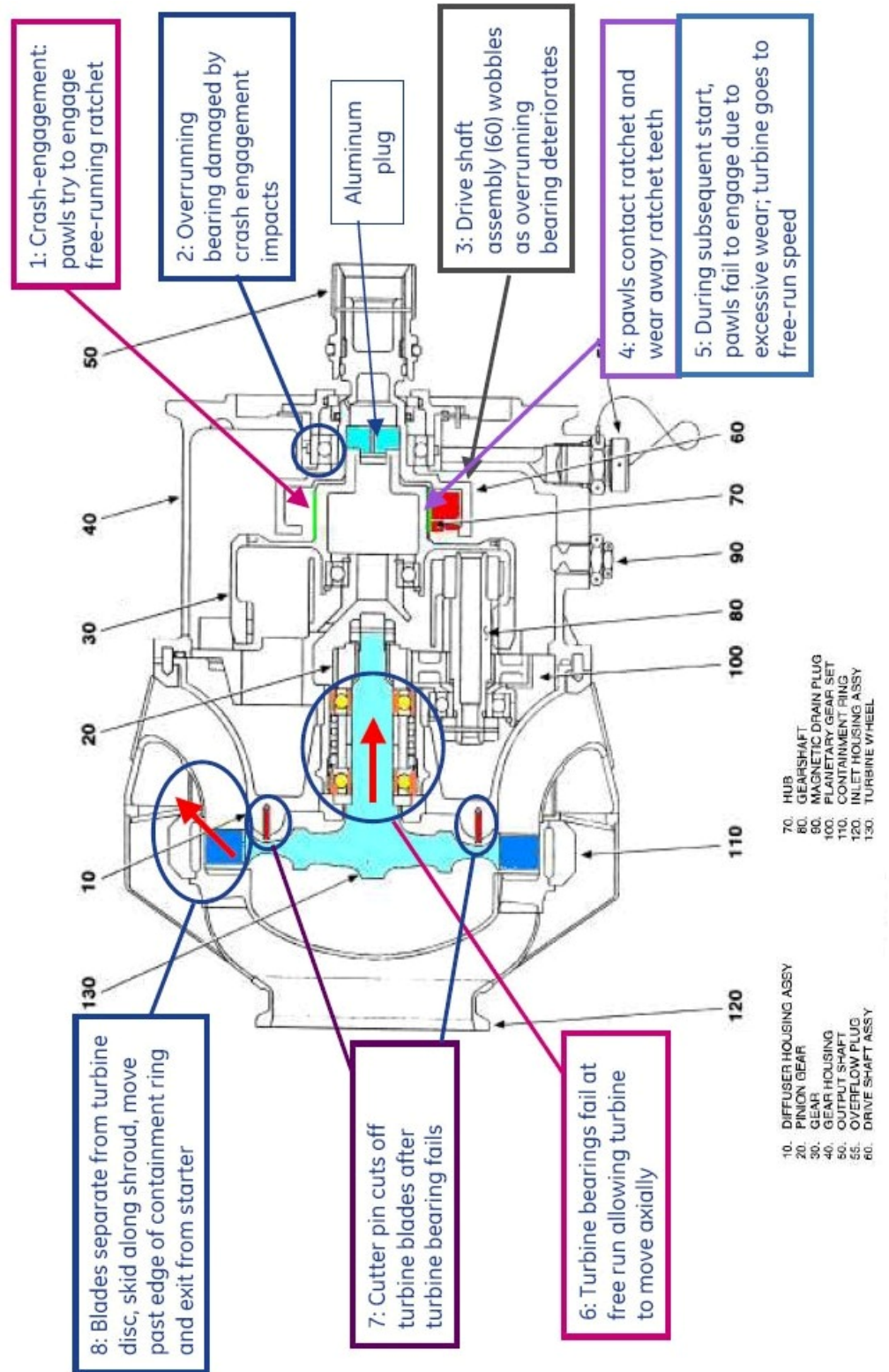
Starter failure history

Information on the CF6-80E1 engine history provided by the manufacturer indicated that at the time of writing, the CF6-80E1 had accumulated 1.28 million engine flight cycles since entering service in 1993 and that there were approximately 385 engines in the CF6-80E1 fleet.

There were a total of 3 starter turbine failures during this time period. Two were uncontained and one was contained. The two uncontained events occurred in 2003 and 2007; the 2007 event being the subject of this report. The contained event occurred in 2006.

One of the incidents involved was an Airbus A330-200, registered VH-EBA, that sustained an uncontained failure of a 3505468-4 starter in 2003, including secondary damage to adjacent oil lines and puncture of the heat shield.

Figure 5. Schematic of starter showing probable sequence of events



ANALYSIS

The failure scenario provided by the starter manufacturer was credible including that the precipitating event was a crash engagement occurring at some time during the life of the starter that resulted in the overrunning bearings being damaged. With continued normal operation cycles contributing to further bearing deterioration.

Although operation of the starter in this condition with no load for an extended period of time ultimately resulted in the starter failure, the starter was designed to separate the blades from the turbine disk and contain them in such an event. Damage to the surrounding components therefore occurred because the starter design failed to contain the separated turbine blades.

A previous uncontained starter failure had ruptured an oil line and therefore it was conceivable that an adjacent fuel line could also be ruptured. However, the risk associated with such an event was considered to be minor due to the fact that:

- Uncontained starter failures are uncommon events.
- Air turbine starters would almost never be used in flight. Therefore, any consequences arising from an uncontained failure would only be likely to occur while the aircraft was on the ground.
- The low vapour pressure and high flashpoint of kerosene-type fuels make them difficult to ignite in the event of a fuel-line rupture.

Notwithstanding the above, the engine manufacturer has proposed corrective actions involving design changes to the starter, to further reduce the likelihood of uncontained starter events.

FINDINGS

From the evidence available, the following findings are made with respect to the uncontained starter failure on the Airbus Industrie A330-300 registered VH-QPE and should not be read as apportioning blame or liability to any particular organisation or individual.

Contributing safety factors

- The susceptibility of the starter to fail was increased as a result of a crash engagement at some time during the life of the starter.
- Extended operation of the starter under no-load contributed to an over-speed condition.
- The starter design was not adequate to contain the separated blades from the turbine disc in the event of starter failure. *[Safety Issue]*

SAFETY ACTIONS

The safety issues identified during this investigation are listed in the Findings and Safety Action sections of this report. The Australian Transport Safety Bureau (ATSB) expects that all safety issues identified by the investigation should be addressed by the relevant organisation(s). In addressing those issues, the ATSB prefers to encourage relevant organisation(s) to proactively initiate safety action, rather than to issue formal safety recommendations or safety advisory notices.

All of the responsible organisations for the safety issues identified during this investigation were given a draft report and invited to provide submissions. As part of that process, each organisation was asked to communicate what safety actions, if any, they had carried out or were planning to carry out in relation to each safety issue relevant to their organisation.

Engine manufacturer

Starter design

Safety issue

The starter design was not adequate to contain the cut-off blades from the turbine disk in the event of starter failure.

Action taken by engine manufacturer

As a result of this incident, the engine manufacturer undertook corrective actions in the form of a starter containment improvement plan, which proposed design improvements to the starter (Figure 6) and allowed rework of existing starters to prevent further uncontained failures.

- The cutter ring would be redesigned to improve cutting efficiency and minimise axial wheel travel.
- The inlet assembly would incorporate a larger, deeper ring pocket to better capture turbine blades after axial wheel travel.
- The stator shroud would be made thinner to allow easier penetration by blades into the containment ring pocket.

The corrective actions were still under development at the time of writing this report.

Figure 6. Starter inlet assembly

