SERIOUS INCIDENT

Aircraft Type and Registration:	BN2A MK.III-2 Trislander, G-BDTO
No & Type of Engines:	3 Lycoming O-540-E4C5 piston engines
Year of Manufacture:	1976
Date & Time (UTC):	27 March 2012 at 0724 hrs
Location:	27 nm north-east of Alderney, Channel Islands
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 1 Passengers - 7
Injuries:	Crew - None Passengers - None
Nature of Damage:	Uncontained engine failure with associated cowling damage
Commander's Licence:	Commercial Pilot's Licence
Commander's Age:	56 years
Commander's Flying Experience:	6,150 hours (of which 3,116 were on type) Last 90 days - 27 hours Last 28 days - 27 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot and additional AAIB enquiries

Synopsis

The aircraft was on a scheduled flight from Alderney Airport, Channel Islands to Southampton International Airport. Shortly after levelling in the cruise, the pilot heard a "very loud bang" and the aircraft experienced severe vibration, which the pilot subsequently identified as a failure of the No 2 tail-mounted engine. The propeller of the inoperative engine could not initially be feathered, and the pilot was unable to maintain altitude, so he declared an emergency. The propeller blades eventually moved to the feather position and the pilot performed an uneventful landing back at Alderney Airport. The No 2 cylinder on the No 2 engine was subsequently found to have released from the crankcase. Two Safety Recommendations have been made.

History of the flight

The aircraft was on a scheduled flight from Alderney Airport, Channel Islands to Southampton International Airport. Shortly after levelling at its cruising level of FL50, 27 nm north-east of Alderney, the pilot heard a "very loud bang" and the aircraft experienced severe vibration. Initially there were no adverse indications on the engine instruments. The pilot subsequently noticed that the No 2 engine oil pressure had started to decrease slowly. He checked the No 2 (mid) engine in the rear-view mirror, and saw that the engine cowling was open on the left side. There were no other abnormal external indications or any indication of the severity of the damage. The pilot selected full power on the No 1 and No 3 engines and advised ATC of his intention to return to Alderney.

While carrying out the engine failure checklist, the pilot was unable to operate the No 2 propeller lever through its feather gate, which left the No 2 propeller unfeathered and 'windmilling'. The aircraft was unable to maintain altitude, despite having full power on the remaining two engines, so he declared an emergency to ATC. The pilot reported the aircraft's rate of descent at this time as being about 200ft/min. At some point during the descent, the propeller blades of the No 2 engine moved to the feather position and the propeller stopped rotating. The pilot was subsequently able to control the rate of descent.

During the return to Alderney, the pilot was cleared by ATC to fly a near continuous descent profile (Figure 1) and thus did not note the altitude the aircraft had drifted down to with one engine inoperative (OEI). The pilot made an uneventful visual approach and landing to Runway 08 at Alderney.

Regulatory Performance Requirements

Commercial transport aircraft performance is categorised separately for aircraft certification purposes and for operational requirements. Compliance with the certification standards must be demonstrated by the manufacturer in order to certify the aircraft type design. Compliance with operational requirements must be demonstrated by the aircraft operators in order to operate the aircraft, although to achieve this they refer to performance data for the aircraft published by the manufacturer.

The Trislander was granted a type certificate by the CAA in 1971, having demonstrated compliance with British Civil Airworthiness Requirements (BCAR), Section K, Issue 3. The aircraft was certified as a performance group C aircraft, with the associated requirements relating to enroute OEI performance stating:

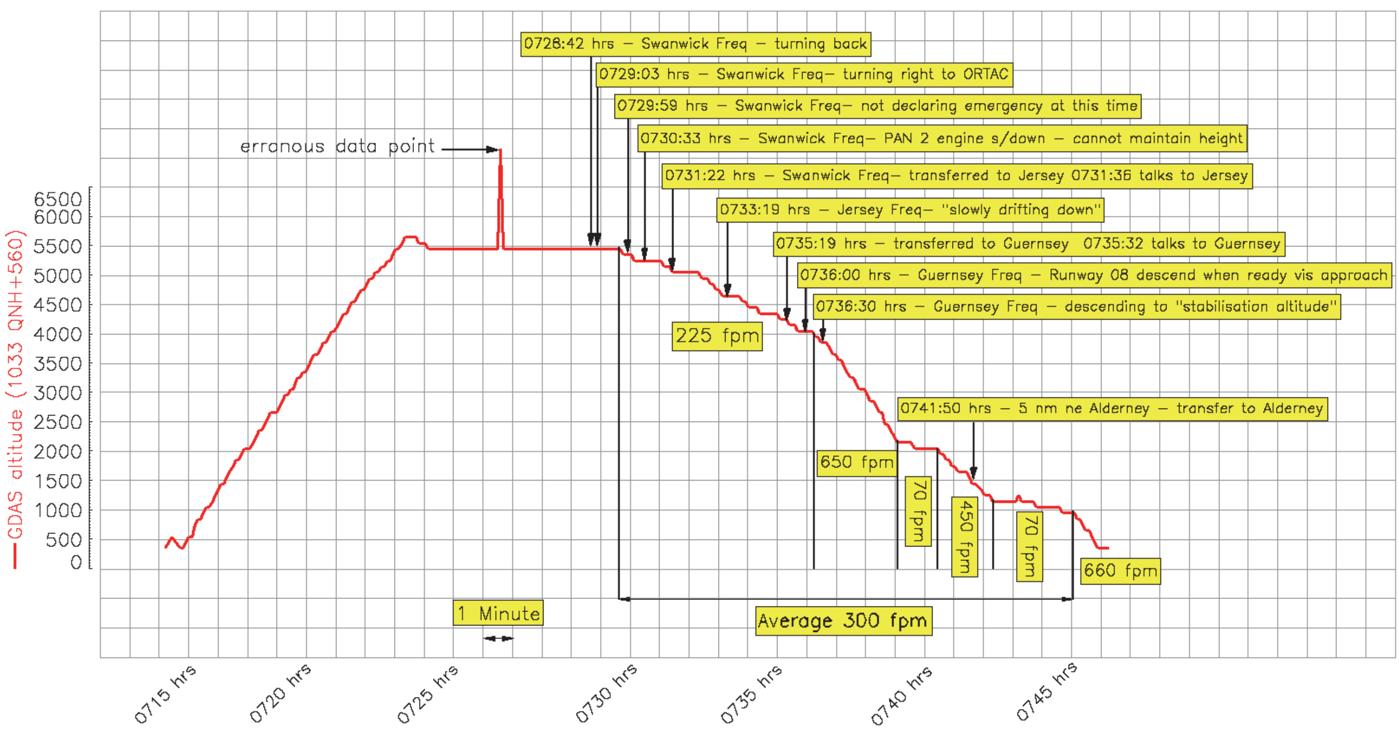

Figure 1

Radar altitude profile of the incident flight

'Sub-section K2

3.3 One-Engine-Inoperative Net Data.

The net gradient of climb with the Critical Engine inoperative[1] shall be determined and scheduled, the condition of the inoperative engine being consistent with correct action having been taken to deal with the occurrence of fire in the zones related to that engine, and shall be the gross gradient of climb with the Critical Engine inoperative diminished by a gradient of 1 %.'

The relevant operational aircraft performance requirements are in EU Regulation 965/2012. The Trislander is classified as performance class C under these regulations, as the aircraft has reciprocating engines and a maximum configuration of more than nine passenger seats. These state:

'CAT.POL.A.415 En-route — OEI

(a) In the meteorological conditions expected for the flight, in the event of any one engine becoming inoperative at any point on its route or on any planned diversion there from and with the other engine(s) operating within the maximum continuous power conditions specified, the aeroplane shall be capable of continuing the flight from the cruising altitude to an aerodrome where a landing can be made in accordance with CAT.POL.A.430 or CAT.POL.A.435, as appropriate. The aeroplane shall clear obstacles within 9,3 km (5 nm) either side of the intended track by a vertical interval of at least:

(1) 1 000 ft, when the rate of climb is zero or greater; or

(2) 2 000 ft, when the rate of climb is less than zero.

(b) The flight path shall have a positive slope at an altitude of 450 m (1 500 ft) above the aerodrome where the landing is assumed to be made after the failure of one engine.

(c) The available rate of climb of the aeroplane shall be taken to be 150 ft per minute less than the gross rate of climb specified.

(d) The width margins of (a) shall be increased to 18.5 km (10 NM) if the navigational accuracy does not meet at least RNP5.

(e) Fuel jettisoning is permitted to an extent consistent with reaching the aerodrome with the required fuel reserves, if a safe procedure is used.'

Actual vs. calculated aircraft OEI performance

The aircraft manufacturer calculated that, based on gross performance and an assumption of 98% engine power, for the conditions on the day of the incident a Trislander at a Take Off Weight (TOW) of 3,693 kg, with OEI, an undamaged cowl and a feathered propeller, should have been able to maintain an altitude of approximately 5,500 ft amsl (FL50).

The manufacturer provided an estimate that the effect on rate of climb of an unfeathered propeller would be a reduction of 140 ft/min, but was not able to confirm at what altitude a zero climb rate would be achieved in this configuration. They were also unable to assess the contribution of the damaged engine cowling, other than to suggest it may be significant.

The manufacturer advised this had not been assessed during certification as there was no requirement

Footnote

[1] The critical engine on the Trislander is the No 1 engine.

to account for an unfeathered propeller within the regulations relating to en-route performance.

The operator's Operations Manual states that a Trislander at Maximum Take Off Mass (MTOM) of 4,546 kg, with OEI and the propeller feathered, would drift down to 3,050 ft amsl in a standard atmosphere. However, these figures are based on net performance. For an assumed 1% decrement from gross to net performance, the manufacturer advised that a zero net climb gradient at 3,000 ft would equate to 5,200 ft altitude using gross performance figures.

The manufacturer's flight manual does not contain performance charts, or guidance to pilots in the event of OEI with an unfeathered propeller. Analysis provided by the CAA, derived from comparison of published OEI takeoff data for the Trislander fitted with and without an autofeather device[2] indicated that the aircraft should have been capable of maintaining height during the incident with an unfeathered propeller.

G-BDTO was last flight tested by the CAA in October 2004. At 4,100 kg, with the No 1 (critical) engine feathered, the aircraft achieved a rate of climb of 212 ft/min on one heading. On the reciprocal heading, at 4,056 kg, the aircraft achieved a rate of climb of 248 ft/min.

Propeller feathering mechanism

In normal operation, the pilot sets a propeller rpm using the propeller control lever. A constant speed governor then maintains that rpm by continuously adjusting the pitch of the propeller blades. An oil pump supplies pressurised oil to a piston to act against a feathering spring; there is also an air charge to assist the spring. Flyweights within the governor control the amount of oil in the piston by acting on a pilot valve. This, in turn, changes the balance of force against the feathering spring, causing the blade pitch to change. An optional modification, embodied on G-BDTO, meant the blades were also fitted with counterweights which biased them to move towards the feather position. A Teleflex cable connects the propeller control lever to the governor. The blades are manually selected to the feather position (normal and emergency), by the pilot moving the propeller control levers rearward through a feather gate on the console. The cable then engages a lift rod, which opens the pilot valve on the cylinder, releasing oil until the propeller blades feather under the action of the spring and, on G-BDTO, the counterweights.

Previous events

An event which occurred under similar circumstances was investigated by the AAIB in 1998 (reference EW/G98/06/40 published in AAIB Bulletin 11/98 refers). The aircraft, a BN2A Mk III-1 Trislander, registration G-AZLJ, suffered an engine failure whilst in the cruise at FL60. The pilot was unable to feather the propeller on the failed engine and despite selecting full power on the remaining engines, the aircraft continued to descend at a rate of 100 to 200 feet per minute. The pilot made a successful emergency landing at Blackpool Airport.

A sample review of the CAA's Mandatory Occurrence Reporting (MOR) database for Trislander and Islander aircraft, fitted with a similar powerplant configuration, identified six other previous events where the propeller failed to feather. This included a fatal accident involving a military operated Islander in 1976, where the pilot was forced to ditch the aircraft after being unable to maintain altitude with a failed engine and unfeathered propeller.

Footnote

2 The mark III-3 variant of the Trislander was fitted with an autofeather device to comply with FAA Part 135, Appendix A requirements relating to OEI performance at takeoff.

Some of these MOR events also identified issues relating to the Teleflex control cable. This was not a comprehensive assessment of all previous events in the history of the aircraft type but a number of these events resulted in safety action, with Airworthiness Directives, being taken by the manufacturer at the time.

The aircraft manufacturer was requested to provide supporting data to allow an assessment of the hazard category and probability, in the event of an engine becoming inoperative, of the propeller blades not moving to the feather position within the 11 seconds after selection by the pilot, specified by the Aircraft Maintenance Manual. They responded that no detailed reliability data exists, but offered an estimated reliability figure of 1.2×10^{-7} failures per flight hour, using assumed flying hours for the piston Islander and Trislander aircraft combined.

Engine description

The O-540-E4C5 is a six-cylinder, horizontally-opposed, direct drive engine. The cylinders are numbered from front to rear, odd numbers on the right (looking forward), and even numbers on the left. The cylinders are of conventional air-cooled construction with the two major parts, head and barrel, screwed together. The piston connecting rods are made from alloy steel forgings. The crankcase assembly consists of two reinforced aluminium alloy castings, fastened together by means of studs and nuts. Double-ended studs run through the crankcase and form two of the eight mounting studs for each of the opposing cylinders. The remaining six studs per cylinder are screwed into fixings in the crankcase using a coarse thread. The cylinders are retained in place on the studs by 'hold down' nuts screwed onto a fine thread. The nuts are torque loaded but have no secondary retaining feature.

The manufacturer recommends an overhaul life of 2,000 hours for this engine type. However, based on a life extension approval granted by the CAA, the operator involved in the incident has increased this life for the engines in their fleet to 3,000 hours. The No 2 engine that failed during the incident had operated 996 hours since overhaul and had a time since new of 11,992 hrs.

Initial inspection

On landing, the operator's maintenance provider inspected the aircraft. They reported that a large section of the engine cowling was missing on the left side of the engine (Figure 2). The remaining cowling and aircraft empennage were heavily stained with oil released from the engine during the failure.

Following removal of the engine from the aircraft, it was clear that the No. 2 cylinder had released from

Figure 2

Engine cowl damage and oil staining

the crankcase after failure of the mounting studs. This had resulted in damage to the surrounding crankcase from the flailing connecting rod. The piston head and push rods were missing, as was the inlet pipe from the manifold and the section of exhaust pipe from the cylinder head to the exhaust manifold. The starter motor had been dislodged from the engine, but remained attached by its power lead and the guide tube for the propeller-feathering unit Teleflex control cable was damaged (Figure 3).

Of the eight studs that secured the cylinder to the crankcase prior to failure, four had been lost with the released sections of the crankcase and cylinder. Two of the 'short' studs remained, as did the two 'through' studs, which ran through the crankcase to the opposing cylinder. All four of these studs were removed and sent for metallurgical investigation.

Further occurrence

Two months after the initial incident, a routine maintenance check of the No. 3 engine fitted to another aircraft (G-RLON) from the same operator's fleet, identified another stud failure (Figure 4). This engine had operated 9,041 hours since new and 460 hours since its last overhaul. Only a single stud had failed and the released section of the stud and 'hold down' nut were found trapped in the baffle between the No 2 and No 4 cylinder barrels. The released section of the stud was sent for independent metallurgical assessment, while

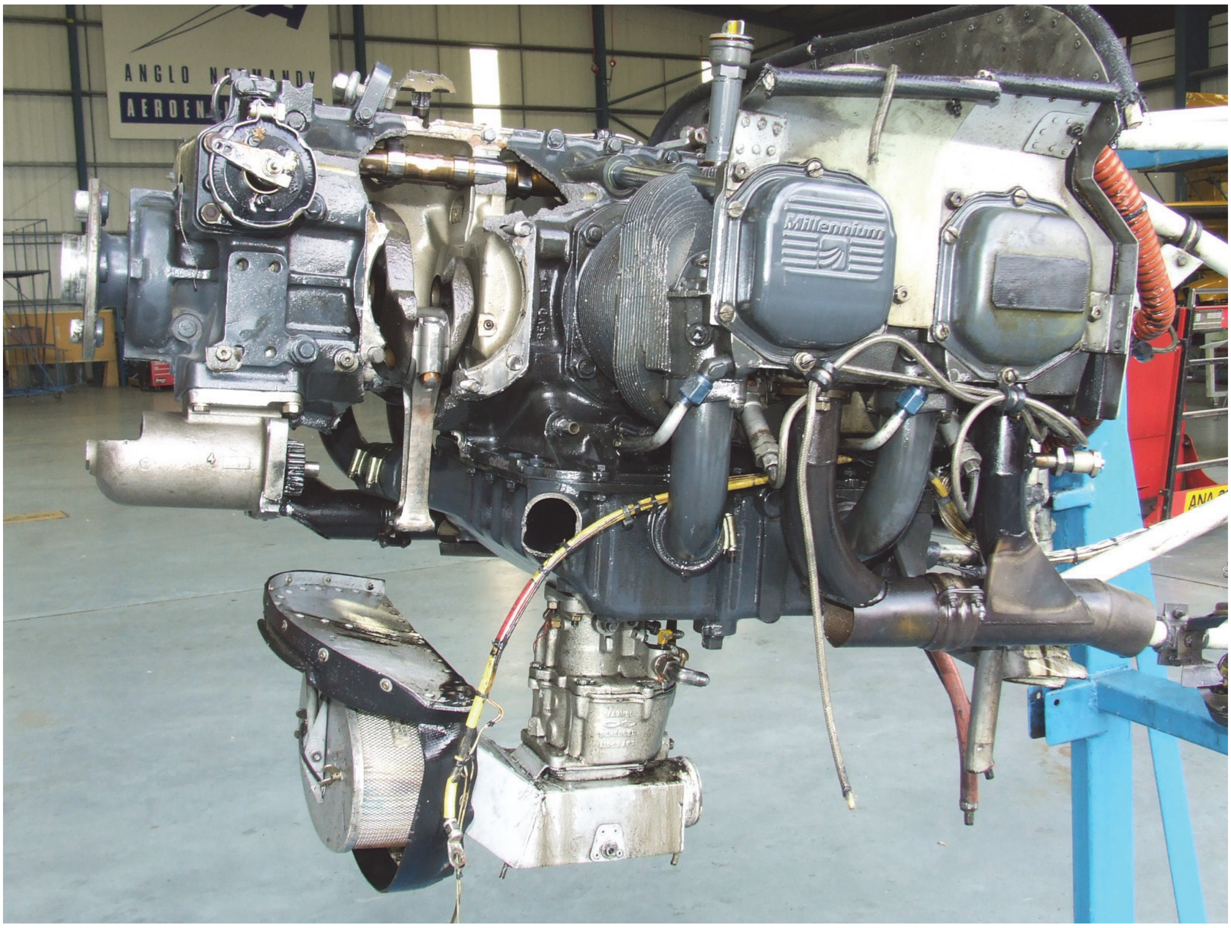

Figure 3

Missing cylinder and associated damage

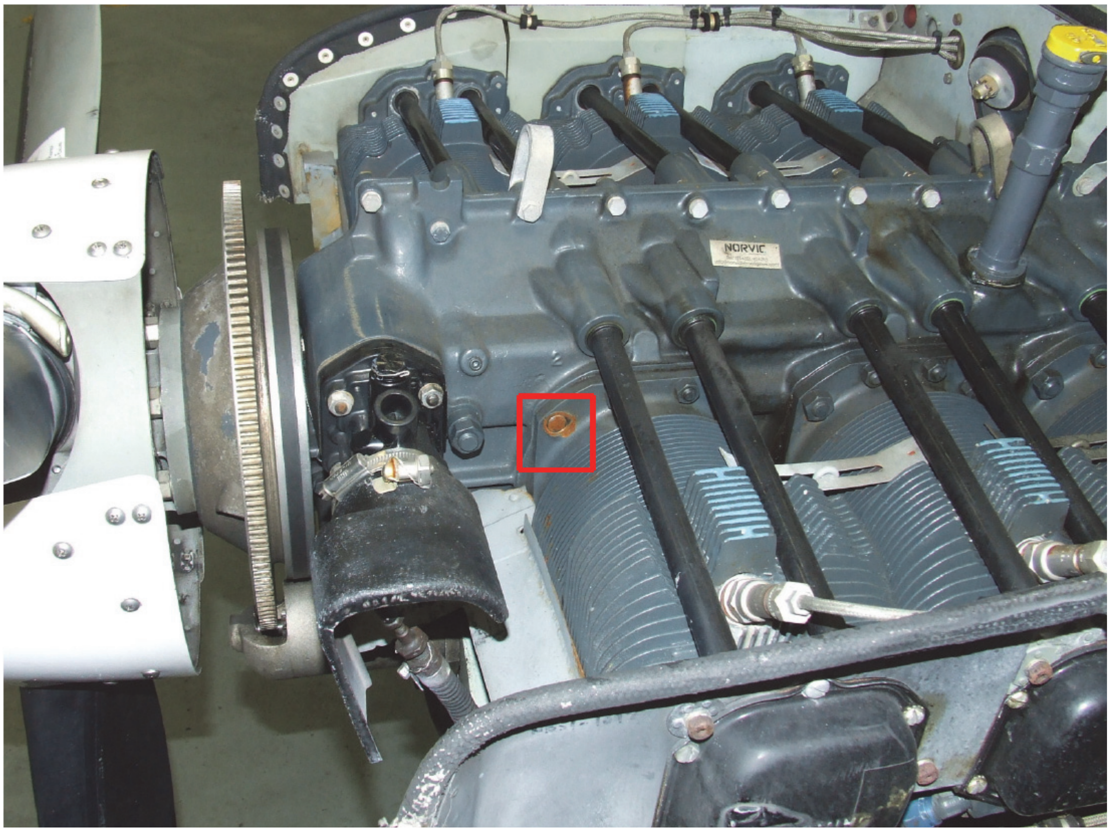

Figure 4

Second mounting stud failure (G-RLON)

the remaining section of the stud was removed from the crankcase and released to the manufacturer for them to carry out their own investigation.

Mounting stud failure investigation

Independent metallurgical analysis using optical and Scanning Electron Microscope (SEM) techniques was conducted on the four failed studs that were recovered from G-BDTO's engine following the incident. The studs were annotated A to D for ease of reference (Figure 5).

The laboratory analysis determined that stud C had suffered a fatigue fracture, which initiated from a single point, coincident with corrosion pitting in one of its thread roots. The stress concentration caused by the pitting had been superimposed onto that provided by the thread root itself. As the pitting grew in depth, the combined stress concentration had exceeded the threshold value for fatigue crack initiation. A primary high cycle fatigue crack initiating from the pitting then propagated across the diameter of the stud, with the continued loading from operation of the engine. The primary crack joined with two secondary fatigue cracks, also initiating from corrosion pits. Eventually, a point was reached when the remaining uncracked ligament of stud C became overloaded and failed. Although the exact time to failure could not be determined from the fracture surface features, the metallurgist advised that in his opinion it was possible for the corrosion pit to develop and the crack to have propagated to failure within the time between engine overhaul of 3,000 hours.

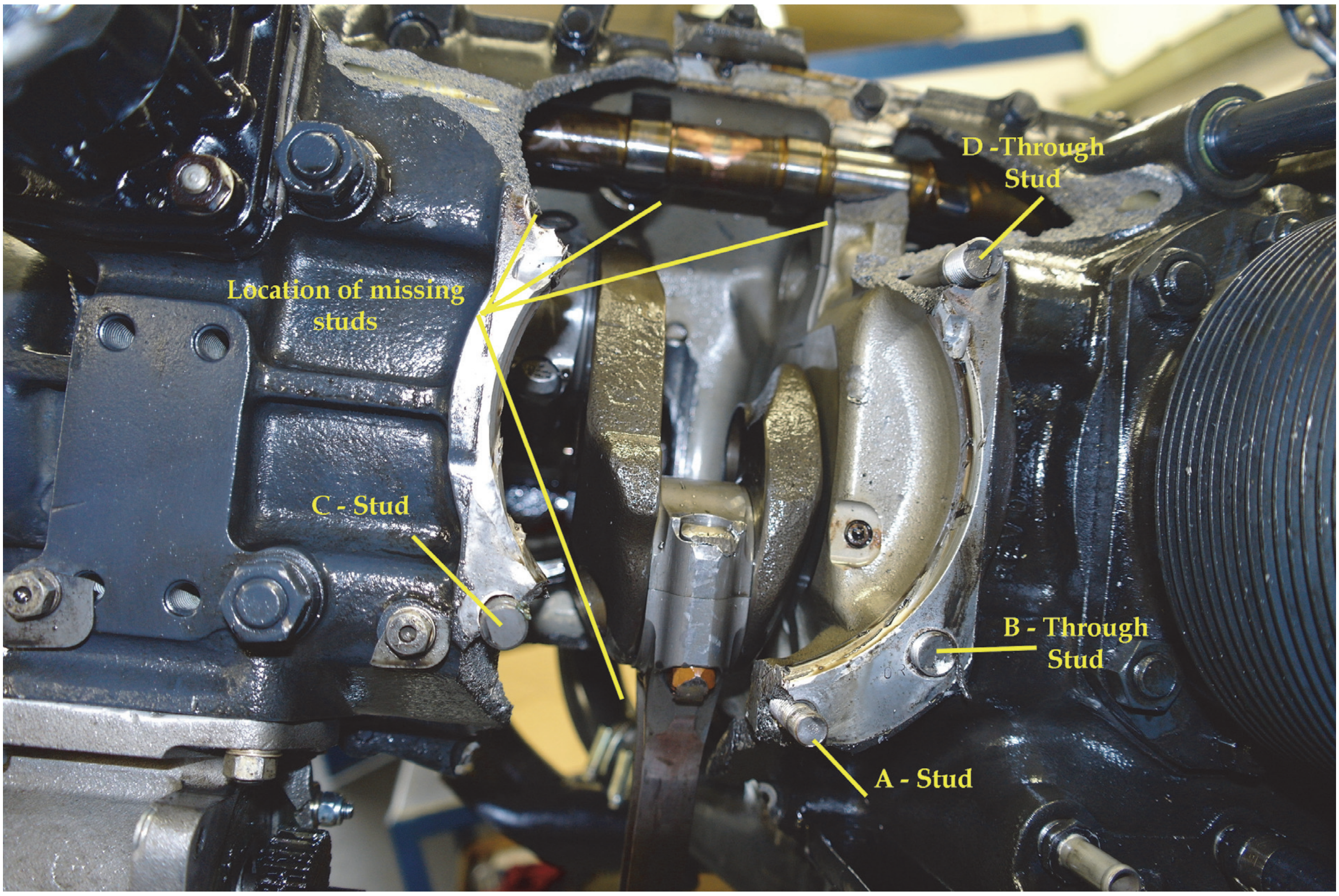

Figure 5
Location of failed studs

Laboratory analysis of stud C confirmed evidence of remains of a protective coating of cadmium on the coarse threaded section of the stud. However, no evidence was present of cadmium coating where the corrosion pit developed, on the fine threaded section. The stud material also tested outside the manufacturer's specification for hardness.

In contrast to stud C, the fatigue fractures of studs A, B and D had all initiated from multiple sites in thread roots ehich were not associated with pre-existing material defects. These were typical of failure of threaded fasteners from abnormal cyclic loading. In this case, the most likely cause of the abnormal loading was following the separation of stud C. However, it was not possible to determine whether the failures of A, B and D had developed concurrently or consecutively to each other. The loss of several of the cylinder mounting studs during the engine failure further restricted the analysis, as no conclusions could be drawn on how they may have contributed to the failure sequence of the retained studs.

Analysis of the failed stud from the engine fitted to G-RLON confirmed that it had also failed in high cycle fatigue initiating from a corrosion pit in the thread root. Again no cadmium coating was found on the section of the stud inspected, although traces of cadmium coating were present on the 'hold down' nut. The inspection techniques could not confirm whether the lack of cadmium coating had been due to corrosion or mechanical action over the life of the stud, or whether the coating on the fine thread had been omitted at manufacture.

Engine manufacturer's response

The engine manufacturer confirmed that the specification for the studs required them to be entirely covered with a cadmium coating during manufacture. They advised that they have not identified any occasions when studs have been delivered to them with the cadmium coating missing. They commented that: "Even though the cylinder deck hold down studs/ bolts are not listed in the Service Bulletin No. 240, 'Replacement of Parts at Normal Overhaul', it is the customer's responsibility to inspect and replace or recondition the parts if any abnormalities were found during normal maintenance or overhaul cycle." They also advised that:"According to the Lycoming Overhaul Manual, Sections 3-22 and 3-33, any studs which are bent, broken, damaged, loose, rusted or pitted, must be replaced."

The engine manufacturer explained that the cadmium coating was in place on the studs as a protective layer to prevent corrosion of the base material, by sacrificially corroding in its place. They advised that it could also be lost due to the chemical cleaning processes carried out on the engine at overhaul.

They confirmed that no specific inspection requirement to assess the condition of the cadmium coating on the studs existed in the overhaul manual and there was no life limit published for the studs. Nor was there a rejection criterion for studs, if a loss of cadmium coating was identified, or a repair scheme for the replacement of the coating. The manufacturer also advised that there was no guidance material issued to operators or overhaul agencies to highlight the presence of the cadmium coating or the implications of operating the engine without the coating present. This was confirmed by the overhaul agency who last overhauled the engine.

The manufacturer also challenged the findings of the independent metallurgical assessment. Their laboratory analysis of the section of failed stud from G-RLON identified overtorqueing of the stud as the cause of the fatigue crack.

Analysis

Engine failure

Review of stud C from G-BDTO's fracture surface confirmed the primary fatigue crack had initiated directly from a corrosion pit before it joined with the two secondary cracks; although, the chronology of each crack initiation was not significant, given that all three cracks were initiated by the same mechanism.

Therefore, the investigation determined that the cause of the loss of the No 2 cylinder during the incident to G-BDTO was the presence of corrosion pitting in the thread root of a cylinder mounting stud. This initiated the growth of fatigue cracks, under the cyclic load of routine operation of the engine, until the stud failed in overload. The same failure mechanism was evident on the stud found on G-RLON.

The engine manufacturer specified a protective cadmium coating on the stud, as it would sacrificially corrode in place of the bulk stud material, in order to prevent fatigue crack growth from corrosion pitting of the kind identified by the investigation. There is a finite period that such a coating provides protection, before it corrodes away and the base material of the stud is exposed. This period is further reduced by the mechanical wear on the studs experienced in service and potentially by aggressive chemical cleaning processes used during overhaul. Despite this, the manufacturer's overhaul manual did not identify the presence of the coating or highlight its purpose, nor did it contain a life limit for the studs or an inspection requirement of the coating condition to initiate rejection or repair of the studs, once the cadmium coating was lost. Whilst the overhaul manual does require corroded studs to be rejected, it is possible for the corrosion and crack propagation, to failure, to occur within the period between engine overhaul inspections. Given the consequences of a stud failure, as demonstrated by this incident, the following Safety Recommendation is made:

Safety Recommendation 2013-001

It is recommended that Lycoming introduce additional maintenance requirements to ensure that the cadmium coating on the cylinder mounting studs, fitted to O-540-E4C5 engines, is not permitted to degrade to a level where corrosion of the base stud material can result in failure of the stud.

It is unlikely that the engines were supplied by the manufacturer with studs that had not been properly cadmium coated as, given the age of both engines involved, without any protection the studs would likely have failed in service much earlier. The stud that initiated the in-flight failure of the engine on G-BDTO (stud C) was found to be outside the manufacturer's specification for material hardness. Again, it was not clear whether this was due to an issue with the manufacturer's supply of studs when the engine was manufactured or whether the stud was an unapproved part that had subsequently been fitted at overhaul. The overhaul agency who last overhauled the engine confirmed that they had no record of the studs having been changed during the life of the engine. As the failure of the stud was initiated by corrosion, the anomaly in the material hardness is not considered to have contributed to the cause of the engine failure. Had stud C been an unapproved replacement part, it is possible that the cadmium coating had never been present on the fine cylinder mounting thread. However, as remnants of the coating were identified on the coarse thread, this is considered unlikely. Given that the same loss of cadmium coating was observed on the failed stud from G-RLON, which did meet the manufacturer's specification and therefore was likely to have been an original manufacturer supplied part, the anomaly identified on the stud from G-BDTO does not affect the concern addressed by the recommendation.

Propeller failure to feather

The operator identified that the propeller had most likely initially failed to feather due to damage to the Teleflex cable guide conduit, preventing the control cable within it from moving freely when the pilot attempted to move the No 2 propeller control lever through the feather gate on the console. They considered the damage may have been caused by the release of the starter motor, which distorted the guide tube. The propeller did eventually feather some time after the pilot shut down the engine. When oil was lost from the engine through the hole in the crankcase, it is likely that there was an associated loss of oil pressure in the blade pitch control piston, allowing the feathering spring and counterweights to move the blades to the feather position.

Performance

The location of the aircraft at the time of the engine failure and the nature of the terrain below the aircraft's return route, meant that Minimum Safe Altitude (MSA) considerations did not present a significant risk to the aircraft and it had adequate range to reach the diversion airport safely. However, the pilot was still sufficiently concerned by the aircraft's performance to declare an emergency. If this had occurred in a remote area with less benign terrain profiles, or had the propeller not eventually feathered, this event may have presented a greater risk to the safety of the aircraft.

During the incident, the aircraft's actual descent rate from FL50 was just over 200 ft/min. Given the manufacturer's assessment that OEI with an unfeathered propeller at this altitude would give a descent rate of 140 ft/min, it would suggest the contribution of the damaged cowl was significantly less in comparison. However, no empirical evidence was available to determine an accurate performance penalty for these factors, so it was not possible to assess if obstacle clearance according to EU 965/2012 would have been maintained.

The assessment carried out by the CAA, based on documented performance data for the aircraft, indicated that the aircraft's performance should have been acceptable even with an unfeathered propeller. An increase in drag from the damaged engine cowl may have contributed to some extent, but given the lack of available data from the manufacturer it was not possible to understand fully the reasons for the difference between the CAA's theoretical assessment of performance and the actual performance of G-BDTO during this incident.

Whilst the OEI performance of the aircraft was affected by the failure of the propeller blades to feather, it is not clear whether the failure to feather can be considered as a completely separate failure to that of the engine. Although a more comprehensive assessment of the history of failures of this nature on the aircraft type is required, the MOR data reviewed shows this was not the first occurrence of a failure of the propeller to feather following an engine failure. There is also evidence that a similar occurrence resulted in a fatal accident, and that causal factors were the failure of the propeller to feather and inability of the aircraft to maintain altitude. The manufacturer stated that the assumed failure rate of a propeller not moving into feather after an engine failure is 1.2×10^{-7}. They quoted that they have no detailed reliability data. Therefore, they would not have been in a position to provide an evidence-based assessment of the different powerplant system failure modes or their probability of occurrence, in order to assess fully the safety implications of this and previous events.

Historical evidence and the commonality of the design suggest this is relevant to both the Islander and the Trislander aircraft. Given the continued worldwide operation of both versions of the aircraft in a public transport role, the following Safety Recommendation is therefore made:

Safety Recommendation 2013-002

It is recommended that the European Aviation Safety Agency, in collaboration with the UK Civil Aviation Authority, conduct a risk-based assessment of the Britten-Norman BN2 MKIII Series Trislander and BN2 Series Islander aircraft, with respect to one engine inoperative performance and the hazard and probability of an associated failure to feather of the affected engine's propeller.

Safety actions

Following the identification of the failed stud from G-RLON, the operator carried out a fleet-wide inspection of all their engines, checking the visual condition of the cylinder 'hold down' nuts and their torque load. No anomalies were found. They have subsequently introduced a replacement programme for the cylinder mounting studs fitted to their engines, prioritising engines in the fleet with the highest time since new.

The CAA have stated that they will add the identified aspects of this investigation to their oversight programme for the continued airworthiness of the type.