

AIRCRAFT INCIDENT REPORT AND EXECUTIVE SUMMARY

				Reference:		CA18/3/2/1185	
Aircraft Registration	ZS-ASW	Date of Accident	8 November 2017		Time of Incident	1738Z	
Type of Aircraft	Avro 146-RJ85A		Type of Operation		International Commercial		
Pilot-in-command Licence Type		Airline Transport Pilot's Licence (ATPL)		Age	36	Licence Valid	Yes
1st Officer Licence Type		ATPL		Age	29	Licence Valid	Yes
Pilot-in-command Flying Experience		Total Flying Hours	8 895.0		Hours on Type	7 035.8	
1st Officer Flying Experience		Total Flying Hours	4 157.1		Hours on Type	81.3	
Last point of departure		Harare International Airport (FVHA), Zimbabwe					
Next point of intended landing		OR Tambo International Airport (FAOR), South Africa					
Location of the accident site with reference to easily defined geographical points (GPS readings if possible)							
During flight at approximately 34 000 ft above mean sea level (AMSL), 240Nm north east of FAOR in the area of UTULI in Limpopo province							
Meteorological Information		Wind direction: 080°; wind speed: 12 kt ; air temperature: 15°C; visibility: CAVOK					
Number of people on board	2 + 2 + 34	No. of people injured	0	No. of people killed	0		
Synopsis							
<p>A South African international scheduled aircraft took off from FVHA on a flight to FAOR. At 38 minutes into the flight, during cruise phase within the bounds of South African controlled airspace, the aircraft experienced engine failure of both port-side engines. A MAYDAY call was broadcast and the distressed condition activated. South African search and rescue was activated and put on standby for dispatch. Aircraft flight monitoring was initiated whereby two airports were contacted in an attempt to make them available for an emergency landing should there be a need. Airforce base Makhado had the required landing approach facilities and was made available, whereas Polokwane was closed at the time. The operator's maintenance control centre (MCC) was contacted by the crew to discuss and obtain advice on the situation. Subsequently, the crew elected to continue with the flight (approximately 240 nm) and they landed safely at FAOR. Aircraft damage was limited to the engines and components hit by debris. No injuries were sustained by any of the aircraft occupants. The investigation revealed that no2 engine uncontained failure was attributed to the LP turbine retaining nut becoming dislodged resulting on the fourth-stage turbine rotor disk disengaged from the LP turbine shaft, the incorrect application of torque settings; or improper installation due to a possible mis-stacking of the over-speed ring during maintenance may have contributed to the incident.</p>							
Probable Cause							
<p>The cause of the no2 engine uncontained failure was attributed to the LP turbine retaining nut becoming dislodged resulting on the fourth-stage turbine rotor disk disengaged from the LP turbine shaft. The fourth-stage turbine rotor disc compromised the turbine casing and turbine debris from the no. 2 engine struck the no. 1 engine, causing an un-commanded shutdown and leading to a catastrophic failure of both port-side engines.</p>							
Contributory factors							
<p>1. The incorrect application of torque settings; or improper installation due to a possible mis-stacking of the over-speed ring during maintenance</p>							
SRP Date		13 November 2018		Release Date			

AIRCRAFT ACCIDENT REPORT

Name of Owner	: S A Airlink (PTY) LTD
Name of Operator	: Airlink (Pty) Ltd
Manufacturer	: British Aerospace
Model	: Avro 146-RJ85A
Nationality	: South African
Registration Marks	: ZS-ASW
Place	: During flight at approximately 34 000 ft AMSL, 240 nm north east of FAOR in the area of UTULI in Limpopo province
Date	: 8 November 2017
Time	: 1738Z

All times given in this report are Co-ordinated Universal Time (UTC) and will be denoted by (Z). South African Standard Time is UTC plus 2 hours.

Purpose of the Investigation:

*In terms of Regulation 12.03.1 of the Civil Aviation Regulations (2011) this report was compiled in the interests of the promotion of aviation safety and the reduction of the risk of aviation accidents or incidents and **not to apportion legal liability**.*

Disclaimer:

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1. FACTUAL INFORMATION

1.1 History of Flight

- 1.1.1 On 8 November 2017 at about 1645Z, a South African registered aircraft (ZS-ASW) operated by Airlink took off from Harare International Airport (FVHA) in Zimbabwe on an international scheduled flight no: 8103, call-sign LNK103 with the intention to land at OR Tambo International Airport(FAOR) in South Africa. On-board the aircraft were 4 crew members and 34 passengers. The aircraft was flown under instrument flight rules (IFR) with fine weather conditions.
- 1.1.2 According to the flight crew, at approximately 1738Z during cruise phase at a height of 34 000 ft (FL340) within South African airspace (over UTULI area), a loud bang was heard on the flight deck and subsequent right yaw experienced. The crew observed an immediate visual indication on the cockpit engines instruments that engines no. 1 and 2 had experienced catastrophic failure. According to the flight recordings, the no. 1 engine failed first. This was due to damage to the full authority digital electronic control (FADEC) box, which had been struck by the turbine blades debris from engine no.2.

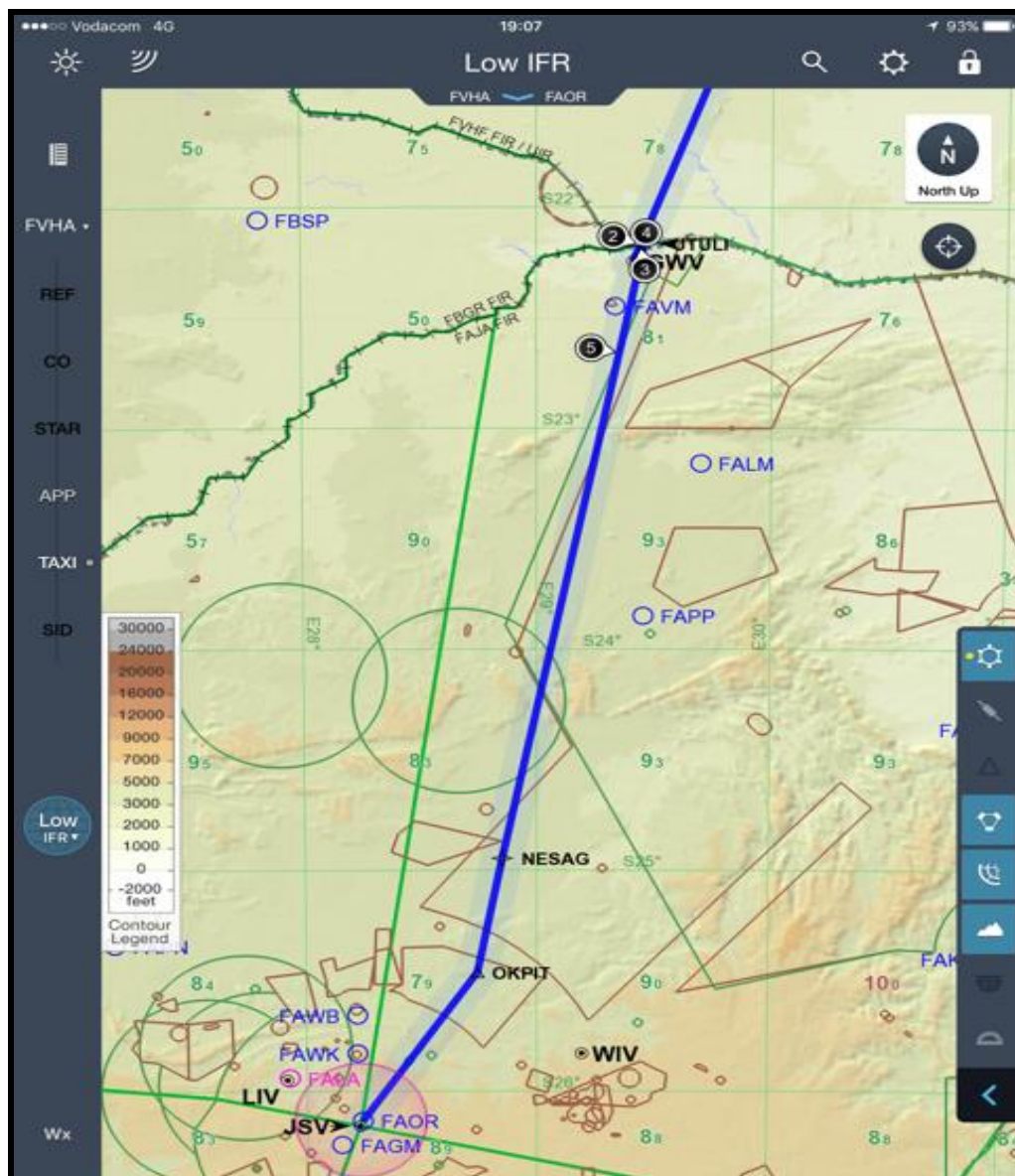


Figure 1: Aircraft route from point of incident

- 1.1.3 Following the incident, the crew declared a MAYDAY call due to the instant failure of the two engines on the port wing, and immediately followed emergency operating procedures. Search and rescue was activated and the dispatch team put on hold. A DETRESFA signal was sent at approximately 1757Z. According to the CVR recordings, the crew requested cabin crew advice the passengers and further take control of the situation in the cabin. Airforce base Makhado (FALM) was put on standby in case the crew decided to divert there. According to the pilot's report, contact was made with the operator's maintenance control centre (MCC) to report and discuss the situation. A decision was then made by the crew following considered assessment of the situation to continue with the flight to the destination (for a distance of approximately 240 Nm).
- 1.1.4 Upon broadcasting their intention to fly to FAOR, they were then requested to change to a dedicated radio frequency (132.15 MHz) at 1810Z. The crew were offered runway 21R, which they accepted, and were handed over to Approach on 124.5 MHz at 1828Z. Prior to landing the cabin crew was heard advising the passengers and preparing them for the emergency landing procedures. The aircraft landed uneventfully on runway 21R at 1839Z and DETRESFA was cancelled.



Figure 2: The two damaged port-side engines

1.1.5 The aircraft incident occurred in instrument meteorological conditions (IMC) within the airspace of South Africa at approximately 240 Nm north-east of FAOR at 34 000 ft (FL340) above mean sea level (AMSL) during cruise phase.

1.2 Injuries to Persons

1.2.1 No injuries were sustained by either the flight crew or passengers during the incident sequence.

Injuries	Pilot	Crew	Pass.	Other
Fatal	-	-	-	-
Serious	-	-	-	-
Minor	-	-	-	-
None	2	2	34	-

1.3 Damage to Aircraft

1.3.1 The aircraft sustained damage to both no. 1 and 2 engines on the port side wing of the aircraft. In addition, the turbine blades of no. 2 engine struck the no. 1 engine assembly pylon covers.



Figure 3: Damage to engine no. 2



Figure 4: Damage to engine no. 1

1.4 Other Damage

1.4.1 None.

1.5 Personnel Information

Pilot-in-command (PIC):

Nationality	South African	Gender	Male	Age	36
Licence Number	0271041477	Licence Type	ATPL		
Licence valid	Yes	Type Endorsed	Yes		
Ratings	Night, Flight Test and Instructor Grade 2				
Medical Expiry Date	31 March 2018				
Restrictions	TBC				
Previous Accidents	None				

Pilot-in-command flying experience:

Total Hours	8 895.0
Total Past 90 Days	181.0
Total on Type Past 90 Days	181.0
Total on Type	7 035.8

First officer:

Nationality	South African	Gender	Male	Age	29
Licence Number	0271069338	Licence Type	ATPL		
Licence valid	Yes	Type Endorsed	Yes		
Ratings	Tug, Night				
Medical Expiry Date	30 September 2018				
Restrictions	None				
Previous Accidents	None				

First officer flying experience:

Total Hours	4 157.1
Total Past 90 Days	121.3
Total on Type Past 90 Days	81.3
Total on Type	81.3

Maintenance personnel (maintenance engineer):

Nationality	South African	Gender	Male	Age	56
Licence Number	0272007022	Licence Type	AME		
Licence valid	Yes	Type Endorsed	Yes		
Ratings					
Medical Expiry Date	30 September 2018				
Restrictions	None				
Previous Accidents	None				

According to the available information, the maintenance engineer was qualified and rated on the engine type for maintenance, including on-wing maintenance and other various advanced maintenance.

1.6 Aircraft Information

Airframe:



Figure 5: The aircraft type

Type	Avro 146-RJ85A	
Serial Number	E2313	
Manufacturer	British Aerospace	
Date of Manufacture	1997	
Total Airframe Hours (At time of Accident)	29 636.11	
Last MPI (Date & Hours)	19 June 2017	29 187.09
Hours since Last MPI	449.02	
C of A (Expiry Date)	27 August 2018	
C of R (Issue Date) (Present owner)	13 June 2017	
Operating Categories	Part 121	

Engine 1:

Type	Honeywell_RJ85
Serial Number	LF07608
Hours since New	26 431.5
Hours since Overhaul	Modular type engine

Engine 2:

Type	Honeywell_RJ85
Serial Number	LF07566
Hours since New	30 594.83
Hours since Overhaul	Modular type engine

Engine 3:

Type	Honeywell_RJ85
Serial Number	P07943
Hours since New	25 268.33
Hours since Overhaul	Modular type engine

Engine 4:

Type	Honeywell_RJ85
Serial Number	LF07642
Hours since New	27691.4
Hours since Overhaul	Modular type engine

- 1.6.1 Engine no. 2 was fitted on the aircraft 2 June 2013. The last shop visit or overhaul on engine no. 2 was carried-out at a time since new (TSN): 23 012 hours and cycles since new (CSN): 20 542 cycles. The engine comprises four different modules. The fourth-stage turbine rotor disc assembly is fitted onto the low-pressure (LP) turbine shaft within the combustor turbine module. The approved maintenance schedule stipulates that after every 16 600 cycles, the fourth-stage turbine rotor disk must be replaced, and that blades are maintained on condition. According to the maintenance records, the fourth-stage turbine rotor disk assembly was replaced by the aircraft maintenance organisation (AMO) on 27 July 2017: part number (P/N) 2-141-170-R60 was replaced with P/N 2-141-170-59. The Certificate of Release to Service indicates that the fourth-stage rotor disk assembly that was fitted in lieu of the replaced disc assembly was a repaired unit with TTSN: 11 885 hours and CSN: 9 419 cycles.
- 1.6.2 According to the AMO, this task was carried-out in accordance with the Aircraft Maintenance Manual (AMM) as an on-wing. No records of parts requisition or dimension checks could be traced during investigation. According to the Engine Illustrated Parts Catalogue (EIPC) LF507-1F (507F.3), dated 13 April 2013, during replacement or maintenance of fourth-stage rotor disc assembly the retaining nut (P/N: 2-141-222-10) is superseded by 2, cup washer (P/N: 2-141-221-05) with a condition of post-service bulletin (SB) LF507-1F-72-31. At the time of incident, the investigation team determined that the retaining nut P/N: 2-141-222-10 was fitted; the cup washer could not be located after the incident. No records of parts withdrawal from the store were found during investigation. The EIPC was revised on 30 April 2013 during the replacement of the fourth-stage turbine disc assembly, carried on the latter. The AMO was supposed to use the retaining nut of latest P/N as per EIPC, but instead they reused the same old P/N. However, the manufacturer indicated that the retaining nuts are interchangeable.
- 1.6.3 All maintenance logbooks and records were reviewed and studied. All applicable Airworthiness Directives (ADs) and SBs published by the engine manufacturer had been adhered to by both the owner and the maintenance organisations. The last borescope inspection (BSI) report was reviewed and found to be carried out within the stipulated interval of 3 000 hours. The life limited parts status record was reviewed and no indication was found of any LLP being overflown. The last hot section inspection (HSI) records were reviewed and no indication of defects were found.

1.7 Meteorological Information

1.7.1 Meteorological information as obtained from the South African Weather Service.

Wind direction	080°	Wind speed	12 kt	Visibility	CAVOK
Temperature	15°C	Cloud cover	None	Cloud base	None
Dew point	10°C				

1.8 Aids to Navigation

1.8.1 The aircraft was fitted with navigational equipment as per Regulator requirements for the operational category of the aircraft type. No anomalies or defects were noted on the equipment during flight.

1.9 Communications

1.9.1 The aircraft was fitted with a very high frequency (VHF) radio as per Regulator requirements for the aircraft operational category. No anomalies were noted on the radio communication equipment prior to or during the incident.

1.10 Aerodrome Information

1.10.1 The incident occurred 240 nm north-east of FAOR during cruise . over the area of UTULI in Limpopo province, within South African controlled airspace. The aircraft later landed safely at FAOR with no casualties reported.

1.11 Flight Recorders

1.11.1 The aircraft was equipped with a solid-state flight data recorder (SSFDR) with the following details:

- Part no.: 980-4700-003
- Serial no.: 0288

1.11.2 The aircraft was equipped with a solid-state cockpit voice recorder (SSCVR) with the following details:

- Part no.: 2100-1020-02
- Serial no.: 000126107

According to CVR analysis, following the occurrence the crew focused on taking control of the aircraft. During this time, emergency landing zones in the surrounding area were organised. The crew demonstrated good airmanship as they worked together and focused on taking control of the aircraft during an emergency situation. They were able to stabilise the aircraft, where after, at their discretion, they made their decision to fly the aircraft to intended destination following a careful evaluation of the aircraft's controllability and stability given the emergency conditions.

1.12 Wreckage and Impact Information

- 1.12.1 The incident occurred during flight at a height of approximately 34 000 ft AMSL during cruise phase. Damage to both engines was due to an uncontained engine failure that originated on the no. 2 engine. The no. 2 engine's left-hand side casing was ripped open by the fourth turbine wheel. The fourth turbine rotor wheel was found stuck on the exhausted casing with the retaining nut in between the turbine disc and the exhaust ribs. All turbine blades on the wheel assembly broke off and flew towards engine no. 1, striking it.



Figure 6: Damage to no. 2 engine's fourth-stage turbine casing



Figure 7: Damage to the shaft assembly and the fourth-stage turbine wheel, as it was found

There was evidence of damage caused by flying objects on the no. 1 engine cowlings. In addition, the turbine blades were found within the cowlings, which caused damage to the engine components, and fuel, oil and pneumatic lines.



Figure 8: Damage to the engine cowlings, fuel and pneumatic lines, and FADEC box from engine no. 1

1.13 Medical and Pathological Information

1.13.1 None.

1.14 Fire

1.14.1 According to passenger eyewitness reports, at the time of the incident sparks were observed from the no. 2 engine exhaust. The pilot used both the no. 1 and no. 2 engine fire bottles to extinguish any possible fire on the engines.

1.15 Survival Aspects

1.15.1 There were no injuries sustained during this incident. The damage to the aircraft was limited to both port-side engines and the engine pylon assembly of engine no: 1. The emergency landing was executed uneventfully at FAOR, with airport fire and rescue crew on standby along the runway.

1.16 Tests and Research

1.16.1 The engine was shipped to the engine manufacturer for teardown and analysis. Prior to the engine teardown, the engine was sealed in a container and was opened in the presence of the South African Investigation Team, National Transport Safety Board, Federal Aviation Administrator accredited representatives and Honeywell Technical Members. The engine component conditions were observed as follows:

- The teardown revealed serious internal damage caused during the incident, which lead to an engine failure. Figure 9 shows some of the major engine drive components that sustained serious damage.



Figure 9: Damage to the drive shaft and the third stator assembly

- The condition of the magnetic over speed pick-up found compromised (Figure 10).



Figure 10: Magnetic over-speed pick-up on the damaged bearing no. 4



Figure 11: Damages to the LP turbine shaft (deformation)

The below information provided by the engine manufacturer was discussed in telephone conference with all relevant parties involved.

- 1.16.2 According to the AMM used during the noted fourth-stage turbine rotor disk change, the following procedures are stipulated:

Fourth-stage turbine rotor removal/ installation procedure

Given that the fourth-stage turbine rotor was replaced on-wing, the AMM is the applicable document (Appendix A).

Removal procedure

To remove the existing fourth-stage turbine rotor, the tabs of the lock cup are straightened. Adapter LTCT-01 and torque wrench PD 2501-SD are used to break the torque on the retaining nut. The retaining nut and lock cup are then removed. The fourth-stage turbine rotor and the third-stage LP turbine shaft are match-marked. Puller LTCT 14818-01 is used to remove the fourth-stage turbine rotor. If difficulty is experienced in the removal process, the shaft-to-rotor assembly interface may be soaked with penetrating oil and dry ice may be packed into the shaft interior. Note that there is an interference fit between the fourth-stage turbine rotor disk and the LPT shaft. Also, note that the over-speed ring is not disturbed and is held in place by the seal.

Installation

(Reference: Bae Series/Avro 146-RJ Series AMM 72-52-01, pages 407–413)

To install the replacement fourth-stage turbine rotor, the rotor is heated with either an LTCT 13873-01 bore heater or in an LTCT 7173-1 furnace. Maintenance paperwork for engine LF-07566 indicates the use of furnace LTCT 7173. Fixture LTCT 14616 is used to lift and install the fourth-stage turbine rotor onto the LPT shaft, aligning match-marks until the rotor assembly is bottomed against the over-speed pick-up ring. Illustrations in the AMM emphasise that the teeth in the fourth-stage turbine disk must fully engaged in the over-speed pick-up ring. The lock cup and retaining nut are installed while the disk is still hot. Adapter LTCT 13857-01 and power dyne torque wrench PD-2501-SD are used to tighten the retaining nut to a torque between 470 and 480 ft.lb. The lock cup retainer tabs are not bent into the nut at this time. The assembly is allowed to cool for approximately 30 minutes. The retaining nut and lock cup are removed after the cooling period. The correct axial placement of the disk is then verified.

- 1.16.3 AMM procedures: findings on work done

Engine LF-07566 is in post-SB ALF/LF 72-1030 configuration. For the post-SB configuration, the engine maintenance manual (EMM) states that the distance between the aft end of the LPT shaft and the aft end of the fourth-stage turbine disk should be between 0.678–0.711 inches. The AMM states (for post-SB ALF/LF 72-1030 configured engines) that the distance between the end of the third stage turbine rotor and the fourth-stage turbine rotor is checked to see that it is within limits.

The AMM does not state or reference numerical dimensions for these limits. Email

correspondence with the operator confirmed that the airline used the procedure in the AMM for pre-SB configured engines. The pre-SB procedure is for the fourth-stage turbine disk and pick-up ring that does not have tangs which require alignment during stacking. The use of the pre-SB dimensional check presents an opportunity for errors by not assuring the correct axial placement and engagement of the fourth-stage turbine with the LPT shaft.

1.16.4 Review of events and investigation findings by the engine manufacturer:

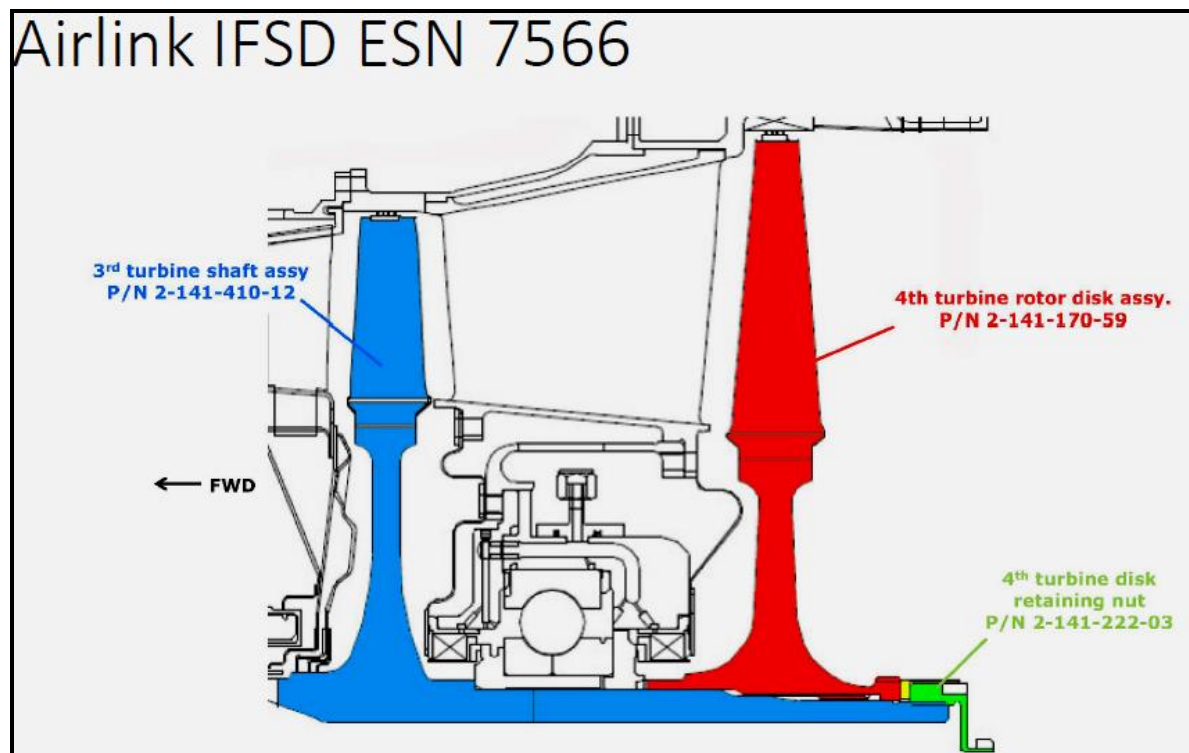


Figure 12: Schematic illustration of the fourth and third turbines

- The fourth-stage PT rotor was replaced on-wing as per the AMM at 320.2 hours, 248 cycles before this event.
- The shaft and nut threads were intact and not sheared, implying the retention nut backed off.
- The fourth-stage PT disk experienced an over-speed as a result of the disk spline disengaging its mating spline on the PT shaft. This led to the release of the fourth-stage PT blades.
- The fourth-stage power rotor is downstream of the control over-speed sensor; as such the over-speed sensor would not have been triggered.

1.16.5 The root cause investigation:

- The primary cause was the retention nut backing off, allowing the fourth-stage rotor to disengage from the LPT shaft.
- The root cause was narrowed down to two potential causes. The clamp load holding the fourth-stage turbine rotor onto the LPT shaft was relieved due to either:
 - mis-stack of the over-speed ring and the fourth-stage turbine rotor disk, or
 - the retention nut was not torqued to requirements.

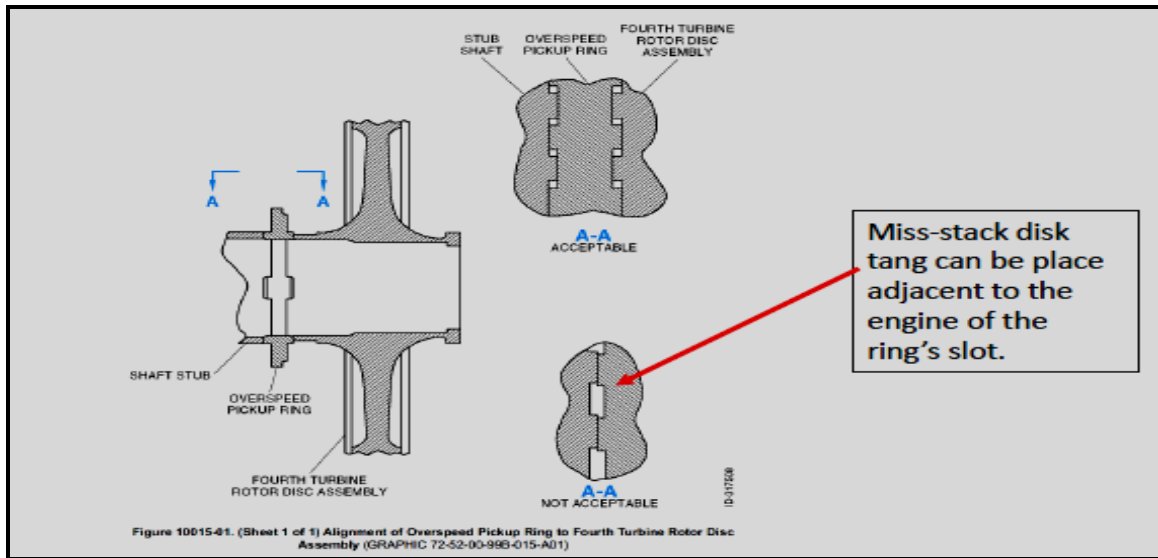


Figure 13: Schematic illustration of the mis-stack and correct stacking of the over-speed ring

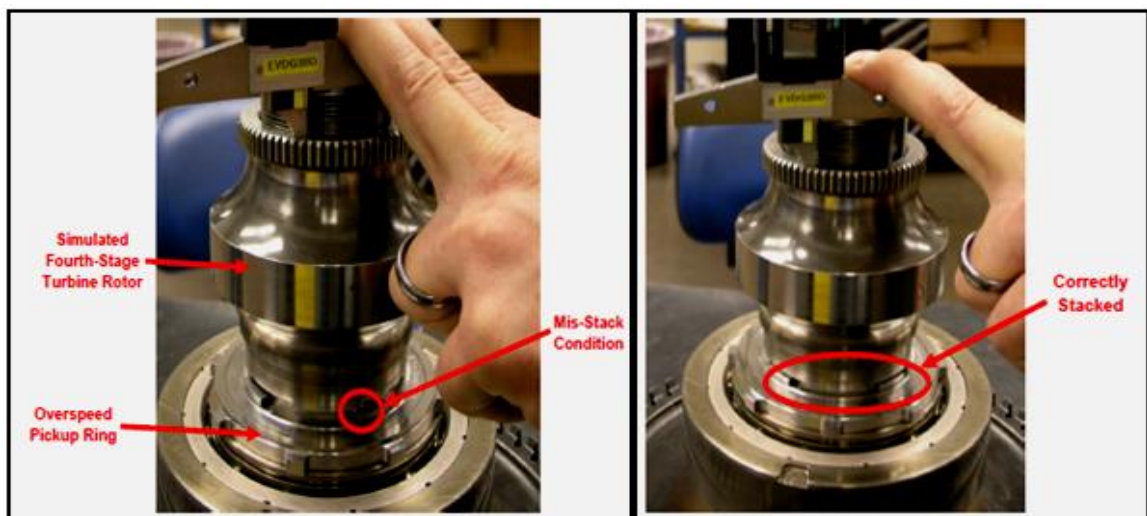


Figure 14: Simulated mis-stacking and correct stacking of the over-speed ring

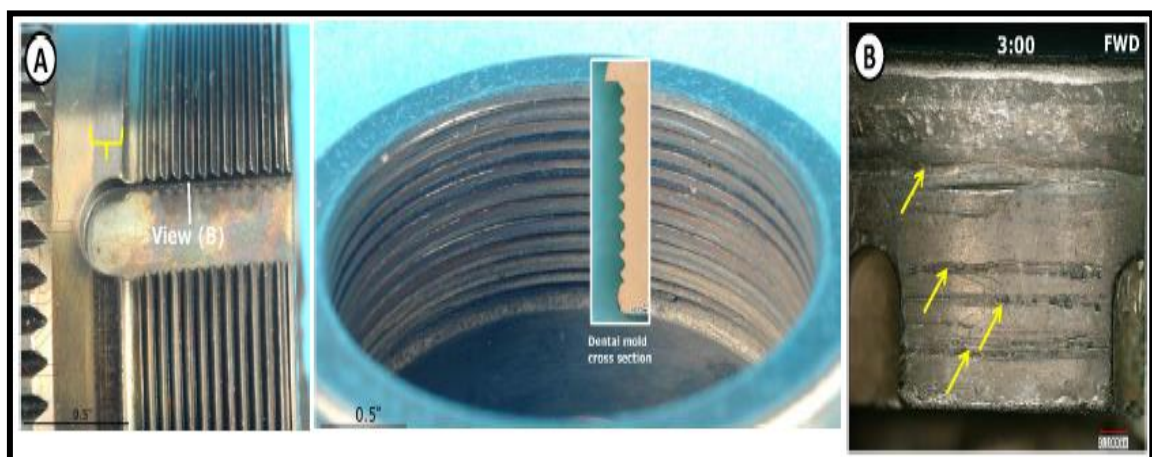


Figure 15: Shows the retaining nut

1.16.6 Confirmation from the operator:

- A new lock cup was installed in July 2017 during a maintenance service.
- A retention nut was reused during maintenance.
- AMM assembly instructions did not have the instructions on how to mark the fourth-

stage rotor assembly to support the alignment of the disk slots into the pick-up ring tang.

- According to the AMO's email correspondence, AMM 72-52-01 page 406 step (12) was followed during the maintenance procedure.

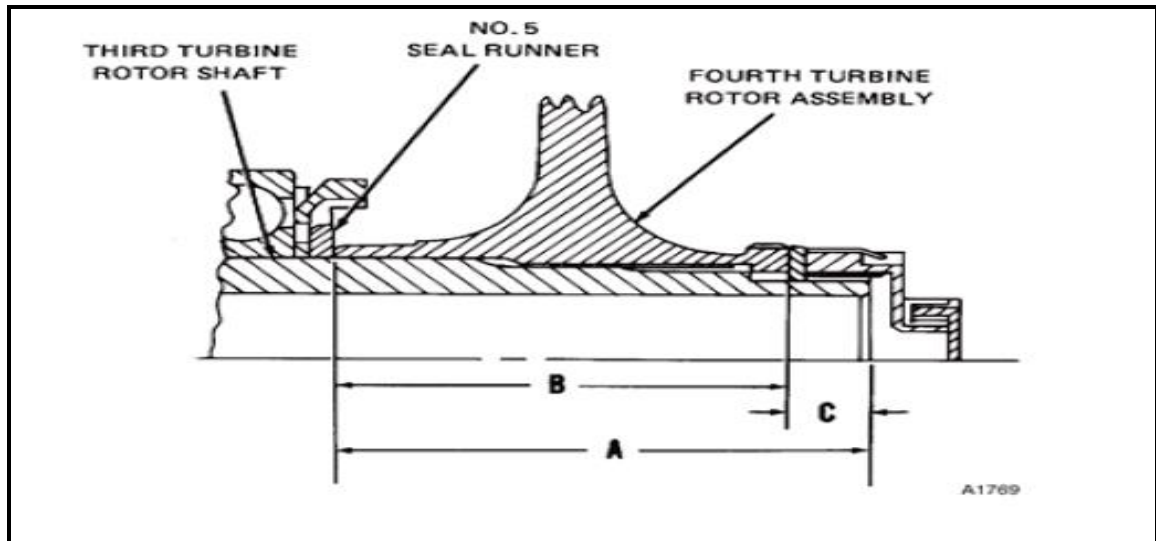


Figure 16: Dimension checks for pre-SB

- The below dimension check is contained in the EMM for the post-SB configuration procedure.

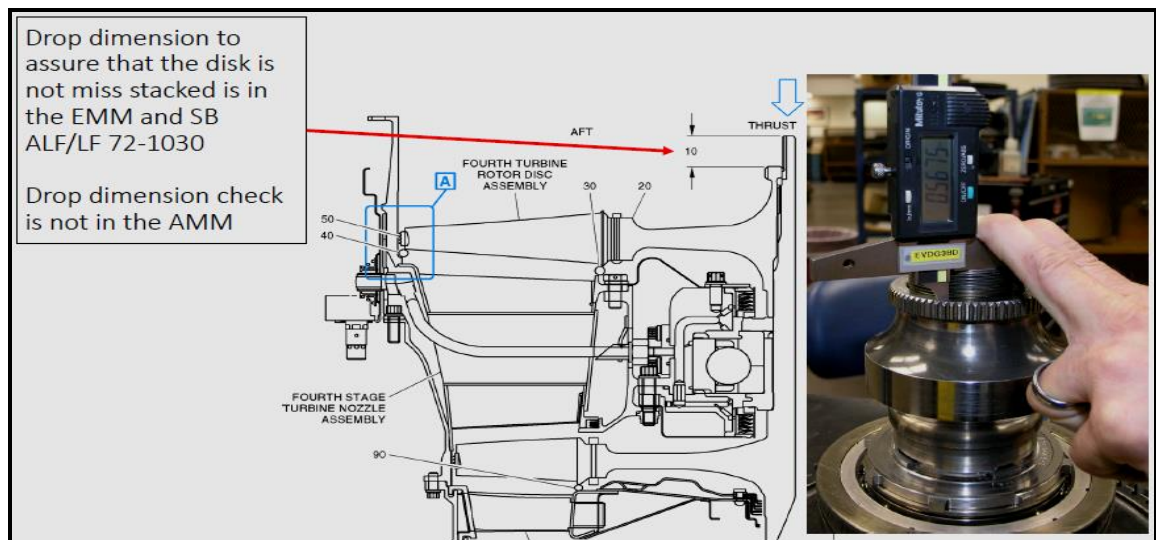


Figure 17: The anti-rotor tangs and slots

- As stated in the EMM: "Apply alignment mark on the end of the fourth turbine rotor disc assembly that is directly in line with the centre of any slot on the forward end of disc."
- AMM assembly procedure did not have a drop dimension check to ensure that the fourth-stage disk is not mis-staked. The AMM stated to check within limits without referencing a sketch or numerical limits or the engine maintenance manual, which lists numerical limits.

1.16.7 Conclusion:

- According to the engine manufacturer, the removal and installation procedure is

described in both the EMM and the AMM.

- The fourth-stage PT disk installed in early 2000 were just starting to reach their life limits, increasing the potential for on-wing maintenance and the potential for mis-staking.
- Service bulletin 72-1030 and 72-1040 were issued in December 1998 followed by the airworthiness directive 96-ANE-36-AD issued in May 2000.
- Implementation of the new single bearing design would be conducted at an engine shop using the EMM and SB instructions. Both have the unambiguous drop measurement.

1.16.8 Actions by the engine manufacturer during investigation:

- Completed on 19 April 2018: Excerpts provided to Air Link Airlines regarding the dimension.
- Underway: Honeywell to provide BAE shared data to support the update of the AMM with the dimension check for the post-SB to ensure proper assembly.
- Underway: Seeking SACAA investigator-in-charge (IIC) permission to issue a fleet notification to release some evidence from the investigation, namely:
 - Recent on-wing replacement of the fourth-stage turbine rotor
 - Use of dimensional checks as described in the EMM and service bulletins 72-1030 and 72-1040.

1.17 Organizational and Management Information

1.17.1 The operator held an Air Operating Certificate (AOC) valid until 30 April 2018, which was issued by Regulator on 20 April 2017.

1.17.2 The aircraft was maintained by an AMO that was in possession of an approved, valid AMO certificate. It was noted that during the said fourth-stage turbine rotor disc change, only the AMM maintenance procedure was followed. Although it has been emphasised that the post-SB procedures were followed, measurement for a dimension check with reference to pre-SB procedure was followed during this service.

1.17.3 During investigation, the engine manufacturer and the aircraft manufacturer indicated the following area in which they believe that improvements are required: A release of all operator message (AOM: Ref. 18-009V-1) that refers to amendment of the AMM's post SB ALF/LF 72-1030 for a dimension check of the fourth-stage turbine rotor disc assembly installation.

Recommendation: BAE Systems recommends that operators make the organisations responsible for the maintenance of their aircraft aware of this investigation finding, emphasising the requirement to pay particular care when installing the fourth turbine rotor disc assembly.

1.18 Additional Information

1.18.1 Investigation review of the AMM procedure for the fourth-stage turbine rotor disc on-wing removal and installation:

(Reference: Honeywell BAE 146 Series/Avro 146-RJ Series AMM: 72-52-01 September 15/02, pages 401–416)

Pages 401–402: (A) Talks to the **removal and installation** of equipment and materials
Pages 402–404: (B) Talks to pre- and post-Honeywell SB ALF/LF 72-1030 removal of the fourth-stage turbine rotor assembly procedure
Pages 404–407: (C) Talks to the pre-Honeywell SB ALF/LF 72-1030 installation of the fourth-stage turbine rotor assembly with reference to **Figure 401**.

- Steps (1) (b) (c) and (d) on page 404 make reference to Figure 402 for dimension checks.
- Step (12) of the procedure requires that measurements of the length of shaft protruding beyond fourth turbine rotor assembly (6) dimension should be within ± 0.005 inches (0.13 mm) of dimension C obtained previously (see para.1.C.(1)(d)).

Note: A preliminary check of the fourth turbine blade axial and tip clearance may be conducted before the final fourth turbine nut torque is applied.

Pages 407–409: (D) Talks to the post-Honeywell SB ALF/LF 72-1030 installation of the fourth-stage turbine rotor assembly with reference to **Figure 401**.

- Step (5) of the post-SB procedure refers to **Figure 404** for over-speed pick-up ring match-marks alignment and full engagement of the teeth during installation of the fourth turbine assembly.
- No reference to Figure 402 under the post-SB procedures was found.
- In addition, nowhere have the AMM made reference note to the EMM for dimension checks.

1.19 Useful or Effective Investigation Techniques

1.19.1 None.

2. ANALYSIS

- 2.1 Both crew members were qualified for the flight in accordance with regulatory requirements. The PIC is a holder of a valid ATPL licence with the aircraft type rating endorsed in it. His aviation medical certificate was valid with no restrictions. He had accumulated a total of 8 895 flying hours and a total of 7 035.8 total flying hours on the aircraft type.
- 2.2 The first officer is also a holder of a valid ATPL licence with the aircraft type rating endorsed on it, and his aviation medical certificate was valid with no limitations. He had accumulated a total of 4 157.1 flying hours. The investigation deduced that the flight crew had sufficient experience to fly the aircraft safely.
- 2.3 The maintenance personnel (chief maintenance engineer) is a holder of a valid aircraft maintenance engineer (AME) licence with the correct engine type rating endorsed on it. He had been employed by the organisation in May 1997 to the engine workshop. During his tenure with the organisation, he had accumulated experience not limited to removal and

installation of accessory gearbox, fan module, fourth turbine rotor, LP turbine module, carbon seals, and hot section, over-temp, foreign object damage (FOD) ingestion and under-power inspections on ALF 502/507 engines.

2.4 The aircraft was in position of both a valid Certificate of Registration (C of R) and Certification of Airworthiness (C of A) at the time of the incident. According to the available records, all maintenance conducted on this aircraft had been carried out by an AMO belonging to the operator and holding a valid AMO certificate. The aircraft was properly maintained in accordance with the existing regulations and an approved maintenance schedule. The aircraft was considered serviceable prior to the flight.

2.5 The aircraft was fitted with four turbofan engines (LF507-1F model type). The no. 2 engine was installed on 2 June 2013 at an engine total time of 23 012 hours and and total of 20 542 engine cycles. Following the incident, a review of maintenance revealed that the fourth-stage turbine rotor disc was changed on engine no. 2 due to time limits. The last maintenance on the engine turbine gas module was carried out on 27 July 2017, during which a fourth-stage turbine disc assembly was due for removal. According to AME personnel and the available information, the AMM removal/installation procedures were followed for the on-wing fourth-stage turbine rotor disc installation. This procedure is aligned with the pre- and post-SB ALF/LF 72-1030 configuration. The post-SB procedures in the AMM did not contain detailed dimension checks for the service. The AMM contains dimension check instructions for pre-SB engine configuration type procedures. Also confirmed during investigation by the engine manufacturer was that only in the EMM is there reference to the dimension drop check; procedure requires that both the AMM and the EMM should be used during the maintenance service. However, this is not noted anywhere in the procedure stipulated in the AMM.

The AME confirmed that the dimension checks from AMM 72-52-01 page 406 step (12) were used. This outlines the step procedures of the pre-SB ALF/LF 72-1030. The pre-SB engine configuration does not include instructions on over-speed ring pick-up with tangs alignment. The AMO used the wrong maintenance procedure during the installation of the fourth-stage turbine rotor disc in which step 12 of pre-SB engine configuration type maintenance procedure was used for dimension checks for a post-SB configuration.

2.6 The complexity of the on-wing fourth-stage turbine rotor disc assembly installation poses a high likelihood of over-speed pick-up ring mis-stacking due to no restricted lateral movement. Unlike engine shop bench base maintenance where the engine is placed along the vertical axes, on-wing maintenance allows lateral movements, which is inevitable as components slide during maintenance. The AMM does not contain the dimension drop check reference for the post-SB procedures. In addition, the AMO used the AMM as the only source of maintenance procedures, as this was an on-wing maintenance requirement. There were no references of written notes taken during the maintenance procedure by AME personnel, and there was no reference to any other document with regard to dimension checking in the procedures except for alignment of the over-speed pick-up ring. However, the engine manufacturer and the aircraft manufacturer have indicated that they will review the AMM and amend the procedures accordingly for the post-SB engine configured service procedure.

2.7 It took the retaining nut and the fourth-stage turbine rotor wheel approximately 320.2 flying hours and 248 cycles since installation to back off and dislodge from its LP turbine shaft assembly. According to the engine manufacturer's analysis, the events during this failure

indicate that the component backed off over time due to two possible conditions, namely: the incorrect application of torque settings; or improper installation due to a possible mis-stacking of the over-speed ring during maintenance. It is easy to mis-stack the over-speed ring without anyone noticing as it is impossible to check visually; it can only be confirmed with a dimension drop check.

- 2.8 During investigation, records of the maintenance dimension checks were requested but could not be provided by the AMO. Records of parts requisition for the new retaining lock cup could not be provided from the store. However, it is likely that the retaining lock cup could have been thrust out during engine failure due to its light weight.
- 2.9 The EIPC, dated 13 April 2013, indicates that during replacement or maintenance of fourth-stage disc assembly, the retaining nut P/N 2-141-222-10 is superseded by 2, cup washer P/N 2-141-221-05 with a condition of post-SB LF507-1F-72-31. At the time of the incident, the investigation team determined that the P/N of the retaining nut that was fitted was 2-141-222-10, and the cup washer could not be located after the incident. The EIPC was revised on 30 April 2013, indicating that a P/N has to be replaced by another for both lock cup and retaining nut. The impact of using an old P/N could not be determined by the investigation and the original equipment manufacturer (OEM) could not clarify. According to the engine manufacturer, the components are interchangeable. The investigation could not establish with any certainty the significance of having two different P/N components being interchangeable.
- 2.10 The investigation revealed that the fourth-stage turbine rotor disc dislodged from its assembly LP shaft due to a retaining nut that backed off over time during operation. The retaining nut might have backed off due to improper installation caused by one of over-speed ring mis-stacking, improper torque application or a missing lock cup washer. However, it is likely that the lock cup washer was lost due to engine thrust during the incident sequence, as the washer is light in weight.

3. CONCLUSION

3.1 Findings

- 3.1.1 The PIC held a valid ATPL with the aircraft type rating endorsed on it, and his aviation medical certificate was valid with no restrictions.
- 3.1.2 The first officer held a valid ATPL with the aircraft type rating endorsed on it, and his aviation medical certificate was valid with no restrictions.
- 3.1.3 The maintenance personnel held a valid AME licence with the engine type rating endorsed on it.
- 3.1.4 The maintenance personnel was highly experienced in the installation of the fourth-stage turbine assembly, with a total record of nine previous installations on other similar engines.
- 3.1.5 The aircraft was properly registered with a valid C of R and C of A at the time of the incident.

- 3.1.6 The AMO that maintained the aircraft held an appropriate, valid certificate.
- 3.1.7 The maintenance records indicated that the aircraft was properly maintained in accordance with existing regulations and approved maintenance schedule. However, during a fourth-stage turbine rotor disc change a wrong procedure was followed: pre-SB engine configuration type procedure was applied during a post SB engine configured installation.
- 3.1.8 During replacement of the fourth-stage disc assembly, a retaining nut that had been fitted before was reused and a new locking cup was used.
- 3.1.9 The fourth-stage disc assembly was fitted on 27 July 2017 as a repaired unit which had a total of 11 885 hours and 9 419 cycles.
- 3.1.10 The incident occurred at approximately 340.2 flying hours and 280 cycles after the fourth-stage turbine rotor disc installation.
- 3.1.11 The aircraft encountered a catastrophic failure of engine no. 2, whereby the turbine blades debris from the fourth-stage turbine rotor disc impacted the no. 1 engine, damaging the FADEC box system and causing an un-commanded shutdown.
- 3.1.12 Following the failure, there was a persistent vibration from engine no. 2, as reported by the crew on engine number 1; therefore, the crew used both the no. 1 and no. 2 engine fire extinguisher bottles.
- 3.1.13 Upon taking manual control of the aircraft and after a careful assessment of the emergency situation, the crew opted to continue with the flight to their destination, and the aircraft landed safely.
- 3.1.14 The crew demonstrated good airmanship and good use of crew resource management.
- 3.1.15 The investigation revealed that no2 engine uncontained failure was attributed to the LP turbine retaining nut becoming dislodged resulting on the fourth-stage turbine rotor disk disengaged from the LP turbine shaft. The incorrect application of torque settings; or improper installation due to a possible mis-stacking of the over-speed ring during maintenance

3.2 Probable Cause/s

- 3.2.1 The cause of the no2 engine uncontained failure was attributed to the LP turbine retaining nut becoming dislodged resulting on the fourth-stage turbine rotor disk disengaged from the LP turbine shaft. The fourth-stage turbine rotor disc compromised the turbine casing and turbine debris from the no. 2 engine struck the no. 1 engine, causing an un-commanded shutdown and leading to a catastrophic failure of both port-side engines.

3.3 Contributory factors

- 3.3.1 The incorrect application of torque settings; or improper installation due to a possible mis-stacking of the over-speed ring during maintenance

4. SAFETY RECOMMENDATIONS

- 4.1 It is recommended that the Director for Civil Aviation (DCA) publish an operator alert for dimension check reference in the EMM for on-wing fourth turbine rotor disc assembly maintenance procedure for post-SB ALF/LF 72-1030 engine configuration. During this investigation, it was revealed that the wrong dimension check reference diagram for pre-SB ALF/LF 72-1030 was used for an on-wing fourth turbine rotor disc assembly installation. In addition, there is no other reference of dimension reference for post-SB engine configuration in the AMM. Although agreement between the investigation team and both the engine and airframe manufacturers was reached, in consideration of the findings, to review and amend the AMM accordingly (which is subsequently underway), a prediction has been made that most of the engines in operation with similar post-SB configuration will soon require a fourth turbine rotor disc change due to time limit. It is therefore encouraged that an interim service advisory be communicated to operators regarding the dimension check reference in the EMM.
- 4.2 That the manufacturer published a document shared with the investigators: (Reference: **BAE SYSTEMS All Operator Message: Ref 18-009V-1**) as stated below.
- 4.2.1 Amendments are to be made to the BAE 146-RJ AMM to include the dimension check reference for the fourth turbine rotor assembly installation for on-wing post-SB ALF/LF 72-1030 engine configuration procedures. A release of an all operator message (AOM: ref. 18-009V-1), referring to amendment of the AMM's post-SB ALF/LF 72-1030 with regard to dimension checking of the fourth-stage turbine rotor disc assembly installation, is underway.

Recommendation: BAE Systems recommends that operators make the organisations responsible for the maintenance of their aircraft aware of this investigation finding, emphasising the requirement to pay particular care when installing the fourth turbine rotor disc assembly. Refer to Annexure B.

5. APPENDICES

- 5.1 Annexure A: LF-07566 Tests, Inspection and Findings Report
- 5.2 Annexure B: AOM: Ref 18-009V-1 Issue: 9, Date: 12/09/2018

Appendicesx

Annexure A: LF-07566 Tests, Inspection and Findings Report

EXAMINATION AND INVESTIGATION OF ONE HONEYWELL MODEL LF507-1F TURBOFAN ENGINE SERIAL NUMBER LF-07566

HONEYWELL AEROSPACE
PHOENIX, ARIZONA

1. INTRODUCTION AND SUMMARY

1.1 PURPOSE

This report, prepared by the Product Integrity Group of Honeywell Aerospace, Inc., presents the findings from an investigation on one Honeywell model LF507-1F turbofan engine, serial number LF-07566. The investigation took place at Honeywell Aerospace, Phoenix, Arizona, from January through April, 2018.

The investigation was conducted at the request and under the cognizance of the South African Civil Aviation Authority (CAA). The United States of America National Transportation Safety Board (NTSB) assigned an accredited representative to the investigation.

1.2 BACKGROUND

On November 8, 2017, at approximately 1750 Zulu, South African Air Link Flight 8103, a British Aerospace BAe-146 RJ-85A passenger aircraft, registration ZS-ASW, experienced an uncontained release of turbine material from the No. 2 engine during cruise flight. The No. 2 engine is a Honeywell model LF507-1F turbofan engine, serial number LF-07566. The captain reported that the airplane was in cruise flight at Mach Number (M) 0.70 and Flight Level (FL) 340 at the UTULI positioning fix when they heard a loud bang that was immediately followed by cockpit indications that the No. 2 engine had lost power ([Appendix A](#)). The crew also noted that the No. 1 engine had lost power. The crew reported that there was a pronounced vibration from the No. 2 engine, although there were no vibrations from the No. 1 engine. The crew stated that the flight attendant reported seeing intermittent sparks and flames from the No. 2 engine's exhaust. The pilots discharged two fire bottles into the No. 2 engine's nacelle. The crew was able to maintain FL 180 and an airspeed of 225 knots. After contacting maintenance control, the pilots decided to continue to Johannesburg, South Africa where the aircraft landed without further incident.

1.3 SUMMARY

Examination and investigation of engine LF-07566 removed from Air Link Flight 8103 disclosed that the turbine retention nut backed off the low-pressure turbine shaft, allowing the fourth-stage turbine rotor to disengage from the low-pressure turbine shaft. Disengagement of the fourth-stage rotor resulted in the liberation of turbine blade material from the No. 2 engine, causing secondary damage to the No. 1 engine and led to an uncommanded shut down of both engines.

Root cause of the retention nut backing off was narrowed down to two potential causes. The clamp load holding the fourth-stage turbine rotor onto the low-pressure turbine shaft relieved either due to (1) a miss-stack of the overspeed ring and the fourth-stage turbine rotor disk, or (2) the turbine retention nut was not torqued to requirements. The consensus opinion at Honeywell is that the miss-stack of the overspeed ring and fourth-stage turbine rotor is the most likely probable cause.

2. INCIDENT DESCRIPTION AND PRELIMINARY OBSERVATIONS

On November 8, 2017 at approximately 1750 Zulu, South African Air Link Flight 8103, a British Aerospace BAe-146 RJ-85A aircraft, registration ZS-ASW, experienced an uncontained release of turbine material from the No. 2 engine (Figure 1). The incident occurred while in cruise flight (FL340, M0.70). Debris from the No. 2 engine impacted the No. 1 engine (Figure 2), causing the No. 1 engine to shutdown (uncommanded). The aircraft landed at O. R. Tambo International Airport (FAOR) without further incident.

2.1 AIRCRAFT POST LANDING OBSERVATIONS

After landing, the aircraft was inspected for damage. Regarding the No. 2 engine, the fourth-stage turbine rotor was lodged into the engine's tail pipe (Figure 3). The fourth stage turbine rotor and retaining nut were recovered. The lock cup was not recovered. Figure 4 illustrates a cross section of the parts discussed above. The No. 2 engine, along with the recovered components, were shipped to Honeywell Aerospace in Phoenix, Arizona, for an engine teardown examination. The teardown examination occurred on January 9-11, 2018.

Debris from the No. 2 engine struck the No. 1 engine. Debris struck and damaged the low oil pressure processor, fuel tubes, air tubes, and severed several wiring harnesses (Figure 5). The No. 1 engine was not returned to Honeywell Aerospace for investigation.

2.2 FLIGHT DATA RECORDING

The flight data recorder (FDR) from the subject aircraft was downloaded and the data was provided to Honeywell Aerospace. Figure 6 contains a tabular listing of the FDR data at the moment of the incident. There was no indication of a N1 spool overspeed on either the No. 1 nor the No. 2 engine. N1 spool speeds for both the No. 1 and No. 2 engines decreased immediately after the incident, in a manner consistent with an engine shutdown (Figure 7).

At the moment that the N1 spool speed on the No. 2 engine began to decrease, the low oil pressure (OILPLE) and FADEC fail flags were set for the No. 1 engine (Figure 6). N1 spool speed on the No. 1 engine began to decrease at the next sampling interval. Power lever angle (PLA) remained momentarily unchanged and was later increased on all four engines. The FDR data and physical damage to the engines is consistent with an uncommanded shutdown of both the No. 1 and No. 2 engines.

2.3 ENGINE MAINTENANCE HISTORY

The No. 2 engine was a Honeywell model LF507-1F turbofan engine, serial number LF-07566. The airworthiness certificate (0 time since new, 0 cycles since new) was issued on December 22, 1996 (Appendix B). According to maintenance records, the engine had accumulated 30,594.8 hours and 26,323 cycles since new at the time of the incident.

The fourth stage turbine rotor was removed and replaced on engine LF-07566 on July 27, 2017 due to an approaching cycle expiration (Appendix B). The fourth stage rotor was replaced on-wing per Aircraft Maintenance Manual (AMM) 72-52-01, revision 120. The replacement fourth stage turbine had accumulated 12,205.2 hours and 9,667 cycles since new at the time of the incident and 320.2 hours and 248 cycles since installation into the engine. The part number and serial number of the replacement fourth stage turbine rotor was 2-141-170-59 and 041365194436, respectively.

3. FOURTH-STAGE TURBINE ROTOR REMOVAL/INSTALLATION PROCEDURE

Removal and installation of the fourth-stage turbine rotor is described in both the engine maintenance manual (EMM) and aircraft maintenance manual (AMM). Since the fourth-stage turbine rotor was replaced on-wing, the AMM is the applicable document ([Appendix C](#)). [Figure 8](#) and [Figure 9](#) illustrate exemplar hardware referred to in the synopsis below.

To remove the existing fourth-stage turbine rotor, the tabs of the lock cup are straightened. Adapter LTCT 13857-01 and torque wrench PD 2501-SD are used to break the torque on the retaining nut. The retaining nut and lock cup are then removed. The fourth-stage turbine rotor and the third-stage low pressure turbine shaft are matchmarked. Puller LTCT14818-01 is used to remove the fourth-stage turbine rotor. If difficulty is experienced in the removal process, the shaft to rotor assembly interface may be soaked with penetrating oil and dry ice may be packed into the shaft interior. Note that there is an interference fit between the fourth-stage turbine rotor disk and the LPT shaft. Also, note that the overspeed ring is not disturbed and is held in place by the seal ([Figure 4](#)).

To install the replacement fourth-stage turbine rotor, the rotor is heated with either a LTCT13873-01 bore heater or in a LTCT7173-01 furnace. Maintenance paperwork for engine LF-07588 indicates the use of furnace LTCT7173 ([Appendix B](#)). Fixture LTCT14818 is used to lift and install the fourth-stage turbine rotor onto the LPT shaft, aligning matchmarks until the rotor assembly is bottomed against the overspeed pickup ring. Illustrations in the AMM emphasize that the teeth in the fourth-stage turbine disk must fully engage in the overspeed pickup ring ([Figure 10](#)). The lock cup and retaining nut are installed while the disk is still hot. Adapter LTCT13857-01 and Power Dyne torque wrench PD-2501-SD are used to tighten the retaining nut to a torque between 470 and 480 ft-lb. The lock cup retainer tabs are not bent into the nut at this time. The assembly is allowed to cool for approximately 30 minutes. The retaining nut and lock cup are removed after the cooling period. The correct axial placement of the disk is then verified.

Engine LF-07588 is of post service bulletin ALF/LF 72-1030 configuration. For the post-service bulletin configuration, the EMM states the distance between the aft end of the LPT shaft and the aft end of the fourth-stage turbine disk should be between 0.678 – 0.711 inches ([Figure 11](#)). The AMM states (for post service bulletin ALF/LF 72-1030 configured engines) that the distance between the end of the third-stage turbine rotor and the fourth-stage turbine rotor is checked to see that it is within limits ([Appendix C](#)).

The AMM does not state or reference numerical dimensions for these limits. Email correspondence with Air Link Airlines confirmed that the airline used the procedure in the AMM for pre-service bulletin configured engines ([Appendix D, Figure 12](#)). The pre-service bulletin procedure is for fourth-stage turbine disks and overspeed pickup rings that do not have the teeth illustrated in ([Figure 10](#)). The use of the pre-service bulletin dimensional check presents an opportunity for errors by not assuring the correct axial placement and engagement of the fourth-stage turbine rotor with the LPT shaft.

The installation concludes with the reinstallation of the lock cup and retaining nut. The retaining nut is torqued to 470 - 480 ft-lb. The lock cup is deformed into the retaining nut ([Figure 13](#)).

4. ENGINE EXAMINATION

Engine LF-07588, along with the recovered components, were received at Honeywell Aerospace in Phoenix, Arizona, on December 19, 2017. A teardown examination of the engine was conducted on January 9-11, 2018. The engine examination was witnessed by representatives from the South African Civil Aviation Authority (CAA), United States National Transportation

Safety Board (NTSB), United States Federal Aviation Authority (FAA), and Air Link Airlines. [Appendix E](#) contains field notes documenting the engine examination.

4.1 INCOMING EXAMINATION

Engine LF-07588 was received in a standard wooden shipping crate, lined with shock resistant foam. The fourth-stage turbine rotor and retaining nut were included in the shipping container. The locking cup was not present in the shipping container.

The retaining nut had witness marks on the outer diameter of the nut ([Figure 14](#)). The access cap, and its locking cup, were installed and intact on the retaining nut. The threads of the retaining nut were intact ([Figure 15](#)).

The disk portion of the fourth-stage turbine rotor ([Figure 16](#)) was intact, but the stub shaft on the front side of the disk was missing ([Figure 17](#)). All fourth-stage turbine blades were separated above the blade platform ([Figure 18](#)). The fourth-stage turbine disk splines were intact and appeared undamaged ([Figure 19](#)).

4.2 OVERSPEED SYSTEM EXAMINATION

Before the engine was torn down, several in-situ tests were accomplished to the overspeed control system ([Appendix E](#)). The control system on LF507-1F engines provides protection against a N1 spool overspeed. The overspeed system consists of three independent magnetic speed pickups, one three channel overspeed controller, an overspeed solenoid valve, and electrical harnesses.

Two magnetic speed pickups are located in the No. 4 bearing package and one pickup is mounted at the 12 o'clock position on the stub frame. The speed pickups permit the measurement of low pressure turbine speed ([Figure 20](#)). When the power turbine speed reaches a pre-set overspeed condition, the controller sends a 28 vdc signal to the overspeed solenoid valve. The solenoid valve then bypasses fuel flow from the engine, causing the engine to shutdown.

The overspeed controller was tested in situ to determine if an overspeed signal from any of the three magnetic speed pickups would initiate a signal to trip the overspeed solenoid. To simulate the magnetic speed pickups, a harness that had three pairs of wires was connected to the overspeed controller ([Figure 21](#)). With the input voltage set at about 2.885 volts rms (vrms), a wave generator was used to vary the frequency from 1000 hertz (Hz) to approximately 2500 Hz when a green light would illuminate. The green light indicated that the controller had initiated a signal to trip the solenoid ([Figure 22](#)). The second part of the test was to set the frequency to 2500 Hz and then increase the input voltage until the green light illuminated. In both tests, the overspeed controller proved to be functional ([Appendix E](#)).

The overspeed solenoid valve was tested by applying a 28 vdc directly to the solenoid and increasing the current. The solenoid could be heard activating at a current draw of approximately 2.7 amps ([Appendix E](#)). The overspeed solenoid valve was functional.

Continuity of the magnetic speed pickups and their associated wiring was measured. The two magnetic speed pickups mounted in the No. 4 bearing package and their associated wiring were open circuit ([Appendix E](#)). The magnetic speed pickups were later isolated from their respective wiring and they were still open circuit. There was significant damage to the No. 4 bearing and speed pick up ring cavity ([Figure 23](#)). The magnetic speed pickup mounted in the stub frame and its associated wiring measured 430.7 ohms. The wires from the overspeed controller to the overspeed solenoid exhibited continuity.

In summary, all components of the overspeed system were functional except for the magnetic speed pickups mounted in the No. 4 bearing package.

4.3 ENGINE TEARDOWN EXAMINATION

The fan gear reduction assembly in engine LF-07566 was intact and largely undamaged. The ring gear was intact (Figure 24) and there was no damage to the ring gear teeth (Figure 25). The planet gear assembly was intact (Figure 26). All the planet gears were in place and there was no damage to the gear teeth (Figure 27). The planet gears rotated freely. The sun gear through bolt was tight. The sun gear was intact (Figure 28). The forward face of the sun gear external splines was rubbed circumferentially with displaced material (Figure 29). There were several metal chips in the external splines. The damper was in place on the inside of the sun gear, but the ends were offset. To summarize, there was no evidence to support a loss of load on the N1 spool due to a fan gear reduction assembly failure. This failure mode is discussed further in section 5.4 regarding two previous ALF502/LF507 incidents.

The low-pressure turbine (LPT) shaft was intact (Figure 30), but had deformation damage on the aft end (Figure 31). 180 degrees opposed to the deformation damage, the LPT splines had sloping deformation damage covering approximately three-quarters of the spline length (Figure 32). The threads on the LPT shaft were intact and appeared to be undamaged 180 degrees opposite to the deformation damage (Figure 32).

The No. 4 bearing outer race was intact, but the bearing cage was partially melted with five balls fused into the cage and seven that were loose (Figure 33 and Figure 34). The balls were still essentially round. The No. 4 bearing stub shaft was melted and remained attached to the aft portion of the LPT shaft (Figure 34). The overspeed pickup ring was fractured into multiple pieces (Figure 35).

5. ROOT CAUSE INVESTIGATION

Thru metallurgical examinations of the turbine hardware from engine LF-07566, testing on surrogate hardware, and engineering analyses, it was concluded that the turbine retention nut backed off the low-pressure turbine shaft allowing the fourth-stage turbine rotor to disengage from the low-pressure turbine shaft. Root cause of the retention nut backing off was narrowed down to two potential causes. The clamp load holding the fourth-stage turbine rotor onto the low-pressure turbine shaft relieved due to either a:

1. Mis-stack of the overspeed ring and the fourth-stage turbine rotor disk, or
2. The turbine retention nut was not torqued to requirements.

5.1 METALLURGICAL EXAMINATION

The fourth-stage turbine rotor, turbine retaining nut, and the low-pressure turbine shaft assembly were submitted for metallurgical examination (Appendix F). Observations from the metallurgical exam lead to the conclusion that the retaining nut backed off the LPT shaft.

The threads on the turbine retaining nut and the LPT shaft were intact and not stripped. Dental impressions of the threads indicate no damage to the LPT shaft threads away from the deformation damage (Figure 36) and only minor damage to the retaining nut threads (Figure 37). The outer diameter of the retaining nut had witness marks consistent with relative motion of the nut to deformations in the lock cup (Figure 38). Similar witness marks were noted during the

anti-rotational capability experiments described in [Appendix G](#). Measurements of the witness mark spacing indicate that they are at an angle consistent with the thread pitch ([Appendix G](#)).

Metallurgical examination of the blades in the fourth-stage turbine rotor confirmed that the fractures surfaces are indicative of overload ([Appendix F](#)). No evidence of fatigue was observed on the blade fracture surfaces. There was circumferential scoring damage to the aft end of the fourth-stage turbine blades ([Figure 39](#)), consistent with aft movement of the fourth-stage turbine rotor and contact with the engine center body.

5.2 BOLTED JOINTS

For the turbine retention nut to back off, the clamp load holding the fourth-stage turbine rotor on the LPT shaft had to be relieved. Machine design articles indicate that some level of tension, or preload, in the bolt and resulting compression in the clamped components is essential to joint integrity. The joint should be designed such that the clamp load is never overcome by the external forces acting to separate the joint. If the external tension forces overcome the bolt preload the clamped joint components will separate, allowing relative motion of the components and the loosening of the fasteners.

A bolt is typically preloaded by the application of a torque to either the bolt head or the nut. The applied torque causes the nut to climb the thread causing a tensioning of the bolt and an equivalent compression in the components being fastened by the bolt. In the case of the LF507-1F engine, the retention nut is torqued to 470 to 480 ft-lbs. This torque results in a clamp load at steady state running condition of 22,500 lb. This level of clamp load is more than adequate to hold the components together for all engine operating conditions.

A fishbone diagram supporting the root cause investigation was created by Honeywell engineering ([Appendix G](#)). The diagram narrowed the possibilities of the retention nut backing off the LPT shaft down to two scenarios. Either there was a mis-stack of the overspeed ring and the fourth-stage turbine rotor disk as illustrated in [Figure 40](#) and [Figure 41](#); or, the turbine retention nut was not torqued to requirements.

In the first scenario, the mating teeth of the fourth-stage turbine disk and the overspeed ring would have to vibrate in the angular direction until the mis-stack condition was removed. The result would be a loss of preload on the clamped joint. As indicated earlier, Air Link Airlines indicated that the pre-service bulletin ALF/LF 72-1030 dimensional check was made, but not recorded. Engine LF-07566 is of the post service bulletin configuration.

In the second scenario, the clamp load or preload on the joint would be dependent on the torque of the retention nut. Air Link Airlines indicated that the nut was torqued to 470 to 480 ft-lb, within the accuracy of 50 ft-lb increments on the torque gauge fixture. Air Link Airlines stated that the installation torque was not recorded.

In either scenario, the locking cup was not able to keep the retaining nut from backing off. A series of static tests was conducted by engineering to quantify the added anti-rotation capability provided by the deformed lock cup ([Appendix G](#)). Measurements indicate that the anti-rotation capability of the lock cup is dependent on the degree of deformation of the lock cup into the nut. The lock cup added between 13 and 47 ft-lb of torque anti-rotation capability.

5.3 OVERSPEED ANALYSIS

When the retaining nut backed off, it allowed the fourth-stage turbine rotor to move aft until the splines in the bore of the disk ultimately lost engagement with the splines on the LPT shaft. The fourth-stage turbine rotor, which would no longer be connected to the N1 spool, would

momentarily overspeed as an individual component. Depending on the magnitude of the overspeed, the disk bore would grow and take a permanent set.

The drawing for the fourth-stage disk indicates that the bore diameter is 2.4300 inch (nominal). The disk manufacturer indicates that the bore dimension is held to a manufacturing tolerance of $\pm .0005$ inches. The fourth-stage turbine disk bore measured 2.4347 inches after the subject incident. Therefore, the residual growth of the bore is .00235 inches radially. Using minimum and nominal material tensile properties, the disk overspeed would be between 134% and 148% speed ([Appendix H](#)).

The fourth-stage turbine blades from engine LF-07566 separated above the blade platform at the airfoil hub. Engineering analysis indicates that the limiting location is at the blade inner lobe shear plane (disk-blade interface). The inner lobe has a speed capability between 136% and 152% speed based on minimum and nominal material tensile properties ([Appendix H](#)). The airfoil hub has a predicted overspeed capability between 150% and 160% based on minimum and nominal material tensile properties. It would be expected that the blades would separate at the inner lobe if the separation was solely due to overspeed. While the fourth-stage turbine rotor did overspeed, engineering analyses indicate that a combination of blade tip rub and overspeed was likely the cause of the fourth-stage turbine blade separations.

Bore measurements were not taken on the third-stage turbine rotor. Manufacturing tolerances are larger for the third-stage turbine disk as compared to the fourth-stage turbine disk. The larger manufacturing tolerances makes the detectability of an overspeed of the third-stage turbine rotor, and hence the N1 spool, less accurate. The gas path extraction capability of the power turbine would have been cut roughly in half at the moment that the fourth-stage turbine rotor became disengaged from the LPT shaft. The N1 spool, including the third-stage turbine rotor, would have experienced a rapid deceleration and not an overspeed condition.

The teardown examination of engine LF-07566 confirmed that the fourth-stage turbine nozzle assembly was not able to contain debris from the disengaged rotor. Containment in this incident was compromised by several factors. These factors include the aft movement of the fourth-stage rotor and the fact that the disk itself was disengaged from the LPT shaft and was striking the housing. No further detailed analysis regarding containment was undertaken during the investigation of engine LF-07566.

5.4 PREVIOUS INCIDENTS

There have been two prior uncontained fourth-stage turbine incidents, and a fourth incident after, the November 8, 2017 incident. The two prior incidents have the same failure mode in which there is a separation of a component in the gear reduction assembly that results in a sudden loss of load on the N1 spool ([Figure 42](#)). The resultant overspeed of the N1 spool was not successfully arrested in either incident due to a second, independent failure in the engine overspeed system. The fourth incident occurred on March 1, 2018 and the investigation is in its preliminary stages and will not be discussed further in this report.

The first incident occurred on August 9, 2004 on British Aerospace Systems AVRO RJ-100 passenger aircraft, registration HB-IXU. The aircraft was on the second flight of the day and was en-route from Amsterdam to Zurich. While in cruise flight at 31,000 feet, the No. 2 engine, a Honeywell model LF507-1F turbofan engine, serial number LF-07510, experienced an uncontained separation of turbine material and shut down.

Debris from the No. 2 engine impacted the No. 1 engine nacelle. The No. 2 engine debris damaged the No. 1 engine fire warning system and N1 speed harness. With the fire warning system activated and no N1 indication, the flight crew initiated a shutdown of the No. 1 engine.

The flight crew declared an emergency, and the aircraft was diverted to Frankfurt, Germany. The flight crew and approximately fifty passengers landed safely.

There was evidence of fatigue in the root area between the ring gear teeth. Two fractures that were present in the ring gear were sufficient to have caused gear tooth disengagement. The ring-to-planet-gear disengagement disconnected the LP turbine from the fan assembly and created the engine overspeed condition. The overspeed system was not able to arrest the overspeed condition due to a defect in the overspeed control unit. The lack of thread locking material on the heat sink threads lead to a fatigue of the voltage regulator electrical wires in the control unit. In summary, dual faults were present during the same flight and caused the in-flight event on engine LF-07510.

The second incident occurred on March 9, 2010 on British Aerospace Systems 146-300 passenger aircraft, registration OB-1949-P. The aircraft experience an uncontained separation of turbine material from the No. 1 engine while on takeoff roll at Jorge Chavez Airport in Lima, Peru. The No. 1 engine is a Honeywell model ALF502R-5-103A turbofan engine, serial number LF-08013AC.

The sun gear separated and there was evidence of fatigue emanating from the forward corners of the gear tooth roots. The separation resulted in a loss of load on the LPT that was not successfully arrested by the engine overspeed system. The failure of the overspeed system to arrest the event was not identified. Several potential causes were ruled out by testing and analysis. Of the remaining potential causes, the most likely cause of the failure of the overspeed system was the lack of aircraft electrical power to the system.

6. CONCLUSIONS

Examination and investigation of engine LF-07588 removed from Air Link Flight 8103 disclosed that the turbine retention nut backed off the low-pressure turbine shaft, allowing the fourth-stage turbine rotor to disengage from the low-pressure turbine shaft. Disengagement of the fourth-stage rotor resulted in the liberation of turbine blade material from the No. 2 engine, causing secondary damage to the No. 1 engine and led to an uncommanded shut down of both engines.

Root cause of the retention nut backing off was narrowed down to two potential causes. The clamp load holding the fourth-stage turbine rotor onto the low-pressure turbine shaft relieved either due to (1) a miss-stack of the overspeed ring and the fourth-stage turbine rotor disk, or (2) the turbine retention nut was not torqued to requirements. The consensus opinion at Honeywell is that the miss-stack of the overspeed ring and fourth-stage turbine rotor is the most likely probable cause. This consensus opinion is based upon multiple factors including:

1. The extended length of time, 320 hours – 248 cycles, that the fourth-stage rotor maintained engagement with the third-stage turbine rotor shaft. An un-torqued retaining nut, with properly stacked hardware, is expected to back off of the shaft in a significantly shorter time frame.
2. The degree of damage to the overspeed pickup ring on the separation of the forward shaft and tangs of the fourth-stage turbine rotor.
3. Admission by the operator that the pre-service bulletin dimensional check was utilized rather than the correct post-service bulletin dimensional check.
4. Although not recorded, reports from the operator that the retaining nut was torqued to requirements.

BAE SYSTEMS All Operator Message: Ref 18-009V-1

All Operator Messages Contain Safety Related Information

Recommended Distribution

- ☒ Engineering
- ☒ All Maintenance Staff
- ☐ All Ground Staff

Aircraft Type: 146/RJ

- ☐ Flight Operations
- ☐ All Flight Crew
- ☐ All Cabin/Operations Staff

SUBJECT: AMM Update Following Uncontained Engine Failure LF507 Investigation
ATA: 72

Reason

To inform operators of a pending AMM update following the investigation of an uncontained LF507 engine failure.

Description

An operator experienced a recent LF507 engine uncontained failure during flight, which resulted in the instigation of an ICAO Annex 13 investigation by the local airworthiness authority. The failed engine was returned to the manufacturer and, following teardown and laboratory investigation, it has been concluded that the failure was likely the result of the incorrect installation of the fourth-stage Turbine Rotor Disc Assembly.

Though not the reason for the incorrect installation and not a causal factor in the uncontained failure, the investigation has identified that the AMM is missing data, which verifies that the fourth-stage Turbine Rotor Disc Assembly has been installed correctly. AMM Section 72-52-01, D step (11), states after installation to check that the distance between the end of the third stage Turbine Rotor and the fourth-stage Turbine Rotor Disc Assembly is within limits, and if not to remove the fourth-stage Turbine Rotor Disc and properly align. However, unlike the information provided in the engine maintenance manual and post modification SB, ALF/LF 72-1030, a numerical limit or reference sketch is not provided in the AMM. This information will be added to the AMM at the next revision release. Figure 1 of this AOM illustrates the key aspect of the proposed AMM change.

Though not a causal factor in this ICAO Annex 13 investigation, an uncontained engine failure is a potential consequence of not correctly fitting the fourth-stage Turbine Rotor Disc Assembly.

Recommendations

BAE Systems recommends that operators make the organisations responsible for the maintenance of their aircraft aware of this investigation finding, emphasising the requirement to pay particular care when installing the fourth Turbine Rotor Disc Assembly.

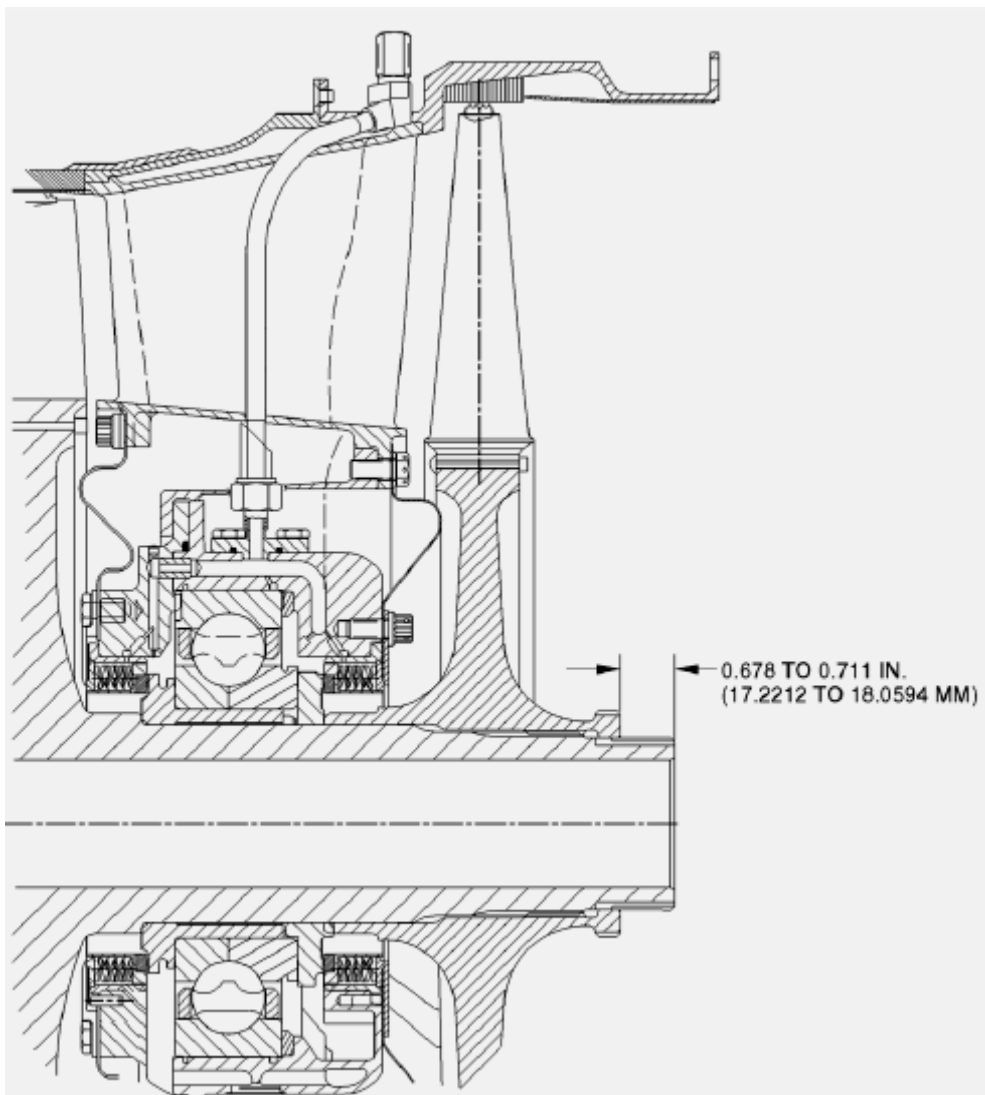


Figure 1 – Dimensional Check of the fourth-stage Turbine Rotor Disc Assembly Installation.