AIR ACCIDENTS INVESTIGATION
INSTITUTE
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Ref. No: CZ-15-110

FINAL REPORT

Investigation on the serious incident to Shorts SC7 Skyvan aircraft, OE – FDN on 8 April 2015

Prague
December 2017

GLOSSARY OF ABBREVIATIONS USED IN THIS REPORT

AC	Altocumulus
AMSL	Above mean sea level
AS	Altostratus
ATC	Air Traffic Control
BASE	Cloud base
BKN	Broken
CPL(A)	Commercial pilot licence
ČHMÚ	Czech Hydrometeorological Institute
CU	Cumulus
E	East
ETSA	German Air Force Base Landsberg
FAA	Federal Aviation Administration
FH	Flight Hour
FI (A)	Flight Instructor
FIR	Flight Information Region
FL	Flight Level
LKKT	Public international aerodrome Klatovy
N	Nord
NIL	None
OVC	Overcast
PF	Pilot Flying
PNF	Pilot Not Flying
p/n	Part number
SC	Stratocumulus
SCT	Scattered
s/n	Serial number
ST	Stratus
STC	Supplemental Type Certificate
SW	South-west
TC	Type Certificate
TEC	Total Equivalent Cycles
TOP	Cloud top
UTC	Co-ordinated Universal Time
ÚCL	Civil Aviation Authority
ÚZPLN	Air Accidents Investigation Institute
VMC	Visual Meteorological Conditions

°C	Celsius
ft	Feet
g	Acceleration due to Earth's gravity
h	Hour(s)
hPa	Hectopascal
KIAS	Knots indicated airspeed
km	Kilometre(s)
kt	Knot(s) (1,852 km h^{-1})
lb	Pound(s)
m	Metre(s)
min	Minutes
mm	Milimetre(s)
MHz	Megahertz
NM	Nautical miles
RPM	Revolutions per minute
s	Second(s)

A) Introduction

Operator:	Pink Aviations Services Luftverkehrsunternehmen GmbH&CoKG, Austria
Aircraft manufacturer and type:	Short Brothers, Ireland, SC7 Skyvan
Registration mark:	OE – FDN
Location of incident:	approx. 15 NM SW of LKKT
Date and time:	8 April 2015, at 13:36 (all times are UTC)

B) Synopsis

On 8 April 2015, while the foreign operator's Skyvan was flying from the Landsberg aerodrome to the Klatovy aerodrome, approximately when crossing the national border of the Czech Republic, the crew overheard a bang coming from the right side of the aircraft. It was accompanied with RPM, torque and oil pressure drop in the right engine. Simultaneously, smoke was blowing from the rear part of the right engine. Shortly afterwards, the cockpit smelt of fuel and continuous depletion of the amount of fuel in the right tank was observed. Upon emergence of the critical event, the instructor took over control, applied single-engine flight procedures and completed the flight at LKKT. Landing was successful. While the aircraft was taxiing to the stand, ground became contaminated with leaking fuel. The aircraft operator sent an incident report to Austro Control on 8 April 2015. The Czech representative of the operator sent an incident notification to the AAII under L 13 only after having been demanded to do so on 13 April 2015. After verification and provision of additional information the event was classified as serious incident. In compliance with international standards and recommended procedures the notification was sent on 21 April 2015.

The cause of the serious incident was investigated by the AAII commission. The investigation team comprised:

Investigator in charge:	Ing. Lubomír Stříhavka
Investigator – operations:	Ing. Stanislav Suchý

NTSB and the Austrian AAIB appointed accredited representatives. The EASA and engine manufacturer appointed technical advisers. In 2017, In 2017, the chairman of the commission replaced Ing. Stanislav Suchý.

The Final Report was issued by:

AIR ACCIDENTS INVESTIGATION INSTITUTE
Beranových 130

199 01 PRAGUE 99

On 18 December 2017

C) The Final Report consists of the following main parts:

1) Factual Information
2) Analysis
3) Conclusions
4) Safety Recommendations
5) Annex

1 Factual information

1.1 History of the flight

1.1.1 Operation over the last 30 days prior to the occurrence

Over the last 30 days prior to the event flight, the aircraft performed 75 flights with the sum of 29:06 flight hours. The aircraft was operated from the aerodromes Zell Am See (from 13 March 2015 to 29 March 2015), Klatovy and subsequently Landsberg (from 7 April 2015). The aircraft performed 10 flights with the sum of 4:19 flight hours here.

1.1.2 The event flight

The event flight was the fifth flight on 8 April 2015. It was described based on the instructor's statement and the record of the E2000 Asterix cat 62 surveillance system. The flight from ETSA to LKKT was carried out as a VFR flight without a flight plan. The crew comprised of the instructor (PNF) and the pilot (PF). There were no other persons on board besides the crew. The flight was also intended for PF to flight training at minimum speed and stalling. The instructor said exactly: "*starting with Stall exercises…*"

The flight callsign SHERPA2 commenced take off from ETSA at 12:39 under VMC. Having climbed to the cruising level, the aircraft was flying at 150 kt[1)] until emergence of the critical event at FL95. At 13:31:20, approx. 15 NM far from LKKT (in the location of 49°16´37.49´´N, 013°00´30.11´´E), the speed decreased to 80–110 kt. This section may be most likely indicated as the time when stall exercises started and also as the time when the critical event occurred. The flight then continued at 120–130 kt with gradual descending until landing on RWY 27 LKKT at 13:42.

The instructor commented on the course of the critical situation that he overheard a bang from the right side of the aircraft. It was accompanied with RPM, torque and oil pressure drop in the right engine. At the same time, the crew noticed smoke blowing from the rear part of the right engine and shortly after that the cockpit smelt of fuel. The instructor took over control and responded to the emergency by setting the right engine control lever to the "Stop" position. Simultaneously, he feathered the right engine propeller. As the engine fire signal light on the central panel was not switched on and no fire was observed visually, the instructor did not use the engine extinguishing system. Having evaluated the situation, he applied single-engine flight procedures and continued in the flight to the Klatovy aerodrome. Meanwhile, the crew observed continuous depletion of the fuel volume in the right tank on the capacity fuel gauge and smelt fuel from the area behind them. The cause of leakage and smell of fuel was identified no sooner than upon stopping at the stand as fuel was leaking from the right fuselage tank to the cockpit space and under the floor. It was further leaking through the gaps in the lower part of the aircraft body outside.

1.2 Injuries to persons

Injury	Crew	Passengers	Other (inhabitants, etc.)
Fatal	0	0	0
Serious	0	0	0
Light/No injury	0/2	0/0	0/0

[1)] Speed derived from the system track records of the E2000 surveillance system

1.3 Damage to aircraft

Upon landing the technical inspection revealed perforation in the lower part of the engine casing. A rupture of the rotor wheel of the second and third stages of the gas turbine occurred in the engine. The largest fragments from the turbine perforated the combustion chamber and the engine casing in the area of the rotor of the third stage of the gas turbine, and left the aircraft through the engine casing. Smaller fragments caused multiple perforation of the fuselage casing on the right side and perforation of the rubber bladder of the fuel tank. The fragments did not strike the load-bearing structure elements of the fuselage. Due to the fuel leakage the passenger compartment of the cockpit was contaminated as well as the space under the floor.

The damaged engine was sent to be inspected by experts at the manufacturer's site and the findings of the inspections were requested to be submitted regarding the damage to the engine. The damage to the other parts of the aircraft was solved by repair or replacement.

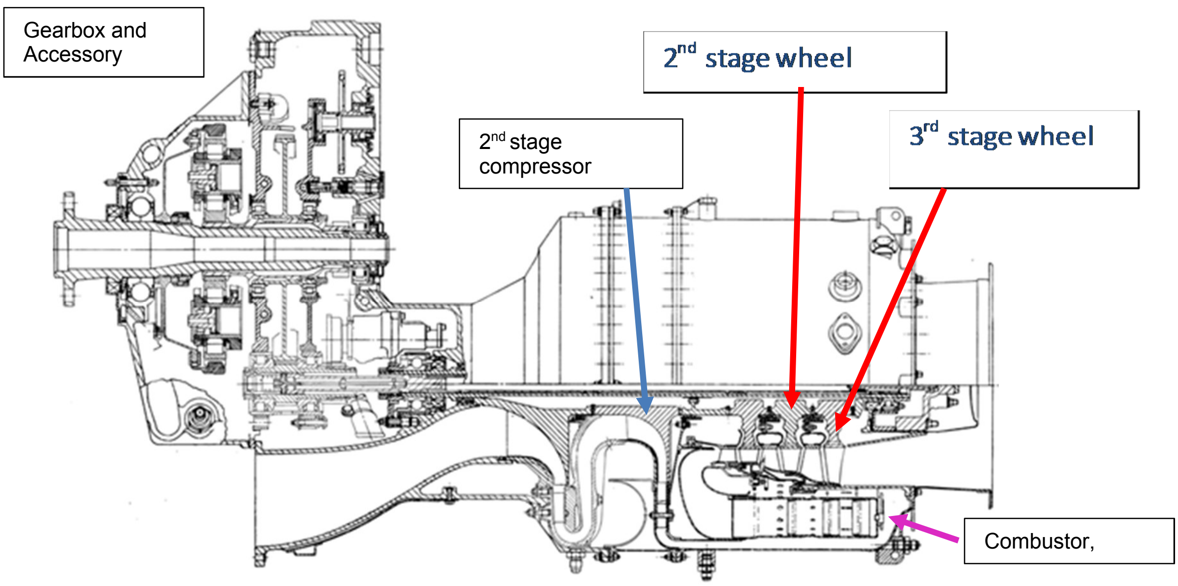


Fig. 1 Layout of the damage to the parts of the engine (source Honeywell)

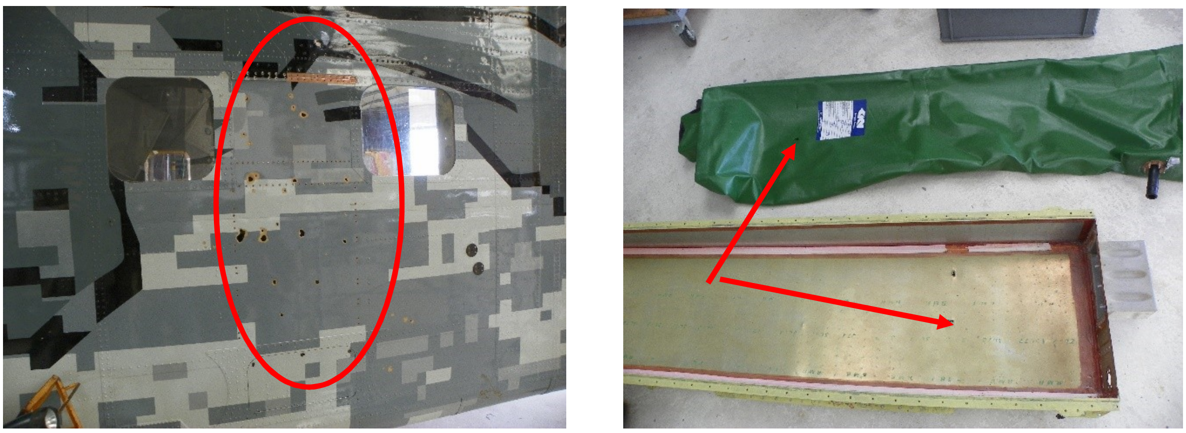


Fig. 2 Damage to the aircraft fuselage and fuel tank.

Fig. 3 Hole in Combustor Plenum Housing at 7:00 O'clock and debris - Fragment of a Turbine Rotor (source Honeywell).

1.4 Other damage

During taxiing to the stand after the landing, the leaking fuel contaminated the surface of the apron of the operator on overall area of approx. 80 – 100 m^2. The fire brigade from Klatovy was summoned to mitigate the consequences of fuel leakage.

1.5 Personnel information

1.5.1 The pilot

The pilot (during the event flight the PF) was sitting in the left seat. He handed over control to the instructor upon occurrence of the critical event.

Male – age:	50 years
Type of licence:	CPL (A) issued on 24 March 2015
Type rating:	In training for the SC7 Skyvan type
Rating:	FI, IRI for SEP/MEP, TMG, Aerobatics
Medical Certificate	Class I, valid
Flying experience:	approx. 10,000 h
Flying experience as PIC:	9,400 h
Flying experience with SC7:	7 h 40 min
Over the last 90 days:	38 h
Over the last 24 hours:	3 h 36 min

1.5.2 Instructor

The instructor (during the event flight the PNF) was sitting in the right seat. During the event flight he was performing the function of an instructor for type training of the pilot flying. In the critical event he took over control and completed the flight.

Male – age:	37 years
Type of licence:	CPL (A) issued on 12 March 2001
Rating:	FI(A) SC7 Skyvan
Medical Certificate	Class I, valid
Flying experience:	6,559 h 55 min
Flying experience as PIC:	5,714 h 22 min
Flying experience with SC7:	5,800 h
Over the last 90 days:	26 h 48 min
Over the last 24 hours:	3 h 36 min

1.6 Aircraft information

1.6.1 General specifications of the aircraft

Shorts SC7 Skyvan is a twin-engined multi-purpose aircraft. It is manufactured by Short Brothers & Harland, Northern Ireland. Bombardier is the current TC holder. The aircraft is powered by two Honeywell TPE331-2-201A turboprop engines and MTV five-blade propellers. The aircraft concerned was designed for transport and parachute jumping of 20 parachutists. The crew is comprised of two pilots. On 28 April 2008, it was approved for VFR Day/Night and IFR operation.

Type:	SC7 Skyvan
Registration mark:	OE–FDN
Year of manufacture:	1979
Serial number:	SH1964
Total hours flown:	6,742:50 FH
Airworthiness review certificate:	valid until 2 June 2015
Release to service certificate:	valid
Liability insurance:	valid
MTOW :	5,680 kg
Weight during the event flight:	4,638 kg
Amount of fuel at the moment of incident:	1,600 lb
Type of fuel used:	Jet A-1

1.6.2 Power units

Engine No. 1

Type:	TPE331-2-201A
Manufacturer:	Honeywell Aerospace, USA
Year of manufacture:	1970
Serial number:	P90078
Total hours flown:	14 680:54 h
Total equivalent cycles	26,888
Propeller – type:	MTV-27-1-E-C-F-R(G)/CFR235-55
Total hours flown:	3,141 h
Serial number:	06158

Engine No. 2 (damaged engine)

Type:	TPE331-2-201A
Manufacturer:	Honeywell Aerospace, USA
Year of manufacture:	1974
Serial number:	P90259
Total hours flown:	3,615 h
Total cycles	4,931 / 5,513 TEC
Propeller – type:	MTV-27-1-E-C-F-R(G)/CFR235-55
Total hours flown:	3,141 h
Serial number:	06159

1.6.3 Aircraft maintenance

Last maintenance according to OMP-PAS-SC7 Rev. 2 in the extent of 100 h/annual was completed on 6 March 2015. On 26 February 2015, as part of this maintenance the engine operation on the ground was checked. No deviations from standard operating values were observed. Since then, the aircraft had flown 39.5 h until the serious incident.

1.6.4 Damaged engine TPE331-2-201A, serial number P90259

With regards to the time for which the engine had been operated since its manufacture, the history of its operation and maintenance was described in the ENG-15-WA-018 report on the engine teardown performed by the manufacturer.

In November 2002, the engine manufacturer issued a binding service bulletin No. SB TPE331-A72-2111, which stipulates the guidelines for the calculation of engine cycles and/or the total equivalent cycles (TEC).

The available records on the operation and maintenance of the engine and its parts were checked in order to verify TBO of individual engine parts and find out whether or not the life limits of monitored life limited parts were reached or exceeded. All the data and supporting materials have been obtained from the operator, CAMO records and information acquired from the foreign maintenance organisation.

The engine was manufactured in 1974 and it was mounted to the Skyvan aircraft with the G-455 registration mark on 9 August 1974. Until 6 January 1977, the engine had been in operation for 222:35 h and there was a note in the engine logbook on this day: "*Power reduction in flight – engine removed for investigation".* Until 7 November 1991, the engine logbook had read no records regarding its operation. On 7 November 1991, the following comment was written down in the logbook: "*Engine has been prepared for long time storage. Fuel system inhibitor. All blanks fitted. Installed in armour bar pack bag with desiccant…"* (the writing is further illegible).

According to the Honeywell quality records, the original 3rd stage rotor that was installed in the engine when new, was P/N 895539-1, S/N 3-01345-7010. In 1991 the new 3rd stage rotor when the engine had recorded 392:00 h and 603 cycles was installed (P/N 868630-9 and S/N 8-01345-6207). Aircrafts Skyvan reg. G-455 and G-450 were operated by Ghana Air Force.

On 19 May 1992, the records read that the engine was mounted into an aircraft with the G-450 registration mark[2)]. The baseline value of hours in operation was recorded as 392:00 h and 603 cycles. The engine was operated until 22 October 1998 when it was installed into an aircraft with the OE-FDE registration mark[3)], serial number SH1886. The status of hours in operation (1,479:33 h) and the number of cycles (1,881) were recorded in the engine logbook.

Records (with the same values of hours and cycles) then continued as of 25 February 2004 when the engine was rebuilt in a foreign maintenance organisation according to national STC Nos. SE 383CH and SA 488CH to the Super 2 modification.

Starting from 28 March 2004 the engine operation records were kept in the electronic form only. Temporary Revision 72-144 against the Inspection and Repair Manual 72-IR-10 was issued on June 13, 2006 to alert owners of the possibility of cracks

[2)] The aircraft with serial number SH1904, later registration mark OE-FDL had an accident in June 1995 and has been discarded.

[3)] Former registration mark C9-ASN.

in the rivet hole. During hot section inspections (HSI) the rivets must be removed and the holes inspected for cracks. If any cracks are found, then the rotor must be scrapped.

On 4 January 2011 the hot section inspections (HSI) with 2545 h and 3526 TEC was performed.

The engine with serial number P90259 was operated in aircraft with the OE-FDE registration mark, OE-FDE, serial number SH1886, until 27 September 2012 when it was demounted and on 25 November 2012 mounted to aircraft with the OE-FDN registration mark, serial number SH1964. At that time the engine had been operated for 2,679.2 h and 3,658 cycles. The last data stated in the electronic data records pertaining to the given engine as at the date of serious incident read 3,615.9 h and 5,513 TEC. The current operator has rendered information that it has been acquiring Skyvan-type aircraft gradually from other foreign operators. For the aircraft history see www.airport-data.com/.

1.7 Meteorological information

1.7.1 CHMI weather report

In the CHMI Aviation Meteorology Department's report the situation in the area of serious incident is described as follows:

An occluding front was passing at the front edge of high-pressure area from North to South East and was affecting namely North East of the Czech Republic.

Surface wind:	280–310°/ 4–14 kt
High-altitude wind:	at FL050 340°/22 kt, FL100 020°/22 kt, FL180 020°/36 kt
Visibility:	variable depending on the cloud base, more than 10 km, at mountain tops occasionally also less than 1 km
Weather situation:	overcast, occasionally clouds and mist, at mountain tops occasionally also fog
Clouds:	BKN / OVC AS, AC, SC, isolated CU, sporadically ST BASE 2,700–4,000 ft AMSL, TOP 6,000–7,500 ft AMSL
Zero isotherm level:	4,000 – 5,000 ft AMSL
Icing:	mild starting from 4,000 ft AMSL

At 13:28:10 the instructor asked the Prague FIC Praha for weather information. At that time the flight was 23.2 NM far from LKKT.

1.7.2 Extract from SYNOP from weather stations on 8 April 2015 at 13:00 and 14:00

TIME UTC	N	VITR KT		DOHL. M/KM	STAV POCASI	OBLACNOST FT(!)AGL	TEPL. ST.C	R.BOD ST.C	MAX KT
1300									
Přimda	7	310	4	18km		7 SC 1800	7.0	1.1	
Plzeň	8	VRB	4	13km		8 SC 2600	9.2	2.8	
Churáňov	8	320	6	9000	BR	8 SC 1400	4.0	-1.0	
Vel. Javor	**8**	**310**	**12**	**0800**	**BCFG**	**7 CU ////**	**0.0**	**-0.2**	
Kocelovice	8	290	12	9000	BR	8 SC 2100	7.0	2.1	
1400									
Přimda	7	300	4	22km		7 SC 1900	7.5	1.1	
Plzeň	8	330	6	18km		8 SC 2900	9.7	2.4	
Churáňov	8	310	6	8000	BR	8 SC 1400	3.4	-0.6	
V. Javor	A	320	14				0.0	-0.1	
Kocelovice	8	290	8	9000	BR	8 SC 2200	7.1	2.2	

N = celkové pokryti, MAX = náraz větru v průběhu, A automatická stanice

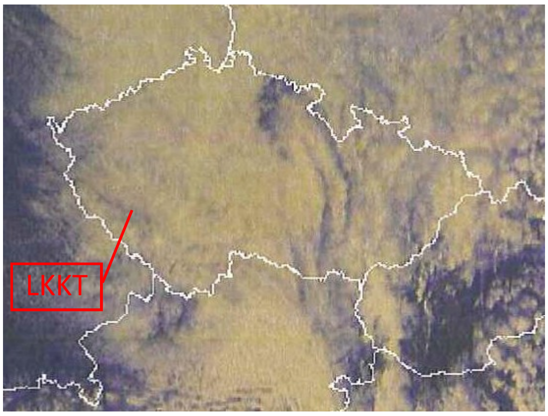


Fig. 4. Satellite image of cloud structure (source: CHMI)

1.8 Aids to navigational

NIL

1.9 Communications

The flight was performed in Munich FIR and Prague FIR. The crew was in contact with the relevant ATS offices.

1.10 Aerodrome information

The aircraft took off from the Landsberg aerodrome (ETSA). The aircraft landed at the Klatovy aerodrome (LKKT).

1.11 Flight recorders and other means of recording

There was neither a flight recorder nor any device on board the records of which could be used for flight analysis. The records of surveillance data processing systems made at the specialised unit of AI Department in the IATCC and records of radio communication between the crew and the FIC Prague were used to confirm the flight route.

1.12 Serious incident location description

NIL

1.13 Medical and pathological information

NIL

1.14 Fire

Fuel leaking from the damaged tank to the aircraft cockpit and the floor space increased the risk of potential outbreak of fire of the aircraft in flight.

1.15 Survival aspects

No search and rescue procedures were organised.

1.16 Tests and research

The engine teardown was done at the Honeywell factory with assistance of the NTSB accredited representative on June 24 – 26. 2015. The report on the engine teardown carried out by the manufacturer (ENG-15-WA-018) has been provided to the AAII and included in the said event file. The report shows that the combustor plenum was pierced in two locations cca in the plane of the 3rd stage turbine wheel.

The 1st stage nozzle was intact, however the leading edges and trailing edges of approximately 2/3 of the vanes were cracked near the midspan. The 1st stage turbine wheel was intact however leading edges of all the blades were dented. The curvic teeth of the forward and aft coupling were intact but moderately deformed.

The 2nd stage nozzle was intact however the leading edges of approximately 1/3 of the vanes were rotationally scored, consistent with contact against the 1st stage rotor. The trailing edges of all the vanes were battered and approximately 1/3 of the vanes were fractured.

The 2nd stage turbine wheel, 3rd stage stator and 3rd stage turbine wheel were not present.

The main shaft was fractured in two locations: just aft of the 2nd stage impeller and just aft of the second stage disk.

Two fractured segments of the 3rd stage nozzle were found and a small segment of the missing turbine rotors was found.

Based on findings during the engine teardown the engine manufacturer provided fracture examinations of the fragment of the 3rd stage turbine wheel, chemistry to identify the alloy and analysis to determine the total number of accumulated cycles. The report ERS-ASYS-PENG-MA-0000350 received AAII of the Czech Republic on August 22. 2017.

In connection with an engine inspection by a foreign maintenance organization the commission requested additional information relevant to the assessment of how the 3rd stage turbine wheel had been performed. This information was received by AAII on 18 September 2017.

1.16.1 Examination of the 3rd stage turbine wheel fragment

According to the manufacturer report (ERS-ASYS-PENG-MA-0000350), the expertise objective was to determine the fractures of the fragment of the 3rd stage turbine wheel, to identify the alloy from which it was made and any cracks in the rivet holes.

The axamined fragmet contained the web and airfoil regions of 5 fractured blades (Figure 5 and Figure 6).

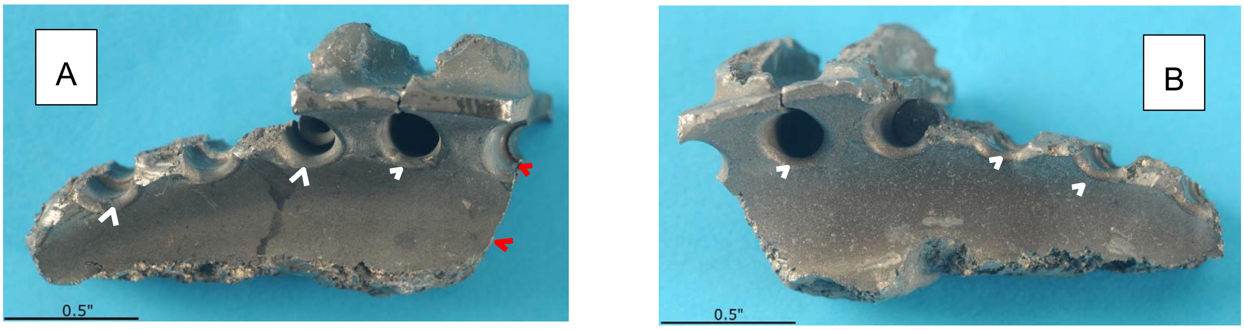


Figure 5. Views showing the front (A) and rear (B) side of the 3rd stage turbine wheel fragment. (Honeywell)

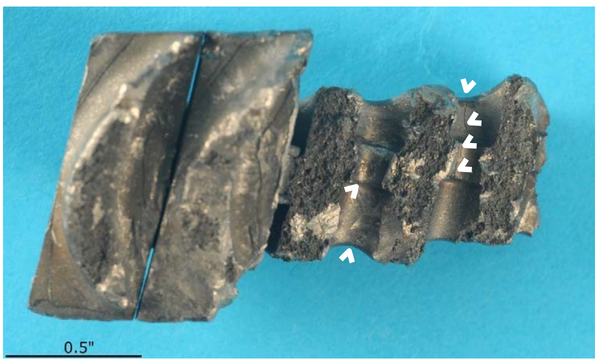


Figure 6. Views showing the airfoil and identify cracks in the rivet holes. (Honeywell)

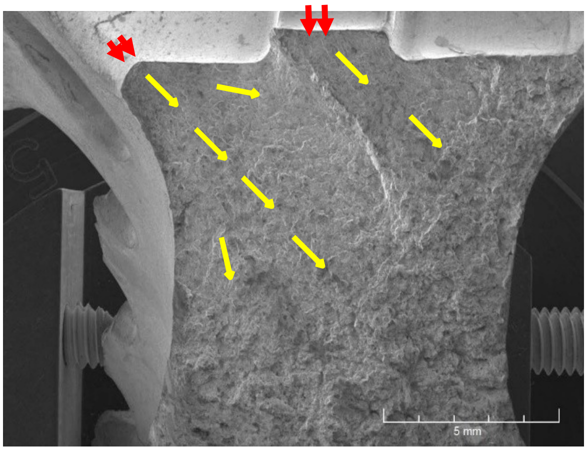
Fractures occurred through two airfoils and three blade posts. Radial separations occurred through the rivet holes on each side of the fragment.

Red arrows in Figure 5 identify the primary fracture surface emanating from the aft corner of the rivet hole. White arrows (Figure 5 and Figure 6) identify cracks in the rivet holes.

Visual inspection of the rivet hole regions revealed cracks at the axial centres (small diameter) of at least 2 holes. Rivets were still installed in the two intact holes. Cracks were also observed in 3 of the 4 aft and forward corner radii.

The fracture features on the airfoil and post separations were indicative of overload. The fracture features were characteristic of fatigue.

Scaning electron microscope SEM) examination of the web separation confirmed the fatigue fracture mode. The primary fracture emanated from the aft corner of the rivet hole at 3rd stage turbine wheel (Figure 7) and a second fatigue origin emanated from the amallest diameter surface at the base of the rivet hole. The two crack fronts converged and propagated inboard cca 11,43 mm in fatigue before the final overload separation of the web segment occurred.



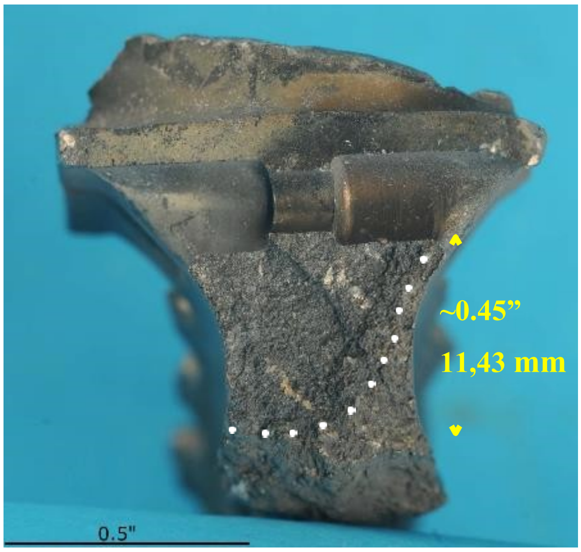


Figure 7. View showing the wheel fragment fatigue fracture of 3rd stage turbine wheel. The primary and secondary origin regions are identified by red arrows. Yellow arrows identify the direction of fatigue crack growth. (Honeywell).

1.16.2 Striation density analysis

Striation density studies were performed on the fracture surface along the primare crack front path using a graph of the striation densities created from empirical count of the striations observed in the digital imagines. The analyse shown indicating that an estimated 12,000 total striations occurred between cracks depths of 0,305 mm to 7,874 mm.

Due to the significant difference between the reported cycles (TEC 5,513) a and the striations density analysis on the fragment (12,000 striations /cycles) of propagation between depths of 0,305 mm a 7,874 mm, a striation density study was performed by manufacturer on a MAR-M247 test specimen of known conditions to identify if a relationship adjustment was necessary.

A relationship adjustment generated for Mar-M247 material applied to the data reduced the total number of accumulated striations from 12,000 to 4,230 between the crack depths of 0,305 mm a 7,874 mm.

SEM evaluation of the aft surface of the segment confirmed the rivet hole cracks The cracks didn't appear to have been associated with surface imperfections/machining marks. The fracture surface of one crack was exposed in the laboratory after cut in rivet hole (Figure 8). The exposed fracture surface revealed one discolored fatigue thumbnail emanating from the aft corner radius of the rivet hole propagated to a maximum depth of cca 1,778 mm from the aft corner of the rivet hole.

1.16.3 Chemistry

Energy dispersive x-ray (EDX) analysis verified that the wheel material was Mar-M247 as specified. No material defects or microstructural features suggestive of high operating temperatures were observed.

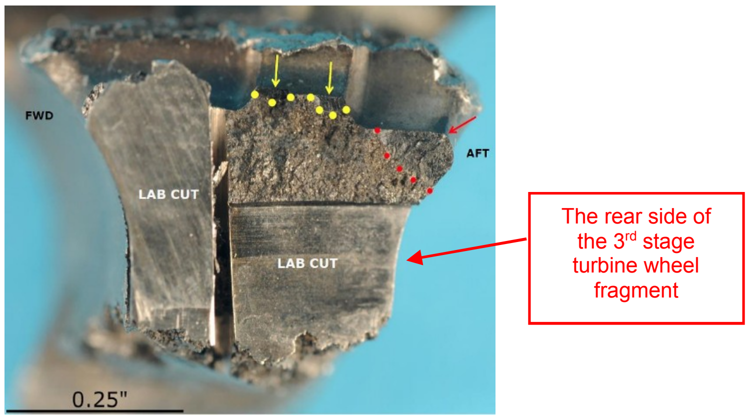


Figure 8. View showing the exposed fracture surface of the crack in the rivet hole of 3rd stage turbine wheel. Fatigue thumbnail patterns emanating from the aft corner of the rivet hole (red arrow) and smallest diameter surface at the base of the rivet hole (yellow arrows). Red and yellow dots outline the extent of fatigue propagation.

1.16.4 Hot section inspections (HSI)

The last major maintenance on the engine was on March 1, 2011. The records on documentation of Danish Aircraft Owners (DAO) confirmed Zyglo inspection of 3rd stage wheel during HIS according to „72-IR-10 rew. 9. - Garrett TPE331 Turboprop Aircraft Engine Inspection manual", at total HSN 2545 h and 3526 TEC.

During the HSI, a visual inspection of the 3rd stage of the turbine and a non-destructive test using the ZYGLO Fluorescent Penetrant Inspection (FPI) was performed. No anomalies were found. The AAII received additional information from DAO that during hot section inspections (HSI) the rivets have not been removed. The test report shows that no anomalies have been found on the 3rd stage of the turbine.

1.17 Organisational and management information

The subject aircraft operator held a valid aircraft operator license. On 19 February 2015, the operator under AIP GEN 1.2.9 reported to the civil aviation authority temporary air operations – parachute jumps for 2015 in the Czech Republic

1.18 Additional information

NIL

1.19 Useful or effective investigation techniques

The serious incident was investigated in accordance with Annex 13 and Regulation (EU) No. 996/2010 of the European Parliament and of the Council.

2 Analysis

2.1 General

During the analysis and determining the causes of the serious incident the testimonies of the instructor, the recordings from the available technical content documentation and the report on the engine teardown performed at the manufacturer's site (Engine teardown report ENG-15-WA-018), the report ERS-ASYS-PENG-MA-0000350 and information from a foreign approved maintenance organisation were used.

2.2 Operational aspects

2.2.1 Crew qualifications & experience

The pilot was proficient to perform the flight which was serving as the training for acquiring a type qualification. Up to the critical situation occurrence he was in the PF position and was piloting the aircraft. He had had the corresponding relevant practice in flying.

The instructor commenced the event flight as PNF and was in the position of an instructor for type training for the PF. He had had the corresponding relevant practice in flying to perform the function of an instructor. After the emergence of the critical situation he took over the piloting and completed the flight safely.

2.2.2 Aircraft condition

Prior to the engine malfunction, the maintenance and operation of the aircraft and the engines had been performed in accordance with the requirements of OMP-PAS-SC7 Rev. 2 and the aircraft TC holder. The condition of the aircraft was adequate to its age and number of hours flown. No defect condition of the aircraft systems and power units had been noticed or recorded within the 30 days prior to the serious incident. The aircraft was approved as airworthy for operation under the given conditions.

The damage to the aircraft was related to the malfunction of the fan wheel of the engine gas turbine No. 2.

When bursting of the 2nd and the 3rd stage turbine, the fragments of the largest size penetrated the combustion chamber and engine casing and left the engine through the engine cover. At the same time, the smaller sized fragments caused multiple breakage of the fuselage wall on the right side and puncture of the fuel tank of the fuel tank.

The fragments did not intercept the structural components of the aircraft hull. By escaping the fuel from the fuel tank, the cabin space and floor space of the aircraft hull were contaminated

2.3 Turbine failure

2.3.1 Engine No. 2 history analysis (serial number P90259)

The manufacturer has issued service bulletins in order to monitor the life limited parts of the engine. The bulletins refer to the methodology for calculating the engine cycles depending on the type of operation.

Bulletin TPE/TSE331-72-0019 applies to operations where the number of take-offs and landings is equal to the number of cycles of starting/shutting down the engine.

Bulletin TPE331-A72-2111 issued in 2002 applies under special-use operations as, for instance, agricultural, skydiving, and certain cargo flight operations, where the number of take-offs and landings does not equal the number of starting/shutting down of the engine.

Regarding the long period elapsed from the manufacture, engine No. P90259 has alternated in both of the stated types of operation. The monitored life limited parts include, among others, the fan wheel of the 3rd stage of the turbine as well. The lifespan of the fan-wheel is, according to Bulletin TPE331-A72-2111, determined to be 6,000 TEC.

In the documentation available submitted by the current operator it has been established that until 2004 the data and records of operation had been carried out by the previous operators in the engine logbook in handwriting. Commencing from 2004 the current operator has been maintaining the documentation and records in digital form. The input data are transcribed from the handwritten daily Flight Log entries pertaining to flights by the relevant aircraft.

From the entries it follows that the engine was manufactured in 1974 as TPE331-2-201A type, serial number P90259. Until 6 January 1977 it had 222:35 hours of operation. The reason for termination of operation of the engine was its dismounting from the aircraft and not specified investigation commencement. From that date until November 1991 the engine was not operated and it was in a long-term storage.

Further entries continue only from 16 May 1992 with the number of operated hours at 392:00 and the first entry about the number of cycles equalling 603. Regarding the preceding entries, the time between 222:35 and 392:00 was not documented by the previous operator.

From 26 May 1992 till 22 October 1998 the entries on operation were performed in the engine logbook. As at 22 October 1998 the engine operated in total 1,479:33 h and 1,881 cycles[4)]. On 4 November (1998)[5)], the engine was conserved, its further operation resumed only in 2004.

From recorded information is an uncertain type of operation at the time of use of the airplane under the terms of the Ghana Air Force. In particular, it cannot be ascertained whether or not there has been a multiple landing between the engine start / stop cycles. Following the issue of Bulletin TPE331-A72-2111 as of 25 February 2004, an increased number of cycles was not counted.

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4) It is evident from the record that the number of engine cycles can be calculated as 1 cycle = 1 take-off/landing.

5) The year is not recorded but from the handwritten record it can be assumed that the year concerned is 1998.

On 25 February 2004, there is the last entry in the engine logbook when conversion was performed at the approved maintenance organisation following the pattern of Danish STC No. SE 383CH and SA 488CH to Super 2 modification. At the same time, transmission inspection (GBI) and HSI (hot section inspection) were performed. According to the engine manufacturer's statement, the conversion into Super 2 modification consists in adjusting the power section of the engine. In this specific case it meant the generator section of the engine of TPE331-2 type and the power part from the engine of TPE331-6 type.

On 8 April 2004, the engine was mounted to aircraft with registration mark OE-FDE, serial number SH1886. Starting from 28 March 2004 the records on operation by the current operator have been performed and maintained in digital form. In the period from 2004 till 2015 the operator registered 3,632 TEC worked by the engine.

2.3.2 Analysis of the 3rd stage turbine wheel in engine No. P90259

According to the manufacturer's records, the engine was in production in 1974 fitted with the fan wheel of the 3rd stage of the turbine p/n 895539-1, s/n 3-01345-7010. In 1991, the wheel was at 392:00 h and number of cycles at 603 replaced by a new wheel (p/n 868630-9, s/n 8-01345-6207). The number of hours and the calculation of the number of engine cycles continued in accordance with the methodology of Bulletin TPE/TSE331-72-0019 until 1998 (1,479:33 h and 1,881 cycles).

Taking into account the unclear record about hours worked by the engine between 1977 and 1991 (that is from the number of operating hours between 222:35 and 392:00) and considering the fact that the wheel was replaced with a new one after 603 cycles, the difference of the unproven time of operation (392:00 – 222:35 = 169:25) has no effect on the calculation of life limits of the wheel of the 3rd stage of the turbine s/n 8-01345-6207.

In the records kept since 2004 (after the engine modification) and changeover to special type of operation, the number of cycles' calculation in accordance with Bulletin TPE331-A72-2111 was used. According to the recording card of the operation of the wheel of the 3rd turbine stage the value input for the calculation of equivalent number of cycles as the initial value was the time until the time of total operated number of engine cycles (1,881) and not the value representing the number of cycles truly operated by the wheel since its replacement in 1991. The correct initial value for the calculation of the equivalent cycles (TEC) should have been 1,278 cycles (1,881 – 603 = 1,278). The initial value for the calculation of the cycles operated by the 3rd stage turbine wheel was not corrected at the maintenance organisation that performed the engine modification in 2004.

After the serious incident, as at 8 April 2015, the operator submitted the final value of the engine operated hours at 3,615.9[6)] h, 4,931 cycles, or rather 5,513 TEC. The rest of the life limits of the turbine third-stage rotor was calculated by the operator to be 487 TEC cycles (6,000 – 5,513 = 487). If the TEC for 3rd stage turbine wheel is reduced by 603 cycles, the wheel failure occurred already at 4910 TEC reported by the operator.

From the HSI documentation on 4 January 2011, it transpires that it took place at a total of 2,545 hrs and 3,526 TEC and therefore the failure occurred after 1987,4 TEC from HSI 3rd stage turbine wheel performed. Part of the HSI was a visual inspection of the

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6) The operator maintains the monitoring of operated hours in digital form and has assumed the format of time monitoring in tenths of an hour.

3rd stage of the turbine and a non-destructive FPI test. No anomalies were detected on the 3rd stage turbine wheel. However, from a statement from the approved maintenance organisation, it emerged that during the visual inspection and FPI rivets were not removed from the holes in the 3rd stage turbine wheel.

2.3.3 Failure of the 3rd stage turbine wheel

Although the 2nd stage turbine wheel, the stator and the 3rd stage turbine wheel were not in the damaged engine, the engine structure, including the penetrations of the casing in the turbine section, showed signs of breaking and separating a part of the second and third stage turbine material. It was only possible to examine the fragment of the 3rd stage turbine wheel.

The evaluation of the 3rd stage turbine wheel failure was divided into several parts. The primary non-destructive evaluation was complemented by fragment analysis (destructive) and computational analyzes. For the fracture examination of the fracture areas of the 3rd stage turbine wheel was selected, as indicated by the engine manufacturer's report (ERS-ASYS-PENG-MA-0000350), fracture which emanated radially from the aft corner radius and center of the rivet hole.

Scanning electron microscope (SEM) examination of the web separation confirmed that the web section separation of the 3rd stage turbine wheel containing 5 blades resulted from a low cycle fatigue fracture mode (LCF).

The fracture had propagated inboard ~11,43 mm in fatigue before final overload separation of the web segment occurred.

Visual inspection of the rivet hole regions revealed cracks at the axial centers (small diameter) of several holes. Cracks were also observed in the rivet radii at the aft and forward corners.

The fracture surface of one crack was exposed in the laboratory. The cracks didn’t appear to have been associated with surface imperfections/machining marks.

2.3.4 Striation density analysis

Striation density analysis created from empirical counts of the striations observed in the digital images shown by SEM indicated that ~12,000 striations had accumulated between the crack depths of 0.305 mm and 7,874 mm.

The Mar-M247 relationship adjustment was applied to the SEM striation density data measured on the 3rd stage turbine wheel fragment fracture. Application of the adjustment relationship reduced the total number of accumulated striations from 12,000 to 4,230 between crack depths of 0.305 mm and 7,874 mm.

The engine manufacturer, based on the analysis of the incidence and propagation of cracks, has hypothesized that:

- If assumed crack initiation occurred at or near HSI (3,526 cycles) and was not detected with FPI then, the wheel would have had 7,756 cycles at the time of failure. (3,526+4,230=7,756 total cycles).
- If assumed crack propagation was occurring at HSI and was not detected by FPI then crack initiation would have had to have started at cycle 1,283 (5,513-4,230=1,283) which does not align with estimates/calculations for crack initiation.

The AAII commission prefers from both hypotheses derived on from the striation density (cycles) analysis for a given material as a more likely assumption that the initiation crack was not detected during HSI.

2.3.5 Chemistry

The manufacturer determined by the Energy dispersive x-ray (EDX) analysis. The microstructure of the wheel was indicative of Mar-M247. No material defects or microstructural features suggestive of high operating temperatures were observed. Energy dispersive x-ray (EDX) analysis verified that the wheel material was Mar-M247, as specified.

2.4 Analysis of the procedure used by the crew at the critical situation

The flight commenced in the Munich FIR under VMC conditions. On the flight route in the Prague FIR between 13:00 and 14:00 it was mostly overcast by SC clouds, occasionally ST covering the highest mountain summits. Until emergence of the critical event the flight was under way at FL95 at the speed of 150 kt.

After the malfunction of the engine had occurred, the instructor took over control and applied the emergency procedure steps in accordance with flight manual SC7-AFM, Section 3 Emergency Procedures. Based on the visual check, the instructor having ascertained that no fire was started on the engine and the same status (fire) was not signalled by the aircraft systems continued in flight to LKKT. The procedures stated in the flight manual have been adapted in accordance with Regulatory Information 94-26-07 AlliedSignal Inc. issued by the FAA.

The continuous drop of the fuel in the right tank observed by the crew was the result of breaking the fuel tank when the fragments of turbine whiles exited the right engine. Fuel flowed into the space of the cabin, under the floor, gaps in the aircraft construction then flowed through the bottom of the fuselage into the surroundings.

The landing was OK. The crew was not injured.

3. Conclusions

3.1 Findings

Operational aspects

- both the crew members were properly licensed and qualified to perform the flight,
- the instructor was qualified for leading the SC7 Skyvan type training, he aircraft had a valid airworthiness review certificate, valid maintenance statement and release,
- the aircraft had valid Airworthiness Review Certificate and Release to service certificate,
- meteorological conditions were suitable for performing of the flight,
- during the flight damage to the right engine occurred and the engine was shut down in accordance with the AFM,
- upon the critical situation the instructor took over the piloting, and stabilised the flight by transiting into single-engine operation,

- based on visual verification that there was no fire on the engine and was not signaled by aircraft systems, the flight continued to the Klatovy airfield,
- the intention of the crew to practice of the flight at minimum speed and the practice of the stall was not carried out after the critical situation,
- single-engine flight procedure was applied and the flight in this mode was completed by safe landing on the Klatovy airfield,

Technical aspects

- third stage of the turbine p/n 868630-9, s/n 8-01345-6207 was installed with 603 cycles recorded on the engine,
- through analysis of the engine operation documentation entries of incorrect numbers of worked hours/cycles by the turbine third-stage wheel p/n 868630-9, s/n 8-01345-6207 were ascertained and this error was also projected into the digital CAMO records,
- for determination of the equivalent number of cycles worked by the wheel of the third stage of the turbine p/n 868630-9, s/n 8-01345-6207 procedure determined by Bulletin TPE331-A72-2111 was applied and it has been ascertained that the number of cycles did not exceed the number of TEC determined by the Bulletin,
- the conversion of the engine to the Super 2 modification was performed in accordance with the Danish STC Nos. SE 383CH and SA 488CH with 1 881 and cycles recorded and the wheel of the 3rd stage turbine wheel has 1 278 cycles,
- it follows from the engine teardown report ENG-15-WA-018 from the expert engine teardown, part D.2.5
- for the following engine operation, the number of third stage of the 3rd stage turbine wheel cycles' calculation in accordance with Bulletin TPE331-A72-2111 was used,
- during the visual inspection of the engine (HIS) in the foreign maintenance organisation at the total of 2,545 hrs and 3,526 TEC no anomalies were detected on the 3rd stage turbine wheel,
- from a statement from the approved maintenance organisation, it emerged that during the visual inspection and FPI rivets were not removed, which was inconsistent with the instructions in the maintenance manual that require rivet removal during inspection,
- the AAII commission was not able to assess the extent to which the method of visual inspection and the FPI affected the result,
- the failure of the 3rd stage turbine wheel occurred at a total of 2,545 hrs and 3,526 TEC counted by operator and therefore after 1987,4 TEC from HSI performed,
- the 3rd stage turbine wheel failure occurred already at 4910 TEC reported by the operator,
- the penetration of the combustion chamber and engine casing corresponded to the separation of the stator pieces and the 2nd and the 3rd stage turbine,
- only the fragments from the critical parts of the 2nd and the 3rd stage turbine containing 5 blades were present,

- the analysis of the 3rd stage turbine fragment confirmed fatigue fracture emanated radially from the corner of the rivet hole radius on the aft side of the wheel,
- the fracture had propagated inboard 11, 43 mm before final overload separation of the web segment occurred,
- visual inspection of the rivet hole regions revealed cracks at the axial centers (small diameter) of holes and on the aft and forward corner radii,
- if these cracks occurred at the time of the HSI and the FPI method, the rivets left in the holes during the inspection could have covered them,
- the microstructure of the wheel was indicative of Mar-M247 material, as specified,
- the 3rd stage turbine wheel has 6000 cycle life limit specified by the manufacturer,
- the manufacturer based upon the analysis of Mar-M247 material reduced the estimated number of accumulated striations to 4 230 between crack depths of 0.305 mm and 7, 874 mm,
- assuming that the crack initiation occurred at or near HIS but was not detected then the 3rd stage turbine wheel would have had 7756 cycles at the time of failure.

3.2 Cause

The cause of the serious incident was the total loss of power of the right engine due to an infringement of the integrity of the 2nd and 3rd stage of the turbine, which led to a penetration of the combustor plenum, damage to the fuel tanks of the aircraft and engine shutdown. The turbine wheel fracture mechanism could not be determined due to lack of evidence. On 3rd stage of the turbine, there was a crack due to the fatigue fracture that emanated from the corner of the rivet.

Factors that may have affected the failure:

- the absence of the airplane operations data led to the fact that during the rebuilding of the engine in 2004 there was no correction of the baseline for the calculation of the equivalent cycles worked around the 3rd stage of the turbine and consequently the exceeding of the lifetime of the third stage turbine set by the manufacturer,
- during inspections by FPI the rivets in the 3rd stage turbine wheel holes have not been removed, which was not in accordance with the maintenance manual, and this could reduce the appearance of cracks.

4. Safety Recommendations

4.1 The AAII issues the following safety recommendations:

It is recommended to the FAA and EASA in coordination with the engine manufacturer consider the necessary actions in order to ensure the quality and timely detection of TPE 331 engine turbine wheel disks by a non-destructive FPI test.

5 Annexes

1/ Photodocumentation

Annex 1

Photodocumentation

Fig. 1 - Engine No. 2 and the detail of the combustor plenum penetration.

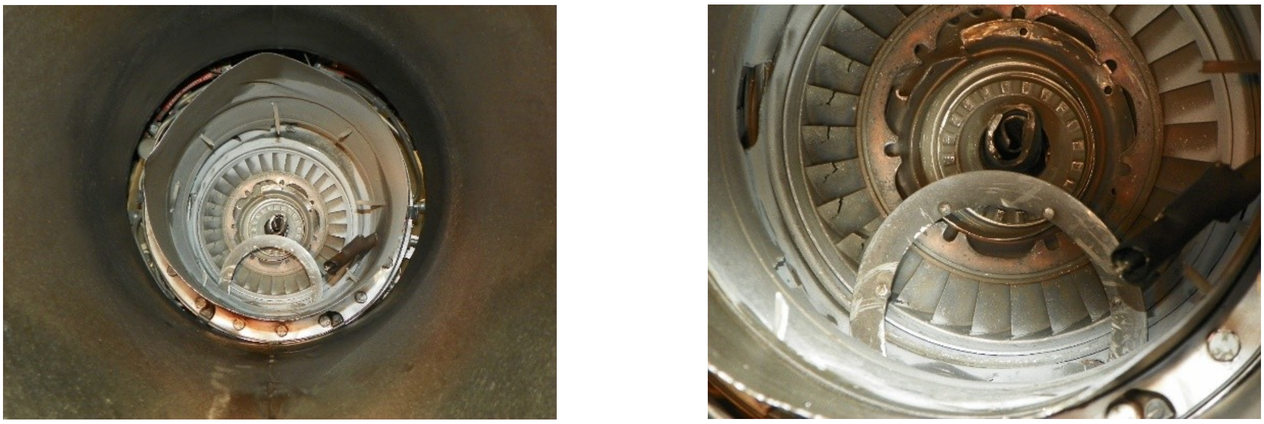

Fig. 2 - Rear view of engine No. 2 and detail of damage.

Fig. 3 – Damage of 2nd Stage Impeller.

Fig. 4 – 1st Stage Nozzle - Cracks on Trailing Edges

Fig. 5 – 1st Stage Turbine Wheel - Aft View.

Fig. 6 – 1st Stage Turbine Wheel – Leading Edge.

Fig. 7 – 2nd Satge Nozzle – Aft View.

Fig. 8 – Fractured Main Shaft and Torsion Shaft