Published: September 2019

INVESTIGATION REPORT

Incident to the ATR 72-212A
operated by Caribbean Airlines
registered **9Y-TTC**
on 4 May 2014
at top of descent to **Piarco airport**
(Republic of Trinidad and Tobago)

BEA
Bureau d'Enquêtes et d'Analyses
pour la sécurité de l'aviation civile
Ministère de la Transition Écologique et Solidaire

Safety investigations

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SPECIAL FOREWORD TO ENGLISH EDITION

This is a courtesy translation by the BEA of the Final Report on the Safety Investigation published in July 2019. As accurate as the translation may be, the original text in French is the work of reference.

Contents

Glossary

ACW	Alternative Current Wild
ASR	Air Safety Report
ATPCS	Automatic Takeoff Power Control System
ATR	Avions de Transport Régional
beta ¾	Technical term used by the manufacturer for the pitch angle of the propeller or a blade
CAT	Commercial Air Transport
CL	Condition Levers
CLB	CLimB
CMM	Component Maintenance Manual
CVR	Cockpit Voice Recorder
DFDR	Digital Flight Data Recorder
EASA	European Aviation Safety Agency
EC	Engineering Changes
EEC	Engine Electronic Control
EHV	ElectroHydraulic Valve
EWD	Engine and Warning Display
FAA	Federal Aviation Administration
FCOM	Flight Crew Operating Manual
FI	Flight Idle
FPI	Fluorescent Penetrant Inspection
ft	Feet
FTR	FeaTheR
FWS	Flight Warning System
HMU	HydroMechanical Unit
kt	Knot
KTAS	Knot True Air Speed

MCDU	Multifunctional Control and Display Unit
MPI	Magnetic Particle Inspection
Np	Propeller rotation speed
NTSB	National Transportation Safety Board (American investigation authority)
NTSC	National Transportation Safety Committee (Indonesian investigation authority)
OEB	Operation Engineering Bulletin
OIM	Operators Information Message
OVRD	OVerRiDe
PA	Precision Approach
PEC	Electronic propeller control
PF	Pilot Flying
PL	Power Levers
PMS	Performance Management System
PNF	Pilot Non Flying
PVM	Propeller Valve Module
QAR	Quick Access Recorder
RVDT	Rotary Variable Differential Transformer
SAIB	Special Airworthiness Information Bulletin
SB	Service Bulletin
SDR	Service Difficulty Report
SEM	Scanning Electron Microscope
SHK	Statens HaveriKommission (Swedish investigation authority)
SHP	Shaft HorsePower
SIB	Safety Information Bulletin
SLPS	Secondary Low Pitch Stop solenoid
TTCAA	Trinidad and Tobago Civil Aviation Authority
UTC	Coordinated Universal Time
VFE	Maximum speed with flaps extended
VLE	Maximum speed with landing gear extended
VMO	Maximum speed in operation
VOR	VHF Omnidirectional Range
VSS	Vibration Stress Survey
WOW	Weight On Wheels

Synopsis

Time	18:20[(1)]
Operator	Caribbean Airlines
Type of flight	Commercial Air Transport
Persons on board	Captain (PF); first officer (PNF); 1 cabin crew member; 71 passengers
Consequences and damage	
Addendum: Significant comments from the equipment manufacturer, Collins, supported by the accredited representative of the NTSB, were transmitted to the BEA after the publication of the report due to Collins' lack of understanding of the consultation process implemented by the BEA. These comments, followed by the BEA's observations, have been appended to the report. This version supersedes the previous version (March 2022).	

(1)Except where otherwise indicated the times in this report are in Coordinated Universal Time (UTC). Four hours should be deducted to obtain the legal time in the Republic of Trinidad and Tobago on the day of the event.

Strong vibrations in flight with right electronic propeller control warning

In descent, the crew reduced the engine power to the minimum possible in flight, by positioning the levers in Flight Idle (FI). The speed of the aeroplane was 246 kt, close to the maximum speed in operation (VMO) of 250 kt. The crew then felt strong vibrations which were followed by a warning associated with the electronic propeller control (PEC) of the right propeller.

After the flight, it was found that the drive shaft of the right engine AC wild generator had ruptured and it was replaced. A maintenance team carried out tests on the two engine/propeller assemblies. No vibration or abnormal operation was revealed.

The flight the next day proceeded normally. During the landing run, the crew reported a loud vibration noise when they moved the power levers from the flight idle to ground idle position.

Following this flight, various maintenance operations were undertaken. Three ground tests of the engine/propeller assemblies were carried out and did not reveal any abnormal operation. A component of the right propeller pitch change mechanism (propeller valve module) was replaced. A fourth ground test was started, during which the power levers were moved to the reverse position. Vibrations appeared and the engines were immediately shut down. After the engine shutdown, blades 1, 2, 5 and 6 of the right propeller were in the feather position while blades 3 and 4 seemed to stay in the reverse position. The findings on the disassembly of the right propeller blades included the rupture of the blade 4 trunnion pin and damage to the propeller blade actuator yoke plate.

The circumstances and damage observed were similar to that which had been observed in an investigation into a serious incident on 18 September 2013 in Indonesia, involving an ATR 72-212A registered PK-WFV. An investigation was opened by the Indonesian investigation authority, the NTSC, who issued an immediate safety recommendation to the operator of the aircraft concerning the verification of the condition of the propeller blade trunnion pins and the search for crack indications on part of the fleet.

On 30 November 2014, a similar new incident occurred in Sweden to an ATR 72-212A registered SE-MDB, for which an investigation was opened by the Swedish investigation authority, SHK. Shortly after this incident, the BEA issued four safety recommendations to EASA in order that it, in particular:

- ensures that all pilots have been informed that there have been severe vibrations during descent at a speed close to VMO with the power levers in the flight idle position and that heavy damage to the propeller pitch change mechanism and, in one case, to the engine mounting brackets, has been observed;
- ensures that pilots planning and carrying out their flights avoid operations close to VMO at flight idle;
- ensures that pilots report to maintenance personnel if they have felt strong vibrations during the descent at a speed close to VMO with the power levers in the flight idle position;
- ensures that an appropriate operational procedure is developed dealing with severe propeller vibrations and including this procedure in the operators' operational documents.

At the end of the investigation into the incident of 30 November 2014, the SHK issued a safety recommendation to EASA, asking that it "*Consider[s] introducing temporary limitations in the manoeuvring envelope, or limitations of the power ranges within the latter, until the problem is resolved and rectified*."

In total, seven cases of vibration phenomena on the ATR 72-212A have been reported in the last few years. In almost all of the cases, the rupture of a trunnion pin of one of the blades and damage to the propeller blade actuator forward yoke plate were observed. The BEA investigation has revealed the existence of alternating overloads causing damage to the yoke plates and of a final overload in one direction resulting in the rupture of the trunnion pin. It was not possible to determine the cause of these overloads and the precise chronology of the damage and vibrations. Nevertheless, several elements may have contributed to it:

- a retention force caused by ball bunching;
- significant loads caused by the trunnion pins striking the ears of the yoke plate on the occurrence of cyclic loads on the forward yoke plate, when the aeroplane speed was close to VMO and the power levers in the flight idle position;
- unplanned operation of the control loop of the propeller pitch change mechanism affected by forward yoke plate cyclic loading and friction.

The investigation also revealed that the maintenance operations carried out on 9Y-TTC following the vibration phenomena did not identify this damage.

As a result, the BEA has issued several safety recommendations to EASA and the FAA. These concern:

- ❐ continuing the analysis of the cyclic load phenomenon on the forward yoke plate revealed at flight idle and at a speed slightly above VMO in order to confirm that the ATR72-212A flight envelope provides sufficient margins to prevent this phenomenon from causing damage to the propeller pitch change mechanism;
- ❐ continuing research in order to understand the sequence of damage to the propeller and the cause(s) of the overloads and that pending the outcome of this research, revising the ATR 72-212A manufacturer's recommended operating procedures for descent to prevent any flight between 240 and 250 kt at flight idle;
- ❐ installing vibration level indicators for each propeller-engine assembly in the cockpits of commercial air transport aircraft equipped with turboprop engines;
- ❐ carrying out an in-depth study into the actual vibration behaviour of each propeller in flight idle with speeds around VMO, during the initial certification of the propellers.

ORGANISATION OF THE INVESTIGATION

On 13 May 2014, ATR informed the BEA of an incident which had occurred a few days previously involving an ATR 72-212A registered 9Y-TTC at Piarco airport. The crew said that in descent, they felt vibrations with the power levels set to flight idle. Subsequently, during a maintenance operation, it was found that the propeller pitch change mechanism was damaged and in particular, that a propeller blade trunnion pin had broken.

These initial elements revealed circumstances and damage to the propeller pitch management system similar to that which had been observed in an investigation into a serious incident on 18 September 2013 in Indonesia, involving an ATR 72-212A registered PK-WFV. The NTSC had opened an investigation in which the BEA participated as the State of Manufacture of the aircraft.

In this context, the BEA immediately notified the Trinidad and Tobago investigation authorities (TTCAA), informing them of the similarities which existed between the two events. On 23 May 2014, the TTCAA responded positively to the BEA's request to be delegated the safety investigation.

In accordance with the provisions of Annex 13 to the Convention on International Civil Aviation, the investigating authorities of Trinidad and Tobago, the United States and Canada appointed an accredited representative respectively as the State of registry/operator, State of propeller manufacture and State of engine manufacture.

The BEA investigation team worked in cooperation with the aircraft manufacturer, the propeller manufacturer, the engine manufacturer, the operator and the Trinidadian, US and Canadian investigation authorities.

On 30 November 2014, a similar new incident occurred in Sweden to an ATR 72-212A registered SE-MDB. The SHK opened an investigation in which the BEA participated as the State of manufacture of the aircraft.

Other similar incidents which occurred in 2012 and 2013 and which were not the subject of a safety investigation enriched the work of the safety investigation.

1 - FACTUAL INFORMATION

1.1 History of the flight

On Sunday, 4 May 2014, the ATR 72-212A registered 9Y-TTC operated by Caribbean Airlines, took off from Arthur Napoléon Raymond Robinson international airport (Tobago) bound for Piarco international airport (Trinidad). It was a regular flight with 71 passengers on board. The captain (PF) in the left seat was at the controls.

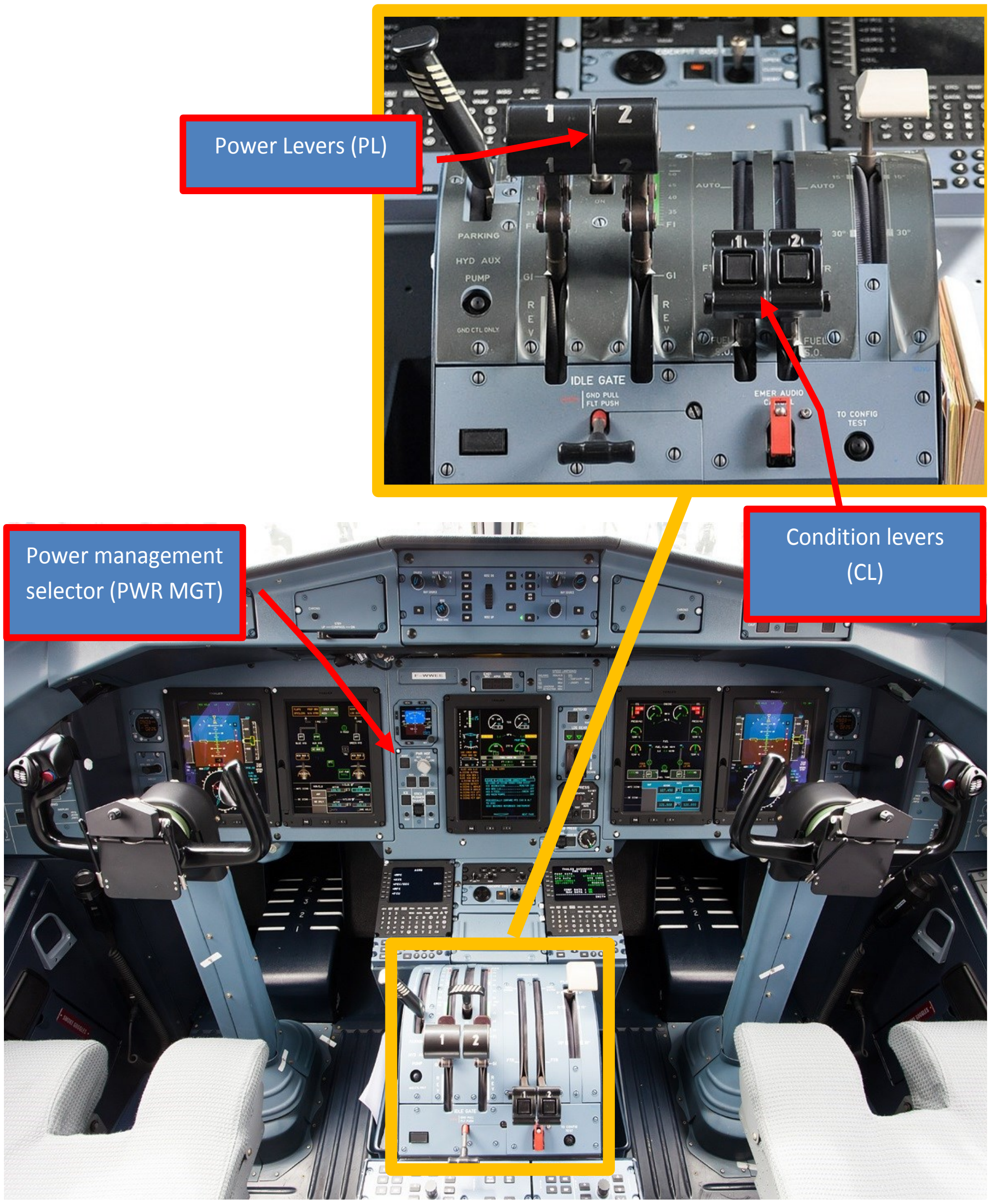


Figure 1: Location of power levers, propeller condition levers and power management selector

At 22:12:41, before the top of the descent, the aeroplane was at an altitude of 6,000 ft and a speed of around 220 kt. The power levers were in the notch. The propeller rotation speeds (Np, expressed as a percentage of the maximum rotation speed) was stable at 82 % Np. The crew engaged the vertical speed mode by setting a descent rate of 1,500 ft/min. The speed of the aeroplane started to increase.

At 22:13:01, the crew reduced the engine power by moving the power levers to an intermediary position between Flight Idle (FI) and notch. The speed was 233 kt and still increasing.

At 22:13:23, the speed of the aeroplane was 246 kt, close to the maximum speed in operation (VMO) of 250 kt. The crew reduced the engine power to the minimum possible in flight, by positioning the levers in FI. The recorded engine torque values decreased by 30 % down to a value of almost zero.

The crew reported that they then felt strong vibrations followed by a master caution associated with the PEC of the right propeller.

The values recorded for the right propeller blade angle had become invalid and the parameter recorded for the PEC of the right propeller had gone into "*FAULT*" mode. The speed of the aeroplane reached a maximum value of 247 kt and then decreased.

At 22:13:35, the power levers were moved slightly forward (around ten degrees[(2)] and then brought back to FI.

At 22:13:47, the rotation speed of the right propeller increased from 82 % Np to 100 % Np. Three to four seconds later, the recorded values for the position of the right propeller blade pitch change actuator became valid again and the PEC values of the right propeller showed that the "*FAULT*" mode had disappeared.

At 22:13:54, the value of the recorded parameter linked to the right engine AC wild generator changed to "*FAULT*". The crew stated that a "*#2 ACW GEN*" caution[(3)] appeared.

At 22:14:10, for three to four seconds, the value of the recorded parameter for the PEC of the right propeller returned to "*FAULT*" mode, the speed of the right propeller increased up to 102 % Np and then returned to 100 % Np.

The crew stated that the "*ENG 2 PEC SGL CH*" caution appeared.

At 22:14:21, the crew increased the power on the left engine. Then the rotation speed of the right propeller decreased to 82 % Np.

At 22:15:23, the crew balanced the power of both engines, by bringing the two power levers to the same position in the notch. From this point, the flight continued normally. Unlike the first part of the flight, the parameters recorded up to the landing, showed a difference in the propeller pitch angle in order to maintain the same propeller rotation speed between the right and left engines, although the torque provided by the engines was very similar (at 22:15:28, the torques of engine 1 and engine 2 were at 94% for a propeller 1 pitch angle at 38° and a propeller 2 pitch angle at 43°). The blade pitch recorded for the right propeller was 2° to 5° more than that of the left propeller

[(2)]The flight operating range of the power levers is from 37° (flight idle) to 82° (maximum power).

[(3)]The engine and propeller assemblies No 1 and No 2 are situated on the left and right wings respectively.

The crew reported that they felt slight vibrations during the landing. The recordings showed that reverse was not used. During the landing run up to the engine shutdown, the different torques provided by the two engines ensured the same propeller speed. The right engine provided 10 % more torque than the left engine. At 22:23:50, for a propeller pitch angle measured at -1° on each engine and a propeller rotation speed of 71 %, the engine 2 torque stood at 15 % whereas the engine 1 torque stood at 5 %.

After the flight, a maintenance team read the PEC fault codes of the left engine[(4)] and reset the PEC. The two engine/propeller assemblies were tested at take-off power and at a propeller rotation speed of 100 % Np. The test did not bring to light vibrations or abnormal operation. Next, the ACW generator of the right engine was replaced. Its drive shaft had been found broken. A final test of the right engine/propeller assembly was carried out following the replacement of the generator, at ground idle with propeller unfeathering[(5)]. The results showed nothing abnormal.

The next day, the aeroplane took off from Piarco international airport bound for Arthur Napoléon Raymond Robinson international airport . The flight proceeded normally. The recorded parameters were normal with no difference in values between the left engine and the right engine. During the landing run, the crew reported a loud vibration noise when they moved the power levers from the flight idle to ground idle position. The recordings showed a reduction in torque of both engines, to around zero whereas the angle of the propeller blades was at 1° and the propeller rotation speed was at 71% Np. The rotation speed of the right propeller decreased with respect to that of the left propeller and the torque provided by the right engine increased again, up to 27 % more than the left (31 % compared to 4 %). Thereafter, the right engine provided around 10 % more torque than the left engine up to its shutdown (Figure 2). The crew reported that the vibrations and noise disappeared when the right propeller was feathered. No warning appeared in the cockpit. The crew taxied to the apron with the left engine.

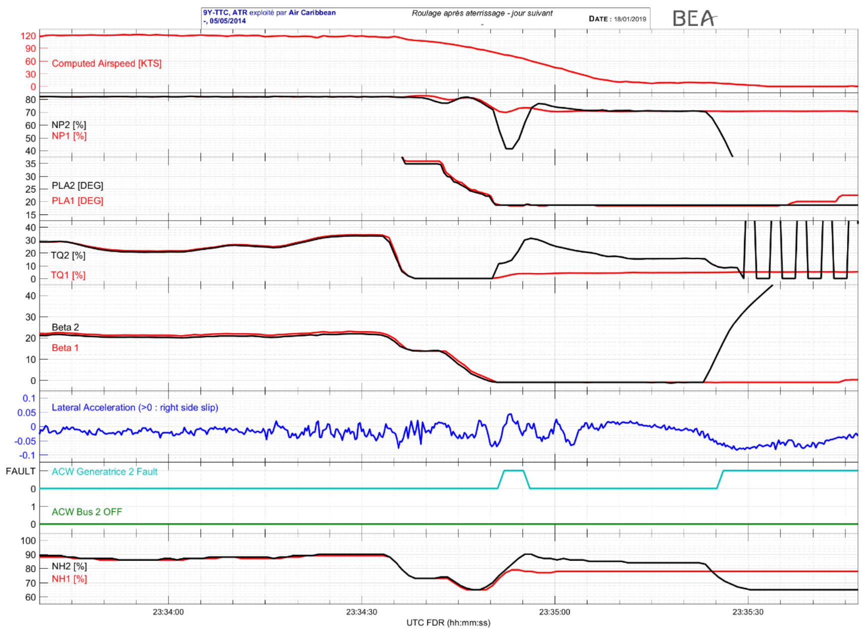


Figure 2: QAR parameters recorded during landing run on 5 May 2014

[(4)] The maintenance documents showed that the operations were carried out on the PEC of the left engine. The investigation was not able to determine whether this was an entry error or if the tests were actually carried out on the left engine.

[(5)] Out of feathered position.

Following this flight, various maintenance operations were undertaken.

An initial ground test was carried out on the engine/propeller assembly at ground idle, at flight idle and in reverse. This test detected nothing abnormal.

Both PECs were reset, and the PEC of the right propeller was calibrated.

A second engine test was suspended upon the appearance of the "*FAULT*" caution on the PEC of the right propeller, when unfeathering the right propeller to the ground fine pitch position. The PEC of the right propeller was replaced, and the new computer calibrated.

A third test was suspended upon the appearance of the "*FAULT*" caution on the PEC of the right propeller, when unfeathering the right propeller to the ground fine pitch position.

During all these tests, no vibration was felt by the maintenance agents.

The right PVM (Propeller Valve Module) was replaced. A fourth ground test was started, during which ground idle, flight idle, an intermediary power between flight idle and take-off at 82 % Np and take-off at 100 % Np were tested, without any warning appearing or any abnormal vibration being felt. When the power levers were moved to reverse, vibrations appeared and the engines were immediately shut down using the propeller condition levers.

After the engine shutdown, blades 1, 2, 5 and 6 of the right propeller were feathered whereas blades 3 and 4 seemed to stay in the reverse position. The findings on the disassembly of the right propeller blades included the rupture of the blade 4 trunnion pin and damage to the propeller blade actuator yoke plate.

1.2 Similar events

1.2.1 Event on 22 March 2007 at Tenerife to an ATR 72-212A registered EC-IYC

This event was not investigated by an official safety investigation authority.

In flight, during the final approach phase, the crew felt considerable vibrations. The "*PEC FAULT*" warning appeared, immediately followed by a fire warning on the right engine and a nacelle overheating message. The crew shut down the right engine and activated the fire extinguishers. The approach continued on one engine.

The trunnion pin of blade 2 of the right propeller was found broken. The six ears of the actuator forward yoke plate were found deformed.

Before the incident, vibration events had been reported to maintenance:

- vibrations were felt by a crew during a high speed descent and when the power levers were quickly moved to the flight idle position. These vibrations disappeared when the power was increased with an engine torque higher than 15 %;
- vibrations were felt by a crew. They were associated with a transient "*PEC FAULT*" warning and a "*SGL CH*" message. The fault codes 67 and 68 were recorded in the PEC memories;
- crews reported vibrations in cruise and in the final approach when the power levers were quickly moved to the flight idle position.

1.2.2 Event on 4 April 2012 in Zanzibar to an ATR 72-212A registered 5H-PWD

This event was not investigated by an official safety investigation authority. However, the data contained in the QAR was protected, making it possible to analyse it.

In flight during the approach phase, at a speed of 247 kt and with the power levers set to flight idle, the crew felt considerable vibrations coming from the right engine. In view of the appearance of an oil low pressure warning, the crew decided to shut down the right engine. The approach continued on one engine.

Five of the six trunnion pins of the right propeller blades and the six ears of the actuator forward yoke plate were found deformed.

1.2.3 Event on 7 January 2013 in Brazil to an ATR 72-212A registered PR-TKA

This event was not investigated by an official safety investigation authority. However, the data contained in the QAR was protected, making it possible to analyse it.

During the flight at a speed of 258 kt, considerable vibrations in the right engine appeared on setting the power levers to flight idle. The crew shut down the engine and continued the flight on one engine.

The trunnion pin of blade 6 of the right propeller was found broken. One of the ears of the forward yoke plate of the right propeller was deformed during the disassembly. Consequently, it was not possible to determine whether it was already deformed before the disassembly operation. The counterweights of blades 1 and 6 had come into contact.

1.2.4 Event on 27 August 2013 in Tanzania to an ATR 72-212A registered 5H-PWG

This event was not investigated by an official safety investigation authority. The flight recorder data was not protected.

During the flight, considerable vibrations appeared in the right engine. The crew shut down the engine and continued the flight on one engine.

The trunnion pin of blade 5 of the right propeller was found broken. The forward yoke plate of the right propeller was not deformed. Light impact marks were observed on the counterweights of blade 5.

1.2.5 Event on 18 September 2013 in Indonesia to an ATR 72-212A registered PK- WFV

This event was investigated by the Indonesian authorities. The data contained in the QAR and the CVR was protected, making it possible to analyse it.

During the descent, at a speed of 251 kt, considerable vibrations in the right engine appeared when the crew set the power levers to flight idle. The crew reported that the engine instruments showed normal values, that there were difficulties in identifying the propeller concerned and that the vibrations increased when they reduced the power. The vibrations continued up to the feathering of the propeller and the shut down of the right engine, after landing. The recordings showed that the crew used both propellers in reverse during the landing.

Two right engine mounting brackets and the drive shaft of the right engine AC wild generator were found ruptured.

The trunnion pin of blade 5 of the right propeller was found broken. The other trunnion pins of the right propeller blades and the ears of the actuator forward yoke plate were found deformed. Impact marks were observed on the counterweights of blades 2, 3, 4, 5 and 6. The counterweights of blades 2 and 3 had come into contact.

No abnormal vibration had been reported by crews and no right propeller PEC fault code had been observed by maintenance personnel in the six months prior to the incident on 18 September 2013.

1.2.6 Event on 30 November 2014 in Sweden to an ATR 72-212A registered SE-MDB

This event was investigated by the Swedish authorities. The data contained in the QAR and the CVR was protected, making it possible to analyse it. The SHK has published the final report[(6)]. The investigation was not able to determine the cause of the vibrations. Nevertheless, a recommendation was sent to EASA[(7)].

During the descent at a speed of 250 kt, the crew felt slight vibrations on setting the power levers to flight idle, these vibrations progressively increasing in intensity until reaching a very high level. The crew then had difficulties with reading their instruments and the cabin crew in moving around the cabin. Firstly, the crew feathered the propeller of the left engine and then, not feeling an improvement, unfeathered it. Secondly, the right propeller was feathered, the vibrations stopped and the right engine was shut down.

The compressor housing of the right engine was found split over 180° and damage was observed to the dampers of the engine mounting brackets. The drive shaft of the right engine AC wild generator was found ruptured.

[(6)] https://www.havkom.se/assets/reports/RL2011_08e.pdf

[(7)] Cf. para. 1.8.9.

The trunnion pin of blade 2 of the right propeller was found broken. The ears of the actuator forward yoke plate were found deformed. The counterweights of blades 1 and 2 had come into contact.

A questionnaire was sent to the operator's pilots to find out if they had already felt abnormal vibrations on SE-MDB. Some pilots reported that they had never felt abnormal vibrations. Eight pilots reported that they had felt abnormal vibrations in the conditions described in the table below:

Intensity of vibrations	Phase of flight	Speed	Power	Disappearance of vibrations
Low	Descent	240-250 kt	Flight Idle	Engine torque > 10% or speed < 220-230 kt
Abnormal	Descent	Close to 250 kt	Flight Idle	Increase in power
Considerable on one propeller	Visual approach (descent)	240-250 kt	Flight Idle	Slight increase in power
Slight	Descent	240 kt	Flight Idle	Slight increase in engine torque
Abnormal	Descent (2000-3000 ft/min)	Close to 250 kt	Flight Idle	Increase in power and decrease in rate of descent
Abnormal	Approach on glide slope (1500-2000 ft/min)	240-245 kt	Close to flight idle	Slight increase in engine torque and decrease in rate of descent
Abnormal	Descent	Close to 250 kt	Flight Idle	Increase in power and decrease in rate of descent
Abnormal	Descent	More than 240 kt	Flight Idle	Engine torque > 5% on right engine

Some of these pilots also reported that they had regularly informed the maintenance department of these vibrations and had carried out flights with the maintenance agents in the cockpit to observe the problem.

As part of the investigation, a SHK investigator took part, as observer, in a flight from Bromma to Visby airport. The flight was performed on an aeroplane of the same type, registered SE-MDC. The aim of this flight was to familiarize the investigator with the operational environment in the cockpit. After taking off from Bromma airport and during the climb to the cruise altitude, low vibrations were felt. They caused movements on the rudder pedals. During the descent to Visby, with the power levers set to flight idle, the vibrations increased in intensity when the speed approached 245 kts. At this time, the vibrations could be felt through the feet in contact with the rudder pedals and in the side panels up to the cockpit door. The vibrations stopped when the power levers were slightly moved forward and when the engine torque increased to around 7- 8 %.

The operator tried to resolve this problem by balancing the propellers, without success. The propeller blades were disassembled to check their balance. Play at the roller bearings of the blade trunnion pins was observed. The roller bearings were replaced and the vibrations disappeared.

1.2.7 Comparative study (see tables in Appendix 1)

Similar events have occurred to ATR72-212As equipped with Hamilton Sundstrand propellers, model 568F-1 and manufactured by UTAS.

The comparative studies in Appendix 1 bring to light the following points:

- Vibration events occurred on the right propeller at a speed close to VMO (250 kt) with the power levers in the flight idle position.
- The incidents occurred from 2007.
- The propeller operating time is variable, between 4,350 and 10,037 hours, for a maximum TBO of 10,500 hours.
- In one case, two of the right engine mounting brackets were found broken. In another case, the compressor housing of the right engine was found split over 180° and damage was observed to the dampers of the engine mounting brackets.
- Out of 42 trunnion pins, five had indications, ten were cracked, 15 were bent, six were broken and one was normal. This damage, generally associated with a deformation of the actuator forward yoke plate, was caused by substantial loads between the yoke plates and the trunnion pins, greater than the design load of the parts.
- The cracks or fracture faces present on certain trunnion pins were characteristic of substantial cyclic loads in two opposite directions. These loads were generated during interactions between the forward and aft yoke plates.
- In half of these cases, the drive shaft of the AC wild generator had ruptured.
- In two cases, when feathering the propeller, the appearance of an interaction between the counterweights of two adjacent blades became apparent. One blade blocked in rotation and the feathering sequence was momentarily stopped. The sequence then continued following the rupture of the trunnion pin of the blocked blade or substantial deformation of the yoke plate ear in contact with the trunnion pin of this blade.
- In five cases, the "*PEC2 FAULT*" warning was activated. In one case it was not activated and in one case it was not possible to determine whether it had been activated. When known, the associated fault codes were codes 67 and 68 [8].

[8] Cf. para. 1.8.4, propeller blade angle position sensor.

1.3 Injuries to persons

	Injuries		
	Fatal	**Serious**	**Minor/None**
Crew	-	-	3
Passengers	-	-	71
Others	-	-	-

1.4 Damage to aircraft

The damage was limited to the propeller pitch change mechanism and the drive shaft of the AC wild generator of the right engine.

After the flight of 4 May, the drive shaft of the AC wild generator of the right engine was found ruptured.

After the flight of 5 May and the tests carried out by the maintenance personnel, blades 3 and 4 of the right propeller were in a position corresponding to reverse whereas the four other blades were feathered. Blade 4 of the right propeller rotated freely around its axis. The disassembly of the right propeller blades revealed the rupture of the trunnion pin of blade 4 (Figure 3) and damage to the propeller blade actuator yoke plate (Figure 4).

Side view of blade root Broken trunnion pin Front view of blade root

Figure 3: Root of blade 4 of right propeller

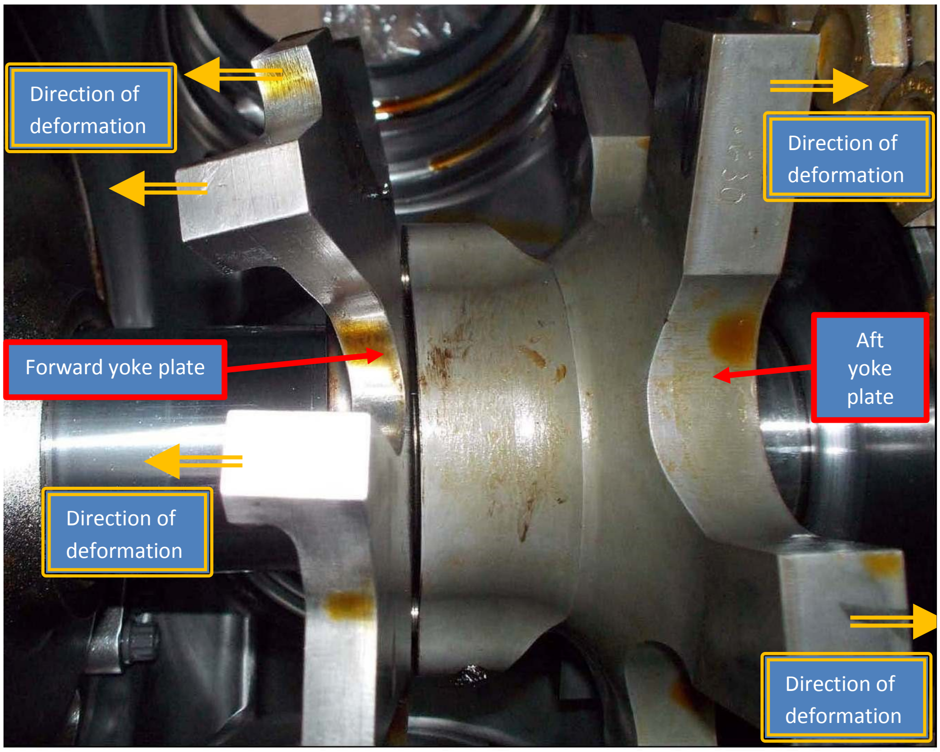


Figure 4: Pitch-change actuator of right propeller

An oil leak was also observed at the high-pressure rotor of the right engine which necessitated its replacement.

1.5 Aircraft information

1.5.1 Airframe

Manufacturer	ATR (Avions de Transport Régional)
Type	ATR72-212A (product name ATR72-600)
Serial Number	989
Registration	9Y-TTC
Entry into service	August 2012
Operation as on 5 May 2014	2,915 flight hours and 6,842 cycles

1.5.2 Engines

Manufacturer: Pratt & Whitney (Canada).
Type: PW127M.

1.5.3 Propellers

Manufacturer: Hamilton Sundstrand (UTAS).
Type: 568F-1.

Information about right engine propeller:

	Propeller	**PVM**
Part Number (P/N)	815500-3	C146440-2
Serial Number (S/N)	FR20111158	1328
Installation date	August 2012	August 2012
Total operating time	2,915 hours and 6,842 cycles	2,915 hours and 6,842 cycles
Operating time since previous overhaul	No maintenance since entry into service	No maintenance since entry into service

	PEC	**Pitch change actuator**
Part Number (P/N)	816332-5-401	815585-7
Serial Number (S/N)	11030017	2011100012
Installation date	August 2012	August 2012
Total operating time	2,915 hours and 6,842 cycles	2,915 hours and 6,842 cycles
Operating time since previous overhaul	No maintenance since entry into service	No maintenance since entry into service

	Part Number (P/N)	Serial Number (S/N)
Blade 1	R815505-6	FR201111020RT
Blade 2	R815505-6	FR201111032RT
Blade 3	R815505-6	FR201111046RT
Blade 4	R815505-6	FR201111048RT
Blade 5	R815505-6	FR201111049RT
Blade 6	R815505-6	FR201111052RT

1.5.4 Description of propeller system

The propeller system (see Appendices 2, 3 and 4) is composed of the following main elements:

- a pitch change actuator;
- an oil transfer tube;
- a Propeller Valve Module (PVM);
- an electronic propeller control (PEC);
- a main hydraulic pump;
- an auxiliary feathering pump;
- an overspeed governor;
- six blades;
- a hub;
- a spinner;
- a bulkhead.

1.5.4.1 Pitch change actuator

The pitch change actuator (see Appendices 3, 5 and 6) is part of the propeller rotating assembly. It converts the hydraulic pressure supplied by the PVM into an axial movement that modifies the angle of the blades (see Appendix 7). The actuator transmits a measured value of blade angle via the transfer tube and the PVM to the PEC which closes the propeller pitch control loop.

The actuator consists of the following main components:

- a piston;
- forward and aft yoke plates;
- a yoke shaft connecting the yoke plates and the piston;
- an anti-torque arm;
- a dome.

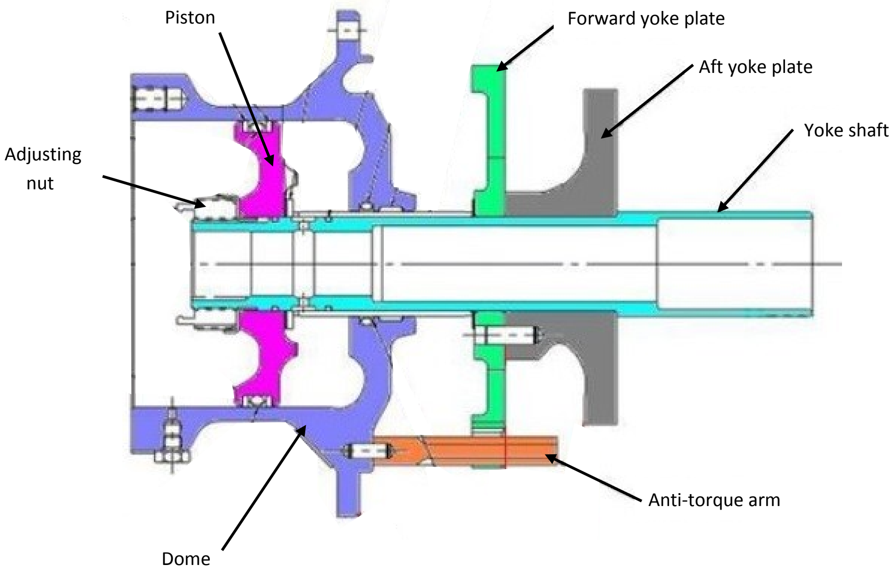


Figure 5: Pitch change actuator

To reduce the propeller pitch, the propeller valve module controls an increase in the fine pitch pressure. This pressure is transmitted through the transfer tube to the fine-pitch chamber. The actuator piston moves towards the front of the aircraft. The yoke plates linked to the piston by the yoke shaft also move forward. Each blade trunnion pin is driven by the yoke plates and makes each blade turn to a finer pitch angle.

To increase the propeller pitch, the propeller valve module controls an increase in the coarse pitch pressure. This pressure is transmitted through the transfer tube to the coarse-pitch chamber. The actuator piston moves towards the rear of the aircraft. The yoke plates linked to the piston by the yoke shaft also move rearward. Each blade trunnion pin is driven by the yoke plates and makes each blade turn to a higher pitch angle.

The aft actuator yoke plate, subject to most of the loads during the flight, is thicker than the forward yoke plate.

The propeller pitch, called beta ¾[9], varies between a maximum of 78.5° (feather position) and a minimum of -14° (full reverse position).

The maximum feather angle value is the actuator's physical limit towards the rear of the aircraft while the minimum reverse value is a forward limit programmed into the PEC and defined by the manufacturer.

In the event of an input on the PLs[10] or a change in the propeller speed selection by the pilots, the pitch variation rate is optimised by the PEC, in order to limit propeller speed variations.

Lastly, in the event of a feathering control, the rate of pitch increase is 20° per second. This rate, linked to the flow rate of the main hydraulic pump, can be reduced when the propeller speed decreases.

[9] Technical term used by the manufacturer for the pitch angle of the propeller or a blade.

[10] Cf. para. 1.5.5.2.

1.5.4.2 Oil transfer tube

The oil transfer tube[(11)] provides the supply oil pressure from the PVM to the piston of the pitch change actuator. It is installed through the front of the pitch change actuator, through the gearbox and into the PVM.

[(11)]Cf. Appendix 3.

1.5.4.3 Propeller Valve Module (PVM)

The PVM[(12)] is mounted on the aft side of the reduction gearbox, in line with the propeller. It is part of the propeller pitch change mechanism. Among other functions, it measures and transmits the propeller pitch angle to the PEC and provides the required hydraulic pressure to the pitch change actuator via the transfer tube.

[(12)]Cf. Appendices 3 and 4.

The PVM consists of the following main components:

- an ElectroHydraulic Valve (EHV);
- a protection valve;
- a propeller pitch angle sensor via the RVDT;
- a feather solenoid;
- a Secondary Low Pitch Stop solenoid (SLPS).

1.5.4.4 Electronic propeller control (PEC)

The PEC is a computer composed of two functionally isolated electronic boards (primary and backup channels). It ensures the closed-loop control of the propeller pitch change mechanism.

The PEC has four functions:

- governing propeller speed;
- controlling the propeller pitch angle in beta mode[(13)];
- synchronizing the propellers between the left and right engines (the left engine is the master and the right engine the slave);
- managing propeller feathering and unfeathering.

[(13)]Cf. para. 1.5.6.

The PEC has been designed so that its output current calculation frequency is at least 87.4 Hz.

1.5.4.5 Hydraulic pump

The main pump is mounted on and driven by the engine reduction gearbox. It provides the PVM with oil at a pressure of 1,000 psi.

The feathering pump (auxiliary pump) is located on the front right face of the reduction gearbox. It uses its own supply of oil located in the reduction gearbox. This oil is not used by the main pump and is sufficient for feathering. The auxiliary pump motor has an operating cycle of 30 seconds. It must be kept off for 10 minutes (cooling time) before being used again.

1.5.4.6 Overspeed governor

The overspeed governor is a hydromechanical unit that provides additional protection to the propeller system. It is not used under normal propeller operating conditions. It is mounted on the main hydraulic pump and driven by the engine reduction gearbox.

Should the PEC fail, the governor mechanically regulates the speed of the propeller in order to prevent any propeller overspeed. In flight, when the speed of the propeller exceeds 102.5 % Np, the governor increases the propeller pitch in order to reduce its speed. On the ground, when the power lever is positioned below flight idle, the regulation is effective from 118 % Np to allow the transition to reverse.

1.5.4.7 Propeller blades

The propeller blades are attached to the propeller hub by two roller bearings located at the blade root, which allow them to turn around their main axis[(14)]. The off-centre trunnion pins located at the end of each blade root are positioned between the two actuator yoke plates. The displacement of these two yoke plates varies the pitch of all the blades in an identical manner[(15)].

(14)Cf. Appendices 8 and 9.

(15)Cf. Appendix 6.

A counterweight, attached by a steel arm at the blade root, creates a moment around the blade axis generated by the propeller rotation speed. It tends to rotate the blade to a greater pitch, in opposition to the moment of aerodynamic loads.

As long as the aircraft remains in its flight envelope, the sum of the moment of the counterweights is generally greater than that of the aerodynamic forces and the blades' inertia. It makes the blades pivot towards the coarse pitch. When the propeller rotation speed decreases, the centrifugal forces generated by the counterweights decrease more rapidly than the aerodynamic forces: the propeller pitch and rotation speed stabilize at a position of equilibrium when the moments balance.

If hydraulic pressure is lost, the PVM and the pitch change actuator can no longer control the propeller. The counterweight assembly is thus designed to prevent any dangerous condition. Its purpose is to prevent any overspeed which could potentially damage the propeller, and any substantial drag which could be caused by a propeller pitch angle below the flight minimum. This design neither requires nor guarantees that the propeller blade trunnion pins remain pressed against the actuator aft yoke plate during all of the flight, in particular at the propeller's reduced rotation speed of 82 % Np which is used for the major part of the flight.

1.5.5 Description of propeller system controls

1.5.5.1 Power management selector

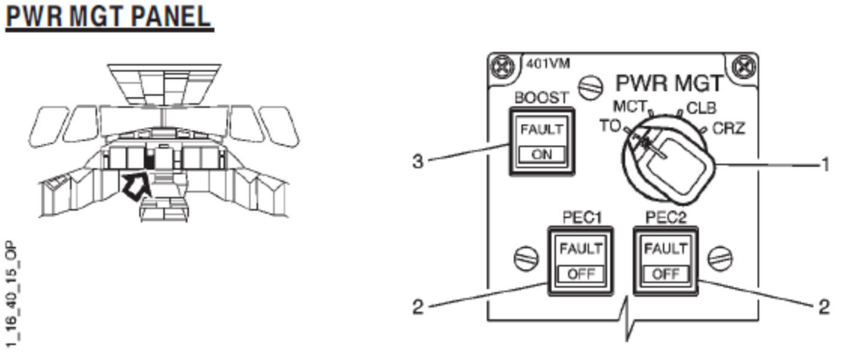


Figure 6: Power management selector
(Power management panel)

The engine provides the propeller with power according to the position of the power lever. The power level is selected by the crew using the power management selector (Figure 7). The power supplied by the engine is calculated as the product of two values provided by sensors located in the propeller reduction gearbox: the propeller rotation speed (Np) and the torque (TQ) between the reduction gearbox and the turbine.

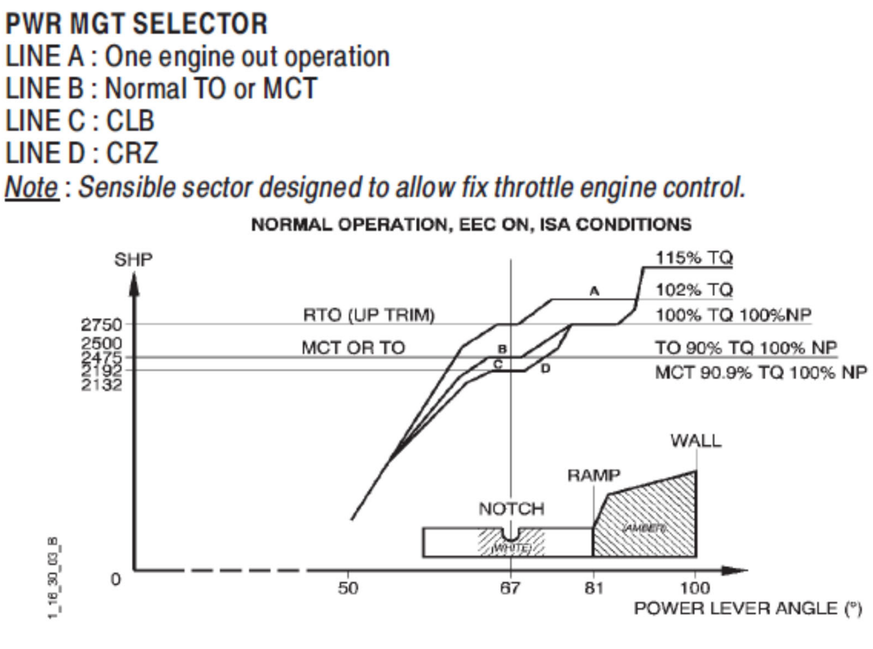


Figure 7: Curve [SHP/power lever position] according to power law selected

When the power lever is in the white sector (Notch), the output power is respectively:

- 2,475 SHP in TO (Take-Off) mode;
- 2,500 SHP in MCT (Maximum Continuous Thrust) mode;
- 2,192 SHP in CLB (climb) mode;
- 2,132 SHP in CRZ (cruise) mode.

The beginning of the amber sector located in line with the ramp is used during a go-around or take-off in the event of a malfunction of the Automatic Take-Off Power Control System (ATPCS). In this lever position, the power supplied is 100 % TQ regardless of the selected power mode.

1.5.5.2 Power levers

These levers control the power of each engine. Each power lever is mechanically connected to the hydromechanical unit which controls the engine fuel flow (HMU) and to the PVM[16]. In flight, the operating range varies from maximum emergency power (forward stop) to Flight Idle (FI). When the aircraft is in flight, a mechanical stop linked to the position of the landing gear shock absorbers prevents the levers from going below flight idle.

[16] Cf. para. 1.5.4.3.

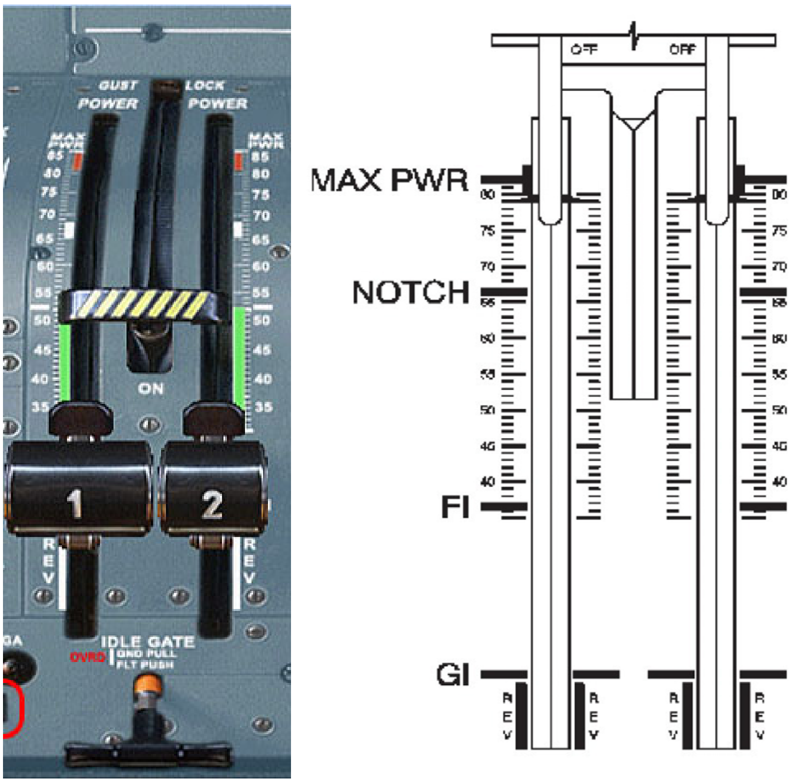


Figure 8: Operating range of the power levers - top view

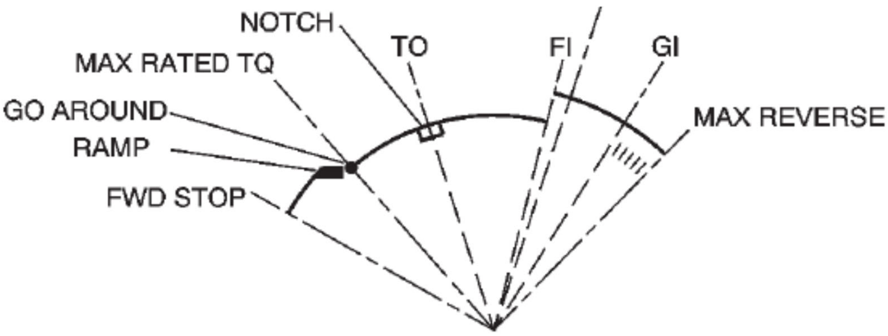


Figure 9: Operating range of the power levers - side view

1.5.5.3 Propeller condition levers

The Condition Levers (CL) control the feathering (FTR) and the engine Fuel Shut-Off (FUEL SO) as well as regulating the rotation speed of the propellers. In the "*AUTO*" position, the propeller rotation speed is regulated by the power management selector [17]. In the "*100 % OVRD*" position, the propeller rotation speed is set at 100 % Np.

[17] Cf. para. 1.5.5.1.

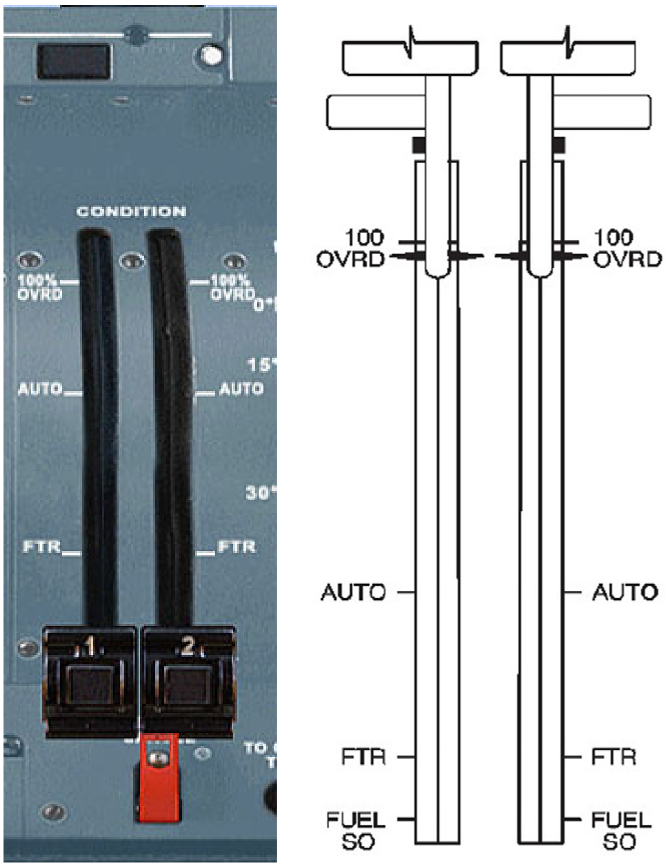


Figure 10: Positions of condition levers - top view

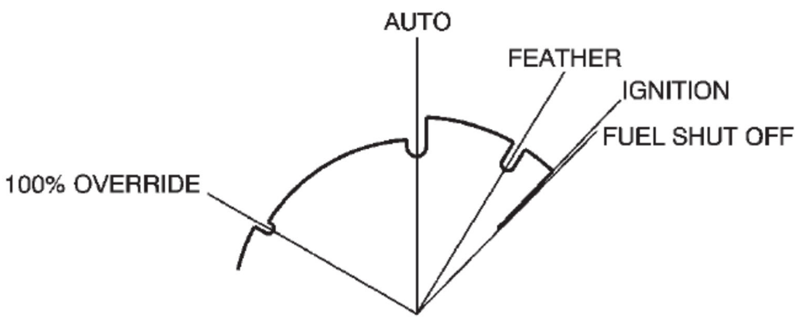


Figure 11: Positions of condition levers - side view

1.5.6 Description of operation of propeller system

The ElectroHydraulic Valve (EHV) of the PVM directs the flow of oil through the protection valve to the pitch change actuator[18]. The PEC sends an electrical signal to the EHV, which reacts by directing the supply pressure either to the coarse pitch chamber or to the fine pitch chamber located on either side of the piston of the pitch change actuator. Unused oil is returned to the reduction gearbox where it is filtered and then sent to the engine tank. The current sent to the EHV determines the blade angle variation.

[18]Cf. Appendix 5.

The protection valve moves axially to increase the propeller blade angle in the following cases:

- feathering;
- propeller overspeed;
- propeller fine pitch protection in flight.

In the event of both PEC channels failing, the operating procedures stipulate that the crew switch off the PEC. With the EHV no longer electrically powered, the pressure is directed to the fine pitch chamber. The propeller speed is then directly regulated by the overspeed governor.

1.5.6.1 Regulating propeller speed in flight

In flight, the Secondary Low Pitch Stop solenoid (SLPS) is open to avoid propeller pitch values in flight of less than 13°. The pitch change mechanism searches for the optimum pitch angle in order to maintain a constant Np in a constantly-changing air mass. The target speed of the propeller depends on the power mode selected and the position of the propeller condition lever:

- With the condition lever in "*AUTO*":
  - 82 % Np (984 rpm) power management selector at CLB or CRZ;
  - 100 % Np (1,200 rpm) power management selector at TO and MCT;
- With the condition lever in "*100 % OVRD*":
  - 100 % Np (1,200 rpm) regardless of the position of the power management selector.

1.5.6.2 Regulating propeller speed on ground

In beta mode, the propeller is no longer regulated in terms of speed. This mode is engaged on the ground or in degraded mode in flight (loss of propeller speed regulation). The propeller pitch is no longer a function of the torques and engine power. The blade angle complies with the values defined in the PEC software:

- while taxiing and in reverse, the position of the power levers determines the level of power supplied;
- when the power levers are beyond the flight idle position, the blade angle depends on the air speed in order to limit the drag which could be caused by an engine failure (Figure 12).

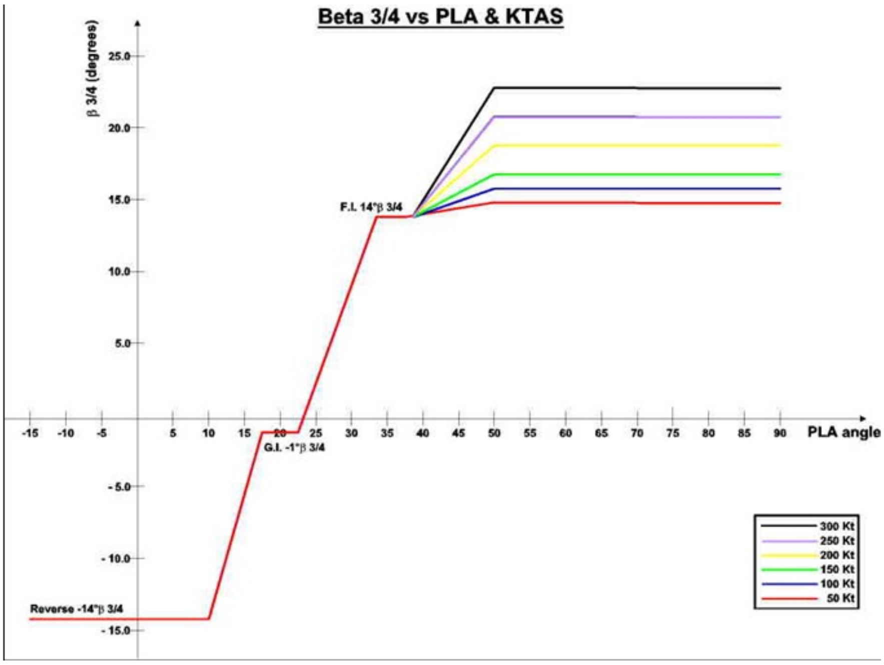


Figure 12: beta ¾ according to airspeed (KTAS) and position of power lever (PLA)

1.5.7 Alternative Current Wild (ACW) generator

The ACW generation system consists of two generators, each located on an engine and driven by the propeller reduction gearbox. Each generator operates normally when the propeller rotation speed is above 66 % Np.

Two main buses, ACW BUS 1 and 2 form part of the ACW distribution network.

The ACW 1 bus is normally powered by the left engine generator, the ACW 2 bus by that of the right engine. In the event of a generator failure, both buses are powered by the remaining generator.

1.5.8 Information from Flight Crew Operating Manual (FCOM) issued by ATR

The FCOM describes, in particular, descent performance along with the procedures to be followed and the associated warnings in the event of a fault associated with the PEC and the AC wild generator.

At the time of the incidents, no specific procedure existed on the appearance of strong propeller vibrations in flight. Nevertheless, the manual contained an emergency procedure in the event of fire or severe damage on an engine in flight.

1.5.8.1 Performance in descent

Three descent performance tables are described in the FCOM. These tables correspond to descent speeds of 200, 220 and 240 kt for an aircraft in a clean configuration and a reference weight of 15,000 kg.

Two types of descent are proposed: constant vertical speed and constant glide path angle.

1.5.8.2 General description of operation of cockpit warnings

The aircraft is equipped with a Flight Warning System (FWS). This system generates aural and visual warnings.

The Master Warning (MW) and the Master Caution (MC) give rise to the respective illumination of the red and amber flashing lights situated in front of each pilot and a CRC[19] and a SC[20].

[19]Continuous Repetitive Chime.

[20]Single Chime.

An alert message (Figure 13) on the EWD of the central engine parameter display and warning screen, guides the crew in the management of the event. This message is presented as follows:

- ❒ the name of the alert in the left window;
- ❒ the procedure to be followed in the right window;
- ❒ the status of the system concerned by the alert under the procedure window.

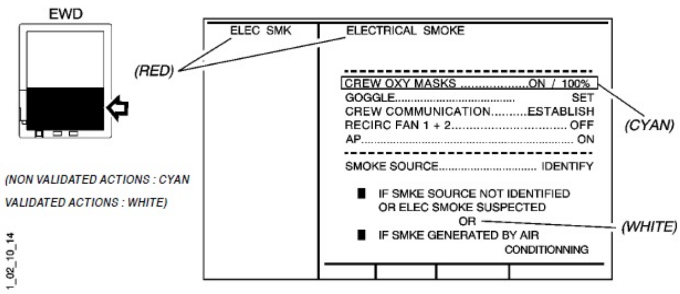


Figure 13: Example of alert display on EWD

Other aural warnings independent of the activation of the MW, MC and EWD can be activated:

- ❒ stall (cricket);
- ❒ VMO, VFE or VLE overspeed (clacker);
- ❒ AP disconnected (cavalry charge);
- ❒ movement of trim (whooler).

Finally, local warning lights linked to the systems and independent of the FWS may illuminate. They reflect the actual status of the system and only extinguish when the latter has returned to normal operation.

1.5.8.3 Procedures in event of fault associated with PEC

Anomaly on the primary channel or the backup channel of a PEC

When an anomaly is detected on the primary channel or the backup channel of a PEC, the following warnings appear:

- ❒ flashing of MC buttons;
- ❒ SC type aural warning;
- ❒ ENG 1(2) PEC SGL CH message displayed in amber on EWD;
- ❒ SGL CH in amber appears on the central screen of the EWD (Figure 14).

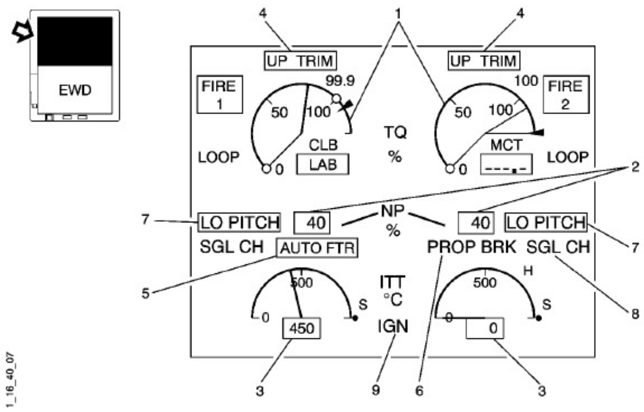


Figure 14: SGL CH (8) displayed on EWD

No crew action is required. The associated procedure specifies that the PEC concerned must not be reset in flight and that a PEC fault must be anticipated on landing. In this case it is specified not to move the power levers to below the flight idle position before the nose landing gear has touched down and not to use the reverse of the engine concerned.

PEC fault

When an anomaly is detected on both the primary and backup channels, the PEC switches to "*PEC FAULT*" mode. If incorrect beta values were detected on both the primary and backup channels, the PEC continues to operate in an alternative operating mode until it is switched off by the crew.

The following warnings appear:

- ❒ flashing of MC buttons;
- ❒ SC type aural warning;
- ❒ ENG 1(2) PEC message displayed in amber on EWD;
- ❒ illumination of amber PEC pushbutton on central panel (Figure 15).

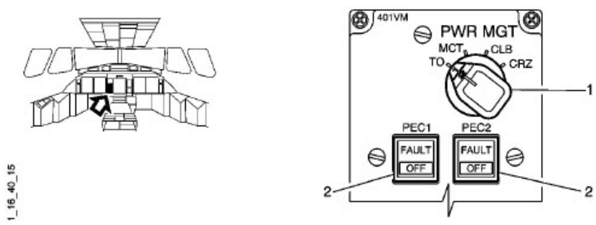


Figure 15: PEC pushbuttons (2) on central panel

The procedure to be followed by the crew is the following:

- carry out a go-around if the height is less than 400 ft;
- put the CL[21] of the propeller concerned in the 100 % OVRD[22] position.
- restart the PEC concerned;
- if the PEC fault disappears, the crew returns the CL to the "*AUTO*" position and continues its flight;
- if the PEC fault persists, the crew switches off the PEC concerned and avoids sudden movements on the power lever of the engine concerned. Before landing, the two CLs are put in the 100 % OVRD position and reverse is not used.

It is specified that the crew must expect a rotation speed of 102.5 % Np on the propeller concerned (overspeed protection[23]. It is specified not to move the power levers to below the flight idle position before the nose landing gear has touched down. Reverse is not usable as the SLPS is deactivated. The propeller speed is no longer regulated on the ground at 850 rpm by the EEC of the engine concerned. Finally, the ACW generator of the engine concerned may stop if the propeller rotation speed decreases to below 65.5 % Np.

[21] Cf. para. 1.5.5.3.

[22] In order to minimize the variations in propeller rotation speed when the PEC is restarted.

[23] Cf. para. 1.5.4.6.

1.5.8.4 Procedure in event of ACW generator anomaly

When an anomaly is detected, the following warnings appear:

- flashing of MC buttons;
- SC type aural warning;
- ELEC ACW GEN 1 (2) message displayed in amber on EWD;
- ACW GEN FAULT message displayed and ACW section of electrical system diagram shown in amber on EWD;
- amber illumination of the generator pushbutton on the overhead panel (Figure 16).

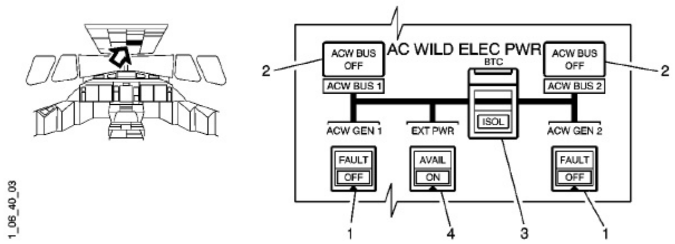


Figure 16: ACW GEN pushbuttons (1) and warning lights (2)

The procedure to be followed by the crew is the following:

- turn off the generator affected by the fault;
- leave and avoid icing conditions;
- in case of failure of the right generator, after landing taxi with both engines in operation.

It is specified that if the cause of the anomaly is an underspeed of the generator, the restart is automatic.

1.5.8.5 Severe mechanical damage in flight

There are warnings associated with a fire but no warning solely linked to severe damage to an engine in flight.

The procedure to be followed by the crew in case of fire or severe damage to one of the engines is the following:

- ❐ move the Power Lever (PL) of the engine concerned to the Flight Idle position (FI);
- ❐ move the Condition Lever (CL) of the engine concerned to the feather position (FTR) and switch off the fuel supply (FUEL SO).

It is recommended to land as quickly as possible and not to attempt to restart the engine.

1.6 Flight recorders

The data recorded by the QAR was decoded in engineering value with the dataframe identified V4 in the manufacturer's document, referenced Service Letter 72 No ATR72-31-6010, DFDR recorded parameters decoding law, revision No 11.

1.6.1 Data recorded during maintenance operations

Note: The decoded information from the QAR concerning ground maintenance operations following the flights on 4 May and 5 May is given in Appendix 10.

After the flight on 4 May, the QAR recorded two test sequences performed by the maintenance personnel: a first test of the two propellers at take-off power with a propeller speed of 100% Np and then a second test with unfeathering and feathering of the right propeller with the right engine in ground running mode (this second test was consecutive to the replacement of the AC wild generator of the right engine).

After the flight on 5 May, the QAR recorded numerous test sequences:

- ❐ Test with propellers in ground idle, flight idle and reverse engaged twice for two to three seconds. In both cases, the minimum pitch angles of the right propeller remained more than -10°, the right engine torque value remained less than 13 % and the right engine fuel flow remained less than 255 k/h.
- ❐ Engines shut down, both PEC reset.
- ❐ Without starting the engines, the power lever of the right propeller was set to the take-off, flight idle and then ground idle positions (sequence which corresponds to the calibration of the PEC of the right propeller);
- ❐ Start of both engines and unfeathering of both propellers. Just before the end of the unfeathering of the right propeller, the right PEC went into "*FAULT*" mode, the PEC controlling the right propeller was reset, resulting in some invalid blade angle values being recorded, for a few seconds the fuel flow decreased on the right engine and at the same time the speed of the right propeller decreased from 71 to 35 % Np, then the fuel flow increased again and the speed of the right propeller returned to its nominal value of 71 % Np, the PEC of the right propeller stayed in "*FAULT*" mode. The propellers were feathered and the engines shut down.

- The PEC of the right propeller was still in "*FAULT*" mode, it was reset twice and then switched off for 38 seconds (the blade angle position values of the right propeller became invalid for this time).
- Without starting the engines, with the PEC of the right propeller still in "*FAULT*" mode and with the power lever of the right propeller placed between the ground idle and flight idle positions, the PEC exited the "*FAULT*" mode, then the lever was set to the ground idle position (sequence which corresponded to the calibration of the PEC of the right propeller).
- Start of right engine and unfeathering of right propeller. Just before the end of the unfeathering of the right propeller, the right PEC went into "*FAULT*" mode. It was then reset. Some of the values recorded for the blade angle position were invalid, for a few seconds the fuel flow decreased on the right engine and at the same time the speed of the right propeller decreased from 71 to 38 % Np, then the fuel flow increased again and the speed of the right propeller returned to its nominal value of 71 % Np, the PEC of the right propeller remained in "*FAULT*" mode. The right propeller was feathered and the engine shut down. The pitch of the right propeller reached the angle of 77° corresponding to the feather position and then stabilized at an angle of 73°. The PEC of the right propeller remained in "*FAULT*" mode despite a reset of the computer.
- A test of the two propellers in ground idle, flight idle, with sufficient power to reach 100 % Np without reaching take-off power then engagement of reverse followed by a sudden change to the take-off position. The right propeller slowed down with respect to the left propeller (up to a difference of 28 %) while the fuel flow of the right engine increased by 25 %, the NH2 increased up to 93 % and the torque of the right engine increased from 20 to 71 % TQ. The levers were positioned at flight idle then ground idle, the propellers were feathered and the engines shut down. The right propeller actuator stayed in a position corresponding to a blade angle of 35° for ten seconds before moving to a position of 76° corresponding to feathering and then stabilized at a position of 69°.

The other sequences recorded corresponded to the tests carried out after the replacement of the right propeller and right engine.

1.6.2 Data recorded when using reverse

The data contained in the QAR showed that reverse was used in 13 landings out of the 60 recorded flights preceding the event flight (period from 29 April 2014 to 4 May 2014).

A comparative study of the parameters linked to the engines and propellers when engaging reverse can be found in Appendix 11.

This study showed that when the power levers were in identical positions, the parameters linked to the left and right engines and propellers were normal and similar, even when maximum power was supplied. Flight n-14 (14 flights before that of the incident) is the last for which the parameters linked to the engines and propeller can be compared.

1.7 Tests and research on aeroplane 9Y-TTC

1.7.1 Tests performed on damaged AC wild generator

After the flight of 4 May, the drive shaft of the AC wild generator was replaced. The generator successfully passed all the tests and check for the maintenance release certificate.

1.7.2 Tests performed on right propeller valve module

After the incident, the PVM passed the check tests for the maintenance release certificate. All of the results were correct with one exception. The oil flow to the "*coarse pitch*" chamber (PC pressure)[24] was, in certain operating ranges, too low compared with the flow rate from the protection valve (PD pressure)[25]. This defect affected the gain of the overspeed governor. It can be caused by a leak in an internal seal or a defect in the protection valve. It had no impact on the operation of the PVM.

[24] Cf. Appendix 5.

[25] Cf. Appendix 5.

1.7.3 Check for conformity of propeller pitch change mechanism

The geometry of the pitch change actuator, propeller hub and blade trunnion pins was checked and complied with the manufacturer's specifications except for the damaged parts (deformed ears of forward yoke plate, broken trunnion pin 4 and other bent trunnion pins). The quality of the materials from which these parts were made was checked and complied with specifications.

No sign of corrosion was observed. No assembly anomaly was revealed.

1.7.4 Examination of propeller pitch change actuator

The actuator forward yoke plate was found deformed[26]. The ear of the forward yoke plate of blade 3 [27] had marks on one side corresponding to interactions with the trunnion pin roller bearing and its support plate (Figure 17). The trunnion pin of blade 3 had passed to the other side of the forward yoke plate and was found between the actuator dome and the yoke plate assembly.

[26] Cf. Appendix 4.

[27] Cf. Appendix 6.

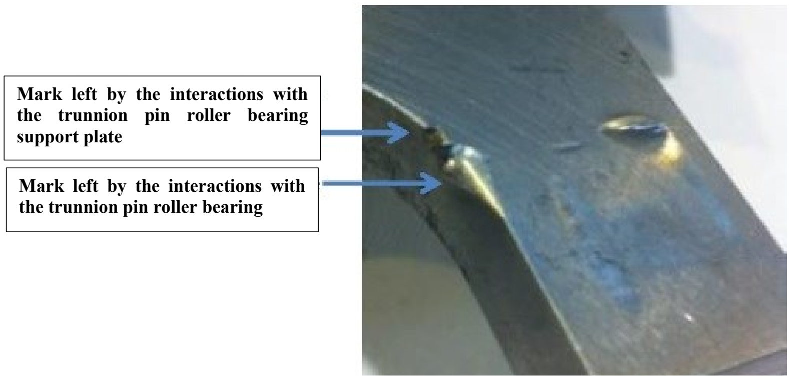


Figure 17: Marks on side of ear of forward yoke plate of blade 3

Taking into account the geometry of the pitch change actuator, the minimum deflection[28] of the ear of the forward yoke plate of blade 3 needed for the trunnion pin to pass onto the other side of the yoke plate is:

- 8 mm with a plate position corresponding to a blade angle of -20°;
- 11 mm with a plate position corresponding to a blade angle of -14°.

The maximum measured deflection (Figure 18 and Table 1) of the yoke plate ear associated with blade 3 is 8.88 mm. The trunnion pin therefore passed behind the yoke plate while reverse was being used in ground engine tests (reminder: the minimum blade angle in reverse is -14°).

According to the maintenance manual (CMM 61-13-12), the maximum distance between the forward and aft yoke plates is 41.43 mm.

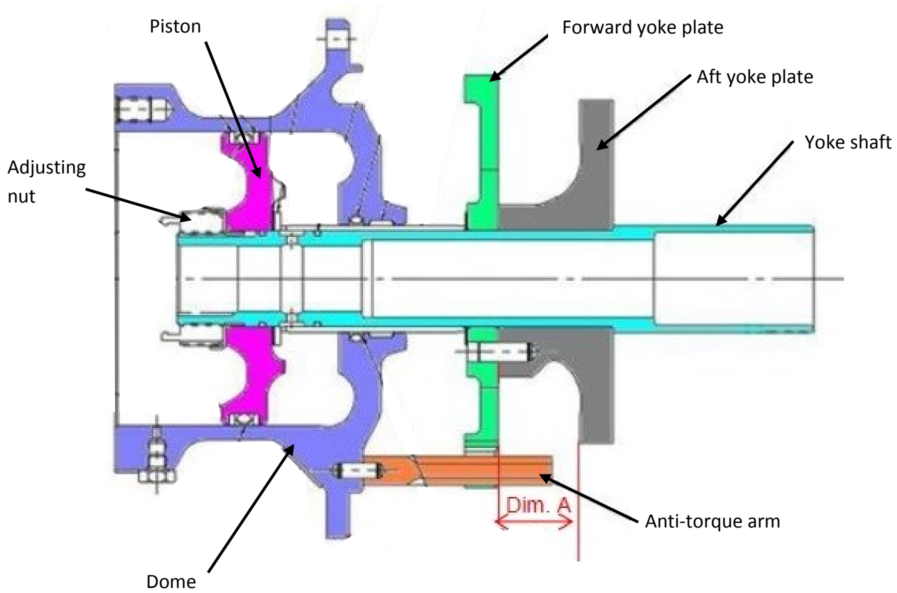


Figure 18: Measurement of distance Dim A between forward yoke plate (green) and aft yoke plate (grey)

The following table shows the maximum distance measured (Figure 18) separating each of the six ears of the two yoke plates associated with each blade of the right propeller.

	Ears of blade 1	Ears of blade 2	Ears of blade 3	Ears of blade 4	Ears of blade 5	Ears of blade 6
Distance Dim A (mm)	51.48	58.73	50.31	64.6	54.3	48.16
Deformation (mm)	10.05	17.3	8.88	23.17	12.87	6.73
Deformation (%)	24%	42%	21%	56%	31%	16%

Table 1: Distance measured between forward and aft yoke plates

[28]For an arc of a curve $\widehat{AB}$ the deflection is the segment limited by the middle of the chord [AB] and the middle of the arc $\widehat{AB}$.

The deformations observed on the majority of ears were greater than for ear 3. It can be inferred from this that initially the deformation of ear 3 was greater than the deformation of the other ears. Consequently, trunnion pin 3 passed to the other side of the forward yoke plate while reverse was being used in ground engine tests. Subsequently, the deformations of the other ears increased until the values observed were reached.

The actuator adjusting nut (Figure 18) was not sufficiently tightened. It was not possible to determine if this lack of tightening was a consequence of the event, an assembly fault or a maintenance fault.

1.7.5 Examination of right propeller blades

1.7.5.1 Examination of blades

The examinations carried out on all the right propeller blades gave rise to a certain number of observations which are summarized in Table 2 below:

	Blade No 1	Blade No 2	Blade No 3	Blade No 4	Blade No 5	Blade No 6
Light marking from the bearing balls on the bearing race of the blade root	✓			✓	✓ signs of oxidation	✓
Signs of friction on the roller bearing support plate of the blade trunnion pin		✓	✓	not established as trunnion pin broken	✓	
Scores on the roller bearing surface of the blade trunnion pin		✓	✓	not established as trunnion pin broken	✓	✓
Roller bearing of blade trunnion pin damaged		✓ blocked	✓	not established as trunnion pin broken	✓	
Marking(s) on the counterweight arm	✓		✓	✓ signs of friction		✓ signs of friction
Markings on the edges of both sides of the counterweight	✓	✓	✓	✓	✓	✓
Signs of friction on the flange of the blade tulip[29]				✓	✓	

Table 2: Observations regarding right propeller blade roots

[29] Cf. Appendix 9.

1.7.5.2 Examination of blade trunnion pins

The blade trunnion pin 4 was found broken. SEM examinations of the fracture surface revealed the presence of dimples on the entire surface, characteristic of a sudden ductile fracture by overload. The fracture was initiated on the side of the trunnion pin which corresponds to the position of the actuator forward yoke plate, and spread to the diametrically opposite edge. No apparent material or manufacturing anomaly was observed on the trunnion pin (the pin is an integral part of the blade tulip).

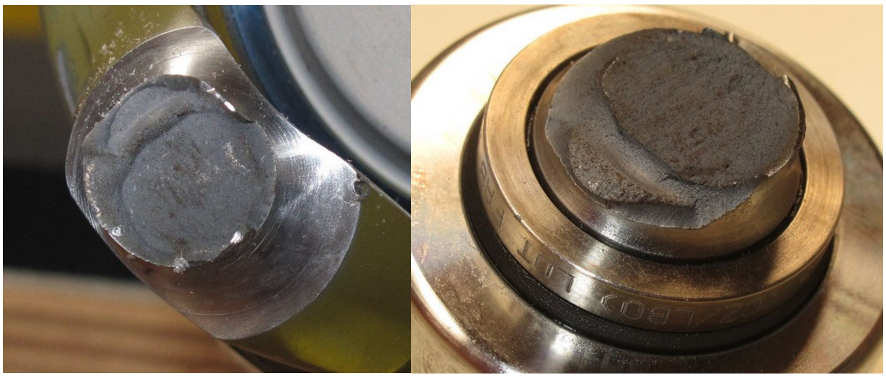


Figure 19: Trunnion pin fracture surface (on left, tulip side, on right, end of trunnion pin side)

The trunnion pins of blades 1, 3 and 6 were bent with deformation values respectively of 51 µm (2.5 times the tolerance), 41 µm (2 times the tolerance) and 45 µm (2.25 times the tolerance). Their bending direction was oriented towards the centre axis of the blade and did not correspond to the direction of loads from contact with an actuator yoke plate.

Trunnion pins of blades 2 and 5 were bent in the directions indicated in Appendix 12. Their deformation corresponded to the direction of loads generated when the trunnion pins were in contact with the forward yoke plate. The strain value was 126 µm (6.3 times the tolerance) for blade 2 and 169 µm (8.45 times the tolerance) for blade 5.

A Magnetic Particle Inspection (MPI) of the unbroken trunnion pins revealed indications[30] located on either side of the unbroken trunnion pins. An examination by binocular microscope seemed to show the absence of cracks.

[30] Indications are lines which can appear during a MPI.

Lastly, a mark on the arm of the blade 1 trunnion pin was observed, probably due to contact with the broken trunnion pin of blade 4 moving freely inside the hub.

1.7.6 Interaction between blades

It could be observed that when the trunnion pin of blade 3 passed behind the actuator forward yoke plate[31], the counterweight arms of blades 3 and 4 came into contact. The markings observed on the counterweight arms[32] were consistent with this sequence of operations. In this situation, in the event of a feathering control, the interference between the counterweight arms counters the movement of blade 4 to the feathering position.

[31] Cf. para. 1.7.4.

[32] Cf. para. 1.7.5.1.

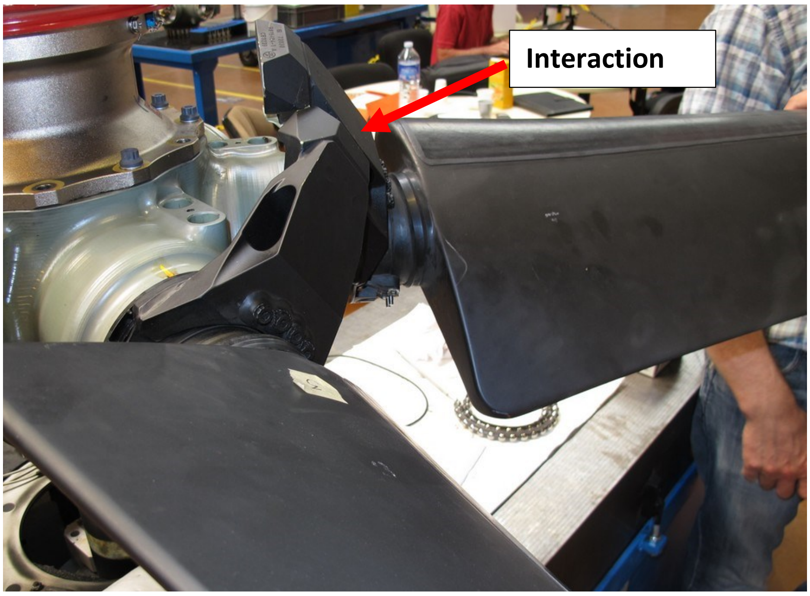


Figure 20: Interaction between the counterweight arms of blades 3 and 4

It could also be seen that when the trunnion pin of blade 4 was broken, the blade was able to rotate freely on its axis and interact with blade 5. The markings observed on the counterweight arm of blade 4 and the counterweight of blade 5[33] were consistent with this sequence of operations.

[33]Cf. para. 1.7.5.1.

Figure 21: Interaction between the counterweight of blade 4 and the counterweight arm of blade 5

1.7.7 Loads required to damage ears of propeller actuator yoke plate and blade trunnion pins

The propeller actuator yoke plates and the blade trunnion pins are designed to withstand the maximum load applied by each blade[34]. These trunnion pin/yoke plate interface loads result from the combination of the following:

- The centrifugal force on the blade.
- The centrifugal force on the counterweight.
- The cyclic and static aerodynamic forces (1P frequency = 1 propeller revolution) applied to the blade, associated with the fact that the blades do not move exactly in a plane perpendicular to the aerodynamic flow field present at the propeller disk. This flow depends on the speed vector of the aircraft and the disturbances caused by the fuselage, wings and nacelle.
- The friction forces at the blade root roller bearings.

The average loads depend on the centrifugal forces on the blade and the counterweights as well as on the average aerodynamic forces. The cyclic loads are a combination of frictional forces and cyclic aerodynamic forces.

Within the flight envelope of the aircraft, the moments applied to the blade tend, generally, to turn the blades toward the coarse pitch; the trunnion pins are then, for most of the time, in contact with the ears of the thick yoke plate of the actuator (aft yoke plate). These torques are reversed by design (trunnion pins in contact with the thin, forward yoke plate) in the following two specific phases of flight:

- Use of the propellers in reverse.
- Propeller feathering sequence. During this sequence, the blades move towards the coarse pitch under the effect of their counterweights. The thin yoke plate (forward yoke plate) only intervenes at the end of the sequence and is subject to very little load.

Non-linear finite element calculations were performed by the manufacturer, UTAS, in order to determine the loads required to plastically deform (exit from the elastic range, irreversible deformation) the ears of the thin (forward) yoke plate and the trunnion pins:

- ears: 3,000 daN (6,800 Lbf);
- trunnion pins: 2,500 to 3,000 daN (5,600 to 6,800 Lbf).

A bench test[35] performed by UTAS showed that the static load required to break a trunnion pin was 6,400 daN.

The propeller hydraulic pitch-change actuator can supply a force of around 11,000 daN.

Note: The initial trunnion pin design specification provided for a theoretical maximum load on a trunnion pin in operation of 1,000 daN +/- 300 (2,250 Lbf +/- 670) without exiting the elastic range. The calculations and tests showed that the final design provided a margin of 2.5 to 3 times the theoretical value.

[34] Cf. para. 1.5.4.7.

[35] This test confirmed the results of non-linear finite element calculations performed by UTAS.

1.7.8 Ball bunching

1.7.8.1 Theory

Due to the different loads applied on the propeller blade, the blade root bearings roll back and forth in their raceway and their angle of contact varies during one propeller revolution (load cycle 1P). Ball migration occurs because the balls move a different amount in each of these back and forth directions.

A ball and its inner and outer raceways act like a planetary gear system with the inner race as the central gear and the outer race as the outer gear. The ball corresponds to the planet gear. When the angle of the blade varies with respect to the hub, the ratio varies between the blade rotation movement during a pitch change, and the ball movement. Thus, for a constant back and forth rotation of the blade tulip within the hub, the varying contact angle will cause a ball to roll further in one direction than the other.

Since all the balls have different angles of contact but share the same constant tulip rotation, each ball migrates at a different speed. Balls can then approach each other and bunch, causing an increase in their friction on the separator that separates them.

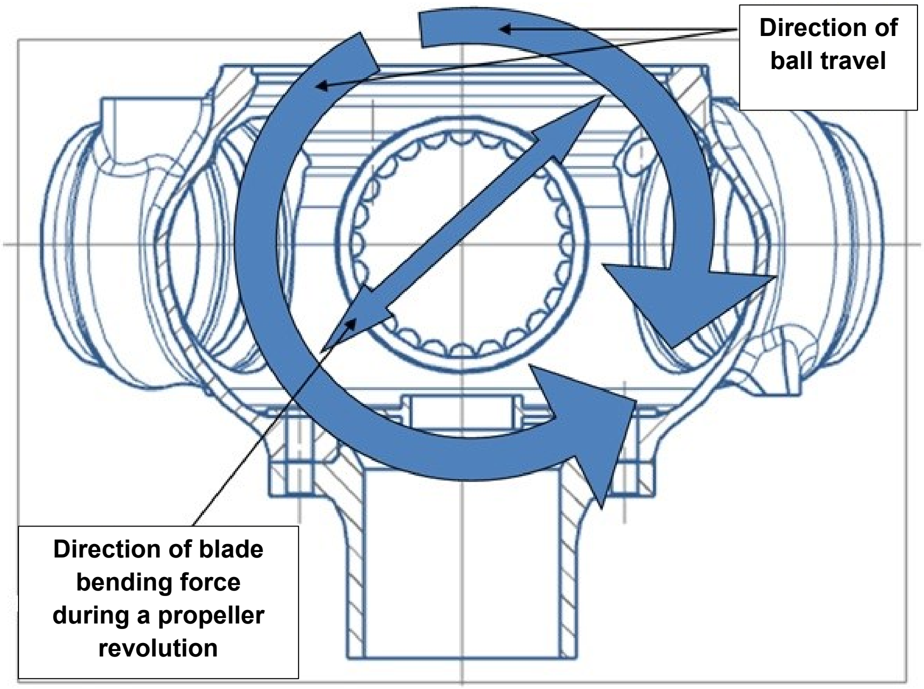


Figure 22: Illustration of ball migration

The mechanism that causes the increase in friction seems to be self-limiting. According to the propeller manufacturer, there has been no feedback from operators concerning crushed or broken ball separators.

The friction resulting from the bunching remains high until the components at the origin of the retention of the blade are sufficiently unloaded. A decrease in magnitude of the load cycle 1P associated with a change in blade angle can reduce the load levels between the balls (according to the existing friction levels) and consequently their friction. Stopping propeller rotation makes the phenomenon completely disappear. The cancellation of the resulting centrifugal force in fact allows the balls to return to their original position.

1.7.8.2 Background

In the early 2000s, the ball bunching phenomenon was observed during the development of another type of propeller on an aircraft equipped with engines supplying 5,000 SHP. The blade attachment system (two bearings per blade) and the pitch change system were similar to those equipping the 568F propellers (differences in size). The aircraft had particular aerodynamic characteristics and was sensitive to the vibration frequencies generated by the propeller which meant that the vibration phenomena could be more easily observed.

Difficulties in the operating conditions of this propeller had been encountered:

- ❒ fluctuations in the rotation speed;
- ❒ blocking and sliding of the pitch change actuator;
- ❒ propeller sensitive to vibration modes.

The phenomenon occurred during phases of flight with a very high propeller load 1P. It was reproduced. The in-depth analysis of these problems made it possible to show that the cause was a ball bunching phenomenon. The ball bunching phenomenon was also discovered at this time. Through these tests, a new separator was developed and produced. The technical solution implemented to prevent the ball bunching from occurring was to modify the shape of the separator and improve its lubrication. Tests on aircraft confirmed that the problem had been resolved. Since then, no similar problem had been reported.

The new vibration phenomena observed from 2012 could not be reproduced during flight tests, unlike the problems encountered in the 2000s.

The propeller manufacturer considers that this bunching phenomenon exists on all the propellers of similar design (similarity of blade retention system). The manufacturer judges that operational feedback shows that this phenomenon remains without repercussions on correct propeller operation.

1.7.8.3 Evaluation of level of rubbing of balls on their separator

Bench tests were conducted by the propeller manufacturer to evaluate the level of friction of a ball on its separator.

The friction force depends on the propeller load, the speed of displacement of the pitch change actuator and the duration of application. A friction peak occurs when the actuator begins its displacement.

The results showed that the measured friction values could theoretically generate sufficient retention forces to damage the blade trunnion pins and the ears of the propeller actuator yoke plates, if the following conditions were met:

- this phenomenon only appeared on one of the six blades of the propeller;
- more than half of the bearing balls[36] of this blade caused significant friction.

[36] There are 24 balls per bearing and two bearings per blade.

Additional bench tests were carried out by the propeller manufacturer to determine the effect of the compression of the balls in their separator on the friction of the blade retention system. During the test, the friction levels per blade reached no more than 44 % of the level required to damage the blade trunnion pins and the ears of the actuator yoke plate. The tests also showed that the friction fluctuations, observed with the initial separator and attributed to the transitions between static and dynamic friction, were nearly eliminated with the new separator[37].

[37] Cf. para 1.8.9.12.

1.7.9 Effect of a vibration on appearance of PEC fault codes

Bench tests were carried out by the propeller manufacturer to assess whether vibrations of just the transfer tube and the PVM/transfer tube assembly could generate PEC fault codes.

The translation vibration test of the transfer tube confirmed that an oscillatory movement with speeds greater than two inches per second caused the display of fault codes 67 and 68[38]. These warnings occurred even when the magnitude of the oscillation of the propeller blade angle was small (between 1 and 2°).

[38] Cf. para. 1.8.4.

The tests also confirmed that the exposure of the PVM/transfer tube system to external vibrations could generate transfer tube displacement speeds causing the display of the PEC fault codes 67 and 68.

The appearance of these fault codes is helped by the direction of vibration along the axis of the transfer tube.

1.7.10 Flight tests

Two Vibration Stress Survey (VSS) flight tests were carried out on two 568F-1 propellers installed on a ATR72-212A test aircraft in Toulouse, France. A summary of the results of the two tests is given in Appendix 13.

The first test to examine the vibration response on the ground with calm and adverse winds and in flight, was carried out in November 2014. The main objectives were to assess whether the vibration response could have changed since 1995, to assess the effect of the ball bunching phenomenon and to improve knowledge of the behaviour of the aeroplane during specific phases of flight. It was carried out in the scope of the investigation in coordination with the BEA and NTSB.

The second test to characterize the vibration response of the propeller in flight was carried out in May 2016. The primary objective was to assess the reduction in friction loads with a redesigned bearing ball separator necklace. The secondary objective was to study the effect of an increased gap between the forward and aft yoke plates of the pitch change mechanism. The increased gap, created by machining the forward yoke plate, mimics 0.05 in[39] of plate wear due to interaction with the trunnion pin roller. The propeller manufacturer considered that the yoke plate wear resulting in increased clearance between the pin and the yoke plates may contribute to increased friction loads.

[39] i.e. 1.27 mm.

1.7.10.1 Static and cyclic loads on blade trunnion pin

The loads measured during the flight tests showed maximum trunnion pin loading far below levels required to produce permanent deformation of the trunnion pins and pitch change actuator. The results from the tests were consistent with the results found during the 1994-1995 certification process.

The following elements were also revealed:

- during flight with wings level, the cyclic loads on the left propeller blades were 5 % higher than on the right propeller;
- specific loads appeared on the trunnion pins during two phases of flight:
  - during the transient manoeuvre to a speed close to VMO at the beginning of descent: appearance of loads directed towards the rear of the propeller with the trunnion pin interacting with the forward yoke plate,
  - during full reverse operation: appearance of peak loading.
- The right propeller blade cyclic loads, compared to the left, during the transient manoeuvre to maximum aircraft speed at the beginning of descent were on average higher by 25 % at 22,300 to 21,55 Kg gross weight and by 33 % at 15,600 to 14,700 Kg gross weight.

1.7.10.2 Ball bunching forces

The hysteresis loops performed during the VSS tests in 2014 confirmed the existence of an increase of the trunnion and actuator loads during flight operation. These loads corresponded to a friction build-up and were in the region of 370 daN i.e. 15 % of the static load required to permanently deform the trunnion pin.

The smoother hysteresis loops obtained during the VSS tests in 2016 with the new bearing ball separator revealed a reduction in friction forces with respect to the VSS tests in 2014. The maximum friction load observed was in the region of 300 daN. It was reduced by approximately 10 to 18 % after the introduction of the new ball bearing separator.

1.7.10.3 Increase in trunnion pin cyclic loading (forward yoke plate cyclic loading)

The increase in trunnion pin cyclic loading (forward yoke plate cyclic loading) occurs within the propeller pitch change mechanism and is of low magnitude. During the phenomenon, the magnitude of the trunnion pin cyclic loading increases for a short duration. This vibration should not be confused with the vibration observed after pin failure that is thought to be caused by blade-to-blade imbalance.

Test results show that the occurrences of forward yoke plate cyclic loading:

- were only observed during descent manoeuvres at 250 kt, but not all descent manoeuvres at 250 kt were accompanied by the occurrence of these forward yoke plate cyclic loadings;
- were only observed on four out of nine recorded descent manoeuvres at 250 kt;
- were observed during both slam and normal pullbacks;
- occurred with and without an enlarged 0.050" yoke plate gap on the right propeller;
- did not occur during descent manoeuvres at 230 kt.

In addition, during the VSS tests in 2016, forward yoke plate cyclic loading occurred on the left propeller although there was no enlarged gap between the yoke plates.

Consequently, the slam manoeuvre and the yoke plate gap cannot each be singled out as the root cause of forward yoke plate cyclic loading.

Each time there was forward yoke plate cyclic loading, the trunnion pin escaped from the aft yoke plate. In this context, it is possible that the low static and cyclic loads observed on the trunnion pin may lead to propeller vibration.

In one case, the data indicated that the forward yoke plate had in fact been loaded. The maximum loads observed were in the region of 450 daN, i.e. 18 % of the static load required to permanently deform the trunnion pin. They should not cause fatigue damage. According to the propeller manufacturer, such behaviour would certainly be exacerbated by a larger yoke plate gap.

1.8 Additional information

1.8.1 Air Safety Reports

Flight of 4 May 2014

The following information comes from the ASR written by crew 030/14 and page No 40304 of the technical log[(40)].

The following elements were noted:

- on initial descent as PWR levers retarded, high vibration #2 engine; then #2 engine PEC fault;
- check list accomplished;
- PEC recovered;
- then PEC 2 single channel and #2 ACW GEN faults;
- check lists accomplished;
- normal landing with slight vibration.

Flight of 05 May 2014

The following information comes from Service Difficulty Report (SDR) and page No 40305 of the technical log.

No 2 engine made very loud vibrating noise after landing when power levers reduced to ground idle. No 2 engine feathered and noise ceased. No fault is given on EC.

1.8.2 Maintenance procedures

1.8.2.1 Identification of cause of vibrations occurring in flight

In view of the difficulties encountered by the maintenance organizations in troubleshooting in-flight vibrations, a specific procedure was set up to help identify the cause of the phenomenon: maintenance personnel had to fill out a three-page form and forward it to ATR for analysis.

1.8.2.2 Dynamic balancing of propellers

Two ground and in-flight measurement procedures allow the maintenance personnel to characterize the vibrations encountered and then balance the propellers. Accelerometers are positioned on the locations provided on the two engines and are connected to wiring pre-installed on the aeroplane.

1.8.2.3 Engine performance ground test

The maintenance personnel must carry out the following operations[(41)]:

- ground idle with the propellers feathered;
- ground idle with the propellers unfeathered (propeller condition levers in AUTO);
- flight idle;
- take-off power;
- engagement of reverse;
- maximum power.

(40) Technical log.

(41) Cf. Appendix 14.

1.8.2.4 Calibration of an EEC

The calibration of an EEC is initially carried out with the engines shut down, the Power Lever (PL) in the Ground Idle position (GI), the DC and AC electric buses powered-on and with the EEC and PEC switched on.

The maintenance personnel must carry out the following operations:

- the EEC/PEC selector (Figure 23) is set to the EEC position;
- the TRIM function is selected on the MCDU. The actions to be performed are displayed on the MCDU screen:
  - the power management selector (PWR MGT) is set to the Take-Off position (TO),
  - the engine bleeds are switched off by pressing the ENG BLEED button,
  - the PL is set to the TO position,
  - the TRIM/LRU selector is set to the TRIM position for more than 5 seconds,
  - the PL is set to GI,
  - the EEC/PEC selector is set to neutral,
  - the engine bleeds are switched on by pressing the ENG BLEED button,
- the power supply of the aircraft is cut off.

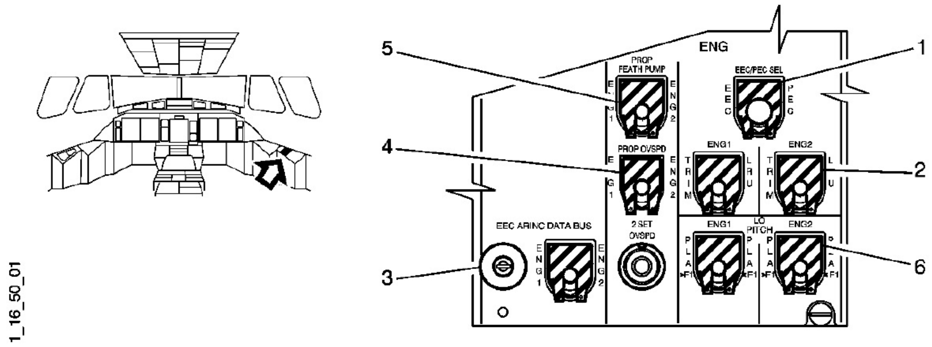
1.8.2.5 Calibration of a PEC

The calibration of a PEC is initially carried out with the engines shut down, the propeller in full feather position, the DC and AC electric buses powered-on and with the EEC and PEC switched on.

The maintenance personnel must carry out the following operations:

- with the propeller Condition Lever (CL) in the feather position (FTR), the EEC/PEC selector (Figure 23) is set to the PEC position;
- the TRIM function is selected on the MCDU. The actions to be performed are displayed on the MCDU screen:
  - The power management selector (PWR MGT) is set to the cruise position (CRZ),
  - the PL is set to the TO position,
  - The TRIM/LRU selector is set to the TRIM position for more than 5 seconds,
  - the PL is set to the FI position,
  - The TRIM/LRU selector is set to the TRIM position for more than 7 seconds,
  - the PL is set to GI,
  - the power management selector (PWR MGT) is set to the TO position,
  - the EEC/PEC selector is set to neutral,
- the power supply of the aircraft is cut off.

This calibration procedure is automatically validated the next time the propeller is unfeathered.



1: EEC/PEC selector
2: TRIM/LRU selectors engines 1 and 2
3: ARINC BUS selector
4: PROP/OVSPD selector
5: Feathering pump selector
6: ENG/LO PITCH selectors

Figure 23 - Side maintenance panel

After replacing a PVM, maintenance personnel must carry out the following operations[42]:

- calibration of PEC (see 1.8.2.5);
- ground idle with the propellers unfeathered (CLs in AUTO);
- several feathering operations until the propeller responds correctly;
- an engine performance ground test (see 1.8.2.3);
- an oil leak check;
- with engine running, a test of the propeller fine pitch protection;
- a test of the propeller overspeed protection system;
- an overspeed governor test;
- part of the engine performance ground test[43] without engaging reverse;
- an operational test of the propeller;
- an ATPCS test.

[42]The operations are detailed in Appendix 14.

[43]Cf. para. 1.8.2.3.

1.8.3 Maintenance operations carried out after flights of 4 and 5 May 2014

After flight of 4 May 2014

The following information comes from ASR 030/14 and page No 40304 of the technical log.

"*APM bite and reset. #1 PEC bite and reset, #2 ACW generator changed due shaft sheared. APM checked satisfactory*. *Engine performance run, NIL vibration or fault found, Engine functional check.*"

After flight of 5 May 2014

The following information comes from the SDR and page No 40305 of the technical log.

The following elements were noted:

- check of torque sensor;
- calibration of EEC;
- calibration of PEC;

- engine ground run performed and result satisfactory;
- engine ground run and PEC fault came on;
- replacement and trimming of PEC;
- engine ground run and PEC fault came back on[44];
- PVM changed;
- engine run with power levers operating from ground idle to flight idle and to T/O power and back to ground idle. No vibration or abnormal warnings observed. However, when power levers moved from ground idle to reverse, vibration observed. Engines were immediately shut down;
- it was observed that on #2 engine, four propeller blades were in their normal position while two propeller blades were stuck in reverse position[45];
- blades (propeller) were removed from their assembly and during inspection it was observed that #4 propeller blade trunnion pin sheared and propeller yoke on actuator was damaged.

[44]During this engine test, no engine or propeller vibration was observed.

[45]Engine No 1 operated normally.

1.8.4 Propeller related events

1.8.4.1 History of propeller related technical events on 9Y-TTC

The technical events linked to aircraft propellers that occurred in the six months preceding the incident are listed in the following table. This information comes from the operator's maintenance operations recording system.

Date	Crew report and maintenance operations
25 January 2014	**Crew report** #2 PEC fault in flight on descent. PEC single channel. Vibration on #2 engine as well during fault process. **Maintenance operation** #2 engine fault cleared. Engine run, system check OK.
15 March 2014	**Crew report** PEC 2 fault light came on in flight with severe vibration when power levers were put to idle. **Maintenance operation** MCDU bite check. PEC 2 failure codes 21, 67 and 68 * recorded. Failure code erasing procedure carried out. Engine ground run all parameters normal.
28 March 2014	**Crew report** PEC #2 fault illuminated in flight with PL at flight idle. Severe vibration at this point. PWR lever advanced. Fault cleared and vibration ceased. **Maintenance operation** #2 PEC reset. System tested normal on engine ground run.

8 April 2014	**Crew report** NO 2 Engine Np falling in amber range when PWR lever advanced when taxiing on number two engine only. **Maintenance operation** NO 2 Engine flow divider and dump valve change, EEC changed. OPS Check OK, Engine run NIL, IAW (in accordance with) AMM 72-00-00
23 April 2014	**Crew report** Difference of 5 % in torque between the left engine and the right engine and need to position the power lever in reverse so that the left propeller switched to beta mode. **Maintenance operation** Calibration of the right and left PECs.
23 April 2014	**Crew report** PEC #2 fault unable to reset. **Maintenance operation** PEC #2 memory erased. Check OK.
24 April 2014	**Crew report** Engine #2 PEC fault. **Maintenance operation** T/S accomplished. PRC shows code 27 SLPS enabled. Fault #2 PEC replaced. EEC trimmed. PEC trimmed.
4 May 2014	**Crew report** On initial descent as PWR levers retarded, high vibration #2 engine; then #2 engine PEC fault. Check list accomplished. PEC recovered. Then PEC 2 single channel and #2 ACW GEN fault check lists accomplished. Vibration reduced considerably. Normal landing with slight vibration. **Maintenance operation** APM bite and reset. #1 PEC bite and reset, #2 ACW generator changed due shaft sheared. APM checked satisfactory. Engine performance run, NIL vibration or fault found, Engine functional check normal.
05 May 2014	**Crew report** On landing, NO 2 Engine vibrating with very loud noise when power levers reduced from FI to ground idle. With power lever moved back from ground idle to flight idle, noise and vibration ceased. NO 2 engine feathered. No faults given on EC. **Maintenance operation** PEC calibrated then engine ground test performed, nothing abnormal found.
07 May 2014	**Maintenance operation** Faulty propeller changed.
14 May 2014	**Maintenance operation** Examination of right engine, oil leak at high pressure rotor, right engine changed.

1.8.4.2 Meaning of PEC fault codes which appeared on 9Y-TTC

The meanings of the PEC fault codes reported in crew reports in the six months prior to the incident are described below:

Code 21 - Weight On Wheel

The Weight On Wheel (WOW) signal is not consistent with the speed information.

This fault code is immediately generated on one of the two following combinations occurring:

- the speed is more than 190 kt and the signal indicates weight on wheel (aeroplane on the ground);
- the speed is less than 30 kt and the signal indicates weight off wheel (aeroplane in flight).

Code 27 - Secondary Low Pitch Stop (SLPS) enabled fault

The SLPS was not activated (excitation voltage) when the power lever was below the FI position.

This fault code is immediately generated on the fault occurring and sets the PEC to "PEC FAULT".

Code 67 - Primary channel actuator position fault

The actuator position signal[46] shows a malfunction in the PEC primary channel.

[46]Cf. Appendix 15.

This fault code is generated by one of the following malfunctions:

- the actuator is located at a position more than 3.81 mm away from the zero angle position in the forward direction (blade angle value less than -28°);
- the actuator is located at a position more than 63.5 mm away from the zero angle position in the rear direction (blade angle value more than +97°);
- the actuator travel speed is more than 50.8 mm per second calculated at each cycle of the PEC. A travel distance of 50.8 mm corresponds approximately to a blade angle of 80°;
- the voltages transmitted by the RVDT to the PEC are incorrect or exceed limit values.

Code 68 - Backup channel actuator position fault

The actuator position sensor[47] shows a malfunction in the PEC backup channel.

[47]Cf. Appendix 15.

This fault code is generated in the same way as for the PEC primary channel (Code 67).

1.8.4.3 Failover time to backup channel and confirmation of faults by PEC

Most of the PEC faults which give rise to a warning have a two-second confirmation period from when the problem is first detected to the confirmation and display of the fault. Some faults have to persist for longer before being confirmed (for example, a defect in the measurement of the propeller rotation speed) and others for a shorter period.

When there is a propeller blade angle[(48)] measurement fault, the logic of the PEC failover from the primary channel to the backup channel is as follows: at least every 11.44 ms, in parallel for each primary and secondary channel, an event counter is increased by the value 3 if the beta angle is not valid (the maximum value of the counter is 12) and decreased by 1 if the beta angle is correct[(49)]. Another counter (DT counter) increases its value by 11.44 ms as long as the event counter is not zero. The DT counter is reset to zero if the event counter reaches zero. When the DT counter reaches the value of two seconds, the PEC switches to the backup channel. If the backup channel is also defective, the "*PEC FAULT*" warning appears; when the beta values are considered incorrect on the primary and secondary channels, the PEC continues to operate in alternate mode.

A beta angle measurement fault therefore takes at least two seconds to be confirmed in flight and give rise to a "*PEC FAULT*" warning. The same fault on the ground with the power lever below the flight idle position is confirmed in about 50 ms.

(48)The propeller blade angle is called the beta angle, Cf. Appendix 15.

(49)With this logic, the beta value is considered erroneous as soon as it is not valid for at least one cycle out of three for a period of two seconds.

1.8.4.4 Consequences of a PEC restart

When the PEC is no longer powered, it no longer controls the electrohydraulic valve of the PVM[(50)]. The position of the valve in this case requires a reduction of the propeller pitch. The speed of the propeller will therefore increase to the mechanical overspeed protection value [(51)].

(50)Cf. para. 1.5.4.3.

(51)The overspeed mechanical protections were still active, Cf. para. 1.5.4.6.

1.8.5 Certification of propeller on ATR 72-212A

As part of the ATR72-210/PW127/568F-1[(52)] certification process, VSS tests were carried out in Toulouse in December 1994 and January 1995. The purpose of these tests was to determine the vibration response of the propeller on the ground in calm wind and tailwind conditions as well as during in-flight operations.

Vibration measurements were made solely on the left engine. Due to the aeroplane's design, the left propeller was in fact considered to be the most loaded of the two in operation. The measurements made on the left propeller were therefore considered conservative with respect to the right propeller.

With regard to the analysis of the loads on the propeller blade trunnion pins, the flight test programme specified that only the trunnion pin of blade 6 was to be equipped with a strain gauge. Trunnion pin loads were only to be recorded during a first test flight and during the following specific flight phases:

- on take-off flaps extended by 15°;
- on flap retraction during the initial climb;

(52)ATR 72-210 equipped with Pratt and Whitney PW 127 engines and Hamilton Sundstrand 568F-1 propellers.

- ❒ during climb to altitudes of 1,000, 5,000 and 10,000 ft with the PMS in the MCT and CLB positions;
- ❒ in cruise at a high altitude (above 20,000 ft) at an indicated airspeed of 170 kt with the PMS in the MCT position;
- ❒ in cruise at a high altitude (above 20,000 ft) at an indicated airspeed of 220 kt with the PMS changed from the MCT to CRZ position;

The VSS report contains no results or analysis of the trunnion pin loads. According to the manufacturer, no measurement could be analysed because the strain gauge had failed. Nevertheless, the absence of this data did not constitute an obstacle to continuing the propeller certification process. The investigation was not able to determine the elements which lead the certifying body to take this decision.

1.8.6 Changes in propeller definition

UTAS provided the BEA with a list of all the Engineering Changes (EC) to the Hamilton Sundstrand Model 568F-1 propeller since it was put into service. As part of this investigation, all the changes to the propeller were reviewed by UTAS and the BEA. No element which could explain the appearance of the first incidents in 2007, 12 years after the propeller had been put into service, was found.

The number of changes is as follows:

- ❒ blades = 60;
- ❒ propeller components = 30;
- ❒ hub = 9;
- ❒ pitch change actuator = 11.

These modifications were all reviewed and approved by the FAA based on a safety impact analysis. The VSS tests were carried out for the initial certification of the propeller in 1994-1995. None of the modifications made to the propeller, between its entry into service in 1995 up to the flight tests in 2014 and 2016 following the incidents, had required its behaviour to be checked by the carrying out of VSS tests.

According to the propeller manufacturer, there have been no "certification" based tests to "verify the behaviour of the propeller assembly in operation" since 1995. The manufacturer added that VSS testing for certification purposes focuses on aerodynamic loads applied to the airfoil sections of the blade. The 2014 and 2015 VSS tests were conducted as a result of, and were specific to, the trunnion pin investigation. The instrumentation was thus different from a typical propeller certification VSS, having only blade shank strain gages to reference unlike previous VSS certification tests. UTAS understands that even minor changes to components can functionally or structurally alter operating characteristics. In the late 1990's, the UTAS "*Flight Safety Parts*" program was created to enhance and reinforce this concern**.** The "*UTAS Engineering Change*" system is designed to minimize the potential of making changes that adversely affect prime structural and functional components. In addition, the propeller system operation and function are monitored via the UTAS operator support program and ATR flight testing. UTAS added that it should be noted that certification testing was performed on the 568F-5 propeller system for the CASA C295 aircraft in the 1999 time frame. This propeller is structurally identical to the 568F-1 model.

1.8.7 Method of certification of propeller on ATR 72-212A

At the time of the propeller's certification (1994-1995), the propeller certification conditions were described for the FAA in the Code of Federal Regulation, Title 14 "*Aeronautics and Space*", Part 35 "*Airworthiness standards: propellers*", incorporating the amendments 35-1 to 35-6 of 18 August 1990. The propeller equipping the ATR 72-212A was certified according to the CFR 14 PART 35 of the FAA. The CS-P European regulation did not exist at this time.

Sub-part C of the CFR 14 part 35 dealt with the tests and examinations. In chapter 35.37 it is stated that the fatigue evaluation must include consideration of all reasonably foreseeable vibration load patterns.

The FAA circular 20-66 of 29 January 1970, in force at the time of the certification, proposed a method for assessing propeller vibrations on the aeroplane.

1.8.8 Current method of certification of a propeller

The current propeller certification conditions are described for EASA in the CS-P document amendment 1 of 16 November 2016 and for the FAA in the Code of Federal Regulation, Title 14 "*Aeronautics and Space*", part 35 "*Airworthiness standards propellers*."

1.8.8.1 FAA certification

Sub-part C of the CFR 14 part 35 deals with the tests and examinations. In particular, it is stated, in chapter 35.37, that the fatigue limits must take into account all known and reasonably foreseeable vibration and cyclic load patterns that are expected in service

The FAA circulars 20-66A (in force from 17 September 2001 to 24 March 2011) and 20-66B (in force from 24 March 2011) propose a method for assessing the vibration stresses on a propeller. In particular, it is stated that:

- when a study cannot adequately show the applied loads for the fatigue assessment, strain gages can be positioned on the components of the propeller pitch change system;
- multi-engine installations may require testing on more than one propeller, depending on aeroplane configuration and previous test experience;
- during the flight tests, it is recommended to carry out flight idle descents at various speeds.

It should be noted that at the time of the propeller's certification, the circular in force (20-66) did not explicitly recommend performing flight idle descents at various speeds but more generally to check all the conditions likely to cause an aerodynamic excitation of the propeller.

1.8.8.2 EASA certification

CS-P Subpart C deals with type substantiations. In particular, it is stated that the propeller fatigue characteristics must be taken into account:

- ❒ all known and reasonably foreseeable vibration and cyclic load patterns that are expected in service;
- ❒ expected service deterioration;
- ❒ variations in material properties;
- ❒ material fatigue scatter;
- ❒ manufacturing variations and environmental effects.

Subpart D deals with propeller vibration, fatigue evaluation and flight functional tests. In particular, it is stated that:

- ❒ it must be demonstrated by tests, analysis based upon tests or previous experience on similar designs that the propeller does not experience harmful aero-elastic effects (including flutter) or harmful effects of vibration throughout the operational envelope of the aircraft with suitable stress margins;
- ❒ when necessary for complying with the safety objective of CS-P 530 (a), the magnitude of the propeller vibration stresses or loads, including any stress peaks and resonant conditions, must be determined throughout the declared operational envelope of the intended aircraft by either:
  - ■ measurement of stresses or loads through direct testing or analysis based on direct testing of the propeller on the aircraft and engine installation for which approval is sought, or
  - ■ comparison of this propeller to similar propellers installed on similar aircraft installations for which these measurements have been made,
- ❒ any operating conditions or speed ranges shown by the fatigue evaluation and vibration survey to require limitation must be clearly stated in the propeller certification documentation.

1.8.9 Safety actions carried out

1.8.9.1 Immediate recommendation by Indonesian investigation authorities

Following the event on 18 September 2013 in Indonesia involving the ATR72-212A registered PK-WFV[53], the NTSC issued an immediate recommendation on 21 September 2013 to the aircraft operator.

[53]Cf. para. 1.2.5.

The NTSC described the following safety issue: "*impact of the broken of the [sic] propeller blade roller bearing support resulted the propeller pitch angles was uncontrolled and impacted to the heavy vibration of the engine that caused the engines mounting brackets broken and the engine was tilting up and down during operation indicated by the exhaust duct was touching and scratching the upper heat shield duct*." It recommended that the operator check the condition of the trunnion pins and to search for crack indications. This inspection concerned part of the ATR 72-212A fleet operated by Wings Air whose operating time or number of cycles since being put into service were close to that of the damaged aircraft.

1.8.9.2 Inspection campaign on fleets of three airline companies

The right propellers of the ATR 72-212A belonging to three operators (Trip Linhas Aéreas, Precision Air and Wings Air) where the actuators or blades had logged more than 3,200 flight hours or more than 3,200 flight hours since the last major inspection (carried out after 10,500 flight hours) were checked between January and February 2014. The distance separating the two actuator yoke plates was measured and the propeller blade trunnion pins were checked for cracks using the fluorescent penetrant inspection (FPI) method. No anomaly was found on the 44 aeroplanes concerned.

1.8.9.3 Modification of maintenance procedures

ATR operator information message

On 23 September 2014, ATR issued an Operators Information Message regarding ATR 42-400, 42-500 and 72-212A[54] implementing a new maintenance procedure for early detection of deformation of the propeller pitch change mechanism when a vibration event associated with a PEC FAULT warning is reported by the crew.

[54] Cf. Appendix 16, OIM 2014/10.

UTAS Service Bulletin

On 2 October 2014, UTAS issued a Service Bulletin[55] concerning the Hamilton Sundstrand model 568F propellers and describing the procedure to detect deformation of the propeller pitch change mechanism. This SB is linked to the ATR OIM 2014/10 described above.

[55] Cf. Appendix 17, SB 568F-61-67.

1.8.9.4 BEA Safety Recommendations

On 23 December 2014, the BEA sent four safety recommendations[56] to EASA.

[56] Cf. Appendix 18.

Recommendation FRAN-2014-016

EASA takes the necessary actions in order to ensure that all pilots operating ATR equipped with Hamilton Sundstrand Propellers, model 568F-1, are informed that severe vibrations have occurred during descent at a speed close to VMO with power levers in Flight Idle position and that heavy damages to the propeller pitch change mechanism and, in one case, to engine mounting fittings were observed.

Recommendation FRAN-2014-017

EASA takes the necessary actions in order to ensure that all pilots operating ATR, equipped with Hamilton Sundstrand Propellers, model 568F-1, plan and operate their flights to avoid operations close to VMO at Flight Idle.

Recommendation FRAN-2014-018

EASA takes the necessary actions in order to ensure that all pilots operating ATR equipped with Hamilton Sundstrand Propellers, model 568F-1, report to maintenance if they experience severe vibrations during descent at a speed close to VMO with power levers in Flight Idle position.

Recommendation FRAN-2014-019

EASA takes the necessary actions in order to ensure that ATR develops an appropriate operational procedure addressing severe vibrations of a propeller and that airlines operating ATR equipped with Hamilton Sundstrand Propellers, model 568F-1, include that procedure in their operational documentation.

1.8.9.5 EASA Safety Information Bulletin

On 30 January 2015, EASA issued a Safety Information Bulletin to the owners and operators of ATR 42-400, 42-500 and 72-212A equipped with Hamilton Sundstrand propellers, model 568F-1[(57)].

[(57)] Cf. Appendix 19,SIB 2015/03.

As a precautionary measure and in order to limit the risk of propeller vibrations occurring in flight, EASA recommends that:

- Operators of aeroplanes as defined in the Applicability of this SIB should follow as much as possible the aeroplane manufacturer recommendation for a standard descent speed at maximum 240 knots. If, for any reason, during descent the speed becomes close to VMO and the power levers have to be reduced to 'flight idle' position, a smooth and progressive reduction of the power levers should be accomplished.
- Should an operator anyway encounter the described phenomenon during descent, the crew should try to discriminate and shut down the affected engine, carrying-on operations with one engine operative.
- In case of any difficulty to discriminate and shut down the affected engine, the crew should avoid using 'reverse' mode on engines.
- Because the on-going investigation evidenced that prior to the flights during which the propeller pitch change mechanisms were severely damaged, sudden and unusual vibration, for a short duration, were sometimes reported by pilots during the descent with airspeed close to VMO, when they reduced PLA to FI position, pilots operating aeroplanes as defined in the Applicability of this SIB should report any sudden and unusual vibration encountered during descent or approach to their maintenance organisation.
- Operators of aeroplanes as defined in the Applicability of this SIB should consider the recent publications issued by ATR ,and UTC Aerospace Systems[(58)], providing operators with guidelines for troubleshooting:
  - ATR Operators Information Message (OIM), ref: 2014/10 issued 1, dated 23/09/2014,
  - UTC Aerospace Systems Service Bulletin (SB), ref: 568F-61-67, dated 02/10/2014,

  and to report to ATR, the aeroplane manufacturer, whenever exposed to the symptoms mentioned in the "Description" section of this SIB.

[(58)] Cf. para. 1.8.9.3.

1.8.9.6 ATR All Operators Message

On 23 February 2015, ATR issued a message to all the operators of ATR 42-400, 42-500 and 72-212A[(59)] in order to inform them about occurrences of sudden appearance of severe vibration in flight which were due to propeller blade pitch change mechanism damage.

The message recalled the maintenance operations requested by ATR OIMs and UTAS SBs[(60)]. It introduced an Operation Engineering Bulletin[(61)] describing the procedure to be followed by the pilot to identify in flight the propeller assembly causing the vibrations. The EASA SIB[(62)] figured in the appendix.

[(59)] Cf. Appendix 20, AOM 42/72/2015/01.

[(60)] Cf. para. 1.8.9.3.

[(61)] Cf. Appendix 21, EOB No 25.

[(62)] Cf. para. 1.8.9.5.

1.8.9.7 EASA response to first three BEA safety recommendations

Recommendation FRAN-2014-016

- ❒ EASA response (6 March 2015): EASA has issued SIB No 2015-03. The concern of this safety recommendation is addressed in the description section.
- ❒ BEA opinion (8 April 2015): The BEA considers that the combination of EASA SIB No 2015-03 and ATR AOM 42/72/2015-01 issue 1 meets the safety recommendation.

Recommendation FRAN-2014-017

- ❒ EASA response (6 March 2015): EASA has issued SIB No 2015-03. The concern of this safety recommendation is addressed by the SIB's No 1 recommendation.
- ❒ BEA opinion (8 April 2015): Recommending to follow existing ATR FCOM as much as possible is not completely addressing the recommendation because experience has shown that current procedure leads flight crews to regularly fly close to VMO. Furthermore, BEA would like to ensure that EASA took into account the impact of the recommendation on the ATR FCOM "*emergency descent*" procedure where it is requested to move both power levers to flight idle and to follow a speed close to VMO.

Recommendation FRAN-2014-018

- ❒ EASA response (6 March 2015): EASA has issued SIB No 2015-03. The concern of this safety recommendation is addressed by the SIB's No 4 and No 5 recommendations.
- ❒ BEA opinion (8 April 2015): The BEA considers that EASA SIB 2015-03 is an adequate response to the safety recommendation.

1.8.9.8 FAA Special Airworthiness Information Bulletin

On 20 April 2015, the FAA issued a Special Airworthiness Information Bulletin to the owners and operators of ATR 42-500 and 72-212A equipped with Hamilton Sundstrand Model 568F-1 propellers[63]. The bulletin referred to the EASA SIB[64] and recommended that operators follow the instructions in the ATR OIM and UTAS SB[65].

[63] Cf. Appendix 22, SAIB NM-15-14.

[64] Cf. para. 1.8.9.5.

[65] Cf. para. 1.8.9.3.

1.8.9.9 Revision of EASA Safety Information Bulletin

On 19 January 2016, EASA issued a revised Safety Information Bulletin for owners and operators of ATR 42-400, 42-500 and 72-212A equipped with Hamilton Sundstrand Propellers Model 568F-1[66].

[66] Cf. Appendix 23.

The revision concerned the method to be applied to determine the engine concerned by the vibrations, in accordance with the ATR AOM[67].

[67] Cf. para. 1.8.9.6.

1.8.9.10 EASA response to fourth BEA safety recommendation

Recommendation FRAN-2014-019

- ❒ EASA response (28 January 2016): EASA published an updated SIB 2015-03R1 in which it recommended operators to incorporate ATR EOB No 25 in their operational documentation.

- ❒ BEA opinion (4 March 2016): The BEA considers that the procedure is not suitable. This procedure, which is too complex, can only be accepted as a temporary solution. When the engine concerned cannot be identified, which seems to be often the case, the procedure requires propeller No 2 to be feathered and if this action has no effect, to restore engine No 2 and to feather propeller No 1. The complexity of this procedure introduces the risk that the crew will not be capable of safely implementing it. If a simpler, more effective proposal cannot be made, then a change in design or fleet operational limitation may be implemented to eliminate the risk of the vibration phenomenon occurring.
- ❒ EASA response (7 June 2016): The recommended procedure was jointly assessed by ATR & EASA Flight Test experts. There is no evidence that it is too complex and [to EASA's knowledge] there is no negative feedback from Operators on record. No further events leading to mechanical damage have been reported since March 2015. SIB 2015-03R1 constitutes already an operational mitigation. It consists of a two-step guidance which basically iterates good practices: Avoid speeds close to VMO during descent and reduce power gently if vibrations are encountered. EASA confirms the response already provided on 28 January 2016. EASA remains at the BEA's disposal if the latter wish to organise a teleconference to further discuss the topic if deemed useful.
- ❒ BEA opinion (29 June 2016): The BEA notes EASA assessment that recommended procedure is not too complex and does not lead to operational risks. Therefore the BEA assesses EASA response as partially adequate. The need for additional safety actions may be reconsidered in the frame of the final reports of the on-going investigations.

1.8.9.11 SHK Safety Recommendations

On 19 October 2016, SHK published the final report concerning the event on 30 November 2014 in Sweden involving the ATR 72-212A registered SE-MDB[68].

SHK's assessment is that additional extensive engineering initiatives are necessary in order to find the cause of the incident and that such initiatives should be the responsibility of the aircraft and propeller type certificate holders, under supervision of the certifying authorities. SHK adds that it has also been possible to establish that incidents of a similar nature have taken place under similar circumstances.

Recommendation SWED-2016-002

EASA is recommended to consider introducing temporary limitations in the manoeuvring envelope, or limitations of the power ranges within the latter, until the problem is resolved and rectified.

- ❒ EASA response (17 January 2017): On 19 January 2016, EASA issued Safety Information Bulletin (SIB) 2015-03R1. Since then, there were no further events on record where propeller vibration caused damage to the hardware. Operators flying aeroplanes as defined in the Applicability of this SIB should follow as much as possible the aeroplane manufacturer recommendation for a standard descent speed at maximum 240 kt. If, for any reason, during descent the speed becomes close to VMO and the power levers have to be reduced to 'flight idle' position, a smooth and progressive reduction of the power levers should be accomplished. Additionally, the UTAS company issued in August 2015 (SB568F-61-69) "*Propeller - Variable Pitch Aircraft - Introduction Of New Ball Separator*", addressing reduction of internal friction loads which are suspected to contribute to the observed vibration. Testing coordinated between the Aircraft and Propeller Type Certificate holder is still ongoing. These tests are necessary to confirm the possible causes of severe vibrations.

[68] Cf. para. 1.2.6.

1.8.9.12 Entry into service of new bearing ball separator

A new design of the propeller blade bearing ball separator was developed by UTAS[69]. ATR and UTAS recommended to operators that they replace the former bearing ball separators with this new model which reduces friction loads on the bearing ball retention system. At the time of writing this report, 14,145 separators had been supplied to operators (this number covers more than 60 % of the fleet equipped with this type of propeller). ATR received confirmation of the replacement of the separators for 428 propellers, i.e. 23 % of the fleet concerned.

[69]Cf. Appendix 24, ATR AOM 42/72/2015/01 issue 2 and UTAS SB 568F-61-69.

2 - ANALYSIS

2.1 Scenario of propeller vibration events for 9Y-TTC

Propeller related vibrations felt by crew during previous flights

During the months prior to the incident, crews of the ATR 72-212A registered 9Y-TTC had reported three propeller related vibration events:

- On 25 January 2014, the crew had felt vibrations during the descent and PEC FAULT then PEC SINGLE CHANNEL warnings associated with the right propeller had appeared.
- On 15 March 2014, the crew had felt severe vibrations during the flight when they moved the power levers to the flight idle position. The PEC FAULT warning associated with the right propeller appeared. Reading the right propeller PEC fault codes revealed an operating fault of the propeller pitch angle position sensors of the PEC primary and back-up channels (fault codes 67 and 68). Propeller vibrations can generate this type of failure.
- On 28 March 2014, the crew had felt severe vibrations during the flight when they moved the power levers to the flight idle position. The vibrations disappeared when the power levers were moved forward. The PEC FAULT warning associated with the right propeller appeared.

Maintenance teams carried out ground engine tests following each of these events, the tests detected nothing abnormal

The possibility of damage to the propeller pitch change mechanism before the flight of 4 May 2014 cannot be ruled out. Nevertheless, the analysis of the parameters recorded in the QAR showed that this damage, if it existed, was not significant. For the previous flights, the left and right engine and propeller parameters were similar when using reverse, even in the cases where there was maximum power.

Vibrations during flight on Sunday, 4 May 2014

During the descent, at an increasing speed of 246 kt close to the VMO (250 kt), the crew reduced power to the minimum by putting the levers in the flight idle position. The torques of the two engines reached zero or negative values which indicated that the propellers were windmilling. The crew then felt strong vibrations.

Given the strength of the vibrations, the right propeller pitch angle position sensors probably sent a sufficient number of out-of-tolerance values to the PEC to trip the PEC FAULT warning. The vibrations also led to the rupture of the drive shaft of the right engine AC wild generator. The intensity of the vibrations subsided when the decreasing speed reached 236 kt and the crew started the PEC fault management procedure by putting the right propeller condition lever in the "*100 % OVRD*" notch. The values recorded in the QAR showed a reduction in the number of pitch angle erroneous values. Finally, three or four seconds later, the vibration level had sufficiently dropped for these values to become constantly valid and the PEC FAULT warning went off.

The vibrations lasted for around 20 seconds during which time the PEC stayed in FAULT mode. It was not possible to conclude with certainty that the ears of the actuator forward yoke plate were damaged during this vibration episode. This damage could in fact have been caused during the last engine test on 5 May. However, there were numerous similarities with the vibration episode in the incident on 30 November 2014 concerning ATR SE-MDB where it was shown that the damage had occurred during the in flight vibrations.

The crew then continued the procedure by restarting the right PEC, by putting the right propeller condition lever in the "*AUTO*" notch and then balancing the power of the two engines.

After restarting the right PEC, an anomaly, the cause of which has not been determined, appeared on its primary channel which tripped the ENG 2 PEC SGL CH warning.

Continuation of flight on Sunday, 4 May 2014

As the actuator forward yoke plate is only loaded in flight in very specific configurations, the crew was able to continue their flight normally with a possibly deformed right propeller forward yoke plate.

However, until landing, the recorded parameters showed the pitch of the right propeller as being 2° to 5° more than for the left propeller. The rupture of the drive shaft of the AC wild generator was probably the cause of this difference. As the damaged generator was no longer absorbing its share of the power provided by the engine, the power transmitted to the right propeller was in fact greater than the power transmitted to the left propeller. Consequently, in order to maintain the same propeller rotation speed, the pitch change mechanism controlled a greater blade angle on the right propeller.

During the landing, the crew reported that they felt slight vibrations. Reverse was not used. During the taxiing and up to engine shutdown, the recordings showed a torque difference between the right and left engine in order to keep the same propeller rotation speed. The right engine provided 10 % more torque than the left engine. The cause of this difference in torque was not determined.

Maintenance operations carried out after flight of 4 May 2014

The maintenance documents showed that after the flight, the PEC fault codes of the left engine were checked and the PEC reset when the checks should have concerned the PEC of the right engine. The investigation was not able to determine if this was an entry error in the maintenance documents and what fault codes were recorded in the PEC memories.

A test with take-off power and a propeller rotation speed of 100 % Np of the two engine/propeller assemblies did not reveal vibrations or abnormal operation. However, this engine operating range does not load the actuator forward yoke plate and, consequently, does not allow its condition to be checked. The blade trunnion pins only come into contact with the forward yoke plate during two flight phases: reverse and propeller feathering(70).

(70)Flight tests have shown that the trunnion pins can also come into cyclic contact with the forward yoke plate at high speed and reduced power (Cf. para 1.7.10).

The complete engine performance ground tests include a transition to reverse with maximum power. This test may have revealed the existence of damage to the right propeller pitch change mechanism but it was not carried out.

Vibrations during flight on Monday, 5 May 2014

The flight proceeded normally. The recorded parameters were normal with no difference in values between the left engine and the right engine, unlike the end of the previous flight. The replacement of the AC wild generator of the right engine before the flight was probably why this difference disappeared.

During the landing run, the crew nevertheless heard a loud noise when they moved the power levers from the flight idle to ground idle position. The recorded parameters confirmed abnormal operation of the right propeller: a decrease in the speed of the right propeller compared with the left propeller and, at the same time, an increase in the torque of the right engine of up to 17 % more than the left engine.

Thereafter, the right engine provided 10 % more torque than the left engine up to its shutdown. The cause of this difference in torque, also present during the previous flight, was not determined.

The crew reported that the noise disappeared when the right propeller was feathered. No warning appeared in the cockpit. The crew continued taxiing to the apron using the left engine only.

Maintenance operations carried out after flight of Monday, 5 May 2014

In a first ground test of the use of reverse, the maintenance agents did not feel any abnormal vibration. The data recorded by the QAR showed that during this first test, the maintenance agents twice set the power levers to the reverse position for a period of less than three seconds. In this lapse of time, the right engine did not have the time to supply maximum power and the right propeller blades were not able to reach a sufficient angle for the trunnion pin of blade 3 to pass behind the actuator forward yoke plate on which ear 3 was probably already deformed.

A second and third test were interrupted by the appearance of the PEC FAULT warning before the end of the unfeathering sequence of the right propeller. The maintenance agents had calibrated the right PEC before the second test and then replaced and calibrated the right PEC before the third test. They reported that they felt no abnormal vibration.

The right PVM was replaced. A fourth ground test was started, during which were tested ground idle, flight idle and sufficient power to reach 100 % Np without reaching take-off power, without any warning occurring or any abnormal vibration being felt. This engine operating range does not load the actuator forward yoke plate and, consequently, does not allow its condition to be checked. The power levers were then put in the reverse position. The maintenance agents felt abnormal vibrations and shut down the engines.

The pitch angle reached during this last use of reverse was sufficient for the trunnion pin of blade 3 of the right propeller to pass behind the actuator forward yoke plate. The blade 3 counterweight arm came into contact with that of blade 4, locking the pitch angle of the latter blade. When the maintenance agents tried to feather the right propeller, this was prevented by blade 4, which was still blocked. Its trunnion pin, bearing on ear No 4 of the forward yoke plate, blocked the movement of the pitch change actuator. Then, after around ten seconds, the power supplied by the actuator was sufficient to break the blade 4 trunnion pin. The actuator then moved to the feathering position. When trunnion pin 4 failed, blade 4 became free to rotate and its counterweight interacted with that of blade 5.

After shutting down the engines, blades 1, 2, 5 and 6 were feathered whereas blade 3 (whose trunnion pin had passed behind the actuator yoke plate) and blade 4 (free to rotate, trunnion pin broken) were in unusual positions.

This incident showed that despite the maintenance procedures implemented, it was possible to perform a flight with significant damage to the propeller pitch change mechanism. With this in mind, all the elements established during the analysis of similar events need to be examined to try and determine a scenario in which the propeller pitch change mechanism is damaged, and to determine the cause.

2.2 General analysis of propeller vibration events

2.2.1 Identification of potential safety risks

2.2.1.1 Separation of an engine in flight

The separation of an engine-propeller assembly in flight could result in the loss of control of the aeroplane. In one case, following a vibration event, engine mounting brackets were found damaged. In another case, the rupture of two right engine mounting brackets was observed. However, as the crew continued the flight without feathering the right propeller and used reverse for landing, it was not possible to know whether the mounting brackets had failed in flight or on the ground during the landing phase.

2.2.1.2 Blocking of feathering system in flight

The blocking of a propeller feathering sequence in flight could lead to the loss of control of the aeroplane. In the cases where reverse was used, the counterweight of one blade locked the adjacent blade, blocking the feathering.

In one case, the deformation of the ear of the forward yoke plate released the blocked blade and allowed the four other blades to feather.

In another case, the propeller pitch change mechanism remained blocked at a pitch angle of around 35° (the feathered angle is 78.5°). Only the rupture of the trunnion pin of the locked blade allowed the feathering of the four other blades. This rupture was caused by the actuator which, supplied by the feathering auxiliary pump, can produce a load of around 11,000 daN, which is more than the load required to break a trunnion pin (6,400 daN). However, this theoretical design does not necessarily lead to the rupture of a trunnion pin followed by the feathering of the other blades. The rupture of the blocked trunnion pin is in fact not necessarily immediate (around ten seconds in the case observed) and the auxiliary pump has an operating time limited to 30 seconds.

It should not be possible for this type of blockage to occur in flight however, as a blade has to reach a pitch angle of less than -14° to lock the adjacent blade.

The numerous marks observed on the blade counterweights showed that during incidents, interactions between the blades were frequent. The propeller manufacturer does not think that it is possible that the counterweights came into contact during vibrations in flight, but that rather this occurred on the ground.

2.2.1.3 Erroneous identification by crew of propeller concerned, leading to in-flight shut down of engine of sound propeller

An error by the crew in identifying the propeller concerned, leading to the shut down of the engine corresponding to the propeller in good condition, could cause a substantial loss of altitude and, if the event should occur at a low height, difficulties in maintaining the desired flight path. Indeed, the conditions for vibrations to appear in flight can simultaneously occur in flight phases at a low height. The statements given by certain pilots who said that they had encountered abnormal vibrations in a glide path final approach and in a visual approach seem to confirm this.

It does not seem to be easy for crews to identify the propeller concerned. A crew in fact first feathered the sound propeller as they had difficulties in reading their instruments. In another case, the crew reported that they had had difficulties in identifying the propeller concerned and that the vibrations increased when they reduced power on the damaged propeller.

2.2.1.4 Internal damage to engine and its accessories

The intensity of propeller vibrations can cause internal damage to the engine and its accessories leading to a deterioration of the flight situation.

The following internal damage to the engine and its accessories was observed:

- ❒ loss of oil pressure;
- ❒ compressor housing split over 180° and start of erosion on turbine-propeller coupling shaft (risk of shaft failure and turbine overspeed);
- ❒ failure of AC wild generator drive shaft (three confirmed cases).

These observations show that a vibration event in flight will often result in the loss of the AC wild generator (the AC wild electrical power will then be provided by the generator on the non-affected engine) and the failure of the engine associated with the propeller.

2.2.2 Damage to propeller pitch change mechanism scenario

The elements collected during the various investigations carried out on similar incidents have made it possible to determine that the damage to the propeller pitch change mechanism was linked to the appearance of overloads on blade trunnion pins successively bearing on the actuator forward and aft yoke plates.

The following paragraphs describe various types of propeller behaviour which could intervene in the appearance of these overloads and propose elements of a scenario, without being able to draw definitive conclusions.

2.2.2.1 Particular types of propeller behaviour

Ball bunching

The existence of the ball bunching phenomenon was revealed during the 2014 and 2016 flight tests. Bench tests showed that it was theoretically possible to generate a sufficient load to damage the propeller. The conditions required to irreversibly deform the ears of a yoke plate are:

- ❒ more than half of the blade root bearing balls are compressed by the bearing ball separator and
- ❒ only four out of six blades are subject to friction (as the actuator produces a force of around 11,000 daN, these loads divided between the six ears of the yoke plate are 1,833 daN per ear. They are thus not sufficient to simultaneously and permanently deform the six ears of the yoke plate which can each withstand 3,000 daN).

The retention force measured during the flight tests was insufficient to damage the propeller. It corresponded to 15 % of the static load required to irreversibly deform a yoke plate ear.

“Forward yoke plate cyclic loading”

In flight, the sum of the moments generated by the aerodynamic loads, the counterweight and the blade inertia generally tend to make the blade pivot towards the coarse pitch. The propeller trunnion pin thus bears for most of the time, on the actuator aft yoke plate. For a constant propeller rotation speed, the moments of the counterweight and inertia are constant and the moment of the aerodynamic loads is cyclic with a period of one propeller revolution (1P).

During the flight tests in 2014 and 2016, specific behaviour of the right propeller was observed with a high speed close to VMO and a zero or negative engine torque. In these particular aerodynamic load conditions, the sum of the moments applied to a blade changes direction during a propeller revolution. The blade trunnion pin then moves away from the aft yoke plate to then return to and bear on this yoke plate. During this cyclic travel, the trunnion pin sometimes comes into contact with the forward yoke plate. This travel produces vibrations at the propeller pitch change actuator.

Vibrations in the same conditions were observed by the Swedish investigators during a familiarization flight. A gap which was too big between the blade trunnion pins and the two actuator yoke plates was the cause of these vibrations. A slight increase in the engine torque led to these vibrations disappearing. It is probable that this increase in torque sufficiently modified the aerodynamic loads so that the trunnion pins continued to bear on the aft yoke plate for a complete propeller rotation.

The reason for this phenomenon being principally observed on the right propeller (only one case observed on the left propeller) is probably due to the fact that the left and right propellers, having the same direction of rotation, are subject to different aerodynamic loads because their air flows interact differently with the fuselage.

In flight tests, the loads which were measured on a trunnion pin during “forward yoke plate cyclic loading” were no more than around 450 daN, i.e. 18 % of the static load required to irreversibly deform it. However, according to the propeller manufacturer, these loads could increase with the distance separating the forward and aft yoke plates. These load increases were not quantified.

It is important to mention that during these forward yoke plate cyclic loading phenomena, a substantial load factor was observed. As the design of the propeller pitch change mechanism was based on static and cyclic loads and not on vibration stresses, it is not possible to estimate the effects of this on the material from which the yoke plates and trunnion pins are made. This vibration stress on the forward yoke plate in these flight conditions indicates mechanical operation which does not correspond to the conditions for which the parts were designed.

The forward yoke plate cyclic loading phenomenon seems to be connected with the aeroplane's airspeed. During flight tests, this phenomenon was observed during manoeuvres at 250 kt but not at 230 kt. Likewise, the strong vibrations which occurred during the incidents or which were reported in operation by crews, all occurred at speeds above 240 kt. The severity of the vibrations could also increase with the speed. In the incident concerning PR-TKA, a blade trunnion pin broke in flight at a recorded speed of 258 kt. However, the impact of a speed greater than 250 kt on the shape and level of loads applied to the pitch change mechanism has not been studied. Consequently, the speed margins available in operational use are not known.

Propeller pitch change mechanism control loop

Severe vibrations associated with a ball bunching force could affect the operation of the propeller pitch change mechanism control loop. It was not possible to determine their actual impact, in particular whether in the conditions encountered during the incidents, the movements of the pitch change actuator, controlled by the PEC, could have amplified the vibrations.

Nevertheless, it is important to describe, without being able to quantify, the impact of the vibrations and friction on the operation of the pitch change mechanism:

- The existence of friction modifies the attenuation of the control loop.
- A jog movement is sent to the system when a blade blocked by friction starts to turn (sudden reduction in friction loads on bearing).
- The severe vibrations which cause the pitch change actuator to move are such that the signals sent by the actuator position sensors are considered in turn as valid and then not valid (as outside tolerances) by the PEC. When the PEC no longer receives a valid signal regarding the actual position of the actuator which it uses to calculate the propeller pitch angle, it nevertheless continues to send hydraulic pressure setpoints to the electrohydraulic valve in order to maintain a constant propeller rotation speed (82 % Np), but using predefined values. Each time the state of the actuator position signal changes (valid/not valid), the PEC status changes from normal to degraded.
- The vibration frequency caused by the six propeller blades (6P, i.e. 98.4 Hz at 82 % Np) is close to the minimum design frequency of the PEC output current (87.4 Hz). The sampling of the actuator position values is therefore not sufficient to ensure optimum operation of the PEC. The latter could send controls which are out of phase with the actuator oscillations and accentuate them.

2.2.2.2 Chronology of damage

Hypothesis of a deformation in several steps

In all the known incidents, no element showed the existence of a deformation of the pitch change mechanism, in particular of the forward yoke plate, before the vibration episode.

However, the possibility that the forward yoke plate was already deformed cannot be dismissed. Flights can continue normally with a damaged propeller pitch change mechanism without the crews observing abnormal vibrations if the following conditions are present:

- the deformations are limited to the forward yoke plate;
- the crew do not use reverse on landing;
- the crew do not descend at a speed close to VMO and with the power levers in flight idle.

The forward yoke plate is then only generally used at the end of each flight when feathering the propeller, an intermediate phase which applies small loads to the plate.

Such deformation would nevertheless be recent. During flights preceding the incidents, crews had not reported any abnormal vibration when using reverse. In addition, a study of the QAR recordings of the 60 flights prior to the 9Y-TTC incident confirmed that the parameters linked to the engines and left and right propellers were normal and similar during the use of reverse.

Assuming that a deformation of the yoke plate occurred before the final damage to the propeller pitch change mechanism, there is no element to explain why this deformation only appears on the right propeller, except if it is caused by previous "forward yoke plate cyclic loading".

Final damage to propeller pitch change mechanism

For the seven incidents, a vibration phenomenon was felt by the crew when the aeroplane was descending, its speed close to VMO and the power levers in flight idle. In five cases, the crew shut down the engine of the propeller concerned after the appearance of the vibrations. The rupture of a blade trunnion pin and/or the substantial deformations of the yoke plate ears therefore occurred during these vibrations. In the two other cases, as the crew continued the flight without feathering the propeller concerned, the pitch change mechanism may have suffered damage after the vibration episode.

The final damage to the propeller pitch change mechanism therefore seems linked to the vibration phenomenon which occurred in specific flight conditions: speed close to VMO and power levers in flight idle position.

The investigation was not able to determine whether the severity of the phenomenon could increase with speed, in particular for speeds greater than VMO.

2.2.2.3 Hypotheses concerning cause of overloads

It was not possible to determine the cause(s) of the overloads from the elements collected during the various investigations.

Several hypotheses explaining the appearance of alternating overloads at the trunnion pins, the deformation of the forward yoke plate ears and sometimes, even the failure of a trunnion pin on the right propeller, can be proposed:

- A ball bunching phenomenon generating loads seven to eight times greater than those observed during flight tests. It nevertheless remains difficult to explain why this deformation would only appear on the right propeller as this friction phenomenon exists on both propellers. Furthermore, the investigation was not able to link an increase in the magnitude of the friction phenomenon with the flight phase in which the speed is close to the VMO and the power levers are in flight idle.
- "Forward yoke plate cyclic loading" of an intensity five to six times more than that observed during flight tests. It should be noted that the intensity of the loads can be greater if the distance between the actuator yoke plates is higher than normal.
- "Forward yoke plate cyclic loading" combined with ball bunching and/or coupled with the propeller pitch change mechanism control loop.

According to the aircraft manufacturer, extensive investigation has not highlighted any root cause related to design, conformity to design and operations, which could explain load increase up to hardware damage. The ball bunching phenomenon is inherent to this type of propeller retention design, and is the only hypothesis identified that could explain such load increase. It has been demonstrated that new ball separators reduce the friction in the retention system and thus decrease loads resulting from ball bunching. It could not be established that this mitigating action is sufficient alone to ensure no more load increase up to hardware damage. The manufacturer's on-going investigation is therefore focused on the identification of potential contributing factors to ball bunching and the associated loads

2.2.3 Analysis of effectiveness of safety measures taken

2.2.3.1 Pilot information

No new incident has been reported by operators since the incident of 30 November 2014. The installation of new bearing separators on less than a quarter of the fleet (at the time of writing this report) cannot explain in itself why this phenomenon has not reoccurred. It is possible that the pilots, informed of cases of vibrations suddenly appearing in flight by the publication of the EASA SIB and ATR AOM, avoided reducing power at flight idle at a speed close to VMO and that this contributed to it disappearing. It is probable that this raised awareness will not last over time. It could be perpetuated by more clearly integrating the manufacturer's recommendation to avoid descents at a speed of more than 240 kt, in the operator's operational documentation.

2.2.3.2 Operational procedures

The day of the incident there was no specific procedure linked to the appearance of vibrations in the propeller-engine assembly. Nevertheless, the crew could use the emergency procedure linked to severe damage to an engine in flight. However, this procedure does not explain how to identify the engine concerned and could lead to the sound propeller being feathered and the sound engine being shut down.

The incident concerning PK-WFV on 18 September 2013 in Indonesia, illustrates that moving the power levers does not always allow the crew to easily distinguish the propeller concerned. The crew had in fact had difficulties in identifying the propeller concerned as the vibrations increased when they reduced power.

On 23 February 2015, a procedure linked to damage to the propeller pitch change mechanism was introduced. Initially, the pilot is asked to move the power levers one after the other and to observe changes in the vibrations in order to try and distinguish which propeller is concerned. If this step is not conclusive, the pilot is then asked to first feather the right propeller and then if the vibrations continue, to unfeather the right propeller and feather the left propeller.

The incident to SE-MDB on 30 November 2014 in Sweden, shows that the damage caused to the propeller and engine may get worse during the implementation of this new procedure and in particular, that the feathering of the propeller concerned takes time. The actions carried out by the crew corresponded to this new procedure and the damage observed on the engine was substantial: engine compressor casing found split over 180° and damage to the dampers of the engine mounting brackets.

2.2.3.3 Maintenance procedures

Preventive and corrective maintenance should allow defects or damage on the propeller pitch change mechanism to be identified.

At the time of the incident, there was no specific troubleshooting procedure following an abnormal vibration event occurring in flight. In view of the difficulties encountered by the maintenance organizations to determine the cause of the vibrations in flight, it was recommended to complete a form and to send it to ATR for analysis.

The maintenance documents relating to 9Y-TTC show that after each vibration event, a ground engine test was carried out. When the vibrations were associated with a PEC FAULT warning, the maintenance personnel calibrated the PEC and, in certain cases, read the fault codes saved in the PEC memory. Pilots at the operator concerned by the SE-MDB incident stated that the maintenance department had been informed of the regular appearance of vibrations in flights and that maintenance agents had flown in the cockpit to try and observe the phenomenon. After each event, the aeroplanes were returned to flight without the cause of the vibrations being determined and without checking the actual condition of the pitch change mechanism.

In October 2014, ATR published a specific maintenance procedure to prevent an aeroplane which may have a significantly damaged propeller pitch change mechanism from being returned to flight. It is carried out according to the content of the air safety reports (severe vibrations associated with the appearance of a PEC FAULT warning) and fault codes in the PEC memory. It consists of a manual check for possible significant deformation of the actuator yoke plates. However, this procedure depends on the pilot's subjective assessment of the intensity of the vibrations felt and does not permit the detection of the onset of deformation of the yoke plates or damage without rupture of the blade trunnion pins. In addition, without significant damage to the pitch change mechanism, the procedure does not permit the cause of the vibrations to be determined or prevent them from reoccurring in flight. Lastly, it only applies when severe vibrations occur in flight leading to the activation of the specific PEC warning.

2.2.3.4 Certification of propeller system

The tests carried out during the propeller certification campaign in 1994-1995 did not reveal certain phenomena observed during the flight tests in 2014 and 2016: the ball bunching, the forward yoke plate cyclic loading phenomenon when the aeroplane is descending at a speed close to VMO with the power levers in flight idle, the loads on the forward yoke plate when this phenomenon is present, with the intensity of the loads caused by the impact of the trunnion pin on the yoke plate ear increasing, according to the propeller manufacturer, with the gap between the actuator forward and aft yoke plates.

Certain choices and hypotheses led to this situation.

First of all, the vibration measurements were only made on the left engine in the certification flight tests in 1994-1995. Due to the aeroplane's design, the left propeller was in fact considered to be the most loaded of the two in operation. The measurements made on the left propeller therefore seemed conservative with respect to the right propeller. However, the flight tests carried out in 2014 and 2016 showed that the right propeller was more sensitive to certain vibration phenomena than the left propeller.

Next, despite the malfunctioning of the sole sensor positioned on the trunnion pin of a left propeller blade, it was decided not to carry out new flight test campaigns. Finally, as the blade counterweights were designed so that the forward yoke plate of the propeller pitch change mechanism is not generally loaded in flight, only the study of the static loads applied to the blade trunnion pin in climb and cruise was envisaged, and not its vibration behaviour in descent, a flight phase where the static loads applied to the aft yoke plate are theoretically lower.

The FAA published several circulars proposing a method for assessing the vibration stresses borne by a propeller within the scope of its certification. At the time of the propeller's certification, the FAA circular 20-66 did not explicitly recommend performing a descent at flight idle with different speeds[71].

[71] The description of AC 20-66 clearly states that this advisory circular provides guidance and describes one method, but not the only method, for demonstrating compliance with paragraphs 23.907 and 25.907 of Title 14 of the Code of Federal Regulations (14 CFR) for the evaluation of vibratory stresses on propellers installed on aeroplanes.

Since 17 September 2001, circular 20-66A (replaced by 20-66B in 2011) recommends in particular, to perform descents at flight idle with different speeds during the flight tests.

The systematic implementation of this type of check with different speeds around VMO, including speeds slightly above VMO, could make it possible to confirm that the propeller design has sufficient margins before the appearance of vibration phenomena such as that observed during the incidents.

2.2.4 Additional studies and measurements

2.2.4.1 Detection and quantification of damage to propeller pitch change mechanism

The detection of damage to the propeller pitch change mechanism relies on statements from crews. There is no objective means for quantifying the vibration level (for example with a vibration sensor) at each engine-propeller assembly. However, the vibrations generated at a propeller can sometimes be very different to those which propagate in the cockpit. In addition, the notion of "severe" vibrations is subjective. It is not defined by intensity values and measured waveforms. The vibration assessment method, solely based on what the crew and maintenance agents feel, does not ensure objective quantification of their intensity at the propeller. Therefore, it does not guarantee the effective detection of existing damage or its quantification.

Vibration level indicators for each propeller-engine assembly, situated in the cockpit, could help with the identification and implementation of safety actions linked to the propeller concerned. In addition, they could appreciably improve the ground maintenance operations by providing a means of confirming existing damage, in particular with respect to the propeller pitch change mechanism, by the objective check of the vibration level. Accelerometer locations already exist on the two engines and the corresponding wiring is pre-installed on each aeroplane. They are used to measure the vibrations encountered on the ground or in flight to help balance the propellers. The possibility of using the same accelerometers to feed an information system has not, to the BEA's knowledge, been explored.

2.2.4.2 Propeller modifications and continuing airworthiness

The propeller's vibration behaviour was assessed during its certification in 1994-1995. Up to 2014 and 2016, dates at which flight tests consecutive to the incidents were carried out, the propeller type certificate holder and its primary certification authority had not identified the need to carry out tests again, despite the more than a hundred EC made since it was put into service. They were all validated by a theoretical assessment of impact on propeller behaviour. These validations were carried out in accordance with the procedures in force and the investigation was not able to show a link between each modification taken individually and the occurrence of the incidents.

The UTAS propeller organization understands that even minor changes to components can functionally or structurally alter operating characteristics. Furthermore, the accumulation of numerous modifications to the propeller since it was put into service may have a sufficiently serious impact on the propeller's behaviour. To enhance and reinforce this concern, the UTAS Flight Safety Parts program was created in the late 1990's. The UTAS Engineering Change system is designed to minimize the potential of making changes that adversely affect prime structural and functional components. In addition, the propeller system operation and function is monitored via the UTAS operator support program and ATR flight testing.

2.2.4.3 Areas of research

During the writing of this report, it was not possible to determine the cause of the overloads observed in the propeller pitch change mechanism.

The research in progress must be continued with a view to understanding the sequence of damage to the propeller and the cause(s) of the overloads. It must also be confirmed that the introduction of new blade bearing separators is a sufficient measure to prevent such incidents from occurring again.

3 - CONCLUSION

3.1 Investigation's findings regarding 9Y-TTC

- The aircraft had a valid airworthiness certificate.
- The crew held the necessary licenses and ratings to accomplish the flight.
- During descent at a speed of 246 kt close to the VMO (250 kt) , the crew fully reduced power by setting the power levers to flight idle. The maximum speed reached was 247 kt .
- For a period of two minutes, the crew were confronted with the appearance of various warnings associated with the PEC and the AC wild generator of the right engine.
- The vibrations led to the rupture of the drive shaft of the AC wild generator of the right engine.
- The crew felt slight vibrations during the landing. They did not use reverse.
- The maintenance operations carried out on the ground after the flight of 4 May 2014 did not show any vibration or abnormal operation of the propeller.
- A test was carried out with take-off power and a propeller rotation speed of 100 % Np[72]. This test does not load the actuator forward yoke plate and, consequently, does not allow its condition to be checked.
- The engine performance ground tests include a transition to reverse with maximum power test. This test was not carried out.
- The possibility that significant deformations of the forward yoke plate of the right propeller blade pitch change actuator were present after the vibration event that occurred during the flight on May 4, 2014 cannot be dismissed.
- The flight of 5 May 2014 proceeded normally up to the landing run when the crew moved the power levers from flight idle to ground idle. They then heard a loud vibration noise.
- The recorded parameters confirm a problem situated at the right propeller.
- No warning appeared in the cockpit.
- The vibrations and noise disappeared when the right propeller was feathered.
- Tests were interrupted by the appearance of the PEC FAULT warning before the end of the unfeathering sequence of the right propeller. The maintenance agents reported that they had felt no abnormal vibration.
- During a ground test, abnormal vibrations appeared when reverse was selected. After the engines were shut down, the maintenance agents observed that four of the right propeller blades were feathered, while the other two seemed to remain in the reverse position.
- The disassembly of the right propeller blades revealed the rupture of a blade trunnion pin and damage to the propeller blade actuator yoke plate.
- In the months prior to the incident, crews of the ATR 72-212A registered 9Y-TTC had reported three propeller vibration events. The maintenance agents carried out ground engine tests following each of these events, which revealed nothing abnormal.

[72] The propeller rotation speeds are expressed as a percentage of the maximum rotation speed.

- The day of the incident there was no specific crew procedure linked to the appearance of vibrations in the propeller-engine assembly.
- The maintenance operations carried out following the vibration events which occurred between January and May 2014 did not determine their cause and the aeroplane was returned to flight without checking the actual condition of the pitch change mechanism.
- At the time of the incident, in view of the difficulties encountered by the maintenance organizations in troubleshooting in-flight vibrations, the procedure set up to help identify the cause of the phenomenon was to fill out a form and forward it to ATR for analysis.

3.2 Investigation's finding regarding all propeller vibration events

- In seven events registered between 2007 and 2014, severe vibrations appeared in a specific flight phase (speed close to VMO and power levers in flight idle). Severe damage to the propeller pitch change mechanism was observed (deformation of forward yoke plates and blade trunnion pins along with rupture of blade trunnion pin). It was not possible, however, to establish a precise chronology of the appearance of the damage and vibrations.
- Vibration stress surveys[(73)] in flight in 2014 and 2016 showed the existence of a ball bunching phenomenon, but the retention force measured was too low to damage the propeller.
- Flight tests (VSS in 2014 and 2016) showed cyclic load phenomena between the forward yoke plate and the trunnion pins of the right propeller blades when the aeroplane was in descent with its speed close to VMO and the power levers in the flight idle position. The static and dynamic loads measured were too low to damage the propeller. However, it was a particular vibration signature and led to subsequent analyses.
- Flight tests (VSS in 2014 and 2016) showed that the forward yoke plate could be loaded during this flight phase. This was particular behaviour as the trunnion pins generally remain against the aft yoke plate during the flight.
- Flight tests (VSS in 2014 and 2016) showed that the forward yoke plate could be loaded during these vibration phenomena during which the intensity of the loads caused by the impact of the trunnion pin on the yoke plate ear increased with the distance between the forward and aft yoke plates of the pitch change actuator. It was not possible to quantify this increase in load.
- There is no objective means of quantifying the vibration level of each engine-propeller assembly in normal operation. The detection of existing damage depends on the pilots' assessment of the vibrations.
- It is possible that continued flight operations could occur without incident or vibration with a deformed forward yoke plate, the latter generally only being loaded when using reverse, when feathering and during a specific flight phase (power lever in flight idle and speed close to VMO).

(73) VSS.

- The existence of an abnormal gap between the two yoke plates of the propeller pitch change mechanism can cause severe damage in flight to the pitch change mechanism.
- In one case, engine mounting brackets were broken. The crew had continued the flight without feathering the propeller and had used reverse on landing. The investigation was unable to determine at what point in the flight the mounting brackets were damaged.
- Tests performed during the propeller certification campaign prior to TC issuance in 1995 did not reveal the increased retention friction observed during the 2014 and 2016 flight tests because the recent testing was conducted specifically to investigate the trunnion pin loading.
- The theory of the migration of blade retention bearing balls was not developed until 2001 on a different propeller system.
- The significant vibration phenomena was not reported or observed with the 568F-1 propeller on the ATR aircraft until 2012.
- The real vibration behaviour of the propeller was not re-evaluated between its certification in 1994-1995 on ATR72-212A and the VSS flight tests performed in 2014 and 2016 linked to the incidents.
- Since the propeller was put into service, more than a hundred engineering changes (EC) have been made on the various components of the propeller 568F-1 assembly.
- Since October 2014, ATR has published a specific maintenance procedure, following an abnormal vibration event which occurred in flight, to prevent an aeroplane which may have a significantly damaged propeller pitch change mechanism from being returned to flight. This procedure is based on a Service Bulletin published by UTAS on 2 October 2014, (SB) 568F-61-67, which sets out an on-wing inspection procedure that provides operators with instructions for measuring blade angle backlash on all six blades should vibration in combination with the indication of PEC fault codes 67 and 68 (sensed blade angle fault, primary and secondary) be experienced. The instructions include a visual/dimensional actuator yoke plate inspection to be performed should the maximum allowable value be exceeded at any blade.
- Since 23 February 2015, a procedure to manage in flight vibrations has been introduced.

3.3 Causes of incident

Seven vibration phenomena on the ATR 72-212A have been reported in the last few years. In almost all of the cases, the rupture of a trunnion pin of one of the blades and damage to the propeller blade actuator forward yoke plate were observed. The investigation revealed the existence of alternating overloads causing damage to the yoke plates and of a final overload in one direction resulting in the rupture of the trunnion pin. It was not possible to determine the cause of these overloads and the precise chronology of the damage and vibrations. Nevertheless, several elements may have contributed to it:

- A friction force caused by a ball bunching phenomenon.
- Significant loads caused by the trunnion pin striking the ear of the plate on forward yoke plate cyclic loading appearing when the aeroplane speed was close to VMO and the power levers in the flight idle position.
- Unplanned operation of the control loop of the propeller pitch change mechanism affected by forward yoke plate cyclic loading and friction.

The maintenance operations carried out on 9Y-TTC following the vibration phenomena did not identify this damage.

4 - SAFETY RECOMMENDATIONS

Note: in accordance with the provisions of Article 17.3 of Regulation No. 996/2010 of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation, a safety recommendation in no case creates a presumption of fault or liability in an accident, serious incident or incident. The recipients of safety recommendations report to the authority in charge of safety investigations that have issued them, on the measures taken or being studied for their implementation, as provided for in Article 18 of the aforementioned regulation.

4.1 Further research

The flight tests carried out in 2014 and 2015 allowed the behaviour of the propeller at 230 kt and 250 kt to be studied. A cyclic load vibration phenomenon on the forward yoke plate was observed at 250 kt, creating loads of a small amplitude of around 450 daN, i.e. 18% of the static loads required to irreversibly deform a trunnion pin. During the incidents studied, in the same speed range (246 to 258 kt), loads leading to permanent deformations or failure were reached. These phenomena were never observed below 230 kt.

The revealing of this cyclic load phenomenon on the forward yoke plate raises questions as to the behaviour of the propeller at speeds close to 250 kt, the maximum speed in operation (VMO). The evolution of this phenomenon at speeds slightly greater than 250 kt has never been studied. Additional efforts to improve modelling capabilities at speeds of around 250 kt would allow the sensitivity of this phenomenon to be better estimated, notably with respect to speed. It would then be possible to evaluate the margins available in operational use given a probable dispersion of the sensitivity to this phenomenon.

Consequently, the BEA recommends that:

- **EASA ensure that ATR and UTAS continue to analyse the cyclic load phenomenon on the forward yoke plate revealed at flight idle and at a speed slightly above VMO in order to confirm that the ATR72-212A flight envelope provides sufficient margins to prevent this phenomenon from causing damage to the propeller pitch change mechanism [Recommendation 2019-016]**

4.2 Restriction of ATR72-212A operation conditions

The investigation was not able to identify the most probable damage scenario leading to the overload of the mechanical elements of the propeller pitch change mechanism. However, this vibration stress on the forward yoke plate in flight idle and at a speed close to VMO indicates specific mechanical behaviour. When the moment generated by the aerodynamic load of a blade becomes greater than that generated by the counterweight and the inertia of the blade, the trunnion pin cyclically moves away from the aft yoke plate and sometimes comes into contact with the forward yoke plate. Sometimes the direction of the sum of the moments may change during a cycle. This phenomenon depends on the speed of the aircraft. The elements collected in the safety investigations show that this phenomenon can appear above a speed of 240 kt. During flight tests, this phenomenon was not observed at a speed of 230 kt.

Consequently, the BEA recommends that:

- **EASA ensure that research is pursued with a view to understanding the sequence of damage to the propeller and the cause(s) of the overloads and that pending the outcome of this research, the operational procedures recommended by the ATR72-212A manufacturer for the descent are reviewed to prevent any flight between 240 and 250 kt at flight idle. [Recommendation 2019-017]**

4.3 Improvement of detection and quantification of propeller vibration

Airplanes equipped with turbojets are for the most part equipped with vibration detectors placed on each engine. The information on the levels of certain vibrations is sent to an indicator placed in the cockpit. This system alerts pilots when the vibration level exceeds the design limits and allows them to identify the engine concerned.

The regulations do not require that turboprop aircraft be equipped with them. ATR offers optional installation of accelerometers at both engines for maintenance purposes but the information provided by these sensors is not usable by the crews. In general, the vibrations generated in a turboprop / propeller assembly can sometimes be very different from those that propagate in the cockpit. Relying on what crews feel is not an effective way of identifying the engine or propeller concerned.

Consequently, the BEA recommends that:

- **EASA assess the benefit of imposing the installation of vibration level indicators for each propeller-engine assembly in the cockpits of commercial air transport aeroplanes equipped with turboprop engines. [Recommendation 2019-018]**

4.4 Improvement of certification criteria

Certain choices and hypotheses meant that the tests carried out during the propeller certification campaign in 1994-1995 did not show certain phenomena observed during the flight tests in 2014 and 2016, in particular the friction at the blade root bearings (ball bunching) and the cyclic loads on the forward yoke plate of the propeller pitch change mechanism when the aeroplane is in descent at a speed close to VMO, with the power levers in the flight idle position.

The FAA circular currently in force and proposing an assessment method of the vibration stresses borne by a propeller during its certification, recommends incorporating descents with flight idle at various speeds in the flight test programme. Its systematic implementation at various speeds around VMO would allow the existence of vibration phenomena, such as that observed during tests in 2014 and 2016, to be checked for.

Consequently, the BEA recommends that:

- **EASA and the FAA impose that the initial certification of propellers includes the carrying out of an in-depth study of the actual vibration behaviour of each propeller in flight idle with speeds around VMO. [EASA: Recommendation 2019-019]**
  [FAA: Recommendation 2019-034]

LIST OF APPENDICES

Appendix 18
BEA letter to EASA concerning propeller vibrations in flight on ATR aircraft

Appendix 19
EASA Safety Information Bulletin

Appendix 20
ATR All Operators Message

Appendix 21
ATR Operation Engineering Bulletin

Appendix 22
FAA Special Airworthiness Information Bulletin

Appendix 23
Revision of EASA Safety Information Bulletin

Appendix 24
Latest ATR All Operators Message and UTAS Service Bulletin

Appendix 25
Comments made by equipment manufacturer Collins and BEA's observations

APPENDIX 1

COMPARATIVE TABLES BETWEEN SIMILAR EVENTS

Date	Operator	Place	Serial Number Registration	Date of entry into service	Flight hours	Number of cycles
22 March 2007	Binter Canaria	Tenerife	709 EC-IYC	May 2004	5,337	10,271
04 April 2012	Precision Air	Zanzibar	880 5H-PWD	July 2009	7,463	7,396
07 January 2013	Trip Airlines	Brazil	926 PR-TKA	September 2010	6,343	6,556
27 August 2013	Precision Air	Tanzania	923 5H-PWG	September 2010	8,258	Information not available
18 September 2013	Wings Air	Indonesia	985 PK-WFV	December 2011	4,350	4,810 (estimate)
05 May 2014	Caribbean Airlines	Trinidad and Tobago	989 9Y-TTC	Not available	Not available	Not available
30 November 2014	Braathens Regional	Sweden	822 SE-MBD	2008	10,037*	Not available

* Maximum propeller operating time = 10,500 hours.

ENVIRONMENT WHEN THE VIBRATIONS OCCUR

	EC-IYC	5H-PWD	PR-TKA	5H-PWG	PK-WFV	9Y-TTC	SE-MDB
Phase of flight	Final approach	Approach	Information not available	Information not available	Descent	Descent	Descent
Speed (NB: VMO = 250 kt)	Information not available	247 kt	258 kt	Information not available	251 kt	246 kt	250 kt
Positions of power levers	Information not available	Flight Idle	Flight Idle	Information not available	Flight Idle	Flight Idle	Flight Idle
PEC FAULT warning	Yes (ASR)	Yes (saved data)	No (saved data)	Information not available	Yes (saved data)	Yes (saved data)	Yes (saved data)

DAMAGE OBSERVED ON RIGHT PROPELLER PITCH CHANGE MECHANISM

	EC-IYC	5H-PWD	PR-TKA	5H-PWG	PK-WFV	9Y-TTC	SE-MDB
Propeller pitch change actuator	All the ears of the forward yoke plate deformed	All the ears of the forward and aft yoke plates deformed	One ear of the forward yoke plate deformed	No deformation	All the ears of the forward and aft yoke plates deformed	All the ears of the forward and aft yoke plates deformed	All the ears of the forward and aft yoke plates deformed
Blade trunnion pins	One trunnion pin broken	Five trunnion pins bent no crack present	One trunnion pin broken and the others cracked*	One trunnion pin broken and the others cracked*	One trunnion pin broken and the others bent	One trunnion pin broken and the others bent with indications**	One trunnion pin broken and the others with indications**

CONDITION OF TRUNNION PINS AND DISTANCE BETWEEN EARS OF ACTUATOR AFT AND FORWARD YOKE PLATES

	EC-IYC	5H-PWD	PR-TKA	5H-PWG	PK-WFV	9Y-TTC	SE-MDB
Blade No 1	Information not available	Trunnion pin bent Distance + 34%	Trunnion pin cracked* Distance normal	Trunnion pin cracked* Distance - 1%	Trunnion pin bent Distance + 9%	Trunnion pin bent and indications* Distance + 24%	Indications* on trunnion pin Distance + 29%
Blade No 2	Trunnion pin broken	Trunnion pin bent Distance + 33%	Trunnion pin cracked* Distance + 1%	Trunnion pin cracked* Distance - 1%	Trunnion pin bent Distance + 40%	Trunnion pin bent and indications* Distance + 42%	Trunnion pin broken* Distance + 33%
Blade No 3	Information not available	Trunnion pin normal Distance + 19%	Trunnion pin cracked* Distance normal	Trunnion pin cracked* Distance - 1%	Trunnion pin bent Distance + 28%	Trunnion pin bent and indications* Distance + 22%	Indications* on trunnion pin Distance + 17%
Blade No 4	Information not available	Trunnion pin bent Distance + 25%	Trunnion pin cracked* Distance + 1%	Trunnion pin cracked* Distance - 1%	Trunnion pin bent Distance + 12%	Trunnion pin broken Distance + 24%	Indications* on trunnion pin Distance + 15%
Blade No 5	Information not available	Trunnion pin bent Distance + 25%	Trunnion pin cracked* Distance normal	Trunnion pin broken* Distance - 1%	Trunnion pin broken Distance + 23%	Trunnion pin bent and indications* Distance + 31%	Indications* on trunnion pin Distance + 15%
Blade No 6	Information not available	Trunnion pin bent Distance + 25%	Trunnion pin broken Distance - 17%***	Trunnion pin cracked* Distance - 1%	Trunnion pin bent Distance + 14%	Trunnion pin bent and indications* Distance + 16%	Indications* on trunnion pin Distance + 15%

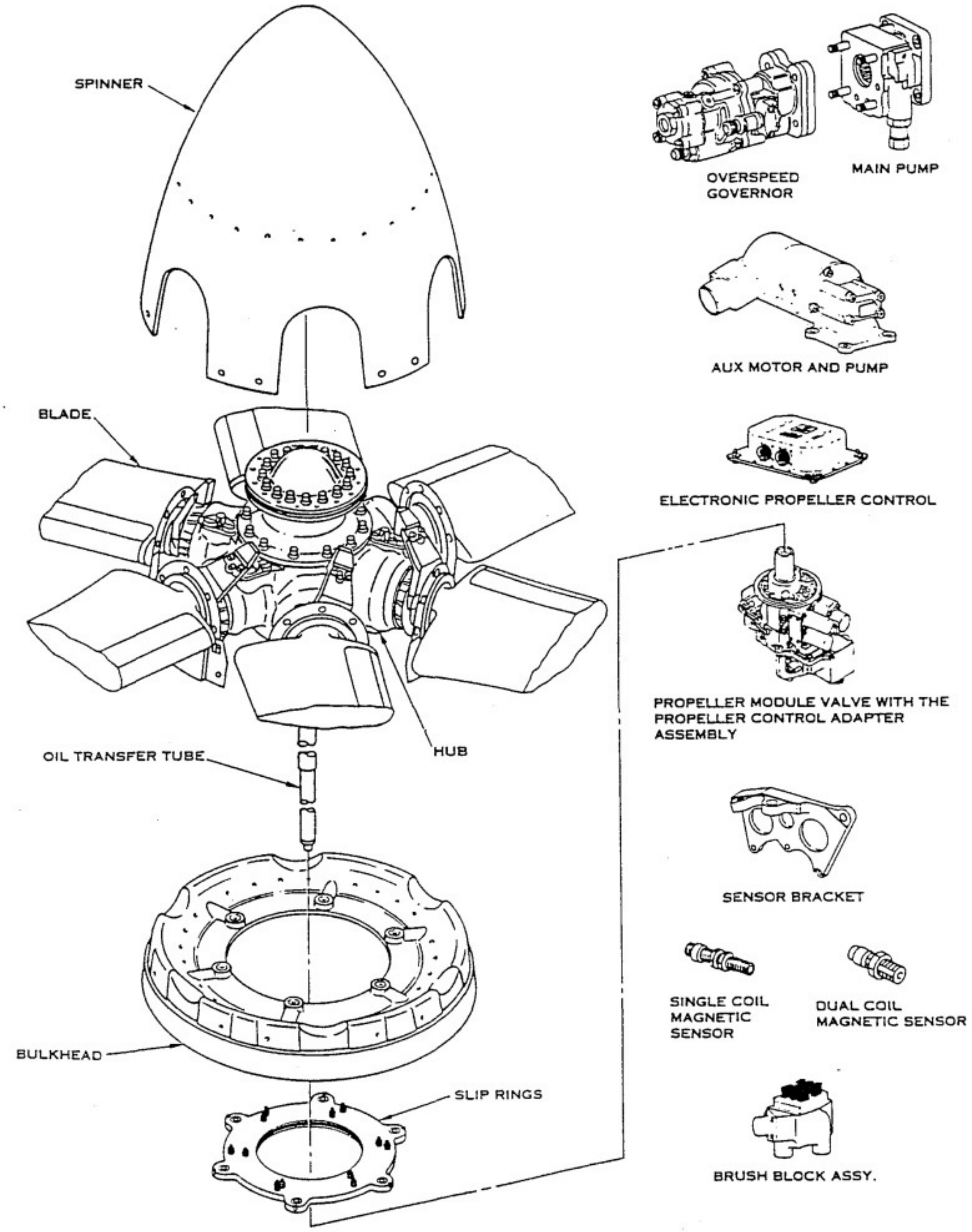
*The cracks or fracture surfaces correspond to the loads applied cyclically by the forward and aft yoke plates. This is not fatigue failure.
**A magnetic particle inspection revealed indications located on either side of the unbroken trunnion pins. An examination by binocular microscope seemed to indicate the absence of cracks.
***Deformation of the plate ear caused during disassembly.

OTHER DAMAGE TO THE RIGHT ENGINE/PROPELLER ASSEMBLY

	EC-IYC	5H-PWD	PR-TKA	5H-PWG	PK-WFV	9Y-TTC	SE-MDB
Engine	Information not available	Information not available	Information not available	Information not available	Two engine mounting brackets broken	No damage	Engine compressor casing broken and engine mounting bracket shock absorbers damaged
AC wild generator	Information not available	Information not available	No damage	Information not available	Drive shaft sheared	Drive shaft sheared	Drive shaft sheared
Unusual position of blade trunnion pins	Information not available	Information not available	Information not available	Information not available	Blade 2 trunnion pin passed in front of forward yoke plate	Blade 3 trunnion pin passed in front of forward yoke plate	Normal position
Interactions between counterweights of propeller blades	Circular marks on blade 2 counterweight	Information not available	Contact between blades 1 and 6	Impact marks on blade 5	Impact marks on blades 2,3,4,5 and 6 Blockage between blades 2 and 3 during feathering	Impact marks on all blades Blockage between blades 3 and 4 during feathering	Contact between blades 1 and 2 during disassembly

APPENDIX 2

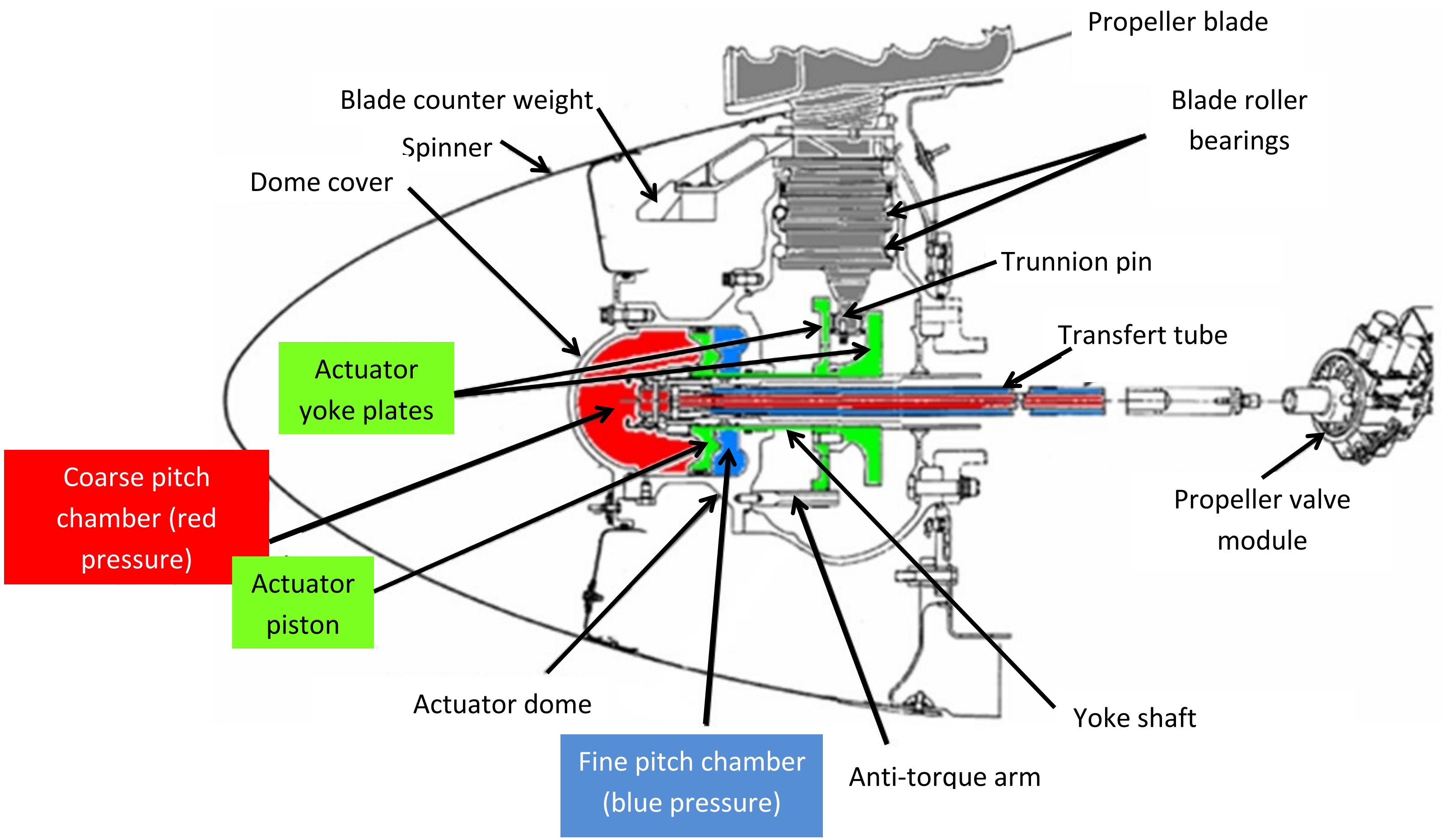
DESCRIPTION OF PROPELLER SYSTEM



Source: BEA

APPENDIX 3

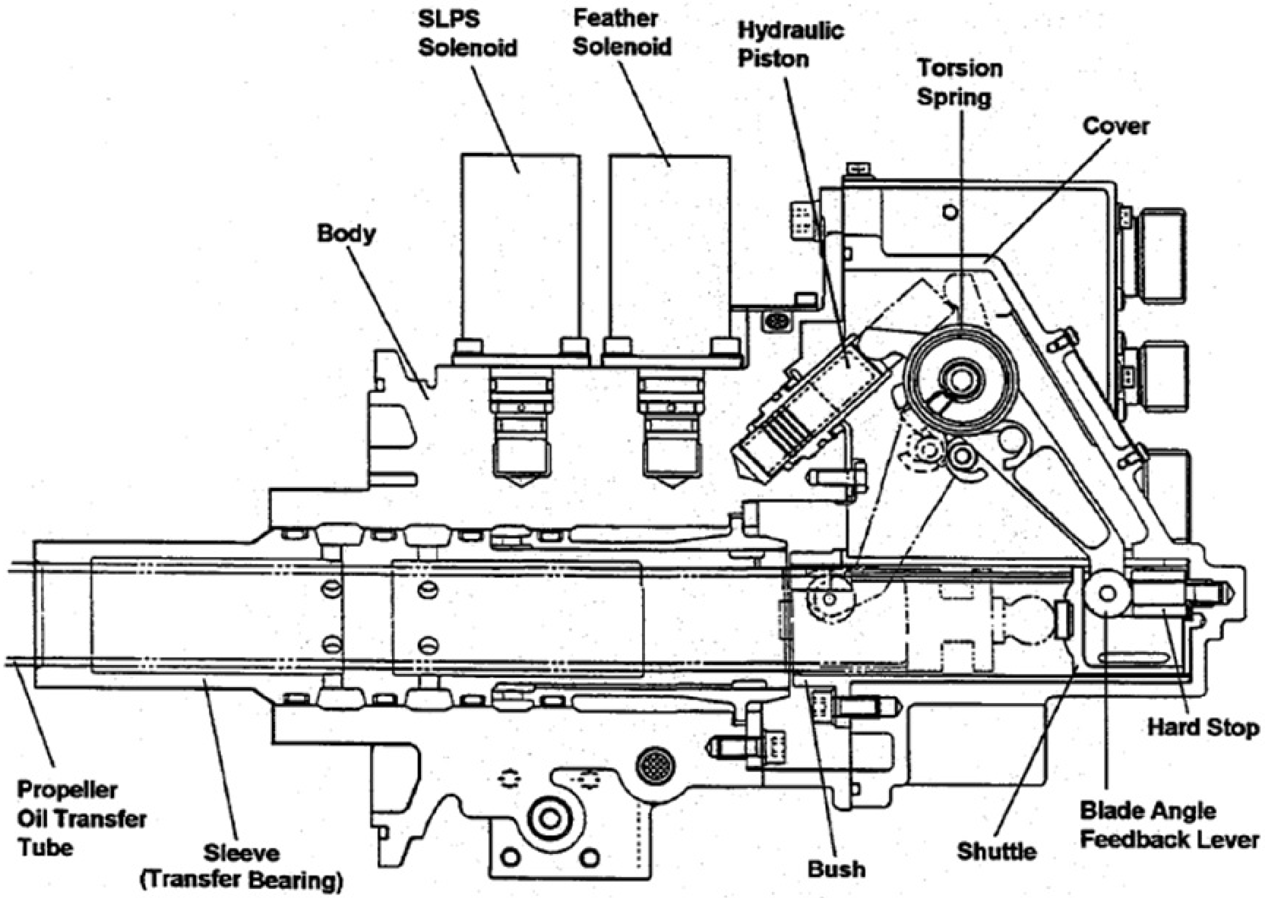
PROPELLER PITCH CHANGE MECHANISM



Source: BEA

APPENDIX 4

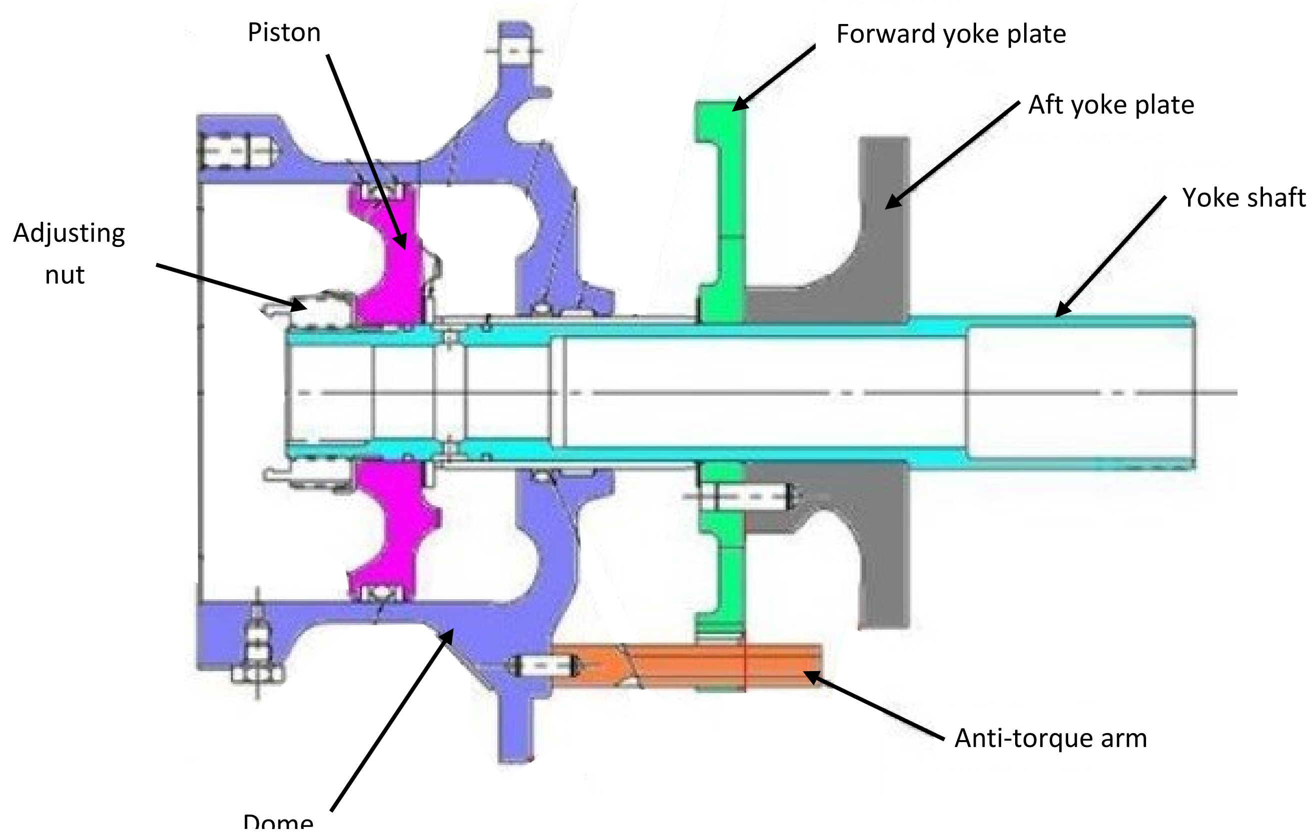
PROPELLER VALVE MODULE - PVM



Source: BEA

APPENDIX 5

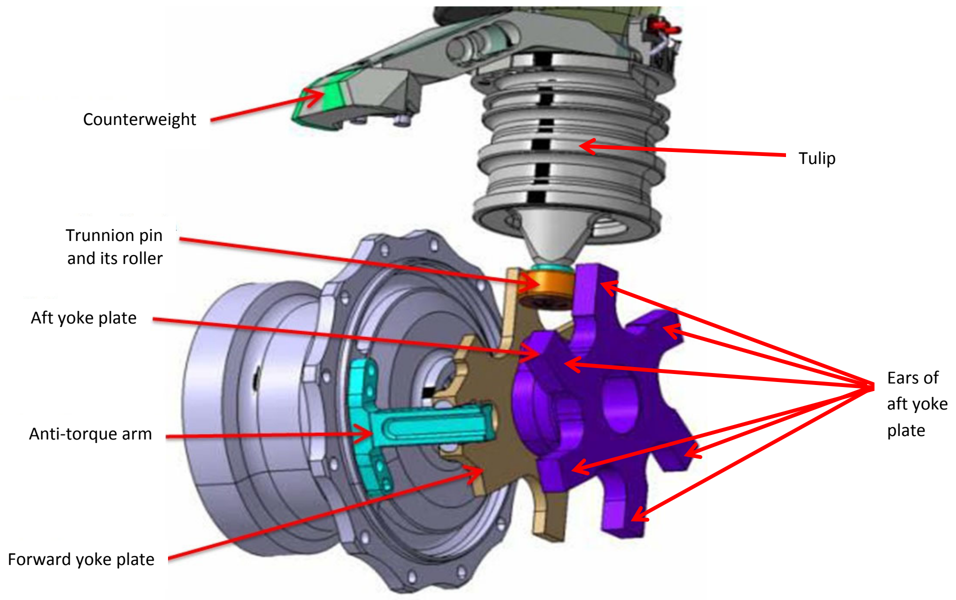
HYDRAULIC OPERATION OF PROPELLER PITCH CHANGE MECHANISM



Source: BEA

APPENDIX 6

CONNECTION BETWEEN PROPELLER BLADE AND PITCH CHANGE ACTUATOR

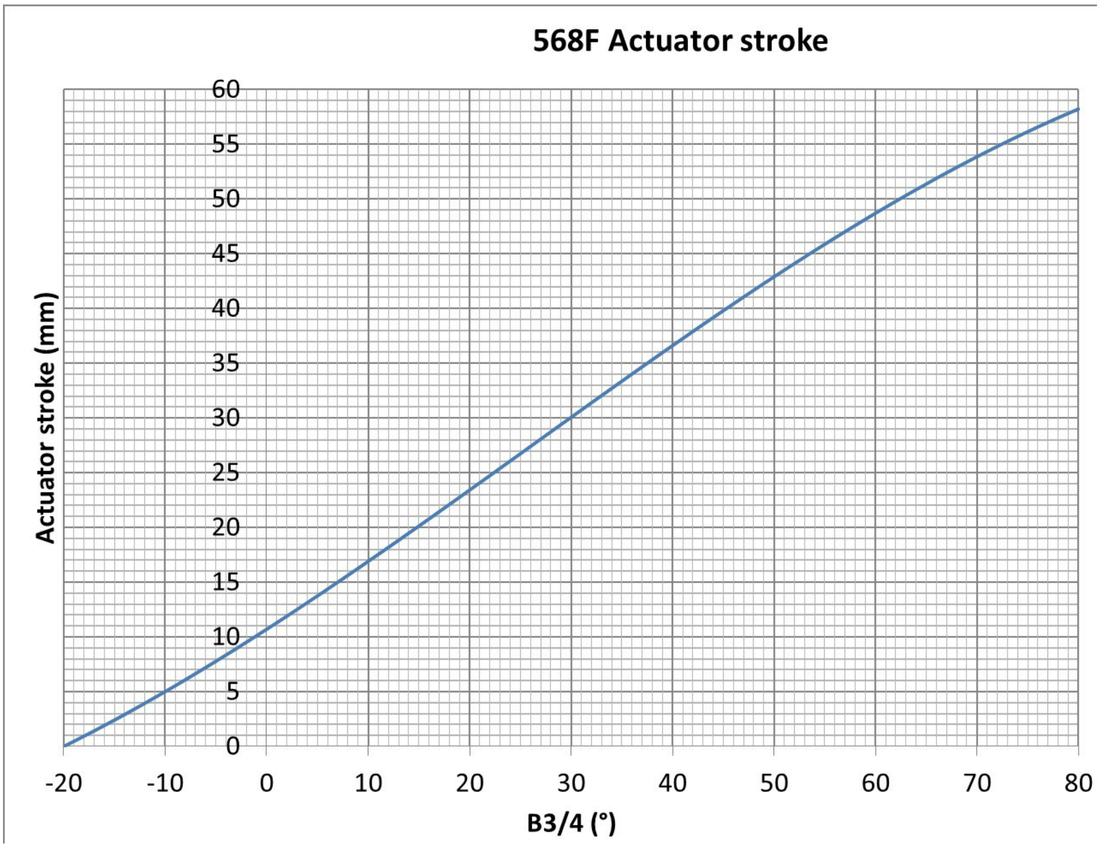


Source: BEA

APPENDIX 7

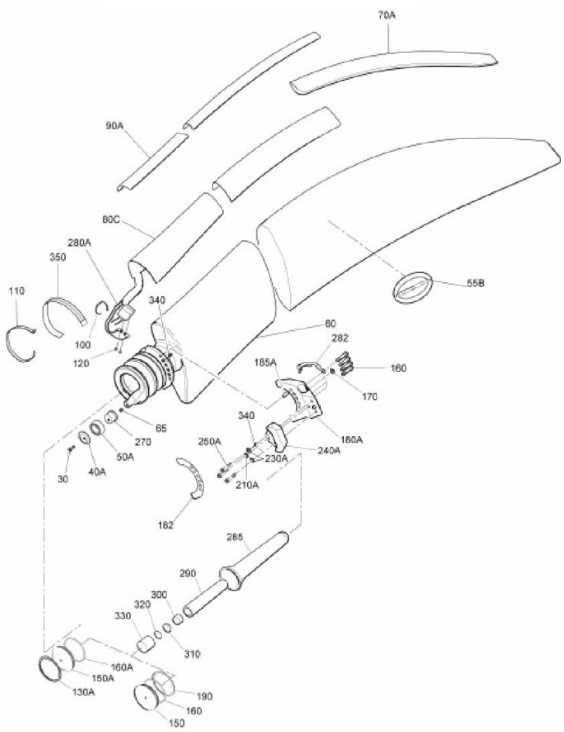
RELATIONSHIP BETWEEN POSITION OF PITCH CHANGE ACTUATOR AND PROPELLER BLADE ANGLE

The following graph shows the physical relationship which exists between the longitudinal position of the pitch change actuator (actuator stroke) and the angle formed by the propeller blades (B¾).



APPENDIX 8

DESCRIPTION OF PROPELLER BLADE

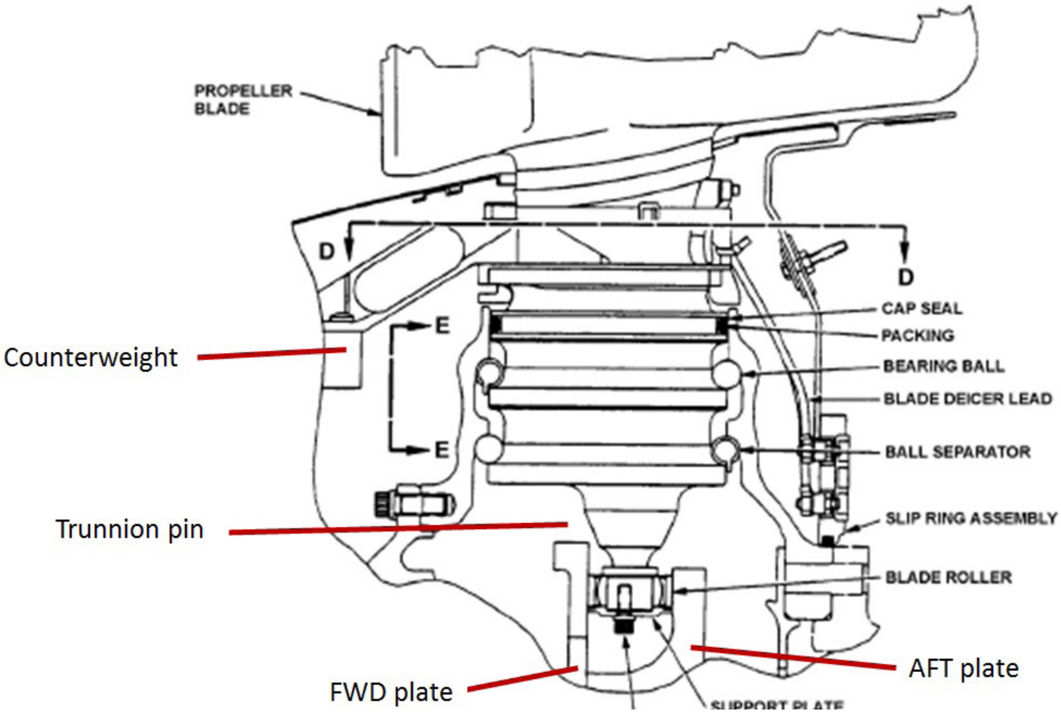


30	Screw	100/110	Strap tiedown	185A/290	Pin
40A	Support plate	120	Nut	210A/230A	Washer
50A	Roller	130A	Ring	240A	Counterweight weight
55B	Decal	140A	Packing	270	Trunnion sleeve
60	Blade	150	Plug	280A	Wire lead block
65/340	Insert	160/250A	Bolt	282	Jumper
70A	Nickel sheath	170	Washer	285	Tube balance
80C	Deicer	180A	Counterweight arm	300/310/320/330	Plug
90A	Anti-erosion film	182	Shim	350	Protection strip

Source: BEA

APPENDIX 9

DESCRIPTION OF PROPELLER BLADE ROOT



Source: BEA

APPENDIX 10

MAINTENANCE OPERATIONS RECORDED IN QAR

Note: the QAR has a recording logic which limits the information concerning the maintenance operations. Without any specific action, the QAR starts recording after ignition of the first engine and stops recording ten minutes after the shut-down of the second engine. Maintenance operations can therefore be carried out without them being recorded.

The data recorded by the QAR during the maintenance operations which followed the flight of 4 May contains the following information:

First sequence

- Right engine started without propeller brake
- Left engine started
- Propellers (which were feathered) unfeathered - propeller pitch stabilized at -1°
- ACW2 generator still faulty
- Power levers moved to flight idle
- Power levers at 60° - propeller rotation speed increased and reached 100 % (power management selector in TO position)
- Power levers in take-off (TO) position. Power levers in flight idle
- Power levers in ground idle
- Transition of propellers to feathering position
- Right propeller brake
- Left engine shut down
- Right engine shut down

Second sequence

- Right engine started with propeller brake
- Right propeller brake released
- Right propeller (which was feathered) unfeathered
- No error on ACW2 generator
- Generator stopped and restarted
- Transition of right propeller to feathered position
- Right propeller brake
- Right engine shutdown

The data recorded by the QAR during the maintenance operations which followed the flight of 5 May contains the following information:

First sequence

- Right engine started with propeller brake
- Cranking of left engine started
  - Five seconds later, fuel flow opened
  - Oil low pressure master warning 30 s after opening fuel
  - Fuel closed
  - Cranking stopped eight seconds later

- Inactivity: 55 seconds
- Left engine started
- Right propeller brake released
- Propellers (which were feathered) unfeathered
- Power levers in flight idle
- Power levers in ground idle
- Power levers between ground idle and flight idle
- Power levers above flight idle
- Power levers in ground idle
- Power levers in reverse for two to three seconds (right propeller minimum pitch angle -10°, right engine torque 13 % and right engine fuel flow rate 255 kg/h)
- Power levers in intermediate position between ground idle and flight idle
- Power levers in reverse for two to three seconds (right propeller minimum beta -9°, right engine torque 11 % and right engine fuel flow rate 239 kg/h)
- Power levers in intermediate position between ground idle and flight idle
- Power levers in flight idle
- Power levers in ground idle
- Right power lever in flight idle
- Right power lever in ground idle
- Transition of propellers to feathering position
- Right propeller brake applied
- Engine shut down
- External power supply used
- Two PECs reinitialized
- Right power lever in take-off position
- Right power lever in flight idle
- Right power lever in ground idle
- Recording stopped

Second sequence after engines shut down for two hours

- Left engine started
- Left propeller (which was feathered) unfeathered
- Right engine started (propeller brake released at the same time)
- Right propeller (which was feathered) unfeathered
- Just before the end of the unfeathering, the right propeller PEC switched to “FAULT” status
- The PEC was switched off, the propeller speed dropped (the speed of all the compressor stages dropped)
- Transition of propellers to feathering position
- Left engine shutdown
- Right propeller brake applied
- Right engine shut down

The right propeller PEC was reinitialized three times (third time switched off for around 38 s).

- Right propeller power lever between ground idle and flight idle positions
- Right propeller PEC exited "FAULT" status
- Right propeller power lever in ground idle
- Recording stopped

Third sequence (30 min later)

- Right engine started with propeller brake
- Right propeller brake released
- Right propeller (which was feathered) unfeathered
- Just before the end of the unfeathering, the right propeller PEC switched to "FAULT" status
- PEC 2 reinitialized (twice)
- Transition of right propeller to feathered position
- Right engine shut down
- DC1 & 2 buses off
- The right propeller pitch change actuator position reached 77° corresponding to feathering and then stabilized at 73°. Right propeller PEC continued to have "FAULT" status
- DC1 & 2 buses on

Fourth sequence (after engine shut down for four hours)

- Right engine started (propeller brake not applied)
- Right propeller (which was feathered) unfeathered
- Left engine started
- Left propeller (which was feathered) unfeathered
- Power levers in flight idle
- Power increased up to transition limit to 100 % Np for TO
- Power levers in flight idle
- Power levers above automatic 100 % Np position
- Power levers in flight idle
- Power levers in ground idle
- Power levers in reverse for three to four seconds (right propeller minimum pitch angle -14°)
- Levers moved in two seconds to take-off position
    - From the beginning of this sequence, the right and left engines behaved differently
    - The engine 2 torque increased up to 70 % TQ
    - The right propeller slowed down with respect to the left propeller (difference of up to 28 %) while the fuel flow to the right engine increased by 25 %, the NH2 increased up to 93 % and the right engine torque increased from 20 to 71 % TQ
- Power levers in flight idle position: engine 2 parameters are similar to the engine 1 parameters
- Transition of propellers to feathering position commanded
- Power levers in ground idle

- Fuel to right and left engines cut-off
- The blade angle actuator of the right propeller stayed at 35° for ten seconds before moving to the 76° position corresponding to feathering and then stabilized at an angle of 69°

Fifth sequence (after an engine shutdown of 15 h 30 min)

- The left propeller pitch change actuator was in the 58° position which is different from the feathering position (79°)
- Right engine started (propeller brake not applied)
- Right propeller (which was feathered) unfeathered
- Transition of right propeller to feathered position
- Right propeller (which was feathered) unfeathered
- Transition of right propeller to feathered position
- Right propeller (which was feathered) unfeathered
- Left engine started
- Transition of left propeller to feathered position
- Transition of right propeller to feathered position
- Propellers (which were feathered) unfeathered
- Power levers set to cruise
- Right propeller power lever from ground idle to flight idle
- Right propeller power lever in intermediate position between flight idle and take-off
- Right propeller power lever in ground idle
- Power levers in reverse
- Power levers in ground idle
- Power levers in reverse
- Power levers in ground idle
- Right engine power lever in intermediate position between flight idle and take-off
- Left engine power lever in idle between ground idle and flight idle
- Transition of engine to climb power
- Left propeller power lever in intermediate position between flight idle and take-off
- Right propeller power lever a bit higher but still below the take-off position
- Power levers in flight idle
- Power levers in take-off position
- Propeller speed regulated at 82% Np
- Power levers in flight idle
- Transition of engine to take-off power
- Power levers in take-off position
- Propeller speed regulated at 100 % Np
- Power levers in flight idle
- Left engine power lever in take-off position
- Right engine power lever between flight idle and take-off

- ❒ Power levers in flight idle
- ❒ Power levers in ground idle
- ❒ Power levers in reverse
- ❒ Power levers between ground idle and flight idle positions
- ❒ Power levers in ground idle
- ❒ Power levers in reverse
- ❒ Power levers between ground idle and flight idle positions
- ❒ Power levers in ground idle
- ❒ Power levers in reverse
- ❒ Power levers between ground idle and flight idle positions
- ❒ Power levers in ground idle
- ❒ Transition of propellers to feathering position
- ❒ Both engines shut down
- ❒ Engine power set to cruise
- ❒ Left propeller power lever in take-off position
- ❒ Left propeller power lever in flight idle
- ❒ Left propeller power lever in ground idle
- ❒ Engine power set to take-off
- ❒ Left propeller power lever in take-off position
- ❒ Left propeller power lever in ground idle
- ❒ Cranking of right engine started twice with fuel injection
- ❒ Left engine started
- ❒ Right engine started (propeller brake not applied)
- ❒ Propellers (which were feathered) unfeathered
- ❒ Power levers in reverse
- ❒ Power levers between ground idle and flight idle positions
- ❒ Power levers in reverse
- ❒ Power levers between ground idle and flight idle positions
- ❒ Power levers in ground idle
- ❒ Transition of propellers to feathering position
- ❒ Engine shut down

APPENDIX 11

USE OF REVERSE DURING PREVIOUS FLIGHTS

The data contained in the QAR makes it possible to trace back to 20 April 2014, i.e. 162 flights (flight N-162) before the flight of 4 May 2014 (flight N).

The data of the 59 flights preceding the flight of 4 May 2014 was analysed. The following table lists those flights that ended with the use of reverse.

Flight number	Beta value[74] recorded in transition to reverse	Comments
N-48	-11° left engine -9° right engine	Normal parameters during flight. **See note 1**
N-39	-6°	Normal parameters during flight and in transition to reverse.
N-37	-9°	Normal parameters during flight and in transition to reverse.
N-33	-6°	Normal parameters during flight and in transition to reverse.
N-31	-5°	Normal parameters during flight and in transition to reverse.
N-25	-9°	Normal parameters during flight. **See note 2**
N-21	-9°	Normal parameters during flight. **See note 3**
N-23	-8° left engine -7° right engine	The movements of the power levers prevent any analysis.
N-17	-14° left engine -12° right engine	Normal parameters during flight. **See note 4**
N-16	-8° left engine -7° right engine	Normal parameters during flight. **See note 5**
N-15	-14°	Normal parameters during flight and in transition to reverse.
N-14	-14°	Normal parameters during flight and in transition to reverse.
N-5	-7°	Normal parameters during flight. No analysis possible during transition to reverse (too many fluctuations in parameters linked to the engines and the propeller).

[74] Beta: angle of the propeller blades.

Note 1: At the beginning of the transition to reverse, the beta value of the left engine reached -11° while that of the right engine was -9° The torque and rotation speed values of the left engine propeller were lower than those of the right engine. Likewise, the power lever positions and rotation speeds of the high pressure section of the engines were different. After a period of five seconds, the torque and propeller rotation speed values of the engines became similar again.

Note 2: At the beginning of the transition to reverse, when the beta value of the right engine reached -9°, the propeller rotation speed of the right engine was lower than that of the left engine for two seconds. Given the short time during which reverse is used, no conclusion can be drawn.

Note 3: At the beginning of the transition to reverse, when the beta value of the right engine reached -9°, the torque value of the right engine was slightly lower than that of the left engine for three seconds.

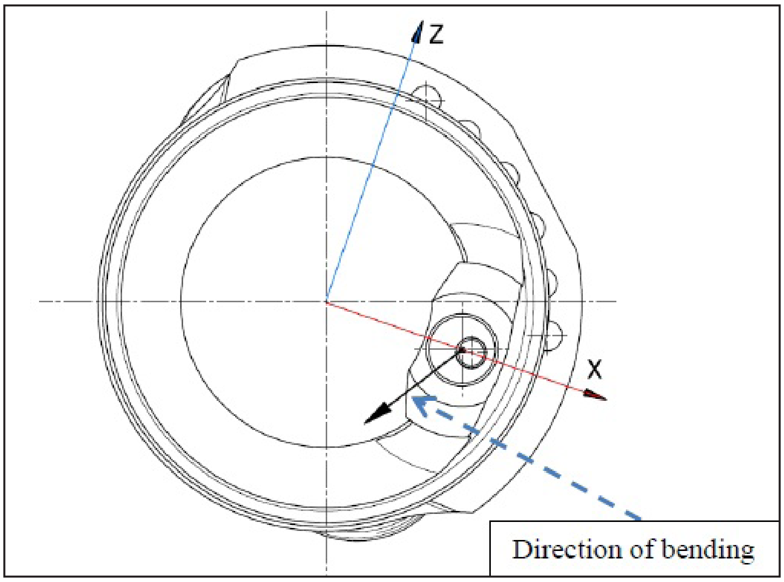
Note 4: At the beginning of the transition to reverse, the beta value of the left engine reached -14° while that of the right engine was -12°. Since the position of the power lever of the left engine differed by 2° in relation to that of the right engine and that as a consequence, many of the engine and propeller parameters were different, no conclusion can be drawn.

Note 5: At the beginning of the transition to reverse, the beta value of the left engine reached -8° while that of the right engine was -7°. Since the position of the power lever of the left engine differed by 2° in relation to that of the right engine and that as a consequence, many of the engine and propeller parameters were different, no conclusion can be drawn.

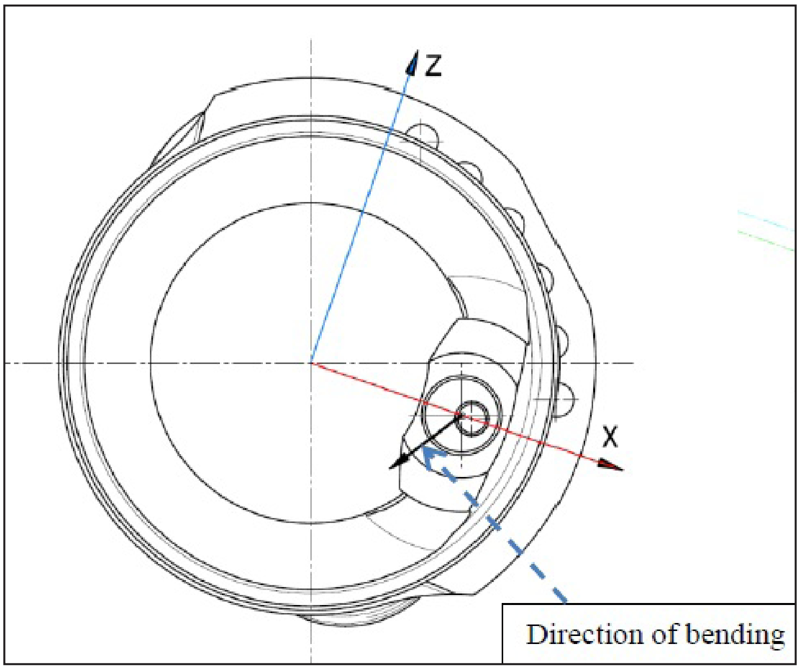
APPENDIX 12

DIRECTIONS OF DEFORMATION OF THE TRUNNION PINS OF BLADES 2 AND 5

Note: The following figures are bottom views of the blades.



Direction of deformation of the trunnion pin of blade 2



Direction of deformation of the trunnion pin of blade. 5

APPENDIX 13

ABSTRACT SUMMARY OF THE VSS REPORTS

Table of contents

1 VIBRATION STRESS SURVEY OBJECTIVES

Two propeller vibration stress survey were performed on two 568F-1 propellers installed on an ATR72-212A flight test aircraft in Toulouse, France.

The first VSS was performed in November 2014. The survey was conducted to determine vibratory response during calm and adverse winds, and during flight operations. It was performed within the framework of the investigation in coordination with BEA and NTSB.

The second VSS was performed in May 2016. The survey was conducted to determine vibratory response during flight operations. A primary objective was to identify a reduction in trunnion friction load with a redesigned bearing ball separator necklace, and a secondary objective was to determine the effect of an increased gap between the fore and aft yoke plates. The increased gap, created by machining the forward plate, mimics 0.05 inches of yoke plate wear due to interaction with the trunnion pin roller. Yoke plate wear results in increased clearance between the pin and the yoke plates and may contribute to increased friction.

2 DEFINITIONS

The **cyclic** value is determined by searching for the differences between maximum and minimum strain level divided by two during a 1/8 of a second time interval.

The **steady** value is determined by calculating the average strain level during 1/8 of a second.

3 TEST INSTALLATION

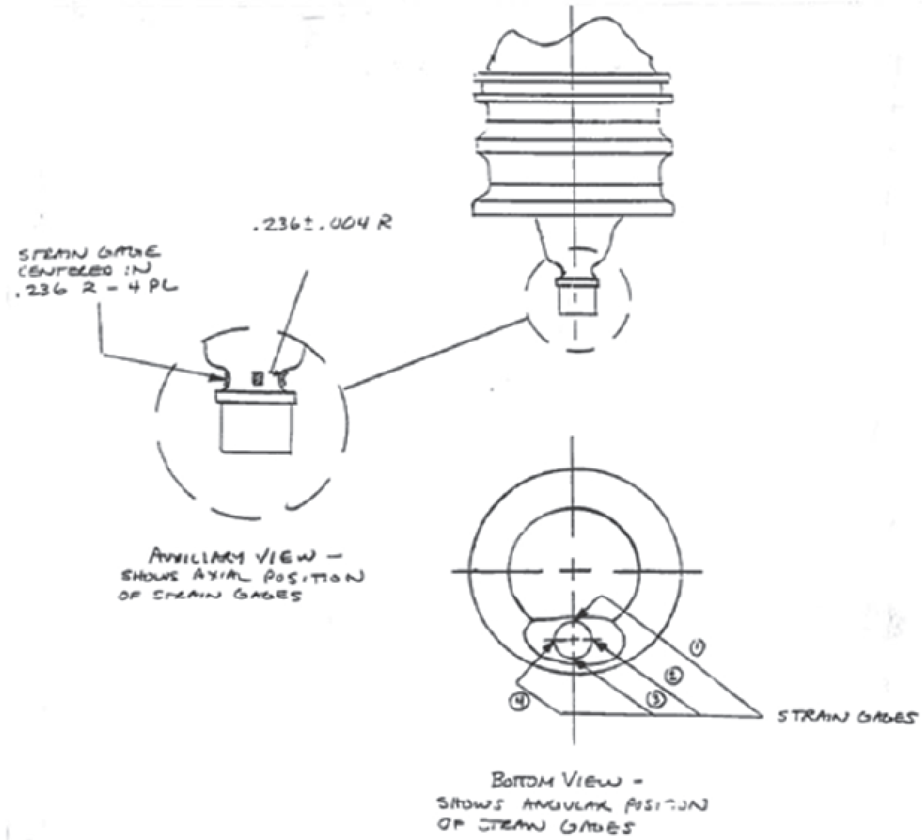
Two instrumented propeller systems were installed and tested on the left and right nacelle of the aircraft. The propeller was comprised with six all-composite blades given the designation of 568F-1. Three blades were instrumented with shank strain gages. In addition, gages were applied to the blade trunnion pins to monitor trunnion and estimate actuator loads. The vibratory strain data reported here is for the flatwise and edgewise directions in the blade shank region and for tangential (TT) and radial (TR) gage directions in the blade trunnion region.

Blade trunnion gage values are named:

- 22TT for propeller 2 blade 2 tangential value;
- 26TT for propeller 2 blade 6 tangential value;
- 25TT for propeller 2 blade 5 tangential value;
- 22TR for propeller 2 blade 2 radial value;
- 26TR for propeller 2 blade 6 radial value;
- 25TR for propeller 2 blade 5 radial value.

Gages locations are shown in the following figure.

568F BLADE TRUNNION GAGE LOCATIONS
ATR72-210 Commuter Aircraft



4 GROUND RUNNING

NB: Ground testing was performed only during 2014 VSS. However, for 2016 VSS, instrument checkouts and engine cycling were performed on the ground prior to the two flight tests.

During ground running, vibratory strains were unsteady, with typically irregular variations in amplitude caused by turbulent unsteadiness in the ground operating environment.

Tabulated trunnion data shows the maximum cyclic force of about 1,000 pounds during rear quartering wind conditions. Maximum trunnion cyclic ground loads are about twice what was observed during flight operation.

The maximum peak trunnion loads were observed to be about 3,000 pounds while dwelling at high torque during rear quartering wind conditions. These peak levels are well below the 5,600 - 6,800 pounds load needed to cause permanent deformation of the actuator plates and blade trunnion parts. The yield strength varies depending on the vertical position of the roller bearing relative to the actuator plate centerline.

Blade continuous operating limits were exceeded by 30% during rear quartering wind ground conditions. These conditions are restricted and considered outside the propeller normal operating envelope. **Trunnion loads did not exceed any load limits.**

The flatwise gage response is made of 1P and 2P harmonics, where the 1P harmonic is dominate on propeller 1 at 1200 rpm and high power conditions. Trunnion response is at 1P and 2P harmonics at high power conditions and at 1P and 3P harmonics at 850 rpm and low power conditions. Ground spectral analysis showed that the frequency response was harmonic and due to forced excitations. No nonsynchronous response was observed. **There was no evidence of blade self-excitation or flutter.**

5 FLIGHT TESTS

5.1 Flight test conditions

During 2014 VSS, two flights were performed. One flight at low gross weight (15,600 kg) and another flight at high gross weight (22,300 kg).

During 2016 VSS, two high gross weight (22,200 kg) flight tests were performed based on results from the 2014 VSS. The first flight used the original ball separator necklace (P/N 815522-1) and the second flight used a ball separator of a new design (P/N 1024538-1) intended to reduce blade retention friction. The first flight was performed with the original ball separator and included maneuvers for a 250 knot "slam" from a cruise condition, a 250 knot normal pullback, a 230 knot slam, a 230 knot pullback, and other typical parts of a flight profile. The second flight test was an abbreviated version of the first test using the redesigned ball separator.

5.2 Blade continuous operating limits

During 2014 VSS high aircraft gross weight flight, blade response reached continuous operating limits at the peak of a transient maneuver with a vertical load factor of 1.26 performed during climb. Maneuvers of this type are not normally performed during commercial operation.

5.3 Actuator trunnion pin steady and cyclic loads

During flight operation with wings level, the left propeller cyclic blade loads were 5% higher compared to the right propeller.

During the transient maneuver to maximum aircraft speed at the beginning of descent, the right propeller blade cyclic loads were higher compared to the left side. The magnitude of the blade cyclic loads during these decent maneuvers is lower than all other phases of flight with the exception of cruise.

Trunnion loads were as expected during the entire flight envelope except for two conditions, during the transient maneuver to maximum aircraft speed at the beginning of descent and peak loading during full reverse operation.

Operating at maximum reverse, the trunnion force data shows that the blade was loading the front yoke plate of the pitch change actuator. This condition was the only case in the entire survey where there was measurable steady load applied to the front plate of the actuator.

5.4 Ball bearing friction loads

5.4.1 2014 VSS results

Hysteresis loops performed during 2014 VSS ground operation before and after flight verified that there is an increase of the trunnion and actuator loads from the effect of friction buildup that occurred during flight operation.

Some evidence of stick-slip friction phenomenon was observed during approach at low altitude during 2014 VSS flight 1. The load increase due to friction is moderate and seems to occur randomly, resulting in a very low amount of accumulated stick-slip cycles. This exposure is of short duration.

5.4.2 2016 VSS results

Several items suggest a reduction in friction due to the redesigned ball separator. These include:

1. Maximum trunnion loads were reduced during the after landing hysteresis loop, where friction should be most evident;

2. Hysteresis loop data indicates less roughness in the measured load as a function of blade pitch, which suggests less sticking/unsticking due to friction as the blade traverses.

Hysteresis loops performed after-landing/engine-on and post-flight/engine-off indicate lower roughness in the trunnion load as a function of blade pitch angle (beta ¾), indicating that stick-slip friction had been reduced. The after-landing measurements provide the best measurement of retained friction as the centrifugal loads have not been relieved. The trunnion load data indicate that for the min-range (-14 to -1 deg), the overall load has been reduced from 4470 to 3700 lbf after the introduction of the new ball separator. For the mid-range (-1 to 14 deg), the load has been reduced from 2870 to 2560 lbf. For the max-range (15 to 22 deg) the load has been reduced from 3720 to 2410 lbf. The actuator loads corroborate these reductions.

In the after landing data, the maximum friction experienced in several ranges has been reduced by approximately 10-18% after the introduction of the redesigned ball bearing separator.

5.5 Vibration events

References to "vibration event" refer to a trunnion cyclic load increase. The magnitude of this observed load increase was not a concern, but the vibration signature initiated further investigation.

THE TRUNNION CYCLIC LOAD INCREASE (VIBRATION EVENT) OCCURS WITHIN THE PROPELLER PITCH CHANGE MECHANISM AND IS OF LOW MAGNITUDE. DURING THESE CONDITIONS THE TRUNNION CYCLIC LOAD AMPLITUDE INCREASES FOR A SHORT DURATION. THIS VIBRATION SHOULD NOT BE CONFUSED WITH THE VIBRATION OBSERVED AFTER PIN FAILURE THAT IS THOUGHT TO BE CAUSED BY BLADE-TO-BLADE IMBALANCE.

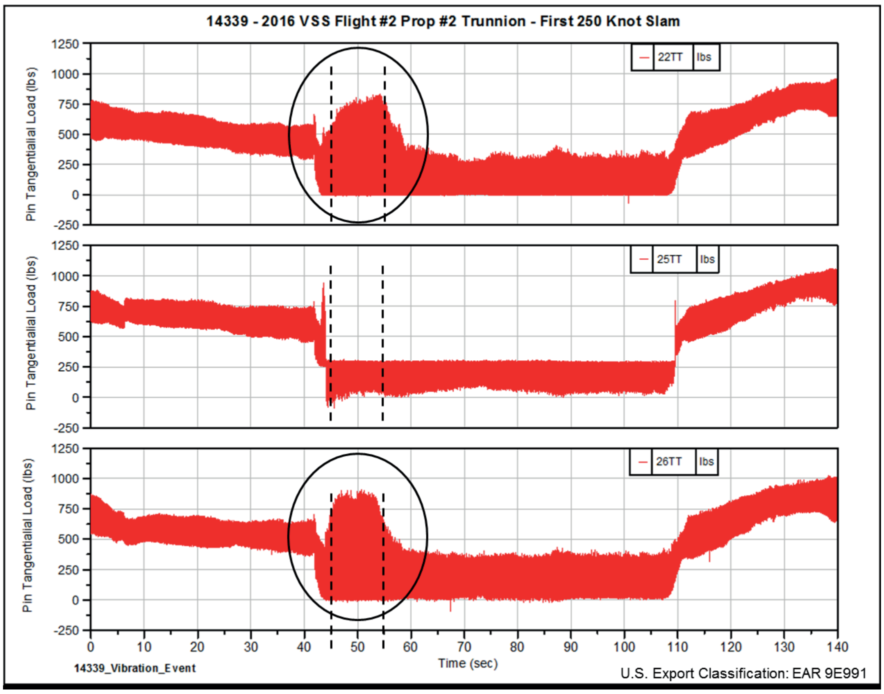
Vibration events were not examined in 2014 VSS report. However, to compare with 2016 VSS findings, 2014 VSS data were re-examined. New 2014 VSS analysis results were presented in

2016 VSS report. Four of the nine 250 knot descent maneuvers performed exhibited this trunnion vibration event, two during 2014 VSS and two during 2016 VSS.

5.5.1 Trunnion pin loading signal (2016 VSS) during vibration events

During 2016 VSS flight, trunnion cyclic load increase event was noted on two 250 knot descent maneuvers. This trunnion load "vibration event" occurred immediately after the first 250 knot slam on flight 2.

The two following figures show the complete prop 2 tangential and radial 2000 Hz strain gage recordings. The 'vibration event' is the load amplitude increase on gages 22TT, 26TT, 22TR and 26TR that occurs immediately after the PLA reduction.



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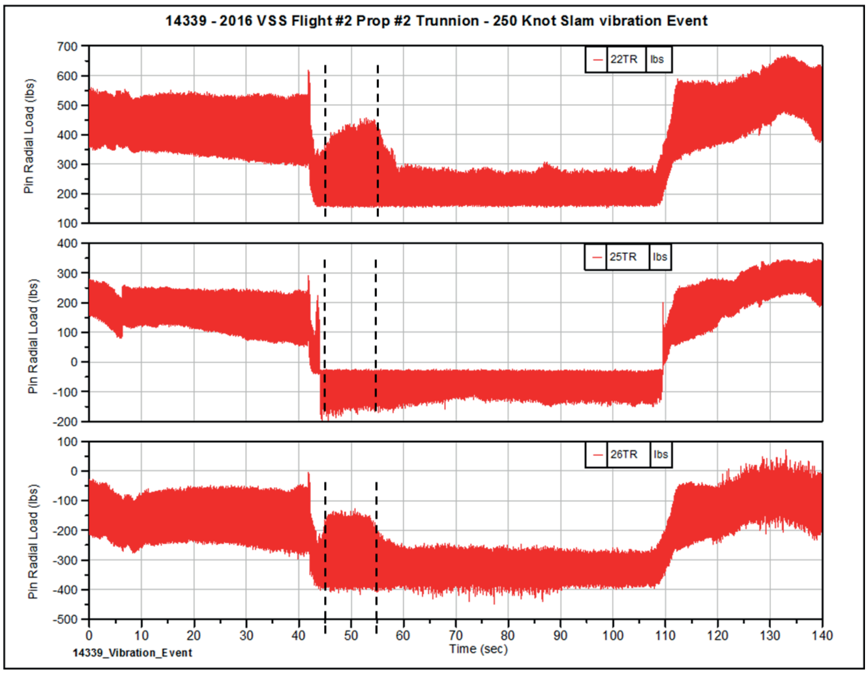
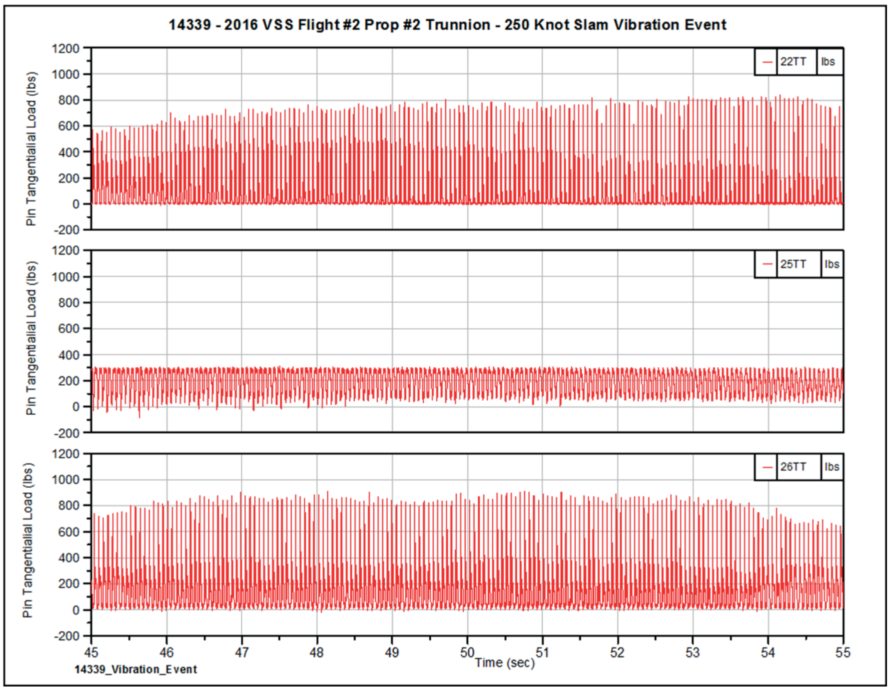


The following figure shows a blown-up view of the tangential signals for 5 seconds duration window:



The following figure focuses on a time sample of two seconds:

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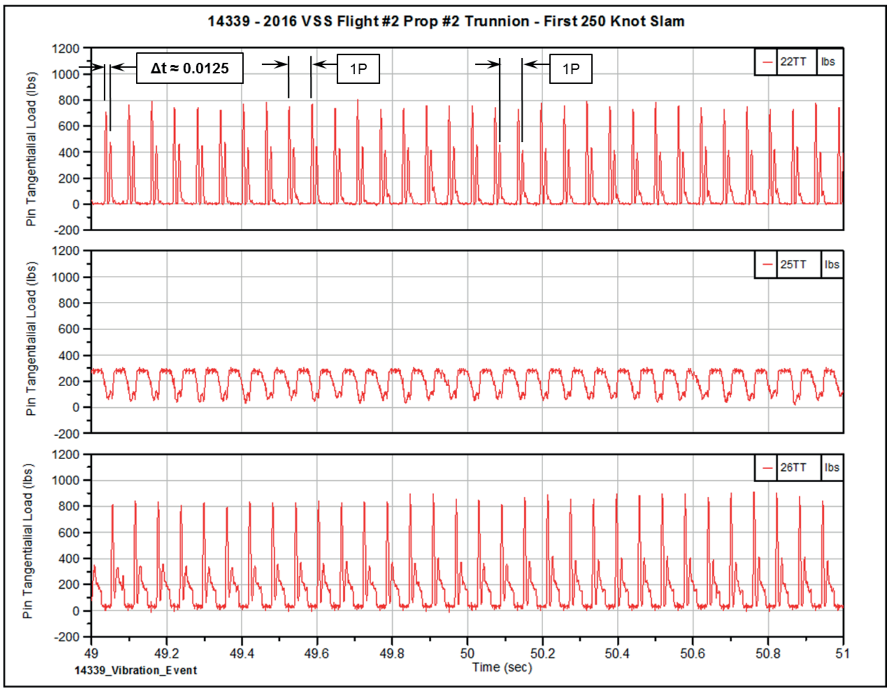
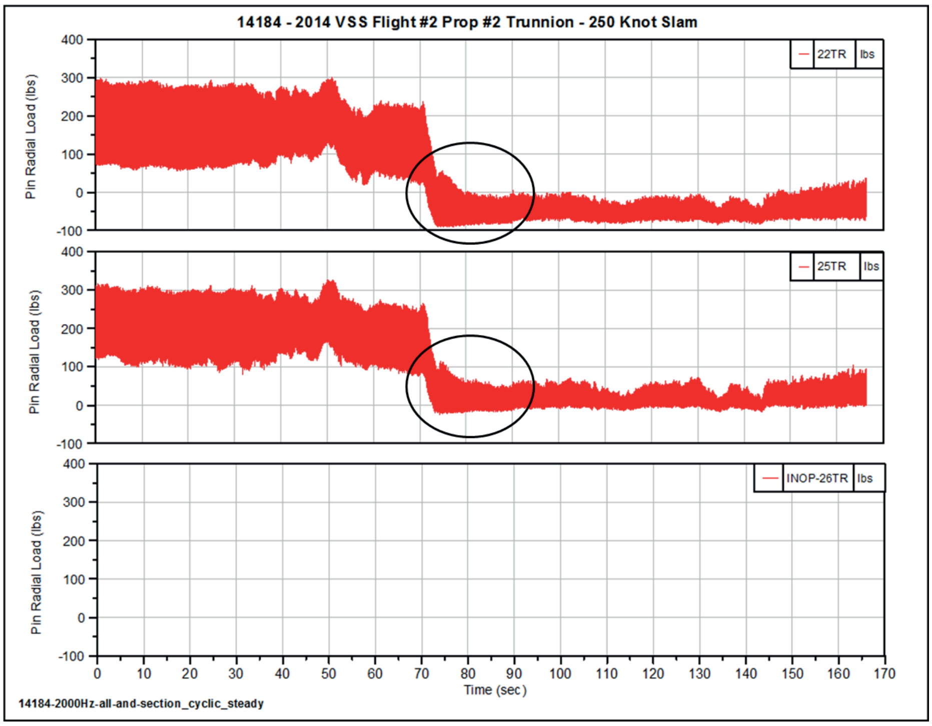


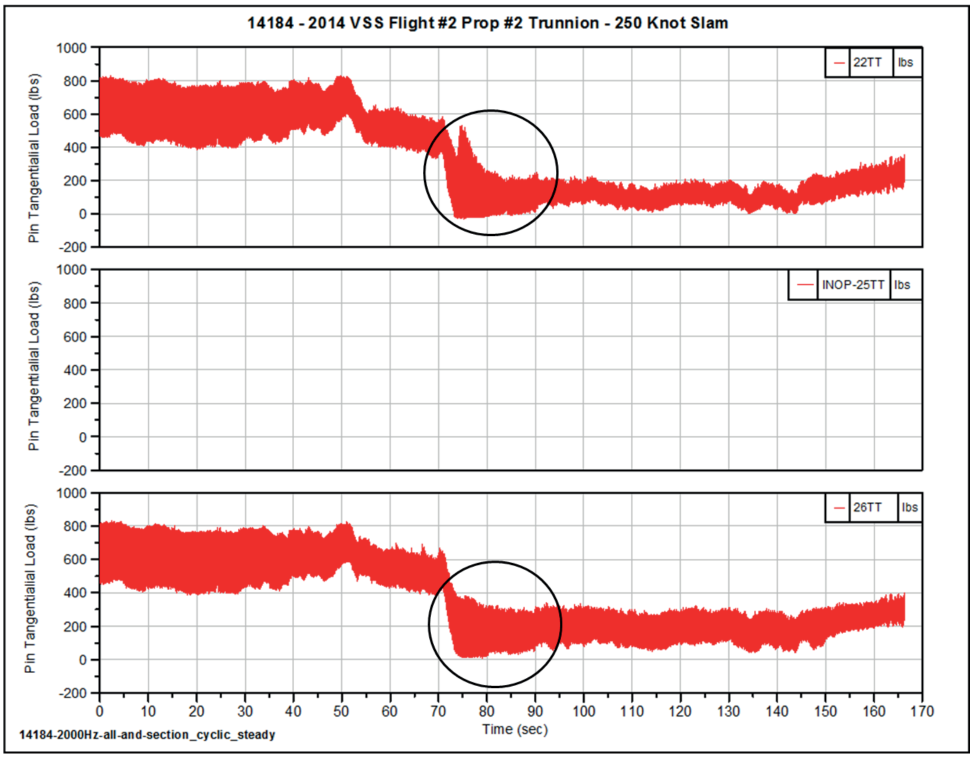
At this resolution, two distinct load peaks occurring at 1P intervals are visible in the 22TT and 26TT signals. The first peak is the higher load on the aft plate. The second peak occurs 0.0125 seconds after the first peak, also on the aft plate. This implies a double impact load on the aft plate. No double impact was observed for the forward plate for any case. Since the air data is only sampled at 0.125 second intervals, it cannot be directly correlated to the load data to identify drivers of such a double impact load. Additionally, blade angle is derived from actuator position, which disallows identification of different blade angles for different blades.

5.5.2 Trunnion pin loading signal comparison (2014 VSS) during vibration events

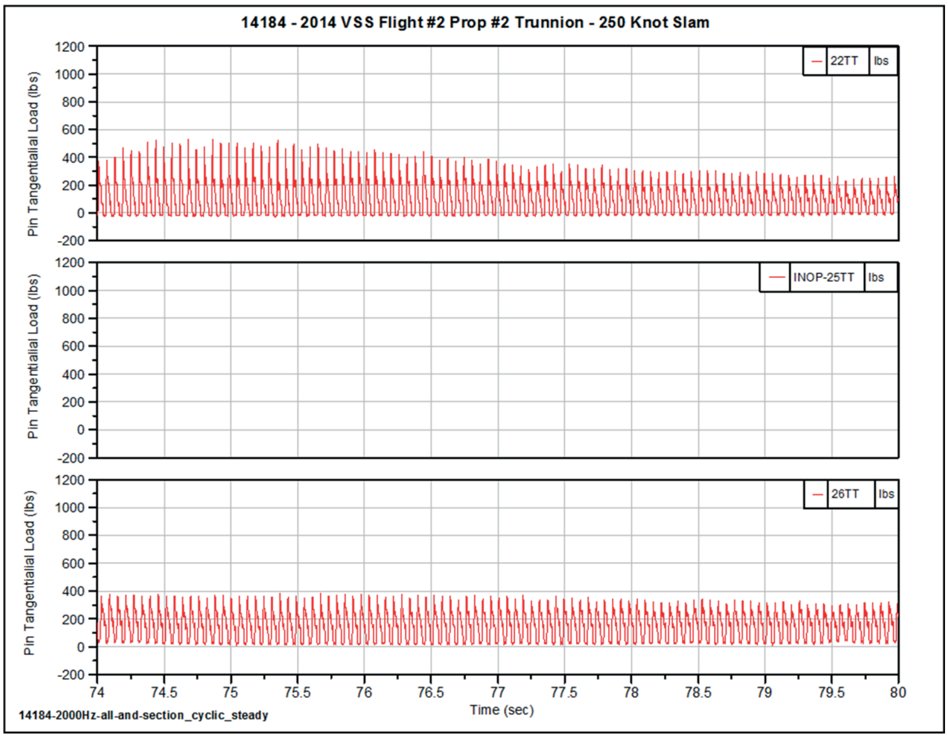
For comparison, 2014 VSS 250 knot slam data was analyzed. Prop 2 trunnion gages show a small dip in the cyclic load after PLA reduction occurring during 6 seconds. Trunnion data shows that it is unloading the aft plate to a near zero load between impacts.

The two following figures show the tangential and radial trunnion pin signals, respectively:

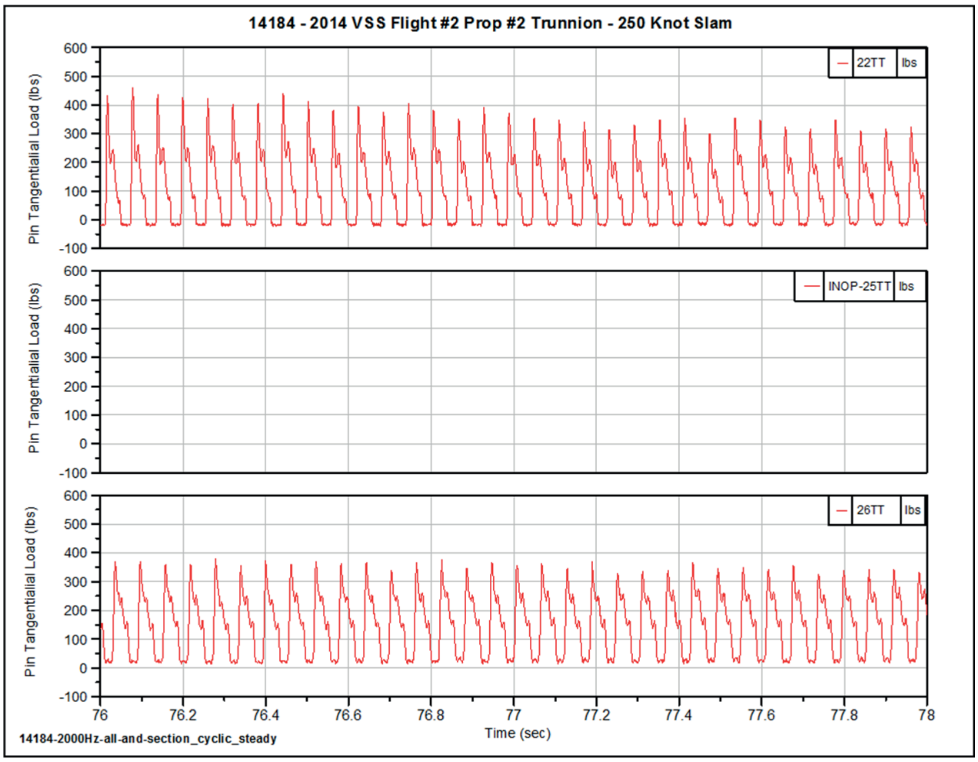




The following figure shows 22TT and 26TT during the 6 seconds:



The following figure focuses on a time sample during 2 seconds:



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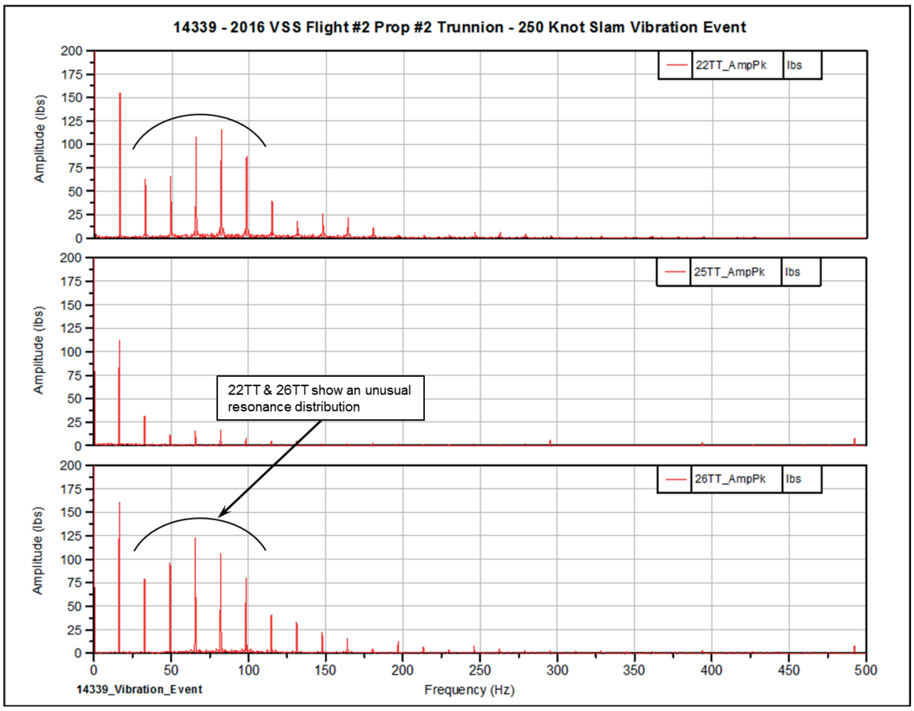
The 26TT sensor does not dip below zero because of a positive offset in the gage. Similarly, although both 22TR and 25TR 2000 Hz signals show a dip after slam, both are below zero due to gage offset.

5.5.3 Trunnion pin frequency analysis (2016 VSS) during vibration events

FFTs of gages 22TT, 25TT and 26TT for the period of the vibration event are shown in the following figure:



FFT plots for 22TT and 26TT show an unusual peak pattern. Typically 1P and 2P predominate. But in this case 1P is dominant while 2P through 6P are also major contributors to trunnion loading. A physical explanation for this 'ringing' phenomenon would be similar to a response observed after an impact load. The obvious candidate for such an impact would be the cyclic load of the trunnion loading and unloading the yoke plate. The 25TT FFT appears normal in that 1P dominates.

The 22TT and 26TT unusual resonance distribution compared to 2014 VSS (see chapter 5.5.4) could be an evidence that the machined gap between the plates exacerbates the vibration event.

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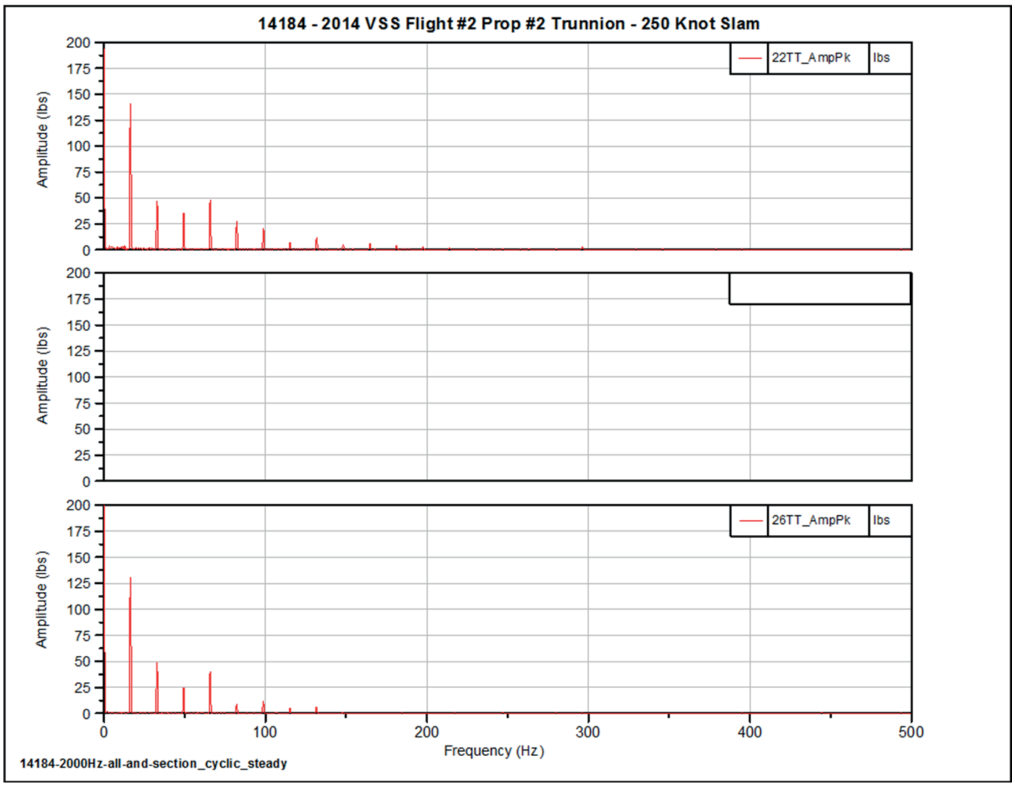
5.5.4 Trunnion pin frequency analysis comparison (2014 VSS) during vibration events

The following figure is an FFT of the trunnion data after the slam:



It reveals a broadband frequency response similar to that of 2016 VSS (250 knot slam.).

5.5.5 Effect of the yoke plate clearance on vibration events

The gap between forward and aft plates itself does not appear to be a driver as vibration events were noted to occur during 2014 F2 where the gap was not modified and during 2016 F2 where the gap was modified. Additionally, 2016 F1 (with a modified gap) did not show any vibration events at 250 knots. Based on evaluation of similar maneuvers (power reduction to flight idle at 250 kt during descent) with and without the gap between forward and aft plates, the data suggests that although **the increased yoke plate clearance itself does not drive the vibration event,** it can affect interaction between the trunnion pin and yoke plate during a Power Lever slam transient and change the cyclic loading characteristics of the trunnion pin. **When the gap is enlarged during the power lever transient, the data shows evidence of impact loading** (as opposed to harmonic loading). Spectral analysis of such impact loading shows more broadband response than does the typical trunnion cyclic loading. All three instrumented blade trunnions showed rear yoke plate unloading.

5.5.6 Effect of the bearing retention friction on vibration events (2016 VSS)

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Two distinct behaviors occurred during the vibration event that occurred immediately after the first 250 knot slam on flight 2 of 2016 VSS. First, blade 2 and blade 6 trunnions appear to be unloading under vibration. During this flight segment, the combination of cyclic and steady loads leads to very low loading on the aft plate. **Bearing retention friction due to the fast slam resists the total twisting moment keeping the rear yoke plate lightly loaded** on blades 2 and 6. Second, it appears that **blade 5 retention friction is elevated compared to the other blades, causing the trunnion pin to remain on forward yoke plate**.

Under certain conditions (such as a quickly executed 250 knot slam), blade retention friction can cause the trunnion pin load to switch from the rear yoke plate to the front yoke plate.

5.5.7 Transmission of vibrations to the aircraft (2016 VSS)

Based on a spectral analysis of the shank gages during the vibration event that occurred immediately after the first 250 knot slam on flight 2 of 2016 VSS, no vibratory loads were noted above 4P. Blade vibration loads at 2P, 3P and 4P are reactionless at the shaft and cannot transfer to the aircraft. Reduction of flight data around **the trunnion "vibration event" has shown no evidence of transmitting vibration to the aircraft.**

5.5.8 Trunnion loading during vibration event (2016 VSS)

The trunnion vibration events can increase cyclic load magnitudes as much as four times the normal cyclic magnitudes. The peak loads during these events reach magnitudes of about 900 lbf. Data from flight operation showed **maximum peak trunnion loading far below levels required to produce permanent deformation** of the trunnion and actuator hardware.

5.5.9 Effect of airspeed on vibration events

The airspeed seems to be a factor in whether or not the propeller undergoes a trunnion "vibration event" after power lever reduction. For 230 knot power lever transients, no trunnion vibration events were noted and the trunnion pin was found to remain loading the aft yoke plate in all instances. Four of the nine 250 knot descent maneuvers performed during 2014 and 2016 VSS exhibited this trunnion vibration event.

5.5.10 Effect of a power slam on vibration events

The power lever slam does not appear to be a primary driver since vibration events occurred at 250 knots for both slam and normal pullbacks.

5.5.11 Summary of power lever pullbacks performed in the 2014 and 2016 VSS

The table below summarizes slam and normal power lever pullbacks performed in the 2014 and 2016 VSS.

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				Vibration Event		Rear Plate Unload	
Case	Speed	Slam	P2 Gap	Prop 1	Prop 2	Prop 1	Prop 2
2014 F1 14056	250 kt	No, 7 sec	No	No	Yes	-	B2/B5/B6
2014 F1 14065	250 kt	Yes, 1 sec	No	No	Yes	-	B2/B5/B6
2014 F1 14082	250 kt	Yes, 1 sec	No	No	No	-	B2/B5/B6
2014 F2 14195	250 kt	Yes, 2 sec	No	No	No	-	B2/B5
2014 F2 14201	250 kt	Yes, 2 sec	No	No	No	-	B2
2016 F1 14298	230 kt	Yes, 1 sec	Yes	No	No	-	-
2016 F1 14301	250 kt	Yes, 2 sec	Yes	No	No	-	B2
2016 F1 14303	250 kt	No, 7 sec	Yes	No	No	-	B2
2016 F1 14305	230 kt	No, 20 sec	Yes	No	No	-	-
2016 F2 14339	250 kt	Yes, 1 sec	Yes	Yes, minor	Yes, major	B2/B5/B6 B5 load front plate	B2/B5/B6 B5 load front plate
2016 F2 14340	230 kt	Yes, 1 sec	Yes	No	No	-	-
2016 F2 14341	250 kt	No, 12 sec	Yes	No	Yes	-	B2/B5/B6
2016 F2 14342	230 kt	No, 8 sec	Yes	No	No	-	-

Instances that produced either a vibration event after the slam (as evidenced by increased trunnion cyclic load) or an unloading of the aft yoke plate are highlighted.

6 CONCLUSIONS

6.1 Ball bearing friction

Hysteresis loops performed during 2014 VSS ground operation before and after flight verified that there is an increase of the trunnion and actuator loads from the effect of friction buildup that occurred during flight operation.

Based on the smoother hysteresis plots obtained with the replacement bearing ball retainer during 2016 VSS, compared to the original bearing ball retainer hysteresis plots in 2014 VSS, blade retention friction is reduced overall. The maximum friction experienced in several ranges has been reduced by approximately 10-18% after the introduction of the redesigned ball bearing separator.

6.2 Vibration events

The results indicate that vibration events:

- Were only noted on 250 knot descent maneuvers, but not all 250 knot descent maneuvers caused vibration events
- Have occurred on only four out of nine recorded 250 knot descent maneuvers
- Have occurred during both slam and normal pullbacks
- Have occurred with and without an enlarged 0.050” yoke plate gap on prop 2
- Have not occurred during 230 knot descent maneuvers

Additionally, 2016 F2 PDAS 14339 shows that the vibration event occurred on propeller 1, which did not have an enlarged gap. Consequently, the slam maneuver and the yoke plate gap cannot each be singled out as the root cause of such a vibration.

In all cases where a vibration event occurred, the trunnion pin unloaded the rear yoke plate, which is unexpected behavior within the flight envelope. This suggests that the prop may have been dithering due to low steady and cyclic loading on the trunnion pin.

In an extreme case (14339) the data indicate that the front plate had actually been loaded, which is even farther from expected behavior during normal flight operation. Such behavior would certainly be exacerbated by a larger yoke plate gap. Although such trunnion pin behavior is unexpected, the observed loads are well below the trunnion pin cyclic load limit, and do not cause fatigue damage.

APPENDIX 14

EXCERPTS FROM THE MAINTENANCE MANUAL

Engine performance check

The engine checks are first carried out with the air bleeds off and the EECs and PECs on.

The maintenance personnel must carry out the following operations:

- After starting up the engine, with the power levers (PL) in ground idle (GI) and the condition levers (CL) in the feathered (FTR) position, the engine parameters are checked;
- With the PLs in GI, the CLs are set to AUTO and the engine parameters are checked;
- With the CLs in AUTO, the PLs are set to flight idle (FI) and the engine parameters are checked;
- With the CLs in AUTO, the PLs are set to take-off (TO), the engine parameters are checked and then the PLs are set to GI;
- With the CLs in AUTO, the PLs are set to maximum reverse (REV), the engine parameters are checked and then the PLs are set to GI;
- The EECs are set to off, the PLs are moved forward until maximum power (RTO) is reached, the engine parameters are checked and then the PLs are set to GI;
- The EECs are set to on, the CLs are set to FTR, and the engines shut down.

Tests after replacing a PVM

- The PEC is calibrated (refer to paragraph 1.8.2.4);
- After starting up the engine, the power lever (PL) is set to ground idle (GI) and the condition lever (CL) to AUTO ;
- The CL is moved several times from the AUTO position to the FTR position until the propeller correctly responds to the CL inputs;
- Once the on-ground engine performance tests have been completed (refer to paragraph 1.8.2.3), the propeller must be feathered for more than 20 seconds and then the engine shut down;
- A check for oil leaks is carried out;
- After starting up the engine, the feathering pump is de-energized;
- An operational test of the low pitch protection is carried out:
    - The CL is set to AUTO;
    - The PL is pushed above flight idle (FI) and then returned to the FI position;
    - The ENG/LO PITCH selector[75] is set to PLA<FI;
    - The PL is set to GI and the engine parameters are checked;
    - The ENG/LO PITCH selector is set to neutral and the engine parameters are checked;
    - The PL is pushed above FI and then returned to the FI position;
    - The ENG/LO PITCH selector is set to PLA>FI and the engine parameters are checked;
    - The PL is set to GI and the engine parameters are checked;
    - Once the propeller is feathered, the ENG/LO PITCH selector is set to neutral, the propeller moves out of the feather position and the engine parameters are checked;
    - The PL is set to GI;

[75] Cf. Figure 23.

- ❒ An operational test of the overspeed protection system is carried out:
  - The power management (PWR MGT) selector is set to take-off (TO) and the CL is set to AUTO;
  - The PL is pushed above FI;
  - The PEC is set to off by pressing the PEC/FAULT/OFF button (refer to Figure 6);
  - The PL is moved forward and the propeller rotation speed is checked (Max 102.5 % Np +/-1%);
  - The PL is returned to FI;
  - The PEC is set to on by pressing the PEC/FAULT/OFF button;
  - The PL is moved forward until the propeller rotation speed stabilizes at 100 % Np;
  - The PROP OVSPD selector(76) is held at ENG, the propeller speed is checked (102.5 % Np then 100 % Np after 15 s), then the selector is released;
  - The PL is returned to GI, the CL set to FTR and the PEC reset by pressing and releasing the PEC/FAULT/OFF button;
- ❒ An operational test of the overspeed governor is carried out:
  - The two engines must be running and the PL of the propeller which has not been checked at FI;
  - The power management (PWR MGT) selector is set to take-off (TO) and the CL is set to AUTO;
  - The PL is pushed forward until the propeller rotation speed stabilizes at 100 % Np;
  - The PROP OVSPD selector(77) is held at ENG, the propeller speed is checked (102.5 % Np), and then after three seconds, the SET/OVSPD button is pressed;
  - As soon as the propeller speed increases, the two buttons are released;
  - The PL is returned to GI, the CL is set to FTR and the PEC reset by pressing and releasing the PEC/FAULT/OFF button;
- ❒ Part of the on-ground engine performance test(78) is carried out:
  - With the engine running, the PL in ground idle (GI) and the CL in FTR, the engine parameters are checked;
  - With the PL in GI, the CL is set to AUTO and the engine parameters are checked;
  - With the CL in AUTO, the PL is set to FI and the engine parameters are checked;
  - With the CL in AUTO, the PL is set to take-off (TO), the engine parameters are checked, then the PL is returned to GI;
  - The EEC is set to off, the PL is moved forward until maximum power (RTO) is reached, the engine parameters are checked, the PL is set to GI, the EEC is set to on;

(76) Cf. Figure 23.

(77) Cf. Figure 23.

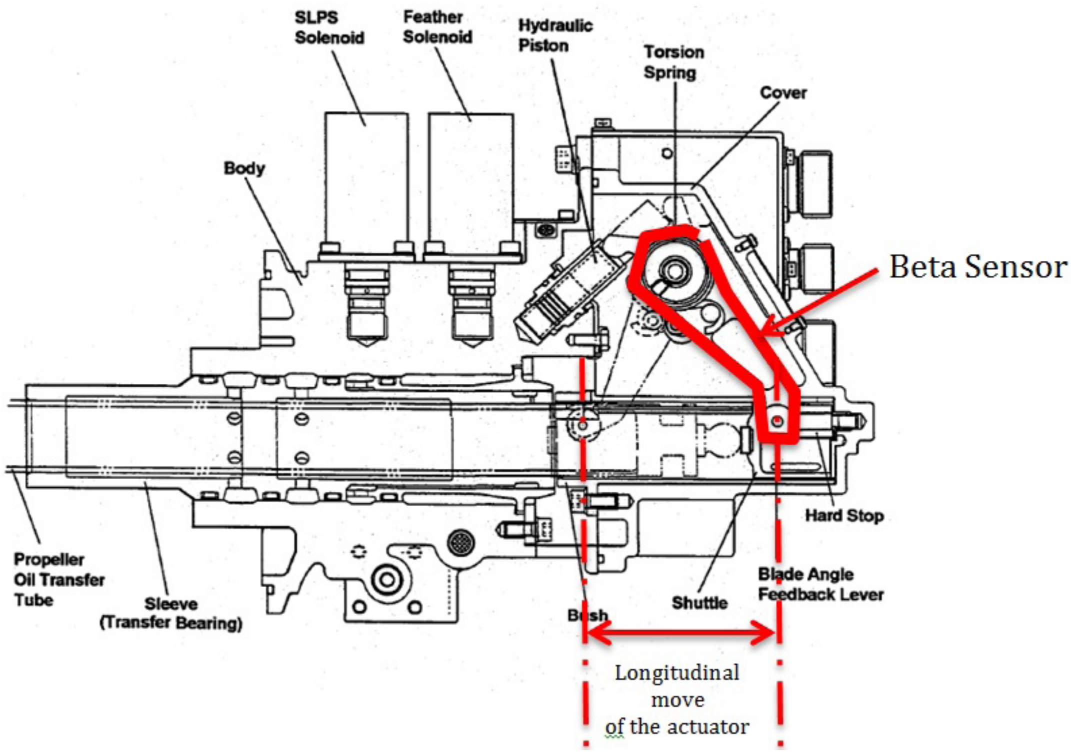
(78) Cf. 1.8.2.3.

- An operational test of the propeller is carried out:
  - The PL is set to GI and the CL to AUTO;
  - The CL is moved several times from AUTO to FTR until the propeller correctly responds to the CL input, then the engine is shut down;
  - The engine oil level is topped up and the engine started up;
  - With the CL in AUTO, the PL is set to FI and the engine parameters are checked (test only compulsory if not carried out previously);
  - With the EECs on and the air bleeds off, the power management (PWR MGT) selector is set to cruise (CRZ) and the engine and propeller parameters are checked;
  - The PL is moved forward and the propeller speed checked (around 82 % Np) then the PL is set to GI;
  - The CL is set to OVRD;
  - The PL is moved forward and the propeller speed checked (around 100 % Np) then the PL is set to GI;
  - With the CL at AUTO, the PL is set to maximum reverse (REV), the engine parameters are checked and then the PL is set to GI;
- The ATPCS test is carried out.

APPENDIX 15

PROPELLER BLADE ANGLE SENSOR

The angle of the propeller blades is controlled by the longitudinal movement of the pitch change actuator. The off-centred blade trunnion pins are positioned between the ears of the two actuator yoke plates. The longitudinal movement of the actuator changes the angle of the propeller blades.



The "beta" angle sensor of the propeller blades is located inside the PVM. It is kept in contact with the end of the transfer tube by a torsion spring and a hydraulic piston.

The sensor is a Rotary Variable Differential Transformer (RVDT). It provides an output voltage linearly proportional to the angular displacement. The beta angle is therefore directly connected to the longitudinal position of the transfer tube.

APPENDIX 16

ATR OPERATORS INFORMATION MESSAGE

OPERATORS INFORMATION MESSAGE

Ref OIM 2014/010 Issue 1:

Date : 23/09/2014 **Page :1**

AIRCRAFT TYPE : ATR 42-400/500 & 72-212A **ATA : 61**

SUBJECT: 568F-1 PROPELLER PITCH CHANGE MECHANISM DAMAGE

PURPOSE

In-service events have been reported, featuring damage on propeller pitch change mechanism (blade trunnion pin broken or cracked, actuator forward yoke plate distorted).

First investigation results showed that the reported events were preceded by these symptoms: during descent or approach phases, sudden and high propeller vibrations often associated with PEC Faults (codes 67&68).

ATR and UTAS are releasing troubleshooting guidelines to detect early stage of hardware damage.

STATUS

Investigation is in progress to isolate the root cause.

RECOMMENDATIONS

Attached procedure will be introduced in next revision of ATR TroubleShooting Manual, to provide operators with guidelines to be followed if above symptoms occur.

This new TSM item features propeller pitch change mechanism inspection procedure through UTAS SB568F-61-67 along with guidelines to secure information related to the event (pilot report, QAR).

In case of sudden and high propeller vibrations associated with PEC Fault, ATR recommends to:

- Immediately apply attached troubleshooting procedure
- If damage is confirmed after UTAS SB application, consider securing CVR data for potential noise spectral analysis in the frame of the technical investigation.

Writer signature	Service Director signature	Technical Support signature
Propulsion systems specialist Vianney LANGUILLE	Propulsion & Air Systems Director Franck LACOSTE	Airline Technical Support VP Carlo SCHETTINO

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FAULT SYMPTOM:			EQUIPMENT INVOLVED:
On panel 401VU, on PEC 1(2) P/BSW, **FAULT** legend is illuminated during flight phase associated with high and sudden vibrations.			
PREREQUISITES: 45-15-00 RDG 10000 Reading of PEC memory			
USEFUL DOCUMENTS:			
ASM:	AWM:	JIC:	OTHER:
		05-51-35 PRO 10000 31-31-00 PRO 10020 45-15-00 RDG 10000	UTAS (Hamilton) SB568F-61-67 UTAS (Hamilton) Maintenance Manual 61-27-00 fault isolation

1 Apply prerequisites. Are there fault codes 67 and 68 stored ?

NO → 201 Refer to UTAS (Hamilton) Maintenance Manual 612700 for fault isolation.

YES → 202 Apply UTAS (Hamilton) SB568F-61-67 and send all data to ATR :

- Vibrations sheet as per JIC055135PRO10000.
- Detailed pilot report (including procedures applied by the crew).
- AIDS reports as per JIC313100PRO10320.

Figure 120

IL6121003A15001-01

FAULT SYMPTOM:	EQUIPMENT INVOLVED:
On panel 401VU (401VM), on PEC 1(2) P/BSW, **FAULT** legend is illuminated during flight phase associated with high and sudden vibrations.	

PREREQUISITES:
45-15-00 RDG 10000 Reading of PEC memory

USEFUL DOCUMENTS:

ASM:	AWM:	JIC:	OTHER:
		05-51-35 PRO 10000 45-12-00 RDG 10000 45-15-00 RDG 10000	UTAS (Hamilton) SB568F-61-67 UTAS (Hamilton) Maintenance Manual 61-27-00 for fault isolation

1 Apply prerequisites. Are there fault codes 67 and 68 stored ?

NO → 201 Refer to UTAS (Hamilton) Maintenance Manual 612700 for fault isolation.

YES → 202 Apply UTAS (Hamilton) SB568F-61-67 and send all data to ATR :
- Vibrations sheet as per JIC055135PRO10000.
- Detailed pilot report (including procedures applied by the crew).
- ALL available QAR data as per JIC451200RDG10000.

Figure 120

IL6121003A15002-01

APPENDIX 17

UTAS SERVICE BULLETIN

UTC Aerospace Systems

Hamilton Sundstrand Corporation, a UTC Aerospace Systems Company

SERVICE BULLETIN

PROPELLERS - ACTUATOR - INSPECTION OF YOKE PLATES

1. PLANNING INFORMATION

A. Effectivity

(1) Hamilton Sundstrand Propellers, Model 568F, PN 815500-2 and 815500-3, used on ATR 42-400, ATR 42-500, ATR 42-600, ATR 72-210A, ATR 72-500, and ATR 72-600 aircraft.

B. Concurrent Requirements

(1) Confirmation of existing condition and indicated fault codes [refer to paragraph 1.C.(1)(a)] as directed by ATR OIM and/or Troubleshooting Manual.

C. Reason

(1) Problem

(a) Vibration has been experienced in combination with the indication of Propeller Electronic Control (PEC) fault codes 67 and 68 (sensed blade angle fault, primary and secondary).

(2) Cause

(a) In these circumstances, a change (increase) in the distance between the ears of the forward and aft actuator yoke plates may be indicated.

(3) Solution

(a) Measure blade angle backlash on all six blades. If the value at any blade exceeds the maximum allowable value, visually and dimensionally inspect the actuator yoke plates.

(4) Substantiation

(a) The measurements and inspections in this service bulletin will determine if bending of the yoke plates has occurred.

D. Description

(1) This bulletin gives the instructions to measure blade angle backlash on all six blades of the 568F propeller, remove the actuator and measure the distance between the ears of the actuator forward and aft yoke plates if indicated, and return the actuator and blades for engineering investigation if necessary.

E. Compliance

(1) Incorporation of this service bulletin is to be accomplished before the next flight, if directed by ATR OIM and/or Troubleshooting Manual (refer to paragraph 1.B. of this bulletin).

F. Approval

(1) The technical content of this Service Bulletin has been accepted by the FAA on October 2, 2014.

G. Manpower

(1) Approximately 2.0 man-hours are required to do the blade angle backlash measurements on all 6 blades of the 568F series propeller and inspect the actuator yoke plates.

H. Weight and Balance

(1) None

I. Electrical Load Data

(1) Not changed

J. Software Accomplishment Summary

(1) Not Applicable

K. References

(1) Hamilton Sundstrand Component Maintenance Manual (CMM) 61-13-12

(2) Hamilton Sundstrand Maintenance Manual (MM) P5206

(3) Hamilton Sundstrand Maintenance Manual (MM) P5214

L. Other Publications Affected

(1) Hamilton Sundstrand CMM 61-13-12 will be revised to incorporate this bulletin.

(2) Hamilton Sundstrand MM P5206 will be revised to incorporate this bulletin.

(3) Hamilton Sundstrand MM P5214 will be revised to incorporate this bulletin.

M. Interchangeability or Intermixability of Parts

(1) The incorporation of this bulletin does not affect the interchangeability or intermixability of the 568F series propeller, PN 815500.

2. MATERIAL INFORMATION

A. Material - Price and Availability

(1) No new parts are required to do the procedures in this service bulletin.

B. Industry Support Information

(1) All costs associated with the incorporation of this bulletin are at the operator's expense.

(2) Actuators removed from service as directed in 3.D.(4)(a) are to be sent to the UTAS Maastricht Repair Station for engineering investigation, at the address shown below. Documentation should include a reference to Service Bulletin 568F-61-67.

Hamilton Sundstrand
Customer Support Center - Maastricht
Horsterweg 7
6199 AC
Maastricht Airport
The Netherlands

(3) Propeller blades removed from service as directed in 3.D.(4)(b) are to be sent to the Ratier-Figeac Service Station for engineering investigation, at the address shown below. Documentation should include a reference to Service Bulletin 568F-61-67.

D. Ravello or R. Colin
Ratier-Figeac
B.P. No 2
46101 Figeac Cedex France

C. Material Necessary For Each Unit

(1) Refer to Hamilton Sundstrand CMM 61-13-12 for expendable parts information.

(2) Material to be Purchased

(a) None

(3) Material Supplied by the Operator

(a) Refer to Table 1.

Table 1
Material Required

Material Name and Number	Source	Use
Isopropyl alcohol, TT-I-735 or ASTM D770	Commercially available	Clean bulkhead surface
Masking tape, 1 inch wide	Commercially available	Marking surface for blade angle measurements
Pencil	Commercially available	Put marks on masking tape to measure blade angle

D. Material Necessary For Each Spare

(1) The same as the material necessary for each unit.

E. Reidentified Parts

(1) Not Applicable

F. Tooling - Price and Availability

(1) No tooling other than that required for shop maintenance of the 568F series propeller is required to do this modification.

(2) If a N.A.C.A. Type Universal Propeller Protractor, GS18217-1 or equivalent, is available, it may be used to do the blade angle backlash measurements (refer to paragraph 3.C.).

G. Special Tooling Necessary to do this Service Bulletin

(1) No special tooling or equipment are required to do this modification. But, the maintenance and overhaul tools in the manuals listed in paragraph 1.K. References can be necessary. Examine the operator tool supply to make sure all necessary tools are available.

3. ACCOMPLISHMENT INSTRUCTIONS

A. General

CAUTION: THE 568F PROPELLER CONTAINS DESIGN CRITICAL CHARACTERISTICS, PROCESSES, AND PROCEDURES. THE DESIGN CRITICAL CHARACTERISTICS ARE IDENTIFIED WITH THE SYMBOL >>DCC<<. REFER TO THE INTRODUCTION SECTION OF HAMILTON SUNDSTRAND CMM 61-13-12 FOR A COMPLETE EXPLANATION OF DESIGN CRITICAL CHARACTERISTICS.

(1) The facility performing the work (user) should obtain the material safety data sheets [Occupational Safety and Health Act (OSHA) Form 20 or equivalent] from the manufacturers or suppliers of materials to be used. The user must become completely familiar with the manufacturer/supplier information and adhere to the procedures, recommendations, warnings, and cautions of the manufacturer/supplier for the safe use, handling, storage, and disposal of these materials. The user should also read the long version of the warnings contained in this bulletin. The long version warnings are contained in Hamilton Sundstrand Warnings Registry SPM 20-00-04, available free of charge to all organizations that are on distribution for this bulletin. The Warnings Registry SPM 20-00-04 is also available at myhs.hamiltonsundstrand.com.

(2) A unit modified according to this service bulletin might be returned to the shop for maintenance or repair before the new or modified part numbers or procedures in this bulletin are incorporated into the applicable CMM.

Until this service bulletin is incorporated into the CMM, operators are allowed to disassemble, clean, check, repair, assemble, and test the unit according to the applicable CMM, using the new or modified part numbers or procedures in this bulletin.

After this service bulletin is incorporated into the CMM, the CMM procedures will supersede this bulletin.

B. Blade Angle Backlash Measurement

(1) Verify that the propeller is in full feather position.

NOTE: The propeller must be in full feather position before you begin the procedure.

(2) Rotate the propeller to put the blade to be measured in the six o'clock position.

WARNING: USE ISOPROPYL ALCOHOL, TT-I-735 OR ASTM D770, CORRECTLY. ISOPROPYL ALCOHOL IS FLAMMABLE, EXPLOSIVE, AND A MILD POISON. IT CAN HAVE A BAD EFFECT ON YOUR HEALTH OR SAFETY. BEFORE YOU USE THE ALCOHOL, GET THE MATERIAL SAFETY DATA SHEET FROM THE MANUFACTURER OR SUPPLIER OF THE MATERIAL AND READ IT CAREFULLY. READ THE DETAILED WARNING, W0046SE, IN THE WARNINGS REGISTRY SPM 20-00-04. BEFORE YOU USE THE ALCOHOL, PUT ON CHEMICAL-SPLASH GOGGLES. MAKE SURE THAT YOU HAVE SUFFICIENT AIRFLOW TO KEEP THE ALCOHOL FUMES BELOW THE MATERIAL SAFETY DATA SHEET LIMIT.

(3) Use isopropy alcohol, TT-I-735 or ASTM D770, to clean the local surface of the bulkhead.

(4) Apply a clean piece of masking tape, 4-6 inches (101.6-152.4 mm) in length, to the leading edge of the bulkhead (adjacent to the trailing edge of the spinner). Center the tape at the blade (refer to Figure 1).

(5) Twist the blade toward the feather position. Use two hands.

(6) Put a pencil flat against the face side of the blade, perpendicular to the masking tape surface. Put the tip of the pencil on the aft edge of the masking tape (refer to Figure 2).

NOTE: Keep a light twisting force on the blade toward the feather position with one hand while using the pencil.

(7) Make a mark on the masking tape by sliding the pencil along the face side of the blade from aft to forward (refer to Figure 3).

NOTE: Keep the pencil flat against the blade surface and perpendicular to the masking tape surface as you move it.

(8) Apply minimal force to twist the blade in the opposite direction, toward the reverse position. Use two hands.

NOTE: Apply only the force sufficient to take up the backlash between the blade trunnion bearing and the actuator yoke plate. If more twisting force is applied, it will cause the actuator to move and the blade angle to change.

(9) Put a pencil flat against the face side of the blade, perpendicular to the masking tape surface. Put the tip of the pencil on the aft edge of the masking tape (refer to Figure 2 for pencil position reference only).

NOTE: Keep a light twisting force on the blade toward the reverse position with one hand while using the pencil.

(10) Make a mark on the masking tape by sliding the pencil along the face side of the blade from aft to forward (refer to Figure 4).

NOTE: Keep the pencil flat against the blade surface and perpendicular to the masking tape surface as you move it.

(11) Measure and record the distance between the two reference lines on the masking tape at their most forward points (refer to Figure 5).

NOTE: Record the measured dimension in the Yoke Plate Damage Report (refer to APPENDIX A).

(12) If the measured distance is 0.38 inches (9.65 mm) or less, do steps 3.B.(2) through 3.B.(11) for the next blade.

NOTE: Do not rotate the propeller until steps 3.B.(2) through 3.B.(11) have been completed for the current blade.

NOTE: If the blade angle backlash measurement has been completed for all six blades, proceed to step 3.B.(14).

(13) If the measured distance is greater than 0.38 inches (9.65 mm), blade angle backlash measurements are complete. Proceed to paragraph 3.D. and do a dimensional inspection of the yoke plates.

(14) Review the measurements recorded in step 3.B.(11) for all six blades.

(a) If the measured distance is 0.38 inches (9.65 mm) or less for each of the six blades, the propeller may remain in service.

NOTE: Record all of the blade angle backlash measurement results and required information in the Yoke Plate Damage Report (refer to APPENDIX A). Send a copy of the report to the address or fax number shown on the last page of the report.

(b) If the measured distance is greater than 0.38 inches (9.65 mm) for one or more blades, do a dimensional inspection of the yoke plates (refer to paragraph 3.D.).

C. Blade Angle Backlash Measurement (Alternate Method)

(1) Verify that the propeller is in full feather position.

NOTE: The propeller must be in full feather position before you begin the procedure.

(2) Put the blade to be measured in the three or nine o'clock position.

(3) Twist the blade toward the feather position. Use two hands.

(4) Put a N.A.C.A. Type Universal Propeller Protractor, GS18217-1 or equivalent, along the 58.050-inch (1,474.470 mm) Station Reference Stripe of the blade.

NOTE: The blade angle template, GS23418-1, and the protractor and template holder, GS20834-1, are not required for this procedure.

NOTE: It is not necessary to adjust the protractor to zero against the propeller before doing the measurements in this procedure.

NOTE: Keep a light twisting force on the blade toward the feather position with one hand while using the protractor.

(5) Measure and record the blade angle.

(6) Apply minimal force to twist the blade in the opposite direction, toward the reverse position. Use two hands.

NOTE: Apply only the force sufficient to take up the backlash between the blade trunnion bearing and the actuator yoke plate. If more twisting force is applied, it will cause the actuator to move and the blade angle to change.

(7) Put the protractor along the 58.050-inch (1,474.470 mm) Station Reference Stripe of the blade.

NOTE: Keep a light twisting force on the blade toward the reverse position with one hand while using the protractor.

(8) Measure and record the blade angle.

(9) Calculate the difference between the blade angle measurements recorded in steps 3.C.(5) and 3.C.(8).

(10) Record the calculated difference in the Yoke Plate Damage Report (refer to APPENDIX A).

(11) If the difference between the blade angle measurements is 5.38 degrees or less, do steps 3.C.(2) through 3.C.(10) for the next blade. If all six blades have been measured, proceed to step 3.C.(13).

NOTE: Do not rotate the propeller until steps 3.C.(2) through 3.C.(10) have been completed for the current blade..

(12) If the difference between the blade angle measurements is greater than 5.38 degrees, blade angle backlash measurements are complete. Proceed to paragraph 3.D. and do a dimensional inspection of the yoke plates.

(13) Review the values recorded in step 3.C.(10) for all six blades.

(a) If the difference between the blade angle measurements is 5.38 degrees or less for each of the six blades, the propeller may remain in service.

NOTE: Record all of the calculated differences and required information in the Yoke Plate Damage Report (refer to APPENDIX A). Send a copy of the report to the address or fax number shown on the last page of the report.

(b) If the difference between the blade angle measurements is greater than 5.38 degrees for one or more blades, do a dimensional inspection of the yoke plates (refer to paragraph 3.D.).

D. Actuator Yoke Plate Dimensional Inspection

(1) Disassemble the propeller (-1 or -1A, IPL Figure 1, Section 61-10-00, MM P5206 or P5214) as necessary to remove the actuator assembly (330A, -330B, -330C, -330D, -330E, or -330F) (refer to MM P5206 or P5214, Section 61-10-00, DISASSEMBLY).

(2) Visually inspect the forward plate (190 or -190A, IPL Figure 5, CMM 61-13-12 or IPL Figure 6, Section 61-10-00, MM P5214) and the aft plate (220) for signs of bending.

(3) Measure the distance between the forward plate (190 or -190A) and the aft plate (220) at each of the six ears (refer to Figure 6).

NOTE: Measure the distance between the plates at the largest diameter (the outer edge).

NOTE: Do not measure across areas that are worn by contact with the blade bearings.

(4) Record the measured dimension at each of the six ears in the Yoke Plate Damage Report (refer to APPENDIX A).

(5) Do the following if the measured dimension at any of the six ears is greater than 1.631 inches (41.43 mm):

(a) Remove the actuator from service immediately.

(b) Remove all six blades of the propeller from service immediately.

(c) Record all of the inspection results and required information in the Yoke Plate Damage Report (refer to APPENDIX A). Send a copy of the report to the address or fax number shown on the last page of the report.

(d) Send the actuator and all six blades from the propeller for engineering investigation to the specified facilities, as follows:

1 Send the actuator to the Maastricht Repair Station [refer to paragraph 2.B.(2)].

2 Send the six blades to the Ratier-Figeac Service Station [refer to paragraph 2.B.(3)].

(6) Do the following if the measured dimension at each of the six ears is 1.631 inches (41.43 mm) or less:

(a) Record all of the inspection results and required information in the Yoke Plate Damage Report (refer to APPENDIX A). Send a copy of the report to the address or fax number shown on the last page of the report.

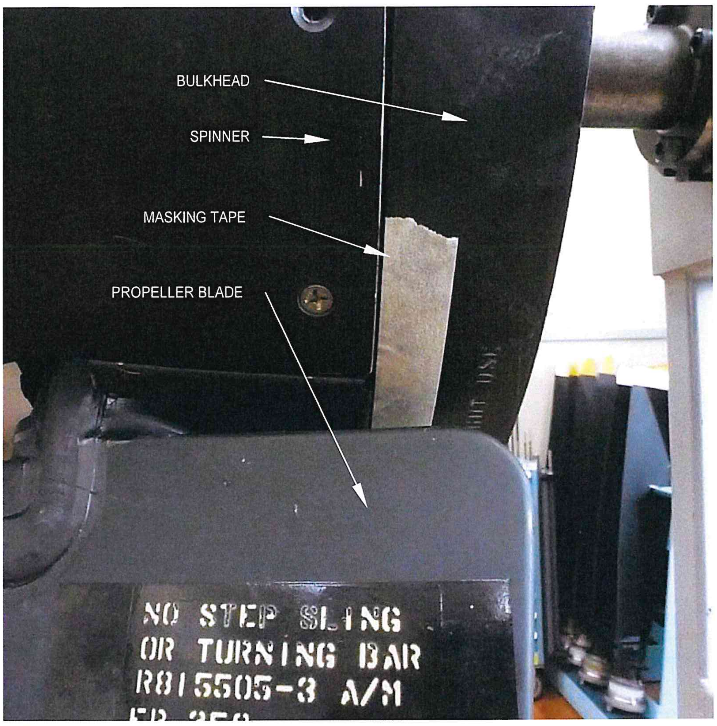
(b) Install the inspected actuator assembly (330A, -330B, -330C, -330D, -330E, or -330F, IPL Figure 1, Section 61-10-00, MM P5206 or P5214) in the propeller (-1 or -1A) (refer to MM P5206 or P5214, Section 61-10-00, ASSEMBLY).

(c) Assemble the propeller (-1 or -1A) (refer to MM P5206 or P5214, Section 61-10-00, ASSEMBLY).

UTC Aerospace Systems

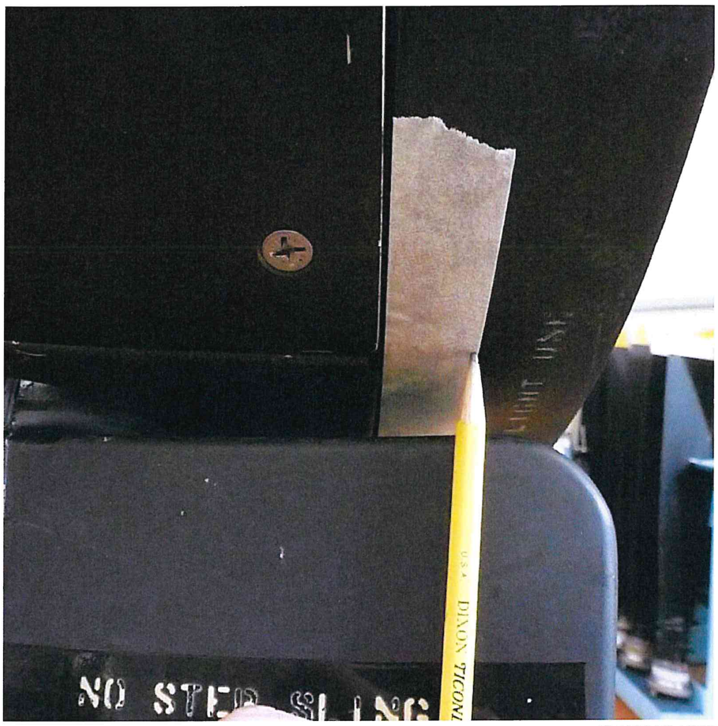
Hamilton Sundstrand Corporation, a UTC Aerospace Systems Company

SERVICE BULLETIN



SB-568F6167-118564

Figure 1
Application of Masking Tape to the Leading Edge of the Bulkhead



SB-568F6167-118565

Figure 2
Pencil Tip at Aft Edge of Masking Tape

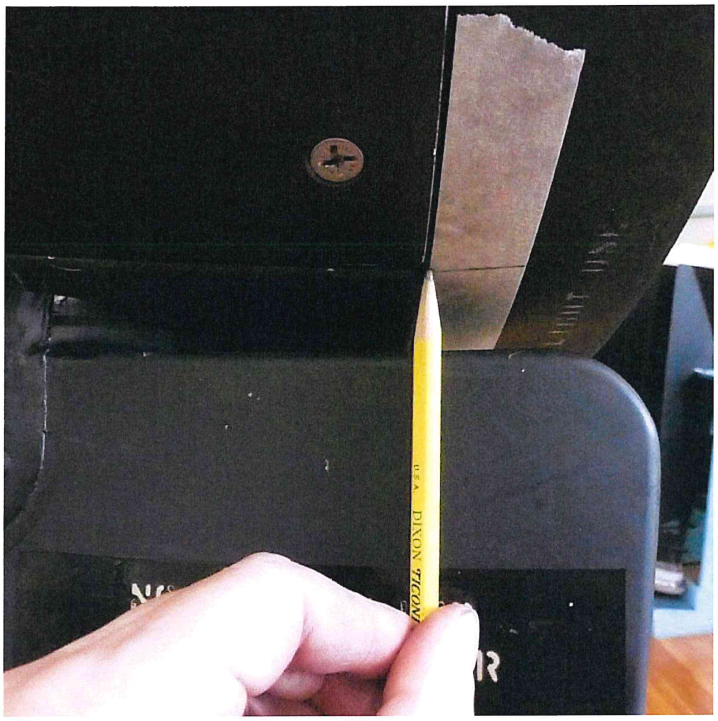
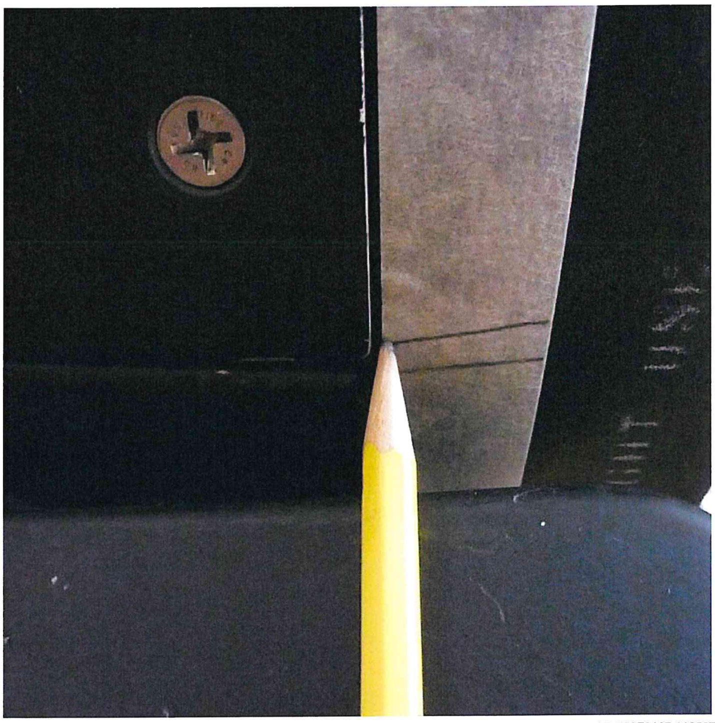

SB-568F6167-118566

Figure 3
Blade Angle Reference Line Marked on Masking Tape for the Full Feather Position



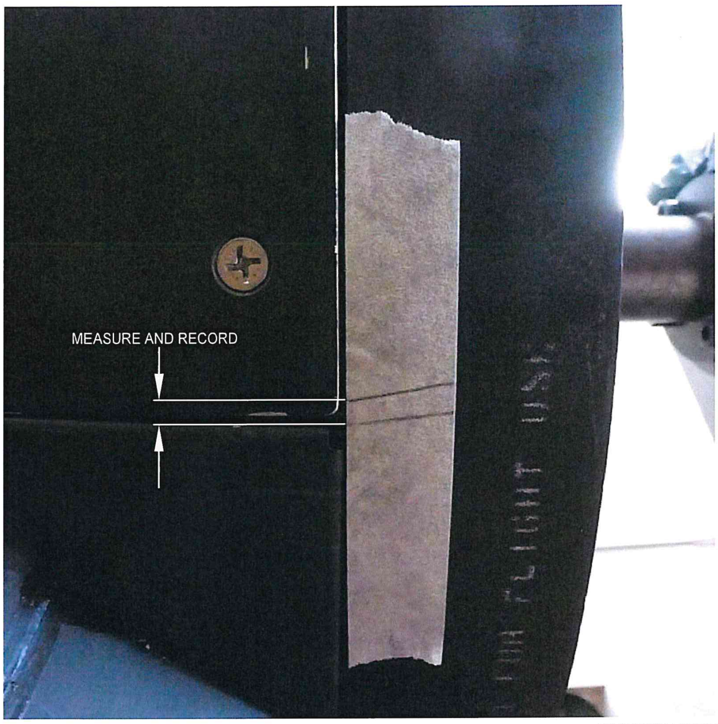
SB-568F6167-118567

Figure 4
Blade Angle Reference Line Marked on Masking Tape for the Reverse Position

UTC Aerospace Systems

Hamilton Sundstrand Corporation, a UTC Aerospace Systems Company

SERVICE BULLETIN



SB-568F6167-118568

Figure 5
Measurement Between Blade Angle Reference Lines at their Most Forward Points

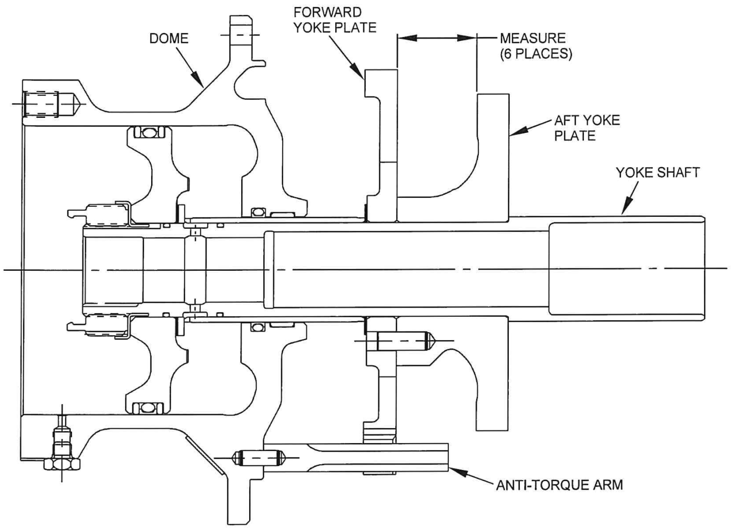


Figure 6
Measurement Between Ears of the Actuator Forward and Aft Yoke Plates

APPENDIX A - YOKE PLATE DAMAGE REPORT

1. Record the information required. Make sure that all characters are easy to read.

General Information

Date of Inspection: ________________
Operator: ____
Individual Submitting Report: ____________________ Location: ________________
Phone #: __________________
Fax #: __________________

Propeller Information

Propeller Model: ________ Serial Number: ____________ Part Number: ____________

Blade Serial Number: 1 ______________ Blade Part Number: 1 ______________
2 ______________ 2 ______________
3 ______________ 3 ______________
4 ______________ 4 ______________
5 ______________ 5 ______________
6 ______________ 6 ______________

Measurement Information

Blade Angle Backlash:

Distance between reference lines **OR** Difference between angles

Blade: 1 ______________ Blade: 1 ______________
2 ______________ 2 ______________
3 ______________ 3 ______________
4 ______________ 4 ______________
5 ______________ 5 ______________
6 ______________ 6 ______________

Distance between Ears of the Forward and Aft Yoke Plates:

At Yoke Ears for Blade: 1 ______________
2 ______________
3 ______________
4 ______________
5 ______________
6 ______________

NOTE: The Yoke Plate Damage Report continues on the page that follows.

Additional Information

Description of Visual Damage to Yoke Plates: ______________________________

Remarks: ______________________________

Reporting Requirements

Fax or mail a copy of this report to:

Propeller Technical Team
Mail Stop: 1A-3-Z63
One Hamilton Road
Windsor Locks, CT 06096 USA

Fax: (860) 654-5107

APPENDIX 18

BEA LETTER TO EASA
CONCERNING PROPELLER VIBRATIONS IN FLIGHT ON ATR AIRCRAFT

Liberté • Égalité • Fraternité
RÉPUBLIQUE FRANÇAISE

Ministère de l'Ecologie,
du Développement durable
et de l'Energie

BEA
Bureau d'Enquêtes et d'Analyses
pour la sécurité de l'aviation civile

Le Bourget, le 23 décembre 2014

Monsieur KY
Directeur exécutif
Agence Européenne de la Sécurité Aérienne
(AESA)
Ottoplatz, 1
D-50679 KOELN
ALLEMAGNE

N° 708/BEA/D

Objet. : Recommandations n° FRAN-2014-016 à 019
Vibrations d'hélice en vol sur avions ATR

Monsieur le Directeur exécutif,

Trois enquêtes de sécurité actuellement conduites par la France, l'Indonésie et la Suède concernent de fortes vibrations sur l'hélice droite d'avions ATR72-212A équipés d'hélices Hamilton Sundstrand, modèle 568F-1, fabriquées par UTAS.

Suite aux premiers résultats de ces enquêtes, le BEA adresse à votre organisation quatre recommandations de sécurité visant à limiter le risque de récurrence et les conséquences possibles de tels événements.

Vous les trouverez dans le texte annexé à la présente, en version anglaise.

Afin de faciliter leur traitement et leur diffusion interne, je vous joins une traduction de courtoisie en anglais de la présente.

Je vous saurais gré d'informer le BEA au plus tard le 23 mars 2015 des mesures préventives que vous avez prises ou que vous envisagez de prendre. Merci de bien vouloir rappeler dans votre réponse les numéros des recommandations concernées.

Je vous prie de croire, Monsieur le Directeur exécutif, à l'assurance de ma considération distinguée.

Le Directeur du Cabinet
PO
Luc ANGERAND

Le Directeur du BEA

Aéroport du Bourget
Zone Sud – Bâtiment 153
200 rue de Paris
93352 Le Bourget Cedex
France
Tél. : +33 1 49 92 72 00
Fax : +33 1 49 92 72 03
www.bea.aero

Pour communiquer avec le BEA sur ce sujet, veuillez utiliser l'adresse électronique :
reco@bea-fr.org

BEA

Attachment to letter n°708/BEA/D dated 23rd December 2014

On 18th September 2013, the ATR 72-212A MSN 985 registered PK-WFV encountered severe vibrations on engine #2 propeller during descent at a speed of 251 kt as the crew was moving power levers to the Flight Idle position. Vibrations persisted until the engine #2 was shut down after landing. The blade angle actuator forward plate was found bent and one blade was turning freely as its trunnion pin was broken. Two engine fittings were found broken.

On 4th May 2014, the ATR 72-212A MSN 989 registered 9Y-TTC encountered severe vibrations on engine #2 propeller during descent at a speed of 246 kt as the crew was moving power levers to the Flight Idle position. On 5th May 2014, right propeller vibrations were reported by the crew after landing. Propeller pitch change mechanism was found severely damaged after maintenance performed test runs on the ground. The blade angle actuator forward plate was found heavily bent and one blade was turning freely as its trunnion pin was broken.

On 30th November 2014, the ATR 72-212A MSN 822 registered SE-MDB encountered severe vibrations on engine #2 propeller. According to preliminary results, vibrations occurred during descent at a speed around 250 kt when power levers were in Flight Idle position. The crew reported that the level of vibrations made it impossible to read the instruments. Vibrations ceased when the engine #2 was shut down in flight. After landing, the blade angle actuator forward plate was found heavily bent and one blade was turning freely as its trunnion pin was broken. Damages were observed on the engine's compressor housing and on some engine shock mounts.

At least three other incidents, not investigated by a safety investigation authority, that led to vibrations and propeller pitch change mechanism damages have occurred on ATR equipped with 568F-1 propellers since 2012:

- On 4th April 2012 to the ATR 72-212A MSN 880 registered 5H-PWD. The flight crew moved the power levers to Flight Idle position at a speed of 247 kt, but the precise moment the vibrations started could not be determined.

- On 7th January 2013 to the ATR 72-212A MSN 926 registered PR-TKA. Vibrations occurred at 258 kt when crew moved power levers to Flight Idle position.

- On 27th August 2013 to the ATR 72-212A MSN 923 registered 5H-PWG. The FDR data was not preserved.

The six aircraft involved in these events were all equipped with Hamilton Sundstrand Propellers, model 568F-1, manufactured by UTAS.

A Service Bulletin (ref SB568F-61-67) was issued by UTAS on 2nd October 2014. An Operators Information Message (ref OIM 2014/010 Issue 1) was issued by ATR on 23rd September 2014. Both documents are applicable to all ATR aircraft operating with Hamilton Sundstrand 568F-1 propellers.

Extensive analysis, research, test and design work have been carried out. However, the root cause of these events has not been determined yet.

All events have occurred on the right engine propeller and when it has been possible to determine the moment the vibrations started, they appeared during descent at a speed close or above VMO (250 kt) with power levers in Flight Idle position.

Improving the flight crew awareness of the conditions that have led to these vibrations might limit the risk of recurrence of such events.

Consequently, the BEA recommends that:

- **EASA takes the necessary actions in order to ensure that all pilots operating ATR equipped with Hamilton Sundstrand Propellers, model 568F-1, are informed that severe vibrations have occurred during descent at a speed close to VMO with power levers in Flight Idle position and that heavy damages to the propeller pitch change mechanism and, in one case, to engine fittings were observed. [Recommendation FRAN-2014-016]**

- **EASA takes the necessary actions in order to ensure that all pilots operating ATR equipped with Hamilton Sundstrand Propellers, model 568F-1, plan and operate their flights to avoid operations close to VMO at Flight Idle. [Recommendation FRAN-2014-017]**

- **EASA takes the necessary actions in order to ensure that all pilots operating ATR equipped with Hamilton Sundstrand Propellers, model 568F-1, report to maintenance if they experience severe vibrations during descent at a speed close to VMO with power levers in Flight Idle position. [Recommendation FRAN-2014-018]**

The operational documentation of airlines operating ATR aircraft equipped with Hamilton Sundstrand Propellers, model 568F-1, does not contain any procedure in case of severe vibration of a propeller. Consequently, the BEA recommends that:

- **EASA takes the necessary actions in order to ensure that ATR develops an appropriate operational procedure addressing severe vibrations of a propeller and that airlines operating ATR equipped with Hamilton Sundstrand Propellers, model 568F-1, include that procedure in their operational documentation.[Recommendation FRAN-2014-019]**

APPENDIX 19

EASA SAFETY INFORMATION BULLETIN

EASA SIB No: 2015-03

EASA Safety Information Bulletin

SIB No.: **2015-03**
Issued: **30 January 2015**

Subject: **ATR 42-400, 42-500 and 72-212A aeroplanes - Propeller / Engine Vibrations In Flight**

Ref. Publications: ATR Operators Information Message (OIM), ref : 2014/10 Issue 1, dated 23/09/2014;
- UTC Aerospace Systems Service Bulletin (SB) 568F-61-67, dated 02 October 2014;
- ATR Flight Crew Operational Manual (FCOM) – Section 3-07 'Descent – Approach';
- ATR FCOM – Section 3-09 'One engine inoperative';
- ATR Aircraft Flight Manual (AFM) – Section 5-03 'Flying with one engine inoperative'.

Applicability: ATR 42-400, 42-500 and 72-212A aeroplanes, equipped with Hamilton Sundstrand model 568F-1 propellers.

Description: EASA, by means of this Safety Information Bulletin (SIB), informs registered owners/operators of ATR 42-400, 42-500 and 72-212A aeroplanes (as defined through Type Certificate Data Sheet EASA.A.084) of an airworthiness concern.

In-service events have been reported, featuring damages on propeller pitch change mechanism (blade trunnion pin broken or cracked, actuator forward yoke plate bent and damaged).

Those occurrences were associated with sudden and severe propeller vibrations during the descent performed at a speed close to VMO (Velocity Maximum Operation) with power levers in Flight Idle position, often associated with PEC (Propeller Electronic Control) faults message (Code 67 & 68) found upon subsequent maintenance troubleshooting.

Based on the available information, EASA considers that improving crew awareness about this type of vibration event will allow a better and prompt identification of the issue and the application of conservative measures.

At this time, the safety concern described in this SIB is not considered to be an unsafe condition that would warrant Airworthiness Directive (AD) action under EU 748/2012, Part 21.A.3B.

This is information only. Recommendations are not mandatory.

Recommendation(s): As preventive measures to limit the risk of occurrence of such phenomenon, EASA recommends the following:

1- Operators of aeroplanes as defined in the Applicability of this SIB should follow as much as possible the aeroplane manufacturer recommendation for a standard descent speed at maximum 240 knots (refer to ATR FCOM – Section 3.07). If, for any reason, during descent the speed becomes close to VMO and the power levers have to be reduced to 'flight idle' position, a smooth and progressive reduction of the power levers should be accomplished.

2- Despite this recommended speed, should an operator anyway encounter the described phenomenon during descent, the crew should try to discriminate and shut down the affected engine, carrying-on operations with one engine operative (refer to ATR AFM – Section 5.03 and FCOM – Section 3-09).

3- In case of any difficulty to discriminate and shut down the affected engine, the crew should avoid using 'reverse' mode on engines.

4- Because the on-going investigation evidenced that prior to the flights during which the propeller pitch change mechanisms were severely damaged, sudden and unusual vibration, for a short duration, were sometimes reported by pilots during the descent with airspeed close to VMO, when they reduced PLA to FI position, pilots operating aeroplanes as defined in the Applicability of this SIB should report any sudden and unusual vibration encountered during descent or approach to their maintenance organisation.

5- Operators of aeroplanes as defined in the Applicability of this SIB should consider the recent publications issued by ATR, and UTC Aerospace Systems, providing operators with guidelines for troubleshooting:

- ATR Operators Information Message (OIM), ref : 2014/10 Issue 1, dated 23/09/2014.

- UTC Aerospace Systems Service Bulletin (SB), ref : 568F-61-67, dated 02/10/2014

<u>and</u> to report to ATR, the aeroplane manufacturer, whenever exposed to the symptoms mentioned in the "Description" section of this SIB.

Contact(s): For further information contact the Safety Information Section, Certification Directorate, EASA. E-mail: ADs@easa.europa.eu.

For any question concerning the technical content of the recommendations in this SIB, please contact:
ATR - GIE Avions de Transport Régional,
Continued Airworthiness Service,
Tel.: +33 (0)5 62 21 62 21 - Fax: +33 (0) 5 62 21 67 18
E-mail: continued.airworthiness@atr.fr.

This is information only. Recommendations are not mandatory.

APPENDIX 20

ATR ALL OPERATORS MESSAGE

ATR

ALL OPERATORS MESSAGE

Date: 23 February 2015 Ref AOM: 42/72/2015/01 issue 1

This AOM is for information only and does not give instructions to Operators. It advises Operators of matters, which are currently, either under investigation or dealt with by ATR. However, Operators may consider initiating their own action. This AOM may be re-issued to inform Operators of the closing action (Service Bulletin, No action required, etc…).

Aircraft model: ATR 42-400, 42 -500 & 72-212A ATA: 61

SUBJECT: Severe vibration due to propeller blade pitch change mechanism damage

REASON

The aim of this AOM is to inform ATR operators about occurrences of sudden appearance of severe vibration in flight which were due to propeller blade pitch change mechanism damage.

DESCRIPTION

Over the last two years, ATR has received reports of severe vibration in flight that were due to propeller blade pitch change mechanism damage on ATR aircraft models equipped with the 568F-1 propeller.

All these occurrences were reported while the aircraft was in descent phase, with high airspeed (at or close to VMO), while Power Levers (PLs) were reduced to Flight Idle (FI).

The encountered severe vibration was due to the rupture of one blade trunnion pin and lasted until the shut down of affected engine. During one event, the affected engine was not shut down and reverse was used during the landing roll. For this event significant damage was found at the level of engine fittings. In most of the reported cases, the propeller forward yoke plate was found significantly deformed.

So far the event described in this AOM has only been observed on RH engine but the investigation did not evidence any findings which could explain this fact. Therefore it cannot be excluded that a similar event occurs on LH engine.

Investigations are on-going, involving UTAS, ATR and investigation authorities working on establishing the root cause of this issue and any potential corrective action.

For a few occurrences, the investigation evidenced that unusual and sudden vibrations, lasting a few seconds, were sometimes reported by pilots, on the same aircraft, over the months that preceded the events. Each time, these brief vibrations were experienced in descent, at high speed, when reducing PLs to FI and disappeared when advancing PLs slightly above FI. When combined to a PEC Fault (with codes 67 &68), these brief vibrations, could be associated to a forward yoke plate deformation.

ACTION

Maintenance instructions and information have been provided by ATR and UTAS to all relevant operators for specific troubleshooting to be performed whenever a pilot reports having experienced unusual and sudden vibration during descent phase at high airspeed (at or close to VMO) when reducing PLs to FI. These instructions and information are available through the following documents:

- ATR Operators Information Message (OIM) 2014/10 issue 1
- UTAS Service Bulletin (SB) 568F-61-67

In order to ensure that pilots are properly informed about these occurrences and to guide them in the identification of the affected engine, should they encounter a similar occurrence, ATR has issued the Operation Engineering Bulletin (OEB) n° 25 (see attachment 2 hereto).

The EASA has issued the Safety Information Bulletin (SIB) N° 2015-03 (here attached) to inform operators of ATR 42-400, 42-500 and 72-212A about these occurrences and to provide operational and maintenance recommendations.

RECOMMENDATION

ATR recommends to operators of ATR models 42-400, 42-500 and 72-212A, to ensure that pilots are properly informed about this type of occurrences and report any unusual and sudden vibrations similar to the ones described in this AOM.

ATR also recommends that the OEB be inserted in the on-board operational documentation and be made readily available to all pilots.

As to maintenance actions, ATR recommends that UTAS SB 568F-61-67 be performed each time a pilot reports unusual vibration in descent, associated to a PEC Fault (with codes 67 & 68).

REFERENCE DOCUMENTS

- EASA SIB 2015-03 (attachment 1)
- ATR OEB n°25 (attachment 2)
- UTAS SB 568F-61-67
- OIM 2014/10 issue 1

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APPENDIX 21

ATR OPERATION ENGINEERING BULLETIN

SUBJECT: OEB n°25: Propeller blade pitch change mechanism damage.

1 - Reason for issue.

This OEB is issued to inform and provide operators with operational recommendations about in-service events of sudden and high powerplant vibrations resulting from mechanical damages on the propellers.

TYPICAL EVENT DESCRIPTION:
Investigations showed that all the reported events occurred in the following context:
-On engine 2
-During descent at high speed (close to VMO)
-When reducing PL towards FI

Subsequent associated symptoms:
-Sudden and high powerplant vibrations
-Abnormal powerplant parameters
-Transient or steady alerts (PEC or ACW Faults)

2 - ATR action.

Investigations are in progress to identify the root cause of the reported events and define appropriate corrective actions.

3 - Procedure.

Even if all the reported cases occurred on engine 2, the recommended procedure aims at confirming/identifying the affected engine first and then to shut it down.
The identification of the affected engine can be performed thanks to engine parameters fluctuations monitoring or alerts displayed on one side.
However, the identification may be less obvious depending on the damages and the level of vibrations. In this case, the following procedure will request to perform Power Lever and Propeller speed variations on one engine at a time and to assess which engine makes vibrations change (increase or decrease).

In any case, every vibration occurrence is to be reported to maintenance.

If the power levers has to be reduced to flight idle position during descent at high speed (close to VMO), it is recommended to perform a smooth and progressive power levers reduction.

IN CASE OF SUDDEN AND HIGH VIBRATIONS:

ICING CONDITIONS..CHECK
Unbalanced blade icing may also generate propeller vibrations.
In this case refer to:
-QRH 3.21 AT FIRST INDICATION OF ICE ACCRETION procedure, or
-QRH 1.09 SEVERE ICING procedure

ENG PARAMETERS ....CHECK
Check for any fluctuations of powerplant parameters that may indicate the affected engine, mainly TQ and Np. Check also for transient or steady alerts (PEC, ACW faults or any other alerts) that may be associated with powerplant vibrations and indicate the affected engine.
If affected engine cannot be identified via engine parameters, flight crew should move one PL at a time: it may help to determine the affected side, as the vibrations level and frequency may change with PL position.

- **IF AFFECTED ENGINE IS IDENTIFIED**

PL affected eng...FI
CL affected eng...FTR THEN FUEL SO
LAND ASAP
SINGLE ENG OPERATION procedure (2.04)....APPLY

- **IF AFFECTED ENGINE CANNOT BE IDENTIFIED**

PL 2 ....FI
CL 2...FTR

  - **IF VIBRATIONS SIGNIFICANTLY CHANGE**

    Engine 2 failure is suspected and should be shut down
    CL 2...FUEL SO
    LAND ASAP
    SINGLE ENG OPERATION procedure (2.04).............APPLY

  - **IF VIBRATIONS PERSIST**

    Restore engine 2 and same check repeated on engine 1
    CL 2 ....AUTO
    PL 2 ....AS RQRD
    PL 1 ....FI
    CL 1 ....FTR

    - **IF VIBRATIONS SIGNIFICANTLY CHANGE**

      Engine 1 failure is suspected and should be shut down
      CL 1...FUEL SO
      LAND ASAP
      SINGLE ENG OPERATION procedure (2.04)..................APPLY

APPENDIX 22

FAA SPECIAL AIRWORTHINESS INFORMATION BULLETIN

FAA
Aviation Safety

SPECIAL AIRWORTHINESS INFORMATION BULLETIN

SAIB: NM-15-14
SUBJ: Propellers/Propulsors **Date:** April 20, 2015

This is information only. Recommendations aren't mandatory.

Introduction

This Special Airworthiness Information Bulletin advises owners and operators of **ATR – GIE Avions de Transport Régional** Model **ATR42-500 and ATR72-212A airplanes equipped with Hamilton Sundstrand Model 568F-1 propellers** of sudden and severe propeller vibrations during descent or approach phases.

At this time, the airworthiness concern is not an unsafe condition that would warrant an FAA airworthiness directive (AD) action under Title 14 of the Code of Federal Regulations (14 CFR) part 39.

Background

The European Aviation Safety Agency (EASA), which is the Technical Agent for the Member States of the European Union, has issued Safety Information Bulletin (SIB) 2015-03, dated January 30, 2015. The SIB provides information on incidents, found during maintenance troubleshooting, of sudden and severe propeller vibrations during the descent performed at a speed close to Velocity, Maximum Operation (VMO) with power levers in Flight Idle position, associated with Propeller Electronic Control (PEC) fault messages (Code 67 & 68). Based on these incidents, EASA issued the SIB to improve crew awareness and allow better and timely identification of this type of vibration, in order to apply appropriate actions.

Recommendations

The FAA recommends that all owners and operators of the airplanes identified above follow the instructions outlined in ATR Operators Information Message (OIM) 2014/10, Issue 1, dated September 23, 2014; and UTC Aerospace Systems Service Bulletin 568F-61-67, dated October 2, 2014. The instructions include measuring the blade angle backlash on all six blades of the 568F-1 propeller; and removing the actuator and measuring the distance between the ears of the actuator forward and aft yoke plates, if necessary. The instructions also provide guidelines to follow if sudden and severe propeller vibrations occur.

We request that owners and operators report any damage found on the propeller pitch change mechanism (blade trunnion pin broken or cracked, actuator forward yoke plate bent or damaged) to ATR - GIE Avions de Transport Régional, as specified under "Related Service Information Contact" below. Under the provisions of the Paperwork Reduction Act (44 U.S.C. 3501 et seq.), the Office of Management and Budget (OMB) has approved the information collection contained in this SAIB, and assigned OMB Control Number 2120-0731.

APPENDIX 23

REVISION OF THE EASA SAFETY INFORMATION BULLETIN

EASA SIB No.: 2015-03R1

EASA European Aviation Safety Agency

Safety Information Bulletin

Airworthiness

SIB No.: 2015-03R1

Issued: 19 January 2016

Subject: ATR 42-400, 42-500 and 72-212A aeroplanes - Propeller / Engine Vibrations In Flight

Ref. Publications:

- ATR Operators Information Message (OIM), ref: 2014/10 Issue 1, dated 23/09/2014;
- UTC Aerospace Systems Service Bulletin (SB) 568F-61-67, dated 02 October 2014;
- ATR All Operators Message (AOM) ref : 42/72/2015/01 Issue 1;
- ATR Operation Engineering Bulletin (OEB) No 25;
- ATR Flight Crew Operational Manual (FCOM) – Section 3-07 'Descent – Approach';
- ATR FCOM – Section 2-04 'In Flight Engine Fire or severe mechanical damage' and Section 3-09 'One engine inoperative';
- ATR Aircraft Flight Manual (AFM) – Section 5-03 'Flying with one engine inoperative'.

Applicability:

ATR 42-400, 42-500 and 72-212A aeroplanes, equipped with Hamilton Sundstrand model 568F-1 propellers.

Description:

EASA, by means of this Safety Information Bulletin (SIB), informs registered owners/operators of ATR 42-400, 42-500 and 72-212A aeroplanes (as defined through Type Certificate Data Sheet EASA.A.084) of an airworthiness concern.

In-service events have been reported, featuring damages on propeller pitch change mechanism (blade trunnion pin broken or cracked, actuator forward yoke plate bent and damaged).

Those occurrences were associated with sudden and severe propeller vibrations during the descent performed at a speed close to VMO (Velocity Maximum Operation) with power levers in Flight Idle position, often associated with PEC (Propeller Electronic Control) faults message (Code 67 & 68) found upon subsequent maintenance troubleshooting.

Based on the available information, EASA considers that improving crew awareness about this type of vibration event will allow a better and prompt identification of the issue and the application of conservative measures.

This SIB is revised to update references included in the Ref. Publication section and to specify the action recommended after experiencing a propeller / engine vibration.

This is information only. Recommendations are not mandatory.

At this time, the safety concern described in this SIB is not considered to be an unsafe condition that would warrant Airworthiness Directive (AD) action under Regulation (EU) 748/2012, Part 21.A.3B.

Recommendation(s):
As preventive measures to limit the risk of occurrence of such phenomenon, EASA recommends the following:

(1) Operators flying aeroplanes as defined in the Applicability of this SIB should follow as much as possible the aeroplane manufacturer recommendation for a standard descent speed at maximum 240 knots (refer to ATR FCOM – Section 3.07). If, for any reason, during descent the speed becomes close to VMO and the power levers have to be reduced to 'flight idle' position, a smooth and progressive reduction of the power levers should be accomplished.

(2) Despite this recommended speed, should an operator anyway encounter the described phenomenon during descent, the crew should try to discriminate and shut down the affected engine by applying the procedure described through the section 3 of the ATR OEB No 25 (refer to ATR AOM ref : 42/72/2015/01 issue 1 - Attachment 2) and continue to accomplish the flight with one engine operative (refer to ATR AFM – Section 5.03 and FCOM – Section 3-09).

(3) In case of any difficulty to discriminate and shut down the affected engine, the crew should avoid using 'reverse' mode on engines.

(4) Because the on-going investigation evidenced that prior to the flights during which the propeller pitch change mechanisms were severely damaged, sudden and unusual vibration, for a short duration, were sometimes reported by pilots during the descent with airspeed close to VMO, when they reduced PLA to FI position, pilots operating aeroplanes as defined in the Applicability of this SIB should report any sudden and unusual vibration encountered during descent or approach to their maintenance organisation.

(5) Operators of aeroplanes as defined in the Applicability of this SIB should consider the recent publications issued by ATR, and UTC Aerospace Systems, providing operators with guidelines for troubleshooting :
    - ATR Operators Information Message (OIM), ref : 2014/10 Issue 1, dated 23/09/2014.
    - UTC Aerospace Systems Service Bulletin (SB), ref : 568F-61-67, dated 02/10/2014

    and to report to ATR, the aeroplane manufacturer, whenever exposed to the symptoms mentioned in the Description section of this SIB.

Contact(s):
For further information contact the EASA Safety Information Section, Certification Directorate. E-mail: ADs@easa.europa.eu.

For any question concerning the technical content of the recommendations in this SIB, please contact:
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APPENDIX 24

LATEST ATR ALL OPERATORS MESSAGE
AND UTAS SERVICE BULLETIN

ATR

ALL OPERATORS MESSAGE

Date: 26 October 2015 | Ref. AOM: 42/72/2015/01 issue 2

This AOM is for information only and does not give instructions to Operators. It advises Operators of matters, which are currently, either under investigation or dealt with by ATR. However, Operators may consider initiating their own action. This AOM may be reissued to inform Operators of the closing action (Service Bulletin, No action required, etc…).

Aircraft model: ATR 42-400, 42 -500 & 72-212A **ATA: 61**

SUBJECT: Severe vibration due to propeller blade pitch change mechanism damage

REASON

The aim of this AOM is to inform ATR operators about occurrences of sudden appearance of severe vibration in flight that were due to propeller blade pitch change mechanism damage.

This AOM is updated to add reference to the design improvement developed by UTAS to reduce the friction at blade retention bearing level.

DESCRIPTION

Over the last three years, ATR has received six reports of severe vibration in flight that were due to propeller blade pitch change mechanism damage on ATR aircraft models equipped with the 568F-1 propeller.

All these occurrences were reported while the aircraft was in descent phase, with high airspeed (at or close to VMO), while Power Levers (PLs) were reduced to Flight Idle (FI).

The encountered severe vibration was due to the rupture of one blade trunnion pin and lasted until the shutdown of affected engine. During one event, the affected engine was not shut down and reverse were used during the landing roll. For this event significant damage was found at the level of engine fittings. In most of the reported cases, the propeller forward yoke plate was found significantly deformed.

So far the event described in this AOM has only been observed on RH engine but the investigation did not evidence any findings that could explain this fact. Therefore it cannot be excluded that a similar event occurs on LH engine.

Investigations are on-going, involving ATR, UTAS and investigation authorities working on establishing what are the factors at the origin of these events and how to correct them.

For a few occurrences, the investigation evidenced that unusual and sudden vibration, lasting a few seconds, were sometimes reported by pilots, on the same aircraft, over the months that preceded the events. Each time, these brief vibrations were experienced in descent, at high speed, when reducing PLs to FI and disappeared when advancing PLs slightly above FI. When combined to a PEC Fault (with codes 67 & 68), these brief vibrations, could be associated to a forward yoke plate deformation.

ACTION

Maintenance instructions and information have been provided by ATR and UTAS to all concerned operators for specific troubleshooting to be performed whenever a pilot reports having experienced unusual and sudden vibration during descent phase at high airspeed (at or close to VMO) when reducing PLs to FI. These instructions and information are available through following documents:

- ATR Operators Information Message (OIM) 2014/10 issue 1
- UTAS Service Bulletin (SB) 568F-61-67

UTAS has identified the "ball bunching" scenario as a potential contributor as this phenomenon can generate higher friction in the retention bearing when commanding a blade pitch change. The level of additional friction generated via this phenomenon has been further assessed through flight test. Even though the loads resulting from this phenomenon are not significant enough to explain the yoke plate bending and trunnion pin rupture, UTAS has developed a new ball separator that reduces friction loads. Further information and instructions to replace the ball separator are available through following documents :

- ATR Operators Information Message (OIM) 2015/09 issue 1
- UTAS Service Bulletin (SB) 568F-61-69

In order to ensure that pilots are properly informed about these occurrences and to guide them in the identification of affected engine, should they encounter a similar occurrence, ATR has issued the Operation Engineering Bulletin (OEB) n° 25 (here attached).

The EASA has issued the Safety Information Bulletin (SIB) N° 2015-03 to inform operators of ATR 42-400, 42-500 and 72-212A about these occurrences and to provide operational and maintenance recommendations.

RECOMMENDATION

ATR recommends to operators of ATR models 42-400, 42-500 and 72-212A, to ensure that pilots are properly informed about this type of occurrences and will report any unusual and sudden vibrations similar to the ones described in this AOM.

ATR also recommends that the OEB be inserted in the on board operational documentation and be made readily available to all pilots.

As to maintenance actions, ATR recommends that UTAS SB 568F-61-67 be performed each time a pilot reports unusual vibration in descent, associated to a PEC Fault (with codes 67 & 68) and to replace the ball bearing separator at first maintenance opportunity according to the instructions of the UTAS SB 568F-61-69.

ATR recommends that UTAS SB 568F-61-69 be performed at the first opportunity

REFERENCE DOCUMENTS

- EASA SIB 2015-03
- ATR OEB n°25
- OIM 2014/10 Issue 1
- OIM 2015.09 Issue 1
- UTAS SB 568F-61-67
- UTAS SB 568F-61-69

ATTACHED DOCUMENTS

- UTAS SB 568F-61-69

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Collins Aerospace
A United Technologies Company

PropS21-0008
Page **2** of **5**

Items Resulting from the Translation Process

Collins Aerospace believes the following statements in the English Language version of the report are inaccurate as the result of the translation process from French to English. Alternative wording for the statements is presented for each statement. The BEA could consider incorporating the revised wording into the body of the report or making it part of the proposed appendix.

1. **Section 1.2.7, Comparative study on page 18, states** *"The cracks or fracture faces present on certain trunnion pins were characteristic of substantial cyclic loads in two opposite directions. These loads were generated during interactions between the forward and aft yoke plates"*

   The underlined portion of the statement implies that the forward and aft yoke plates are interacting. "*Interactions with the forward and aft yoke plates*" is a more appropriate statement. Also the metallurgical analysis performed by Collins Aerospace indicated the primary failure mechanism for the fractured blade pin was dimpled rupture due to overload, not cyclic stress. Indications were observed on the other five blade pins that did not fail, consistent with cyclic loading resulting from contact with both the forward and aft yoke plates

2. **Section 1.5.4.7, Propeller Blades on page 24** states that *"the propeller blades are attached to the propeller hub by two roller bearings located at the blade root".*

   The 568F propeller blades are actually retained in the hub with two rows of angular contact ball bearings located at the blade root.

3. **Section 2.2.2.1, Particular Types of Propeller Behavior, Forward Yoke Plate Cyclic Loading, on page 66** states *"It is important to mention that during these forward yoke plate cyclic loading phenomena, a substantial load factor was observed. As the design of the propeller pitch change mechanism was based on static and cyclic loads and not on vibration stresses, it is not possible to estimate the effects of this on the material from which the yoke plates and trunnion pins are made."*

   Collins Aerospace believes that the word substantial overstates the magnitude of the cyclic loading phenomenon that was observed during the vibratory stress survey flight test. The cyclic stresses that occurred as the result of the blade pin moving between the forward and aft yoke plates were well within the high cycle fatigue material allowable. It is recommended that the wording "a *load was evident, but not of a magnitude that would cause fatigue damage*" replace "*a substantial load factor was observed*".

Items of Disagreement between the BEA and Collins that were not Resolved during the Report Review Process

Collins Aerospace had previously objected to the following statements in the report. These objections were documented in the comments spreadsheet along with Collins rationale for the objections. However, agreement could not be reached with the BEA on these items. Therefore, Collins believes it is appropriate that our perspective be recorded in an appendix to the report.

1. **The Synopsis section on page 8 of the report (and other paragraphs)** states that "*unplanned operation of the control loop of the propeller pitch change mechanism affected by forward yoke plate cyclic loading and friction*" may have contributed to the alternating overloads that damaged the yoke plates and overloaded the trunnion pins.

   Collins Aerospace has objected to this assertion since it was originally raised by the BEA. The investigation found no evidence that the propeller control system contributed to damaging the yoke plates and trunnion pins. Collins is not aware that either EASA or the FAA is considering any actions related to the 568F-1 propeller control system as part of the safety recommendations process, where this disagreement could be resolved. Collins Aerospace previously took exception to this statement in comment (UTAS_30) provided to the BEA by T. Corley in an E-mail dated 1/10/2019 before the BEA issued the final report.

   The statement excludes factual information previously provided to the BEA that the bandwidth of the propeller control system is in the range of 2.0 Hz to 3.0 Hz. None of the strain gage data collected during the two vibratory stress surveys conducted to investigate this phenomenon revealed any significant cyclic loading in this frequency range. Also excluded was information provided by Collins Aerospace that the propeller pitch change system is incapable of responding at the 1P frequencies observed for the blade pin load and blade shank bending moment data (16.4 Hz to 20.0 Hz).

2. **Section 2.2.2.1 Particular types of propeller behavior, Propeller pitch change mechanism control loop (pg. 67)** states **"***The severe vibrations which cause the pitch change actuator to move are such that the signals sent by the actuator position sensors are considered in turn as valid and then not valid (as outside tolerances) by the PEC. When the PEC no longer receives a valid signal regarding the actual position of the actuator, which it uses to calculate the propeller pitch angle, it nevertheless continues to send hydraulic pressure set points to the electrohydraulic valve in order to maintain a constant propeller rotation speed (82 % Np), but using predefined values. Each time the state of the actuator position signal changes (valid/not valid), the PEC status changes from normal to degraded"*

   The description of the PEC control algorithm is incorrect. The speed governing control algorithm used by the PEC inflight does not reference sensed blade angle. Blade pitch during governing is only controlled as a function of sensed propeller speed, which was not faulted. There is no reference to a pre-defined value of blade angle for speed governing control in the PEC software. Therefore, normal PEC speed governing was not disrupted, even though the PEC light was illuminated in the cockpit. Collins' objection to this statement was previously documented in spreadsheet comment (UTAS_029).

3. **Section 2.2.2.1, Particular types of propeller behavior, Propeller pitch change mechanism control loop (pg. 67)** states "*The vibration frequency caused by the six propeller blades (6P, i.e. 98.4 Hz at 82 % Np) is close to the minimum design frequency of the PEC output current (87.4 Hz). The sampling of the actuator position values is, therefore, not sufficient to ensure optimum operation of the PEC. The latter could send controls which are out of phase with the actuator oscillations and accentuate them."*

   Collins is confident that the sampling rate of blade angle neither hinders the performance of the control system nor contributes to behavior that may have caused high cyclic pin stresses. There is no need for the control system to respond to inputs at the blade excitation frequency, as they have nothing to do with propeller speed control. Even if 6P frequency content is detected by motion of the transfer tube, the PEC is not controlling blade angle based on transfer tube position in the governing mode of operation. There is no correlation between the blade excitation frequency and the command current frequency required for proper control. Collins' position was previously documented in spreadsheet comment (UTAS_030).

4. **Section 2.2.3.3, Maintenance Procedures (page 71)** states **"***In October 2014, ATR published a specific maintenance procedure to prevent an airplane, which may have a significantly damaged propeller pitch change mechanism from being returned to flight. It is carried out according to the content of the air safety reports (severe vibrations associated with the appearance of a PEC FAULT warning) and fault codes in the PEC memory. It consists of a manual check for possible significant deformation of the actuator yoke plates. However, this procedure depends on the pilot's subjective assessment of the intensity of the vibrations felt and does not permit the detection of the onset of deformation of the yoke plates or damage without rupture of the blade trunnion pin"*

   The procedure discussed above is intended to be conducted per Service Bulletin 568F-61-67 when a PEC fault occurs that is accompanied by a noticeable increase in vibration. The PEC fault is an objective criterion. All of the incident flights for which Collins has DFDR data exhibited PEC faults. Therefore, the crew's subjective judgment of the magnitude of the vibration is not critical to effectively applying the service bulletin. Data indicates that the Caribbean aircraft experienced high vibration accompanied by a PEC fault during a flight prior to rupture of the blade pin. Deformation of the yoke plates likely was sufficient to cause the vibration and PEC fault. If the Service Bulletin would have been performed in this case the damage to the yoke plates would have been detected before the pin broke.

   Section 3.2, Investigation's findings regarding all propeller vibration events (8th bullet) states "*The existence of an abnormal gap between the two yoke plates of the propeller pitch change mechanism can cause severe damage in flight to the pitch change mechanism."*

   Although the BEA made changes to this section in response to comment (UTAS_32) to separate the presence of an abnormal gap between the forward and aft yoke plates from the incident where damage to the engine mounts occurred, the implication that the abnormal gap may result in severe damage to the pitch change mechanism itself remains. The investigation provided no conclusive evidence to support this assertion. Neither modeling and analysis nor the results of Vibratory Stress Survey aircraft testing performed with the gap between the forward and aft yoke plates intentionally increased provided results that support this statement.

5. **Section 3.3 Causes of the incident (Page 76) states** "*Seven vibration phenomena on the ATR 72-212A have been reported in the last few years. In almost all of the cases, the rupture of a trunnion pin of one of the blades and damage to the propeller blade actuator forward yoke plate were observed. The investigation revealed the existence of alternating overloads causing damage to the yoke plates and of a final overload in one direction resulting in the rupture of the trunnion pin. It was not possible to determine the cause of these overloads and the precise chronology of the damage and vibrations. Nevertheless, several elements may have contributed to it"* including:

   "Unplanned operation of the control loop of the propeller pitch change mechanism affected by forward yoke plate cyclic loading and friction"

The underlined statement summarizes the BEA's positions presented in items 1, 2 and 3 above. Collins had previously asserted prior to release of the final report that the investigation has revealed no evidence that anomalous operation of the propeller control system contributed to any of the on aircraft incidents. This conclusion was conveyed in the following replies to the BEA's positions that were documented in the comments spreadsheet.

- The design of the propeller control system allows normal propeller speed governing control to be maintained even when the sensed propeller blade angle is determined to be invalid.
- The vibratory stress surveys did not detect any appreciable vibratory stresses at the characteristic frequency of the control system (2.0 Hz to 3.0 Hz).
- The propeller control and actuation system is incapable of responding at the frequencies where vibratory stresses were detected by the stress surveys (1P and harmonics).
- The pitch change system can only impart sufficient force to damage trunnion pins and yoke plates if all of the actuator force was reacted by one or two blades. The control system has no capability to cause this.

Thank you again for your willingness to consider revision or appendment of the subject report in order to address Collins Aerospace's concerns. If you require any additional information please let us know. We will respond immediately.

BEA’s observations to Collins and NTSB comments

Items Resulting from the Translation Process

1. Section 1.2.7, Comparative study on page 18, states

The English Language version of the report actually differs from the French version.

The statement *“These loads were generated during interactions between the forward and aft yoke plates”* is incorrect and should be replaced with *“These loads were generated during interactions with the forward and aft yoke plates”*

2. Section 1.5.4.7, Propeller Blades on page 24

The word *“roulement”* used in the French Language version of the report is more general and covers both types of bearings, ball and roller bearings.

The statement *“the propeller blades are attached to the propeller hub by two roller bearings located at the blade root”* is incorrect and may be replaced with *“the propeller blades are attached to the propeller hub by two rows of angular contact ball bearings located at the blade root”,* which is more precise than the French version of the report.

3. Section 2.2.2.1, Particular Types of Propeller Behavior, Forward Yoke Plate Cyclic Loading, on page 66

During the vibratory stress survey flight tests, the magnitude of the cyclic load phenomenon that was observed was effectively within the high cycle fatigue material allowable. This is clearly reflected on the same page of the report, a few lines above : “*In flight tests, the loads which were measured on a trunnion pin during “forward yoke plate cyclic loading” were no more than around 450 daN, i.e. 18 % of the static load required to irreversibly deform it*”

The wording “*a substantial load factor was observed*” is used in the report to indicate that the magnitude of the observed load factor was high enough to support the hypothesis that under different conditions, such as a greater distance between the forward and aft plate, or combined with other phenomena that could not be fully identified during the investigation, the cyclic load factors could become even higher and cause structural damage, even without fatigue phenomenon.

Items of Disagreement between the BEA and Collins that were not Resolved during the Report Review Process

1. **The Synopsis section on page 8 of the report (and other paragraphs)**

The BEA takes note of Collins' and NTSB' objection. However, the propeller manufacturer did not provide any technical substantiation to justify its statement that the bandwidth of the propeller control system is in the range of 2.0 Hz to 3.0 Hz, nor did it demonstrate that the propeller pitch change system could not respond to any cyclic solicitation out of its bandwidth in the particular operating conditions discussed in the report (in particular when vibrations render the sensed blade angle signal alternatively valid and invalid).

The strain gage data collected during the two vibratory stress surveys did not highlight any loading high enough to cause damage. However, the investigation report describes events where damage occurred during vibration events in flight. This indicates that the vibratory stress survey test flights did not succeed in fully reproducing the vibration and cyclic loading behavior that occurred during the investigated events.

2. **Section 2.2.2.1 Particular types of propeller behavior, Propeller pitch change mechanism control loop (pg. 67)**

The BEA clearly grasps that the speed governing control algorithm uses the propeller speed in the propeller control system control loop as a target value in normal flight mode. The BEA's intention has never been to let the reader think that the system was using the sensed blade angle as the main parameter of the feedback loop to control the propeller speed.

However, the sensed blade angle is used to calculate the gain of the control loop. Therefore, BEA considers that severe vibrations can generate sensed blade angle signals that can be considered as valid then not valid by the PEC. In such circumstances, the control loop gain will swing between a calculated value and a predefined value. Control loop gain fluctuations may have an unexpected impact on the complete propeller control system behaviour.

In the sentence *"When the PEC no longer receives a valid signal regarding the actual position of the actuator, which it uses to calculate the propeller pitch angle, it nevertheless continues to send hydraulic pressure set points to the electrohydraulic valve in order to maintain a constant propeller rotation speed (82 % Np), but using predefined values",* the wording *"predefined values"* refers to values of the control loop gain, and the wording *"which it uses to calculate the propeller pitch angle"* refers to the propeller pitch angle information used to set the value of the control loop gain.

3. **Section 2.2.2.1, Particular types of propeller behavior, Propeller pitch change mechanism control loop (pg. 67)**

The BEA takes note of Collins' and NTSB' objection. However, even though the propeller manufacturer states that it "*is confident that the sampling rate of blade angle neither hinders the performance of the control system nor contributes to behavior that may have caused high cyclic pin stresses*", it did not technically demonstrate that the propeller control system would not react when facing vibrations close to the PEC internal computation rate. Stating that "*There is no need for the control system to respond to inputs at the blade excitation frequency*" is not a demonstration that it is not capable of doing so.

4. Section 2.2.3.3, Maintenance Procedures (page 71)

The BEA disagrees with Collins' and NTSB' statement : *"Therefore, the crew's subjective judgment of the magnitude of the vibration is not critical to effectively applying the service bulletin"* : Indeed, if pilots do not report abnormal vibrations, the SB will not be applied, even if a PEC Fault occurs. This is why the BEA considers that the procedure depends on the pilot's subjective assessment of the intensity of the vibrations.

Section 3.2, Investigation's findings regarding all propeller vibration events (8th bullet) states

The investigation has shown that there have been events where damage occurred during flight and was associated with abnormal vibrations. The BEA considers that, in these specific circumstances and for reasons that could not be clearly explained during the investigation process, damage can occur when trunnion pins are alternatively interacting with the forward and aft yoke plates.

Furthermore, the BEA believes that the existence of an abnormal gap between the two yoke plates of the propeller pitch change mechanism can favour triggering or aggravate the vibration phenomena leading to substantial damage.

5. Section 3.3 Causes of the incident (Page 76) states

BEA's position has already been developed in items 1, 2 and 3 above.

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