FINAL INVESTIGATION REPORT

ACCIDENT OF PIA FLIGHT PK-661 ATR42-500 AIRCRAFT REG NO AP-BHO NEAR HAVELIAN 24 NM NORTH OF BBIAP PAKISTAN ON 07 DECEMBER 2016

Dated: 16 November 2020

SCOPE

Aircraft Accident Investigation Board (AAIB), Pakistan investigations are conducted in accordance with Annex-13 to the ICAO Convention on International Civil Aviation and Civil Aviation Authority (CAA), Pakistan Rules 1994 (CARs 94).

The sole objective of the investigation of an accident or incident under above stated regulations is the prevention of future accidents and incidents of similar nature. It is not the purpose of such an investigation to apportion blame or liability. Accordingly, it is inappropriate to use AAIB investigation reports to assign fault or blame or determine liability, since neither the investigation nor the reporting process has been undertaken for that purpose.

This report contains facts which have been determined up to the time of publication. Such information is published to inform the aviation industry and the public about the general circumstances of civil aviation accidents and incidents.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF APPENDICES

ABBREVIATIONS & CODES

Abbreviation / Code	Description
AAIB	Aircraft Accident Investigation Board
AC	Alternating Current
ACW	Alternating Current Wild Frequency
AD	Airworthiness Directive
ADF	Automatic Direction Finding
ADS	Automatic Dependent Surveillance
ADU	Air Data Unit
AFU	Auto Feather Unit
AGB	Accessory Gear Box
AGL	Above Ground Level
AHRS	Attitude and Heading Reference System
AIP	Aeronautical Information Publication
AMM	Aircraft Maintenance Manual
AMO	Approved Maintenance Organization
AMSL	Above Mean Sea Level
ANO	Air Navigation Order
AOA	Angle of Attack
AOC	Air Operator Certificate
AP	Auto-Pilot
ATC	Air Traffic Controller
ATPCS	Automatic Takeoff Power Control System
ATPL	Air Transport Pilot License
ATR	Avion de Transport Régional
ATS	Air Traffic System
β	Propeller Blade Pitch Angle

Abbreviation / Code	Description
BBIAP	Benazir Bhutto International Airport
BEA	Bureau of Enquiry and Analysis
BR	Blade Rate
CAA	Civil Aviation Authority
CAP	Crew Alerting Panel
CAT	Category
CCAS	Centralized Crew Alerting System
CDS	Centralized Documentation System
CFD	Computational Fluid Dynamics
CL	Condition Lever
CLA	Condition Lever Angle
CMM	Component Maintenance Manual
CPL	Commercial Pilot License
CRC	Continuous Repetitive Chime
CRM	Crew Resource Management
CS-E	Certification Specification – Engine
CSP	Component Support Program
CS-P	Certification Specification – Propeller
CT Scan	Computerized Tomography Scan
CVR	Cockpit Voice Recorder
DC	Direct Current
DC	Drag Count
DCI	Aerodynamic Load Increment
DET	Detectability
DFDR	Digital Flight Data Recorder

Abbreviation / Code	Description
DNA	Deoxyribonucleic Acid
DPO	Divisional Police Officer
EASA	European Aviation Safety Agency
ECO	Engineering Change Order
EEC	Engine Electronic Control
EHV	Electro Hydraulic Valve
EMM	Engine Maintenance Manual
FAA	Federal Aviation Administration
FCOM	Flight Crew Operating Manual
FCTM	Flight Crew Training Manual
FDAU	Flight Data Acquisition Unit
FDM	Flight Data Monitoring
FFS	Full Flight Simulator
FHA	Functional Hazard Assessment
FL	Flight Level
FMEA	Failure Modes and Effects Analysis
FO	First Officer
FOD	Foreign Object Debris
FPM	Feet Per Minute
FSO	Fuel Shut Off
Ft	Feet
FTB	Feathering Test Bench
FTR	Feather
GACA	General Authority of Civil Aviation
GNSS	Global Navigation Satellite System
HDG	Heading

Abbreviation / Code	Description
HMU	Hydro Mechanical Unit
HP	Horse Power
HP	High Pressure
IAS	Indicated Air Speed
ICAO	International Civil Aviation Organization
IFSD	In Flight Shutdown
ILS	Instrument Landing System
ITT	Inter Turbine Temperature
JAR	Joint Aviation Requirements
L/H	Left Hand
lbf	Pound Force
LP	Low Pressure
LRU	Line Replaceable Unit
MCT	Maximum Continuous Thrust
MFC	Multi-Function Computer
MFCU	Multi-Function Control Unit
MIP	Main Impact Point
MMEL	Master Minimum Equipment List
MOE	Maintenance Organization Exposition
MP&R	Maintenance Program and Reliability
MRO	Maintenance Repair and Overhaul
MSN	Manufacturer Serial Number
NCD	Non Computed Data
NH	High pressure Turbine Speed
NHA	Next Higher Assembly

Abbreviation / Code	Description
NL	Low Pressure Turbine Speed
NM	Nautical Mile
NP	Propeller Speed
NTSB	National Transport Safety Board
OCC	Occurrence
OEM	Original Equipment Manufacturer
ºF	Fahrenheit
OM	Operations Manual
OSG	Overspeed Governor
OVRD	Over Ride
P&WC	Pratt and Whitney Canada
P/N	Part Number
PCU	Propeller Control Unit
PD	Drain Pressure
PEC	Propeller Electronic Control
PEI	Prince Edward Island
PF	Pilot Flying
PFMEA	Process Failure Modes and Effects Analysis
PIA	Pakistan International Airline
PIMS	Pakistan Institute of Medical Sciences
PL	Power Levers
PLA	Power Lever Angle
PM	Pilot Monitoring
P_{OSG}	Overspeed Governor Pressure
P_S	Supply Pressure
PSI	Pound per Square Inch

Abbreviation / Code	Description
PSI_D	Differential pressure in PSI
P_{SIG}	Pounds per Square Inch Gauge
PSSA	Preliminary System Safety Assessment
PST	Pakistan State Time
PT	Power Turbine
PVM	Propeller Valve Module
QA	Quality Assurance
QPM	Quart Per Minute
QRH	Quick Reference Handbook
R/H	Right Hand
RAR	Run as Received
REG	Registration
RGB	Reduction Gear Box
RMI	Radio Magnetic Indicator
ROD	Rate of Descent
RPM	Revolution Per Minute
RPN	Risk Priority Number
RPT	Regular Public Transport
RRB	Reliability Review Board
RT	Radio Telephony
RTD	Resistive Temperature Device
S/N	Serial Number
SARPS	Standard and Recommended Practices
SB	Service Bulletin
SC	Single Chime

Abbreviation / Code	Description
SEC	Seconds
SEV	Severity
SHP	Shaft Horse Power
SIB	Safety Investigation Board
SL	Service Letter
SLPS	Secondary Low Pitch Stop
SMS	Safety Management System
SOP	Standard Operating Procedure
SR	Shaft Rate
SSA	System Safety Assessment
SSE	South Southeast
TAS	True Air Speed
TAWS	Terrain Avoidance and Warning System
TCCA	Transport Canada Civil Aviation
TQ	Torque
TSA	Technical Standard Agreement
TSB	Transport Safety Board
TTM	Total Twisting Moment
USA	United States of America
USOAP	Universal Safety Oversight Audit Program
UTAS	United Technologies Aerospace Systems
UTC	United Technologies
UTC	Universal Time Coordinated
VDC	Volt Direct Current
VMC	Visual Meteorological Condition
V_{mca}	Minimum Control Speed in the Air

Abbreviation / Code	Description
V_{mcg}	Minimum Control Speed on Ground
V_{mcl}	Minimum Control Speed at Landing
VOR	VHF Omnidirectional Range
VS	Vertical Speed
VVI	Vertical Velocity Indicator
W	Watt
YD	Yaw Damper

EXECUTIVE SUMMARY

Introduction.

1. On 07 December 2016 morning, after a routine daily inspection at Benazir Bhutto International Airport (BBIAP) Islamabad, Pakistan International Airlines (PIA) aircraft ATR42-500 Reg No AP-BHO operated 05 flights (ie Islamabad to Gilgit and back, Islamabad to Chitral, Chitral to Peshawar and back). As 6th and last flight of that day, it took off from Chitral at time 10:38:50 UTC (15:38:50 PST) with 42 passengers (including 01 engineer) and 05 crew members (03 pilots and 02 cabin crew) aboard for Islamabad. It crashed after 42 minutes of flight at 11:20:38 UTC (16:20:38 PST) about 3.5 Nautical Miles (NM) SSE of Havelian, and 24 NM North of BBIAP Islamabad. All 47 souls aboard were fatally injured.

2. The accident was reported to Aircraft Accident Investigation Board (earlier SIB), Pakistan, by Airport Manager CAA BBIAP Islamabad[1] and General Manager Safety & QA PIA[2]. The accident was notified[3] in accordance with ICAO Annex-13. Aviation Division, Government of Pakistan issued Notification[4] on 8 December 2016 authorizing AAIB Pakistan to investigate the accident, and issued a corrigendum[5] to review the composition of investigation team. The investigation has been conducted by AAIB Pakistan.

3. Owing to an un-precedent combination of technical malfunctions, this accident proved to be a unique case of its kind in the entire operational life of ATR aircraft flying all around the world since 1984. Consequently, three states (France, Canada & USA) responsible for the manufacturing of the aircraft, its engine and propeller, became part of the investigation with additional involvement of respective advisors. All these international participants worked tirelessly in conducting forensic examinations of the relevant parts / engines, analysis of the accrued facts, developed possible scenarios including the most probable scenario at the request of AAIB Pakistan and rendered various technical reports from time to time. During the course of investigation two safety recommendations were issued to address immediate safety concerns. During the concluding stage of the investigation, NTSB in January 2020 proposed formation of a maintenance group to deeply analyse the available OSG maintenance records, which was mutually agreed. Due to COVID-19 travelling restrictions the responsibility was delegated to NTSB by AAIB and the activity concluded in October 2020. AAIB Pakistan remained a nerve centre to manage all these activities with a sole aim to identify the cause(s) and ascertain measures that can avoid recurrence of such nature.

4. AAIB Pakistan acknowledges with profound gratitude the dedicated involvement of Bureau of Enquiry and Analysis (BEA) of France, Transport Safety Board (TSB) of Canada, National Transport Safety Board (NTSB) of USA, their respective advisors, Original Equipment Manufacturers (OEMs), and Maintenance Repair & Overhauls (MROs) representatives, who have contributed in fact finding and analysis.

[1] Accident Report by Airport Manager Benazir Bhutto International Airport (BBIAP) Islamabad.
[2] Mandatory Occurrence Report by PIA.
[3] Notification by AAIB Pakistan earlier SIB Pakistan in accordance with ICAO Annex-13.
[4] Government of Pakistan Notification No AT-8(7)/2016 dated 8 December 2016.
[5] Government of Pakistan Corrigendum No HQCAA/1901/386/AAIB/424 dated 16 November 2020.

The Event Flight.

5. The aircraft remained in air for about 42 minutes before crash (all timings in UTC). These 42 minutes have been split into **three stages of flight**, described hereunder: -

(a) **Initial Stage:** From 10:38 to 11:04 (~26 minutes) degraded speed governing accuracy of the port propeller was evident in the DFDR data, but was apparently not observed by the cockpit crew[6]. The flight stabilized at an altitude 13,500ft AMSL and a cruising speed of 186 knots IAS (instead of expected 230 knots IAS). There were two latent[7] pre-existing technical anomalies in the aircraft (a Fractured / dislodged PT-1 blade due to a known quality issue and a fractured pin inside the OSG), and one probable latent pre-existing condition (external contamination) inside the PVM of No 1 Engine[8]. Digital Flight Data Recorder (DFDR) analysis indicates that No 1 Engine was degraded.

(b) **Middle Stage (Series of Technical Malfunctions):** From 11:04 to 11:13 (~09 minutes), a series of warnings and technical malfunctions occurred to No 1 Engine (left side) and its related propeller control system. These included Propeller Electronic Control (PEC) fault indications, followed by No 1 Engine power loss, and uncontrolled variation of its propeller speed[9] / blade pitch angle (abnormal system operation). The propeller speed which was initially at 82% (cruise setting) decreased gradually to 62% and later at the time of engine power loss it increased to 102% (and stayed at that value for about 15 to 18 seconds). It then reduced down to Non Computed Data (NCD) as per DFDR. At this point, (based on simulation results) the blade pitch angle increased (possibly close to feather position). Later, the propeller speed increased to 120% to 125% (probably caused due to unusual technical malfunctions) and stayed around that value for about 40 to 45 seconds. It finally showed an abrupt drop down to NCD again. At this point, (based on simulation results) the blade pitch angle may have settled at a value, different from the expected feathered propeller[10]. During this unusual variation of propeller speed, there were drastic variations in the aircraft aerodynamic behaviour and sounds. The directional control was maintained initially by the Auto-Pilot. A relatively delayed advancement of power (of No 2 Engine) post No 1 Engine power loss, reduction of power (of No 2 Engine) for about 15 seconds during the timeframe when left propeller rpm was in the range of 120% to 125%, and once again a reduction of power towards the end of this part of flight, were incorrect pilot actions, and contributed in the IAS depletion. Auto-Pilot got disengaged. Towards the end of this part of flight, the aircraft was flying close to stall condition. No 1 Engine was already shutdown and No 2 Engine (right side) was operating normal. At this time, IAS was around 120 knots; aircraft started to roll / turn left and descend. Stick shaker and stick pusher activated. Calculated drag on the left side of the aircraft peaked when the recorded propeller speed was in the range of 120% to 125%. During transition of propeller speed to NCD, the additional component of the drag (possibly caused due to abnormal behaviour of left propeller) suddenly reduced. The advancement of power of No 2 Engine was coupled with excessive right rudder input (to counter the asymmetric

---

[6] BEA2016-0760_tec02, FDR and CVR Analysis, dated 21 December 2016.

[7] The word latent has been used to highlight that the pre-existing / technical anomalies and the condition were unknown, and inert till the time a sequence of technical failures was triggered.

[8] BEA2016-0760_tec34, Most Probable Scenario on the Powerplant #1 Behavior, dated 26 November 2018.

[9] BEA2016-0760_tec02, FDR and CVR Analysis, dated 21 December 2016.

[10] BEA2016-0760_tec29, Report on UTAS and ATR Simulations, dated 19 September 2018.

condition). This coincided with last abrupt drop in the propeller speed[11]. As a combined effect of resultant aerodynamic forces aircraft entered into a stalled / uncontrolled flight condition, went inverted and lost 5,100ft AMSL altitude (ie from ~13,450ft to 8,350ft AMSL).

(c) **Final Stage:** The final stage of flight from 11:13 to 11:20 (~07 minutes) started with the aircraft recovering from the uncontrolled flight. Although blade pitch position was not recorded (in the DFDR – by design), and it was not possible to directly calculate that from the available data, a complex series of simulations and assumptions estimated that the blade pitch of left propeller may have settled at an angle around low pitch in flight while rotating at an estimated speed of 5%[12]. Aircraft simulations indicated that stable additional drag forces were present on the left side of the aircraft at this time and during the remaining part of flight. Aircraft had an un-expected (high) drag from the left side (almost constant in this last phase); the aircraft behavior was different from that of a typical single engine In Flight Shutdown (IFSD) situation. In this degraded condition it was not possible for the aircraft to maintain a level flight. However, that level of drag did not preclude the lateral control of the aircraft, if a controlled descent was initiated. The aircraft performance was outside the identified performance envelope. It was exceptionally difficult for the pilots to understand the situation and hence possibly control the aircraft. Figure hereunder shows different stages of flight.

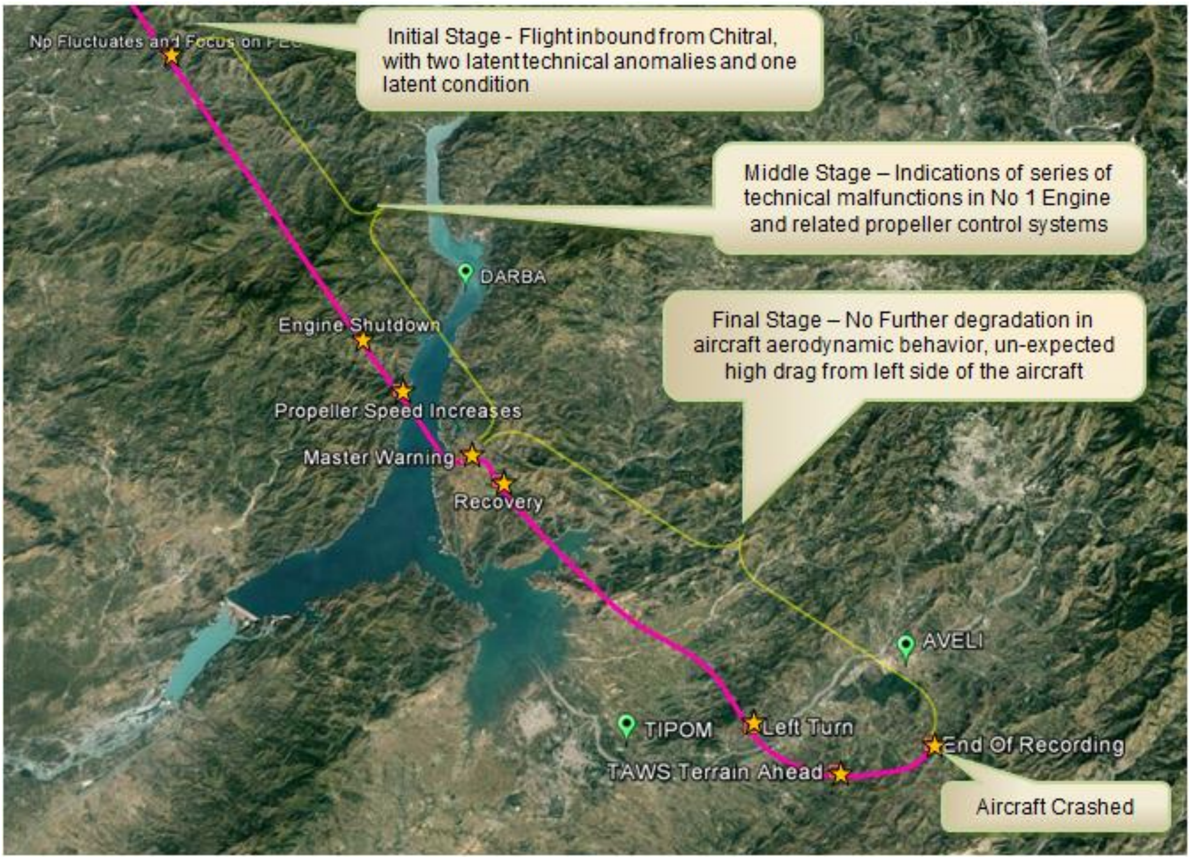


Figure: A-1

---

[11] Review / analysis of DFDR Data, and CVR recording at AAIB Pakistan.
[12] BEA2016-0760_tec34, Most Probable Scenario on the Powerplant #1 Behavior, Dated 26 November 2018.

6. In PIA there had been cases of ATR aircraft single engine IFSD. However, being a known emergency procedure, the PIA pilots (during such situations experienced earlier than this event) were able to handle the situation safely by following the steps provided in Quick Reference Handbook (QRH), Flight Crew Operating Manual (FCOM), and Flight Crew Training Manual (FCTM) etc. In this particular single engine IFSD, coupled with its propeller still rotating at around 5% rpm (estimated) and possible blade angle position near the low pitch stop[13], the pilots came across a situation which was neither experienced earlier, nor expected. Due to system redundancy and accumulated probability of independent failures, it was not considered as a condition to be addressed by the aircraft OEM (ATR), therefore, it was not explained in any operational publication(s)[14].

Tests, Research, Analysis.

7. For forensic analysis various parts of the aircraft were sent to specialized locations / respective OEMs. During the course of investigation, the volume of activity which involved contribution of various participants included numerous root cause analysis collaboration sessions (about 45), around 10 teleconferences, joint meetings / discussion sessions, simulations, test flights, advance forensic tests / analyses and thousands of emails. As an outcome of the analyses, tests and research, numerous presentations / reports were generated from time to time by the Member State Accredited Representatives and their Technical Advisors by putting in immense efforts and man-hours[15].

Findings.

8. The findings have been organized, in a sequence, according to relevance to the cause of the crash (direct or indirect attribution). Several findings of general interest, that are considered important, however, may not have attribution to the cause, have also been included. All these findings have been based on the factual information; reports generated from time to time, and detailed analysis of failure events, actions and possibly related considerations known so far, till the time of completion of this report.

(a) **Latent Pre-existing Technical Anomalies / Condition before the Flight.**

(i) The flight took off at 10:38 hrs (UTC) with two latent pre-existing technical anomalies inside the No 1 Engine and same side propeller system and one probable latent pre-existing condition[16]. One anomaly was a fractured Power Turbine Stage 1 (PT-1) blade, and the second anomaly was a fractured pin inside the Overspeed Governor (OSG) of the same side. The probable latent pre-existing condition was contamination (external from the engine) observed in Propeller Valve Module (PVM).

(ii) Most probably, the PT-1 blade had fractured during previous flight[17] (Peshawar to Chitral), however this defect is not observable during regular operations.

---

[13] BEA2016-0760_tec29, Report on UTAS and ATR Simulations dated 19 September 2018.
[14] Analysis / discussion between BEA and AAIB during November 2019 meeting at BEA, and ATR presentation on aircraft certification aspects.
[15] The number of events and activities has been summarized (approximated) by AAIB.
[16] Analysis / discussion during final concluding meeting in November 2018 at BEA, and review / analysis between AAIB and the ACCREPs.
[17] Analysis / discussion during final concluding meeting in November 2018 at BEA.

(iii) Fracture or distress of PT-1 blade may not essentially lead to an immediate IFSD, however, if it happens, (and if not combined with other independent failures) the aircraft can fly on the other engine and land.

(iv) It was determined that the pin inside the OSG was fractured due to improper re-assembly[18]. Metallurgical evaluation of the OSG pilot valve pin fracture surface, at Woodward USA determined that the pin had failed in overload resulting from the valve being forced together using an improper re-assembly method during some un-authorized / undocumented maintenance activity[19].

(v) Analysis of complete records / history of OSG revealed that there was no reported unauthorized / un-documented maintenance activity[20]. Since manufacturing, this particular OSG was sent to its certified maintenance facility (Woodward / Honeywell) first time in 2011, then in 2012 and lastly in April, 2015[21].

(vi) It was not possible to ascertain when and where unauthorized / undocumented maintenance of OSG may have occurred[22].

(vii) OSG can continue to be functional without any problem detected with a sheared pin of the pilot valve, until further deterioration. Continued operation with a broken pin may possibly have weakened component(s) inside OSG (ie the flyweights at the toe location)[23].

(viii) Probable latent pre-existing contamination / debris found in PVM were most likely introduced when the propeller system LRU's were not installed on the gearbox. However it is not possible to ascertain when and where the contamination in the PVM was induced.

(ix) It has been established that any of the latent pre-existing technical anomalies and probable latent pre-existing condition (ie fractured PT-1 blade, or fractured pin inside OSG, or external contamination in PVM) alone may not lead to such a catastrophic / hazardous situation except in the presence of unusual combination and / or additional contributing factor(s)[24].

(b) **Sequence of Technical Failures and Crash.**

(i) The summarized sequence of the technical failures was as follows: -

---

[18] Analysis / discussion during final concluding meeting in November 2018 at BEA.

[19] Maintenance Group Investigation Report, Service Review of Woodward Overspeed Governor P/N 8210-097, S/N 14967680, by NTSB, dated 02 October 2020 attached as **Appendix-1**.

[20] Review of PIA maintenance records by AAIB.

[21] Same as above.

[22] Maintenance Group Investigation Report, Service Review of Woodward Overspeed Governor P/N 8210-097, S/N 14967680, by NTSB, dated 02 October 2020 attached as **Appendix-1**.

[23] AAIB analysis / understanding on the issue.

[24] Analysis / discussion during meeting in November 2019 at BEA.

<table>
<tr><th>Time</th><th colspan="2">Event</th></tr>
<tr><td>Before Event Flight</td><td colspan="2">• Engine Power Turbine Stage 1 (PT-1) Blade fractured / dislodged causing imbalanced rotation of PT shaft.
• OSG pin fractured.
• Probable contamination (external from the engine) in PVM.</td></tr>
<tr><td>Prior to 11:05:31</td><td colspan="2">Engine degraded and caused engine oil system contamination.</td></tr>
<tr><td rowspan="2">Subsequent to above</td><td rowspan="2">Propeller Control Fault indications and Power-plant malfunctions.</td><td>Left OSG caused un-commanded decrease in propeller speed. This was due to the fractured OSG pilot valve pin combined with oil contamination from the engine system.</td></tr>
<tr><td>PEC Fault triggered and crew reset and eventually permanently de-powered the PEC.</td></tr>
<tr><td>11:10:34</td><td colspan="2">No 1 Engine suffered power loss.</td></tr>
<tr><td>Subsequent to above</td><td colspan="2">Crew requested feathering, propeller speed decreased.</td></tr>
<tr><td>11:10:57</td><td colspan="2">Crew positioned CL in FSO position.</td></tr>
<tr><td>Subsequent to above</td><td>Continued technical malfunctions</td><td>OSG became non-functional due to loss of contact with broken flyweights.</td></tr>
<tr><td>11:11:18
to
11:11:53</td><td colspan="2">Propeller went out of feather (Np-1 over shoot to 120%) most probably due to contamination inside the overspeed line of the PVM. This caused the protection valve to leave the protected mode, resulting in propeller movement towards low pitch below low pitch value in flight.</td></tr>
<tr><td>~11:12:30 onwards</td><td colspan="2">Sharp decrease in Np-1, blade pitch angle most likely moved further beyond the previous position (ie below low pitch in flight) and settled with Np-1 below 5% (estimated) with a drag force of about 2,000 lbf (estimated).</td></tr>
</table>

(ii) The aircraft crashed after 42 minutes of flight at 11:20 about 3.5 NM SSE of Havelian, and 24 NM North of BBIAP Islamabad. All 47 souls (42 passengers and 05 crew members) were fatally injured.

(c) **PIA Maintenance, Anomaly of PT-1 Blades, Latent Pre-Existing OSG Fractured Pin and PVM Contamination.**

(i) The distress mode of PT-1 blades was from a known issue on P&WC "PW127" series engines since 2007. To address this issue, the OEM undertook various improvements (in the management / design of the blades). As a final effort, in October 2015 (ie ~08 years since the trending failures in the industry were being observed), the OEM introduced a new design of the PT-1 blade, through a Service Bulletin No 21878. Subsequently, the OEM amended the Engine Maintenance Manual in May 2016 (ie ~06 months prior to the crash) by specifying replacement criteria for both new and old design blades[25].

(ii) Past maintenance records at PIA indicated that the No 1 Engine of the aircraft was removed from another ATR aircraft (AP-BHP) during the second week of November 2016 (ie ~26 days prior to the occurrence) on a defect of rubber FOD stuck inside engine LP impeller. This was an unscheduled activity[26].

(iii) During shop visit, the blades had accumulated 10004.1 hrs and the PT Assembly was removed (to take out the FOD stuck inside LP impeller). Pre-conditions to replace the PT-1 blades were met as per OEM's defined criteria given in the revised Engine Maintenance Manual Chapter-5. However, these blades were not replaced and PIA Engine Shop cleared the engine. This engine was later installed on 16 November 2016 at No 1 position on AP-BHO[27].

(iv) This engine after operating for another 93 hrs on AP-BHO, had one of its PT-1 blades fractured (from a known issue). This event triggered a sequence of technical malfunctions in the event flight[28]. However, it can be assumed that if this engine had not encountered a rubber FOD, the said PT-1 blade might have continued operating (as per OEM's instructions) and might have fractured around same time frame (ie 10004.1 + 93 hrs)[29].

(v) Fractured pilot valve pin of OSG was present since it was last accessed during a maintenance activity. It was not possible to ascertain when and where this maintenance activity took place[30].

(vi) Probable pre-existing contamination / debris found in PVM were most likely introduced when the propeller system LRU's were not installed on the gearbox. It was not possible to ascertain when and where this contamination was introduced[31].

[25] Engine Maintenance Manual and relevant publications.
[26] Scrutiny / Analysis of PIA records at AAIB.
[27] Same as above.
[28] Discussion / Analysis during concluding meeting at BEA in November 2018.
[29] AAIB analysis.
[30] Maintenance Group Investigation Report, Service Review of Woodward Overspeed Governor P/N 8210-097, S/N 14967680, by NTSB, dated 02 October 2020 attached as **Appendix-1**.
[31] Analysis at AAIB.

(d) **Nature of Technical Malfunctions and Degradation in Aircraft Performance.**

(i) In this particular single engine IFSD, coupled with a propeller possibly rotating at 5% (estimated) rpm and a blade pitch assumed to be near (or below) the low pitch stop, the pilots came across a situation which was neither experienced earlier, nor expected. Due to system redundancy and accumulated probability of independent failures, and since the probability meets and exceeds applicable safety regulations, it was not considered as a condition to be addressed, therefore, it was not explained in any operational publication by the aircraft OEM (ATR).

(ii) Due to this combined technical anomaly, during following parts of the flight[32], the conditions were exceptionally difficult (ie may be considered as conditions of hazardous consequence) and it was expected that the cockpit crew may not be able to cope with the situation, and therefore they may not be relied upon to undertake the required / expected actions correctly[33]. These are as follows: -

A. **11:10:33 to ~11:10:56:** During this part at the time of No 1 Engine IFSD, Np-1 had increased (before engine shutdown) to about 102%.

B. **11:10:56 to ~11:11:45:** Np-1 decreased and became NCD. Its behavior looked like a feather request. Then, Np-1 unexpectedly increased again at an abnormal slow rate[34], corresponding to propeller un-feathering.

C. **11:11:45 to ~11:12:35:** During this part Np-1 increased to a very high value range of 120 to 125 %, gradually reduced to 116.5%, and then increased to 123% again. During this part of flight the left side of the aircraft produced high drag values, until the propeller speed began to rapidly decrease in an un-expected manner.

D. **11:12:45 to ~11:13:09:** During this part the aircraft entered an uncontrolled / stalled condition of flight where the aircraft lost about 5,100ft and rolled right by 360º and beyond[35]. This had immense psychological impact on the cockpit crew, and it impaired their capacity to perform normally[36].

E. **11:12:36 to ~11:20:39:** During this last part of flight when there was no further technical degradation and the blade pitch angle and Np-1 had stabilized at a particular value. This new pitch angle was possibly beyond the low pitch in flight (ie in fine pitch range normally corresponding to ground operations). The aerodynamic drag of the left side of the aircraft was estimated to be seven times[37] more than the drag usually expected during single engine flight envelope (with the effected side propeller in feather position).

---

[32] DFDR data analysis at AAIB.
[33] Discussion on aircraft controllability / certification aspects with ATR at BEA during November 2019.
[34] Confirmed by ATR flight test.
[35] DFDR data analysis at AAIB. The aircraft stalled at a speed of 120 knots indicating a significant aerodynamic degradation in the aircraft performance.
[36] AAIB analysis deduced from DFDR / CVR recordings and flight animation.
[37] Discussion on aircraft controllability / certification aspects with ATR at BEA during November 2019.

(iii) All flight parts subsequent to un-feathering (except first condition ie sub para A of para ii above) are not covered in QRH / FCOM of ATR aircraft. ATR describes the failure condition (corresponding to un-feathering and not to subsequent phases) in risk factor / safety assessment paradigm as failure condition No 1.003 "engine failure in cruise without propeller feathering" (System Safety Analysis 42.0078/95 issue 5), as of "Hazardous Consequence", with further explanation about the possible results[38].

(iv) All flight parts subsequent to un-feathering (ie sub para A of para ii above) were understandably much more complicated and difficult to handle, than "engine failure in cruise without propeller feathering" (ie the first condition), and therefore are considered more severe for their possible consequence(s). Moreover, the aircraft was flying with Pitch Disconnect which probably brought in additional challenges for the aircrew in terms of aircraft handling and control authority[39].

(v) The torque value of No 2 Engine during the flight conditions (sub para E of para ii above) was sufficient enough to fly, cross over the mountains and land the aircraft with No 1 Engine IFSD (if the propeller was in feather condition, and there was no additional drag due to complicated technical malfunctions of No 1 Engine propeller system).

(vi) The event was unexpected and the cockpit crew was not trained for this specific sequence of event. This event highlights importance of adhering to the cardinal principle of ***Fly, Navigate, and Communicate***, especially in an unusual emergency situation. The crew actions indicated several events of incorrect prioritization. Top priority must always be accorded to the control of the aircraft first and then consume the remaining effort in effective management of cockpit resources for mitigation of hazards, and subsequent safe recovery of the aircraft. This aspect is however considered an overboard expectation from the pilots especially when they were unable to understand and correct the situation, and had no method available to them to reach to the correct understanding about possible descend / landing profiles (on any nearby airfield or attempt ditching elsewhere), without any specific guidelines provided in any form.

(e) **Crew Training, Qualification, Performance and Matter of Dubious Pilots' Licenses[40].**

(i) The Captain had a total of 11265:40 hrs of flying experience, with 1216:05 hrs (as Captain) on ATR aircraft. He held valid licenses, and ratings, and met the required training / regulatory prerequisites of PIA and CAA. During his career, in addition to ATR aircraft he flew (as a First Officer) Fokker F-27, Airbus 300, Airbus 310, Boeing 737, and Boeing 777 aircrafts. He had a family and led a normal family life.

[38] Certification process presentation by ATR provided an overview of risk assessment paradigm, and an understanding about possible consequences that could be related to hazardous flight conditions. These possible consequences included a large reduction in safety margins of aircraft functional capabilities and capabilities of flight crew; and may even lead to fatal injuries to few of the occupants.

[39] AAIB analysis.

[40] In June 2020, the matter of dubious licenses by the pilots was made public during a formal joint session of the National Assembly of Pakistan by the Federal Minister of state for Aviation.

There were no social / psychological issues reported / documented by PIA / CAA Pakistan in their respective records.

(ii) The First Officer (A) had a total of 1742:30 hrs of flying experience with 1416:00 hrs (as First Officer) on ATR aircraft. He held valid licenses and ratings, and met the required training / regulatory prerequisites of PIA and CAA. During his career, in addition to ATR aircraft he flew (as First Officer) Twin Otter and Fokker F-27 aircrafts. He had a family and led a normal family life. There were no social / psychological issues reported / documented by PIA / CAA Pakistan in their respective records.

(iii) The First Officer (B) had a total of 570:00 hrs of flying experience with 369:15 hrs (as First Officer) on ATR aircraft. He held valid licenses and ratings, and met the required training / regulatory prerequisites of PIA and CAA. He was unmarried and lived with his mother and siblings. There were no social / psychological issues reported / documented by PIA / CAA Pakistan in their respective records.

(iv) During 2019 CAA Pakistan initiated scrutiny of licensing records of pilots. It was discovered that there were irregularities regarding the conduct of ground examinations by the licensing branch of CAA. This rendered a suspicion about licenses of few of the pilots who appeared in the exams during a specified period of time, and their attendance / physical participation could not be verified from the records. CAA has reconciled the matter by seeking clarification from the individuals, and disposing off the cases by adopting a legal / formal procedure. Names of Captain and First Officer (B) appeared in the initial list of pilots whose licenses were considered suspicious. CAA has removed these names on the basis of criteria / standard being followed during the review process[41].

(v) Career training records of the pilots highlighted few observations. Similar observations were also noted during the event flight. Based on the analysis of actual crew performance in comparison with the expected crew actions, AAIB has concluded that their performance was commensurate with their respective experience / training records etc. The matter of dubious licenses surfaced during the course of investigation therefore becomes irrelevant. However pilots' actions for attribution to the crash have been discussed in detail in analysis part of the investigation.

(f) **CAA Pakistan Oversight and Safety Management System of PIA:** CAA Pakistan as a regulator is required to maintain an oversight of all the operators. The primary objective of airworthiness directorate regulatory oversight is the efficient maintenance management by the operators, which is in accordance with the OEM prescribed procedures (and is in light of purposes and objectives of relevant ICAO publications and applicable SARPs). CAA Pakistan conducts annual audits of all the operators at the time of renewal of AOC. Audit reports of PIA for the years 2014 to 2018 were examined[42] during the course of investigation. It was observed that there were gaps in the monitoring and evaluation in the domain of Airworthiness

[41] AAIB letter to CAA for seeking clarification on the matter and CAA response.
[42] Annual audit / AOC renewal audit reports by CAA Pakistan of PIA for the years 2014 to 2018.

and Safety Oversight by CAA. Based on these audits or other oversight tools, CAA Pakistan was unable to demonstrate proportionate conclusions, identify the trends, and undertake proactive interventions. Furthermore, Safety and Quality Management of PIA is responsible to have a strong internal mechanism to ensure compliance to the required procedures and meet the expected safety standards. PIA Safety Management System did not identify and implement appropriate corrective measures. Some important observations are as follows: -

(i) P&W Canada identified that the reliability of PIA PW127 series engines is lower than the entire fleet operating in rest of the world[43]. The oversight mechanism established by CAA Pakistan was found to be inadequate to identify and monitor performance indicators that can reflect such findings. Furthermore the mechanism for a proactive intervention upon such findings was in-effective.

(ii) PIA has established Maintenance Repair Overhaul (MRO) Facility for the maintenance of PW127 engine series. Such setup is authorized for the maintenance in accordance with the conditions and requirements prescribed by the respective OEM. During a site survey of the said PIA MRO facility by P&WC in April 2017, few anomalies (deviations from requirements / procedures given by P&WC) were observed[44], which were not registered / documented by CAA Airworthiness during audits (or any activity related to the oversight). The oversight mechanism of CAA Pakistan (Directorate of Airworthiness) was inadequate / ineffective to identify such weak areas.

(iii) Non implementation of SB-21878 (and related deviation from relevant engine maintenance manual) was neither identified by PIA Quality and Safety Management System nor by CAA Airworthiness oversight system.

(iv) A number of IFSD cases were recorded on ATR aircraft in PIA, from 2008 to 2016 (ie before the crash)[45]. These cases and all other occurrences / incidents are mandatorily reported to CAA Pakistan. PIA Quality and Safety Management System, and the CAA Pakistan were unable to identify the trend(s) and undertake any proactive intervention.

Probable Causes of Occurrence.

9. **Probable Primary Factors.**

(a) The dislodging / fracture of one PT-1 blade of No 1 Engine triggered a chain of events. Unusual combination of fractured / dislodged PT-1 blade with two latent factors[46] caused off design performance of the aircraft and resulted into the accident[47].

(b) The dislodging / fracture of PT-1 blade of No 1 Engine occurred after omission from the EMM (Non-Compliance of SB-21878) by PIA Engineering

[43] P&WC provided classified data about ATR aircraft reliability the world over and a comparative analysis in the form of a presentation.
[44] P&WC Shop survey of Pakistan International Airlines MRO Facility, Karachi, Pakistan dated 01 May 2018.
[45] AAIB data about ATR aircraft IFSD cases for the years 2008 to 2016.
[46] AAIB analysis - the two latent factors include broken pin inside OSG and probable contamination inside PVM.
[47] AAIB analysis - had any of these factors existed alone, or had these not been coupled with an IFSD of the same side engine (in the manner it was experienced during this event), it may have resulted in different and / or less serious consequences.

during an unscheduled maintenance performed on the engine in November 2016, in which the PT-1 blades had fulfilled the criteria for replacement, but were not replaced[48].

(c) Fracture / dislodging of PT-1 blade in No 1 Engine, after accumulating a flying time slightly more than the soft life of 10,000 hrs (ie at about 10004.1 + 93 hrs) due to a known quality issue. This aspect has already been addressed by re-designing of PT-1 blades by P&WC [49].

10. **Probable Contributory Factors.**

(a) A fractured pin (and contamination inside the OSG), contributed to a complex combination of technical malfunctions. The pin fractured because of improper re-assembly during some unauthorized / un-documented maintenance activity. It was not possible to ascertain exact time and place when and where this improper re-assembly may have occurred[50].

(b) Contamination / debris found in overspeed line of PVM of No 1 Engine probably introduced when the propeller system LRU's were not installed on the gearbox, contributed to un-feathering of the propeller. It was not possible to ascertain exact time and place when and where this contamination was introduced.

Important Observations.

11. There were several findings discovered during the course of investigation, which did not have any direct contribution to the crash / causes. However, these findings were of significant importance, and have been included as observations. These are as follows: -

(a) In February 2017 PIA Engineering reviewed the life of the old design PT-1 blades. PIA Engineering decided to change the soft life as a hard life of 10,000 hrs irrespective of the conditions given in the maintenance manual (an action overboard towards safe side). The enabling reasons for this review and details of participation of CAA Pakistan in this review were not recorded / provided.

(b) After issue of First Immediate Safety Recommendation by AAIB in Jan 2019, both PIA Engineering and CAA Pakistan (Directorate of Airworthiness) maintained the stance that the SB-21878 was not important (non-mandatory / non-critical / optional etc), contrary to the related revision in Engine Maintenance Manual (which recommends to discard the blades on completion of 10,000 flight hours when the PT assembly or turbine disk is accessed).

(c) CRM training of the cockpit crew is governed by CAA Pakistan ANO ANO-014-FSXX-2.0. The refresher sessions are undertaken at prescribed periodicity (two years), by the operators by designated / qualified CRM facilitators. These trainings, were not effective, and did not yield the expected improvement in the behaviors / responses by cockpit crew. Operators as well

---

[48] If PIA during the said unscheduled maintenance had changed the blades, the said PT-1 blade fracture may not have occurred.

[49] Had there been no unscheduled repair (by PIA) on subject engine, PT blades would have continued in service passing 10,000 hrs soft life without being replaced. Probability of blade failure in such case (where the engine is not subjected to any scheduled / unscheduled maintenance enabling access to the relevant area) cannot be ruled out.

[50] Maintenance Group Investigation Report, Service Review of Woodward Overspeed Governor P/N 8210-097, S/N 14967680, by NTSB, dated 02 October 2020 attached as **Appendix-1**.

as CAA Pakistan (Directorate of Flight Standards) did not have an effective mechanism to gauge the efficacy of the CRM trainings.

(d) Flight Data Monitoring (FDM) is useful tool for the operators to observe trends about the cockpit crew during regular flight operations. PIA has established an FDM analysis mechanism; however it was not being effectively utilized. In case if such systems are utilized effectively, detailed records of operational trends are established and used to feed the airline SOP and training program.

(e) Flight inspectors from CAA Pakistan (Directorate of Flight Standards) supervise the periodic Simulator Sessions of the cockpit crew of all operators. During the conduct of these CAA supervised Simulator Sessions, response to exposure to different situations is formally evaluated and weak areas are identified. PIA needs to undertake necessary improvements and establish a continuous monitoring system (during regular flight operations) for the identified weak areas by using suitable tools (ie FDM analysis etc).

(f) It was established that metal debris (small particles), likely from No 6 bearing seal of engine travelled inside OSG through contaminated engine oil. Same oil is used by Propeller Control System components (ie OSG, PVM, Feathering & SLPS solenoids etc). The OSG incorporates orifices and polyester screens protecting downstream components from contaminants too large to exit through the PVM solenoid hydraulic drain, whereas the protection valve inside PVM has wire mesh screens.

(g) As a redundant design, PEC ‘ON’ is a secondary control for feathering as PEC commands to the PVM’s EHV. In the AP-BHO event (engine in flight shutdown with PEC ‘OFF’ (depowered) plus pre-existing independent conditions), normal feathering method using PEC command to PVM's EHV might have provided additional margin. However, an acceptable means of incorporating a specific operating procedure change, into the overall fault accommodation philosophy utilized on ATR aircraft systems, has not been identified by ATR.

(h) CMM of OSG has been recently revised by OEM. AAIB understands that the revised CMM must essentially encompass all conditions to rule out possibility of incorrect assembly of the lower body of the OSG and consequent damage to the pin. Furthermore it is expected that once an OSG goes through any inspection at the MRO facility, it has no hidden / latent defect.

Safety Recommendations.

12. The Safety Recommendations have been divided into two parts. The first part provides overview of Immediate Safety Recommendations issued by AAIB during the course of investigation (implementation already in progress); while the second part provides recommendations having direct bearing / relationship with the probable cause(s) of occurrence along with additional safety recommendations which have been based on findings provided as important observations.

13. **Immediate Safety Recommendations:** As various findings were established progressively, AAIB issued two Immediate Safety Recommendations to PIA Engineering and CAA Pakistan Airworthiness Directorate: -

(a) **The First Immediate Safety Recommendation[51]:** was issued on 09 January 2019. In that AAIB advised PIA to implement SB-21878 (incorporated as a revision in EMM Chapter 5 about six months prior to crash) for replacement of PT-1 blades on entire ATR fleet held at PIA according to the prescribed schedule / criteria. AAIB also advised CAA Pakistan (Airworthiness Directorate) to improve oversight function / mechanism accordingly.

(b) **The Second Immediate Safety Recommendation[52]:** was issued on 20 August 2019 at the request of Collins and the NTSB, in order to identify and correct any pre-existing failure related to incorrect re-assembly of OSG. AAIB advised PIA to initiate recycling / inspection (in a phased manner) at an OEM facility (Collins USA), of all (Qty 48) OSGs, either installed on ATR aircraft in operation or held in inventory with PIA.

14. **PIA.**

(a) PIA is to ensure replacement of PT-1 blades as per schedule given in EMM Chapter 5 in letter and spirit on the entire fleet of ATR aircrafts (in light of First Immediate Safety Recommendation)[53].

(b) PIA is to ensure recycling of all the Qty-48 OSGs (currently held with PIA) from an OEM's certified MRO facility to verify and confirm that no other OSG is having any internal pre-existing anomaly (in light of Second Immediate Safety Recommendation)[54].

(c) PIA is to ensure strict compliance of service information letter (SIL-568F-796)[55] issued by Collins Aerospace to maintain proper cleanliness and FOD prevention during engine and propeller storage and maintenance.

(d) PIA is to undertake improvements (and ensure continued compliance) in all the areas identified in P&WC site survey report of the MRO facility established for the maintenance of PW127 series engines[56].

(e) PIA Safety Management must identify critical performance indicators both in the domains of airworthiness as well as flight operations. The data is to be utilized for establishing trends and weak areas, further leading towards proactive corrective measures and corresponding improvements in SOPs / training programme.

(f) PIA is to ensure effective utilization of FDM system, observations noted during the simulator check flights and training sessions to identify and maintain records of operational trends. This mechanism may also include continuous monitoring and must enable requisite / proportionate improvements in relevant SOPs and training program.

(g) PIA is to revamp its CRM training system (in light of purposes and objectives of relevant ICAO publications and applicable SARPs) and evolve a purposeful internal assessment mechanism to gauge the effectiveness of CRM training.

[51] First Immediate Safety Recommendation attached as **Appendix-2.**
[52] Second Immediate Safety Recommendation attached as **Appendix-3.**
[53] Refer para 11 (a), PIA Engineering has already decided to change the soft life as a hard life of 10,000 hrs irrespective of the conditions given in the maintenance manual (an action overboard towards safe side).
[54] Implementation of the said safety recommendation was initiated soon after its issue and is under process at the time of publication of this report.
[55] Collins Aerospace Service Information Letter SIL-568F-796 attached as **Appendix- 4**
[56] P&WC Shop survey of Pakistan International Airlines MRO Facility, Karachi, Pakistan dated 01 May 2018.

15. **CAA Pakistan.**

(a) CAA Pakistan (Directorate of Airworthiness, State Safety Programme Management and / or any other relevant departments), must identify relevant performance indicators and establish a mechanism of monitoring of such indicators (in light of purposes and objectives of relevant ICAO publications and applicable SARPs). P&WC data about comparison of reliability of PIA ATR fleet, and details of IFSD cases of ATR (as per records held with PIA / CAA), can be considered as a reference. The established mechanism must also include relevant management tools to identify trends and recognize weak areas, and execute proactive intervention(s), proportionate with the nature and extent of identified concerns.

(b) CAA Pakistan (Directorate of Airworthiness), must undertake necessary improvements (in light of purposes and objectives of relevant ICAO publications and applicable SARPs) to ensure that appropriate management tools are evolved / adopted, and effective procedures are established to identify weak areas, related to the compliance with the OEM specified requirements / procedures etc. P&WC shop visit of PIA MRO for the maintenance of PW127 series Engines can be considered as a reference.

(c) Keeping in view the actions by the cockpit crew regarding Energy State Management, Automation Management, Crew Resource Management (CRM) failure aspects, CAA Pakistan (Directorate of Flight Standards) is to consider following measures: -

(i) Revamp the CRM training system (in light of purposes and objectives of relevant ICAO publications and applicable SARPs) and institute and implement regular / periodic CRM facilitator’s interactive training workshops for emphasizing upon the objectives of CRM, sharing of experiences and knowledge from accident / incident investigations of aviation industry, and evaluating the positive outcomes of CRM.

(ii) Evolve a purposeful internal assessment mechanism (for the operators), to increase the effectiveness of CRM training by identifying tangible performance indicators, and may consider to develop a software module to accumulate database of CRM observations for analysis.

(iii) Institute and implement feedback and analysis tools for use by the operators along with necessary training / guidelines. It may include use of existing systems of FDM analysis, hazard reporting system, voluntary reporting of events, and self-assessment by the cockpit crew etc.

(iv) Institute and implement an elaborate mechanism for the operators, of separately recording the weak areas identified during CAA Flight Inspector’s supervised flights / simulator tests, and continuous monitoring during regular training sessions, and FDM analysis. Ensure effective utilization by establishing detailed records of operational trends and utilize same to feed the airline SOP and training program etc.

16. **ATR:** ATR is to consider inclusion, as part of the training philosophy, of a procedure in the relevant aircraft publications to handle the aircraft in case of severe structural damage (to correlate an aerodynamic degradation similar to the event), to enable the cockpit crew to respond to such situations in a more appropriate manner.

17. **FAA:** Woodward has completed review and update to OSG CMM. Maintenance group review report[57] by NTSB summarizes the completion of this activity. FAA may re-evaluate that the revised CMM encompasses all conditions to rule out possibility of incorrect assembly of the lower body of the OSG and consequent damage to the pin.

18. **FAA / Collins Aerospace:** Collins Aerospace has issued a service information letter (SIL-568F-796) to remind operators to maintain proper cleanliness and FOD prevention during engine and propeller storage and maintenance. FAA and Collins Aerospace are to consider a system review and possible improvements to the oil system filtration inside the propeller control system to enhance existing protections against debris entering the PVM OSG line (including feather solenoid and SLPS solenoid) that could affect safety functions.

[57] Maintenance Group Investigation Report, Service Review of Woodward Overspeed Governor P/N 8210-097, S/N 14967680 by NTSB, dated 02 October 2020 attached as **Appendix-1**.

SECTION 1 - FACTUAL INFORMATION

SECTION 1 - FACTUAL INFORMATION

1.1 History of Flight.

1.1.1 On 07 December 2016 morning, after a routine daily inspection at Benazir Bhutto International Airport (BBIAP) Islamabad, Pakistan International Airlines Corporation (PIA) aircraft ATR42-500 Reg No AP-BHO operated 05 flights (ie Islamabad to Gilgit and back, Islamabad to Chitral, Chitral to Peshawar and back). As 6^{th} and last flight of that day, it took off from Chitral at time 10:38:50 UTC (15:38:50 PST) with 42 passengers (including 01 engineer) and 05 crew members (03 pilots and 02 cabin crew) aboard for Islamabad. It crashed after 42 minutes of flight at 11:20:38 UTC (16:20:38 PST) about 3.5 Nautical Mile (NM) SSE of Havelian, and 24 NM North of BBIAP Islamabad. All 47 souls aboard were fatally injured.

1.1.2 The accident was reported to Aircraft Accident Investigation Board (then SIB), Pakistan, by Airport Manager CAA BBIAP Islamabad[58] and General Manager Safety & QA PIA[59]. The accident was notified[60] in accordance with ICAO Annex-13. Aviation Division, Government of Pakistan issued Notification[61] on 8 December 2016 authorizing AAIB, Pakistan to investigate the accident, and issued a corrigendum[62] to review the composition of investigation team. The investigation has been conducted by AAIB Pakistan.

1.1.3 The aircraft remained in air for about 42 minutes before crash (all timings in UTC). These 42 minutes have been split into **three stages of flight**, described hereunder: -

1.1.3.1 **Initial Stage:** From 10:38 to 11:04 (~26 minutes) degraded speed governing accuracy of the port propeller was evident in the DFDR data, but was apparently not observed by the cockpit crew[63]. The flight stabilized at an altitude 13,500ft AMSL and a cruising speed of 186 knots IAS (instead of expected 230 knots IAS). There were two latent pre-existing technical anomalies in the aircraft (a Fractured / dislodged PT-1 blade due to a known quality issue and a fractured pin inside the OSG), and one probable latent pre-existing condition (external contamination) inside the PVM of No 1 Engine[64]. Digital Flight Data Recorder (DFDR) analysis indicates that No 1 Engine was degraded.

1.1.3.2 **Middle Stage (Series of Technical Malfunctions):** From 11:04 to 11:13 (~09 minutes), a series of warnings and technical malfunctions occurred to No 1 Engine (left side) and its related propeller control system. These included Propeller Electronic Control (PEC) fault indications, followed by No 1 Engine IFSD, and uncontrolled variation of its propeller speed[65] / blade pitch angle (abnormal system operation). The propeller speed which was initially at 82% (cruise setting) decreased gradually to 62% and later at the time of engine IFSD it increased to 102% (and stayed at that value for about 15 to 18 seconds). It then reduced down to Non Computed Data (NCD) as per DFDR. At this point, (based on simulation results) the blade pitch angle increased (possibly close to feather position). Later, the propeller speed increased to 120% to 125% (probably caused due to unusual technical malfunctions) and stayed around that value for about 40 to 45 seconds. It finally

[58] Accident Report by Airport Manager Benazir Bhutto International Airport (BBIAP) Islamabad.
[59] Mandatory Occurrence Report by PIA.
[60] Notification by AAIB Pakistan earlier SIB Pakistan in accordance with ICAO Annex-13.
[61] Government of Pakistan Notification No AT-8(7)/2016 dated 8 December 2016.
[62] Government of Pakistan Corrigendum No HQCAA/1901/386/AAIB.
[63] BEA2016-0760_tec02, FDR and CVR Analysis, dated 21 December 2016.
[64] BEA2016-0760_tec34, Most Probable Scenario on the Powerplant #1 Behavior, dated 26 November 2018.
[65] BEA2016-0760_tec02, FDR and CVR Analysis, dated 21 December 2016.

showed an abrupt drop down to NCD again. At this point, (based on simulation results) the blade pitch angle may have settled at a value, different from the expected feathered propeller[66]. During this unusual variation of propeller speed, there were drastic variations in the aircraft aerodynamic behaviour and sounds. The directional control was maintained initially by the Auto-Pilot. A relatively delayed advancement of power (of No 2 Engine) post No 1 Engine IFSD, reduction of power (of No 2 Engine) for about 15 seconds during the timeframe when left propeller rpm was in the range of 120% to 125%, and once again a reduction of power towards the end of this part of flight, were incorrect pilot actions, and contributed in the IAS depletion. Auto-Pilot got disengaged. Towards the end of this part of flight, the aircraft was flying close to stall condition. No 1 Engine was already shutdown and No 2 Engine (right side) was operating normal. At this time, IAS was around 120 knots; aircraft started to roll / turn left and descend. Stick shaker and stick pusher activated. Calculated drag on the left side of the aircraft peaked when the recorded propeller speed was in the range of 120% to 125%. During transition of propeller speed to NCD, the additional component of the drag (possibly caused due to abnormal behaviour of left propeller) suddenly reduced. The advancement of power of No 2 Engine was coupled with excessive right rudder input (to counter the asymmetric condition). This coincided with last abrupt drop in the propeller speed[67]. As a combined effect of resultant aerodynamic forces aircraft entered into a stalled / uncontrolled flight condition, went inverted and lost 5,100ft AMSL altitude (ie from ~13,450ft to 8,350ft AMSL).

1.1.3.3 **Final Stage:** The final stage of flight from 11:13 to 11:20 (~07 minutes) started with the aircraft recovering from the uncontrolled flight. Although blade pitch position was not recorded (in the DFDR – by design), and it was not possible to directly calculate that from the available data, a complex series of simulations and assumptions estimated that the blade pitch of left propeller may have settled at an angle around low pitch in flight while rotating at an estimated speed of 5%[68]. Aircraft simulations indicated that stable additional drag forces were present on the left side of the aircraft at this time and during the remaining part of flight. Aircraft had an un-expected (high) drag from the left side (almost constant in this last phase); the aircraft behavior was different from that of a typical single engine IFSD situation. In this degraded condition it was not possible for the aircraft to maintain a level flight. However, that level of drag did not preclude the lateral control of the aircraft, if a controlled descent was initiated. The aircraft performance was outside the identified performance envelope. It was exceptionally difficult for the pilots to understand the situation and hence possibly control the aircraft. Figure hereunder shows different stages of flight.

[66] BEA2016-0760_tec29, Report on UTAS and ATR Simulations, dated 19 September 2018.
[67] Review / analysis of DFDR Data, and CVR recording at AAIB Pakistan.
[68] BEA2016-0760_tec34, Most Probable Scenario on the Powerplant #1 Behavior, dated 26 November 2018.

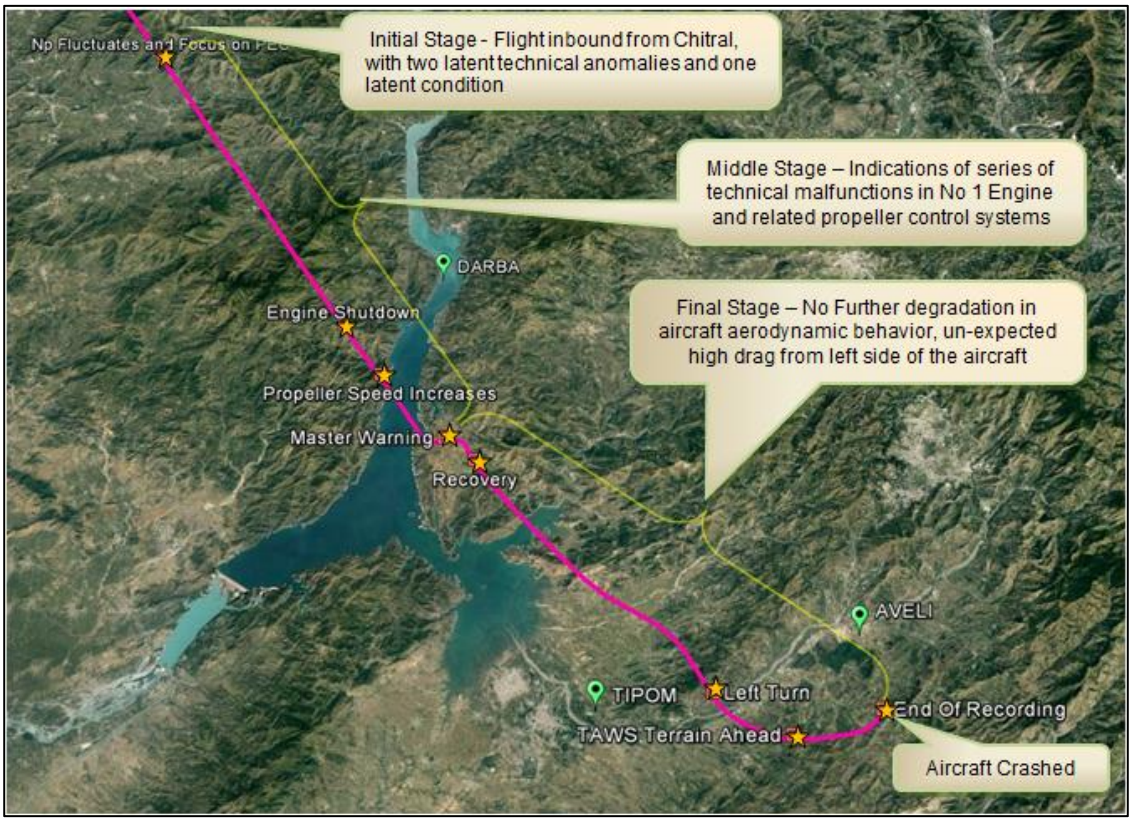


Figure 1-1: Different Stages of Flight

1.1.4 **Initial Stage: Take Off, Climb, & Initial Cruise (10:38:50 - 11:04:44).**

1.1.4.1 The flight was scheduled with three Pilots including one Captain and two First Officers. All three Pilots held valid licenses, and medical fitness. They fulfilled the desired qualification criteria, and met the related formal prerequisites, (in the respective assigned capacity) which were required for the event flight. One First Officer was scheduled to undergo a “route training”, whereas the other First Officer was already qualified for this route. The flight initiated with trainee First Officer on the right seat (to fly as a Co-Pilot) and is termed in this investigation as the First Officer A (FO(A)), whereas the First Officer on the jump seat (who was already route cleared) is termed as the First Officer B (FO(B)). As per PIA SOP the trainee pilot flies, however, in case of any abnormal situation, he is to be replaced with the other pilot (who has completed the training). Later during flight both the FOs changed their positions. The weather at origin, en-route and at the destination was fine, with no significant activity.

1.1.4.2 The flight commenced with two latent pre-existing technical anomalies, one in No 1 Engine (left side), and second in the same side (ie left hand side) Overspeed Governor (OSG) and a probable third condition, on same side, with particles external to the engine in PVM oil system. Before the event flight, one blade of the No 1 Engine (left side) Power Turbine Stage 1 (PT-1) had already fractured. It was not possible to identify the exact timeframe when this damage may have occurred. Advanced technical analysis revealed that it may have occurred during the previous flight. Depending on secondary damages, it is not always possible for the pilots to identify such defects during pre-flight visual inspection of the aircraft. This defect caused imbalance in the rotation of the Power Turbine Shaft. DFDR indicates that there were fluctuations in related parameters. Though diverging gradually, but being of very small amplitude, these fluctuations remained unnoticed. No 1 Engine was gradually deteriorating, since beginning of this flight, or perhaps since during some part of the previous flight.

1.1.4.3 Figure 1-2 hereunder shows a cross section view of PW127 Engine, along with its main components. The inner stage of two stages Power Turbine, being the first in sequence is Power Turbine Stage -1 (PT-1). Figure 1-3 shows Power Turbine Stage 1 (PT-1) removed from effected engine showing one blade fractured (that had occurred before the flight).

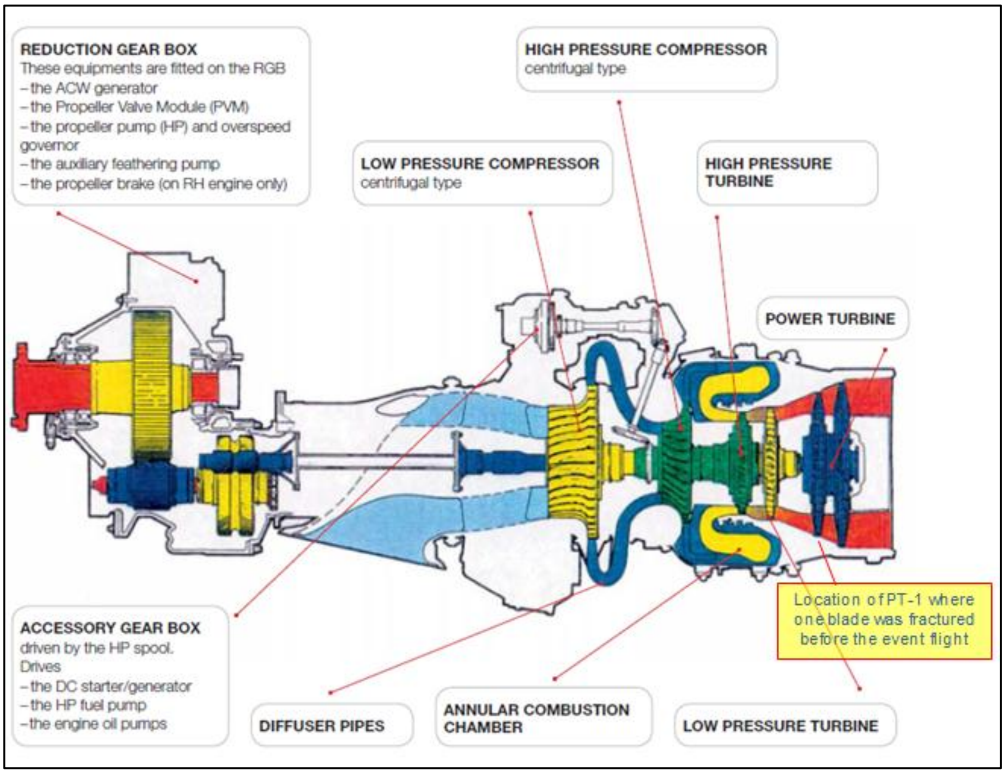


Figure 1-2: Cross Section View of PW127 Engine

Figure 1-3: Power Turbine Stage 1 (PT-1) One Blade Fractured

1.1.4.4 The second pre-existing technical anomaly was a fractured pin inside the same side (ie left hand side) Overspeed Governor (OSG). This defect occurred during some maintenance activity performed on it. Advanced technical analysis has revealed that such defect alone (unless combined with abnormal metallic contamination leading to increased friction inside the pilot valve) may not have any impact on the performance of OSG. Figures hereunder show a serviceable OSG and cross section view of the area inside OSG which had a broken pin.

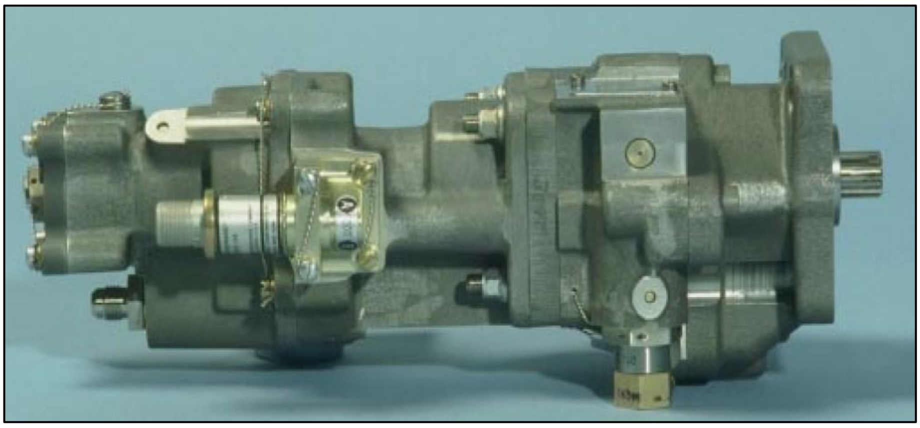


Figure 1-4: Serviceable Overspeed Governor (OSG)

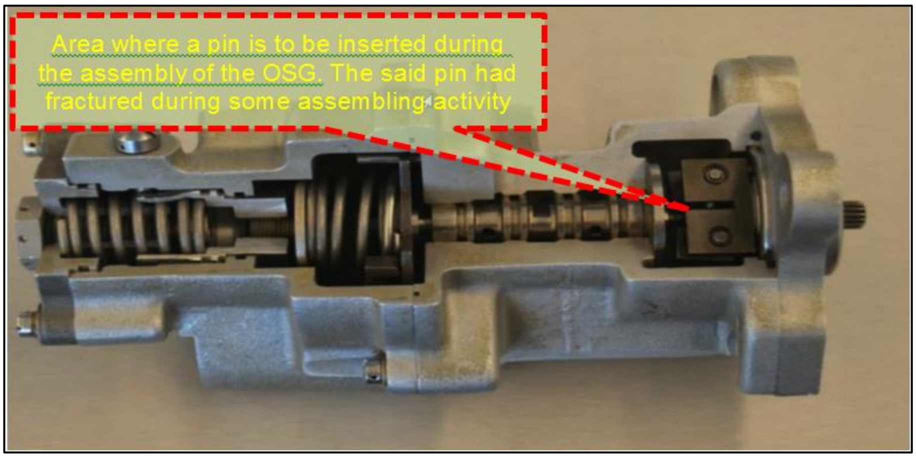


Figure 1-5: Cross Section View of OSG

1.1.4.5 PVM contamination was most likely a pre-existing condition since contaminants, based on their size, could not go through filters / restrictions and were therefore not possibly due to engine contamination. This contamination was likely introduced when the propeller system LRU's were not installed on the gearbox. Figures hereunder show a serviceable PVM and debris found in overspeed line during CT scan.

Figure 1-6: Serviceable Propeller Valve Module (PVM)

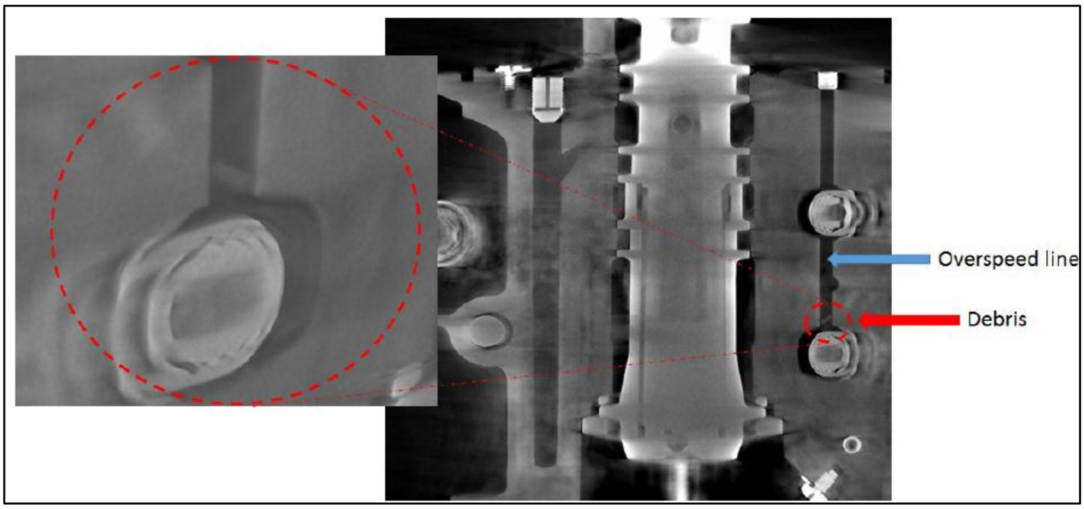


Figure 1-7: CT Scan Indicating Contamination in Overspeed Line of PVM

1.1.4.6 The aircraft took off from runway 20 of Chitral Airport at 10:38:50. Auto-Pilot (AP) was engaged at 10:39:20. At the moment of rotation, control column effort was made on First Officer (FO) side. So it is assumed that the Pilot Flying (PF) was the FO(A) and the Captain was Pilot Monitoring (PM). The recommended climb speed of 160 knots with IAS mode (under those non-icing conditions) was not maintained, and instead an IAS of 145 knots was maintained for optimum climb performance (VS mode was selected at the end of the climb phase). This selection was as per PIA SOP (and usually interpreted / referred by the pilots as) of maintaining a speed of 10 knots higher than the white bug. This use of vertical speed mode in climb is not recommended by ATR FCOM. However, if the crew elects to use such speed, it must be mentioned by the PF and acknowledged by the PM, and additionally the aircraft energy state must also be monitored properly. The aircraft acquired its cruising parameters within 10 minutes after take-off, and levelled off at FL135 at an Indicated Air Speed (IAS) of 186 knots. The CVR transcript does not indicate any discussion on which pilot was to perform the role of PF and PM, and the selection of a different speed during climb[69].

1.1.4.7 During the initial part of the Cruise (ie 10:45:30 - 11:04:45), after level off at FL135, the expected cruise speed (under those non-icing conditions) was 230 knots. The Captain asked to set the Power Levers (PL) out of notch and mentioned about turbulence. The PLs were retarded and IAS stabilized at 186 knots. Flying with PL out of notch was a variation from ATR FCOM, however such variation is permissible if it is undertaken for a specific reason, and is announced and acknowledged. Captain took over PF role (with no specific announcement). During this part of flight Captain took PM and PF roles on his own with no announcements, and FO(A) seemingly followed implicitly. At the beginning of the cruise, FO(B) on the jump seat mentioned the expected cruise parameters, including single engine ceiling ie 18,300ft. However they did not discuss details of single engine strategy. The flight remained uneventful till 11:04:55[70]. Figures here under show relevant portions of QRH.

[69] Extracted from DFDR, CVR, QRH and Crew Action Analysis Report.
[70] Same as above.

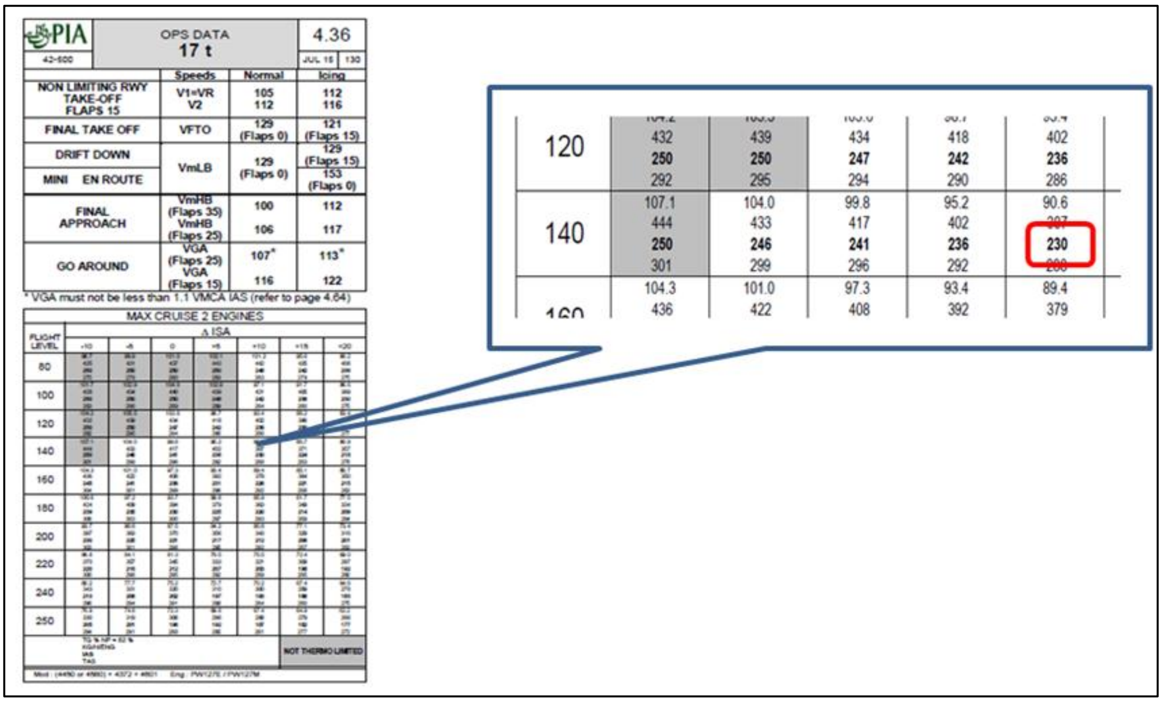


Figure 1-8: QRH Ops Data 17t (4.36) Max Cruise 2 Engines

Figure 1-9: QRH Ops Data (4.61) Single Engine Gross Ceiling (ft) Normal Conditions (Flaps 0)

1.1.5 Middle Stage (Series of Technical Malfunctions) (11:04:45 - 11:13:08).

Part 1: Focus on PEC-1

1.1.5.1 While cruising at FL135 (DFDR recorded altitude of 13,463ft) and an IAS of 186 knots, the Captain at 11:04:45 attempted to make an announcement for the passengers. During the announcement at 11:04:56, the Propeller Electronic Control of the left side propeller (PEC-1) Single Channel fault appeared, followed by PEC-1 Fault. Same was announced by FO(A) and acknowledged by the Captain. The Captain's announcement was interrupted, however during the interruption, he asked for opening the Checklist / QRH. FO(A) asked to bring the power back and asked from the Captain to call the Engineer in the cabin (who was travelling as a passenger). Reduction in power resulted in drop in the IAS gradually to 146 knots.

At 11:05:51 once completed with the announcement the Captain asked again to read the Checklist. PEC-1 reset was attempted at 11:06:34[71].

1.1.5.2 After reset of PEC-1, FO(A) said to put the Condition Lever (CL) to Auto. The PEC-1 fault came on for the second time. FO(B) on the jump seat emphasized to put first the CL to 100% over ride and then reset the PEC. Captain emphasized to open up the Checklist / QRH and read that again[72].

1.1.5.3 In the background the latent pre-existing technical anomalies had led to a sequence of technical malfunctions. A fracture of one blade of 1st stage power turbine (PT-1), inside No 1 Engine, had already occurred (during previous flight). The resulting unbalanced power turbine generated vibrations leading to the distress of No 6 bearing and its seal. During this stage of flight (from 10:56:00 onwards), oil contamination had occurred at No 6 bearing, due to damage to its seal. The resulting metallic contamination migrated (most likely) to the OSG pilot valve, increasing drag on the OSG valve[73]. Due to the missing OSG pilot valve pin and the increased pilot valve drag from contamination, it drained one part of the overspeed line, which decreased the pressure inside OSG at the PVM's protection valve. From 11:04:44, this decrease of pressure moved the protection valve to an intermediate state between the protected mode and the unprotected mode. The blade pitch angle was not under the control of the PEC anymore but rather under the control of the OSG. The blade pitch angle increased and there was an unusual decrease in the propeller speed. No 1 Propeller speed (Np-1) decreased from a normal in flight value of 82%, it dropped to 62%. It was not a propeller system in flight setting value[74].

1.1.5.4 After the Checklist actions were performed, the engine status was not announced. There was state of uncertainty in ascertaining the required actions as well. FCOM recommends one resetting attempt of the PEC, whereas the crew attempted three resets and finally turned the PEC to OFF position. Furthermore the FCOM does not require power modulation. The CL was most probably moved to 100% override position. Its position / movement is not recorded in DFDR. The required result (as per the aircraft design and depicted in FCOM) was not possible because the technical malfunctions (that had already occurred, and were continuing), were unusual. At time 11:07:26, FO(A) cautioned for IAS reduction. During all this time both Power Levers, (which were retarded earlier, by FO(A) while Captain was making the passenger announcement), were progressively advanced again. IAS gradually started to increase[75].

1.1.5.5 Figure hereunder shows relevant portions of FCOM.

[71] Extracted from DFDR, CVR, QRH, CVR & DFDR data Animation and Crew Action Analysis Report.
[72] Same as above.
[73] There may have been some contamination available in engine oil prior to the IFSD, Ref Tech Finding No 12.
[74] BEA2016-0760_tec34, Most Probable Scenario on the Powerplant #1 Behavior, dated 26 November 2018, and discussion / input of BEA and NTSB.
[75] Extracted from DFDR, CVR, QRH, CVR & DFDR data Animation and Crew Action Analysis Report and discussion / input of BEA.

ATR F.C.O.M.	PROCEDURES FOLLOWING FAILURE	2.05.02	
		P 16	001
	POWER PLANT		DEC 10

R **UNCOMMANDED 100% NP ON ONE OR TWO PROPELLERS**

PROCEDURE

R **UNCOMMANDED 100% NP ON ONE OR TWO PROPELLERS**

R CL 1 + 2 .... 100% OVRD

PEC SGL CH

ALERT

CONDITION	VISUAL	AURAL
Anomaly detection on either PEC channel	- SGL amber light on central panel	NIL

PROCEDURE

PEC SGL CH

DO NOT RESET PEC IN FLIGHT - NO SPECIAL CREW ACTION
ANTICIPATE A PEC FAULT AT LANDING
MAINTENANCE IS REQUIRED

COMMENTS
- In case of PEC FAULT at landing :
  . do not set PLs below FI before nose wheel is on the ground
  . do not use reverse on affected engine

Figure 1-10: FCOM PEC SGL CH

ATR F.C.O.M.	PROCEDURES FOLLOWING FAILURE	2.05.02	
		P 17	001
	POWER PLANT		DEC 09

PEC FAULT

ALERT

CONDITION	VISUAL	AURAL
Anomaly detection on both PEC channels	- MC light flashing amber - ENG amber light on CAP - Associated FAULT light on central panel	SC

PROCEDURE

PEC FAULT

■ **If in short final approach (below 400 ft RA)**
GO AROUND procedure (2.03.17) .... APPLY

R ● **Above 400 ft or when adequate**
CL affected side .... 100% OVRD
PEC affected side .... RESET
■ **If successful**
CL affected side .... AUTO
■ **If unsuccessful**
PEC affected side .... OFF
AVOID sudden PL movements
● **Before landing**
CL NON AFFECTED .... 100% OVRD
Reverse is not available on affected side.
TAXI ON BOTH ENGINES
R Note: ACW BTC may be check closed in order to avoid the loss of ACW bus on ground.

COMMENTS
- Expect NP blocked at 102.5% (overspeed stop)
- Do not set PLs below FI before nose wheel is on ground.
- Reverse is not available because the secondary low pitch stop retraction solenoïd is disabled that forbids the blades to go below the low pitch protection.
- When the PEC is deenergized a NP cancel signal is sent to the EEC to cancel the EEC NP governing mode (that controls the NP speed at 850 rpm) on ground.
- ACW may be lost if NP drops below 65.5% on the affected engine.
- CL is set to OVRD to minimize NP transient when PEC is switched OFF/RESET.

Figure 1-11: FCOM PEC FAULT

1.1.5.6 At 11:08:33 while the Captain was PF, FO(B) (at the jump seat) asked Captain to have change over with the trainee FO(A) (who was sitting on the right seat). Captain acknowledged and allowed the changeover. By this time both PL had already been advanced (left and right 61.8º and 60.4º respectively) and resultantly the torque had increased (left and right 73.2% & 61.2% respectively). IAS had gradually increased to around 160 knots. From 11:08:37 to 11:08:50 changeover of FOs was executed. During this time aircraft was flying on a heading of 149º, at an altitude of 13,467ft AMSL[76].

1.1.5.7 At 11:08:54 Captain called the engineer who was also present in the flight. At 11:09:27, Captain asked Cherat Approach for change over to Islamabad. Cherat Approach cleared them to change over to Islamabad Approach and asked to call once 05 miles short of TIPOM. Engineer joined the cockpit discussion at 11:10:05. The aircraft was flying at 13,468ft AMSL, on heading 149º and IAS gradually increased to 196 knots[77].

1.1.5.8 During all this while, Np-2 remained at 82% however Np-1, which at the beginning of the technical anomalies was at around 82%, dropped first to around 62% and then increased again to around 69% (102% is the normal OSG set point expected with the PEC turned off). Np-1 was not being regulated to the prescribed in flight setting value. Crew actions, ie power modulation and three reset attempts, and related conversation reflected that there was an overall state of uncertainty in the understanding of the situation. Three PEC reset attempts did not have any impact on the sequence, nature and extent of technical malfunctions going on in the

[76] Extracted from DFDR, CVR, QRH, CVR & DFDR data Animation and Crew Action Analysis Report.
[77] Same as above.

background. Power that was retarded earlier resulted in depletion of IAS, however once the power was advanced, the IAS started to increase. Pilots did not announce this anomaly on RT. There was no discussion recorded in CVR about unusual behavior of Np-1[78].

Part 2: Engine In Flight Shutdown & Feathering

1.1.5.9 At 11:10:33, a transient sound was heard, which was followed by a sudden abnormal noise. After 01 sec (11:10:34), Torque-1 dropped from 75% to 0% & Torque-2 stayed at 75%, Np-1 increased rapidly from 61.5% to 102% & Np-2 stayed at 82%. Other related parameters of No 1 Engine (ie NH & NL) reduced too, however ITT increased. No 1 Engine torque reducing to zero, meant that the engine had failed. However, Np-1 increasing rapidly to 102% and increase in ITT (instead of decreasing) were unusual. At this time it is likely that during the No 1 Engine power loss the toes of the flyweights broke with the flyweights remaining in contact with the OSG valve. The new position of the valve inside the overspeed governor allowed the protection valve inside PVM to move onto the unprotected mode and the propeller speed increased (to a position that resulted in approximately 102% Np but with a compromised OSG). The overspeed governor seemed regulating again as a nominal overspeed governor. In fact, the valve of the overspeed governor operated stuck on one single broken flyweight[79].

1.1.5.10 At 11:10:38 Captain PF announced “engine gone”. Captain asked PM to set Power Management knob to MCT. The No 1 Engine was no longer producing power. Single Engine Operation procedure requires selection of MCT, however, as the PL was not in the notch position, the engine power would relate to PLA position only. Immediate action for Engine flame out was to retard power of the effected engine. At the time of No 1 Engine power loss, simultaneously the Captain PF retarded both power levers. Figures hereunder show relevant portions of FCOM[80].

[78] Discussion at BEA during November 2019 meeting / analysis at AAIB.
[79] BEA2016-0760_tec34, Most Probable Scenario on the Powerplant #1 Behavior, dated 26 November 2018, and discussion / input of BEA and NTSB.
[80] Extracted from DFDR, CVR, QRH, CVR & DFDR data Animation and Crew Action Analysis Report.

ATR F.C.O.M.	PROCEDURES FOLLOWING FAILURE	2.05.02		
		P 13	001	
	POWER PLANT			DEC 09

ENG FLAME OUT

ALERT

An engine flame out may be recognized by :
- sudden dissymmetry
- TQ decrease
- rapid ITT decrease

PROCEDURE

ENG FLAME OUT

PL affected side . . . . FI

■ **If NH drops below 30% (no immediate relight)**

CL affected side . . . . FTR THEN FUEL SO

■ **If damage suspected**

FIRE HANDLE affected side . . . . PULL

SINGLE ENG OPERATION procedure (2.05.02 page 1) . . . . APPLY

■ **If no damage suspected**

ENG RESTART IN FLIGHT procedure (2.05.02 page 8) . . . . APPLY

■ **If unsuccessful**

SINGLE ENG OPERATION procedure (2.05.02 page 1) . . . . APPLY

COMMENTS

- Shut down the engine if no immediate relight.
- The causes of engine flame out can generally be divided into two categories :
  . External causes such as icing, very heavy turbulence, fuel mismanagement. These causes, which may affect both engines can generally be easily determined and an immediate relight can be attempted.
  . Internal causes which as engine stalls or failures usually affect a single engine and are not so easily determined. In these cases, the engine is shut down then the cause of the flame out investigated. If it cannot be positively determined what caused the flame out, the need for engine restart should be evaluated against the risk or further engine damage or fire that may result from a restart attempt.
- If damage is suspected, as precautionary measure, the FIRE handle is pulled.

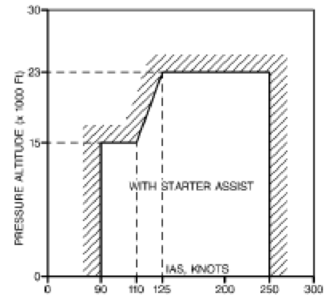
Figure 1-12: FCOM ENG FLAME OUT

ATR F.C.O.M.	PROCEDURES FOLLOWING FAILURE	2.05.02		
		P 8	001	
	POWER PLANT			APR 08

ENG RESTART IN FLIGHT

PROCEDURE

ENG RESTART IN FLIGHT



FUEL SUPPLY . . . . CHECK

CL . . . . FUEL SO

PL . . . . FI

CAUTION: After ATPCS sequence PWR MGT rotary selector must be set to MCT-position before engine restart in order to cancel propeller feathering.

ENG START ROTARY SELECTOR . . . . START A & B

EEC PB . . . . RESET if necessary or DESELECT if FAULT persists

START PB . . . . ON

● At 10 % NH

CL . . . . FTR

RELIGHT . . . . MONITOR

CL . . . . AUTO

PL . . . . ADJUST TO OTHER ENGINE

ENG START ROTARY SELECTOR . . . . AS RQD

SYSTEMS AFFECTED . . . . RESTORE

COMMENTS

- Engine relighting in flight is only guaranteed within the envelope and always necessitate starter assistance.
- The power may be restored immediately after relighting provided OIL TEMP > 0°C.
- Should the engine fail to light up within 10 seconds, select fuel to shut off, the ignition OFF and allow engine to be ventilated for 30 seconds minimum prior to making another attempt.

Figure 1-13: FCOM ENG RESTART IN FLIGHT

1.1.5.11 At this time Np-1 was 102% (instead of being commanded to feather). As engine was not delivering torque anymore, this caused drag and an asymmetric condition, more than what is usually expected in single engine flight envelop. This drag was estimated to be three times more than the value that is experienced during a usual single engine flight envelope when the propeller is in feather position. The directional control was catered by the Auto-Pilot. However as a consequence of high drag and reduced power there was a sudden depletion of IAS to about 154 knots. There was no conversation recorded in CVR to indicate that the cockpit crew had registered unusual behavior of Np-1, however, while following the engine shutdown checklist, an effort to feather the propeller indicated that it was known to the crew. At 11:10:56 it is inferred from other recorded data that the Condition Lever was moved to Fuel Shut Off position. Np-1 started to drop below 30% and became NCD within 08 sec. At 11:11:15 the Captain advanced the power of the No 2 Engine to 66.8% (torque-2 was at 68.5 and Np-2 was at 100%). The rate of depletion of IAS arrested / reduced[81].

1.1.5.12 During technical analysis it has been established that in the background, during this feathering attempt the blade pitch angle increased and the propeller speed decreased. At 11:11:05, Np-1 was below 25%. As a result of the reducing Np-1 and the broken flyweights, the force of the OSG spring pushed the plunger of the valve between the broken flyweights. From that time, the OSG was no longer

[81] Extracted from DFDR, CVR, QRH, CVR & DFDR data Animation and Crew Action Analysis Report.

operational with P_{OSG} (OSG line pressure) being continuously ported to P_S (supply pressure). During the feathering process, with the feathering solenoid, the protection valve moved to the protected mode position with the feathering solenoid porting P_{OSG} to P_D (drain pressure). Instead of staying in this position, the protection valve left the protected mode position and moved towards the unprotected mode position. CT scan images show there may have been externally introduced contamination near the feathering solenoid that may have caused the change in the protection valve position from the expected protected position. It has been established that there were debris found inside the PVM at overspeed line level, which possibly caused a change in the pressures at the protection valve[82].

Part 3: Unusual Increase of Propeller Speed

1.1.5.13 At 11:11:19, the aircraft was flying at 13,465ft AMSL, on heading 146º. Captain (PF) asked FO (B) (PM) to coordinate for a lower altitude (7,500ft AMSL) and also told for a Mayday Call. Np-1 stayed below 25% (at a value similar to that expected for a feathered propeller) for about 40 to 45 seconds only. During the coordination, meanwhile Np-1 started to increase again (initially at a slower rate i.e. from 11:11:19 to 11:11:45 from NC to about 50% in 26 seconds, and then at a very fast rate i.e. from 11:11:46 to 11:11:54 from about 50% to the range of 120 to 125% in 08 seconds). IAS had reduced to 148 knots. FO (B) coordinated for lower altitude, changed over to Islamabad Approach and reported position TYPO, but missed out the Mayday Call. Initially at 11:11:04 an altitude of 9,300ft AMSL was selected, and later on at 11:11:40 an altitude of 7,500ft AMSL was selected[83].

1.1.5.14 While FO (B) was undertaking coordination for a lower altitude. The initial rise of Np-1 went unnoticed; however at 11:11:50 there was an increase in noise (which was consistent with the rapid increase of propeller frequency). Captain was perturbed and asked about that sound. Intensity of noise further increased significantly at 11:11:54[84].

1.1.5.15 During technical analysis it has been considered most probable that in the background during the feathering process performed earlier, the slow movement of the protection valve had increased the time of the feathering process and began to remove the feather command allowing pitch decrease. With the decrease of the blade angle, the propeller speed began to increase, very progressively, up to the time when the propeller speed was sufficient for the driven main pump to reach its full pressure capacity. From that time, the blade pitch angle decreased quicker and the propeller speed increased more rapidly. As the blade pitch angle reached the low pitch in flight limitation (Np-1 around 120% for the conditions of the flight of the event), the Secondary Low Pitch Stop (SLPS) Protection entered into action and stopped further decrease of blade pitch angle. With a constant blade angle, the propeller speed followed the True Airspeed of the aircraft (between 11:11:53 and 11:12:15). Around 11:12:15, based on drag analysis, most likely the SLPS protection was overridden allowing blade pitch angle to further decrease. The blade pitch angle reaching low values at a high rotational speed generated immense drag[85].

1.1.5.16 At 11:11:54 FO(B) was PM and was coordinating with Islamabad Approach. The Captain PF, while being perturbed with the abnormal noise, (presumably not been able to correlate noise with unusual rise in Np-1), retarded power of No 2 Engine. At 11:11:58 the power was moved back from 66.8º to about 41.1º (and kept there for about 3 to 4 sec) and then at 11:12:15 was advanced to

[82] BEA2016-0760_tec34, Most Probable Scenario on the Powerplant #1 Behavior, dated 26 November 2018.
[83] Extracted from DFDR, CVR, QRH, CVR & DFDR data Animation and Crew Action Analysis Report.
[84] Same as above.
[85] BEA2016-0760_tec34, Most Probable Scenario on the Powerplant #1 Behavior, dated 26 November 2018.

71.2º within a total time span of about 16 to 17 sec (again presumably correlating that the noise did not reduce by reduction of power of No 2 Engine)[86].

1.1.5.17 At 11:12:14 Auto-Pilot (AP) got disengaged as per its design, most probably because of the efforts needed to maintain the target aircraft parameters. After this the directional control was required to be maintained by the Captain (PF) by manual input of the controls. At 11:12:15 the aircraft started to turn left and decelerate. The control input by the Captain was not enough to maintain direction. With further reduction in IAS, the control input requirement increased. The deflection of right aileron ranged between 60% to 70% and that of right rudder ranged between 30% to 40% of respective total deflection range. At 11:12:21, Stall warning was recorded in DFDR for 0.1 seconds. At this time the aircraft was at 13,338ft AMSL and 127 knots IAS. The aircraft continued to turn left, its altitude reduced to 12,782ft AMSL, and IAS further reduced to 122 knots. During this time Np-1 varied (initially decreased from 124% to 116.5% from 11:12:01 to 11:12:15 because of reduction in IAS, and later on, as SLPS protection was most probably overridden, it then increased again to 123%). This increase of Np-1 caused a corresponding increase in drag, contributing to speed reduction and hence increasing the difficulty in aircraft controllability[87].

1.1.5.18 Once the AP was disengaged, IAS around 120 knots the Captain, in spite of considerable control inputs towards the right side, was unable to control left turn. By 11:12:35 the aircraft had turned left by 70º (from a heading of 154º to about 084º) and was still turning left. Np-1 had increased again to the range of 123%. At 11:12:36, stall warning blew for 1.2 seconds, and stick shaker was also activated. The aircraft was at 12,953ft AMSL, at an IAS of 125 knots. At 11:12:38 Captain retarded PLA-2 to about 33º, and at 11:12:44 advanced it again to 54º (about)[88].

1.1.5.19 At 11:12:24 it is inferred from other data and pilot conversation that there may have been another attempt to feather the left propeller (however possibility of a restart attempt cannot be ruled out as well). This feather attempt confirms that the crew was monitoring the unusual behavior of Np-1, but was unable to understand its reasons and effects. The CL No 1 was set out of FSO position. The sequence of technical malfunctions was unusual, and the left propeller was not behaving as per its design. During the feather attempt consequently at 11:12:27 DFDR recorded an increase in fuel flow of No 1 Engine, which had resulted because of the movement of CL No 1 outside FSO position. During this time, the blade angle may have decreased below the SLPS while Np-1 was varying in the range of 120% to 125%. At 11:12:44 DFDR has recorded slight rise in No 1 Engine ITT[89].

1.1.5.20 The state of No 1 Engine and its propeller was very unusual and uncertain. It was not possible for the cockpit crew to understand the nature and extent of the technical malfunctions occurring inside No 1 Engine and its propeller. Such variation of Np-1 (initially increasing up to the range of 120% to 125%, staying in that range for a about fifteen seconds, then gradually reducing to around 116% with reduction in the IAS, and after 11:12:33 increasing again to higher range of 123%) was not understandable to the Cockpit crew. The captain remained perturbed. The power modulation of No 2 engine by the Captain (ie first retarding the power from 66.8º to 41.1º and advancing to 71.2º, and then after a while retarding again to 32.7º and advancing again to 54.0º) reflect a possible effort to respond to the unusual sound (by rise in Np-1) and asymmetric condition due to the

[86] Extracted from DFDR, CVR, QRH, CVR & DFDR data Animation and Crew Action Analysis Report.
[87] Same as above.
[88] Same as above.
[89] Same as above.

high drag value. The crew did not try to trade off altitude with speed[90].

1.1.5.21 They did not consider pulling of fire handle at this stage (as the indications / alerts related to Fire or Severe Mechanical damage had not appeared). The possibility of a restart attempt is less likely than a feather attempt[91]. The cockpit crew most probably could not register the slight rise in ITT (as has been identified in DFDR), or (if yes) may not have understood that as a need for pulling of the fire handle. Pulling the fire handle would have prevented fuel flow rise when CL was set out of FSO. It was not possible to ascertain the likely outcome of this action, However, keeping in view the most probable states of contamination inside PVM having its protection valve moved to unprotected mode, and OSG both flyweight toes broken, it was considered very unlikely that the fire handle action could have feathered the propeller[92]. At 11:12:44 blade pitch angle may have decreased further up to a point where the power generated by wind-milling propeller was lower than power absorbed by the engine and it later moved to stable physical position. Np-1 decreased below 25% and then may have stabilized lower than 5%, a blade pitch resulting in a drag value lower than what was experienced during the previous state ie Np-1 range of 120% to 125% RPM. Relevant portions of FCOM regarding Engine Restart in Flight and Severe Mechanical Damage to the Engine, are produced hereunder: -

ATR F.C.O.M.	PROCEDURES FOLLOWING FAILURE POWER PLANT	2.05.02 P 1 001 AUG 15

PROCEDURE

SINGLE ENG OPERATION

LAND ASAP
PWR MGT .... TO if necessary then MCT
FUEL PUMP affected side .... OFF
DC GEN affected side .... OFF
ACW GEN affected side .... OFF
PACK affected side .... OFF
BLEED affected side .... OFF
APM (if installed) .... OFF
TCAS (If installed) .... TA ONLY
OIL PRESSURE ON FAILED ENGINE .... MONITOR

Note: In icing conditions, FLAPS 15 will be selected to improve drift down performances and single engine ceiling.

Note: Refer to QRH pages (4.61) and (4.62) to determine single engine gross ceiling.

Note: If during the flight, a positive oil pressure has been noted on the failed engine for a noticeable period of time, maintenance must be informed.

Note: monitor fuel balance. Recommended operational maximum fuel unbalance is 200 kg (440 lb).

- **When FUEL CROSS FEED is required**

FUEL PUMP affected side .... ON
FUEL X FEED .... ON
FUEL PUMP on operating ENG .... OFF

- **For approach**

MAX APPROACH SLOPE for Steep Slope Approach 5.5°
BLEED NOT AFFECTED .... OFF
CL live engine .... 100% OVRD
V APP .... NOT LESS THAN VGA
■ If affected engine NP above 10%
V APP .... NOT LESS THAN LDG SPEED+ 10kt
■ If V APP is increased
LDG DISTANCE .... MULTIPLY BY 1.13

Note: Refer to part 4 to determine VGA, and landing distance.

Note: At touch down, do not reduce below FI before nose wheel is on the ground.

COMMENTS
- Refer to section Procedures and Techniques for fuel unbalance.
- For approach and landing, comply with Procedures and Techniques, Flight Patterns sub-section 2.02.10.

Figure 1-14: FCOM Single Eng Operation

ATR F.C.O.M.	EMERGENCY PROCEDURES POWER PLANT	2.04.02 P 1 001 OCT 12

IN FLIGHT ENG FIRE OR SEVERE MECHANICAL DAMAGE

ALERT

CONDITION	VISUAL	AURAL
Fire signal	- MW light flashing red - Associated ENG FIRE red light on CAP - red light in associated FIRE handle - FUEL SO red light in associated CL	CRC

PROCEDURE

IN FLIGHT ENG FIRE OR SEVERE MECHANICAL DAMAGE

PL affected side .... FI
CL affected side .... FTR THEN FUEL SO
FIRE HANDLE affected side .... PULL
■ **If oondition persist after 10 seconds**
AGENT 1 affected side .... DISCH
■ **If oondition persist after 30 seconds**
AGENT 2 affected side .... DISCH

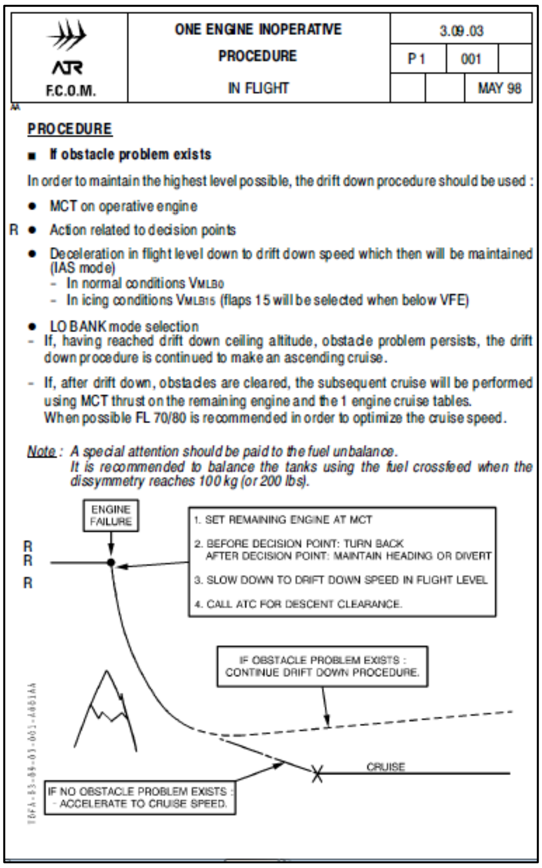
LAND ASAP
SINGLE ENG OPERATION procedure .... APPLY

COMMENTS

- Fire handle remains illuminated as long as a fire is detected.
- The 10 seconds delay allows to reduce nacelle ventilation in order to increase the agent effect.
- CRC stops when depressing MW. May be cancelled by use of EMER AUDIO CANCEL SW.
- Do not attempt to restart engine.
- Refer to SINGLE ENG OPERATION procedure.

Figure 1-15: FCOM in Flight Eng Fire or Severe Mechanical Damage

[90] AAIB analysis based on DFDR, CVR, QRH, CVR & DFDR data Animation and Crew Action Analysis Report.
[91] AAIB analysis based on DFDR, CVR, QRH, CVR & DFDR data Animation and Crew Action Analysis Report.
[92] Discussion at BEA during November 2019 meeting / analysis at AAIB. BEA2016-0760_tec34, Most Probable Scenario on the Powerplant #1 Behavior, Dated 26 November 2018, and discussion / input of BEA and NTSB.



ATR F.C.O.M. | ONE ENGINE INOPERATIVE PROCEDURE IN FLIGHT | 3.09.03 | P 1 | 001 | MAY 98

PROCEDURE

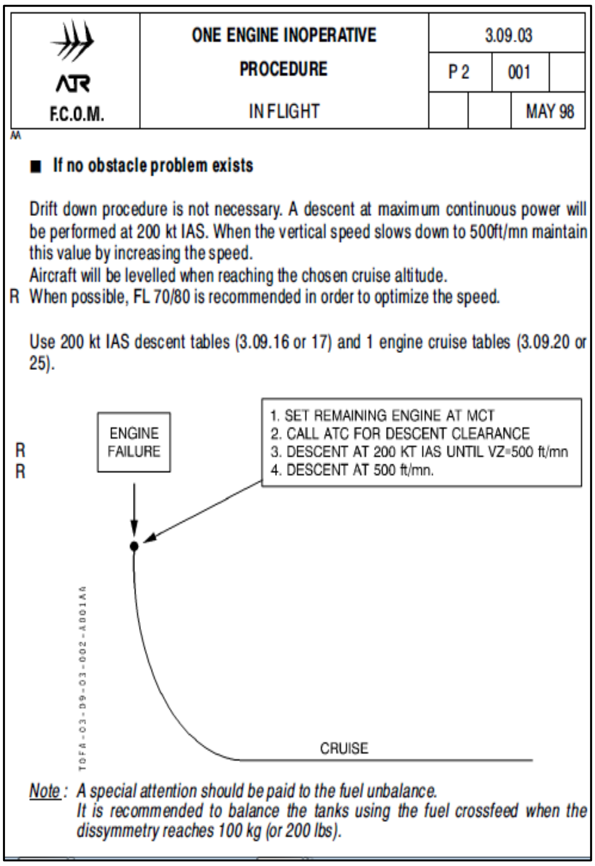
- **If obstacle problem exists**

In order to maintain the highest level possible, the drift down procedure should be used :

- MCT on operative engine
- R Action related to decision points
- Deceleration in flight level down to drift down speed which then will be maintained (IAS mode)
  - In normal conditions VMLB0
  - In icing conditions VMLB15 (flaps 15 will be selected when below VFE)
- LO BANK mode selection
- If, having reached drift down ceiling altitude, obstacle problem persists, the drift down procedure is continued to make an ascending cruise.
- If, after drift down, obstacles are cleared, the subsequent cruise will be performed using MCT thrust on the remaining engine and the 1 engine cruise tables. When possible FL 70/80 is recommended in order to optimize the cruise speed.

Note : A special attention should be paid to the fuel unbalance. It is recommended to balance the tanks using the fuel crossfeed when the dissymmetry reaches 100 kg (or 200 lbs).

Figure 1-16: FCOM Single ENG - Obstacle Problem



ATR F.C.O.M. | ONE ENGINE INOPERATIVE PROCEDURE IN FLIGHT | 3.09.03 | P 2 | 001 | MAY 98

- **If no obstacle problem exists**

Drift down procedure is not necessary. A descent at maximum continuous power will be performed at 200 kt IAS. When the vertical speed slows down to 500ft/mn maintain this value by increasing the speed.
Aircraft will be levelled when reaching the chosen cruise altitude.
R When possible, FL 70/80 is recommended in order to optimize the speed.

Use 200 kt IAS descent tables (3.09.16 or 17) and 1 engine cruise tables (3.09.20 or 25).

Note : A special attention should be paid to the fuel unbalance. It is recommended to balance the tanks using the fuel crossfeed when the dissymmetry reaches 100 kg (or 200 lbs).

Figure 1-17: FCOM Single Engine - No Obstacle

Part 4: Stall / Uncontrolled Flight Condition

1.1.5.22 Because of variable and high drag value (presumably due to unusual Np-1 variation) and less power selection (along with inappropriate modulation) by the Captain (PF), the aircraft was just short of a stalled condition. The stall warning and stick shaker were activated. The advancement of power of No 2 Engine was coupled with excessive right rudder input (to counter the asymmetric condition). This coincided with last abrupt drop (at 11:12:44) in the propeller speed[93] (caused due to presumably unusual technical malfunctions). A considerable amount of drag was eliminated from the left side of the aircraft. At this time the control inputs required in an effort to maintain the directional control became surplus to the requirement, resultantly the aircraft showed sudden yaw to the right side, and entered into a stalled / uncontrolled flight condition. During this unexpected condition (rapid descend and a roll) the aircraft lost about 5,100ft altitude (ie from 13,450ft AMSL at the time of engine flame out to 8,350ft AMSL). The aircraft first rolled right by about 360º and then further rolled by another about 90º and then subsequently rolled left to a wings level state. Figure hereunder provides flight path and lateral view of this part of flight.

[93] Review / analysis of DFDR Data, and CVR recording at AAIB Pakistan.

Figure 1-18: Flight Path and Selected Lateral View

1.1.5.23 This stalled / uncontrolled flight condition lasted from 11:12:45 to 11:13:09 when the aircraft attained a wings level state, and further at 11:13:18 VVI approached zero. During this condition the control inputs in the beginning indicated a significant rudder deflection to the right. This right deflection corresponds to the right pedal force applied by the Captain (required as the AP was disengaged) that had become suddenly surplus to the requirement at the time of abrupt drop in the Np-1 and depletion of drag from the left side. The power lever was advanced up to 86.8º. Right rudder extreme position was eased out (that had lasted for about seven seconds) and was then moved to around neutral position by the Captain. The aileron control continuously showed left deflections to counter the roll towards right side. However the elevator control mostly showed positive (pitch up) deflection occasionally touching the extreme position. During this part of flight the IAS increased just above 200 knots, and the aircraft flight path showed a right turn, on a heading of about 163º. Relevant portion QRH / FCOM is produced hereunder: -

ATR F.C.O.M.	EMERGENCY PROCEDURES / MISCELLANEOUS	2.04.05 / P 11 / 001 / DEC 13

RECOVERY AFTER STALL OR ABNORMAL ROLL CONTROL

CONTROL WHEEL .... PUSH FIRMLY

■ **If flaps 0° configuration**

FLAPS .... 15°
PWR MGT .... MCT
CL 1 + 2 .... 100% OVRD
PL 1 + 2 .... NOTCH
ATC .... NOTIFY

■ **If flaps are extended**

PWR MGT .... MCT
CL 1 + 2 .... 100% OVRD
PL 1 + 2 .... NOTCH
ATC .... NOTIFY

Note: This procedure is applicable regardless the LDG GEAR position is (DOWN or UP).

Figure 1-19: FCOM Recovery after Stall or Abnormal Roll Control

1.1.5.24 This condition was very abnormal and had immense psychological impact[94]. Their breathing was abnormal (hyperventilating) and their voices were trembling. The crew actions were not precise during the recovery. Possible cross-controlling of the elevator control resulted in pitch disconnect. With only one side of elevator available, along with considerable aerodynamic degradation, the degree of difficulty for the aircrew may have further increased. The DFDR did not indicate a specific crew effort to pitch down the aircraft. However, as a combined effect of stick pusher and crew actions, a slight pitch down defection of elevator control has been recorded at the end of this part of flight. Their voices and breathing indicated that they were extremely nervous and traumatized during this part of flight.

1.1.6 **Final Stage (11:13:09 - 11:20:37).**

1.1.6.1 At 11:13:09 while the aircraft had just recovered from the stalled / uncontrolled flight condition, PLA-2 was at 86.2º, (torque was 89% and Np-2 was 100%), VVI showed a reduction in the rate of descend (from 6,000 fpm to a level off state at 11:13:18). IAS was around 200 knots and heading was 163º. At 11:13:11 there was a reduction of PLA-2 to about 66º for a very brief duration and then the power was continuously advanced progressively. At this time, according to the technical analysis, the blade pitch angle may have stabilized to a physical location consistent with lower power generation by the propeller that could be absorbed by the engine. Np-1 had stabilized lower than 5%, and a blade pitch angle close to the low pitch in flight. At this position the generated drag value was around 2,000 lbf. This drag was about seven times more than the drag a propeller can usually produce (once in feather state) during a single engine flight envelope. The SLPS system is designed to control the maximum drag and is designed to mitigate such a catastrophic hazard[95]; however SLPS was most probably already overridden.

1.1.6.2 It has been established during advanced operational analysis that in this aerodynamically degraded state the aircraft was unable to fly a level flight. It could only fly in a gradual descend profile (IAS of 150 to 160 knots and a continuous descend of around 800 to 1000 fpm)[96]. However directional control was possible with right rudder and right aileron inputs of a substantial magnitude. Although the pilots were overwhelmed by the immense psychological impact of the uncontrolled flight condition, their conversation reflected that they were able to come out of that psychologically traumatic situation (to some extent) in about 20 to 30 seconds, after resuming the control of the aircraft[97].

1.1.6.3 The pilots were unable to judge the nature and extent of degradation in the aircraft's aerodynamic performance. At 11:13:19 FO(B) sitting on the right seat inquired about the power. PLA was progressively advanced. However, because of an unprecedented, off design, and a much degraded performance, the aircraft was continuously descending and IAS was gradually reducing, with a rate of descend of about 600 fpm. During this phase whenever the pilots attempted to reduce the ROD the aircraft IAS started to reduce.

1.1.6.4 At 11:15:44 FO(A) at the jump seat asked Captain that should he take LNAV. At 11:15:50 FO(A) repeatedly said don't do anything don't put the aircraft in bank. FO(A) told Captain to look at the altitude (which was decreasing) and asked to hold altitude at 5,200ft AMSL. Captain asked FO(B) to decrease the range at 100 miles. Captain (PF) was trying to hold the altitude. Crew requested shorter vectors with priority landing at BBIAP Islamabad along with mayday calls. ATC requested to switch on the transponder. While the crew were trying to understand and control the

94 AAIB analysis.
95 Based on NTSB input on discussion.
96 Meeting / discussion between AAIB / ATR and BEA in November 2019.
97 AAIB analysis.

situation, their entire conversation reflected a state of confusion and uncertainty, which was overwhelmed by discussion / direction by FO (A) on the jump seat and lack of leadership / decision making by the Captain.

1.1.6.5 At 11:15:51 the aircraft heading was 119º. With right control inputs the aircraft started to turn right, and at 11:17:20 the aircraft heading was 156º. This gradual right turn of about 37º indicated that the Captain may have considered a right turn to avoid mountains. However, there was no discussion to support this right turn. Captain was trying to fly to BBIAP Islamabad. With that intention they were trying to level off the aircraft, but in that bargain they were approaching the stalling speed and were losing the control effectiveness. All this while the aircraft was flying with Pitch Disconnect which probably brought in additional challenges for the aircrew in terms of aircraft handling and control authority.

1.1.6.6 After 11:17:20 the aircraft started to turn left again with an aim to reach BBIAP Islamabad. While the power lever was advanced to 81.7º, and the torque was 99.8%, but the IAS had gradually depleted to 156 knots. A gradually reducing control effectiveness, and an excessive (off design) drag of the left side of the aircraft, resulted in a corresponding increase in control input requirement. The aircraft was maintaining an altitude of 5,280ft AMSL. In this degraded (off design) performance of the aircraft, due to excessive drag of the left side of the aircraft, even with the torque of No 2 Engine at 99.8% the aircraft was unable to maintain a level flight. The Captain did not realize that the aircraft will not be able to cross the mountains.

1.1.6.7 At 11:18:45 stall warning horn blew again for 3.5 seconds. The aircraft altitude & IAS kept on decreasing (4,809ft AMSL ie 2,168ft AGL & 128 knots), and kept turning left with progressively increasing right control inputs from the cockpit crew. At 11:18:52 Terrain Avoidance Warning System (TAWS) alarm “terrain ahead, terrain ahead” blew due to low altitude (4,778ft AMSL ie 1,825ft AGL). At 11:19:02 TAWS alarm “Pull up” warning horn blew with further reduction of altitude (1174ft AGL). At 11:19:45 while the aircraft was 1,205ft AGL, Captain asked can we turn this aircraft.

1.1.6.8 At 11:20:23 the aircraft was continuously turning left, with progressively increasing right control inputs. The aircraft IAS was reducing through 120 knots and stalled at a low altitude of 4,280ft AMSL (850ft AGL). At 11:20:37 the last known flight parameters from DFDR suggest that the aircraft was maintaining heading 324°, altitude 3,659ft AMSL (284ft radio altitude), roll angle 90° (left wing down), pitch 23° nose down, and IAS 138 knots, prior to impact. The aircraft crashed on the base of mountain (lower than the ridge line by about 300ft) almost reciprocal to the originally desired track.

1.1.6.9 Various parameters like IAS, control deflections, VVI, altitude (AMSL, RA), aircraft heading, and No 2 Engine parameters (PLA, torque) for last part of flight are tabulated below: -

Time (UTC)	Speed (IAS)	Controls Deflection			VVI (Ft/Min)	Altitude		Hdg (°)	No 2 Eng	
		Left Aileron ± 15 (>0 RH Wing Down)	Elevator -24 +16 (>0 Nose Down)	Rudder ± 30 (>0 Turn Left)		AMSL (Feet)	RA (Feet)		PLA (°)	Torque (%)
11:13:09	200	-2.3	-8.6	-7.38	-6000	8553	4257	163	83	86.5
11:13:30	163	-3.06	-2.4	-11.19	+100	8334	4247	147	67	83.5
11:14:00	156	-4.44	-4.8	-13.3	-200	8005	4247	140	69	93.5
11:14:30	158	-5.46	-4.6	-12.54	-500	7506	4247	137	70	98
11:15:00	157	-5.32	-5.1	-12.3	-1000	7107	4250	139	**71**	**99**
11:15:30	150	-5.88	-5.5	-12.77	-400	6785	4247	130	**72**	**99.25**
11:16:00	153	-5.69	-6.5	-13.18	-1100	6399	4220	119	**73**	**99.75**
11:16:30	153	-5.15	-6	-14	-1000	6001	3941	131	**73**	**99.75**
11:17:00	158	-4.22	-5.5	-14.06	-1200	5489	3056	154	**73**	**99.75**
11:17:30	147	-5.91	-5.6	-14.47	-200	5290	2952	152	**75**	**99.75**
11:18:00	143	-7.05	-11.1	-15.64	-300	4993	2921	123	77	99.75
11:18:30	133	-8.16	-10	-22.03	-100	4833	2352	109	78	99.75
11:19:00	126	-6.5	-8.1	-27.89	-300	4707	1218	094	78	99.75
11:19:30	125	-8.31	-2.8	-27.95	-400	4503	1191	084	84	113.5
11:20:00	124	-7.81	1	-27.01	-400	4376	1218	069	84	114.75
11:20:30	120	13.93	-2.4	-19.69	-1100	4201	396	025	83	110
11:20:36	133	-1.52	-23	-23.26	-6000	3762	439	336	32	29.75

1.1.6.10 The torque values of No 2 Engine during this part of flight were sufficient enough to fly, cross over the mountains and land the aircraft with No 1 Engine IFSD (had the propeller been in feather condition, and had there been no additional drag on the left side of the aircraft presumably due to complicated technical malfunctions of No 1 Engine propeller system)[98].

1.2 **Injuries to Persons:** All 47 souls on board the aircraft (including 05 crew members and 42 passengers) were fatally injured[99].

1.3 **Damage to Aircraft:** The aircraft was completely destroyed as a result of the accident. There was no evidence (including terrorist activity, sabotage, in flight fire, and bird hit etc) of any other cause of destruction of the aircraft.

1.4 **Other Damages:** No other damage was observed on ground or to any other person as a result of this accident.

[98] AAIB analysis.
[99] PIA Passenger Manifest and post-crash Medical Report.

1.5 Personnel information.

1.5.1 There were three pilots in the cockpit during the entire period of flight. A Captain on the left seat, First Officer ‘A’ on the Co-pilot seat from take-off till 11:08:37 and then onwards First Officer ‘B’ on the Co-pilot seat till aircraft crash. The First Officer ‘A’ after this change over occupied jump seat. Salient details of experience and qualification of all the three cockpit crew are as under: -

Captain (PF at the time of Crash)					
Date of birth: 25 October 1973					**PIC**
License type (*date issued*): ATPL-1591 (issued 16 July 1995)					**Male**
Last medical examination (*date*) 17 August 2016 valid till 28 February 2017					
Medical limitation: Advised to reduce weight gradually					
Flight experience *(flight hours)*					
	Last 24 hours	Last 72 hours	Last 30 days	Last 90 days	Total
– All types	4:00	11:55	-	-	11265:40 hrs
– Accident type	4:00	11:55	-	-	1216:05 hrs
Dates of transition to:					
– Captain position	26 August 2015				
– Captain position on accident type	26 August 2015				
Pilot in Command time *(flight hours)*					
– All types	1316:20 hrs				
– Accident type	1216:05 hrs				
Second in Command time *(flight hours)*					
– All types	9949:20 hrs				
– Accident type	Nil				
Type ratings (*date issued and validity*)					
ATR42-500	17 August 2015				
Instrument rating					
– Date issued	17 September 2016				
– Validity	August 2017				
Trainings and checks					
	Year of accident (N)			N-1	N-2
– Recurrent Ground Training	Nil				
– Proficiency Check	17 September 2016				
– Line Check	7 August 2015				

First Officer B (PM at the time of Crash)					
Date of birth: 21 June 1990					**FO**
License type (*date issued*): CPL-3090 (11 March 2011)					**Male**
Last medical examination (*date*) 17 August 2016 valid till 31 August 2017					
Medical limitation: Nil					
Flight experience *(flight hours)*					
	Last 24 hours	Last 72 hours	Last 30 days	Last 90 days	Total
– All types	3:10 hrs	10:30 hrs	-	-	570:00 hrs
– Accident type	3:10 hrs	10:30 hrs	-	-	369:15 hrs
Pilot in Command time *(flight hours)*					
– All types	Nil				
– Accident type	Nil				
Second in Command time *(flight hours)*					
– All types	570:00 hrs				
– Accident type	369:15 hrs				
Type ratings (*date issued and validity*)					
ATR42-500 (P-2)	31 May 2016				
Instrument rating					
– Date issued	3 May 2016				
– Validity	April 2017				
Trainings and checks					
	Year of accident (N)	N-1	N-2		
– Recurrent Ground Training	18 December 2015				
– Proficiency Check	31 May 2016				
– Line Check	-				

First Officer A (at Jump Seat at the time of Crash)					
Date of birth: 14 May 1976					**FO**
License type (*date issued*): CPL-2398 (21 May 1998)					**Male**
Last medical examination (*date*) 6 September 2016 (valid till 31 March 2017)					
Medical limitation: Nil					
Flight experience *(flight hours)*					
	Last 24 hours	Last 72 hours	Last 30 days	Last 90 days	Total
– All types	3:10 hrs	7:50 hrs	-	-	1742:00 hrs
– Accident type	3:10 hrs	7:50 hrs	-	-	1416:00 hrs
Pilot in Command time *(flight hours)*					
– All types	Nil				
– Accident type	Nil				
Second in Command time *(flight hours)*					
– All types	1742:00 hrs				
– Accident type	1416:00 hrs				
Type ratings (*date issued and validity*)					
ATR42-500 (P-2)	14 February 2008				
Instrument rating					
– Date issued	27 February 2016				
– Validity	February 2017				
Trainings and checks					
	Year of accident (N)	N-1	N-2		
– Recurrent Ground Training	December 2015				
– Proficiency Check	16 September 2016				
– Line Check	16 September 2016				

1.5.2 The cockpit crew training / licensing records were consulted. Details of important aspects are discussed in relevant portion of Analysis in Section 2.

1.6 **Aircraft information:** As per operator, the mishap aircraft was being maintained in accordance with the regulations of Pakistan Civil Aviation Authority. Pertinent aircraft, engine and propeller maintenance and life information is as follows: -

Aircraft	
Aircraft Make & Model	ATR42-500
Registration Marking	AP-BHO
Manufacturer Serial No	663
Year of Manufacture	2007
Certificate of Airworthiness *(S No, expiry date)*	663, Expiry date 17 May 2017
Certificate of Maintenance Review prior to occurrence flight *(date, hrs, expiry date)*	29 June 2016 , 17903 hrs, 18110 cycles Expiry date 26 Dec 2016
Daily inspection prior to occurrence flight *(date, location)*	07 Dec 2016, Islamabad
Total Aircraft Hours prior to occurrence flight	18739:36 hours

No 1 Engine	
Engine S No	EB0259
Manufacturer	Pratt & Whitney, Canada
Engine Type	PW127E
Total Hours Flown prior to occurrence flight	16886 hrs
Date of Installation on AP-BHO	18 Nov 2016
Hours Flown Since Installation	94 hrs

No 1 Propeller	
Propeller S No	FR20070856
Manufacturer	Hamilton Sundstrand Corporation
Propeller Type	HS 568F-1
Total Hours Flown prior to occurrence flight	13236 hrs
Date of Installation on AP-BHO	20 Apr 2016
Hours Flown Since Installation	1252 hrs

No 2 Engine	
Engine S No	ED1112
Manufacturer	Pratt & Whitney, Canada
Engine Type	PW 127M
Total Hours Flown prior to occurrence flight	2767 hrs
Date of installation on AP-BHO	13 Jun 2015
Hours Flown since Installation	2673 hrs

No 2 Propeller	
Propeller S No	FR20061153
Manufacturer	Hamilton Sundstrand Corporation
Propeller Type	HS 568F-1
Date of Manufacturing	27 Nov 2006
Total Hours Flown prior to occurrence flight	13350 hrs
Date of installation on AP-BHO	12 Jun 2016
Hours Flown since Installation	934 hrs

1.6.1 **Type of Fuel Used:** The aircraft was refueled with JET A-1 fuel. The sample of the fuel taken from the source was tested for contamination. The fuel test reports did not reveal any abnormality[100].

1.7 **Metrological Information:** There was no significant weather on departure aerodrome en-route, and destination aerodrome, which could have possibly contributed to the accident. Weather information of BBIAP meteorological office issued before flight on 07 December 2016, and used by the cockpit crew during flight planning is appended below: -

[100] Aviation Fuel Jet A-1 Test Report dated 05 January 2017.

Sr. No.	Stations	Time (UTC)	Metar
1	Chitral	1000	18002KT 9999 SCT100 20/-03 Q1023 22%=
		1100	18002KT 9999 SCT100 19/-05 Q1022 19%=
2	Balakot	1000	00000KT 5000 HZ 22/03 29%=
		1100	00000KT 5000 HZ 20/06 RH42%=
3	Dir	1000	18002KT 9999 SCT035 23/~01 20%
		1100	18002KT 9999 SCT040 SCT100 19/-05 Q1022 19%=
4	M. Jabba	1000	00000KT CAVOK 13/-02 QBB SCT100 FEW200 36%=
		1100	00000KT CAVOK 12/M01 QBB SCT100 FEW200 36%=
5	Saidu Sharif	1000	00000KT CAVOK 22/02 28%=
		1100	00000KT CAVOK 22/02 28%=
6	Kakul	1000	00000KT 9900 FEW200 22/01 26%=
		1100	00000KT 9999 FEW200 21/02 29%=
7	M. Abad	1000	00000KT 6500 HZ FEW 200 21/04 34%=
		1100	00000KT 6500 HZ FEW 200 20/03 34%=
8	Peshawar	1000	05004KT 2100 HZ SCT200 25/08 Q1015 =
		1100	00000KT 2100 HZ SCT200 25/08 Q1014 =
9	Islamabad	1000	13004KT 1000 HZ NSC 24/10 Q1015.9 RH 42%=
		1100	13004KT 1000 HZ NSC 23/10 Q1016.1 RH 41%=

1.8 **Aids to Navigation and Communication:** The aircraft was equipped with navigation equipment (AHRS – Attitude and Heading Reference System, GNSS – Global Navigation Satellite System, VOR - VHF Omnidirectional Range / ILS – Instrument Landing System / MKR – Marker Beacon System, ADF – Automatic Direction Finding, Radio Altimeters, ADS – Automatic Dependent Surveillance etc) & communication equipment (VHF – Very High Frequency System, HF – High Frequency System, Audio Integrating System etc), in accordance with the aircraft certification requirements. The said systems were serviceable and no technical anomaly / failure was documented before the crash. Navigation & Communication facilities at the departure and destination aerodromes are as follows: -

1.8.1 **Chitral:** Aids to Navigation and Communications of Chitral airport as per Aeronautical Information Publication of Pakistan (AIP) are appended below: -

OPCH 2.17 ATS AIRSPACE

1. Designation and lateral limits	Circular area centered on 355310N/0714760E within a 5NM radius.
2. Vertical limits	SFC to 2000 FT
3. Airspace classification	C
4. ATS unit call sign Language(s)	CHITRAL Tower English
5. Transition altitude	-
6. Remarks	-

OPCH AD 2.18 ATS COMMUNICATION FACILITIES

Service designation	Call sign	Frequency	Hours of operation	Remarks
1	2	3	4	5
APRON	CHITRAL Tower	121.80 MHZ	NOTAM	-
TWR	CHITRAL Tower	122.50 MHZ	NOTAM	Primary Frequency

OPCH AD 2.19 RADIO NAVIGATION AND LANDING AIDS - NIL

TYPE OF AID	ID	Frequency	Hours of operation	Site of transmitting antenna coordinates	Elevation of DME transmitting antenna	Remarks
1	2	3	4	5	6	7

OPCH AD 2.20 LOCAL TRAFFIC REGULATIONS: Nil

OPCH AD 2.20.1 AIRPORT REGULATIONS: Nil

OPCH AD 2.20.2 TAXIING TO AND FROM STANDS: Nil

OPCH AD 2.20.3 PARKING AREA FOR SMALL AIRCRAFT (GENERAL AVIATION): Nil

OPCH AD 2. 20.4 PARKING AREA FOR HELICOPTERS: Nil.

OPCH AD 2.20.5: APRON - TAXIING DURING WINTER CONDITIONS: Nil

OPCH AD 2.20.6: TAXIING LIMITATIONS: Nil

OPCH AD 2.20.7: SCHOOL AND TRAINING FLIGHTS - TECHNICAL TEST FLIGHTS - USE OF RUNWAY: Nil

OPCH AD 2. 20.8 HELICOPTER TRAFFIC - LIMITATION: Nil

OPCH AD 2.20.9 REMOVAL OF DISABLED AIRCRAFT FROM RUNWAYS: When an aircraft is wrecked on a runway, it is the duty of the owner or user of such aircraft to have it removed as soon as possible. if a wrecked aircraft is not removed from the runway as quickly as possible by the owner or user, the aircraft will be removed by the aerodrome authority at the owner's or user's expense.

OPCH AD 2.21 NOISE ABATEMENT PROCEDURES: Nil

OPCH AD 2.22 FLIGHT PROCEDURES: Nil

OPCH AD 2.23 ADDITIONAL INFORMATION Nil.

OPCH AD 2.24 CHARTS RELATED TO AN AERODROME:
Aerodrome/ Heliport Chart - ICAO

Figure 1-20: Aids to Navigation and Communications of Chitral Airport

1.8.2 **BBIAP Islamabad:** Aids to Navigation and Communications of BBIAP Islamabad as per Aeronautical Information Publication of Pakistan (AIP) are appended below: -

AIP
Pakistan

AD 2.OPRN-5
31 DEC 16

OPRN AD 2.15 OTHER LIGHTING, SECONDARY POWER SUPPLY

1. ABN/IBN location, characteristics and hours of operation	-
2. LDI location and LGT *Anemometer location and LGT*	LDI at signal area. Anemometer on TWR.
3. TWY edge and centre line lighting	TWY edge lights
4. Secondary power supply / switch-over time	To all facilities at AD. Switch over time less than one minute.
5. Remarks	-

OPRN AD 2.16 HELICOPTER LANDING AREA: Nil

OPRN 2.17 ATS AIRSPACE

1. Designation and lateral limits	Islamabad Approach Area: TIPUR (3449N 07252.5E) - FATEH (3334.9N 07237.7E) - BELKO (330253N 0723738E) - CADIZ (3240N 07305E) - (3248N 07320E) - (3324N 07323E) - BATAL (3435N 07305E)
2. Vertical limits	From ground to FL250 within 25 NM From 4500FT to FL250 beyond 25 NM
3. Airspace classification	B within 25 NM of VOR
4. ATS unit call sign Language(s)	ISLAMABAD APP (English)
5. Transition altitude	12000 FT MSL
6. Remarks	24 Hours

OPRN AD 2.18 ATS COMMUNICATION FACILITIES

Service designation	*Call sign*	*Frequency*	*Hours of operation*	*Remarks*
1	2	3	4	5
APP	Islamabad APP	124.9 MHZ	H24	Primary frequency,
APP	Cherat APP	125.6 MHZ	H24	Primary frequency,
TWR	Chaklala Tower	123.7 MHZ	H24	Primary frequency,
	"	121.5 MHZ	H24	Emergency Frequency
	"	119.7MHZ	H24	Secondary Frequency
	Islamabad APP	125.5 MHZ	H24	Secondary Frequency
ATIS	ATIS	129.6 MHZ	H24	
BS	Radio Pakistan	1150 KHZ	HX	
G/A/G	Radio	5601 KHZ	H24	
G/A/G	Radio	2923 KHZ	H24	

OPRN AD 2.19 RADIO NAVIGATION AND LANDING AIDS

Type of aid. CAT of ILS (VAR VOR/ILS)	*ID*	*Frequency*	*Hours of operation*	*Site of transmitting antenna coordinates*	*Elevation of DME transmitting antenna*	*Remarks*
1	2	3	4	5	6	7
GP/TDME 30	Dots/Dashes	335 MHZ / CH40X	H24	333639.92N 0730629.53E	522M	
LLZ ILS CAT I	IRN	110.3 MHZ	H24	333728.90N 0730451.72E		
DVOR/DME	RN	112.1 MHZ / CH 58X	H24	333621.39N 0730733.37E	504.47M	

OPRN AD 2.20 LOCAL TRAFFIC REGULATIONS:

Due to parking space limitations, domestics / international operators are advised to plan their flights in a manner that prolonged ground stay is avoided as far as practicable.

Aircraft should avoid flying over the town and make a right hand circuit for RWY 30 and left hand for RWY 12.

Dumbells are available on the northern side of RWY 12/30 for turn maneuvers.

All pilots are to exercise extreme caution while landing and takeoff or turning about on dumbell and avoid short turn on dumbbells RWY-12.

All acft after landing from RWY 30 to make anti clock wise turn and after landing RWY 12 to make clock wise turn for back track.

Heavy bird activity around the airfield during dawn /dusk timings.

No aircraft Drone / RPV is permitted to fly within airspace of 1.5 NM radius centered at point 3342.50N 7301.10E. Helicopters operating from Heliports are to stay south of line joining points 334040N 730000E and 334300N 730420E.Ground / FL 070.

All aircraft arriving at BBIAP/Nur Khan are to carry sufficient fuel to cater for excessive delays due to frequent VIP/VVIP movements on short notice and extensive military flying or any contingency in addition to fuel requirements for commencement of a flight laid down in para 4.3.6 of ICAO Annex-6 (Operation of Aircraft) part-1.

ALTIMETER SETTING PROCEDURE

All arriving and departing aircraft will maintain QNH within 25 DME from Islamabad VOR/DME below transition altitude. Aircraft operating below transition altitude will change over to standard altimeter beyond 25 DME from Chaklala.

OPRN AD 2.20.1 AIRPORT REGULATIONS:

Marshaller assistance can be requested and further information about local regulations can be obtained from the TWR or surface movement control (SMC).

Regarding local regulation for the safe operation of aircraft on the apron, the information will be given to each aircraft by the TWR.

OPRN AD 2.20.2 TAXIING TO AND FROM STANDS:

Civil Aviation Authority **AMDT 02/16**

Figure 1-21: Aids to Navigation and Communications of BBIAP Islamabad

1.9 **Aircraft Communications:** The aircraft remained in contact with concerned ATC and radar during entire sequence of events. Two Mayday calls were also transmitted by the cockpit crew after the onset of emergency situation. Chitral ATC Tower[101], Cherat Approach[102] and Islamabad Approach Radar[103] Tape Extracts were retrieved for analysis.

[101] Chitral ATC Tower Tape Extracts.
[102] Cherat Approach Tape Extracts.
[103] Islamabad Approach Tape Extracts.

1.10 **Aerodrome information.**

1.10.1 Detailed aerodrome data of Chitral airport as per Aeronautical Information Publication of Pakistan (AIP) are appended below: -

AD 2.OPCH-4
12 OCT 17

AIP
Pakistan

OPCH AD 2.12 RUNWAY PHYSICAL CHARACTERISTICS

Designations RWY NR	True bearing	Dimensions of RWY (M)	Strength (PCN) and surface of RWY and SWY	THR coordinates	THR elevation and highest elevation of TDZ of precision APP RWY	Slope of RWY/SWY
1	2	3	4	5	6	7
02	27.00°	1768 x 30	16/F/C/Y/T Bitumen	355244.92N 0714743.44E	THR 1485.75 M /4874.51 FT	0.780% UP
20	207.00°	1768 x 30	16/F/C/Y/T Bitumen	355335.67N 0714815.96E	THR 1499.68 M /4920.21 FT	-

SWY dimension (M)	CWY dimension (M)	Strip dimension (M)	RESA dimension (M)	Arresting system	Obstacle Free Zone	Remarks
8	9	10	11	12	13	14
-	-	-	-	--		Rough patches/un even surfaces on RWY
		-		-		Rough patches/un even surfaces on RWY

OPCH AD 2.13 DECLARED DISTANCES (M)

Designations RWY NR	TORA	ASDA	TODA	LDA	Remarks
1	2	3	4	5	6
02	1768	1768	1768	1768	-
20	1768	1768	1768	1768	-

OPCH AD 2.14 APPROACH AND RUNWAY LIGHTS

Designations RWY NR	APCH LGT type LEN INTST	THR LGT colour WBAR	VASIS (MEH) PAPI	TDZM LGT LEN	RWY Centre line LGT Length, spacing, colour, INTST	RWY EDGE line LGT Length, spacing, colour, INTST	RWY End LGT colour WBAR	SWY LGT LEN (M) colour	Remarks
1	2	3	4	5	6	7	8	9	10
02	-	-	NIL						Nil.
20			NIL						Nil.

OPCH AD 2.15 OTHER LIGHTING, SECONDARY POWER SUPPLY

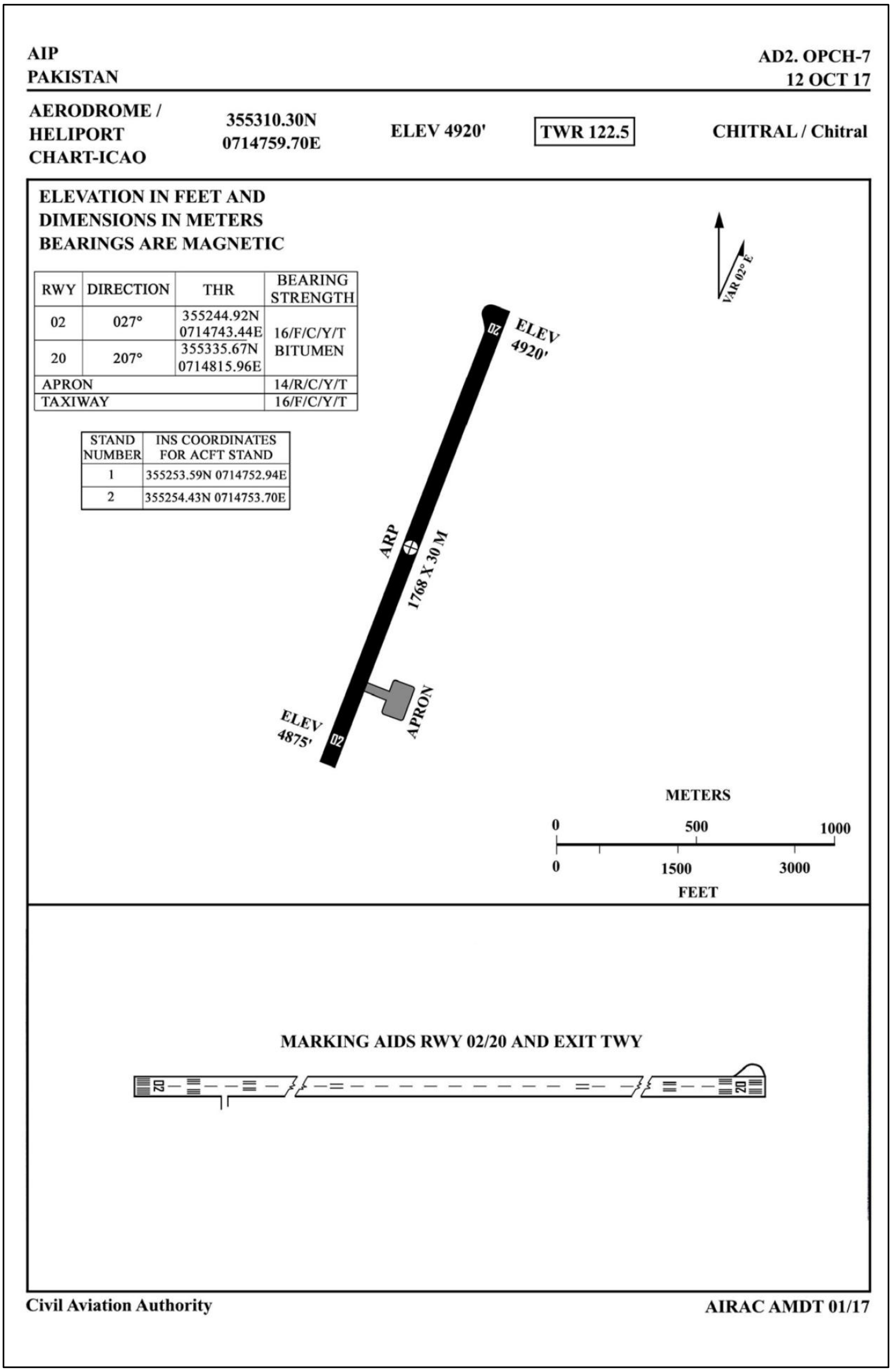
1. ABN/IBN location, characteristics and hours of operation	
2. LDI location and LGT **Anemometer location and LGT**	- -
3. TWY edge and centre line lighting	
4. Secondary power supply / switch-over time	-
5. Remarks	Nil.

OPCH AD 2.16 HELICOPTER LANDING AREA: Nil

AIRAC AMDT 01/17

Civil Aviation Authority

Figure 1-22: Aerodrome Data of Chitral Airport



RWY	DIRECTION	THR	BEARING STRENGTH
02	027°	355244.92N 0714743.44E	16/F/C/Y/T BITUMEN
20	207°	355335.67N 0714815.96E	
APRON			14/R/C/Y/T
TAXIWAY			16/F/C/Y/T

STAND NUMBER	INS COORDINATES FOR ACFT STAND
1	355253.59N 0714752.94E
2	355254.43N 0714753.70E

Figure 1-23: Aerodrome Data of Chitral Airport

1.10.2 Detailed aerodrome data of BBIAP Islamabad as per Aeronautical Information Publication of Pakistan (AIP) are appended below: -

OPRN AD 2.11 METEOROLOGICAL INFORMATION PROVIDED

1. Associated MET Office	ISLAMABAD
2. Hours of service ***MET Office outside airport operational hours***	H24 -
3. Office responsible for TAF preparation Periods of validity	Islamabad (09,12,18,24 HR)
4. Type of landing forecast ***Interval of issuance***	MET REPORT, 01 HR
5. Briefing/consultation provided	Personal consultation (P), telephone (T), self briefing (D)
6. Flight documentation ***Language(s) used***	Charts (C), Cross sections (CR), abbreviated plain language text (PL), Tabular forms (TB), English
7. Charts and other information available for briefing or consultation	Surface analysis (S), Upper air analysis (current chart)- U_{85}, U_{70}, U_{50}, U_{30}, U_{20}, Prognostic upper chart P_{85}, P_{70}, P_{50}, P_{40}, P_{30}, P_{20}. W (significant weather chart), SWH Significant weather high chart, SWM significant weather medium chart, SWL significant weather low
8. Supplementary equipment available for providing information	WXR, receiver for satellite picture (APT), Self Briefing Terminal, Telefax
9. ATS units provided with information	ISLAMABAD APPROACH/ TWR
10. Additional information (limitation of service, etc.)	Phone: (92) (51) 9502261, 92 (51) 9502267. Fax: (92) (51) 9280036. RWY visual range (RVR) not avbl.

OPRN AD 2.12 RUNWAY PHYSICAL CHARACTERISTICS

Designations RWY NR	*True bearing*	*Dimensions of RWY (M)*	*Strength (PCN) and surface of RWY and SWY*	*THR coordinates*	*THR elevation and highest elevation of TDZ of precision APP RWY*
1	2	3	4	5	6
12	118°	3291 x 46	111/F/C/W/T Bitumen	333721.41N 0730508.49E	THR 506M / 1660 FT
30	298°			333639.32N 0730642.38E	THR 505 M / 1657 FT

Designations RWY NR	*Slope of RWY/SWY*	*SWY dimension (M)*	*CWY dimension (M)*	*Strip dimension (M)*	*Obstacle Free Zone*
7	8	9	10	11	12
12	0.15% up till 1981 M from displaced THR	229	-	-	-
30	0.5% up till 762 M from displaced THR then .15%	213	-	-	-

Remarks: THR RWY 12 displaced 274 m. THR RWY 30 displaced 274 m. LCN 68 for 274 m (900') in the portion of runway before displaced THR RWY 12). Fair weather strip on both sides of RWY 12/30 not available due uneven level.

OPRN AD 2.13 DECLARED DISTANCES (M)

Designations RWY NR	*TORA*	*ASDA*	*TODA*	*LDA*	*Remarks*
1	2	3	4	5	6
12	3017	3246	3017	3017	-
30	3291	3504	3291	2743	-

OPRN AD 2.14 APPROACH AND RUNWAY LIGHTS

Designations RWY NR	*APCH LGT type LEN INTST*	*THR LGT colour WBAR*	*VASIS (MEH) PAPI*	*TDZM LGT LEN*	*RWY Centre line LGT Length, spacing, colour, INTST*	*RWY EDGE line LGT Length, spacing, colour, INTST*	*RWY End LGT spacing colour WBAR*	*SWY LGT LEN (M) colour*	*Remarks*
1	2	3	4	5	6	7	8	9	10
12	SALS 518 M LIH	GREEN	PAPI Left/3°	-	2743 M 30 M WHITE LIL	2743 M 60 M WHITE LIL. Last 600 M yellow	RED	Additional Stand by RWY edge lights. Sequence flasher	PAPI Max range 3 NM. Strobe LGT
30	PALS 900 M LIH	GREEN	PAPI Left/3°	-			RED		-

Strobe lights will be available when RWY 12 is in use or Bad WX or on request.

Figure 1-24: Aerodrome Data of BBIAP Islamabad

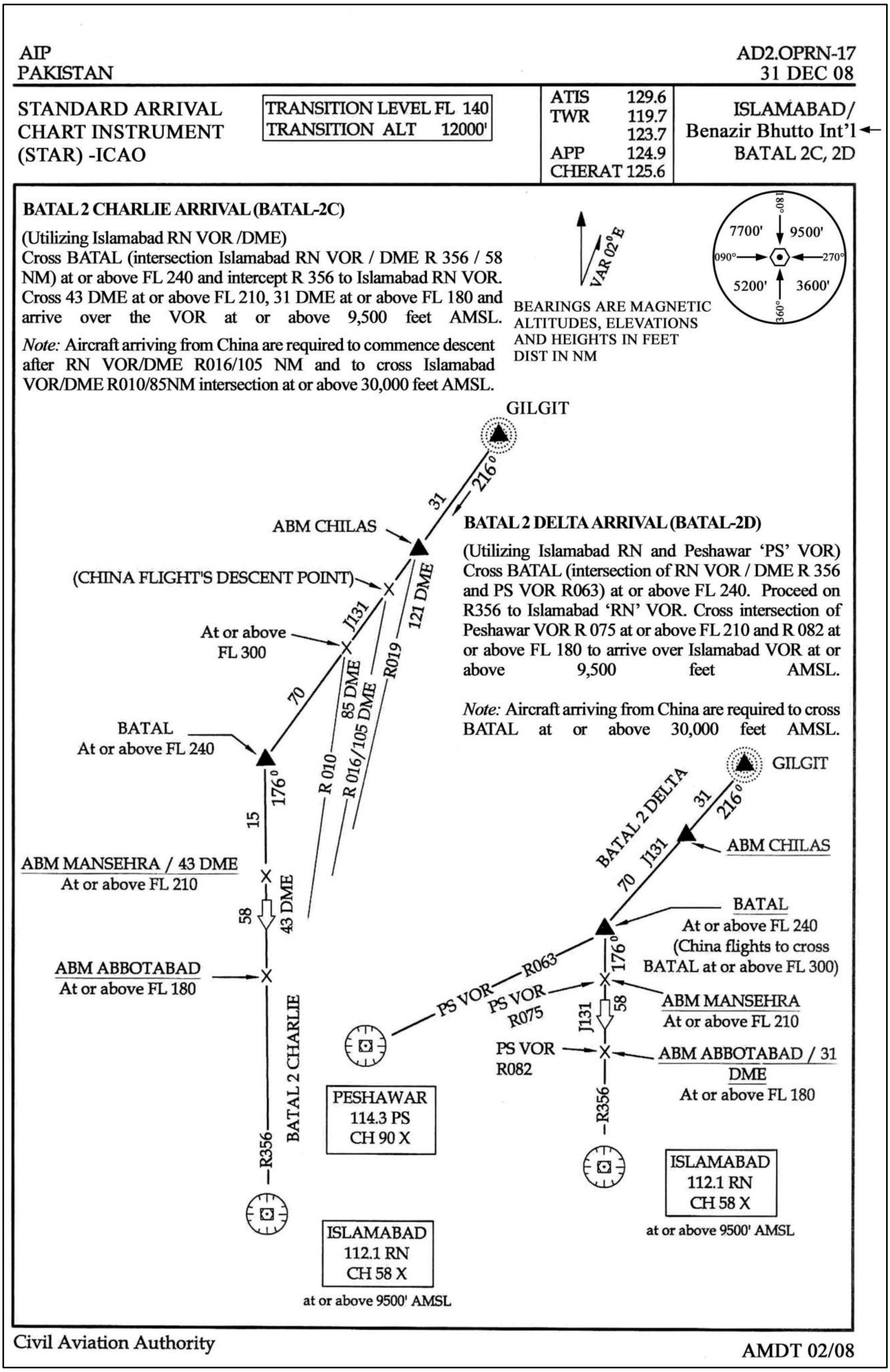


Figure 1-25: Aerodrome Data of BBIAP Islamabad

1.11 **Flight Recorders:** The aircraft was equipped with a solid state Digital Flight Data Recorder (DFDR) and a Cockpit Voice Recorder (CVR). The DFDR and CVR were brought to BEA France by an investigator from AAIB Pakistan on 16/12/2016 and both recorders were successfully downloaded by BEA experts. A team comprising of investigators from AAIB Pakistan, TSB Canada and BEA France performed a preliminary examination of the recorded voice and data. The CVR and DFDR were synchronized and the UTC time in DFDR was used as a standard reference throughout the investigation process. The downloaded data / information were extensively utilized to re-construct the flight profile along with the engine parameters for analysis[104]. Technical details of both recorders are as under: -

Recorder	OEM / Model No	Part No	Serial No
DFDR	L3-COM FA2100	2100-4043-00	000346991
CVR	L3-COM FA2100	2100-1020-02	000749572

Figure: 1-26
Digital Flight Data Recorder

Figure: 1-27
Cockpit Voice Recorder

1.12 **Wreckage and Impact Information:** The last known flight parameters from DFDR suggest that the aircraft was maintaining heading 324°, altitude 3,659ft AMSL (284ft radio altitude), roll angle 90° (left wing down), pitch 23° nose down, and IAS 138 knots, prior to impact. Rescue work started immediately by local populous and subsequently by rescue teams which may have resulted in slight movement / shifting of wreckage from last impact position, however, overall the wreckage remained intact at crash site for analysis.

1.12.1 **Impact Information:** The wreckage site indicated that the aircraft was at a high angle low speed when it impacted the mountain shoulder. Overview of the wreckage spread at crash site is depicted in figure hereunder: -

[104] BEA2016-0760_tec02 FDR and CVR Analysis Report dated 21 December 2016.

Figure 1-28: Overview of the Wreckage Spread at Crash Site

1.12.2 **Wreckage Review:** The crash site (a small valley) was surrounded by hills with general elevation of about 3,500ft to 4,000ft AMSL. The wreckage was spread in approximately 5,000 square meters with major debris portion located around the Main Impact Point (MIP). Owing to aircraft momentum and impact on terrain wreckage parts were found buried in the ground. The sign of heavy post impact fire were visible in entire wreckage except on few major parts like remaining portions of wings (Left, Centre and Right), No 1 Propeller and tail portion of fuselage which were detached and were less affected by ground fire. The entire fuselage including cockpit area was totally crippled and burnt beyond recognition. Broad overview is as follows: -

Figure: 1-29
Rear Fuselage and Structural Parts

Figure: 1-30
Sign of Fire Around MIP

Figure: 1-31
Rear Fuselage and Structural Parts

Figure: 1-32
Rear Fuselage Detached on Impact

1.12.2.1 **Wreckage Identification.**

(a) Primary effort was to identify and recover DFDR and CVR. As the encountered emergency was suspected to be related to the engines, therefore adequate focus remained to identify and recover engines and propellers parts / components.

Figure: 1-33
Cockpit Voice Recorder (CVR)

Figure: 1-34
Digital Flight Data Recorder (DFDR)

(b) The experts from ATR, BEA France, Pratt & Whitney Canada and TSB Canada also visited and provided useful tips on wreckage identification and subsequent analysis. This included identification and recovery of critical propeller and engine parts and components.

(c) Wreckage analysis at the site lasted for two weeks. Power Plants and major parts and associated components were recognized. However, because of damage / being detached from original location on the Next Higher Assembly (NHA) or identification plates missing, many components could not be identified at crash site for relevance with left or right side. Therefore, detailed identification was done with the help of technical experts, IPCs / configuration management system at PIA and by comparison with serviceable parts. The details of power plant and associated parts recovered from the site are as follows: -

List of Power Plants and Associated Parts	
S No	**Item**
1.	No 1 Propeller and its blades
2.	No 2 Propeller and its blades which were detached from the main system and received extensive heat / fire effects
3.	No 1 Turbo machinery (Engine) and Exhaust duct
4.	No 2 Turbo machinery (Engine) and Exhaust duct
5.	No 1 Propeller Electronic Control (PEC) module showing extensive heat effects
6.	Propeller Valve Modules (both propeller system), without reference to configuration on aircraft
7.	Overspeed Governor (OSG) without clear identification
8.	Accessory and Reduction Gear Boxes of both engines were destroyed and could not be recovered. Only sub parts of Gear train and Drive Shafts were individually recovered for further identification
9.	Only one Hydro Mechanical Unit (HMU) was recovered for further identification
10.	Engine mounts and associated structure parts were recovered in badly damaged state
11.	Center Instrument Panel (including crew alert panel) and Power Levers (PLs) and Control Levers (CLs) were also recovered in extensively damaged state

Figure: 1-35
Propeller Valve Module (PVM)

Figure: 1-36
Propeller Electronic Control (PEC)
No 1

Figure: 1-37
Center Instrument Panel

Figure: 1-38
Power Levers and Condition Levers

Figure: 1-39
Right Wing Outboard Flap

Figure: 1-40
Right Wing Portion

(d) Apart from power plant and its associated parts / components, efforts were also made to recover and identify all major structural parts. Hence, portion of Left & Right Wings, Centre Wing, Landing Gears and portion of Vertical Tail along with Rudder (burnt) were also recovered. The extensively burnt / damaged parts / portions / pieces of passenger cabin and cockpit were also recovered. Similarly electrical looms and harnesses in burnt state beyond identification were also recovered.

Figure: 1-41
Elevator

Figure: 1-42
Structure Part

Figure: 1-43
Digging for Wreckage Recovery

Figure: 1-44
Burnt Electrical Looms and Parts

1.12.2.2 **Assessment of Propeller and Turbo Machinery:** The initial survey on apparent condition of both propellers and Turbo Machineries were conducted to assess and collect evidences / facts which may perish / masked with the passage of time or during transportation of wreckage from the site. The assessment is appended below: -

(a) **No 1 Propeller Assembly:** It was found detached from the engine. The sign of post impact damage and fire / heat affects from ground fire were visible. All the blades were still connected with the assembly, though these were damaged due to impact and fire. It is generally the case when blades are not rotating at high RPM at the time of impact on ground. Few Counter Weights were found attached with the assembly and their position indicated that blades were at fine pitch angle post-impact. The last known positions of blades were marked on propeller for reference. Bull gear of RGB was found attached with the propeller. Bull gear of RGB was found attached with the propeller.

Figure: 1-45
No 1 Propeller with Blades Installed and Signs of Ground Fire

Figure: 1-46
No 1 Propeller Blades Damaged due to Post Impact Fire

Figure: 1-47
No 1 Propeller Blades Damaged due to Post Impact Fire

Figure: 1-48
Bull Gear of RGB Attached with No 1 Propeller

Figure: 1-49
No 1 Propeller Counter Weight and Blade Depicting 90°- Fine Pitch

(b) **No 2 Propeller Assembly:** The propeller assembly was detached from the engine. It received severe post impact damage and heavy ground fire signatures were also visible. All the blades were detached near their roots on impact with ground. It generally indicates that blades were rotating at high RPM on impact with ground. Similarly, the Counter Weights position indicated that blades were at fine pitch angle. The last known positions of blades were marked on propeller for reference. Bull gear of RGB was found attached with the propeller.

Figure: 1-50
No 2 Propeller with Blades Detached on Impact

Figure: 1-51
Bull Gear of RGB Attached with No 2 Propeller

Figure: 1-52
A Detached Blade of No 2 Propeller

(c) **No 1 Engine (Turbo Machinery):** The engine was lying in vicinity of detached tail portion of aircraft towards left of main impact point. The exhaust duct was recovered in separated condition from engine. The visual examination indicated no apparent damage on 'LP Compressor' blades. The associated components were mostly found detached from the engine. The post impact damages were visible. The 2^{nd} stage Power Turbine blades were found severely damaged. Similarly, sign of metallization (brownish colour) were consistent in the exhaust duct area as well, which got detached from the engine on impact with ground. Hence, it appears that this metallization was most probably caused in flight.

Figure: 1-53
No 1 Engine

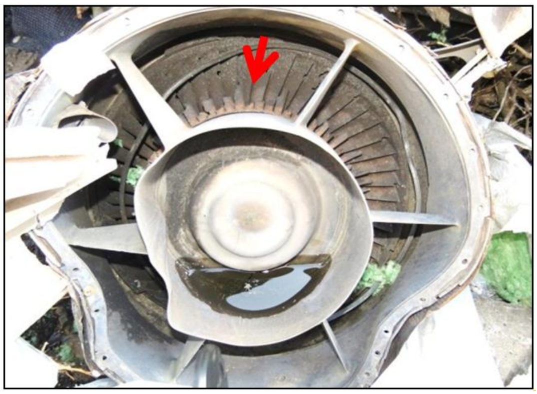


Figure: 1-54
Damage on Power Turbine 2 (View from Rear End)

Figure: 1-55
Power Turbine 2 Damaged Blades (Closer View)

Figure: 1-56
No 1 Engine Impeller – No Damage

Figure: 1-57
No 1 Engine Exhaust Duct – Indentation Marks

Figure: 1-58
View of Tail Pipe – Sign of Metallization in Folds (Brownish Color)

Figure: 1-59
View of Tail Pipe – Sign of Metallization in Folds (Brownish Color)

(d) **No 2 Engine (Turbo Machinery):** The engine was co-located with No 1 Engine most probably because it was moved during rescue operation. The visual condition of LP Compressor revealed bending of blades opposite to rotation. It generally happens when compressor is rotating at high RPM on impact with ground. No damage was observed in rear portion ie on Power Turbine blades. Similarly, exhaust duct got separated on impact and was recovered with no specific observation. The engine components installed on casing got detached on impact.

Figure: 1-60
No 2 Engine LP Impeller – Blades Bent Opposite to Direction of Rotation

Figure: 1-61
No 2 Engine Damaged LP Impeller

Figure: 1-62
No 2 Engine Power Turbine - No Damage

(e) **Reduction Gear Box(s) & Accessory Gear Box(s):** The RGB and AGB of both Engines could not be recovered in one piece as their casings got burnt due to ground fire. However, various drive shafts and gear train parts were recovered from the wreckage. These parts could not be identified on site and were secured for identification later on.

Figure: 1-63 Figure: 1-64
Gear Trains Detached from Main RGB Assemblies

Figure: 1-65 Figure: 1-66
Parts of Gear Train

(f) **Wreckage Transportation from Site:** The wreckage was transported in two phases. In first phase, Propellers and Engines along with associated parts were crated. It was a very difficult task owing to preparation / manufacturing of crates on site and secondly it was not possible to bring recovery vehicles close to the crash site for collection due to inaccessible terrain. Hence, initial movement of these heavy parts was completed on foot with the help of local labourers. In second phase remaining wreckage was moved from the crash site. The complete wreckage was brought back and secured.


Figure: 1-67 Figure: 1-68

Power Plants Secured and Transported on Foot

Figure: 1-69

Propellers secured and transported on Foot

Figure: 1-70

Wreckage Secured and Packed


Figure: 1-71 Figure:1-72

Engines & Propellers Crated and Transported from Crash Site

(g) **Identification of Power Plant Parts:** The process of identification of unknown engine parts was tedious and intricate. The team of technical experts from PIA worked in conjunction with investigation team during this phase. The methodology adopted was to use IPCs and serviceable parts as reference to define the part status. Additionally, to identify a part with respect to engine & propeller; Serial Nos were identified from the parts and then confirmed from Technical Log Books and Technical Records Sections (CARDEX) of PIA. In case of Gear Trains and Drive Shafts it was not possible to exactly identify them with respect to configuration on engine. However, these parts were identified according to major assembly ie RGB and AGB respectively. Hence these parts were kept separately according to major assembly for further identification with respect to engine through OEM. The details of identified parts are as follows: -

S No	Qty	Ref No	Description
1.	02	-	Engine No 1 & 2
2.	02	-	Propeller No 1 & 2
3.	01	P/N 816332-5-401	Propeller Electronic Control (PEC) (No 1 Engine) (Engine S/N EB-0259)
4.	01	P/N 814620-2 S/N 14967680	Overspeed Governor (OSG) (No 1 Engine) (Engine S/N EB-0259)
5.	01	P/N 5009982 S/N 6208	Fuel Pump + HMU (No 1 Engine) (Engine S/N EB-0259)
6.	01	P/N S54313010001 S/N RA1180	Jet Pipe Engine (Exhaust Section) (No 1 Engine)
7.	02	3105192-01	Gear Shaft, Spur, Overspeed Governor Drive (Engine not identified)
8.	01	3117763-01	Shaft Assembly Torque Reduction Gear Box R/H (Right – Hand) (Engine not identified)
9.	01	3119131-01	Shaft Assembly Torque Reduction Gear Box L/H (Left – Hand) (Engine not identified)
10.	02	3106056-01	Gear Shaft Spur Idler Drive (Engine not identified)
11.	02	3015032-01	Gear Shaft, Input Helical Post (Engine not identified)
12.	01	3119131-01	Shaft Assembly Torque, Reduction Gear Box L/H (Left - Hand) (Engine not identified)
13.	01	3117763-01	Shaft Assembly Torque, Reduction Gear Box R/H (Right – Hand) (Engine not identified)
14.	02	P/N 311365-01	Gear Shaft Spur Accessary Drive Post – SB20768 (Engine not identified)
		P/N 3101835-01	Gear Shaft Coupling Accessary Drive (Engine not identified)
15.	01	314834-01	RGB Housing Set Front (Engine not identified)
16.	01	3105187-01	Gear Shaft Spur, Alternator Drive (Engine not identified)
17.	01	3100989-01	Shaft, Drive Accessary Gear Box (AGB) (Engine not identified)
18.	02	3110690	Starter Motor Drive Shaft (Engine not identified)
19.	01	3107872-01	Housing Assembly Accessary Drive (Engine not identified)
20.	02	3104744-01	Oil Pump Drive Shaft (Engine not identified)
21.	01	C146440-2	Propeller Valve Module (PVM) (Engine not identified)

S No	Qty	Ref No	Description
22.	01	-	Central Instrument Panel (Including crew Alert Panel)
23.	01	-	PLAs & CLs
24.	04	P/N 3107863-05	Gear Spur Oil Pump Seven – Teeth (Engine not identified)
		P/N 3116388-01	Coupling Flexible Accessary Gear Box (Engine not identified)
		P/N 3056427-01	Fuel Pump Filter Assembly (Engine not identified)
		P/N 3073908-01	Bearing Roller Flanged Attached In Cover Assy Accessary Drive (Engine not identified)

(h) In the next phase the list of these parts was dispatched to BEA to determine future course of action. BEA France identified dispatch location of these parts according to expertise available for further investigation. The parts related to Propeller were earmarked for BEA and UTAS and for Engine and associated parts Pratt & Whitney Canada was tasked. Additionally, BEA also provided necessary guidelines for packing of sensitive parts like PEC which were adhered to accordingly.

(i) **Packing & Dispatch of Power Plant and Components Abroad:** Post-crash, the Propellers and Engines were not in a condition suited for their normal standard packing. Hence, customized packing containers were designed and manufactured for safe transportation of these units to OEMs for strip examination and analysis, followed by documentation and custom clearances, which took considerable time and efforts.

Figure: 1-73

Figure: 1-74

Figure: 1-75

Figure: 1-76

Overview of Power Plant and Associated Parts
Packing for Dispatch to OEM

Figure: 1-77

Figure: 1-78

No 1 Propeller being Crated

Figure: 1-79

Figure: 1-80

No 2 Propeller being Crated

Figure: 1-81

Figure: 1-82

No 1 and 2 Engines being Crated

Figure: 1-83

Figure: 1-84

Engines Secured from Environmental Effects

1.13 **Medical and Pathological Information.**

1.13.1 All 47 passengers including 05 crew members sustained fatal injuries due to aircraft impact on ground. Most of the bodies were burnt / charred / unidentified. There was no evidence to support any other cause of death. All dead bodies were evacuated from the crash site. 08 dead bodies were identified through personal identification by their relatives, through identity cards and handed over to their relatives by local police and Pakistan Institute of Medical Sciences (PIMS) administration. Rest of the bodies were identified by DNA profiling / matching at PIMS. All these bodies were handed over to their families after fulfilling legal formalities by the district administration.

1.13.2 The Captain was assessed by medical board on 17/08/2016 and his medical record does not reveal any significant problem. His medical fitness was valid until 28/02/2017. His post-mortem was performed by PIMS and forensic toxicology examination through nominee of the DPO Abbottabad at Punjab Forensic Science Agency, Home Department, Government of Punjab, Thokar Niaz Baig Lahore on 13/03/2017. His forensic toxicology analysis report does not show any drugs / volatiles / intoxication.

1.13.3 First Officer (A) was assessed by medical board on 06/09/2016 and his medical record does not show any significant problem. His medical fitness was valid until 31/03/2017. His forensic toxicology analysis report did not show any drugs / volatiles / intoxication.

1.13.4 First Officer (B) was assessed by medical board on 17/08/2016 and does not reveal any significant medical problem. His medical fitness was valid till 31/08/2017. His forensic toxicology analysis report does not show any drugs / volatiles / intoxication.

1.13.5 The CVR recording / transcript also did not reveal any medical abnormality / ailment related to fitness or consciousness of Captain / First Officer's as till end of flight they were talking to each other normally. Captain and both First Officers were medically fit to undertake the scheduled flight.

1.14 **Fire:** The aircraft and its parts were badly damaged / burnt due to post impact fire. The wreckage and surrounding area was thoroughly inspected, however, there was no evidence of pre impact / in flight fire.

1.15 **Survival Aspects:** Search and Rescue operations were undertaken by local administration and was supported by populous of surrounding area. All personnel on board the aircraft were fatally injured because of impact and post impact fire.

1.16 **Test and Research.**

1.16.1 In order to carry out detailed examination, various items / parts of the aircraft were sent to specialized locations / respective OEMs. Some important details are as given below: -

S No	Item	Accredited Representative
1.	Fuel Samples	AAIB Pakistan
2.	Digital Flight Data Recorder (DFDR) and Cockpit Voice Recorder (CVR)	BEA France
3.	Engines	TSB Canada
4.	Propellers	NTSB USA
5.	Propeller Valve Module (PVM)	BEA France
6.	Oil pump, CAP and other relevant components	BEA France
7.	Overspeed Governor (OSG)	NTSB USA and BEA France
8.	Propeller Electronic Control (PEC)	BEA France and NTSB USA

1.16.2 As an outcome of the test and research, various reports / presentation were generated from time to time by the concerned foreign stake holders by putting in tremendous efforts and man-hours with a sole aim to reach to a logical conclusion of this investigation. A tabulated summary of all the major reports / presentations produced is as given below. Important findings / conclusion of all these reports have been incorporated in relevant portions of Section 2 Analysis.

S No	Report Title	Date Received	Received From
1.	**FDR and CVR Analysis Report**	Dec, 2016	BEA, France
	Rationale: To compile history of the flight using validated flight data parameters and CVR information[105].		
2.	**Sounds and Warnings Chronology Version 3**	Mar, 2017	BEA, France
	Rationale: To identify standard time stamp of various Sounds & Warnings generated inside cockpit and for correlation with events & position of various cockpit controls especially that are not recorded in DFDR[106].		
3.	**CVR Transcription Version 3** [107]	Mar, 2017	BEA, France
4.	**Engine Exhaust Pipe, Engine Control Levers and Central Instrument Panel**	Apr, 2017	BEA, France
	Rationale: To mainly examine engine exhaust pipe, status of various warnings / cautions and CL-1 position prior impact[108].		
5.	**CVR Data – Spectral Analysis Report**	Apr, 2017	BEA, France
	Rationale: To analyze spectrum overview of the audio signal of the Cockpit Area / Mic and to improve the intelligibility of the cockpit crew speeches for the CVR transcript. This included analysis of propulsion assembly audio signature not recorded in DFDR such as the propeller Blade Rate (BR), the propeller Shaft Rate (SR), the AC generator drive shaft etc[109].		

[105] BEA2016-0760_tec02 FDR and CVR Analysis Report dated 21 December 2016.
[106] Sounds and Warnings Chronology Version 3 dated 31 March 2017.
[107] CVR Transcription dated 31 March 2017.
[108] BEA2016-0760_tec12 Engine exhaust pipe, Engine control levers and Central instrument panel dated 26 April 2017.
[109] BEA2016-0760_tec06_Rev3 CVR data – Spectral analysis Report – dated 25 April 2017.

S No	Report Title	Date Received	Received From
6.	**CVR & DFDR Data Animation**	May 2017	BEA, France
	Rationale: To describe a 3D animation of DFDR data superimposed with CVR data for last 15 min 53 sec of occurrence flight, showing aircraft flight path, Main cockpit & Engine Indicators display, Crew Alerting panel, Power Lever & Condition Lever movements, control columns and rudder movements.		
7.	**AP-BHO Propellers Preliminary Investigation Results**	May, 2017	NTSB, USA
	Rationale: To examine the recovered propeller hub, blades, actuators & transfer tubes for their condition, last positions and damages etc[110].		
8.	**CVR mp4 File Last 10 Minutes of the Flight**	May, 2017	BEA, France
9.	**PEC Faults Analysis Final Report**	Jun, 2017	BEA, France
	Rationale: To analyze the faults recorded in the 'Propeller Electronics Control' computer memory, in order to identify cause(s) of PEC fault triggered in the cockpit[111].		
10.	**CT Scans Review (PVMs and No 1 OSG)**	Aug, 2017	BEA, France
	Rationale: Before physically opening up / tear down examinations, CT scans were performed to have an overview of their internal status[112].		
11.	**AP-BHO Propellers Investigation Results**	Oct, 2017	NTSB, USA
	Rationale: To produce results based on the propellers teardown examination[113].		
12.	**CAP Analysis**	Nov, 2017	BEA, France
	Rationale: To determine illumination of warning and caution lights during event flight and information on the CL-1 position, which is not recorded in DFDR[114].		
13.	**Propeller Valve Module (PVM) Examination**	Nov, 2017	BEA, France
	Rationale: Being major component of propeller pitch control system, its tear down examination was required for further analysis of its health and functionality[115].		
14.	**Main Pump and Overspeed Governor Examination Field Notes**	Nov, 2017	BEA, France
	Rationale: Being major components of propeller hydraulic system, its tear down examination was required for further analysis of their health, functionality and analysis of internal debris[116].		

[110] RF-DSC 1353-17 V01 AP-BHO Propellers Preliminary Investigation Results dated 09 May 2017.
[111] BEA2016-0760_tec15 PEC faults analysis Final report dated 18 June 2017.
[112] BEA2016-0760_tec24 CT scans review dated 02 August 2017.
[113] AP-BHO Propellers Investigation Results RF-DSC 1353-17 V02, dated 10 October 2017.
[114] BEA2016-0760_tec16 CAP analysis dated 20 November 2017.
[115] BEA2016-0760_tec27 Propeller Valve Module (PVM) examination dated 27 November 2017.
[116] BEA2016-0760_tec30 Main Pump and Overspeed Governor examination Field notes dated 27 November 2017.

S No	Report Title	Date Received	Received From
15.	**Draft Operation Report**	Mar, 2018	BEA, France
	Rationale: The objective of report was to compare crew actions with QRH / FCOM, provide discussion on variations in crew behavior from the expected behavior, and identify attribution of the incorrect actions to the crash. The nature and extent of degradation in the aircraft performance was not considered and the said comparison was only with the aircraft design performance. Important aspects of the crew behavior and actions have been considered and incorporated[117].		
16.	**Service Investigation Accident / Incident Report Pakistan International Airlines ATR72-500, AP-BHO Havelian, Pakistan 07 December 2016 PW127E/M Left S/N EB0259 Right S/N ED1112**	Apr, 2018	TSB, Canada
	Rationale: To finalize the power plant investigation of both engines and to determine the cause of No 1 Engine IFSD[118].		
17.	**Overspeed Governor Investigation Presentation by Woodward**	Apr, 2018	NTSB, USA
	Rationale: Examination of OSG to understand its impact on sequence of events[119].		
18.	**Report on UTAS and ATR Simulations**	Sep, 2018	BEA, France
	Rationale: Objectives of the simulations were to determine the position and state of the left propeller during flight of the event, the aircraft controllability margins and overall aerodynamic state of the aircraft[120].		
19.	**Propeller Systems Pakistan International Airways ATR42-500 Mishap, Analysis of Port 568F-1 Propeller Performance**	Oct, 2018	NTSB, USA
	Rationale: To describe the work performed by United Technologies Aerospace Systems (UTAS) to determine the most likely scenarios for the behavior of the port 568F-1 propeller of AP-BHO during the mishap flight[121].		
20.	**Most Probable Scenario on the Powerplant #1 Behavior**	Nov, 2018	BEA, France
	Rationale: After collection of the facts, all the OEMs were made to sit with to establish a most likely scenario which logically explains all the events encountered during the flight. Series of meetings were held under the umbrella of BEA. The participating OEMs were ATR France, Pratt & Whitney Canada and UTAS / Woodward USA etc[122].		

[117] BEA20170907_INVS Draft Operation Report.
[118] P&WC 8114 (11-98) Report No 16-200 Service Investigation Accident / Incident Report Pakistan International Airlines ATR72-500, AP-BHO Havelian, Pakistan 07 December 2016 PW127E/M Left S/N EB0259 Right S/N ED1112.
[119] Overspeed Governor Investigation Presentation by Woodward dated 26 April 2018.
[120] BEA2016-0760_tec29, Report on UTAS and ATR Simulations dated 19 September 2018.
[121] PropS18-024 Aircraft Systems- Propeller Systems Pakistan International Airways ATR42-500 Mishap, Analysis of Port 568F-1 Propeller Performance dated 16 October 2018
[122] BEA2016-0760_tec34, Most Probable Scenario on the Powerplant #1 Behavior, dated 26 November 2018.

S No	Report Title	Date Received	Received From
21.	**PIA MSN 663 Investigation Update Presentation by ATR**	Dec, 2019	BEA, France
	Rationale : To discuss the probability of similar technical anomalies and combined probability for aircraft certification consideration, to quantify the degraded aircraft performance and compare with the certified / designed single engine performance parameters, and to discuss hypothetical landing possibilities[123].		
22.	**Propeller Systems Pakistan International Airways ATR42-500 Mishap, Analysis of Port 568F-1 Propeller Performance (Revision B)**	Nov, 2018	NTSB, USA
	Rationale: To describe the work performed by United Technologies Aerospace Systems (UTAS) to determine the most likely scenarios for the behavior of the port (left hand) 568F-1 propeller of AP-BHO that occurred during the mishap flight. The revision B was issued to include additional findings of PVM CT Scan[124].		
23.	**Maintenance Group Investigation Report, Service Review of Woodward Overspeed Governor P/N 8210-097, S/N 14967680[125]**	Oct, 2020	NTSB, USA
	Rationale: This report describes findings of maintenance review group on the possibility of OSG sheering off during some maintenance activity.		

1.17 Organizational and Management Information PIA / CAA

1.17.1 Pakistan International Airlines (PIA)[126]

1.17.1.1 PIA is the national flag carrier of Pakistan. It has a well-established organizational structure, and held valid state issued Air Operator Certificate (AOC) Ref No. AOC-003/96-AL Validity 31-12-2016. Its main base is at Karachi, with additional bases located at Lahore and Islamabad. The PIA aims to be safe, efficient, reliable and profitable within the required conditions and limitations of the state approved air transport operations, and is performing the corporate function of provision of air transport service of following types: -

(a) Regular Public Transport (RPT)

(b) Charter

(c) Aerial Work

1.17.1.2 PIA has a management system for the flight operations intended to ensure supervision and control of flight operations, & management of safety & security functions and other associated activities in accordance with standards set forth by PIA itself and requirements & restrictions of the state (AOC). The Flight Operations Department is aimed to achieve these objectives by efficiently managing the personnel, equipment and facilities that have been provided to it. Flights are to be conducted in accordance with the PIA operating policy as follows: -

---

[123] PIA MSN 663 Investigation Update Presentation by ATR dated 20 December 2019.
[124] PropS18-024 Rev B Aircraft Systems- Propeller Systems Pakistan International Airways ATR42-500 Mishap, Analysis of Port 568F-1 Propeller Performance dated 08 November 2018.
[125] Maintenance Group Investigation Report, Service Review of Woodward Overspeed Governor P/N 8210-097, S/N 14967680 by NTSB, dated 02 October, 2020 attached as **Appendix-1**.
[126] PIA Operations Manual - Part A (General).

(a) Safety is always the first priority.

(b) Depending on the actual situation and with due regard to possible consequences, economy, schedule and passenger comfort is weighed carefully.

1.17.1.3 The key position holders of the Flight Operations Department are made responsible for the outcome of safety, quality audits, implementation of accident / incident investigation report's recommendations etc in their respective areas of responsibilities.

1.17.1.4 The Director Flight Operations has been made accountable to Senior Management for ensuring the day to day security, safety and supervision of flight operations and its activities in accordance with conditions and restriction as per AOC and in compliance with all applicable regulations and standards which are outlined in PIA's operations manual.

1.17.1.5 Cockpit crew training requirements are being met in accordance with the applicable provisions contained in PIA's Operations Manual Part D, Training Policy Manual. The management and control of flight operations documentation and / or data used directly in the conduct or support of operations is being maintained through Centralized Documentation System (CDS) on PIA's website. The CDS provides all information pertaining to the control management of documents.

1.17.1.6 These Documents include as a minimum: -

(a) OM Part-A, OM Part-D.

(b) FCTM / SOP (All Aircrafts).

(c) On-Board Technical Library.

(d) Other relevant documents for the crew.

1.17.1.7 A detailed overview of PIA as an organization and its management of operations are provided in PIA's Operations Manual - Part A (General). This publication comprises of all non-type related policies, instructions and procedures needed for safe operations.

1.17.2 **Flight Operations of ATR Aircraft by PIA**

1.17.2.1 PIA has established procedures for the operation of ATR42/72-500 aircraft, and produced the same in the form of a publication namely, PIA Standard Operating Procedures (SOPs) - ATR42/72-500[127]. This Manual establishes sequence, designate individual and collective crew duties and furnish brief explanations in simple form for the understanding of the cockpit crew. It is an elaboration and an extension of the ATR recommended normal & non-normal procedures which for all intent and purposes refer to ATR's latest QRH, FCOM and FCTM etc. It contains the procedures which require elaboration according to customization for Line operations. The SOP is supplement to the procedures given by the OEM and the PIA Operations Manual Part-A (General). Whenever required, in order to provide clarification in interpretation according to some particular situation, circulars will be issued from time to time.

1.17.2.2 For flight operations of PIA's ATR42-500 in Northern areas of Pakistan, PIA Standards Bulletin - Northern Area Operations - ATR42-500[128] was issued in 2014 for utilization by all ATR pilots. This SOP addressed most of the major concerns for safe operations, takeoff / landing, go around and handling of

[127] PIA Standard Operating Procedures - ATR42/72-500.
[128] PIA Standards Bulletin - Northern Area Operations - ATR42-500, dated 07 August 2014.

emergency situations at Gilgit, Chitral and Skardu airports. This publication was implemented and was being followed before 7 December 2016 (ie before the crash).

1.17.2.3 During February 2019, the flight Operations Department of PIA has issued an improved version of this SOP in form of a new publication. This publication is ATR42-500 - Special Operations - Northern Areas[129]. The publication adequately encompasses and includes important guidelines for safe operations, takeoff / landing, go around and handling of emergency situations, including important / relevant aspects.

1.17.3 **Cockpit Crew Training Policy at PIA**

1.17.3.1 PIA has a training policy that provides basic principles for governing the entire domain of training of flight crew, and of oversight and supervision of all flight training activities. This policy is directed towards achieving high standards during operations. This training policy and related functional matters are provided in the PIA Operations Manual Part D (Training)[130], Salient aspects of the Training Policy are as follows: -

(a) It is based on the requirements of the CAA Pakistan as promulgated in the Civil Aviation Rules and Air Navigation Orders. Additionally it also encompasses PIA's own requirements, which relate to simulator and aircraft endorsements, recurrent cyclic training, technical courses, examinations and evaluations, etc.

(b) Chief Pilot Crew Training has been made over all responsible. He ensures that all Training Division personnel are qualified for their respective duties and are familiar and current with the layout and contents of the OM Part-D. These personnel shall include training schedulers, crew licensing and administrative support personnel.

(c) For individuals to perform the functions of instructors to conduct or supervise the training, evaluations and periodic checks towards the performance of their duties, their approvals / endorsements are processed as per guidelines provided by CAA Pakistan and contained therein in the said manual.

1.17.4 **Safety Programme Management of PIA:** PIA has an elaborate safety programme management system. It is supported by adequate resources, a safety policy, relevant management tools, and systems to conduct analysis of related aspects. A Safety Management System Manual[131] has been updated from time to time and encompasses various aspects important for safety management in accordance with the ICAO SARPS. However, non compliance of relevant Engine Maintenance Manual (EMM), chapter 05 was not identified by PIA Quality and Safety Management System. Additionally a number of IFSD cases were recorded on ATR aircraft in PIA, from 2008 to 2016 (ie before the crash)[132]. These cases and all other occurrences / incidents are mandatorily reported by PIA to CAA Pakistan. PIA Quality and Safety Management System, was unable to identify the trend(s) and undertake any proactive intervention.

---

[129] ATR42-500 - Special Operations - Northern Areas, dated 14 Jan 2019.
[130] PIA Operations Manual Part D (Training).
[131] Safety Management System Manual of PIA.
[132] AAIB data about ATR aircraft IFSD cases for the years 2008 to 2016.

1.17.5 **Engineering and Maintenance Management of PIA:** PIA Engineering and Maintenance is an approved ANO 145 Maintenance Organization from CAA Pakistan with approval number PCAA.145.001. Based on this approval, all procedures, means and methods with reference to maintenance and quality assurance of the organization are performed in compliance with ANO 145 regulations. As per intended scope of work defined in the Maintenance Organization Exposition (MOE), PIA Engineering & Maintenance shall perform maintenance that includes any one or combination of the overhaul, repair, inspection, replacement, modification or defect rectification of aircraft / components. This also includes Airworthiness Directives (ADs) / Service Bulletins (SBs) incorporation as per PIA Engineering MOE Chapter 2.12. This chapter outlines the Optional Modification procedures that define PIA Engineering & Maintenance policies for evaluation and accomplishment during maintenance on aircraft / components. The Airworthiness Management division of Engineering deals with the evaluation and implementation of Service Bulletins. The Quality Assurance division of PIA Engineering & Maintenance implements a quality audit program in which compliance with all maintenance procedures is reviewed at regular intervals in relation to each type of aircraft / aircraft component including management of audits and production of audit reports, ensuring that any observed non-compliances are brought to the attention of concerned. Important aspects / observations about PIA maintenance laps in the relevant domain have been discussed in Section 2 Analysis.

1.17.6 **CAA Pakistan as an Oversight Organization.**

1.17.6.1 Civil Aviation Authority (CAA) Pakistan is a public sector autonomous body working under the Federal Government of Pakistan through Aviation Division. CAA was established in 1982 through Pakistan Civil Aviation Authority Ordinance 1982. CAA Pakistan provides regulations for Civil Aviation activities for safe and efficient operations for the Civil Air Transport Service in Pakistan, in accordance with International Standards and Recommended Practices. CAA Pakistan in addition to the regulatory function also performs the service provider functions of Air Navigation Services and Airport Services. The Headquarters of CAA Pakistan is located at Karachi. CAA Pakistan, during Universal Safety Oversight Audit Program (USOAP) visit of June 2011, scored about 83% compliance status against the world average of 65%.

1.17.6.2 The administration of CAA Pakistan is vested with CAA Board which exercises all powers, and performs all functions that are required to be performed by the CAA. The Chairman CAA Board is Secretary Aviation Division. Additionally CAA has an Executive Committee, which is the highest decision making body of the Organization. It exercises powers as delegated to it by the Authority. Director General CAA is the Chairman of CAA Executive Committee.

1.17.6.3 CAA Pakistan has well established setup to oversee all the operators (as per the guidelines provided in relevant Standards and Recommended Practices and ICAO publications) for important aspects related to safe and efficient management of flight operations, maintenance management, training, licensing, and various aspects of quality management and proactive safety programs. Figure hereunder describes the organogram of CAA Pakistan during 2019-20 timeframe.

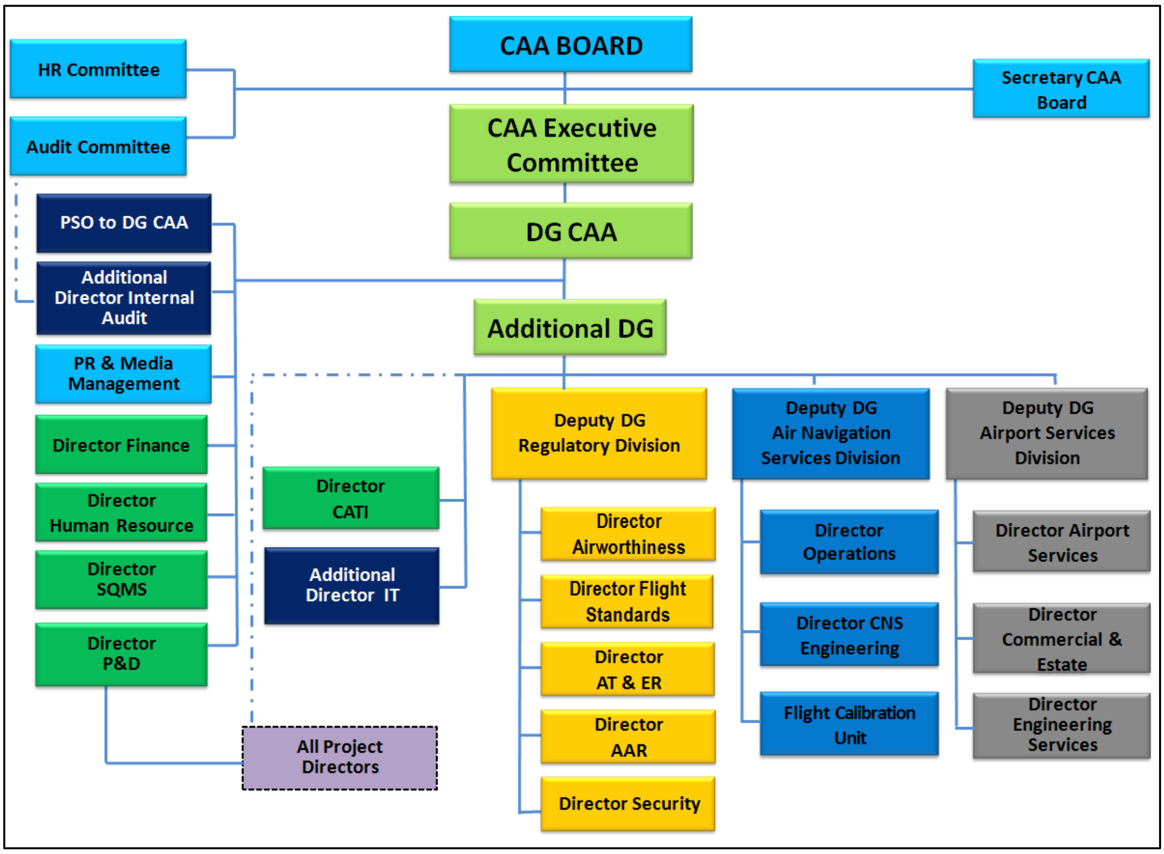


Figure 1-85: Organogram of CAA Pakistan

1.17.6.4 The primary functions of Directorate of Airworthiness are registration of civil aircraft, certification of aircraft design and built standards, licensing of aircraft maintenance engineers, development of standards and safety investigations etc.

1.17.6.5 The Directorate of Airworthiness is solely responsible for regulating and maintaining the airworthiness of all operators that are registered with CAA Pakistan. Airworthiness directorate identifies approved maintenance organizations under its umbrella as per ANO-001-AWRG-5.0 dated 04/04/2011. This document outlines various organizational requirements required to function as an independent AMO (Approved Maintenance Organization). As per ANO requirements, Airworthiness Directorate shall continue surveillance through continuing airworthiness requirements. Airworthiness directorate approves MOE (Maintenance Organization Exposition) of the operator. A MOE shows how the maintenance organization intends to comply with the requirements laid down by the competent authority.

1.17.6.6 As per airworthiness requirements, all reportable occurrences are mandatorily reported to CAA Pakistan along with their investigation reports. These occurrences also include IFSDs (In Flight Shutdowns). On the basis of operator's investigations and in service experiences along with OEM input, weak areas are identified and referred to operator's RRB (Reliability Review Board) for preventive measures, being run by Maintenance Program & Reliability (MP&R) section of Airworthiness division of operator. The Airworthiness Directorate provides guideline for the general requirements for technical performance & reliability program of an operator[133]. In RRB meetings, a representative from CAA Pakistan Airworthiness Directorate is participant as an observer.

1.17.6.7 The Flight Standards Directorate is to perform the task of maintaining regular surveillance of the operational aspects of all Air Transport Operators in order

133 AWNOT-066-AWXX-4.0 General Requirements for Technical Performance & Reliability Program of an Operator Airworthiness Notice dated 26 March 2010.

to ensure safe and efficient flight operations. In order to accomplish these tasks, qualified Flight Operations Inspectors are appointed to conduct Surveillance / Inspection / Checks etc to ensure that the proficiency of the cockpit crew is in accordance with the ICAO SARPS.

1.17.6.8 State Safety Programme has not been completely established and in accordance with ICAO Annex 19 this setup is being evolved. During December 2016 timeframe such overarching oversight was not established and the responsibility was vested with the respective regulatory directorates.

1.17.6.9 CAA Pakistan conducts annual audits of the operators at the time of renewal of AOC. Audit reports of PIA for the years 2014 to 2018 were examined during the course of investigation.

1.17.6.10 Non implementation of SB-21878 and non-compliance of Chapter 5 of Engine Maintenance Manual was not identified by CAA Airworthiness oversight system in an effective manner. Additionally a number of IFSD cases were recorded on ATR aircraft in PIA, from 2008 to 2016 (ie before the crash)[134]. These cases and all other occurrences / incidents are mandatorily reported to CAA Pakistan. CAA Pakistan was unable to identify the trend(s) and undertake any effective proactive intervention.

1.18 Additional Information.

1.18.1 **Crew Resource Management (CRM):** At the time of occurrence, Captain of aircraft was the Pilot Flying (PF) whereas FO(B) was Pilot Monitoring (PM). Both the cockpit crew had valid CRM certification. A detailed procedure for conduct of CRM training by the operators has been stipulated by the CAA Pakistan Air Navigation Order (ANO)[135]. Important aspects of cockpit crew CRM training and behavior are discussed in Section 2 Analysis.

1.19 General Description of ATR42-500 Engine & Propeller Systems[136].

1.19.1 **Engine Overview:** ATR42-500 aircraft is equipped with two engines Pratt & Whitney Canada PW127 E/M certified for a 2400 SHP (Shaft Horse Power) at max takeoff rating. The engine uses a three-shaft configuration, a centrifugal LP compressor (1), driven by a single stage LP turbine (4), supercharges a centrifugal HP compressor (2), driven by a single stage HP turbine (3). Power is delivered to the propeller / reduction gearbox through a third shaft, connected to a 2-stage power turbine (5). The three rotating assemblies / shafts are supported by 07 bearings. No 1, 2 & 7 bearing are for PT shaft, No 3 & 6 for LP shaft and No 4 & 5 are for HP shaft.

[134] AAIB data about ATR aircraft IFSD cases for the years 2008 to 2016.
[135] ANO-014-FSXX-2.0 Crew Resource Management Training Air Navigation Order dated 01 January 2018.
[136] BEA2016-0760_tec34, Most Probable Scenario on the Powerplant #1 Behavior, dated 26 November 2018.

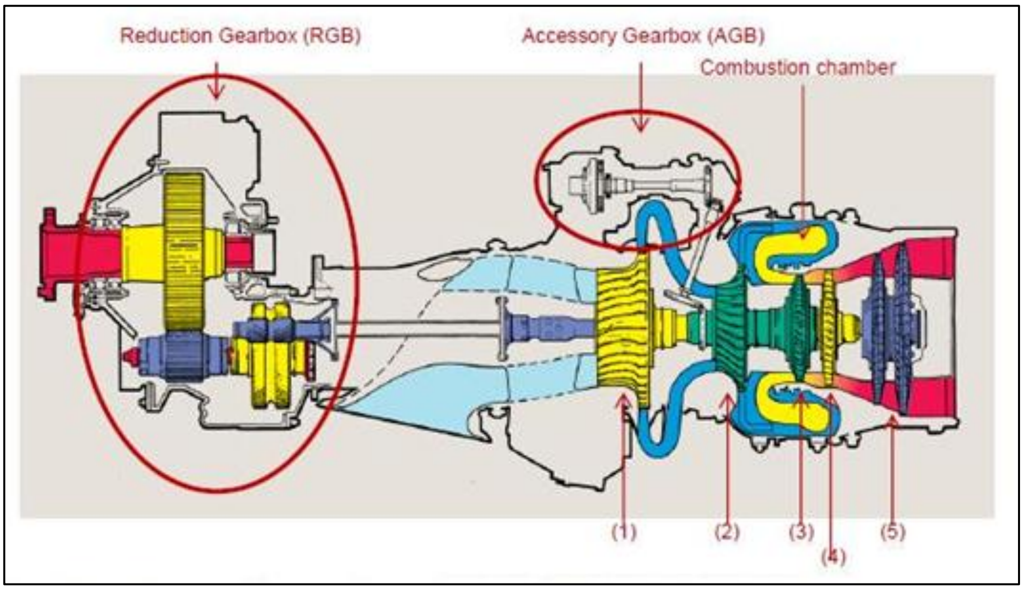


Figure 1-86: General Description of the Engine

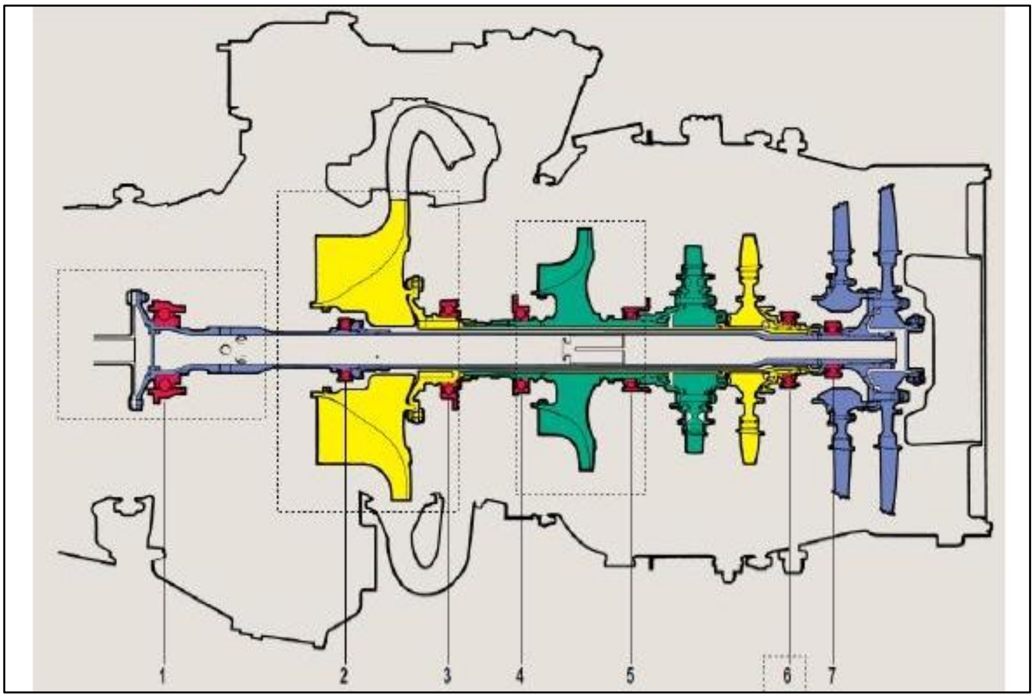


Figure 1-86A: Engine Bearings

Figure 1-87: No 6 Bearing

1.19.1.1 **Engine Oil Supply:** The engine feeds the propeller blade pitch regulation system with the necessary oil pressure. The engine oil pump is connected to the engine Accessory Gear Box (AGB) and is driven by the NH stage of the engine. When oil is contaminated, the filter may get clogged. In this case, a bypass valve opens when the differential pressure across the filter reaches 40 PSID. The oil pressurizing valve opens when the differential pressure reaches 48 PSID. Oil low pressure (engine related) triggers a Master Warning associated with a Continuous Repetitive Chime (CRC). The delay for the ENG OIL LO PR inhibition is controlled by the MFC and starts when the CL leaves the FSO position. The ENG OIL LO PR Centralized Crew Alerting System (CCAS) alarm: -

(a) Triggers when the ΔP is lower than 40 psi and is released when the P is higher than 45 psi.

(b) A 30 seconds time delayed to avoid untimely ENG OIL LO PR during engine start.

(c) Is inhibited when CL of the affected side is in FUEL SO position.

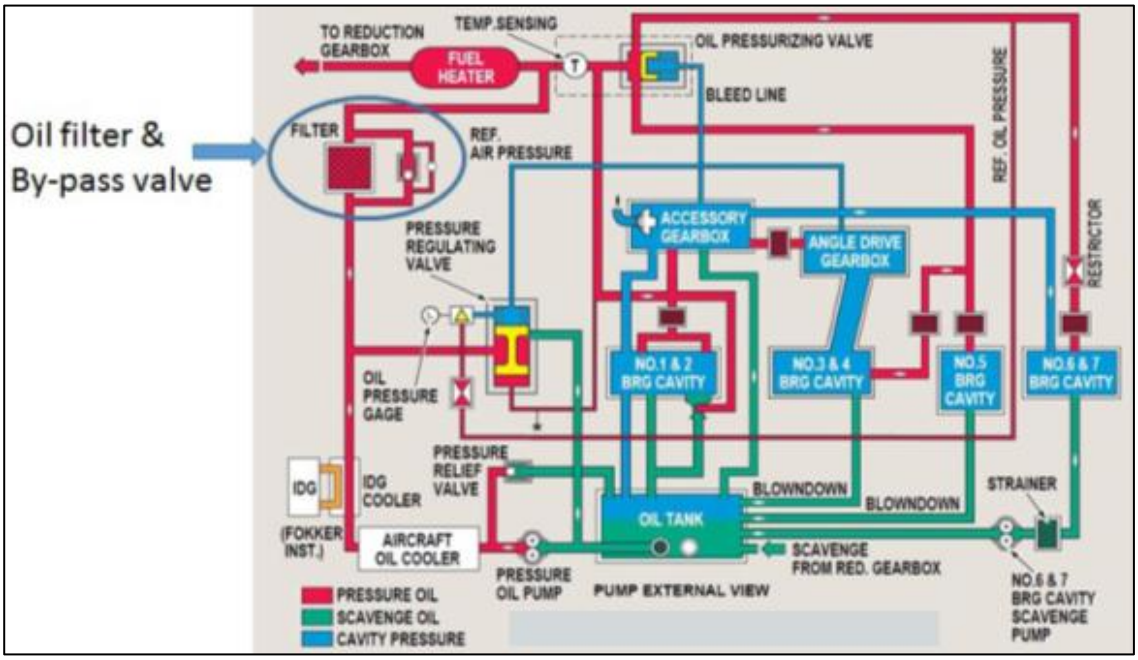


Figure 1-88: Engine Oil System

1.19.1.2 **Reduction Gear Box (RGB) & its Oil System:** RGB is combination of mechanical gears that connects Propeller Hub Assembly to PT drive shaft of the engine to provide torque to the propeller. RGB receives oil from the RGB tank (also called auxiliary tank) as shown in the following figure, which is supplied by the engine main oil pump (dependent on NH). Oil is taken from the RGB tank to the Propeller Valve Module through the main propeller pump and the electrical feathering pump when it is switched ON. The scavenge oil from the Overspeed Governor and the Propeller Valve Module then returns to the main oil tank. The total oil quantity of the RGB tank (useable and unusable oil) is 3.68 liters. Only 0.32L (19.5 in^3) are available for main pump usage (without engine running – 0 PSI engine oil pressure). The electrical feathering pump has a specific useable oil quantity of 3.22L (3.4 US Quart and 196 in^3).When the engine is running, the oil feeding is continuous.

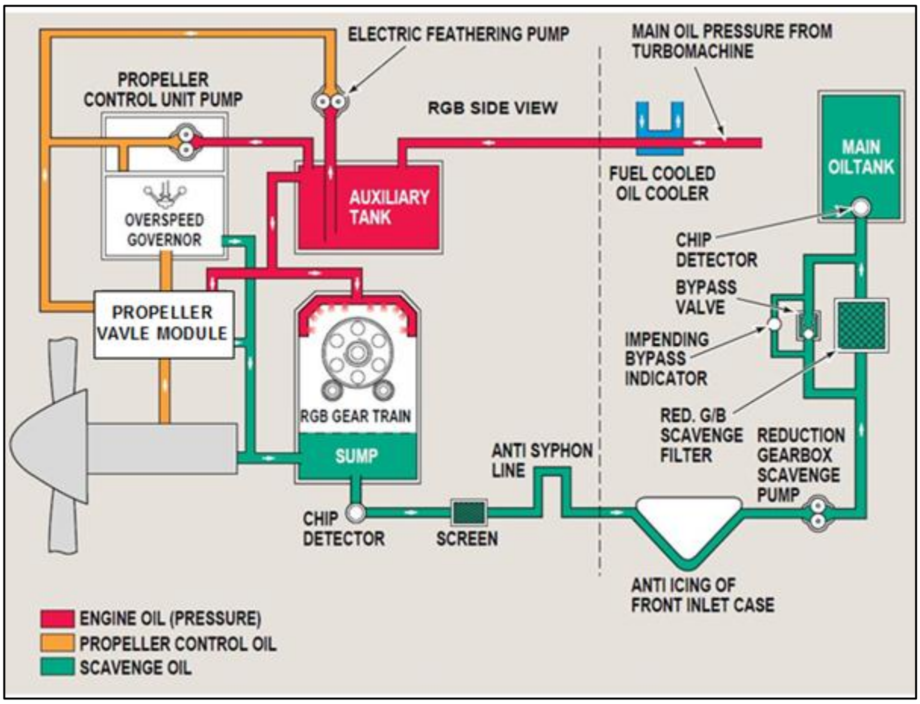


Figure 1-89: Reduction Gearbox Oil System

1.19.1.3 **Engine HP Fuel Pump:** The engine fuel pump provides filtered high pressure fuel flow to the fuel control unit to meet engine fuel requirements at any operating conditions. The HP fuel pump is connected to the Accessory Gear Box (AGB). Following the information provided by the engine manufacturer, “start fuel flow would barely start to be delivered at 5% NH”.

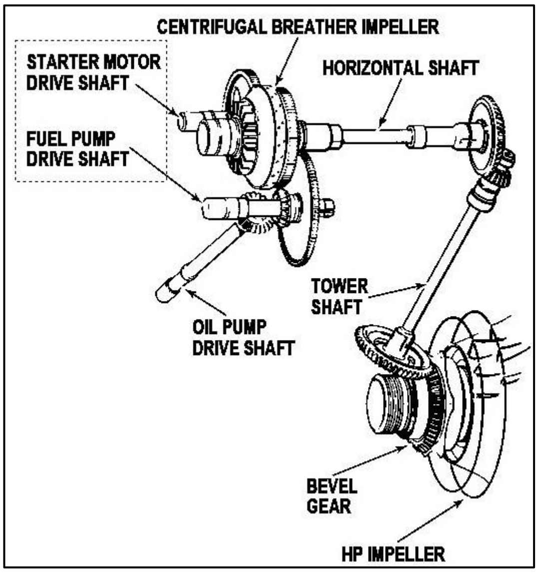


Figure 1-90: Location of the Fuel Pump Drive Shaft

1.19.1.4 **Mechanical Fuel Control Unit (MFCU):** The fuel flow sensor is located on the “metered fuel out” line of the figure below. When the CL is put in the Fuel Shutoff position, the fuel shut off valve opens. The metered fuel out line is then connected to the P0 bypass fuel. The metered fuel out line pressure decreases. When the differential pressure at the minimum pressurizing valve reaches 60 PSID, this valve closes the circuit.

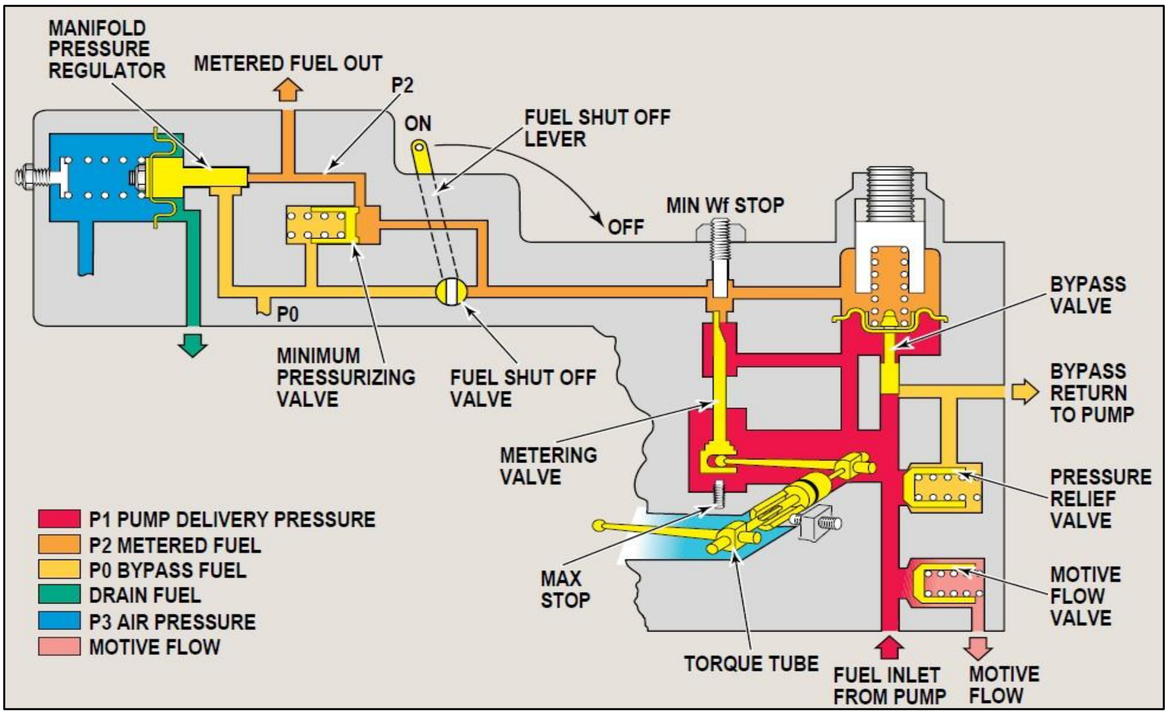


Figure 1-91: The MFCU

1.19.1.5 **Fuel and Engine Fire Handle:** A low pressure (LP) valve is mounted on the wing front spar, at engine level. Each LP valve includes a thermal relief valve which allows fuel trapped between the engine and the LP valve to flow back when the LP valve is closed. The valve is closed by a 28 VDC dual motor actuation installed on the valve. Each valve is supplied separately either by the battery or by GEN 1 (for No 1 Engine). Action on the ENG FIRE handle enables simultaneous energization of the 2 motors of the actuator causing valve closure and engine shutdown. The resulting pressure drop causes the motive flow valve on the engine feed return line to close. The action on the ENG FIRE handle stops immediately any fuel flow through the engine.

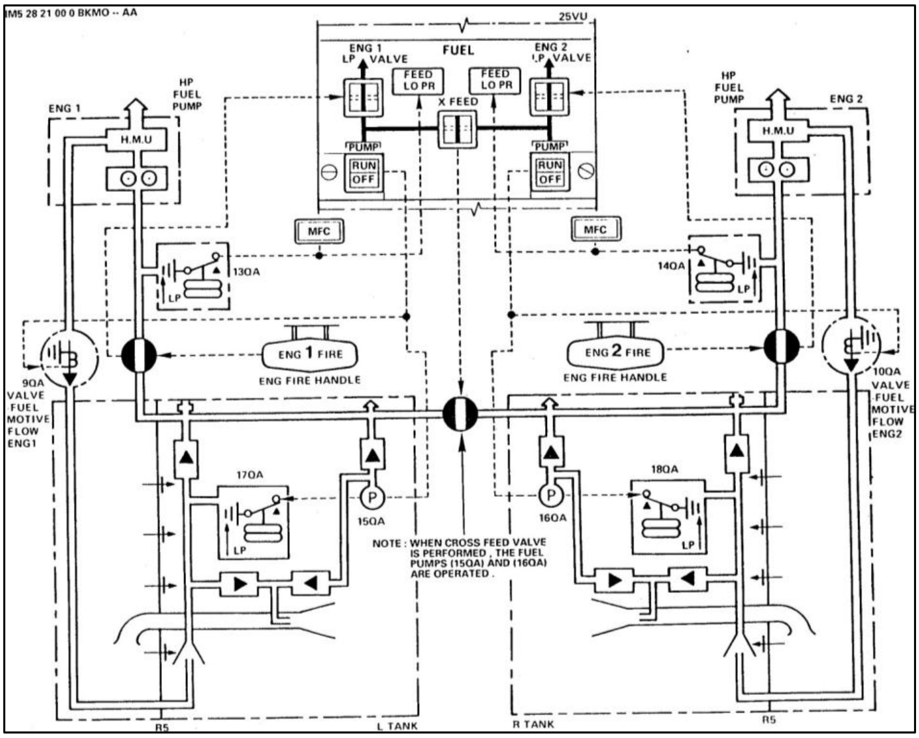


Figure 1-92: Schematic Diagram for Fuel and Engine Fire Handle Operation

1.19.1.6 **Electronic Engine Control (EEC).**

(a) For normal EEC control, requested power is computed and compared against actual power. The result is then translated into NH speed request. The NH request is in turn compared against actual NH to adapt the fuel flow and maintain the requested power. The EEC software operates by selecting a rate of change of NH speed from the several limit loops available.

Figure 1-93: Electronic Engine Control

(b) Compensation for ambient conditions of IAS, air temperature and altitude, ensures correct rated power for the rating selected, at a fixed nominal PLA position. The EEC provides through ARINC 429 words the FDAU with the following recorded parameters: -

(i) The recorded PLA values.

(ii) The engine TQ values.

(iii) The engine Np values.

(iv) The engine NH values.

(c) When NH decreases below 60%, the EEC will trigger the automatic relight. This automatic relight is cancelled when the propeller feathering is requested (CL in or below FTR position) or when the NH values are lower than 30%.When the sensed NH is valid and below 30%, the recorded NH value is 0%. The EEC is monitoring the NH speed. In case of fault detection, the recorded NH values are the NCD pattern.

(d) The EEC logics ignore the Np values if one of the following conditions exists:-

(i) ATPCS test is performed.

(ii) CLA is below 33°65' (a position between FTR and AUTO).

(iii) ATPCS sequence is triggered.

(iv) Fire Handle is pulled.

(v) PEC is retracting Secondary Low Pitch Stop solenoid.

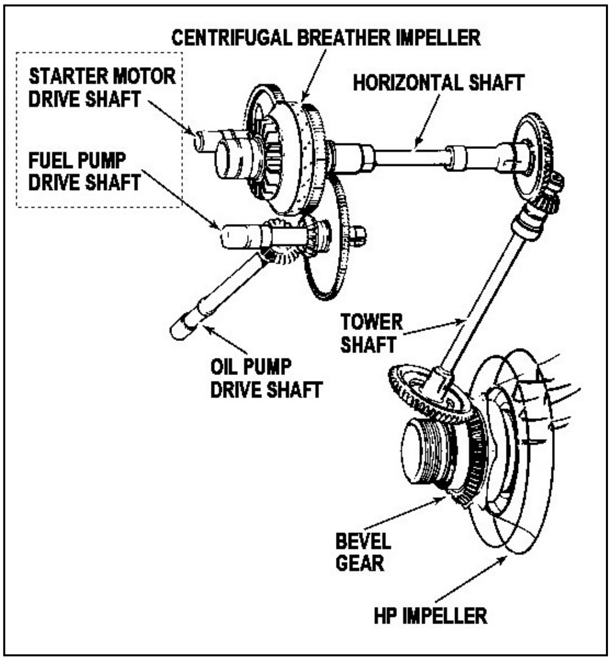
(vi) PEC Switch P/B is "OFF" with Power Lever below Flight Idle.

(vii) PEC Switch P/B is "OFF" and the Overspeed Governor second setting test button is pushed.

1.19.1.7 **NH Sensor:** Two probes are installed on the right side of the rear inlet case. These probes pick up high pressure rotor speed signals from the starter generator driveshaft gear teeth. Each probe has two coils (2 signals): -

(a) Upper NH probe: both signals are sent to the EEC / AFU and NH gauge.

(b) Lower NH probe: one signal is sent to the EEC / AFU, the other signal is not used.



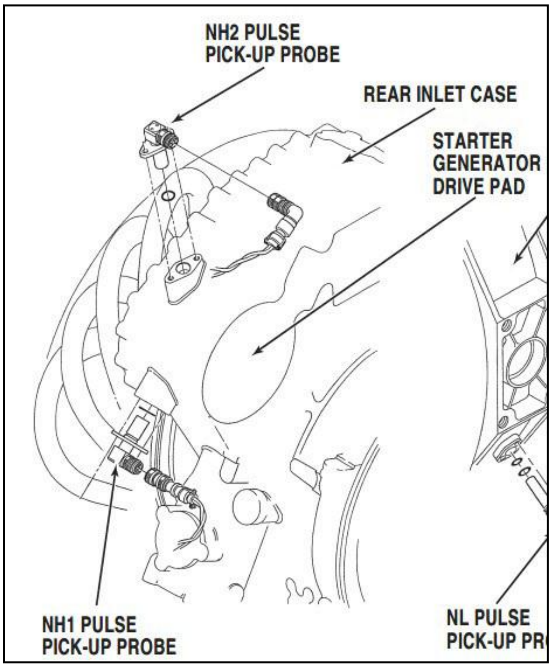


Figure 1-94: NH Probes

1.19.1.8 **Torque Sensors.**

(a) There are two torque shafts located in the reduction gearbox. Each shaft links the first stage helical gear to the second stage pinion gear. As the engine produces power, the torque shaft twists and the amount of twist provides a means to measure engine torque. The torque shaft consists of two concentric tubes (shafts) each carrying a toothed wheel; both tubes are attached together at the rear end only. The torque tube is connected at both ends and will twist when torque is produced, while the reference tube connected only at the front end cannot be twisted. The gap between the teeth on the torque tube and the teeth on the reference tube will change in proportion of the produced torque.

Figure 1-95: Torque Shaft

(b) The torque sensors are magnetic pulse pick-up type; dual coil for PW127 series engine with a built in temperature probe (Resistive Temperature Device-RTD). Each torque sensor protrudes into the RGB and picks up signals on teeth of the torque tube and reference tube toothed wheels.

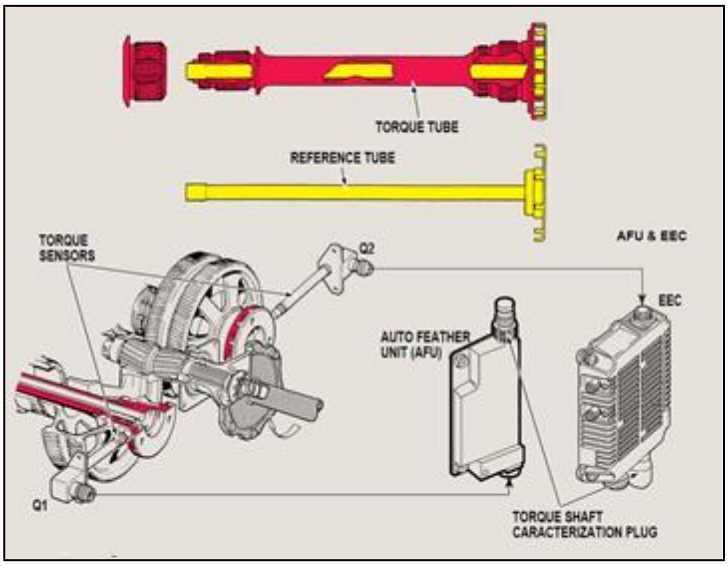


Figure 1-96: Torque Measurement System Components

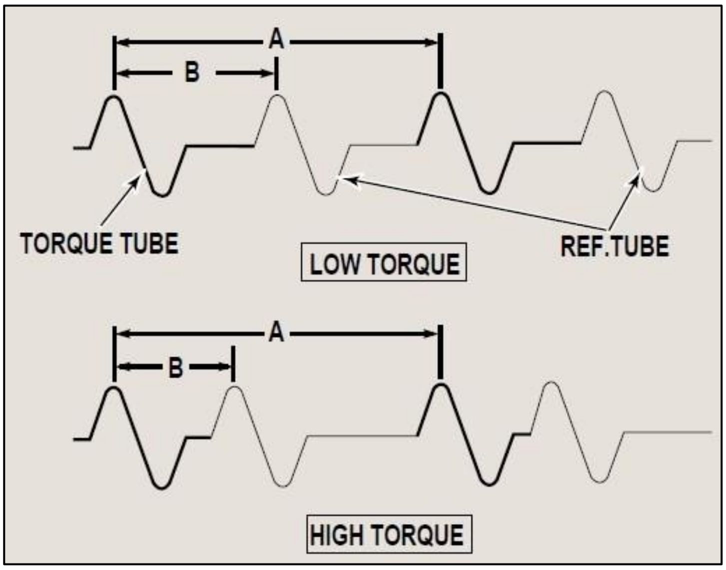


Figure 1-97: Torque Measurement Process

(c) Each sensor detects the phase difference between the teeth on the torque tube and the teeth on the reference tube. The electromagnetic pulses (sign waves), generated when the teeth pass through the sensor's magnetic field are transmitted to the AFU and to the EEC. The left side torque sensor (No 1) signal is transmitted to the AFU for auto-feather logic and analogue torque cockpit indication. The right side torque sensor (No 2) signal is transmitted to the EEC for power management and torque indication in the cockpit. This signal is used by the EEC to provide the torque indication to the FDAU (TQ recorded by the DFDR). The sensors also measure the temperature of the air around the shaft to compensate for a change in torque shaft stiffness. In addition, the EEC derives Np from the right side torque sensor signal. When torque values are negative, the DFDR records a null value.

1.19.2 **Blade Pitch Angle Regulation: System Description.**

1.19.2.1 **Condition levers (CL).**

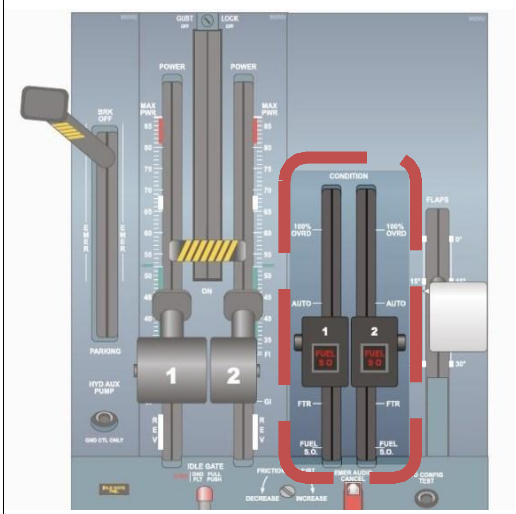
(a) Condition levers are used as a selector operating: -

(i) Feathering control.

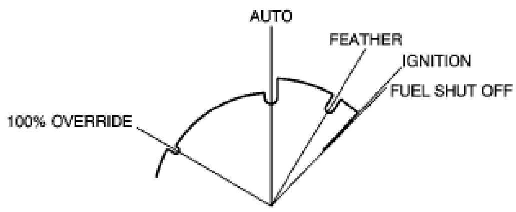
(ii) HP fuel shut off valves.

(iii) AUTO position controls propeller speed through PWR MGT selector position.

(iv) 100% OVRD position sets manually Np max.



Condition Levers



Positions of Condition Levers

Figure 1-98: Condition Levers and Positions

(b) The position of the CL activates micro switches. To travel the lever from AUTO to FTR and from FTR to FSO (and return), it is necessary to act on a trigger located on the lever side. When the CL position is at or below the FTR position, the first feathering signal triggers the feather sequence. This signal allows the continuous powering of the feather solenoid and the powering of the electrical feathering pump (duration 30 sec). This first feathering signal drives also the behavior of the Crew Alerting System for some master caution and / or master warning. For instance: -

(i) The CL at the FSO position inhibits the oil low pressure warning, the DC gen failure etc.

(ii) The move of a CL outside of the FSO position triggers a 30 sec inhibition timer for the oil low pressure warning.

(iii) The CL in the FTR position or below inhibits the ACW gen failure master caution.

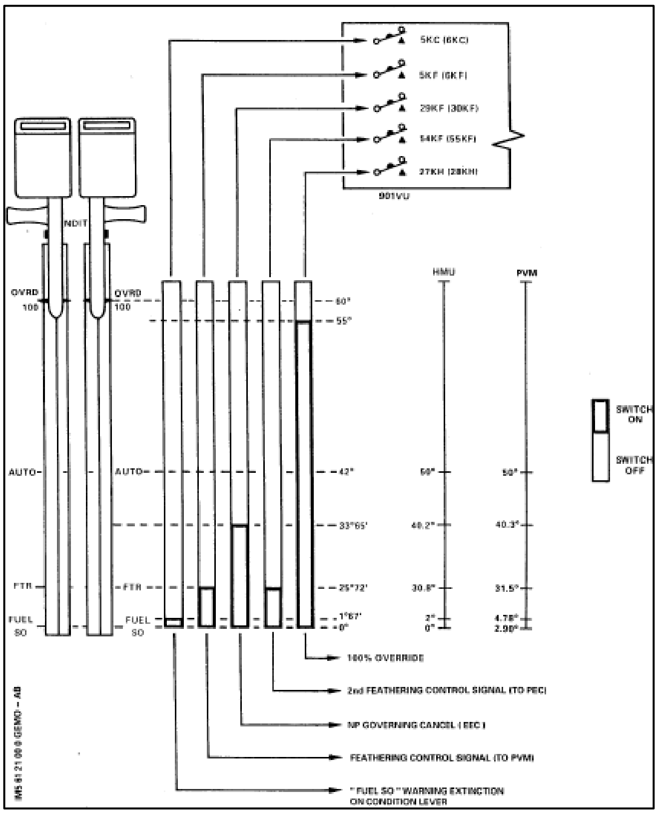


Figure 1-99: CL Micro Switches

1.19.2.2 **Main Pump:** The main pump provides the supply pressure P_S to the blade pitch angle regulation system. It is mounted and driven through the Reduction Gearbox (RGB) of the propeller. It provides the blade pitch angle regulation system with oil from RGB tank at 1000 psi.

1.19.2.3 **Electrical Feathering Pump:** The electrical feathering pump provides additional supply pressure as a back-up to feather the propeller. It has its own dedicated oil supply located in the reduction gearbox that is unavailable to the main pump. This quantity is sufficient for a complete feathering process. The electrical feathering pump motor has a duty cycle of 30 sec ON and 10 minutes OFF (cooling). This ON cycle is controlled by the Multifunction Computer (MFC). No control of the OFF time is performed by any system of the aircraft. In addition, anytime the propeller is commanded to go to feather in flight, the electrical feathering pump is activated to ensure sufficient oil pressure. The electrical feathering pump is not activated when feather is requested on ground (AMM 61-22-00). Except during maintenance tests or when fire handle is pulled, the pump is activated on ground only when the CL is in FSO position and was in FTR position less than 30 sec before.

1.19.2.4 **Propeller Valve Module (PVM):** The Propeller Valve Module, located on the reduction gearbox is composed of several sub-systems: -

(a) The Electro-Hydraulic (solenoid) Valve (EHSV / EHV)

(b) The Protection Valve

(c) The Feather Solenoid

(d) The Secondary Low Pitch Stop retraction solenoid

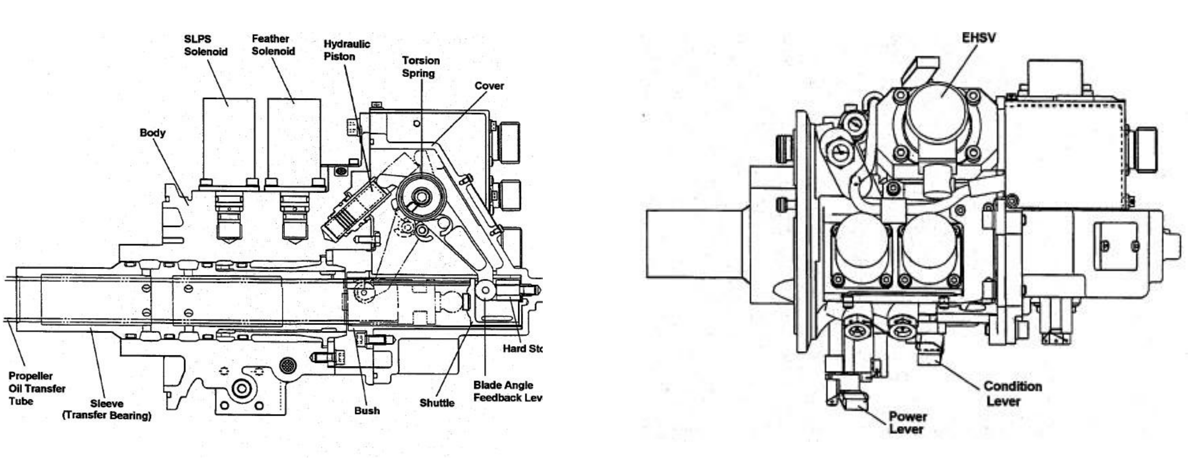


Figure 1-100: Propeller Valve Module

(a) **Electro-Hydraulic Valve:** The Electro Hydraulic Valve (EHV) is the unit that directs flow through the Protection Valve and subsequently to the Actuator. Electrical signal sent from the PEC causes the reaction in the EHV. This reaction re-directs the supply pressure. The Propeller Valve Module (PVM) receives pitch change commands from the Propeller Electronic Control (PEC) via dual windings on the Electro Hydraulic Valve (EHV). When powered by the PEC, the EHV meters oil from the supply oil to either the high pitch (P_C for Coarse Pitch pressure) or the low pitch (P_F for Fine Pitch pressure) hydraulic lines. Oil from the cavity not being supplied is metered to drain. The amount of current to the EHV determines the blade pitch change rate. When PEC is OFF, the EHV is not powered anymore. The EHV is designed such that in a de-powered condition, the flow through the device results in a limited rate for decrease blade pitch angle (EHV bias).

(b) **Protection Valve.**

(i) The protection valve is controlled by 2 control pressures: -

- The supply pressure P_S
- A pressure P_{OSG} coming from the overspeed governor, the feather solenoid and the SLPS solenoid. This pressure is equal or lower than P_S

(ii) It has 4 inputs pressures: -

- P_S: the supply pressure
- P_D: a link to the drain
- The EHV fine command pressure (EP_F)
- The EHV coarse command pressure (EP_C)

(iii) The protection valve provides 2 output pressures to the propeller setting system: -

- The fine chamber pressure (P_F)
- The coarse chamber pressure (P_C)

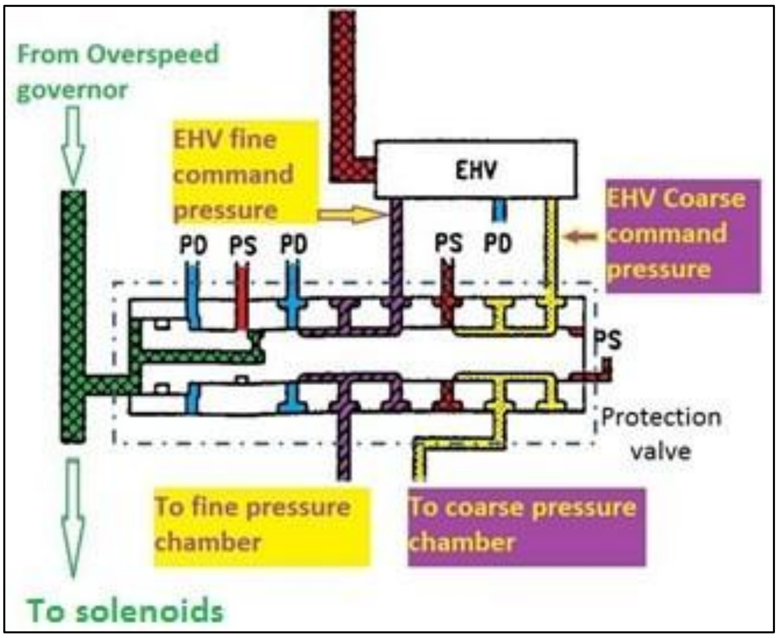


Figure 1-101: PVM Protection Valve in Unprotected Mode

(iv) When the two control pressures P_S and P_{OSG} are equal, the protection valve lets the EHV drive the pressures: it is in the unprotected mode. P_C is then equal to EP_C and P_F to EP_F. When P_{OSG} decreases, the protection valve moves to the left (figure 1-101) and reduces the control of P_C and P_F coming from the EHV. The protection valve connects: -

- P_C to P_S or EP_C (P_C is greater than EP_C)
- P_F to P_D or EP_F (P_F is lower than EP_F)

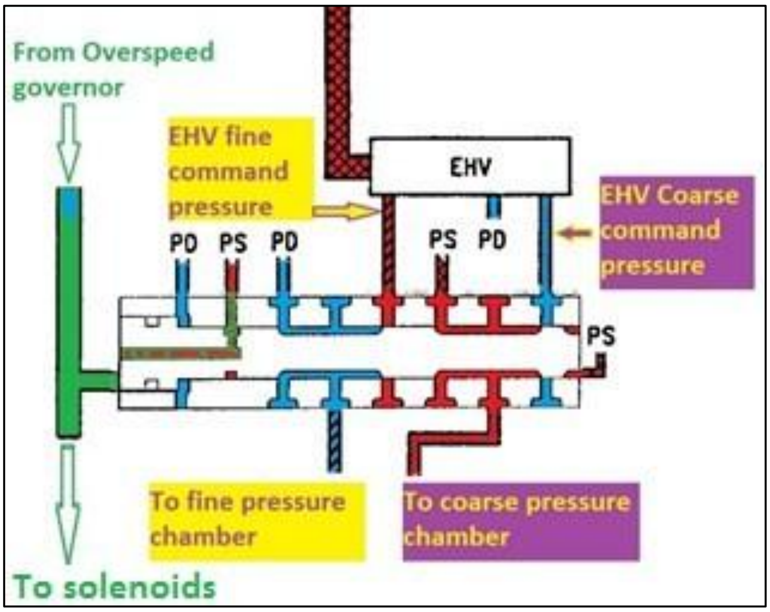


Figure 1-102: PVM Protection Valve in Protected Mode

(v) When P_{OSG} is less than 50% of P_S, the protection valve is in protected mode and does not let the pressure of the EHV go to the propeller pressure chambers.

(c) **Feather Solenoid:** The feather solenoid is powered when feathering is requested. When it is energized (EMER BUS 28 VDC), it directly connects the control pressure P_{OSG} to the drain line pressure (P_D).

Note: The feather solenoid is tested after each flight during which the PEC commands decrease pitch to ensure the functionality of the PVM feather solenoid and protection valve to override the EHV command.

1.19.2.5 **Overspeed Governor (OSG).**

(a) The propeller overspeed governor is a backup system that protects the propeller from over- speed.

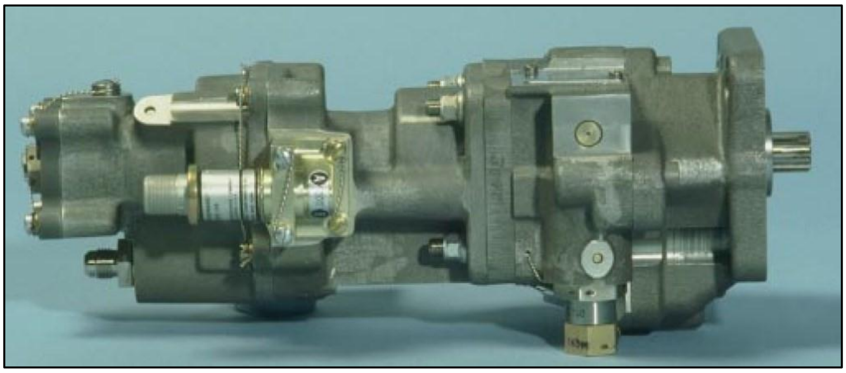


Figure 1-103: OSG and the Main Pump

(b) The propeller overspeed governor is a hydro mechanical unit installed on the main pump of the propeller hydraulic control system. The governor monitors propeller speed (Np). In the event of an overspeed (Np > 102.5% in flight), it bleeds pressurized oil from the overspeed line to the drain.
(c) If the propeller speed exceeds the overspeed threshold, governor flyweight force overcomes spring pressure. The flyweights rotate, lift the valve, connecting the overspeed line to the drain. The protection valve in the PVM moves to the protected mode and the propeller blade angle increases. When propeller speed falls to a point where spring pressure exceeds flyweight force, the valve moves down, restoring the flow of pressurized oil to the overspeed line: the protection valve moves back to the unprotected mode. During the overspeed regulation, a balance position will be reached by the system (protection valve, overspeed governor and blade pitch angle). The governor load spring may be changed by energizing the speed reset solenoid (automatically performed when the PLA is lower than Flight Idle and the CLA greater than feather position). In this case, the overspeed governor threshold increases to 118%.

1.19.3 **Blade Pitch Angle Regulation: System Operation.**

1.19.3.1 **PEC ON Behavior.**

(a) The blade pitch regulation system relies on hydraulic pressure regulation driving the blade pitch angle actuator. The movement of actuator makes the blade rotate around its axis and then change the blade pitch setting.

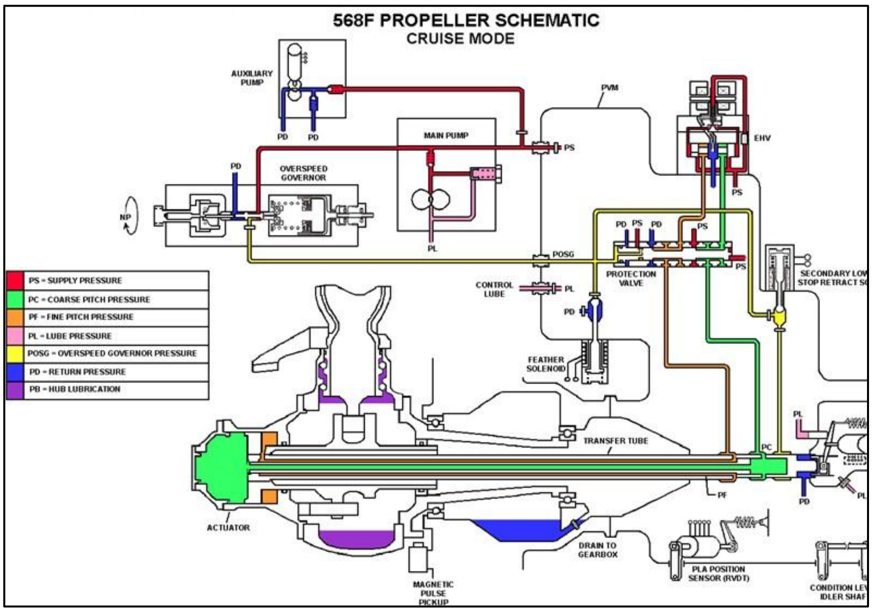


Figure 1-104: The Blade Pitch Angle Regulation System

(b) The blade pitch regulation in flight is based on the following principles: -

(i) Pressure supply P_S is provided by the main pump, driven by the RGB (and then linked to the propeller speed).

(ii) In normal operation during the flight, the PEC drives the EHV with the appropriate current to select the proper fine and coarse pressures sent to the actuator. The PEC receives a feedback control through a sensor located at one end of the transfer tube so as to stay inside the range defined for the blade pitch angle.

(iii) Protections are built around this system to avoid any excursion outside of the desired range, ie the protection valve and the ratio between P_{OSG} pressure and P_S pressure sensed by this valve.

- By default, the P_{OSG} pressure is quite equal to the P_S pressure. The protection valve is in the unprotected position and lets the EHV fully control the actuator.
- When P_{OSG} decreases and protection is activated. The protection valve moves to the protected mode and stops the EHV flow. It uses pressure supply P_S to increase the blade pitch angle (P_S sent to the coarse chamber, Fine chamber connected to the drain).
    - If the propeller speed increases above the defined threshold (around 102.5%), the overspeed governor connects the P_{OSG} line to the drain. P_{OSG} decreases lower than half of P_S the protection valve moves to the protected mode and requests an increase of the blade pitch angle. The increase of the blade pitch angle makes the propeller speed decrease; the overspeed governor stops connecting the P_{OSG} line to the drain. With the increase of P_{OSG}, the protection valve moves back to the unprotected position. The blade pitch angle decreases again, the propeller speed increases and the protection triggers again. After a damping phase, the propeller speed is regulated at the defined threshold.

- If feather is requested, the feather solenoid is powered. It opens and connects the P_{OSG} line to the drain. The protection valve switches to the protected mode and requests increase of the blade pitch angle until the feather command is removed. With the increase of the blade pitch angle, the propeller speed decreases and so does the pressure provided by the main pump (driven by the propeller speed). To avoid any concern with pressure supply, an electrical feathering pump is used to provide sufficient pressure during feathering process (in flight feathering only). The PEC provides redundancy in case of failure of the primary feathering system by requesting the EHV to command feathering.
- The P_{OSG} line ends close to the end of the transfer tube in a metering window. The end of the transfer tube is connected to the drain pressure line. At high blade angles, the transfer tube covers the metering window. The P_{OSG} line is isolated. When the blade pitch angle moves towards low pitch, the actuator moves forward. At a position corresponding to the lowest blade pitch angle allowed in flight (12.8°), the metering window is no more covered by the transfer tube. The P_{OSG} line is connected to the drain. The regulation occurs on same principle that is for the propeller overspeed regulation. After a damping phase, the blade pitch angle stays limited to the lowest blade pitch angle allowed in flight.

Metering Window

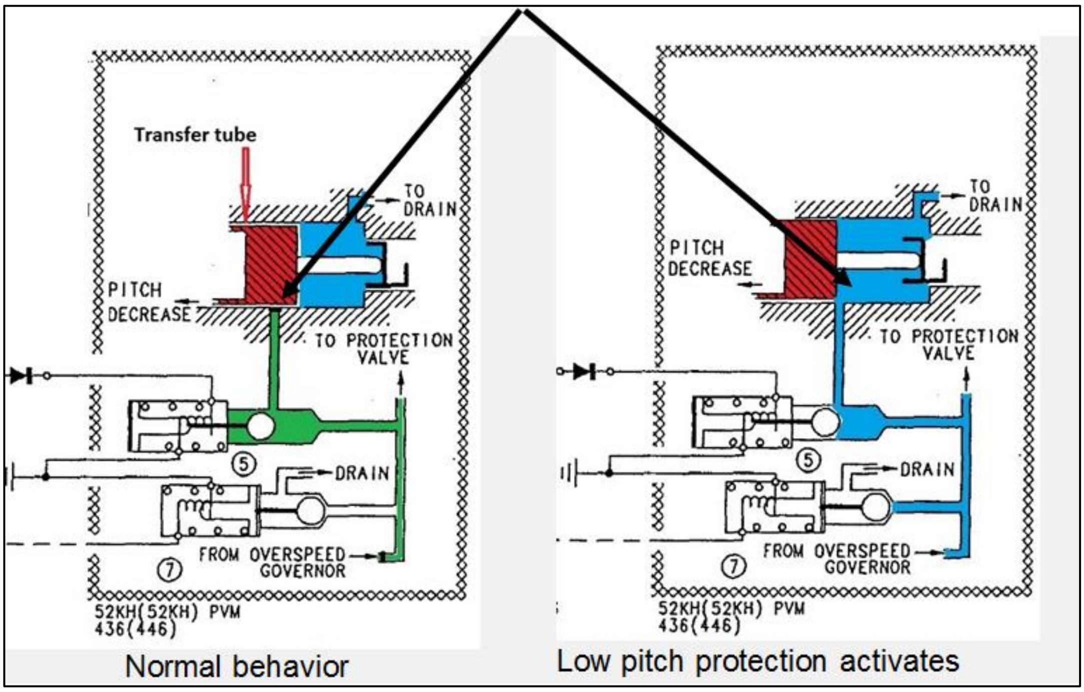


Figure 1-105: SLPS Protection

Note: The protection valve and the relationship between P_{OSG} and P_S sensed by the protection valve are the last safety barriers of the system.

1.19.3.2 **PEC OFF Behavior:** In this case, the EHV is not powered anymore. The EHV valve stays in its rest position, with a bias requesting a decrease of the blade pitch angle. With the decrease of the blade pitch angle, the propeller speed in a normally operating power-plant will increase up to the OSG set point while maintaining the low pitch stop blade angle protection. This is intended by the propeller system design for PEC fault conditions. From that point, the blade pitch angle is controlled by the overspeed regulation and is dependent of the environmental conditions (including Np speed). Otherwise, the blade pitch angle is limited to the low pitch in flight by the SLPS protection. The protection valve and the relationship between P_{OSG} and P_S sensed by the protection valve are still the last safety barriers of the system.

1.19.3.3 **Feathering with PEC OFF:** Feathering through feathering solenoid only (equivalent of feathering with PEC OFF) is tested during every propeller feathering on ground. By design, the primary feathering system is the feather solenoid, and it is not the PEC. Indeed, whatever the status of the PEC, the feathering command coming from either the CLA or the fire handle opens the feather solenoid, leading the protection valve to move to the protected mode. Feather solenoid and protection valve are tested at the end of each flight during the propeller feathering sequence. A PEC OFF condition does not have any impact on the feather, provided the protection valve moves to the protected mode. If the protection valve does not move to the protected mode and stays in intermediate position, then there are 2 possible results depending on the exact position of the valve spool: -

(a) A slow decrease in pitch.

(b) A slow increase in pitch.

1.20 **Useful and Effective Investigation Techniques:** Standard investigation techniques were used, however keeping in view the unusual presence of latent pre-existing technical anomalies / condition, and limited information, extensive brain storming discussion sessions, simulations, test flights, advance forensic test / analysis and tele-conferences etc were undertaken to reconstruct the event flight and correlate that with most probable sequence of technical malfunctions that can explain the off-design aircraft behavior.

SECTION 2 - ANALYSIS

SECTION 2 - ANALYSIS

2.1 **Introduction:** The analysis comprises of three parts. The first part encompasses aspects related to the cockpit crew qualification and experience, the second part encompasses the details of technical aspects, aircraft airworthiness, maintenance management / oversight, and the third part comprises of conduct of flight, Crew Resources Management (CRM), degraded aircraft performance, aircraft certification aspects, landing possibility and related aspects.

2.2 **Cockpit Crew Qualification and Experience[137]:** The cockpit crew were certified and qualified in accordance with applicable Rules of CAA Pakistan. There was no evidence to indicate that the flight crew's performance might have been adversely affected by pre-existing medical conditions, fatigue, medication, other drugs or alcohol etc during the event flight. All three pilots fulfilled the desired qualification / fitness criteria to become cockpit crew, and were accordingly scheduled to operate the event flight in the respective assigned roles.

2.2.1 **Captain.**

2.2.1.1 The Captain started his career in PIA in 1996 as a First Officer on Fokker F-27 aircraft. After Fokker F-27 he flew Airbus 300, Airbus 310, Boeing 737, and Boeing 777 as a First Officer. At the age of 43 years he had accumulated 1216:05 hrs on ATR42-500 aircraft and a total of 11265:40 hrs of flying experience, with a moderate career progression. His training records reflect occasional observations related to slow progress and ordinary performance, however, after necessary reviews he was being considered acceptable as per the PIA policy and had been meeting CAA Pakistan requirements. He held a valid Airline Transport Pilot License (ATPL-1591 date of issuance 16 July 1995). He had valid medical fitness with an advice to reduce weight.

2.2.1.2 **Up gradation Training:** After completion of his training as a Captain on ATR aircraft, and was undertaking flights as Captain since 26 August 2015. There were no significant safety related observations. He attained instructor status on ATR aircraft and was qualified / proficient to impart training in accordance with the PIA Training Policy. He held valid instrument rating and had completed all training perquisites / checks in accordance with the relevant PIA training requirements and applicable CAA Pakistan procedures.

2.2.1.3 **Recurrent Trainings:** Captain's all annual proficiency trainings and checks were studied. Observations about his performance were generally diverse in nature, however few recurring observations were about not been assertive, adherence to SOPs / procedures, speed control during drift down / emergency descend, situational awareness etc. The last simulator training records and route checkout reflected grey areas in his performance about adherence to the SOPs / procedures, and decision making etc. However, the same records indicated that he had passed / cleared the required checks (including proficiency check and line check). The possible attribution of any of these aspects with the crash has been discussed in later parts of analysis.

2.2.1.4 The Captain had a family and led a normal family life. There were no social / psychological issues reported / documented by PIA / CAA Pakistan in their respective records.

[137] CAA Pakistan records regarding crew licensing / medical fitness and PIA records about training and personal information.

2.2.2 **First Officer (A).**

2.2.2.1 The First Officer (A) started career in PIA in 2005. He initially flew Twin Otter and Fokker F-27 aircrafts as a First Officer. He converted on ATR42-500 aircraft in 2007. At the age of 40 years he had accumulated 1416:00 hrs on ATR aircraft and a total of 1742:30 hrs of flying experience, with a meager career progression. His training records reflect frequent observations related to poor / slow progress, and unacceptable performance, however, he remained on the job and after necessary review he was being considered acceptable as per the minimum acceptable standards of PIA and CAA Pakistan. He held a valid Commercial Pilot License (CPL-2398 date of issuance 21 May 1998). He had valid medical fitness.

2.2.2.2 **Up gradation Training:** He joined up gradation training on Airbus 310 as a First Officer, however he was unable to cope with the requirements and was sent back on ATR aircraft (and was restricted to remain a First Officer).

2.2.2.3 **Recurrent Trainings:** The First Officer (A)'s all annual proficiency trainings and checks were studied. Observations about his performance were generally diverse in nature, reflecting occasional poor performance. However, the same records indicated that he had passed / cleared the required checks (including recurrent ground training, proficiency check and line check). The possible attribution of any of these aspects with the crash has been discussed in later parts of analysis.

2.2.2.4 The First Officer (A) had a family and led a normal family life. There were no social / psychological issues reported / documented by PIA / CAA Pakistan in their respective records.

2.2.3 **First Officer (B).**

2.2.3.1 The First Officer (B) started career in PIA in 2012 as a First Officer on ATR42-500 aircraft. At the age of 26 years he had accumulated 369:15 hrs on ATR aircraft and a total of 570:00 hrs of flying experience, with a good progress in applicable domains. He held a valid Commercial Pilot License (CPL-3090 date of issuance 11 March 2011). He had valid medical fitness.

2.2.3.2 **Recurrent Trainings:** The First Officer (B)'s all proficiency trainings and checks were studied. His performance was good and progressive. He had passed / cleared the required checks (including recurrent ground training and proficiency check).

2.2.3.3 The First Officer (B) was unmarried and lived with his mother and siblings. There were no social / psychological issues reported / documented by PIA / CAA Pakistan in their respective records.

2.2.4 **Matter of Dubious Pilots' Licenses[138]:** During 2019 CAA Pakistan initiated scrutiny of licensing records of pilots. It was discovered that there were irregularities regarding the conduct of ground examinations by the licensing branch of CAA. This rendered a suspicion about licenses of few of the pilots who appeared in the exams during a specified period of time, and their attendance / physical participation could not be verified from the records. CAA has reconciled the matter by seeking clarification from the individuals, and disposing off the cases by adopting a legal / formal procedure. Names of Captain and First Officer (B) appeared in the initial list of pilots whose licenses were considered suspicious. CAA has removed their names on the basis of criteria / standard being followed during the review process[139].

---

[138] In June 2020, the matter of dubious licenses by the pilots was made public during a formal joint session of the National Assembly of Pakistan by the Federal Minister of state for Aviation.

[139] AAIB letter to CAA for seeking clarification on the matter and CAA response.

2.2.5 Career training records of the pilots highlighted few observations. Similar observations were also noted during the event flight. Based on the analysis of actual crew performance in comparison with the expected crew actions, AAIB has concluded that their performance was commensurate with their respective experience / training records etc. The matter of dubious licenses surfaced during the course of investigation therefore becomes irrelevant. However pilots' actions for attribution to the crash have been discussed in detail in analysis part of the investigation.

2.3 **Technical Analysis[140]:** The sequence of events for the crash has been covered in history of flight. Due to limited number of DFDR parameters on AP-BHO ATR42-500 recorder configuration (by design in accordance with modifications embodied on this aircraft), the technical analysis remained very complex. Analysis was aimed at ascertaining the causes of No 1 Engine IFSD, the abnormal behavior of No 1 Propeller and interrelation in terms of "Cause & Effect" paradigm, and its effect on aircraft performance. Evidence of in flight fire, structural failure, bird hit or sabotage etc was not found. Moreover, examination of No 2 Engine / Propeller system did not reveal any abnormality that could possibly relate to the event flight.

2.3.1 **Scope of Technical Analysis:** The technical analysis focuses on fracture of Power Turbine Stage 1 (PT-1) blades resulting in No 1 Engine IFSD along with the pre-existing technical anomaly inside Overspeed Governor (OSG) and pre-existing contamination in Propeller Valve Module (PVM)[141], resulting in abnormal behavior of No 1 Propeller. It includes series of simulations and tests by the OEMs to explain the chain of events. The technical analysis has been organized by identifying various phases of flight. Important technical findings (annotated as "Tech Finding" along with a sequential serial number) have been identified. Subsequently based on the technical findings, a most probable scenario for each phase of flight has been discussed.

2.3.2 **Definition of Phases of Flight:** Phases have been defined on the basis of behavior of No 1 Propeller speed (Np-1) and No 1 Engine power loss[142]. These phases are: -

Phase	Start	End	Comment
Phase 1	10:48:00	11:04:44	During the cruise, Np-1 showed oscillations.
Phase 2	11:04:44	11:10:34	Np-1 was no more regulated and decreased gradually.
Phase 3	11:10:34	11:10:55	Np-1 reached a level compliant with the overspeed governor threshold.
Phase 4	11:10:55	11:11:18	Np-1 decreased and became NCD. Its behavior looked like a feather request.

[140] The technical analysis has been extracted mainly from BEA2016-0760_tec34, Most Probable Scenario on the Powerplant #1 Behavior, dated 26 November 2018. This report was generated after colossal effort by BEA so that the event can be reconstructed to explain possible technical failures / anomalies leading to unusual aircraft behavior. This was based on factual information, numerous simulations / tests and few assumptions. Variations from this report have been appropriately referenced, where ever required.
[141] Based on available evidence / analysis the pre-existence of contamination in PVM is probable.
[142] Phases defined herein are same as of the above referred report.

Phase	Start	End	Comment
Phase 5	11:11:18	11:11:46	Np-1 increased again. The rate of the increase was very slow.
Phase 6	11:11:46	11:11:53	Np-1 rate increased.
Phase 7	11:11:53	11:12:34	Np-1 reached values around 120%.
Phase 8	11:12:34	End of flight at 11:20:38	Np-1 decreased and reached NCD values.

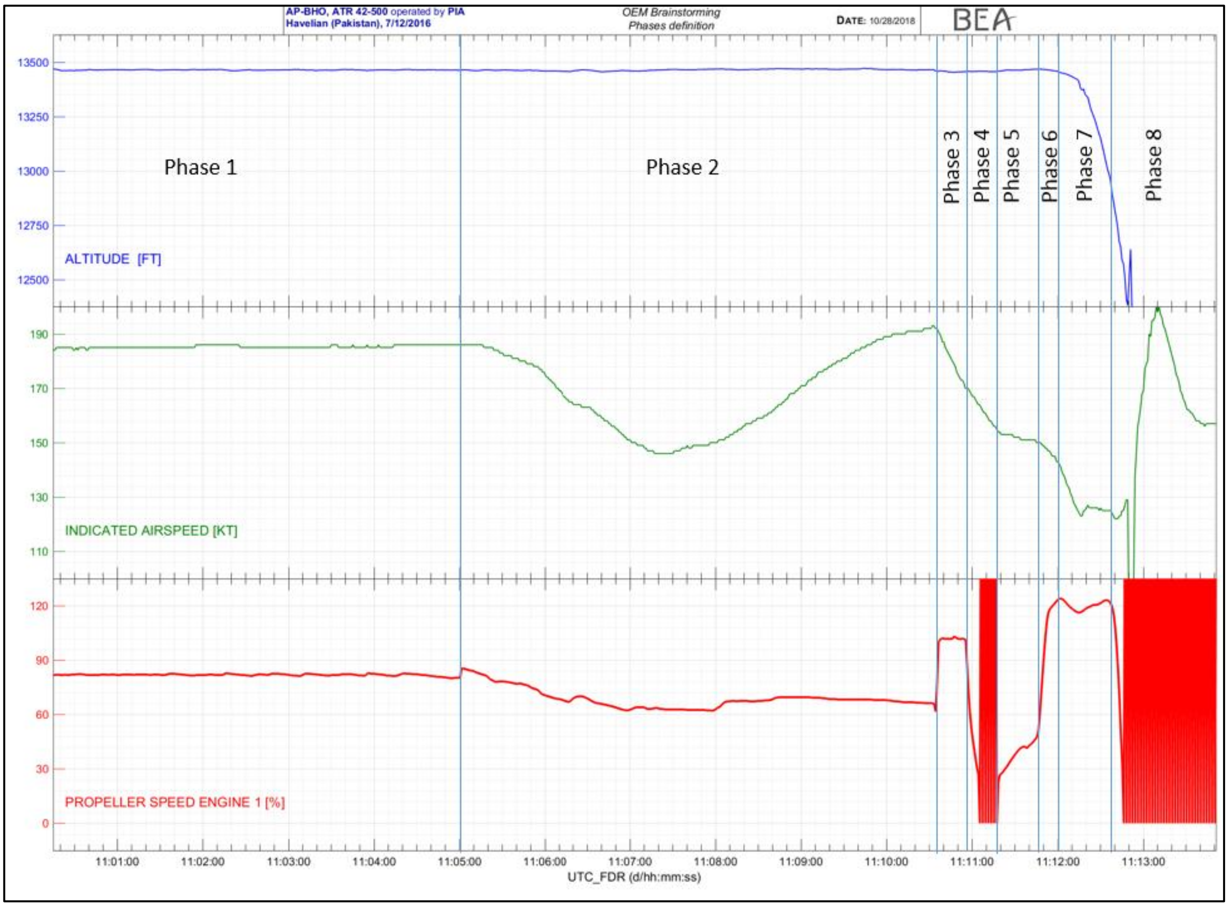


Figure 2-1: Identification of Phases on Selected DFDR Parameters

2.3.3 Tests, Examinations and Analysis.

2.3.3.1 **Aircraft Manufacturer Test Flights:** ATR performed test flights, with a propeller in wind-milling condition (out of feather). During these test flights, in the minute following the engine shutdown, the temperature of the oil decreased to around 158°F and the NH values decreased down and reached values between 5% and 6%.

Tech Finding 1: During test flight, with an engine shutoff and in conditions close to the conditions of the event, NH values stabilized between 5% ~ 8% during the wind-milling phase.

2.3.3.2 **Propeller (Hub, Transfer Tube and Actuator).**

(a) Evidence of degradation was not found during the teardown examination of transfer tube, blades and propeller hub, it was assumed that this part of the system was fully functional. Consequently, in order to investigate the abnormal / off design behavior of No 1 Propeller, efforts were made to identify anomalous components of propeller regulation system, which mainly included PVM, pumps and OSG and oil feeding lines. Special attention was paid to the seals between the fine and coarse lines of the transfer tube. In case of a damaged seal of the transfer tube, leakage would occur between the fine pressure and the coarse pressure. Damage was witnessed on the seal of transfer tube during the examination however it was attributed to the tear down process or the post-crash fire (figure 2-2). Tests were performed on a test bench to determine propeller behavior in case of leakage between the fine and coarse lines at the level of the transfer tube. The behavior of the propeller on test bench did not match the behavior of the propeller during the event flight. In case of leakage, switching off the PEC led to the feathering of the propeller whereas during the event switching off PEC had no effect on propeller. Several tests were performed to: -

- Check the rate of blade pitch angle during feather and unfeather phase.
- Compute the associated forces applied on the actuator.

Figure 2-2: Transfer Tube and Seals – Damage Attributed to Teardown or Post-Crash Fire

(b) **Feathering Tests:** A feathering sequence based only on the counterweights was performed by UTAS, by simulating a loss of hydraulic pressure. In this case, the blade pitch change rate decreases with the propeller speed. Indeed, as the propeller speed decreases, the counterweight action is less efficient. The highest rate reached in this case was $1°s^{-1}$. Furthermore, in case of feathering sequence based on counterweights only, the blades do not reach the full feather position. The expected behavior of the propeller was also tested when feather is requested with PEC switched off (no impact on the real scenario, as feathering relies first on the feather solenoid action). In this case, the blade pitch rate was around $15°s^{-1}$. In 2.6 sec, the propeller speed reached 27%.

(c) **Un-Feathering Tests:** Un-feathering tests were performed by the propeller manufacturer on a test bench (PWC FTB), without using any additional pressure (electrical feathering pump not used). In the nominal case, when a propeller is un-feathered with a PEC switched off, the ß rate was determined to be at least $-7°s^{-1}$ with a maximum rate reaching $-11°s^{-1}$. The test of the un-feathering with PEC OFF provided information on the expected fine pressure P_{Fine} without the electrical feathering pump. It started at the beginning of the un-feathering sequence at 150 PSI before reaching 600 PSI. The coarse pressure P_{Coarse} started from 0 PSI, reached a peak around 500 PSI before decreasing. This test also underlined that in case of closure of the feather solenoid, the main pump is able to reach 1,000 PSI at a propeller speed of less than 40%.

(d) **SHP Computation with Low Blade Angle:** The propeller manufacturer performed several computations to determine the SHP generated by the propeller for different couple of NP and blade angle, for an IAS of 125 knots at an altitude of 13,500ft (condition close to the conditions of the event). The result indicated: When blade angle decreased, below a certain blade angle (depending on the NP), the propeller in wind milling does no longer generate power but need power to stay at the same speed.

(e) **Conclusions from ATR Feathering and Un-Feathering Test in Flight:** Feathering and un-Feathering flight tests performed at aircraft level in conditions equivalent to the PIA event (PEC OFF, altitude, speed) confirms that feathering experienced by AP-BHO was abnormally slow compared to a PEC OFF feathering through feather solenoid. Moreover, it confirms that un-feathering experienced by AP-BHO was also abnormally slow compared to an Engine OFF / PEC OFF un-feathering through feather solenoid de-energization. It indicates that the observed AP-BHO slow feathering was probably not because of loss of feather solenoid. Important conclusions from test performed on propeller are as follows: -

Tech Finding 2: The damage observed to the seal of the transfer tube during the examination was attributed to the tear down process or the post-crash fire.

Tech Finding 3: A feathering request relying only on the counter weight action (no hydraulic power) is performed at a rate lower than the one observed during the flight of the event.

Tech Finding 4: During un-feathering test on a FTB, with nominal hydraulic pressure supply and PEC OFF, the decrease rate of β was determined to be greater than the one observed during the flight of the event.

Tech Finding 5: The main pump is able to reach its maximum capacity with a propeller speed of less than 40% without too high an oil flow request.

Tech Finding 6: If blade angle decreases below a certain angle (depending on the Np and the power absorbed by the engine), the propeller in wind-milling does no longer generate power but needs power to stay at the same rotational speed. With a failed engine, the decrease of the blade pitch angle below a certain threshold leads the propeller speed to decrease.

2.3.3.3 **Main Oil Pump:** The examination of the main pump provided information on oil contamination, but did not underline any concern with its performance. No evidence of cavitation was found. As the main pump had no capability issue due to physical characteristics, a degradation in its performance could only be due to oil feeding (starvation leading to a loss of pressure).

Tech Finding 7: No significant degradation of the main oil pump capacity was detected during its examination. Degradation of the main oil pump performance could only be due to oil starvation.

2.3.3.4 **Electrical Feathering Pump.**

(a) The electrical feathering pump was not recovered. The flights recorded on the DFDR did not meet the prescribed conditions to start the electrical feathering pump on ground therefore status of electrical feathering pump before the event flight could not be ascertained.

(b) At a given time, one pump feed the hydraulic circuit; a check valve blocks the other one. Due to the pumps' capacities, at the time the electrical feathering pump should have stopped, the main pump would have already taken the control of the oil feeding.

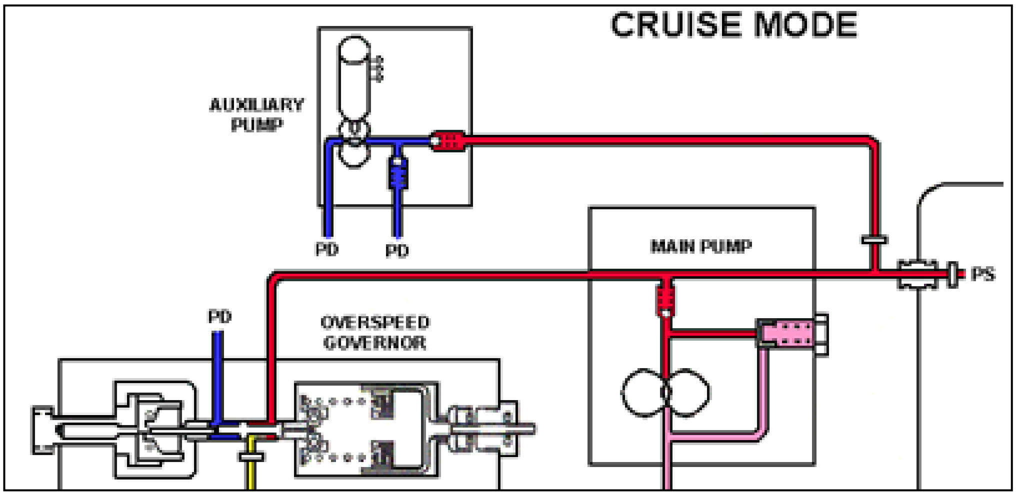


Figure: 2-3: The Pumps Feeding the Hydraulic Circuit

(c) From 11:11:18 to 11:11:25, it was not possible to determine whether: -

(i) The P_S (system pressure) was coming from the main pump only.

(ii) The P_S was coming from the electrical feathering pump only.

(iii) The P_S was coming from an association of both the pumps.

Tech Finding 8: It is impossible to assess the state of the electrical feathering pump during the flight of the event.

2.3.3.5 **Fuel Pump Capacity:** The engine manufacturer tests results indicated that fuel flow can be detected when fuel pump speed is between 4 and 5%.

Tech Finding 9: Fuel flow can be detected when NH is around 5%.

2.3.3.6 Engine Tests, Examinations & Analysis.

(a) **Summary of the Results of No 1 Engine Teardown Examination Performed at Pratt & Whitney Canada:** The engine power loss initiated with the fracture of one blade of the 1st stage Power Turbine. The fracture surface from this blade displayed characteristic features of fatigue originating in a zone where micro-shrinkage (voids) was present. Four other blades were found fractured as secondary to the fracture of the first blade. The other damages of the engine were also due to this primary blade fracture. The engine manufacturer was not able to timestamp the PT-1 blade fracture. The engine manufacturer only stated that it is possible that one or more 1st stage PT blades fractured prior to the ITT increase observed on the DFDR (between 10:56:01 and 11:04:19). The fracture of the 1st stage power turbine blade induced vibrations to the No 6 and No 7 bearing housing, leading to the deterioration of the No 6 bearing and its associated air / oil seal. This deterioration of the air / oil seal could have resulted in an oil leak with subsequent ignition when the oil entered the gas path. The No 6 bearing seal rubbing could also have resulted in subsequent increase in temperature within the seal housing which could have auto ignited the oil.

(b) The BEA studied the flights before the flight of the event. A focus on the propeller behavior is displayed in figure hereunder (limited set of parameters). The propeller speed (Np-1) regulation stayed inside the design specification (margin of 1%), however the oscillations of the propeller speed is not usual and the flight of the event did not show any linear regulation during the whole flight. During the flight N-1, the last area of linear regulation occurred during 3 minutes (in light green inside the figure hereunder).During the flight N-2 and the previous flight, several period of linear regulation existed during the cruise phase. During the flight of the event, the ITT and the fuel flow of No 1 Engine showed a clear trend to increase (area in light red inside figure hereunder). It was not possible to determine the time of the PT-1 blade fracture prior to the event. The increase of the ITT and of the fuel flow indicated that the No 6 bearing seal had already failed. The fracture of the blade occurred before this. As the degradation of the Np-1 regulation started during the flight prior to the flight of the event, the most probable scenario for this fracture / dislodging of the blade can be during that flight.

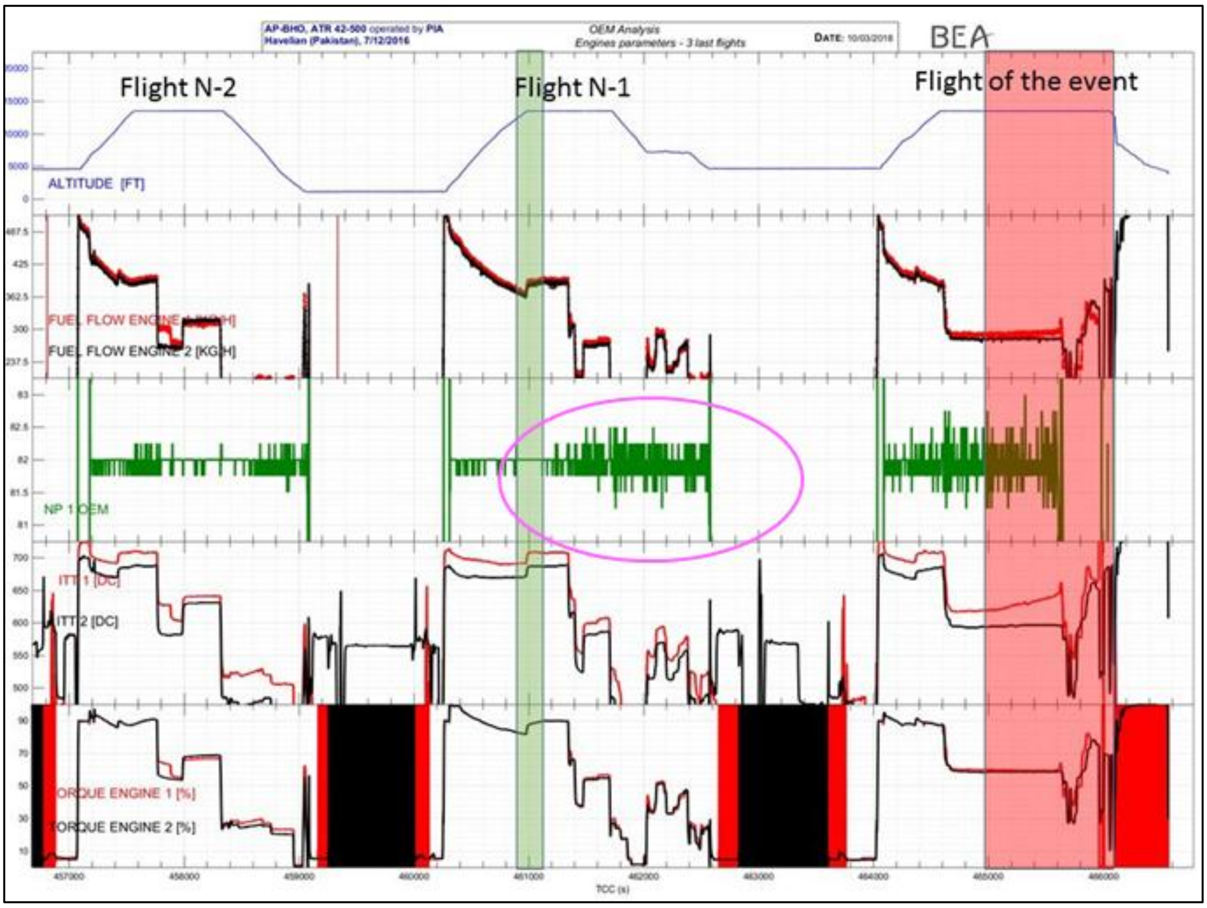


Figure 2-4: Engine Parameters During the Last 3 Flights

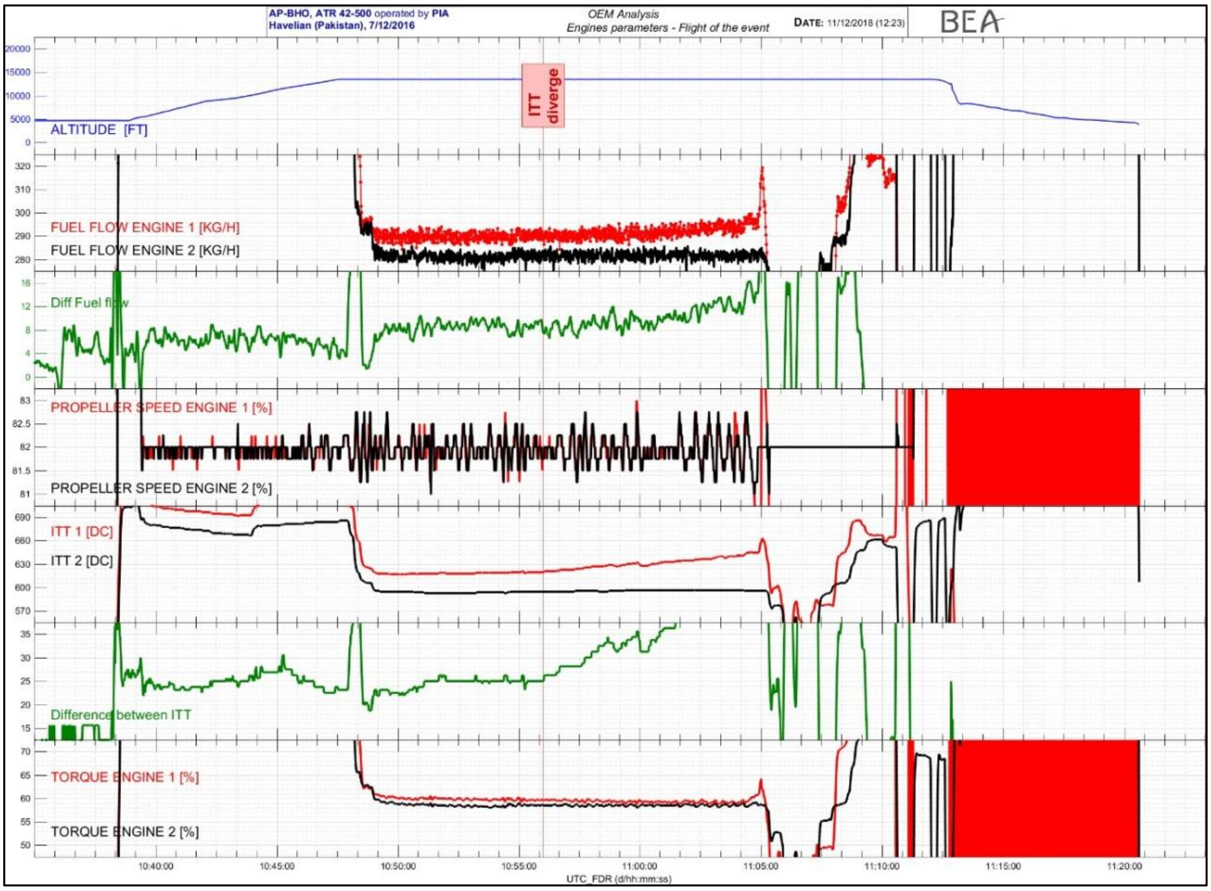


Figure 2-5: Flight of the Event - Engine's Parameters

(c) **Engine No 6 Bearing:** No 6 bearing was heavily damaged. The bearing rollers were no longer in the cage pockets. A total of 08 out of 22 rollers were recovered. They were severely worn and reduced in diameter. The front labyrinth seal was fractured. Particles were found in the last chance strainer of the oil pressure tube, mainly composed of phosphorous residues from burnt oil with metallic nickel based particles similar to Inconel 718.

Figure 2-6 : No 6 Bearing Cage

Figure 2-7 : No 6 Bearing Rollers

(d) **Engine Turbine Rotor Shafts:** The 3 turbine rotor shafts showed rubbing and scoring. The damage was shallow and indicated inter-shaft contact without real impact on the rotation speed of the shaft (in case of friction leading to a change of the turbine rotor shaft speed, the shafts would have been sheared). Given the small rubbing observed on the engine, the Tech Finding 1 can likely be transposed to the flight of the event. The high pressure turbine speed (NH) of the No 1 Engine during the flight of the event may have stabilized between 5% and 8% after the IFSD.

(e) **RGB Oil Feeding:** The distress of No 6 bearing resulted in contamination of oil due to metal particles coming from damage seal (Inconel-718) and likely from damaged bearing rollers. Oil contamination was also found inside the overspeed governor, therefore the engine manufacturer computed the capability of the engine oil pump in following distinct situations: -

(i) **Oil Filter Fully Clogged:** When the oil filter is fully clogged during engine operation, a differential pressure of 40 PSI shall exist at both ends of the filter for the bypass valve to open. Based upon information from the engine manufacturer, such differential pressure requires NH values greater than 25% to be maintained. During the flight of the event after the IFSD, a fully clogged filter would have led to a stop of the RGB oil feeding. Indeed the maximum pressure provided by the engine oil pump when NH value is around 5% (event flight), is too low to open the bypass valve.

(ii) **Oil Filter Not Clogged:** The oil flow delivered to the RGB tank was computed by the engine manufacturer. The results are given for an oil temperature of 180°F. During the event, the oil temperature should have been slightly lower, around 158°F (information from the aircraft manufacturer test flight). The decrease of the temperature would increase the flow capability of the pump. Without clogged filter, the engine oil pump had the capability to provide sufficient oil flow to the propeller hydraulic control system.

(iii) **Oil Filter Partially Clogged:** Oil contamination might lead to a partial filter clogging. In this case, before the IFSD, the engine oil pump capacity was enough to open the bypass valve (NH values greater than 73%).

(f) **Impact of Filter Clogging on RGB Oil Feeding:** A fully clogged filter would have led to an oil starvation inside RGB as soon as NH values got lower than 25% (before beginning of phase 5). The decreased rate of β from phase 5 to 7 computed by the manufacturer indicated a fully clogged filter before IFSD is extremely remote but a partially clogged filter with filter bypass before IFSD was likely. However, the decrease rate of the propeller speed during the phase 8 was higher than the decrease rate when propeller goes onto feather without any hydraulic supply. The probability of a lack of oil feeding at the start of phase 8 is extremely remote.

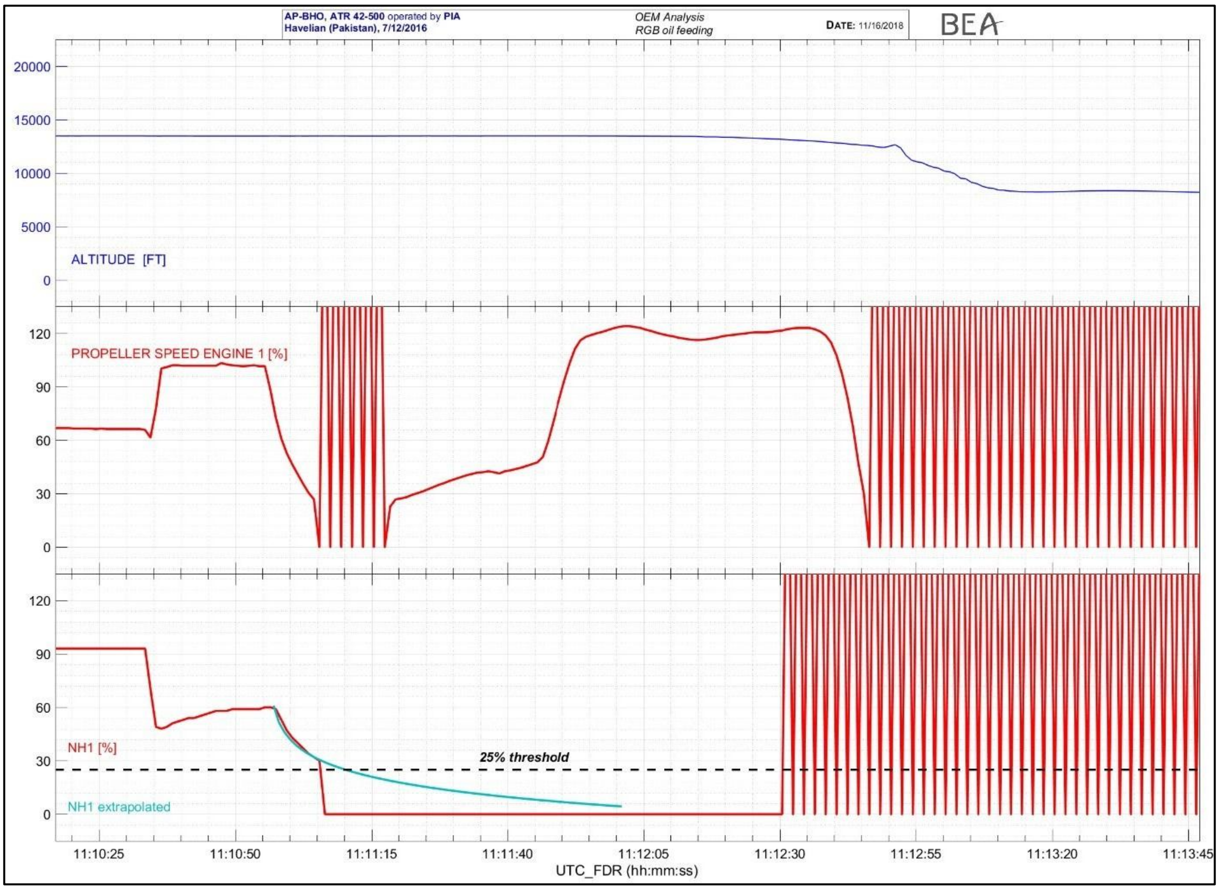


Figure 2-8: RGB Oil Feeding

(g) **No 1 Engine Fuel Flow.**

(i) **Phase 1 and 2:** Did not require discussion in this report.

(ii) **Phase 3 to 5:** At 11:10:57, fuel flow-1 values decreased and reached zero. At that time, CL-1 was set into the FSO position, following a feather request detected 2 seconds before. At the same time, two single chimes (master caution) were interrupted. When engine flame out in flight occurs, DC generator fault and Bleed pack fault are triggered. These 2 master cautions are inhibited when the CL is in the FSO position. At 11:11:18, the No 1 propeller speed parameter recorded valid values again (propeller un-feathering). The recorded fuel flow-1 values were still null; as a result it is likely that a CL-1 was still in FSO position (NH values greater than 5%). If the CL-1 was moved outside of the FSO position at the time the No 1 Propeller was leaving the feather, fuel flow-1 parameter should have recorded non-null values. Taking into account the fuel pump capacity and the results of the test flight (propeller in wind-milling, leading to a NH value around 5%), the probability of CL move without any recorded fuel flow-1 is far remote. The fuel flow-1 values stayed at 0 until 11:12:27. At that time, the fuel flow-1 increased again, reaching around 44 Kgh^{-1}, values consistent with an engine start without NH increase above the starter drive speed. To allow fuel flow, the CL-1 should have set outside of the FSO position. NH-1 extrapolated values were computed. The extrapolated NH-1 values provided a value greater than 10% when the first non NCD values was recorded for the No 1 Propeller speed (fuel flow is available when NH>5%).

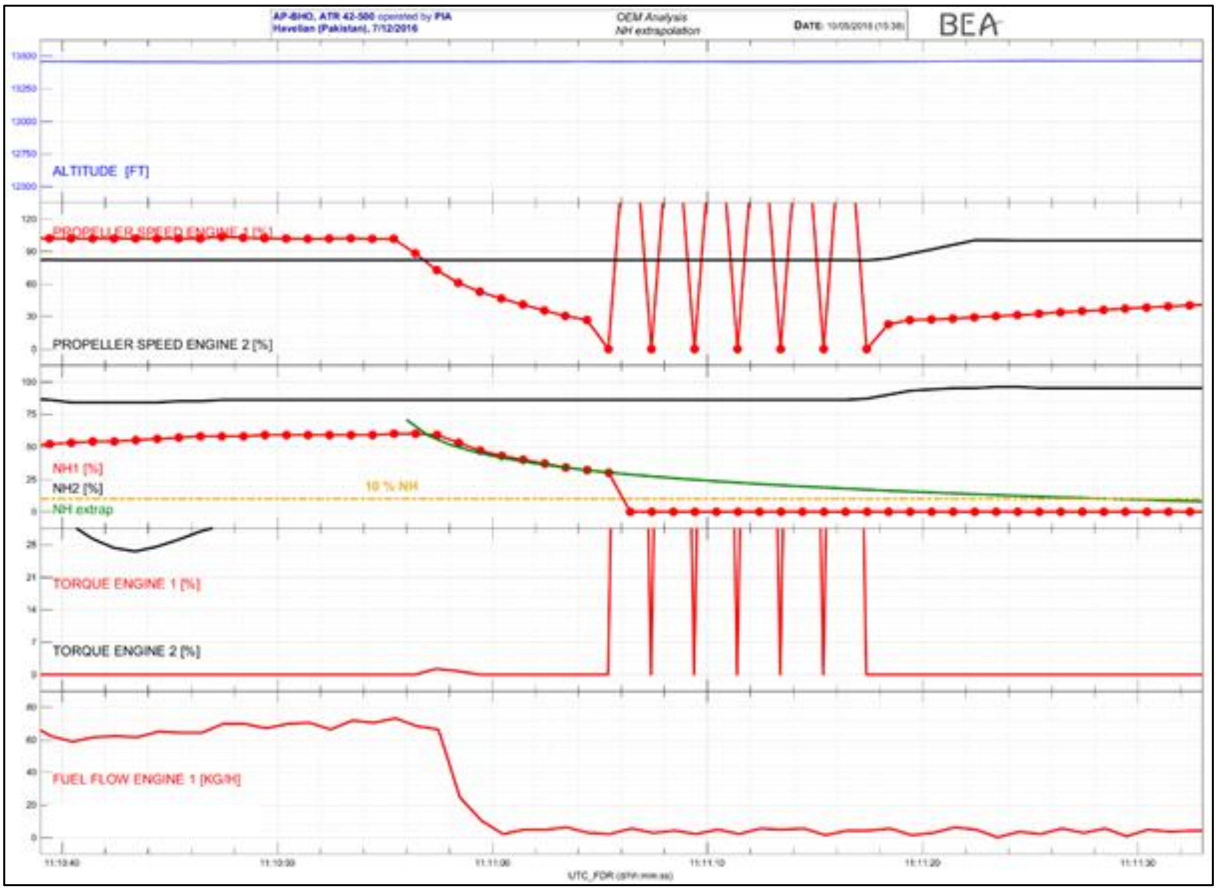


Figure 2-9: Fuel Flow Phase 3 to 5

(iii) **Phase 6:** Did not require discussion in this report.

(iv) **Phase 7 and 8, Re-Feather or Restart Attempt.**

- From 11:12:27, fuel flow-1 values were not null anymore. For those fuel flow values, it was necessary to have the CL-1 outside of the FSO position and NH values greater than 5%. Those fuel flow values reflect that the ENG-1 FIRE handle was not pulled before 11:12:46. After review of CVR the possible action of CL-1 out of FSO position was most likely related to re-feather (as depicted hereunder).

Time	Source	Event	Interpretation
11:12:26	CVR	Put to Feather	Request to move the CL-1 out of the Fuel Shut Off position
11:12:27	DFDR	Fuel Flow-1 values increased	The CL-1 was moved outside of the FSO position

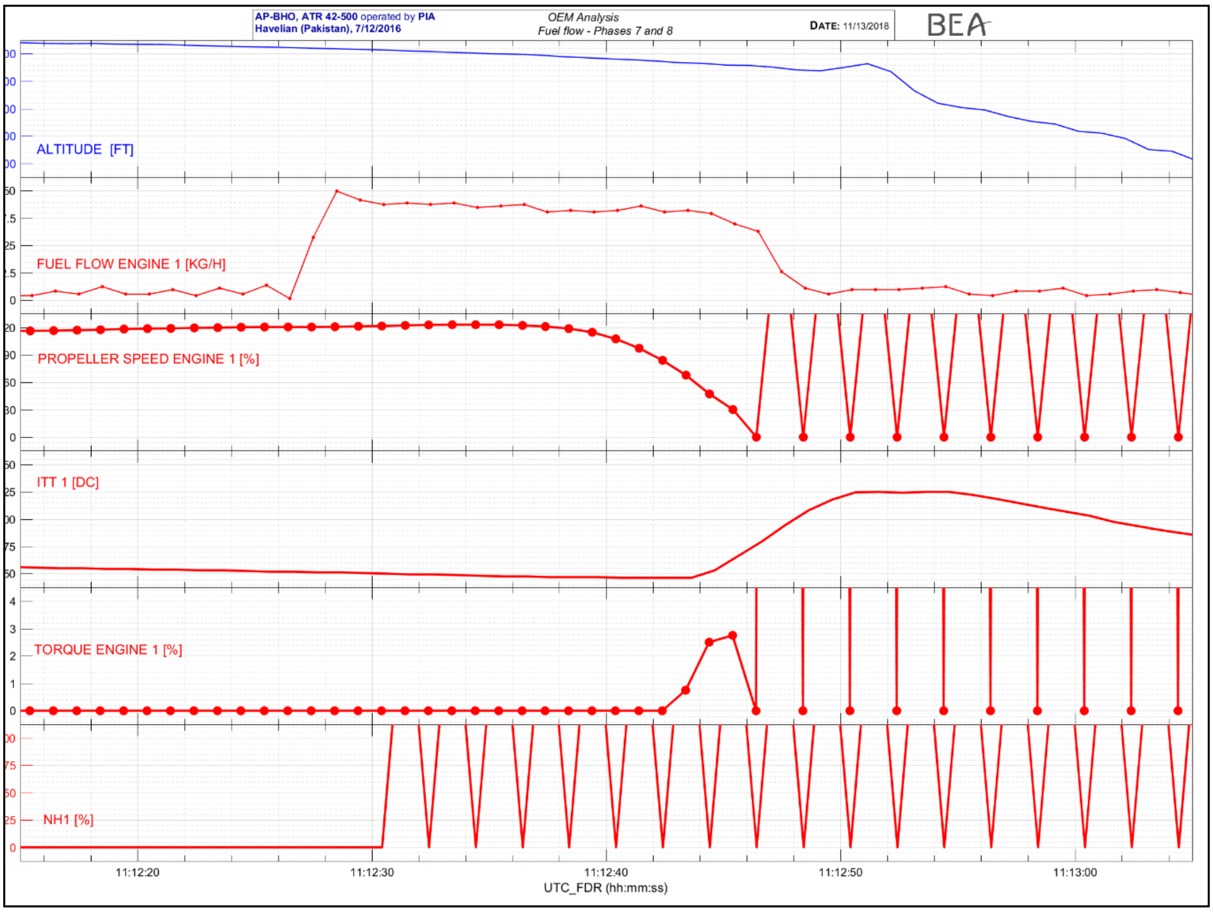


Figure 2-10: Re-Feather or Restart Attempt - Phase 7 and 8

- At 11:12:44, an increase of the ITT-1 values was recorded. Either of the two possible scenarios may have existed for this increase: -
  - Either the ignition of the fuel, which implied a possible movement of CL-1 outside the FSO position, because of re-feather or restart attempt by the crew.
  - Or the ignition of another fluid. This possibility was excluded by engine manufacturer (no oil was supplied to No 3, 4, 5, 6 & 7 bearings).
- Taking into account the CVR transcript, the fact that no oil was supplied inside the No 1, 2, 3, 4 and 5 bearing, and a single chime at 11:12:25 that might be due to re-feather (or possibly a restart) attempt and not due to the ignition of any other fluid.

(h) **Probable Re-Feathering or Restart Attempt and Positive Torque Values at 11:12:25:** At the end of the sequence, an increase of the torque was recorded. The torque is sensed by measuring the difference between the want of the propeller shaft to rotate and the resistivity of the propeller against this rotation. It is impossible to know the value of the torque after 11:12:46. As the propeller speed values were too low, NCD pattern was recorded. The recorded torque values are sensed at the same location as that of the recorded Np values. Following the Np recorded values, the torque values were tagged as NCD at the same time. Due to re-feather or restart attempt, two possibilities exist: -

(i) The re-feather or restart attempt supports the possibility of increase of the ITT, and further provides reason for sufficient power to generate those positive torque values. This possibility explains the small change in the Np decreasing rate (only 1 point before Np values became NCD).

(ii) The engine IFSD did not allow any power generation. In this case, the positive torque values imply that the propeller forced the PT shaft to slowdown.

(iii) **Comment:** The engine manufacturer stated that the possibility of power generated by the engine was more likely than any other cause. At the end of the phase 8, power values of 908 W (1.2 SHP), 2111 W (2.8 SHP) and 1487 W (2 SHP) can be computed from the torque values (11:12:43 and the 2 following seconds).

(i) **Conclusion on the No 1 Engine Examinations and Tests:** A fracture of a 1st stage power turbine blade occurred most probably during the flight prior to the flight of the event. The engine manufacturer was not able to date the PT-1 blade fracture. The manufacturer only stated that it is possible that one or more 1st stage PT blades fractured prior to the ITT increase observed on the DFDR (between 10:56:01 and 11:04:19). The resulting unbalanced power turbine generated vibrations leading to the distress of the No 6 bearing. Oil leakage occurred at the No 6 bearing level, at the time of seal damage (or earlier). The oil was contaminated with metallic particles coming from the damage seal (Inconel 718) and likely from the damaged bearing rollers. A fully clogged filter leading to the use of the bypass valve is not possible after the IFSD but a partially clogged filter with filter bypassed before the IFSD was likely. The engine oil pump was able to feed the propeller hydraulic control system with sufficient oil. At the end of the phase 7, the cockpit crew tried to re-feather No 1 Propeller (however possibility of engine restart cannot be ruled out).

Tech Finding 10: The first distress of the engine was a fracture of a PT-1 blade, possibly during the flight prior to the flight of the event.

Tech Finding 11: Due to the unbalanced PT, vibrations occurred leading to the distress of the No 6 bearing and its seal.

Tech Finding 12: Oil was contaminated with metallic particles from damaged seal and bearing rollers of engine from around 10:56:01 and may have been able to reach the propeller components. However, due to vibrations caused by unbalanced PT leading to the distress of the No 6 bearing and its seal, some contamination may also have existed prior to the IFSD.

Tech Finding 13: At 11:10:57, CL-1 was in FSO position.

Tech Finding 14: It is highly probable that the 2 interrupted single chime detected at 11:10:57 were the DC gen fault and the Bleed pack fault.

Tech Finding 15: At 11:11:18, the No 1 propeller speed parameter recorded valid values again (propeller un-feathering). The recorded fuel flow-1 values were still null; as a result it is likely that a CL-1 was still in FSO position (NH values greater than 5%).

Tech Finding 16: No excessive friction during the whole flight was detected between the several engine shafts. Although PT shaft showed signs of rubbing. Limited power was absorbed by the engine shaft during the wind-milling phase.

Tech Finding 17: Before 11:11:31, the NH values of the flight of the event should have been above 10%. It should have gone on decreasing and should have stabilized between 5% and 6%.

Tech Finding 18: CL-1 movements without any non-null recorded fuel flow-1 values recorded before 11:11:30 is extremely improbable (extrapolated NH greater than 10%).

Tech Finding 19: CL-1 movements without any non-null recorded fuel flow-1 values recorded after 11:11:30 is extremely remote (extrapolated NH lower than 10%).

Tech Finding 20: Lack of oil inside the RGB before 11:11:30 is extremely improbable.

Tech Finding 21: Lack of oil inside the RGB after 11:11:30 is extremely remote, until Np suddenly decreased.

Tech Finding 22: The ENG-1 FIRE handle was not pulled before 11:12:46.

Tech Finding 23: The possibility of a re-feathering or restart attempt at 11:12:25 is highly probable.

Tech Finding 24: The CL-1 may have been moved out of the FSO position at 11:12:27.

Tech Finding 25: At 11:12:31, it was highly probable that the CL-1 position was greater than the FTR position.

2.3.3.7 Overspeed Governor (OSG) Examination, Tests & Analysis.

(a) Summary of the Examinations.

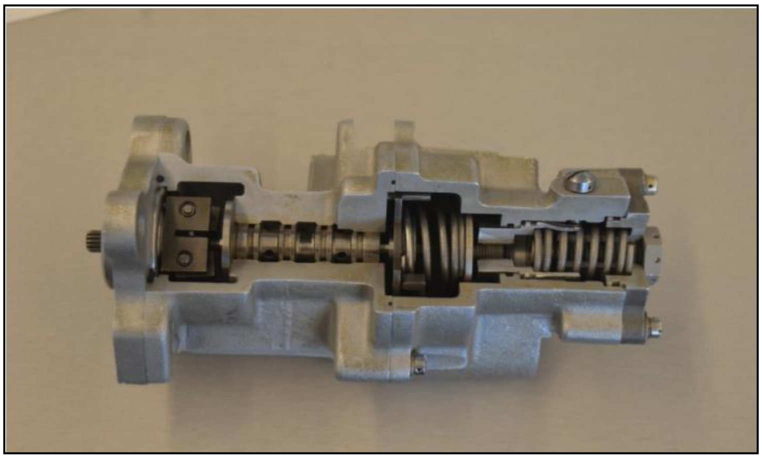


Figure: 2-11 Cross Sectional View of OSG

- Flyweight broken at the toes (figure 2-12).

- Broken toes were missing, but the flyweights were still inside the carrier.

- The carrier ball bearing was rotating freely.

- The rotational pin was broken during an overspeed governor reassembly, as evidenced by markings on top of one flyweight (figure 2-13) and fractured pin (figure 2-14) material analysis (figure 2-15).

- The broken toes and the broken pin were not found inside the OSG.

Figure: 2-12

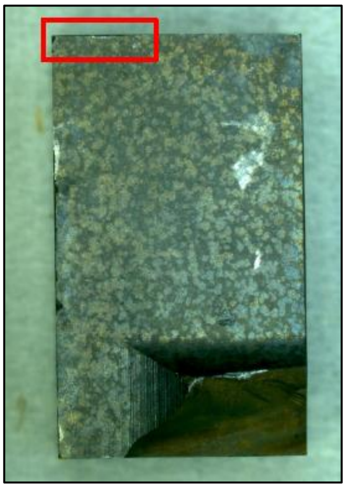


Figure: 2-13

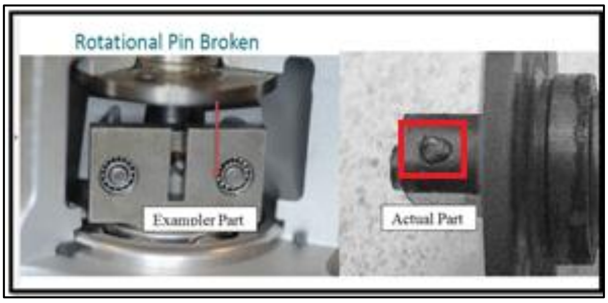


Figure: 2-14

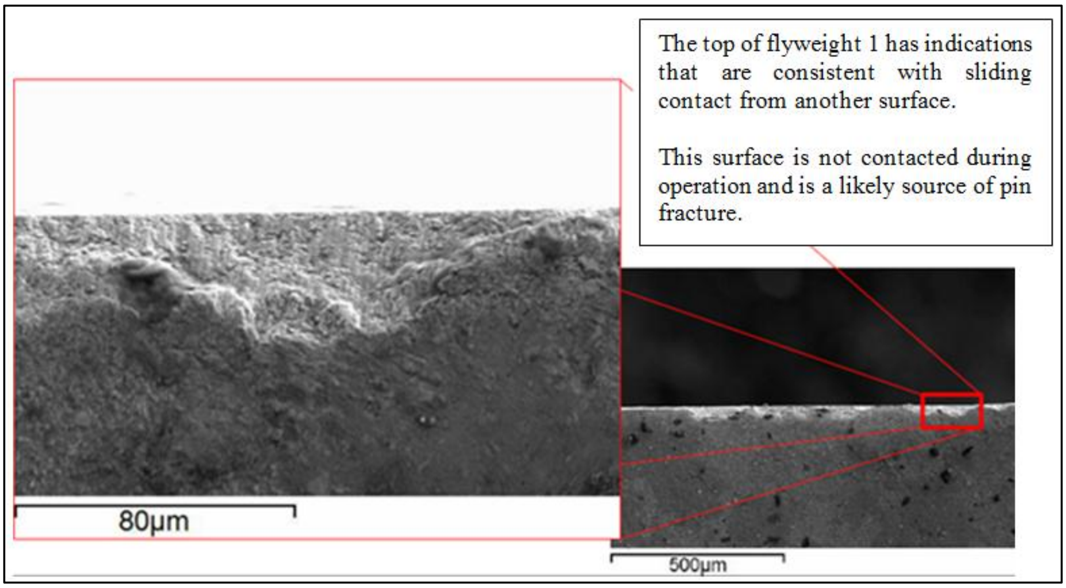


Figure: 2-15

- Contact occurred between the flyweights and the valve in 2 opposite directions.

Figure: 2-16

- With both flyweight toes broken (as they were), it was possible to regulate the propeller speed at a value close to the expected values of 102.5% (tests realized by the manufacturer).

Note: in this case, the "purple" flyweight (Figure 2-17) pulls the valve in rotation and does not push it. During the tests, the manufacturer blocked the valve on the flyweight.

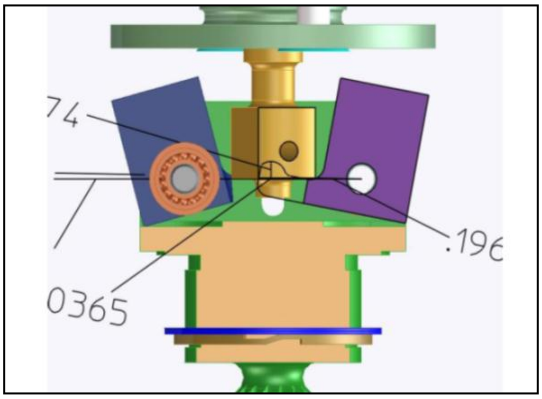
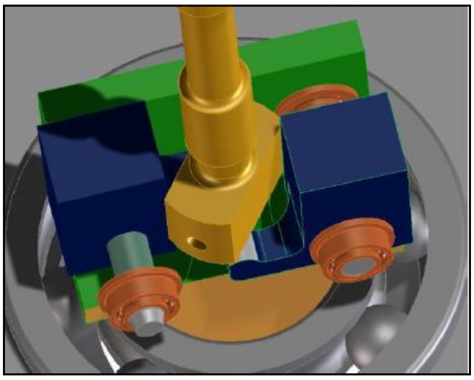
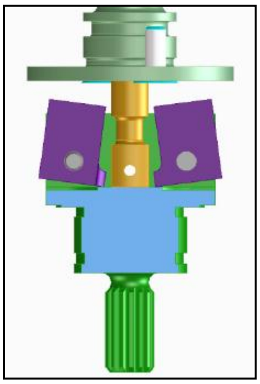
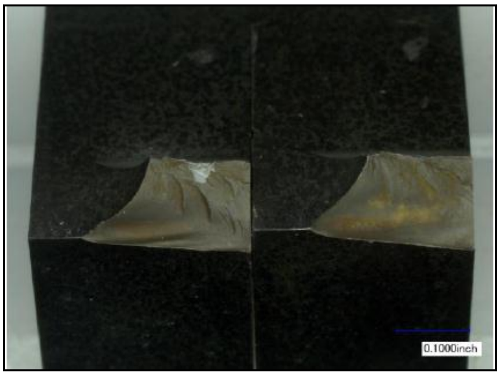
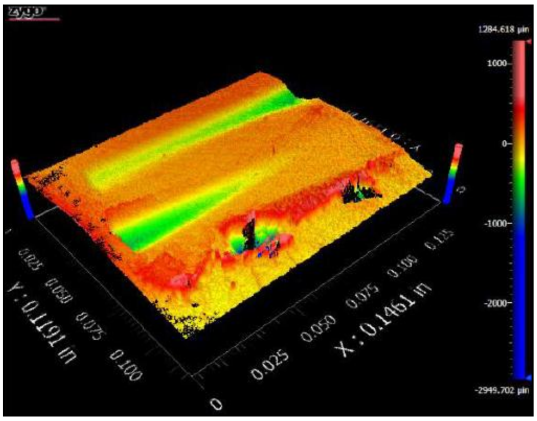


Figure: 2-17

- The "purple" flyweight pulling the valve in rotation would be consistent with the wear on bottom surface of the pilot valve (Figure 2-18).

Figure: 2-18

- When friction is added to the pilot valve, the driving flyweight may become vertical due to the loading. It lifts up the valve, connecting partially the overspeed line to the drain. The quantity of oil drain was computed as 1 QPM.	 Figure: 2-19
- With both flyweight toes broken (as they were), when rotational speed was reduced (propeller going into feather), flyweight force was reduced and spring pushed plunger past the flyweight toes. The overspeed governor was in a constant under-speed condition. Later flyweights could not lift the valve when propeller speed increased.	 Figure: 2-20
- Flyweight fracture path: propagation direction from above the toe. It is not evident if the fracture was caused by tensile overload or fatigue loading.	 Figure: 2-21
- The marks of the flyweights' toes (normal operation) are not centered on the bottom face of the pilot valve. The pilot valve is symmetric and can be positioned in two locations during re-assembly, without any effect on operation. These two locations produce two different wear patterns on the bottom side of the valve. The bottom face of the valve from the event hardware showed 2 distinct marks, indicating it had been re-assembled normally after original manufacture. The damage to the OSG pin as a result of an assembly attempt with the pin on	 Figure 2-22: Marks Underlying a Change in the Contact Between Flyweights / Pilot Valve

top of one flyweight indicates a second re-assembly attempt after the original manufacture. Neither record of these maintenance re-assemblies was found in the MRO logs nor any evidence of such activity was found at the operator level.	

(b) **Additional Tests:** The propeller manufacturer performed tests, simulating the case of vertical flyweights, by draining one part of the overspeed line. This modulation of flow made the propeller follow the behavior recorded by the DFDR data for the propeller of the event (ie Phase 2: Np reducing from 82% to 62%). During that test, PEC behavior was also consistent with the behavior recorded during the flight of the event ie no effect on propeller speed (Np) once PEC was switched OFF whereas it should raise to OSG point ie 102.1% Np (ie switching OFF the PEC did not lead to a change in the propeller behavior).

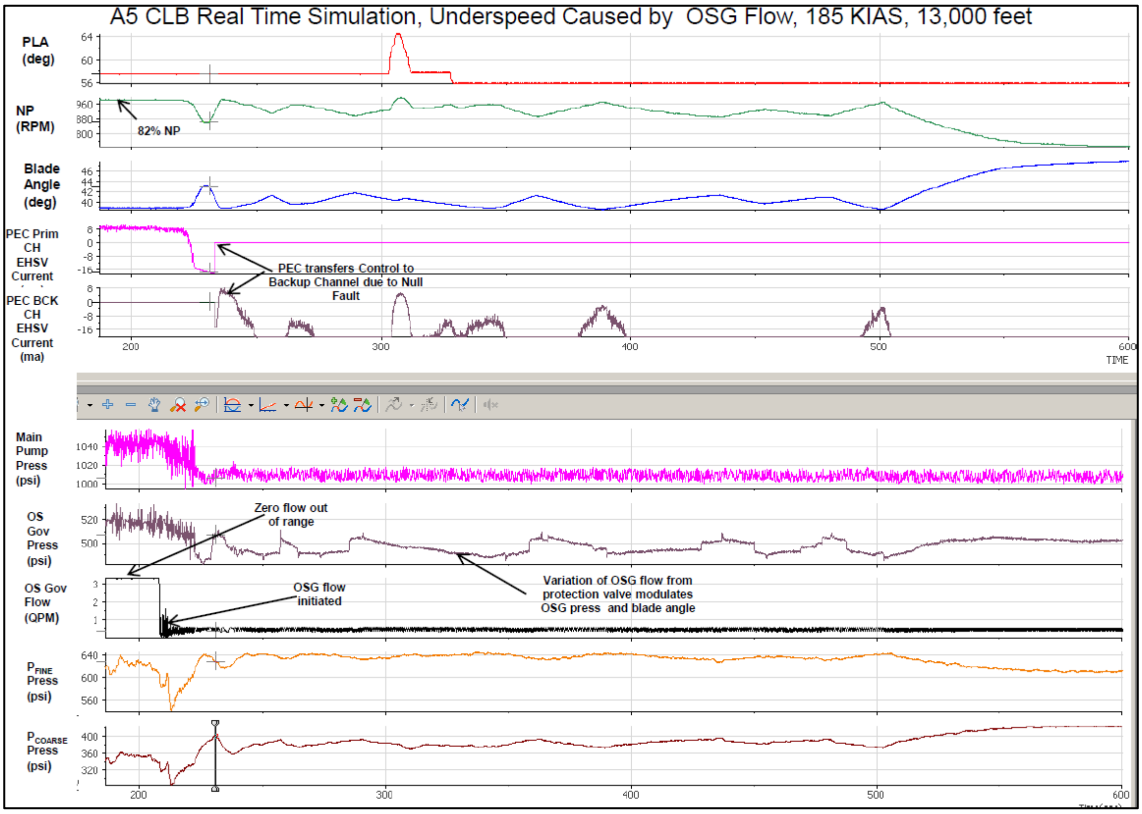


Figure 2-23: Tests of Propeller Behavior Simulating Vertical Toe in Overspeed Governor

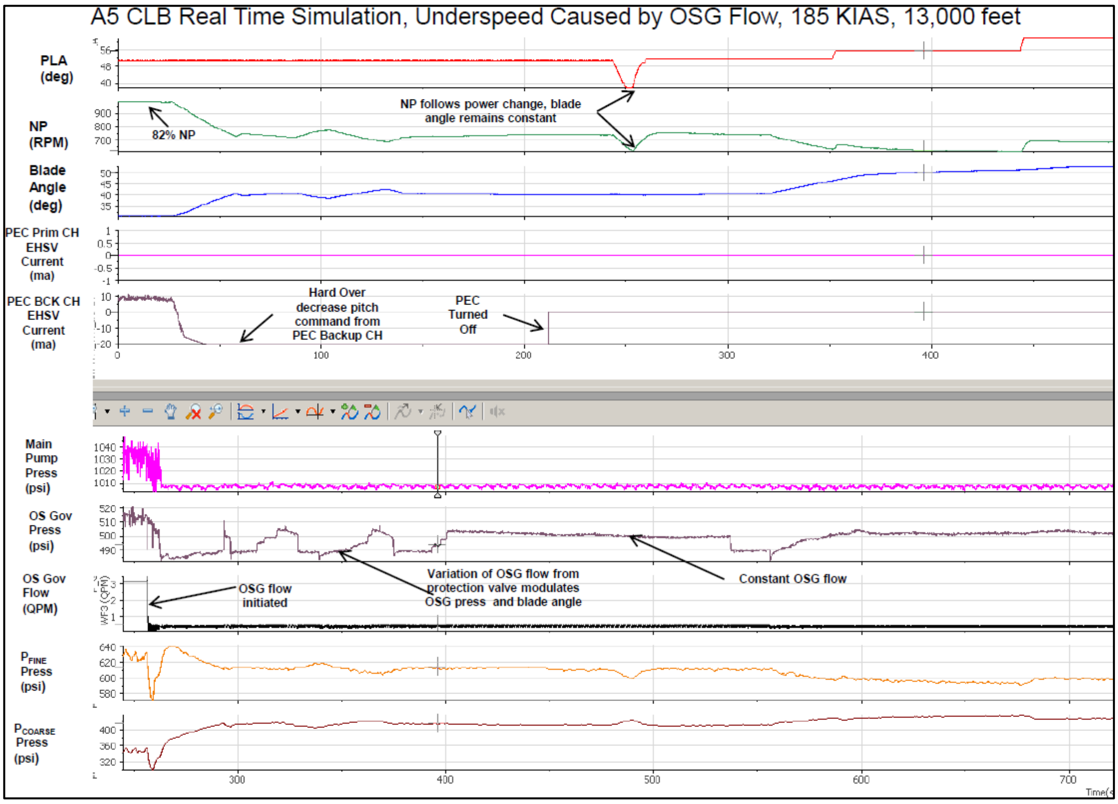


Figure 2-24: Tests of Propeller Behavior Simulating Vertical Toe in Overspeed Governor

(c) **Effects of Damaged Rotational Pin & Oil Contamination on Behavior of OSG.**

(i) As per manufacturer Woodward, an OSG with a damaged / missing pin may remain in operation undetected. Overspeed governor will operate normally with a broken pin. This was verified by Test. Unit may have more hysteresis and limit cycle when operating on overspeed governor. Valve drag will increase loading of the flyweights in this condition.

(ii) Metallic particle contamination was found inside the OSG pilot valve that had reached through the engine oil. This contamination was consistent with Inconel 718 of which the distressed No 6 bearing seal is composed. Engine oil was likely contaminated with these metallic particles around 10:56:01. The distress of the No 6 bearing and its seal was due to vibrations that occurred due to unbalanced PT shaft rotation. The PT was unbalanced due to a fracture of a PT-1 blade, most probably during the flight prior to the flight of the event.

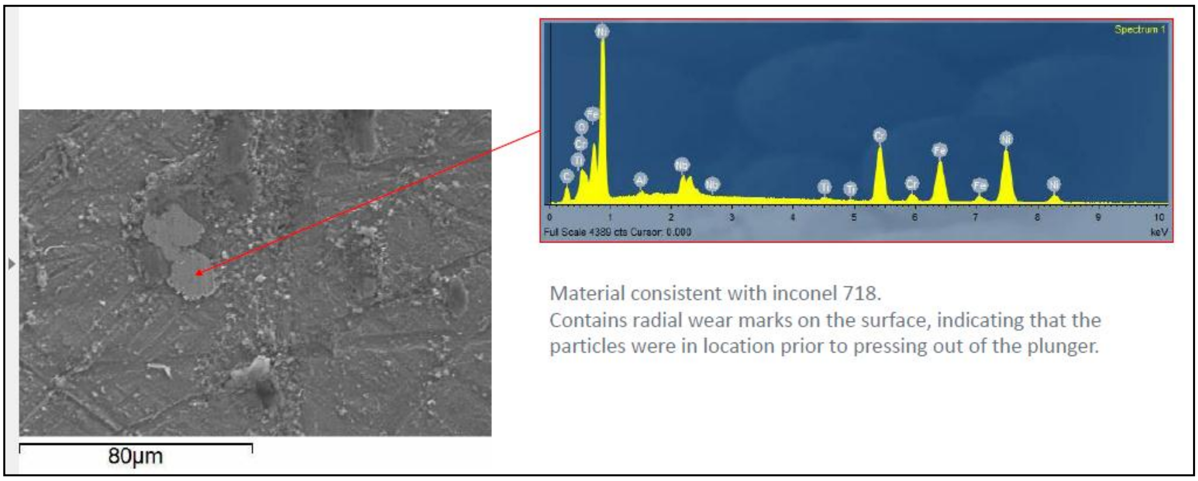


Figure 2-25: Evidence of Inconel 718 in OSG

(iii) At the beginning of the flight, at least one toe was not broken. Indeed, if both toes were broken, the overspeed governor would have been in a constant under-speed condition and no regulation would have occurred during the phase 3. As the rotational pin was broken, when the flyweights' carrier turned, the flyweights entered in contact with the pilot valve and made it turn. During the examination, radial scratches were found on the plunger due to contamination in the engine oil. The contaminant found was consistent with Inconel 718 (oil contamination coming from the No 6 bearing seal - Tech Finding 10, 11, 12).

(iv) At the beginning of phase 2, due to oil contamination, the drag of the pilot valve increased and the driving flyweight moved in a vertical position (figure 2-27), lifting up the pilot valve. The valve was then between the overspeed condition and the under-speed condition. The overspeed pressure (P_{OSG}), driving the behavior of the protection valve, was then a combination of the supply pressure (P_S) coming from the main pump and a leakage to the drain. As tested by the propeller manufacturer, this configuration led to an improper P_{OSG}, leading to a move of the protection valve between the protected mode and the unprotected mode. The pressure sent by the EHV (inside PVM) was no more controlling the blade pitch angle alone. The actuator driving the blade pitch angle gradually moved aft requesting a blade pitch angle increase and the No 1 Propeller speed decreased.

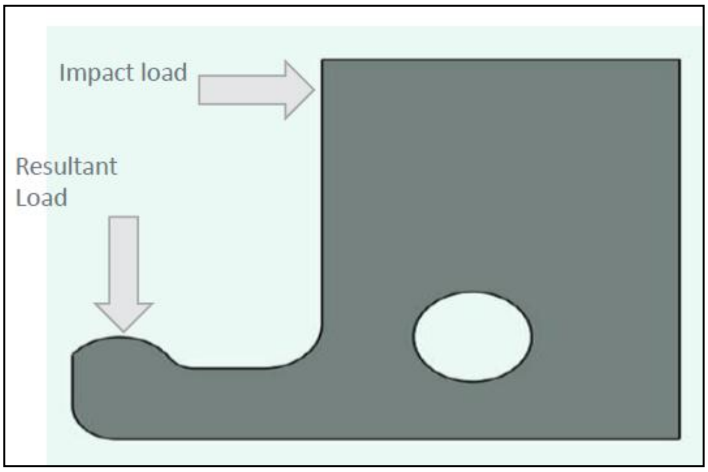


Figure 2-26: Loading Most Likely Caused by Drag on Valve

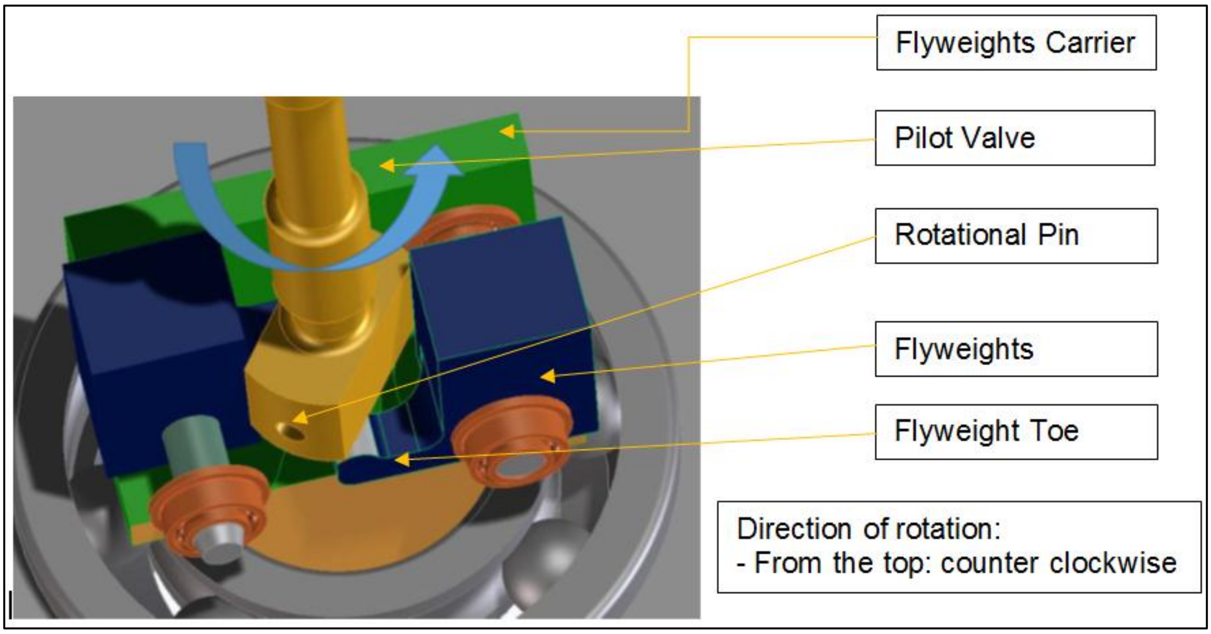


Figure 2-27: Vertical Flyweights Driving the Valve in Rotation

(v) At the end of the phase 2, the sudden decrease of the propeller speed was recorded. The spectral analysis at that time clearly underlined a sharp drop of the propeller speed (figure 2-28 white box). This sharp decrease could not be the result of a blade angle change and might be due to the engine power loss. Most probably at that time, the last toe broke. The pilot valve was not lifted anymore and went down, on the broken part of the toes (figure 2-29). With this movement, the overspeed line was not connected to the drain line anymore and the P_{OSG} increased again and reached the P_S value.

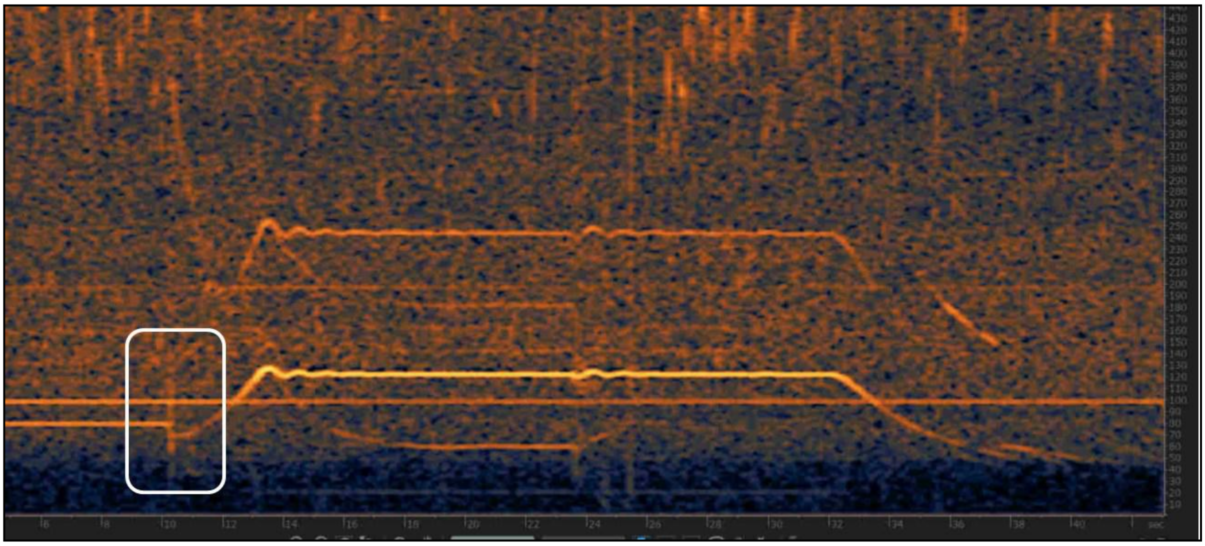


Figure 2-28: Sharp Decrease of the No 1 Propeller Speed

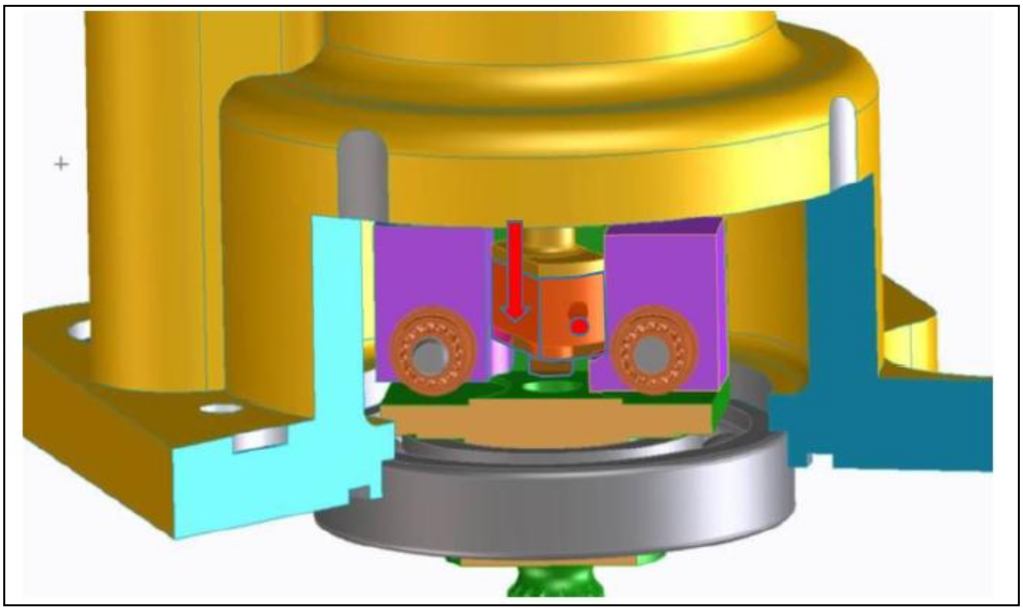


Figure 2-29: Due to Broken Toes, the Valve Moved Down, on the Broken Flyweights

(vi) As the P_{OSG} increased, the protection valve moved to the unprotected mode and P_{FINE} was piloted by the EHV position only. At the end of the sharp No 1 Propeller speed decrease, the blade pitch angle decreased (EHV bias request) and the propeller speed increased. The pilot valve was stuck on the fracture part of one flyweight and this flyweight pulled the valve in rotation. This part of the scenario is consistent with the wear marks observed on the bottom face of the pilot valve (figure 2-31). The fractured flyweight No 1 (figure 2-32 in blue) could not lift the valve and slipped away from the bottom of the valve. The corner of the fractured flyweight No 2 (figure 2-32 in purple) contacted the bottom of the valve and pulled it in rotation.

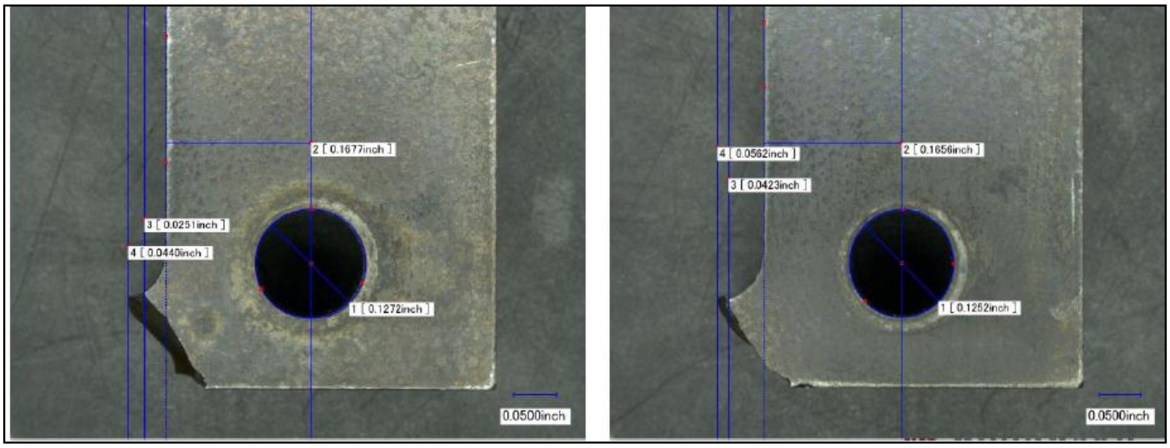


Figure 2-30: Broken Flyweights (No 1 at the Left, No 2 at the Right)

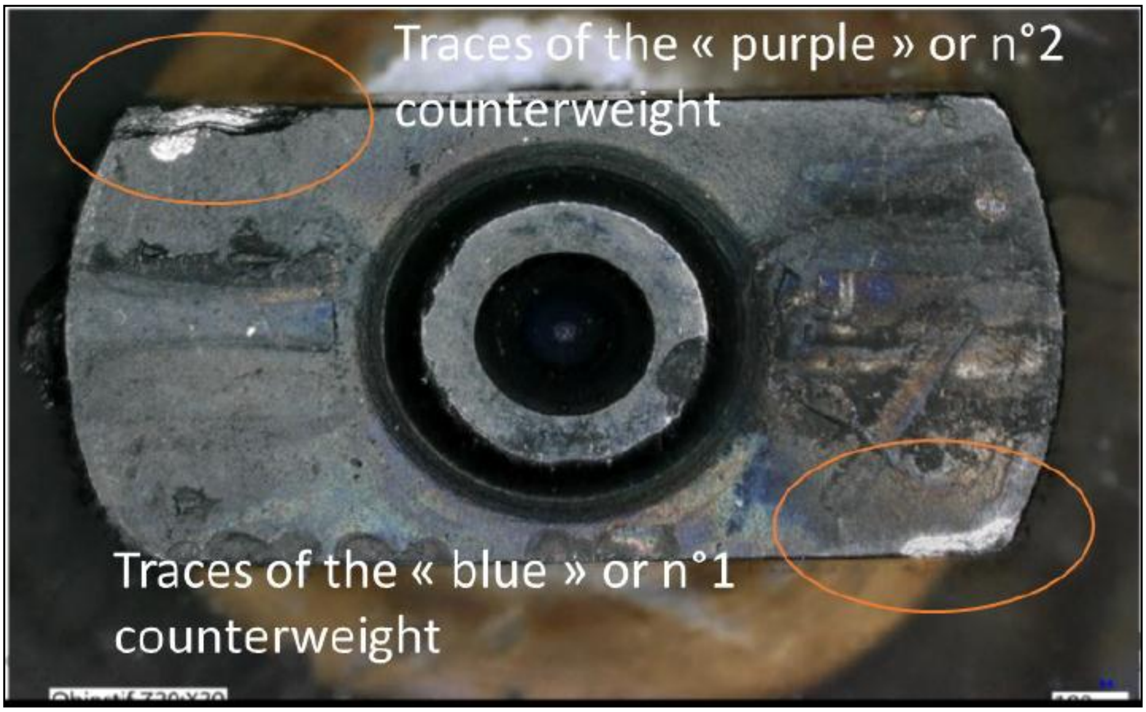


Figure 2-31: Wears on the Bottom Surface of the Valve

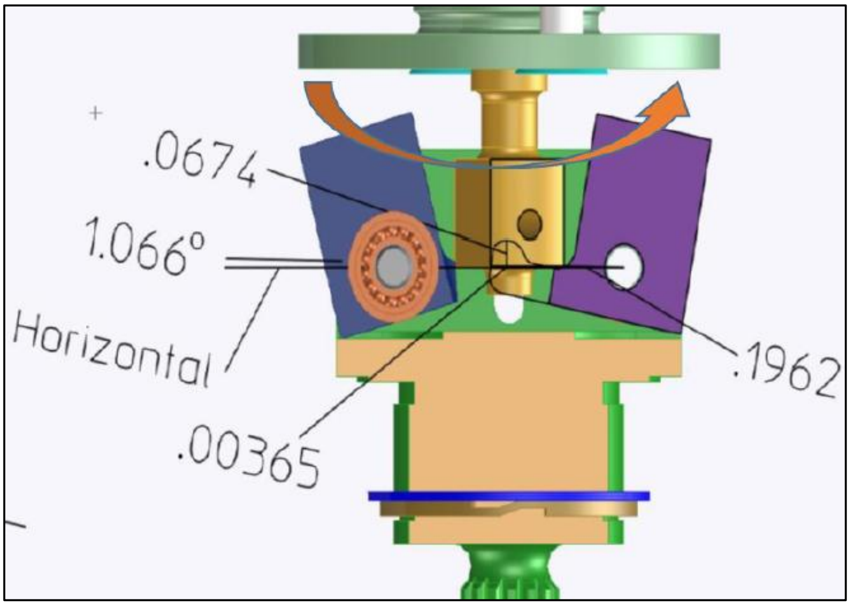


Figure 2-32: Illustration of OSG Operation with Broken Flyweight Toes

(vii) **Effect of Damaged Flyweight Toes of OSG on the Propeller Speed Regulation:** The loss of the toes changed the behavior of the flyweight: the moment arm changed and the moment applied by the valve to the flyweight is reduced. At a given speed, the loss of the toe induced an increase of the centrifugal force (the gravity center of the flyweight changed). As a combined effect, a single broken flyweight in contact with the pilot valve resulting in a short moment arm, may behave quite like 2 non fractured flyweights, provided the valve stays stuck on one flyweight. Computation performed with a valve stuck on the broken flyweight No 2 and tests performed with flyweights broken like the flyweight No 2 of the event demonstrated that the threshold of the overspeed regulation was, in this particular case, between 101% and 103%. During the flight of the event, at the end of the phase 2, both toes were broken. The valve stayed stuck on the corner of the fractured flyweight No 2 that pulled the valve in rotation. No 1 Propeller speed increased during the phase 3. When the No 1 Propeller speed reached 102%, the overspeed governor regulated the speed as if the overspeed governor was in good shape. At the beginning of the phase 4, the cockpit crew requested the feathering of the No 1 Propeller. As No 1 Propeller speed decreased, the broken flyweight No 2 force decreased. The force of the spring pushed plunger past between the broken flyweights. From that time, the overspeed governor remained in an under-speed condition and no longer contributed to the propeller regulation.

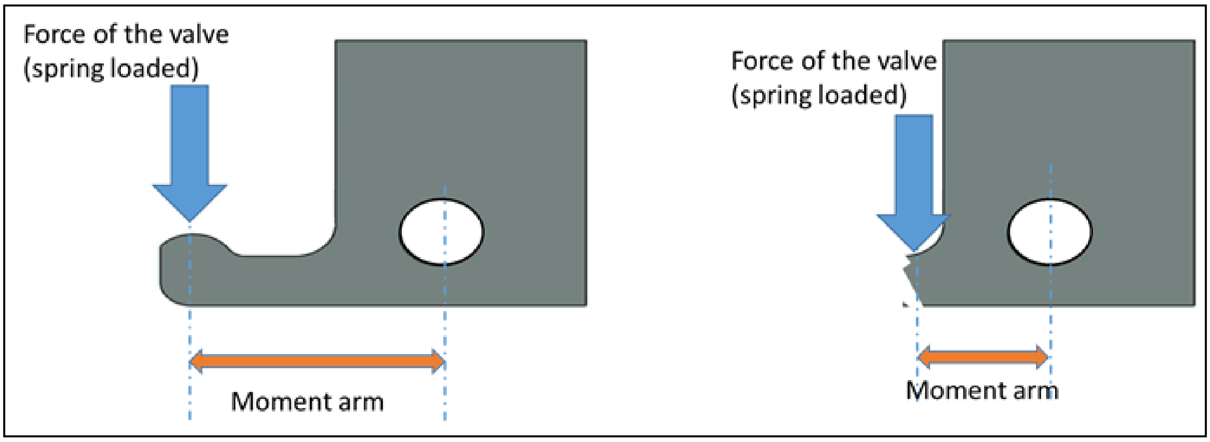


Figure 2-33: Force of the Valve on Fractured / Non Fractured Flyweights

(d) **Limitations of OSG Analysis:** The technical analysis of OSG relies on several points that cannot be formally proven such as: -

(i) The drag inside the overspeed governor : the drag can only be due to oil contamination: -

- On one hand: the oil contamination is a fact. Contaminants were found inside the overspeed governor, inside the main pump of the propeller hydraulic control system and inside the PVM.

- On the other hand: the timing of the contamination in oil of the propeller system cannot be formally determined. Indeed, the contamination of engine's oil was detected about 08 minutes before the beginning of the phase 2 (Tech Finding 12). For the contamination to reach the propeller hydraulic control circuit, it has to go through the bypass valve. No evidence / effect of contamination is present / observed before the slight engine performance variation at around 10:56:01 and onwards.

(ii) The timing of the toes breakdown was not known.

(iii) The move of the pilot valve, from pushed position to a pulled position: -

- The wears on the bottom face of the pilot valve were consistent with the flyweight No 2 pulling the valve in rotation.

- For the valve to be stuck on the corner of the broken flyweight, the valve should not be in contact with the flyweight No 2 in a position where the flyweight pushed it. Otherwise, no geometric position would have led the valve to be lifted up by the broken flyweight.

(e) **Technical Findings of OSG Examinations and Tests:** The rotational pin of the valve was found broken during OSG examination. Without the rotational pin, the valve was driven in rotation by the flyweight, which weakened the flyweight at the location of the toes, due to increased loading from the oil contamination. During the flight of the event, the contamination of the oil led the overspeed governor to interfere with the blade pitch angle regulation system. The position of the flyweights changed the P_{OSG} pressure, which made the protection valve move in a position between the protected mode and the unprotected mode. The EHV did not drive alone the pressure sent to the actuator, leading to an increase of the blade pitch angle and a decrease of the propeller speed. At the time of the engine breakdown, the last flyweight toe broke. The overspeed governor with damaged flyweight toes, behaved like an operational device, leading to an overspeed regulation close to the expected threshold. Then, during engine shutdown checklist, once feathering occurred, the overspeed governor was no more operative and did not interfere any more with the propeller regulation.

Tech Finding 26: The rotational pin of the valve of the overspeed governor was broken before the flight of the event. The pin damage must have occurred during some previous re-assembly of the OSG (when and where this may have occurred was undetermined).

Tech Finding 27: With the rotation pin broken, the valve of the overspeed governor was driven in rotation by the flyweights.

Tech Finding 28: Metallic particle contamination was found inside OSG pilot valve that had reached through engine oil. This contamination was consistent with Inconel 718, of which the distressed No 6 bearing seal is composed.

Tech Finding 29: With both flyweights broken as they were, overspeed regulation may occur at a level consistent with the DFDR recorded overspeed level. However, this regulation occurred with flyweight pulling the valve in rotation instead of pushing it.

Tech Finding 30: With both flyweights broken as they were, when the rotational speed was too low (due feathering once engine shutdown check list was executed), the spring of the pilot valve pushed the plunger past flyweight's broken toes.

Tech Finding 31: When the valve was driven by the flyweights and when friction due engine oil contamination was added to the pilot valve, the driving flyweight might become vertical, lifting up the valve. At this position, the overspeed line was partially connected to the drain.

Tech Finding 32: The connection of the overspeed line and the drain due to vertical flyweights was simulated by the propeller manufacturer on a test bench. The resulting propeller behavior was consistent with the behavior of the propeller and the PEC during the phase 2.

Tech Finding 33: With the flyweights broken, the overspeed governor was no longer able to contribute to the propeller speed regulation after the feathering phase (no longer limited the propeller speed).

2.3.3.8 **PEC Examination and Fault Analysis:** The PEC examination provided the fault codes recorded when the PEC fault triggered. All the faults were due to the monitoring activity of the PEC, about the null current value. The analysis of the faults indicated that the differential pressure regulation failed, leading to a small move of the actuator towards high blade pitch angle. The failure was external to the PEC.

Tech Finding 34: PEC faults were not due to a PEC failure but due to an external cause, leading to an inappropriate response of the actuator to the PEC commands.

2.3.3.9 **Oil Contamination Inside PVM:** The initial CT scan of the PVM showed some debris inside the system (in this case, the overspeed line, close to the feather solenoid). Based on further review from propeller manufacturer: contaminants, based on their size, could not go through filters / restrictions and were then not linked to engine contamination. The particles' material composition and source could not be identified. Most probably this contamination was pre-existing, and debris found in PVM were likely introduced when the propeller system LRU's were not installed on the gearbox. However it is not possible to ascertain when and where the contamination in the PVM was induced.

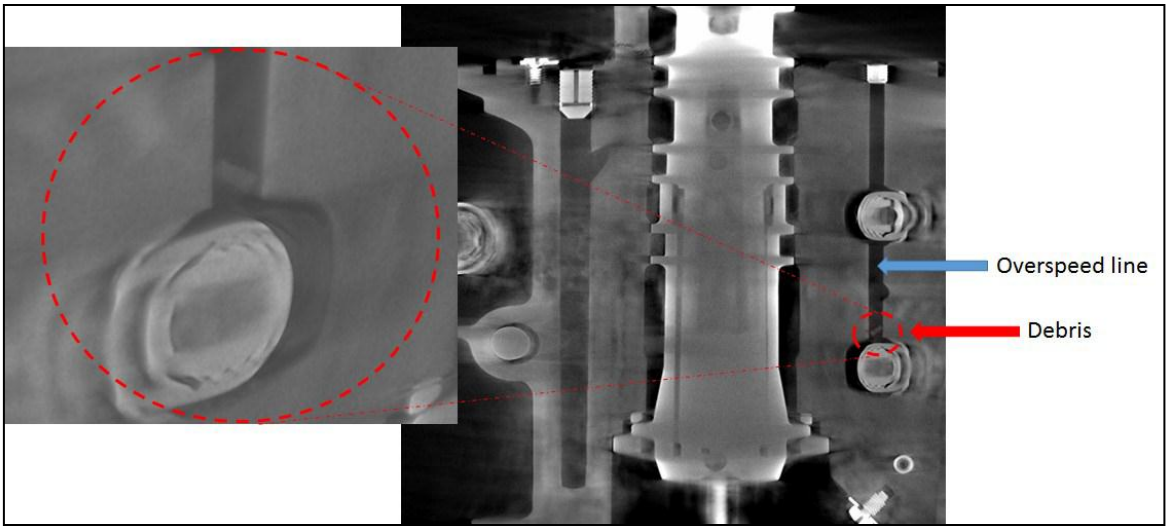


Figure 2-34: CT Scan of PVM - Debris inside the Overspeed Line

Tech Finding 35: Oil passage contamination, external to engine and most likely introduced when propeller system LRU's were not installed on the gearbox, was found inside the PVM overspeed line, close to feather solenoid.

2.3.3.10 **CVR Information.**

(a) **Phase 1:** The CVR information does not reflect discussions about Np-1 values fluctuations (possibly because of low amplitude compared with indication gauge).

(b) **Phase 2:** The CVR information does not reflect discussions about the propeller system out of in flight Np values. From DFDR recorded data, the recorded Np-1 values were below 70% from 11:06:02 and stayed below that threshold until the engine breakdown. Three PEC reset attempts reflect that the pilots may have noticed un-expected results due to propeller system out of in flight Np setting value. At 11:08:33 FO(B) questioned the Captain on the replacement of FO(A). Nothing was said about Np-1 setting.

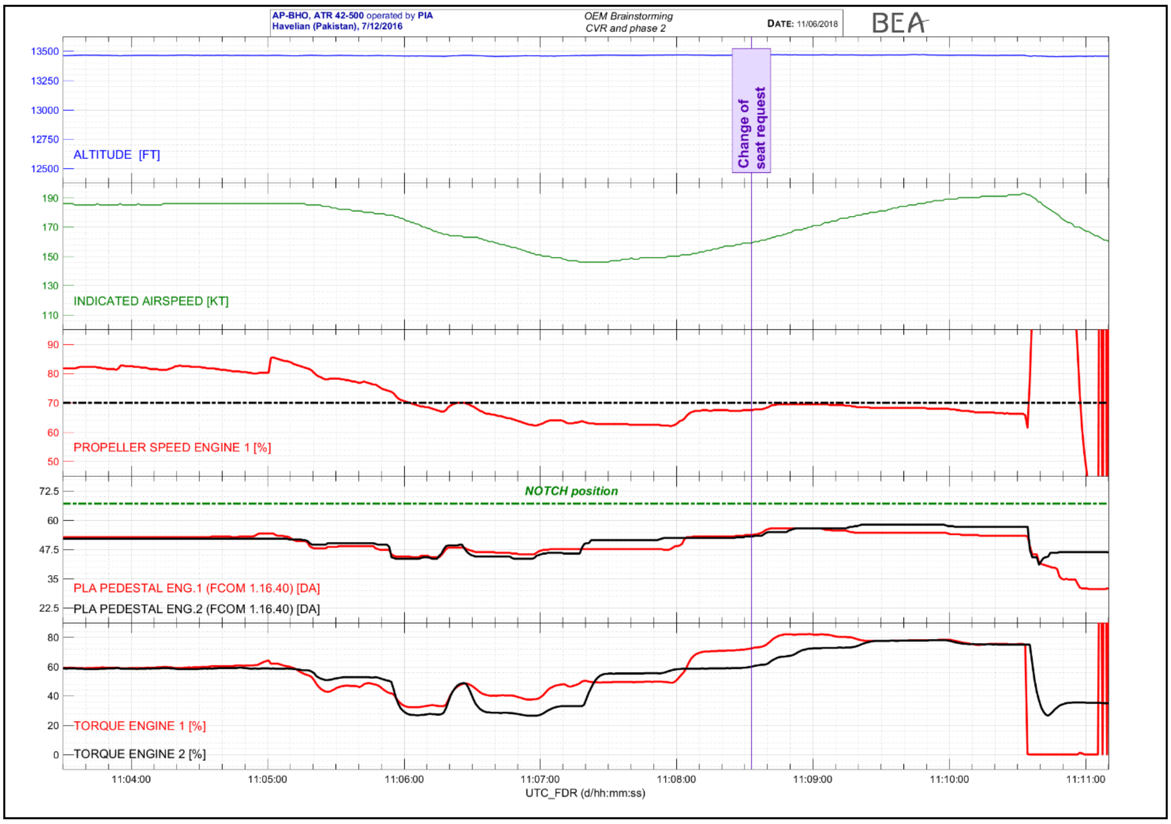


Figure 2-35: Engines Parameters During Phase 2

(c) **Feathering and Un-Feathering Sequence (Phase 3, 4, 5).**

(i) The cockpit crew decided to shutoff the No 1 Engine. From 11:10:51, the cockpit crew followed the engine flame out procedure: -

- Challenge-response on “CL affected side”.
- Then challenge response on the feathering state.
- Then challenge response on the fuel shutoff.

(ii) Once the procedure had been performed, the cockpit crew exchanged on NH indication, on the fact they have to lower the altitude, and they finished the conversation at 11:11:18 by the exchange: -

- *“We only have two”.*
- *“Okay”.*

(iii) At that time of the flight (11:11:18), there is no clue of any trouble inside the cockpit and the propeller speed recorded values were no more NCD. Any movement of the CL-1 by the cockpit crew explaining the un-feathering sequence at 11:11:18 is then extremely improbable. The abnormal un-feathering was most likely caused by contaminants inside PVM which were probably introduced when LRU's where not installed on the gearbox. However it is not possible to ascertain when and where the contamination in the PVM was induced.

(d) **Position of CL-1 – Analysis Based on Generation of Single Chime:** Between 11:10:57 and 11:12:15, no alert was detected by listening to the CVR. A shutoff engine triggers several master cautions like for instance electrical master caution due to DC generator failure, associated with an aural sound: the single chime (SC). These master cautions are inhibited when the CL are in the FSO position. The movement of the CL-1 between 11:10:57 and 11:12:15 is then extremely improbable.

(e) **Position of CL-1 - From around 11:12:24.**

(i) From 11:12:24, some unclear cockpit crew speeches were recorded on the CVR. These speeches were clarified during meeting / discussions in November 2018[143]. The interpretation of some of these speeches could be linked with engine / propeller management: -

- *At 11:12:24* *"Put it on Feather".*
- *At 11:12:26* *"Do Feather".*

(ii) At 11:12:27, the fuel flow-1 recorded data showed an increase. The sound and warning chronology also underlined 2 master cautions around that time: -

- *At 11:12:25* *a first SC triggered.*
- *At 11:12:27* *a second SC triggered.*

(iii) Following sounds were also recorded and correlated with DFDR data: -

- *At 11:12:37* *Propeller sound starts reducing.*
- *At 11:12:39* *Sudden decrease of the propeller frequencies.*
- *At 11:12:45* *No 1 Propeller Np shows NCD on DFDR.*

(iv) If an engine restart sequence in flight is performed, it is on the main battery only. Therefore beginning of the restart sequence leads to a drop of the voltage for around 19 sec, and as NH reaches 45 % value the starter disengages, however these parameters were not observed in such manner to conclude a restart. A master caution is probable due to electrical management at the time of an in flight engine restart attempt. Other probable reasons of master caution triggering could be due to the air systems. Based on the clarification of CVR speeches, movement of CL-1 from Shut Off position to FTR at 11:12:25 is then highly probable and indicates a re-feather attempt (and less probable restart attempt).

(f) **Alarm & Warning Chronology.** The following warning chronology was established: -

[143] Discussion at BEA during November 2019 meeting / analysis at AAIB.

Time	Sound	Explantation
11:05:31	SC (Master caution)	PEC 1 Fault
11:06:47	SC (Master caution)	PEC 1 Fault (after reset – 12 s latency)
11:06:53	SC (Master caution)	63 % Np ACW Gen 1 Fault
11:07:06	SC (Master caution)	PEC 1 Fault (after reset – 12 s latency)
11:07:48	SC (Master caution)	PEC 1 Fault (after reset – 12 s latency)
11:10:36	SC (Master caution)	ITT above limit (ITT 1 greater than 800°C) + DC Gen under-speed (NH<=54%)
11:10:57	2 Short SC – interrupted	DC Gen + bleed valve
11:12:15	Cavalry charge	ADU Caution Active on DFDR (A/P)
11:12:21	Short Cricket (Stall Warning – duration 0.3s)	
11:12:25	SC (Master caution)	
11:12:27	SC (Master caution)	Bleed / DC Gen
11:12:36	Cricket (Stall warning - duration 0.3s)	
11:12:37	Cricket (Stall warning - duration 1.16s)	
11:12:38	SC (Master caution)	NH NCD at 11:12:30: EEC 1 failure
11:12:41	Cricket (Stall warning - duration 7.8s)	
11:12:44		YD (ADU message) and Master Warning
11:12:49	CRC	
11:12:50	Cricket (Stall warning - duration 3.2s)	
11:12:53	CRC (Master Warning - duration 2.8s)	
11:12:56	Cricket (Stall warning - duration 1.4s)	
11:13:00	CRC (Master Warning - duration 0.8s)	
11:13:01	Cricket (Stall warning - duration 1.6s)	
11:13:03	CRC (Master Warning - duration 0.9s)	
11:13:04	Cricket (Stall warning - duration 1s)	
11:13:05	CRC (Master warning - duration 1.8s)	
11:13:07	Cricket (Stall warning - duration 0.6s)	
11:13:09	CRC (Master warning 11.6s)	

(g) **Technical Findings from CVR Information.**

Tech Finding 36: During the phase 2, no evidence underlined that the cockpit crew detected the under-speed of the No 1 Propeller.

Tech Finding 37: Following the CVR information, the cockpit crew followed the procedure for the No 1 Engine flame out.

Tech Finding 38: Following the CVR information (no single chime), a move of the CL-1 outside of the FSO position between 11:10:57 (No 1 Engine shutoff) and before 11:12:15 (A/P disconnection leading to a cavalry charge) is extremely improbable.

Tech Finding 39: Following the CVR information, a re-feathering attempt at 11:12:25 is highly probable (a restart attempt is less likely).

2.3.4 Phase Wise Most Probable Scenarios to Explain Aircraft Behavior.

2.3.4.1 **Phase 1:** The fluctuations of the No 1 Propeller speed during phase 1 could have been generated by various factors. However it is not possible to identify a specific factor.

2.3.4.2 **Phases 2 and 3:** The most probable scenario for the No 1 Propeller behavior during the phases 2 and 3 was abnormal behavior of OSG due to a broken drive pin and contaminated oil.

2.3.4.3 **Phase 4 - Study of Feathering Sequence:** A scenario pertinent to the feathering sequence of the No 1 Propeller is developed in this part. This mainly focuses the rate at which feathering occurred and most probable causes of this behavior.

(a) **Feathering Rate - Flight Tests and Comparison.**

(i) Flight tests performed at aircraft level in conditions equivalent to the event flight (PEC OFF, altitude, speed) confirmed that feathering experienced by AP-BHO was abnormally slow compared to a PEC OFF feathering through feather solenoid. Moreover, it confirms that un-feathering experienced by AP-BHO was also abnormally slow compared to an engine OFF / PEC OFF un-feathering through feather solenoid de-energizing. Thus, it allows to exclude that loss of feather solenoid input would have led to the observed AP-BHO slow feathering / un-feathering. The decrease of the propeller speed between 74.7% and 54% lasted 2 seconds, leading to a pitch increase rate of $4.3° sec^{-1}$, rate which is between a feathering with nominal hydraulic power and a feathering without any hydraulic power.

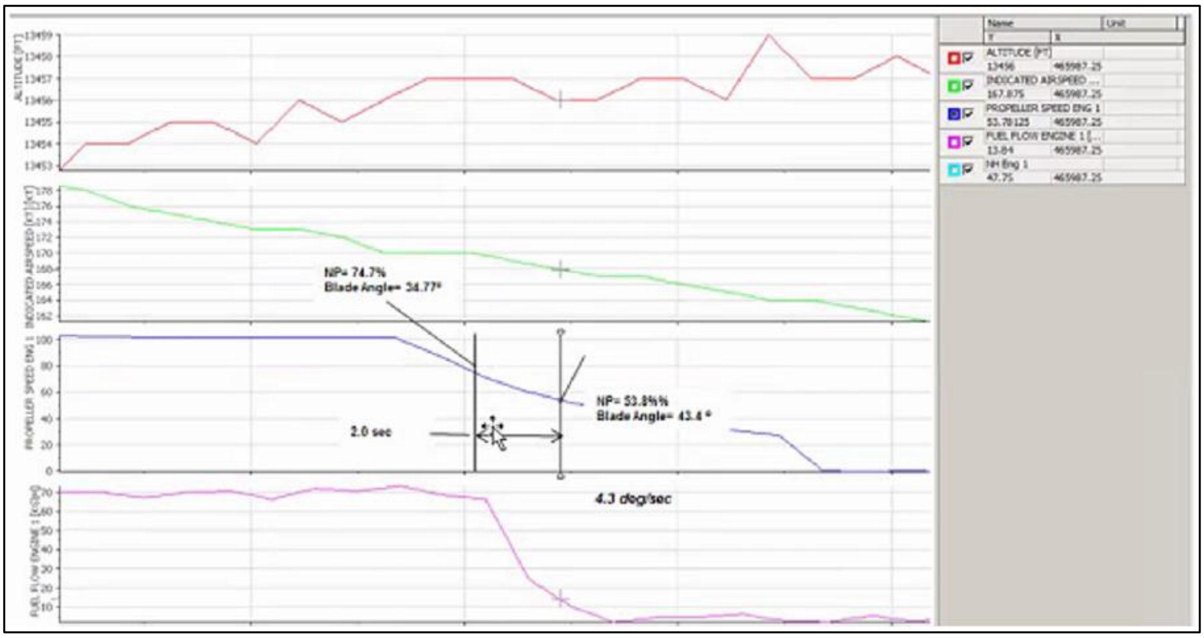


Figure 2-36: Feathering Sequence During the Flight of the Event

(ii) This feathering of event flight was also compared with the previous feathering of the propeller, on ground. On ground, the PEC does not command pitch increase. This PEC's function is inhibited, to force the use of the feather solenoid in order to avoid a pre-existing failure. The feather solenoid function was validated during the N-1 and N-2 flights. During the flight of the event, the true airspeed and the altitude on the blade had an impact on the forces applied on the blades. This is especially true at the beginning of the feathering process when the propeller speed was the most important and the blade pitch angle was at the lowest angle. However, the counterweights are designed to counteract these forces in the whole flight envelope. The behavior of the propeller during the feathering sequence of the flight of the event underlined that: -

- At the beginning of the feathering phase, the propeller speed decreased at a rate consistent with a nominal feathering.
- The slowdown of the propeller speed rate, some seconds after the beginning of the feathering. The feathering was performed at a slower speed than a normal feathering with nominal hydraulic power but faster than expected when no hydraulic power is available.

(iii) It means that the pressure used for the feathering command: -

- Was consistent with the expected pressure at the beginning of the feathering process.
- But decreased with the time.

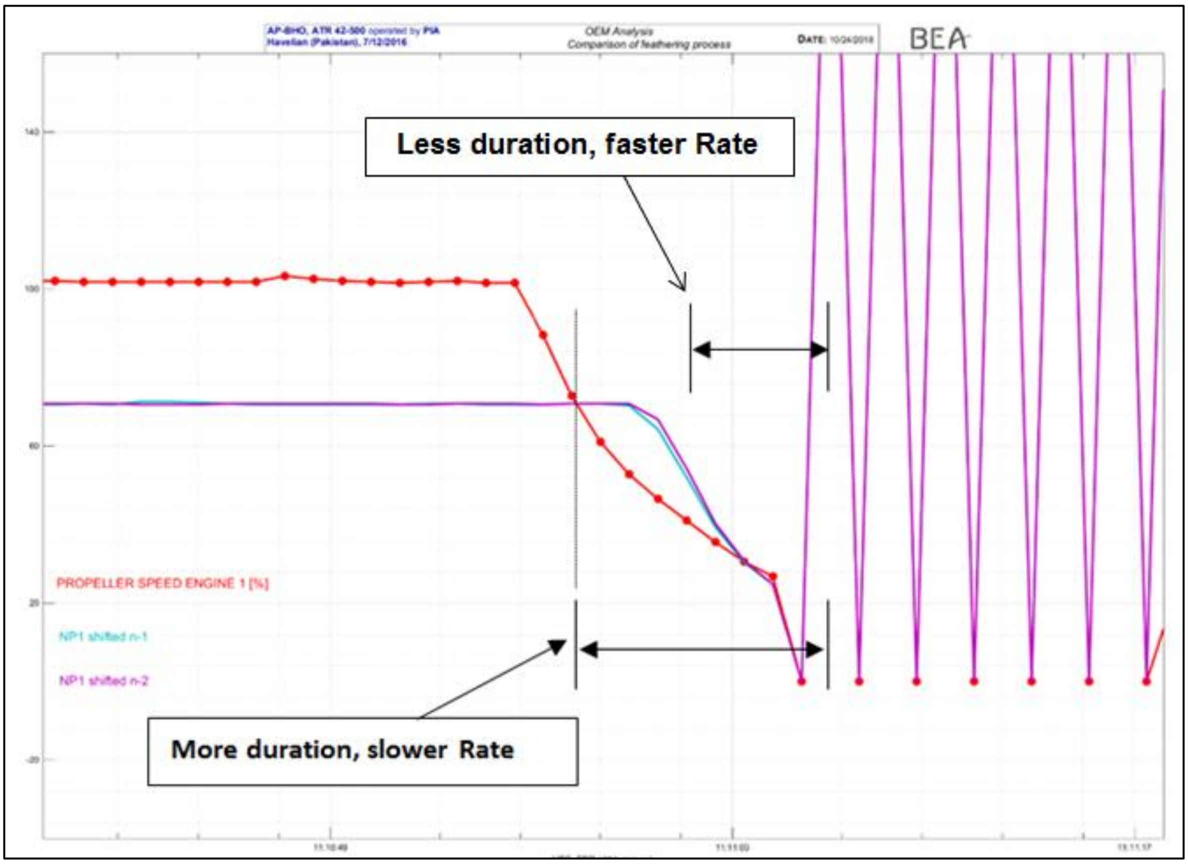


Figure 2-36A: Comparison of the Feathering During the Flight of the Event (in Red) with Feathering During Previous Flights (in Blue and Magenta)

(b) **Feathering Process and Pressure Used to Command the Feathering:** In order to understand as to why the feathering was performed at a slower speed than a normal feathering, the feathering process and the pressure used to command the feathering were analyzed.

(i) When feathering is requested, the feather solenoid should open, the P_{OSG} should drop and the protection valve should move to the protected mode. In this case the P_S would be sent to the coarse chamber, while the fine chamber would be connected to the drain.

(ii) The possible explanations for the slow feathering are the following ones: -

- Case of a P_S lower than expected: A protection valve in the protected mode and a pressure supply P_S lower than expected.
- Protection valve position and pressures: A protection valve that did not stay in the protected mode.

(c) **Case of a P_S Lower than Expected:** When in flight feathering is requested, the P_S relies on the main pump capability and / or the electrical feathering pump capability. Both the pumps are connected to the oil pressure supply line through check valves and only one pump feeds the system at a given time. The analysis shows that before 11:10:57, the main pump should have had the control of the pressure supply P_S. Just before feathering, the NH-1 recorded value was greater than 30%; the main pump provided sufficient oil flow and pressure to feed RGB.

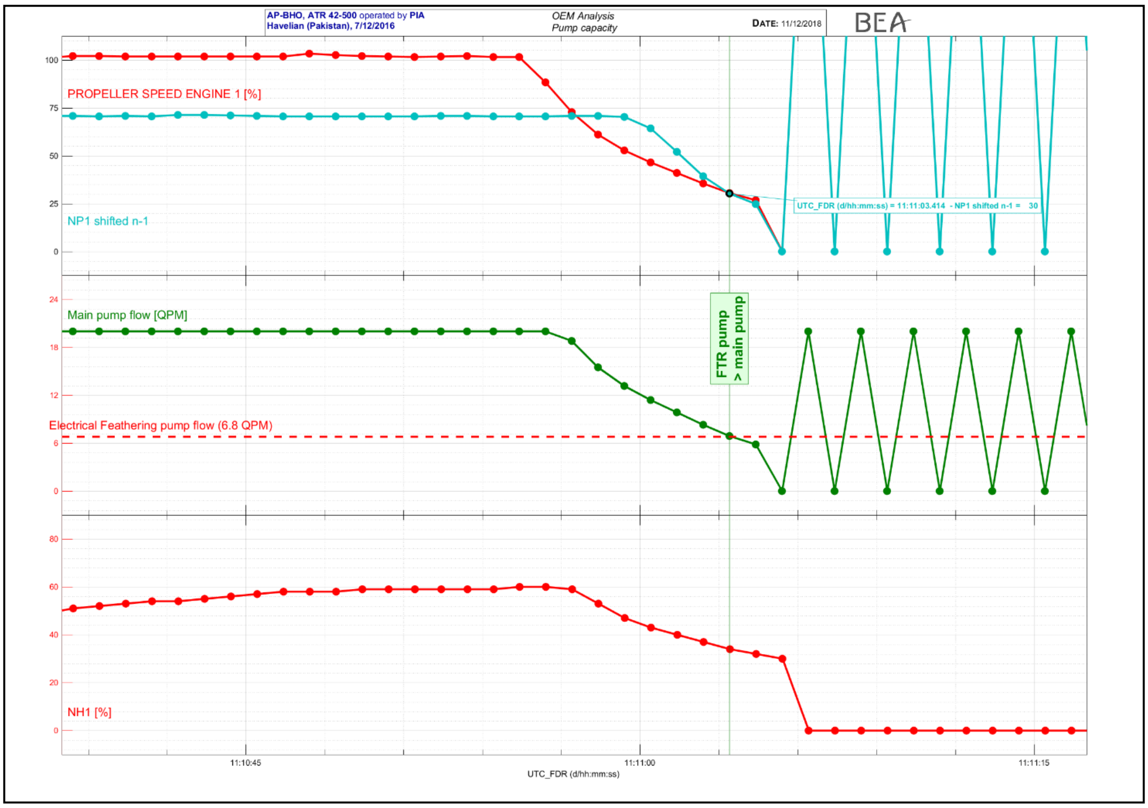


Figure 2-37: Pumps Capacity During the Feathering

(d) **Protection Valve Position and Pressures.**

(i) If the protection valve moves out of the protected mode (between the protected mode and the unprotected mode, as it was the case during the phase 2), then the pressures sent to the actuator would be a combination of the EHV requests and the feathering requests. During the flight of the event, the feathering resulted in the increase of the blade angle, while the EHV requested the decrease of the blade angle (PEC OFF). The difference of the pressures P_S and P_{OSG} ported at the protection valve side drives the protection valve position. For the P_{OSG} during the feathering process, the pressure inside the line relies on: -

- A limited flow going outside of the overspeed governor.
- An energized flow to drain of around 2 in^3 sec^{-1} (~2 QPM) generated by the feather solenoid.

(ii) During the CT scan examination of the PVM before any teardown, debris were found inside the PVM overspeed line, close to the feather solenoid. The particle sizes were digitally measured with the CT scan data. The measurements confirmed that the particles could not have reached the observed location during operation due to propeller system screening of the engine oil (the screens were confirmed present during PVM and OSG examinations). During an additional examination and recovery attempt the particles were not able to be isolated. It should also be noted that the CT scan imagery is capable of detecting materials both metallic and non-metallic and therefore cannot be used to identify the material composition of the particles. As a result it is not possible to determine the particles' material composition, source, nor when the particles were introduced into the PVM. Based on the available evidence, probability of contamination travelling inside PVM after impact could not be ruled out. Therefore, most probably the particles were introduced when the propeller system LRU's were not installed on the gearbox. This supports the additional conclusion that the particles were not introduced in flight. However, it is not possible to determine when and where this contamination was induced[144].

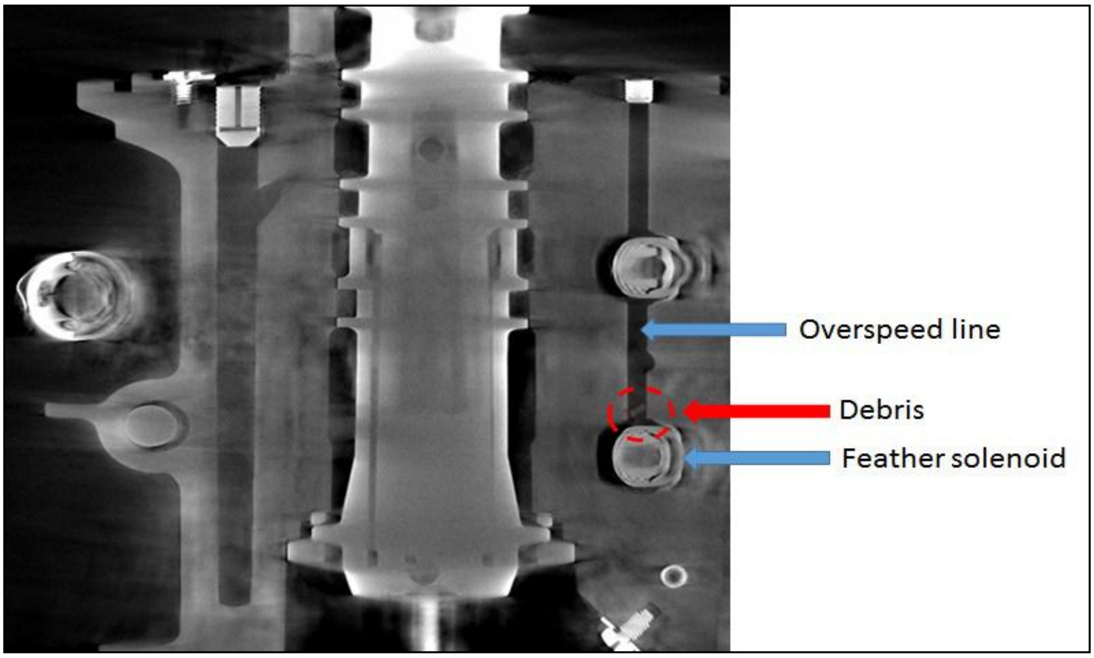


Figure 2-38: CT Scan - Debris Inside the PVM Overspeed Line

(iii) If a restriction occurs inside the PVM overspeed line, after the protection valve, the pressure ported at the protection valve would be affected.

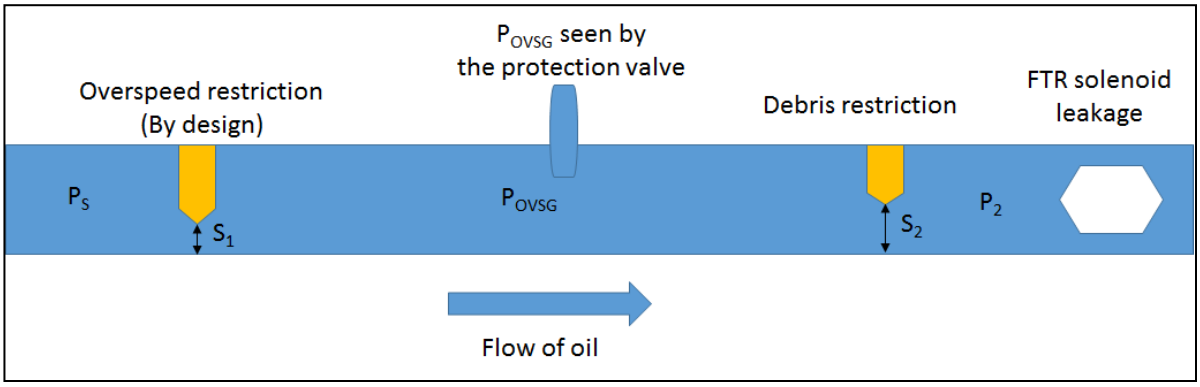


Figure 2-39: Restriction in Flow of Oil Caused by Debris

(iv) If S_2 decreases, the pressure P_{OSG} may increase. When the surface S_1 is greater than the surface S_2, the pressure P_{OSG} increases and reaches P_S. The second possibility to make the protection valve move is to decrease the P_S ported at the protection valve. The P_S provided by the main pump feeds the PVM through the filter. During the CT scan examination, no contamination was detected inside this filter. Even if nonmetallic contamination might have occurred, such a contamination would not have disappeared during the remaining time

144 PropS18-024 Rev B Pakistan International Airways ATR42-500 Mishap, Analysis of Port 568F-1 Propeller Performance, dated 08 November 2018.

of the flight. During the phase 7, the propeller speed had increased up to more than 120%. The probability that this filter was clogged and impacting on the system behavior is then remote.

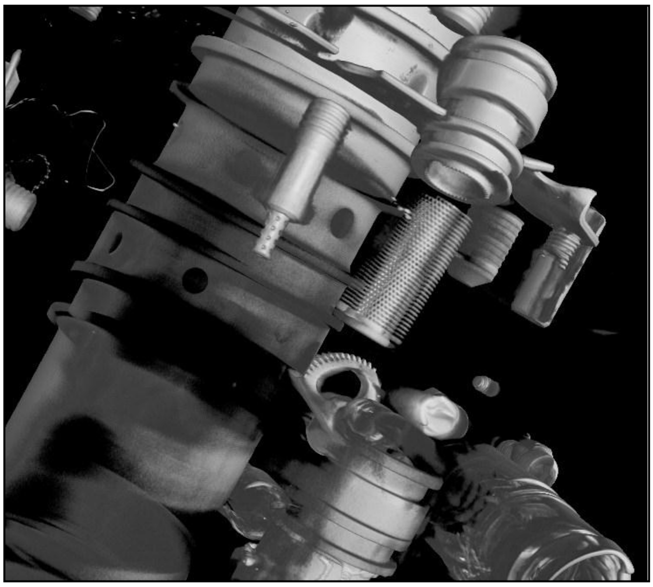


Figure 2-40: CT Scan - Input Strainer (PVM-1)

(e) **Conclusions from Phase 4:** During the feathering phase, the most probable scenario was: -

(i) The cockpit crew requested the feathering of the No 1 Propeller.

(ii) The pumps provided hydraulic flow to the system and the blade pitch angle increased.

(iii) During the feathering process, FOD inside the PVM, that was external to the engine and may have introduced when the propeller system LRU's were not installed on the gearbox, induced partial blockage of the oil flow close to the feathering solenoid. This restriction made the P_{OSG} pressure ported at the protection valve increase.

(iv) Due to the P_{OSG} pressure increase, the protection valve left the protected mode. The EHV command pressures (requesting the pitch to decrease) interfered with the feathering request and the feathering process slowed down.

2.3.4.4 Phase 5 & 6 - Study of the Un-Feathering Sequence.

(a) At 11:10:55, the No 1 Propeller feathering began. For the No 1 Propeller to un-feather (just before 11:11:18), it was necessary for the protection valve to move out of the protected mode. Indeed: -

(i) If the protection valve had stayed in the protected mode, oil flow and pressure would have been sent only to the coarse chamber preventing the blade pitch to decrease.

(ii) If oil had not been available, the counterweight would have prevented the blade pitch angle to significantly decrease and the propeller speed would have stayed below 20% (NCD values would have been recorded in that case).

(b) From 11:11:18, the protection valve was not in the protected mode anymore.

(c) **The Propeller Speed Change.**

(i) The propeller speed change is linked with the change of the blade pitch angle (ß). In the case of the event, the ß variation started at less than -1°sec^{-1} and reached a maximum of -4°sec^{-1}.

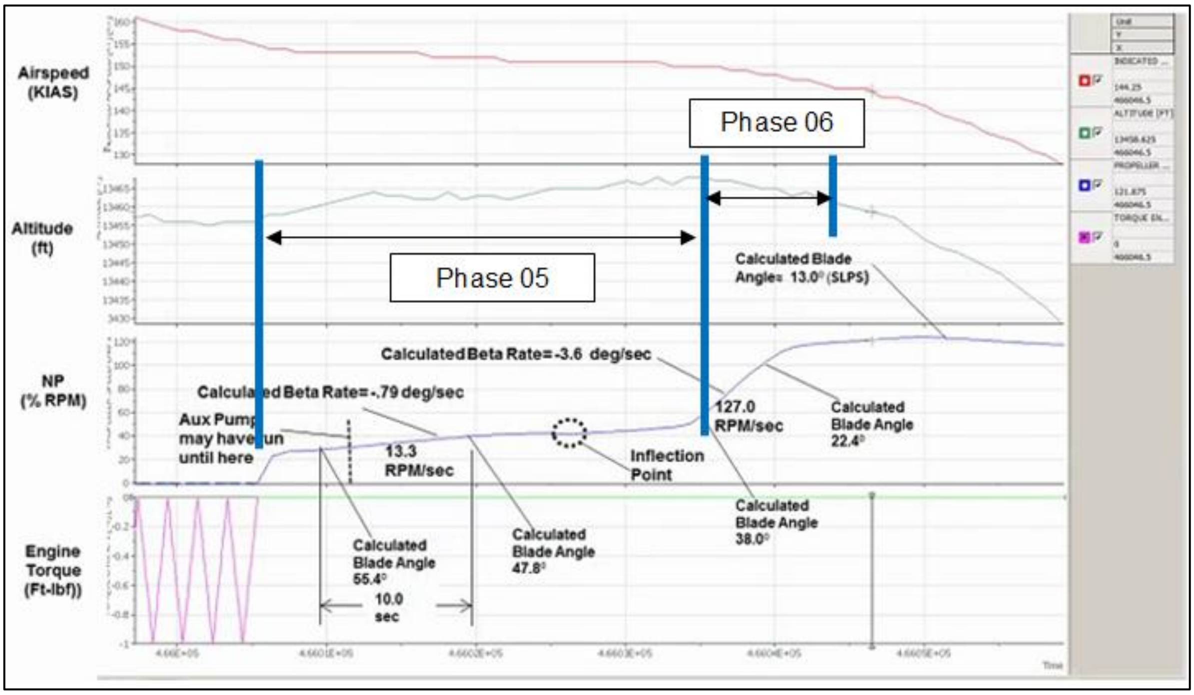


Figure 2-41: Slow Un-Feathering - PEC OFF

(ii) This ß variation was lower than the nominal decrease rate thus underlined limited oil flow associated with limited pressure sent to the actuator (Tech Finding 4).

(d) **Study of a Feather Solenoid Closure (To Let Un-Feather Occur).**

(i) The movement of the CL-1 outside of the FSO position was excluded (in fact, here, the CL should move first outside FSO position and then outside FTR position) (Tech Finding 18). The closure of the feather solenoid without any CL movement (failure case) was studied to check if this possibility was relevant. To understand this scenario, the un-feathering rate (rise in Np) in phase 5 was compared with the rise in Np in start of phase 3 (figure 2-1).The feather solenoid closure may be due to: -

- The failure of the feather solenoid.
- The failure of the electrical supply of the feather solenoid.

(ii) Whatever the reason why the feather solenoid closed, the protection valve would then:

- Move to the unprotected mode.
- Let the EHV drive the blade pitch angle.

(iii) During the flight of the event, the bias of the EHV would have requested the decrease of the blade pitch angle (PEC was OFF). This already occurred during the phase 3. The No 1 Propeller speed, at the start of this phase, moved onto the overspeed governor degraded setting close to regulation one at 11:10:34. The increase of the propeller speed rate of change during the un-feathering process clearly showed that the rate was lower than during the beginning of the phase 3, especially at the beginning of the un-feathering sequence. In the case of a feather solenoid closure, the increase of the propeller speed rate would have been greater than the recorded one.

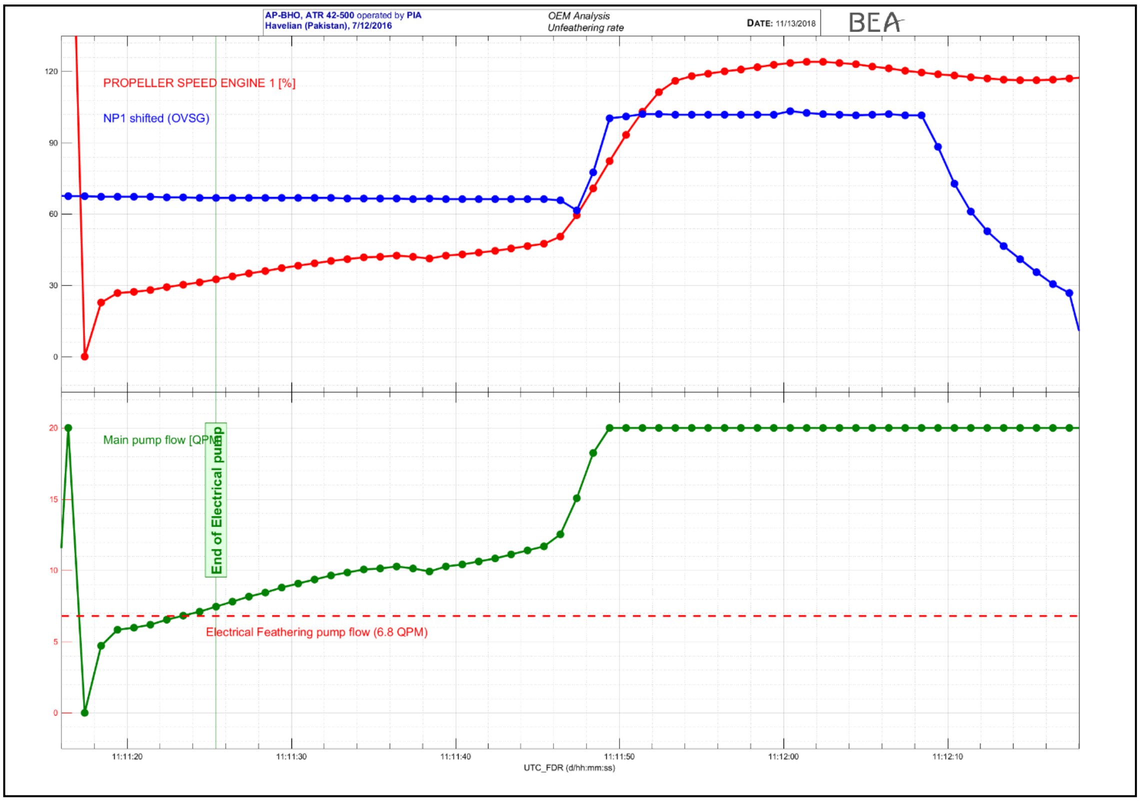


Figure 2-42: Comparison Between the Propeller Speed in the Beginning of Phase 3 and During the Un-Feathering Process

(iv) **ATR Feathering and Un-Feathering Flight Test:** Feathering and un-Feathering flight tests performed at aircraft level in conditions equivalent to the event flight (PEC OFF, altitude, speed) confirms that feathering experienced by AP-BHO was abnormally slow compared to a PEC OFF feathering through feather solenoid. Moreover, it confirms that un-feathering experienced by AP-BHO was also abnormally slow compared to an engine OFF / PEC OFF un-feathering through feather solenoid de-energizing. Thus, it allows to exclude that loss of feather solenoid input would have led to the observed AP-BHO slow un-feathering.

(e) **Protection Valve and Pressure.** Based upon the computation of the actuator force performed by the propeller manufacturer, and the most probable scenario for the slow feathering process, the contamination of the PVM overspeed line with FOD, close to the feather solenoid induced the following behavior: -

(i) At the end of the time when propeller speed values were NCD, the PVM protection valve position was towards unprotected mode.

(ii) With the increase of the propeller speed of around 40%, the main pump should have reached its full capability in pressure if supplied with adequate oil from the engine.

(iii) However, the propeller speed rate underlined that the protection valve did not reach the full unprotected mode position.

(f) **Conclusions from Phase 5 & 6.** The most probable scenario for the un-feathering phase is the continuity of the most probable scenario of the slow feathering (phase 4). Due to FOD inside PVM overspeed line, the protection valve moved more and more towards the unprotected mode, leading the EHV command to slightly superseded the feathering request. Gradually the capacity of the main pump increased up to a level close to Np 40% when it reached quite its full capacity. From that point, the main pump capacity was sufficient enough to overcome the remaining leakage of the feather solenoid and the propeller speed rate increased. However, it did not reach the rate observed during the overspeed phase, underlying that the protection valve did not reach the complete unprotected mode and underlying that leakage still existed through the feather solenoid.

2.3.4.5 **Study of Phase 7.**

(a) After the feathering phase (phase 4), due to broken flyweights, the overspeed governor was no longer able to contribute to the propeller speed regulation and the 102.5% Np threshold of propeller speed was not overshot. With the scenario of the phase 5 and 6 where Np-1 had started to increase, the blade pitch angle would have decreased down and reached to the low pitch in flight, regulated by the SLPS (Secondary Low Pitch System) protection. This assumption is consistent with the propeller manufacturer computation, which underlined in that case, that the propeller would have provided a level of power greater than the usual power absorbed by an unpowered engine. Indeed, the engine absorbing more power than expected is consistent with the spectral analysis (figure 2-43) that underlined a high level of power of the propeller, associated with the banding phenomenon. The spectral analysis of the beginning of the phase showed some oscillations of the propeller speed. However, these oscillations cannot be interpreted. Bandings phenomenon occurred at the same time and mechanical events might have been the cause of these oscillations.

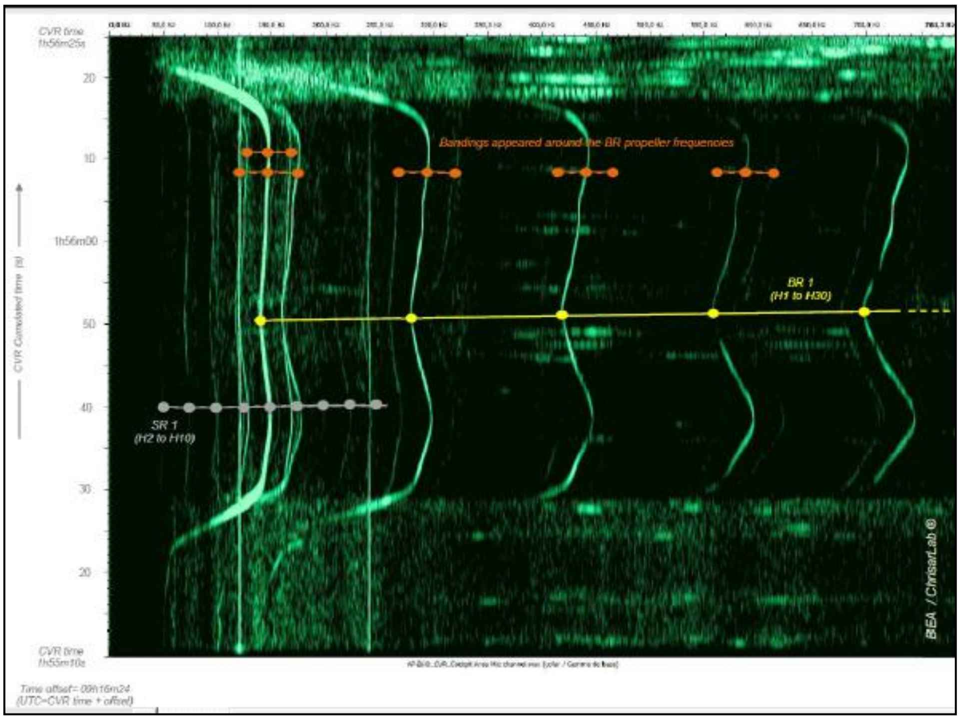


Figure 2-43: Spectral Analysis of the 120% Phase

(b) From 11:12:02 until 11:12:15, the altitude of the aircraft was quite constant and the IAS was decreasing. The propeller speed changes followed the IAS changes, which was consistent with a blade pitch angle quite constant. The CL was put outside of the FSO position around 11:12:26. As identified during CVR listening, a feathering attempt was heard (however a restart attempt cannot be ruled out). At 11:12:31 decrease of the Np-1 was observed.

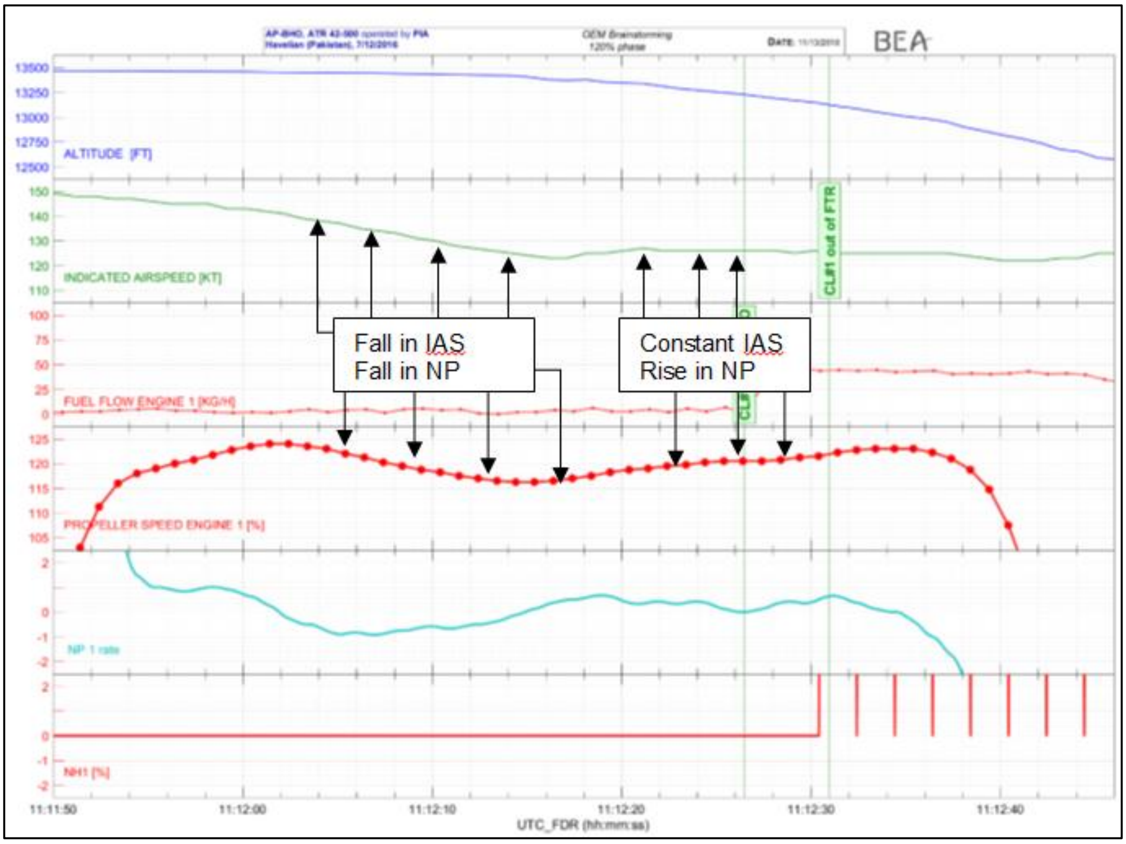


Figure 2-44: The 120% Phase (Phase 7 and 8)

(c) **Conclusions from Phase 7:** The first half of the phase 7 was consistent with what would be expected following the previous Phase 5 & 6: the feather solenoid protection was overridden and the blade pitch angle decreased down to the triggering of the SLPS protection. As the blade pitch angle was fixed, the propeller speed was driven by the IAS and the altitude of the aircraft. The end of the phase 7 is discussed with phase 8.

2.3.4.6 **Study of Phase 8:** During phase 7, the blade pitch angle reached low pitch in flight. At that time, the oil flow was drained on the feather solenoid and the SLPS solenoid. During the first part of the phase 7, the propeller blade stayed at a fix position – low pitch in flight, underlying that SLPS regulation worked during this part. During the second part of the phase 7, Angle of Attack (AOA) of aircraft increased and feather solenoid closed due to likely engine re-feather attempt (restart is less likely). Then, the propeller speed rate decreased. The SLPS protection may have been overridden. The blade pitch angle decreased and the propeller speed increased despite a decrease of the true airspeed. Even if the angle of attack impacted the propeller speed (wind-milling), the propeller speed rate remained stable between 11:12:20 and 11:12:30. Then the propeller speed started decreasing before the increase of the AOA.

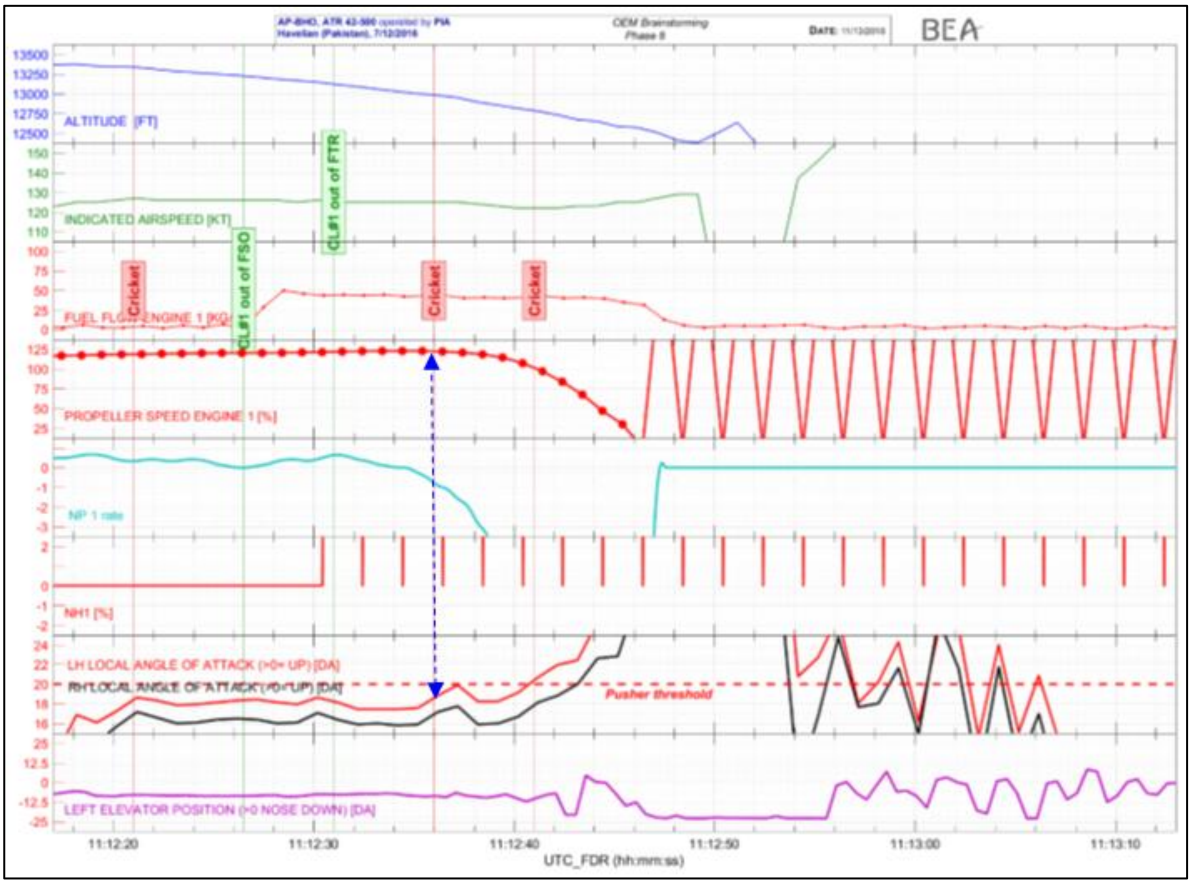


Figure 2-45: Phase 8

(a) **Drag Computation.**

(i) The drag applied on the aircraft during the flight of the event was computed by the aircraft manufacturer. The increase of the drag (decrease of the force - figure 2-46) started before the CL-1 move outside of the FTR position. The closure of the feather solenoid was then not a key point to explain the propeller behavior. Following the CFD computation of the thrust, such increase of the drag may be consistent with the decrease of the blade pitch angle below the low pitch in flight. This blade angle decrease below the low pitch in flight would then imply that the SLPS protection was overridden. During the propeller hardware evaluation no failure of the SLPS system was identified after reviewing of all of the components of this protection system. Also an automated test of the SLPS is performed on aircraft during the first un-feathering after initialization of the PEC. Therefore, the SLPS was successfully tested the day of the accident. During the second half of the phase 7, except the previously mentioned details (SLPS overridden), no other condition explaining the huge increase of the drag computed by the aircraft manufacturer simulation tool was found.

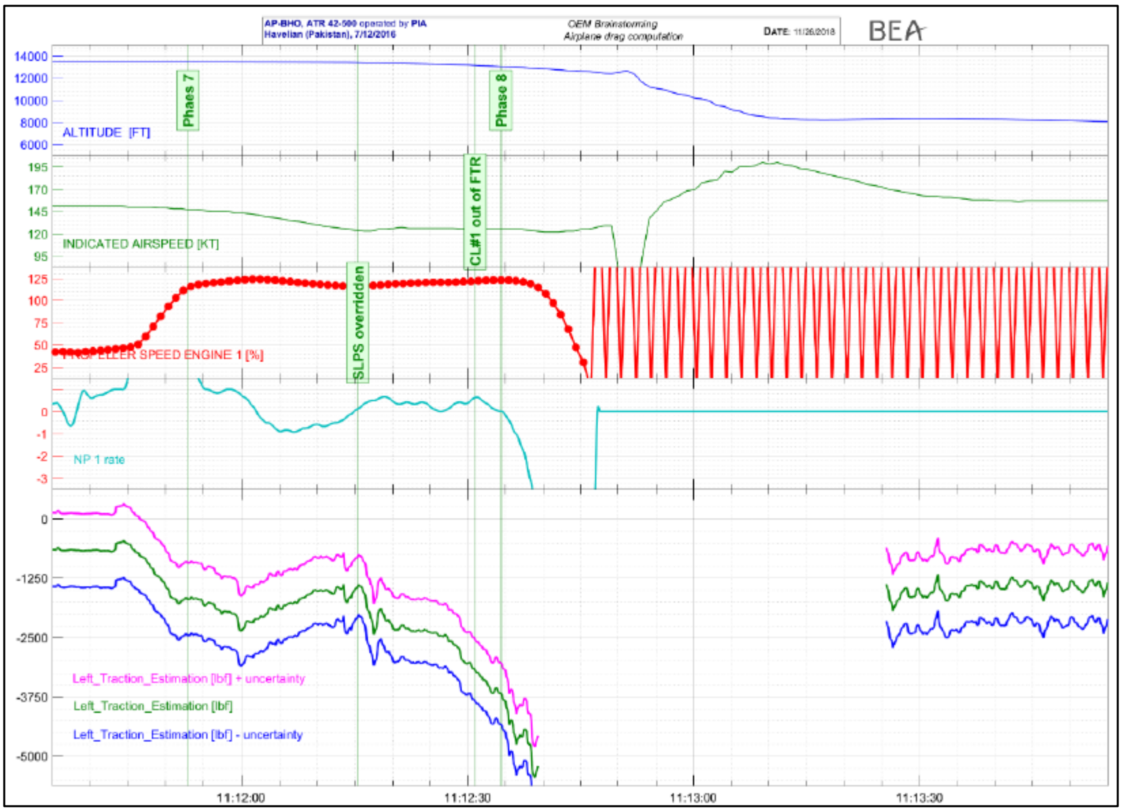


Figure 2-46: Aircraft Drag Computation

(ii) With the SLPS protection overridden, the blade pitch angle was not limited anymore, except by hydraulic power. The blade pitch angle went on decreasing. With the decrease of the blade pitch angle, the propeller left the operation area where it generated power greater than the power absorbed by the failed engine. Following Tech Finding 6, the propeller speed started to decrease, as the blade pitch angle was too low. During this propeller speed decrease, from 11:12:40, the angle of attack of the aircraft started to increase and reached stall condition. The aerodynamic forces applied to the wind milling propeller should have been impacted by these high angles of attack. Without being able to weight the impact of one versus the other one, the angle of attack and the too low blade pitch angle contributed to the slowdown of the propeller leading the propeller to force the PT shaft to slow down. After the recovery of the aircraft, the propeller speed stayed NCD, underlying a propeller speed lower than 25%. During the propeller speed decrease below 25%, as long as hydraulic power was present, blade pitch angle decreased and propeller speed went on decreasing too. When the propeller speed was too low, the main pump was not able to provide sufficient oil flow and sufficient hydraulic pressure anymore. When the hydraulic pressure was not sufficient anymore: -

- If the power generated by the propeller was greater than the power absorbed by the engine and its associated RGB, the propeller speed would have increased. This increase would have been limited to 25% (otherwise valid propeller speed values would have been recorded). At one specific Np lower than 25%, the power generated by the propeller would have been equal to the power absorbed by the engine and its associated RGB.

- This balanced position of the system should provide a drag of the propeller consistent with the drag computed by the aircraft manufacturer: a drag between 700 lbf and 2,200 lbf (average values in Figure 2-46). Following the extrapolation provided by the propeller manufacturer, it implies a propeller speed lower than 5% with a blade pitch angle close to either the low pitch stop or the aerodynamic 0 total twisting moment pitch position.

- If the power generated by the propeller was lower than the power absorbed by the engine and its associated RGB, the propeller speed may have decreased. This propeller speed would have decreased until the power generated by the propeller would have been equal to the power absorbed by the engine and its associated RGB.

- In line with the reasoning given in the above point, the propeller speed would have decreased at a speed between 0% and 5% of Np with a blade angle close to the low pitch in flight.

(b) **Conclusions from Study of Phase 8.**

(i) As a most likely scenario, during the second part of the phase 7, it is possible that the SLPS protection was overridden and the blade pitch angle went below the low pitch in flight. This decrease of blade pitch angle until 4° generated an increase of the drag consistent with the drag computed by the aircraft manufacturer. At 11:12:24, a re-feathering or a restart attempt is consistent with CL moving out of FSO position and most likely finally positioned at Feather. As the blade pitch angle went on decreasing, the propeller was not able to generate sufficient power in comparison with power absorbed by the engine and its associated RGB. As a result, propeller speed decreased quickly, after the stall, blade angle most probably settled close to low pitch in flight with a propeller speed, likely below 5%.

2.3.5 Distress of 1st Stage Power Turbine Blades of PW127 Engines in Industry– Modifications and their Implementation.

2.3.5.1 P&W Canada issued various Service Bulletins to address the issue of distress of 1st Stage Power Turbine Blades of PW127 Engines in Industry. Review of these SBs and their implementation status with respect to PIA, is as follows: -

S No	SB Ref No	Details	PIA Action	Observation
1	SB-21766 Mar 2008 Cat 3	A shrinkage porosity condition in excess of inspection limits has been identified on some first stage PT blades. P&WC has identified the potentially affected blades and recommends the replacement of these blades at different intervals based on the observed conditions.	Not applicable on the engines held with PIA at that time.	The manufacturing / design issue in PT blades was noticed and a CAT 3 was assigned to it.
2	SB-21823 Sep 2012 Cat 5	This SB provides instructions for a one time inspection on a range of PT-1 blades part numbers and serial numbers as per an improved X-Ray inspection as currently used in manufacturing.	Complied.	CAT was lowered from previous 3 to 5.

S No	SB Ref No	Details	PIA Action	Observation
3	SB-21828 Feb 2013 Cat 3	A shrinkage porosity condition in excess of inspection limits has been identified on some first stage PT blades. P&WC has identified the potentially affected blades and recommends the replacement of these blades at different intervals based on the observed conditions.	Complied.	The CAT was changed from 5 to 3.
4	SB-21863 Jul 2014 Cat 3	This SB provides instructions to replace the first stage PT blades at next shop visit opportunity. This recommendation is applicable only for the blade part & serial numbers listed in Table-1 of SB.	Complied.	CAT 3 was assigned.
5	**SB-21878** **Oct 2015** **Cat 7**	**The durability of PT-1 blades is not optimal. Change the blades to one without an internal cavity to limit the possibility of porosity.**	**Not Complied on Engine S/N EB0259.**	**The CAT was lowered to 7 (compliance codes given hereunder).**

2.3.5.2 Service Bulletin (SB) Compliance Codes for Transport Canada Civil Aviation (TCCA) Certified Products[145] (which define the categories) are as follows: -

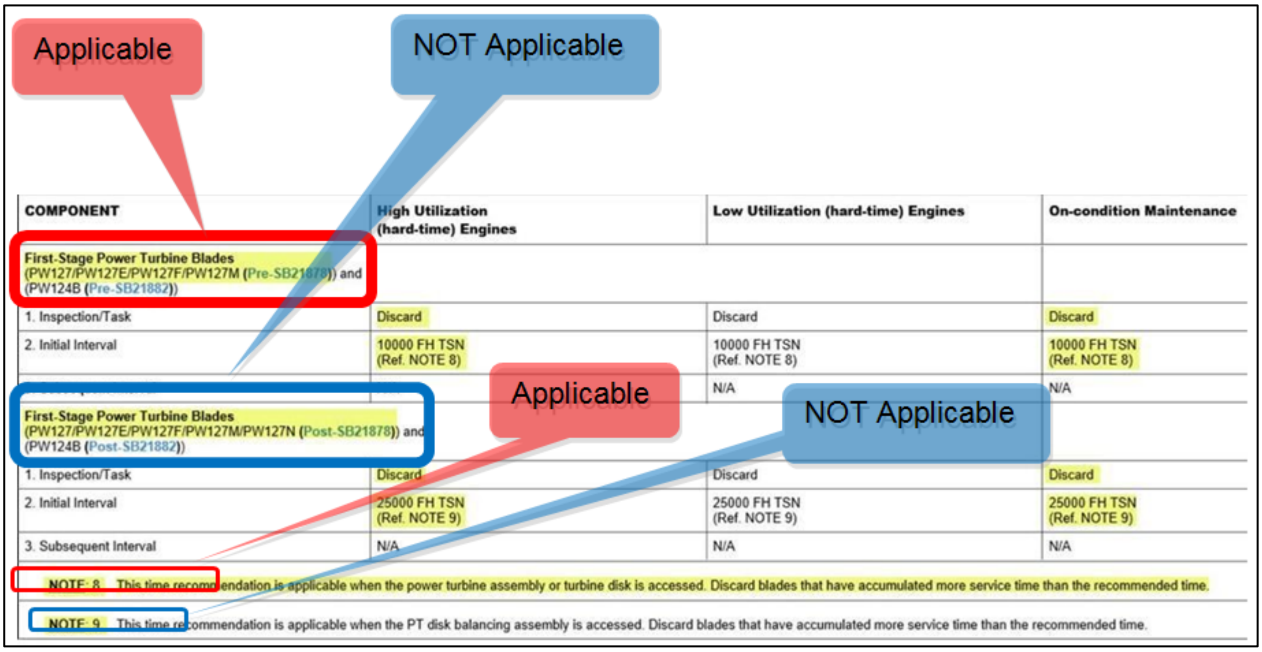
Bulletin Category	Implementation Timing Recommendation
Category 1	P&WC recommend to do this service bulletin before the next flight.
Category 2	P&WC recommend to do this service bulletin in the first time the aircraft is at a line or maintenance base that can do the procedures.
Category 3	P&WC recommend to do this service bulletin within ____ hours or ____cycles.
Category 4	P&WC recommend doing this service bulletin the first time the engine or module is at a maintenance base that can do the procedures, regardless of the scheduled maintenance action or reason for engine removal.
Category 5	P&WC recommend to do this service bulletin when the engine is disassembled and access is available to the necessary subassembly (ie module, accessories, components, or build groups). Do all spare subassemblies.
Category 6	P&WC recommend doing this service bulletin when the subassembly (ie module, accessories, components, or build groups) is disassembled and access is available to the necessary part. Do all spare sub-assemblies.
Category 7	You can do this service bulletin when the supply of superseded parts is fully used.
Category 8	This service bulletin is optional and can be done at the discretion of the operator.
Category 9	Spare Parts Information.

[145] S.I.L No GEN-030-R3 Pratt and Whitney Service Information Letter Amended Service Bulletin Compliance Statements.

Bulletin Category	Implementation Timing Recommendation
Category 10	For information only.
Category 11	This is the old Omnibus category of Service Bulletin and is no longer in use except for the PW1000 program. This paragraph is being kept for historical purposes only. This Service Bulletin is issued to document the modifications done on all engines, after engine certification but before aircraft entry into service. The result is that no Pre-SBXXXXX configuration will appear in the technical publications or the modification accomplished prior to aircraft entry into service.
Category 15	This Service Bulletin is issued to document the modifications done on all engines, after engine certification but before aircraft entry into service. The result is that no Pre-SBXXXXX configuration will appear in the technical publications for the modification accomplished prior to aircraft entry into service.
Category CSU	Operators who participate should include this Service Bulletin at the discretion of Customer Engineering.

2.3.5.3 **Revision in Engine Maintenance Manual (EMM) and its Applicability on Engine S/N EB0259.**

(a) The contents of SB-21878 were incorporated through an amendment in the EMM Chapter-5 in May 2016 by P&WC. EMM Chapter-5 recommends that PT-1 old design blades be replaced in the first available opportunity after completing 10,000 flight hours (as below): -



COMPONENT	High Utilization (hard-time) Engines	Low Utilization (hard-time) Engines	On-condition Maintenance
First-Stage Power Turbine Blades (PW127/PW127E/PW127F/PW127M (Pre-SB21878)) and (PW124B (Pre-SB21882))			
1. Inspection/Task	Discard	Discard	Discard
2. Initial Interval	10000 FH TSN (Ref. NOTE 8)	10000 FH TSN (Ref. NOTE 8)	10000 FH TSN (Ref. NOTE 8)
[illegible]	[illegible]	N/A	N/A
First-Stage Power Turbine Blades (PW127/PW127E/PW127F/PW127M/PW127N (Post-SB21878)) and (PW124B (Post-SB21882))			
1. Inspection/Task	Discard	Discard	Discard
2. Initial Interval	25000 FH TSN (Ref. NOTE 9)	25000 FH TSN (Ref. NOTE 9)	25000 FH TSN (Ref. NOTE 9)
3. Subsequent Interval	N/A	N/A	N/A

NOTE: 8 This time recommendation is applicable when the power turbine assembly or turbine disk is accessed. Discard blades that have accumulated more service time than the recommended time.

NOTE: 9 This time recommendation is applicable when the PT disk balancing assembly is accessed. Discard blades that have accumulated more service time than the recommended time.

Figure 2-47: EMM Chapter 5 Criteria for PT-1 Blade Replacement

(b) Engine S/N EB0259 visited engine shop for a suspected non-metallic FOD repair, ~93 hrs prior to crash. At this time PT-1 blades had already accumulated 10,004.1 hrs. The engine was disassembled at Engine Shop by removing the Power Turbine Assembly and subsequent modules of the engine till LP impeller. Since the power turbine assembly was accessed during repair and the PT-1 blades had met the criteria for replacement (as per EMM Chapter-5) therefore old design PT-1 blades should have been replaced. However, same was not done by PIA Engine Shop. One of these PT-1 blades failed after flying ~93 hrs (since last shop visit) and contributed to the catastrophic sequence of technical malfunctions leading to crash.

2.3.5.4 Technical Findings about Industry Distress of 1st Stage PT Blades, Revision in EMM (SB-21878) and it's Applicability on Engine S/N EB0259 During Last Repair.

Tech Finding 40: In industry since 2008, the distress of 1st Stage PT blades on PW127 engines is a known issue. The OEM issued multiple SBs with various assigned categories, which were complied with and have been effective in reducing the rate of events[146], and latest SB-21878, was introduced in Oct 2015.

Tech Finding 41: SB-21878 introduced the new blade design, which eliminates the overspeed protection pocket, which is being replaced by a scallop on the airfoil. Contents of this SB were subsequently incorporated in the EMM Chapter-5 in May 2016.

Tech Finding 42: After review of records of No 1 Engine, the life of PT-1 blades at the last shop visit was found to be 10,004.1 hrs, ie crossing the soft life threshold of 10,000 hrs as outlined in Engine Maintenance Manual recommending discarding of the blades.

Tech Finding 43: During last shop visit, engine was "stripped to access LP spool" and a piece of rubber was removed. In order to access the LP spool, the power turbines were removed and PT blades were accessible. As per EMM Chapter-5, old design PT-1 blades should have been replaced. However, same was not done by PIA Engine Shop.

Tech Finding 44: Had there been no unscheduled repair on subject engine, PT blades would have continued in service passing 10,000 hrs soft life without being replaced. Probability of blade fracture / dislodging in such case (where the engine is not subjected to any scheduled / unscheduled maintenance enabling access to the relevant area) cannot be ruled out.

2.3.6 Repair / Overhaul History of Overspeed Governor and Maintenance Group Investigation Report by NTSB.

2.3.6.1 Review of Records at PIA and Overhaul History at MRO.

(a) Since induction of the ATR fleet in PIA, the OSG is a repair abroad item. PIA Component Support Program (CSP) requires that repairable OSG is routed to its authorized MRO abroad and a serviceable OSG is provided by the vendor as a replacement. PIA is not required / authorized to do any maintenance / repair of OSG. PIA has a small fleet of ATRs and has large quantity of OSG's in stock (Qty-48).

(b) All previous shop reports / repair work orders of the subject OSG (P/N: 8210-097 S/N: 14967680) were reviewed. Following are the salient details regarding three shop visits at MRO[147]: -

[146] Established after necessary input from TSB (P&W Canada).
[147] Hamilton Sundstrand Shop Findings Reports of relevant activities.

S No	Received at OEM	Work Order	Remarks
1	07/02/2011	T343403	**Reason for return**: Engine power turbine burnt **Findings and work performed**: Run as Received (RAR) testing performed and found pneumatic valve test was 4 RPM low out of limits (minor calibration adjustment). Unit received as P/N 8210-095 and SB83374-61-001 was performed to modify unit to P/N 8210-097 (Update Overspeed Governor Assembly with new filter & replaced seal). **Date Shipped :** 10/05/2011
2	09/07/2012	5005488277	**Reason for return:** In flight engine shutdown **Findings and work performed:** RAR test was performed and revealed no faults. Unit passed all test points. Also ran unit on speed for 30 minutes with no incident. Unit recertified with no disassembly performed and no parts replaced. **Date Shipped:** 12/10/2012
3	01/06/2015	5008582822	**Reason for return**: Repair **Findings and work performed:** RAR resulted in unit only failing one test point. Unit failed reset speed setting due to reset solenoid not functioning. Solenoid replaced. **Date Shipped:** 18/07/2015

2.3.6.2 **Maintenance Group Investigation Report, Service Review of Woodward Overspeed Governor P/N 8210-097, S/N 14967680 by NTSB[148].**

(a) NTSB proposed formulation of a joint maintenance review group in January 2020 to review OSG broken pin possibility. The group was planned to be comprised of members from AAIB Pakistan, NTSB, and OEM / MRO of OSG. However, due to COVID-19 restrictions AAIB was unable to join the group. So it was mutually agreed that the Maintenance Review Group activity be completed under the leadership of NTSB and without the physical participation of AAIB Pakistan.

(b) Maintenance Group Review studied this aspect by having a detailed review of following: -

(i) Maintenance record of PIA.

(ii) Maintenance records of overhauling activity at MRO (for three visits of OSG in 2011, 2012, and 2015).

(iii) Metallurgical analysis reports.

(iv) Failure possibilities scenarios analysis.

(v) Failure modes / discussion.

(vi) Review of existing procedures / revised procedure of CMM.

[148] Maintenance Group Investigation Report, Service Review of Woodward Overspeed Governor P/N 8210-097, S/N 14967680 by NTSB, dated 02 October 2020 is attached as **Appendix-1.**

(c) This activity was able to factually establish from the hardware evidence that the OSG pilot valve pin was sheared off during the second of two undocumented post manufacture lower body assemblies. Maintenance Group Review summarized the following: -

(i) Based upon Process Failure Modes and Effects Analysis (PFMEA), Woodward discusses three conditions of improper assembly in the report and found that the CMM assembly procedure does not permit the mis-assembly (assembly with the pin on top of the flyweight) that produced the fractured pin and observed hardware markings. Any assembling in this condition would require disregard of assembly order, which ignores a CMM Caution, and forcible seating of the ballhead assembly, which requires excessive force.

(ii) For the other two possible assembly conditions of the OSG pin, it was determined that they resulted in seizure of the OSG pilot valve and an untestable condition at product acceptance test. The CMM was updated to provide a measurement that checks for such misplacement before reaching product acceptance test.

(iii) There were two lower body access events identified after the manufacturing and initial assembly of the component, based on the accident hardware examination. The first access resulted in the observed second wear pattern on the pilot valve block (the first pattern being produced from pin placement during original manufacture). The second access is considered to be when the pin was fractured due to incorrect assembly.

(iv) First lower body access during visit to an MRO was possible (for main drive bearing inspection) without being specifically noted in repair work scope.

(v) The second lower body access that fractured the pin was considered likely to have been unauthorized and undocumented given the findings at para 2.3.6.2 (c) (i) above. Woodward's review of MRO reliability data since 1994 found no reports of a unit received with a sheared pin. It also can be noted that assembly with the pin atop a flyweight is more difficult and does not save time, indicating that only an untrained mechanic would attempt this method. All of this makes it unlikely, but not impossible, that the improper assembly was performed by a certified OSG repair technician at the Woodward-approved repair facility.

(vi) Review of the service history revealed several periods for which the OSG location was not established. Without removal / installation records it is unknown whether the OSG was operated in support of other aircraft, and possibly accessed. However, most of these gaps can be ruled out using the wear signature evidence.

2.3.6.3 **Technical Findings of Maintenance Aspects of OSG.**

Tech Finding 45: Being a repair abroad item, any defective OSG once removed from the aircraft / engine; is routed directly abroad. PIA is not required / authorized to undertake any maintenance of the said component.

Tech Finding 46: This OSG was sent three times to its MRO repair facility abroad in 2011, 2012 and 2015.

Tech Finding 47: No evidence / documentation was found for maintenance of the OSG after April 2015 when it was last received from repair abroad.

Tech Finding 48: The OSG pin was fractured / broken during some un-authorized / undocumented maintenance. It was not possible to ascertain when and where such maintenance may have occurred.

Tech Finding 49: The revised CMM adequately identifies possible improper assembly conditions of OSG.

Tech Finding 50: OSG can continue to operate normally without any problem detected with a sheared pin of the pilot valve, until further deterioration.

2.3.7 **Maintenance History of AP-BHO at PIA.**

2.3.7.1 The maintenance history of the subject aircraft was investigated for following: -

(a) Last two years Aircraft Service & Maintenance History: Technical Log Book data - Engine/Prop in-service faults troubleshooting data.

(b) EB0259 Installation Record-Last Engine Change Sheet-PVM & OSG Installation & post Installation Tests.

(c) No 1 Propeller S/N FR20070856 Assembly Shop Card Details.

2.3.7.2 The records revealed no significant event that may have any attribution to the sequence of technical malfunctions of the event flight.

Tech Finding 51: Except the noncompliance of relevant portion of EMM Chapter 5, no other direct contribution towards the event could be observed.

2.3.8 **CAA Oversight of PIA Engineering.**

2.3.8.1 Noncompliance of EMM Chapter 5 (SB-21878) was not identified by CAA Airworthiness oversight system before the crash.

2.3.8.2 Immediately after this accident on 07 December, 2016, CAA Pakistan sealed PIA Engine Shop and conducted a detailed technical audit.

2.3.8.3 In February 2017 PIA Engineering reviewed the life of the old design PT-1 blades. PIA Engineering decided to change the soft life as a hard life of 10,000 hrs irrespective of the conditions given in the maintenance manual (an action overboard towards safe side). The enabling reasons for this review and details of participation of CAA Pakistan in this review was not recorded / provided.

2.3.8.4 CAA Pakistan conducts annual audits of the operators at the time of renewal of AOC. Audit reports of PIA for the years 2014 to 2018 were examined during the course of investigation.

Tech Finding 52: The oversight of PIA Engineering by CAA Pakistan in the domain of Airworthiness was inadequate.

2.3.8.5 **Overview of Shop Survey of PIA by P&WC.**

(a) A shop survey of Pakistan International Airlines MRO Facility was performed by P&WC in accordance with their Quality Control Specification (QCS) 3040336 rev 4. This survey was conducted during April 17 to 19, 2017. The scope of the survey was to identify the areas requiring review in order to have full overhaul capability for PW127 engines and align the Pakistan International Airlines Quality System to P&WC requirements. At the end of the survey a report was provided[149]. Salient aspects of the survey report are as follows: -

(i) Pakistan International Airlines MRO performs the base and line maintenances under the approval of Civil Aviation Authority (CAA) Pakistan. The base maintenance (Airframe, Engine and Component shops) has the ANO145 approval from CAA Pakistan and approved for Boeing 747-300, Boeing 747-200, Boeing 777-200, Boeing 737-300, Airbus A300B4, Airbus A300B2 and Airbus A310-300.

(ii) The engine MRO shop has the following capabilities: GE CF6-50C2/E2, GE CF6-80C2, CFM56-3B. Auxiliary Power Units-from Honeywell GTCP 660-4, GTCP 700-5, GTCP 85-129K/H.

(iii) PIA's Engineering at Jinnah International Airport, Karachi, extend its services to Asia, Middle East, Central Asian countries, Far East and South East Asia Countries.

(iv) PIA E&M has been the pioneers in the region to achieve the EASA Part 145 certification and currently holds ANO145 approval from CAA Pakistan and GACA 145 from Saudi Civil Aviation.

(v) In support of its engine overhaul facility, PIA utilizes two engine test cells for turboprop and large turbofan engines.

(b) Important conclusions of the survey report are as follows: -

(i) Pakistan International Airlines engine MRO facility has good capabilities in terms of Machining, Peening, Welding, heat treatment, balancing, plating, plasma, laboratory and gage inspection and control.

(ii) The areas which required most significant upgrade to gain full compliance with P&WC requirements were identified as; the Cleaning, NDT, Painting, Assembly / Disassembly, bearing inspection and cleaning, material handling / preservation. Additionally the development of repair processes defined in the Standard Practice Manual, Overhaul Manual and CIR Manual is required for the PW127 engine.

(c) The Gaps highlighted in the report were required to be closed before the processing of Technical Standard Agreement (TSA) certification and Overhaul Level Training.

Tech Finding 53: The compliance by PIA Engineering to the OEM's recommended maintenance procedures for PW127 engines highlighted a need for improvement in a few technical aspects.

[149] Shop survey of Pakistan International Airlines MRO Facility, Karachi, Pakistan Dated 01 May 2018.

2.3.8.6 **Comparison of PIA with Worldwide Fleet for Reliability of ATR Aircraft / PW127 Engine.**

(a) During further course of investigation P&WC was requested to provide data about comparison of reliability of the ATR aircraft / PW127 series engines between PIA and rest of the ATR fleet operating world over. A classified data was provided to compare the PW127 engine reliability, between the Pakistan International Airline (PIA) fleet and worldwide fleet. The rate of occurrence for each type of events (ie in Flight shutdown, inability to modulate power, aborted take-off, air turn back, and use of emergency procedure) were considered. Statistical modeling was used to show the standard deviation as a function of flying hours for various operators' fleets. It was observed that the variances were statistically significant.

(b) Summarized interpretation of data included: -

(i) PIA fleet engine reliability was found to be significantly lower than that of other fleets around the world. This remains true even when comparing with operators in similar operating environments.

(ii) P&WC had been working with PIA to identify causes for this variance. A number of opportunities were already identified and shared with PIA (Oil filter maintenance practices, Repair & Overhaul shop corrective actions following on-site audit, access to latest engine manuals etc).

Tech Finding 54: The comparison of PIA with worldwide fleet for reliability of ATR aircraft / PW127 engine indicated very low reliability and a need for deep analysis / review in the respective domains by PIA Engineering / Safety & Quality Managements.

2.4 **Crew Action Analysis, Aircraft Controllability and Performance Margins:** In order to evaluate cockpit crew actions about the abnormal situations (emergencies) encountered during flight, AAIB Pakistan with the participation of BEA and ATR, simulated the abnormal situation in Full Flight Simulator. Crew actions were evaluated in-light of relevant portions of QRH / FCOM. The activity included detailed analysis of required / expected crew behavior and observations about anomalies in actions actually performed during the flight. Additionally, it was considered that Visual Meteorological Conditions (VMC) prevailed at the time of the departure (ie no adverse weather conditions as reported for the event flight).

2.4.1 **Overview of Simulator Activity[150].**

2.4.1.1 AAIB Pakistan Team visited simulator during March 2018 for the discussion / analysis of crew actions. Following aspects were discussed by the ATR participant about the said simulator activity: -

(a) While Full Flight Simulator (FFS) could simulate some failure cases which were for training, the FFS could not simulate the actual event (both in terms of the mechanical behavior and the resulting aerodynamic effects).

(b) The full flight simulators are designed and certified for training purposes based on mandatory items defined by the respective certification authorities (such as the European Aviation Safety Agency (EASA) and Federal Aviation Administration (FAA)). In that intent any test performed on

[150] AP-BHO Operational Group Minutes of Meeting & FFS Sessions, 19th to 21st of March 2018 in ATR.

an FFS, outside of the above mentioned mandatory items, may not be fully representative of the aircraft handling characteristics.

2.4.1.2 The objective of each item performed was demonstration of a standard crew performance in accordance with the relevant FCOM procedures as well as the associated aspects like: -

(a) CRM

(b) Decision Making

(c) Workload

(d) Task-Sharing and workload

(e) Task-Sharing and aircraft Energy State Management

2.4.1.3 Following activities were performed during numerous simulator sessions and standard crew actions were demonstrated in accordance with the referred QRH / FCOM procedures: -

Sr No	Situation	Reference
(a)	PEC Single Channel	FCOM 2.05.02 P16, QRH 2.10A
(b)	PEC Fault	FCOM 2.05.02 P16, QRH 2.10A
(c)	Engine Flame Out in Cruise	FCOM 2.05.02 P13, QRH 2.10
(d)	Single Engine Operations	FCOM 2.05.02 P1, QRH 2.04
(e)	Severe Mechanical Damage	FCOM 2.04.02 P1, QRH 1.02
(f)	Stall Recovery	FCOM 2.05.05 P11, QRH 1.10
(g)	Pitch Disconnect	FCOM 2.05.06 P6, QRH 2.22

2.4.1.4 It was also established that the most accurate means to evaluate aircraft responses were the engineering simulation(s) performed by ATR and validated by the BEA. An elaborate engineering simulation / aircraft controllability report was provided in November 2018[151].

2.4.2 **Crew Actions vs Expected Behavior[152]:** The analysis of crew actions was compiled and a draft report was generated by BEA. This draft contains detailed and elaborate discussions on crew actions during flight. It was also intended to include various operational data. This draft report has been referred / utilized in this investigation for relevant portions about discussions on crew actions, however the other operational data which was not finalized at that stage, has been incorporated in this investigation report directly and has not been referred from / included from the said draft report.

2.4.2.1 The crew action analysis was based on ICAO framework for the training of pilots, crews and air traffic controllers based on competencies that make up the performance of these operators[153]. This framework proposes definitions of each of

[151] BEA2016-0760_tec29, Report on UTAS and ATR Simulations dated 19 September 2018.
[152] Draft Operational Report (Crew Actions Vs Expected Behavior) March 2018.
[153] Document 9995 - Manual of Evidence-based Training (Edition 1 of 2013).

the competences identified but also a certain number of observable behavioral indicators (in training). The principle was to observe in a factual way, (according to the behavioral markers), the competences of the pilots, in simulator and in flight, with the aim of improving them, and did not provide "Why" part of the discussion. The analysis was done by dividing the flight into various phases, and assigning color coding to the deviation from the expected behavior according to its seriousness / importance in relation to its contribution to crash.

2.4.2.2 This analysis of the crew actions and comparison with the expected behavior was based on expected aircraft performance (ie as per the designed / certified parameters). The understanding / knowledge about the nature and extent of degradation in the aircraft performance were not established at that stage. Furthermore it was important to quantify the degradation in aircraft performance to correlate and understand the possible attribution of the crew actions with the crash, and understand possible crew actions which could avoid crash. Consequently the conclusions of this crew action analysis draft report have been discussed in light of the degraded aircraft performance actually experienced by the crew, by using phases (same as defined in that report and applicable to this part of investigation only)[154]. Significant results are tabulated below: -

Phase	Summary of Crew Actions and Discussion
Phase 1 The Cruise 10:46:20 to 11:04:44	(a) There were few observations regarding SOP adherence, communication, trajectory management & automation, and CRM aspects (ie leadership, decision making & problem solving, situational awareness, and workload management) etc. **Discussion:** (b) During this phase the aircraft performance / cockpit indications etc were as per the aircraft design / certification parameters. Most observations were categorized as **"for consideration"** and were of mild nature. Few observations about deviations from FCOM, situational awareness, and task sharing etc were categorized as **"medium"** in severity and are as follows: - (i) Selection of Power Lever out of notch. (ii) Cruising at 186 knots IAS. (iii) Not discussing details of single engine strategy. (iv) Transfer of controls without announcement / acknowledgement. (c) These observations reflected inaccuracy in the actions of the pilots, and low priority consideration on Energy State Management. The cockpit crew was not well organized.

[154] This part of the report has been compiled on the basis of Draft Operational Report (Crew Actions Vs Expected Behavior) March 2018, meeting at BEA Paris in November 2019, relevant extracts from CVR / DFDR recordings, and AAIB Analysis.

Phase	Summary of Crew Actions and Discussion
Phase 2 No Proper Np Regulation 11:04:45 to 11:10:33	(a) There were several observations regarding SOP adherence, communication, trajectory management & automation, CRM aspects (ie leadership, decision making & problem solving, situational awareness, and workload management) etc. Few observations were categorized as **"for consideration"** and few others as **"important"** in relation to their significance, many observations were categorized as of **"medium"** importance. **Discussion:** (b) During this phase, few cockpit indications were off-design (not as per the aircraft design / certification parameters) and therefore were not specifically mentioned in QRH / FCOM in the manner and sequence of appearance in the cockpit. Important conclusions from this phase of flight are as follows: - (i) Transfer of controls without announcement / acknowledgement. (ii) No discussion on the off-design parameters. (iii) Three PEC reset attempts (contrary to QRH), and conversation on unexpected response reflects that the cockpit crew may have noticed the off-design parameters. (iv) Reduction of PLA by FO (A) was incorrect action and it subsequently resulted in a decrease of IAS from 186 knots to 146 knots. (v) Engineer joined the cockpit on Captain's request. (vi) First Officers exchanged seats. (vii) The Captain's comment "do we have to bring the power back?" does not correlate with the actions; therefore, this comment may have been an in-assertive way of questioning the reduction of PLA by FO (A). (viii) Power Levers increased progressively, IAS increased to 196 knots. (ix) Np-1 expected to be at 102.5% (with PEC OFF), whereas actual value was at 62%. (x) The conversation became confused and unstructured; the Captain became more disorganized / unclear about the situation.

Phase	Summary of Crew Actions and Discussion
Phase 3 TQ Drop / No 1 Engine IFSD 11:10:34 to 11:11:44	(a) There were several observations regarding SOP adherence, communication, trajectory management & automation, CRM aspects (ie leadership, decision making & problem solving, situational awareness, and workload management) etc. Most observations were categorized as **“important”** in relation to their significance. Only few observations were categorized as of **“medium”** or **“for consideration”** importance. **Discussion:** (b) During this phase, the cockpit indications, as well as few aspects of the aircraft behavior were off-design (not as per the aircraft design / certification parameters) and therefore were not specifically mentioned in QRH / FCOM in the manner and sequence of experience by the crew, and the manner of appearance in the cockpit. Important conclusions from this phase of flight are as follows: - (i) Abrupt engine run-down noise was recorded. (ii) No 1 Engine parameters dropped (NH, NL, TQ), however ITT increased. (iii) Np-1 increased from about 62% to 102.5%, this was an off-design indication / performance of respective component. (iv) Immediately both PLAs were reduced slightly, followed by a slight and gradual increase in PLA-2. (v) IAS progressively decreased. Reducing PLA of good engine was an incorrect action. Np-1 at 102% instead of being at feathering position had an additional drag. Slight increase of PLA-2 was not sufficient to maintain IAS (especially with such high drag). This action indicated that the cockpit crew had the understanding about which engine had the problem, however, had a low understanding about Energy State Management. (vi) No 1 Engine shutdown actions accomplished. (vii) Since PLA-2 was out of notch, selection of MCT was not effective and this action reflected low knowledge about the aircraft systems. (viii) The crew attempted to feather No 1 Propeller. (ix) Np-1 decreased consistent with the commanded feathering, however this reduction was at a slower than usual rate. (x) PLA-2 increased to 66.8º (close to notch).

Phase	Summary of Crew Actions and Discussion
Phase 3 TQ Drop / No 1 Engine IFSD 11:10:34 to 11:11:44	(xi) IAS continued to reduce, however its rate of reduction was considerably less during the time when No 1 Propeller was in feather state and PLA-2 was at 66.8º. (xii) Request for lower altitude reflects low priority accorded to Energy State Management. The conversation remained confused and unstructured; the Captain remained disorganized / unclear about the situation.
Phase 4 Np Increase 11:11:45 to 11:12:35	(a) There were several observations regarding SOP adherence, communication, trajectory management / automation / manual flight, CRM aspects (ie leadership, decision making & problem solving, situational awareness, and workload management) etc. Most observations were categorized as **“important”** in relation to their significance. Only few observations were categorized as of **“medium”** or **“for consideration”** importance. **Discussion:** (b) During this phase, the cockpit indications, as well as the aircraft behavior were grossly off-design (not as per the aircraft design / certification parameters) and beyond any possible imagination of the crew. These conditions were not mentioned in QRH / FCOM. The pilots had no clue as to what was happening to the aircraft; they had never experienced or simulated such situation. Important conclusions from this phase of flight are as follows: - (i) No 1 Propeller speed increased progressively to 50% and then increased abruptly to the range of 123% to 125%. (ii) It was presumably due to technical malfunctions inside No 1 Engine and same side OSG and most likely due to pre-existing contamination in PVM (overspeed line that were external to the engine), sequentially leading towards a combined technical malfunction of unexpected / unusual nature. (iii) There was unusual sound and an excessive rise in drag from the left side of the aircraft. (iv) The Captain got perturbed and inquired about the sound, PLA-2 was reduced but after few seconds PLA-2 increased rapidly. (v) Because of large variation in asymmetric condition the Auto-Pilot got disengaged. (vi) The aircraft started to turn left.

Phase	Summary of Crew Actions and Discussion
Phase 4 Np Increase 11:11:45 to 11:12:35	(vii) The requirement of control inputs by the cockpit crew progressively increased with decrease in speed. However, it remained lesser than the requirement to maintain heading. (viii) Np-1 gradually reduced to about 116.5%. (ix) At about 127 knots IAS, Np-1 increased again due probable technical malfunction and reached a value of about 124%. (x) IAS continuously dropped, and the aircraft was very close to stall state. (xi) The cockpit crew attempted to feather the left propeller once again (however possibility of restart cannot be ruled out). Cockpit crew actions and related indications / DFDR recordings reflect that the cockpit crew had registered that there was an off-design performance; however there were no discussions / conversation recorded in CVR specific to this aspect. (xii) There were large control inputs by the cockpit crew to cater for the asymmetric conditions. (xiii) The power modulation of No 2 Engine by the Captain (ie first retarding the power from 66.8º to 41.1º and advancing to 71.2º, and then after a while retarding again to 32.7º and then abruptly advancing again to 54.0º) to cater for the asymmetric conditions, was an incorrect action and contributed in rapid depletion of speed. (xiv) Power modulation to cater for the asymmetric condition and flying at speed range around the white bug on the IAS indicator (later experienced by the cockpit crew to be just above the stall), resultantly caused an improper Energy State Management. (xv) The cockpit crew did not try to trade-off altitude with speed. (xvi) The cockpit crew did not attempt to re-engage Auto-Pilot. (xvii) The cockpit crew did not consider pulling of fire handle. (xviii) It has been established during the technical analysis, that pulling of the fire handle would not have had any impact on the sequence, extent or nature of technical malfunctions that had occurred inside No 1 Engine.

Phase	Summary of Crew Actions and Discussion
Phase 4 Np Increase 11:11:45 to 11:12:35	(xix) Such high values of Np-1 along with erratic variations caused due to unusual blade pitch variation, resulted in a corresponding strange / unusual change in drag. This was an off-design aircraft behavior, neither expected nor experienced earlier. High Np-1 values corresponded to very high drag values and resulted in severe controllability issues. The aircraft behavior was very unpredictable. The cockpit crew was unable to understand the situation. (xx) The conversation remained confused and unstructured; the Captain remained disorganized / unclear about the situation; conversation and actions reflected inability to cope up with the situation.
Phase 5 End of the Flight 11:12:36 to 11:20:39	(a) There were several observations regarding SOP adherence, communication, trajectory management (automation / manual flight), CRM aspects (ie leadership, decision making & problem solving, situational awareness, and workload management) etc. Most observations were categorized as **“important”** in relation to their significance. Only few observations were categorized as of **“medium”** or **“for consideration”** importance. **Discussion:** (b) During this phase, the cockpit indications, as well as the aircraft behavior were grossly off-design (not as per the aircraft design / certification parameters) and beyond any possible imagination of the crew. These conditions were not mentioned in QRH / FCOM. The aircraft performance was much inferior than the expected (designed) performance in a Single Engine flight envelope. Important conclusions from this phase of flight are as follows: - (i) There was sudden drop in Np-1. (ii) It was because of the reason that the blade pitch angle (most likely) decreased further up to a point where the power generated by propeller was lower than power absorbed by the engine and it may have later moved to a stable physical position. Np-1 decreased below 25% and then stabilized lower than 5%, with blade pitch angle close to low pitch in flight. (iii) This sudden decrease in the Np-1 resulted in sudden depletion of large amount of drag. (iv) The Auto-Pilot was already disengaged; therefore large control inputs to cater for asymmetric condition (especially right rudder) were maintained manually by the cockpit crew (PF) effort.

Phase	Summary of Crew Actions and Discussion
Phase 5 End of the Flight 11:12:36 to 11:20:39	(v) Sudden depletion of a large amount of drag from the left side rendered the control deflections surplus to the requirement and resulted in a sudden yaw to the right side. (vi) Simultaneously, as the aircraft was close to stall stage, it entered into an un-controlled / stalled condition. (vii) The aircraft lost about 5,100ft of altitude and rolled right beyond 360º. (viii) This condition was very abnormal and had immense psychological impact on the cockpit crew. (ix) The cockpit crew breathing was abnormal (hyperventilating) and their voices were trembling. (x) The cockpit crew attempted to recover out of this situation; however their actions were not precise during the recovery. (xi) Possible cross-controlling of the elevator control resulted in pitch disconnect, which may have further added up towards existing aerodynamic degradation. (xii) The cockpit crew voices and breathing indicated that they were extremely nervous and traumatized during this part of flight. (xiii) The aircraft recovered from the stalled / uncontrolled flight condition and regained IAS. (xiv) The blade pitch angle had most probably decreased further beyond the earlier fine pitch value (at which the Np-1 was in the range of 120% to 125%). This new pitch angle was possibly beyond the low pitch in flight (from fine towards reverse angle). At this position the generated drag value was around 2,000 lbf. This drag was about seven times more than the drag a propeller can usually produce (once in feather state) during a single engine flight envelope. (xv) In this aerodynamically degraded state the aircraft was unable to fly a level flight. It could only fly in a gradual descend profile (eg an IAS of 150 to 160 knots and a continuous descend of around 800 to 1,000 fpm). (xvi) The cockpit crew did not re-engage Auto-Pilot again. (xvii) The cockpit crew did not consider diversion to nearby airfields.

Phase	Summary of Crew Actions and Discussion
Phase 5 End of the Flight 11:12:36 to 11:20:39	(xviii) In spite of a reasonably advanced position of PLA-2 (in the range to 85% to 95% in the beginning, further increasing to 110%), the IAS continued to drop gradually (because of the unusual / off-design additional drag from the left side of the aircraft). (xix) The cockpit crew attempted to trade off altitude with speed but could not quantify the magnitude of disadvantage created because of the additional drag and could not judge whether they would be able to cross the mountains ahead or reach BBIAP (Islamabad), or not. (xx) Even after several minutes from the uncontrolled flight condition the conversation still reflected that the cockpit crew was under immense physiological stress and trauma, and their voices were trembling and their breathing reflected fear. (xxi) The cockpit crew tried to overcome this state of physiological stress and trauma, and their breathing normalized, however they remained grossly confused and scared. Their discussions remained unstructured. (xxii) Due to the exposure / experience of such un–controlled flight conditions, the capacity of the cockpit crew was impaired, rendering it to be further less possible to understand an unusual situation (nature and extent not known) and imagine a corrective action strategy beyond their training experience and knowledge. (xxiii) The Captain remained disorganized / unclear about the degradation in the aircraft performance (which was much beyond the expected / designed performance). Conversation and actions reflected inability to cope up with the situation.

2.4.2.3 **Conclusions from Analysis of Crew Actions vs Expected Behavior.**

(a) In this particular single engine IFSD, coupled with a propeller possibly rotating at 5% (estimated) rpm and a blade pitch assumed to be near (or below) the low pitch stop, the pilots came across a situation which was neither experienced earlier, nor expected. Due to system redundancy and accumulated probability of independent failures, and since the probability meets and exceeds applicable safety regulations, it was not considered as a condition to be addressed, therefore, it was not explained in any operational publication by the aircraft OEM (ATR).

(b) Due to this combined technical anomaly, during following parts of the flight[155], the conditions were exceptionally difficult (ie may be considered as conditions of hazardous consequence) and it was expected that the cockpit

[155] DFDR data analysis at AAIB.

crew may not be able to cope with the situation, and therefore they may not be relied upon to undertake the required / expected actions correctly[156]. These are as follows: -

(i) **11:10:33 to ~11:10:56**. During this part at the time of No 1 Engine IFSD, Np-1 had increased (before engine shutdown) to about 102%.

(ii) **11:10:56 to ~11:11:45:** Np-1 decreased and became NCD. Its behavior looked like a feather request. Then, Np-1 unexpectedly increased again at an abnormal slow rate[157], corresponding to propeller un-feathering.

(iii) **11:11:45 to ~11:12:35**. During this part Np-1 increased to a very high value range of 120 to 125 %, gradually reduced to 116.5%, and then increased to 123% again. During this part of flight the left side of the aircraft produced high drag values, until the propeller speed began to rapidly decrease in an un-expected manner.

(iv) **11:12:45 to ~11:13:09**. During this part the aircraft entered an uncontrolled / stalled condition of flight where the aircraft lost about 5,100ft and rolled right by 360º and below[158]. This had immense psychological impact on the cockpit crew, and it impaired their capacity to perform normally[159].

(v) **11:12:36 to ~11:20:39**. During this last part of flight when there was no further technical degradation and the blade pitch angle and Np-1 had stabilized at a particular value. This new pitch angle was possibly below the low pitch in flight (ie in fine pitch range normally corresponding to ground operations). The aerodynamic drag of the left side of the aircraft was estimated to be seven times[160] more than the drag usually expected during single engine flight envelope (with the effected side propeller in feather position).

(c) All flight parts subsequent to un-feathering (except first condition) are not covered in QRH / FCOM of ATR aircraft. ATR describes the failure condition (corresponding to un-feathering and not to subsequent parts) in risk factor / safety assessment paradigm as failure condition No 1.003 “engine failure in cruise without propeller feathering” (System Safety Analysis 42.0078/95 issue 5), as of “Hazardous Consequence”, with further explanation about the possible results[161].

(d) All flight parts subsequent to un-feathering were understandably much more complicated and difficult to handle, than “engine failure in cruise without propeller feathering” (ie the first condition), and therefore are considered more severe for their possible consequence(s)[162].

2.4.2.4 The torque value of No 2 Engine during the flight conditions ie 2.4.2.3 (b) (v) above was sufficient enough to fly, cross over the mountains and land the aircraft with No 1 Engine IFSD (if the propeller was in feather condition, and there was no

[156] Discussion on aircraft controllability / certification aspects with ATR at BEA during November 2019.
[157] Confirmed by ATR flight test.
[158] DFDR data analysis at AAIB. The aircraft stalled at a speed of 120 knots indicating a significant aerodynamic degradation in the aircraft performance.
[159] AAIB analysis deduced from DFDR / CVR recordings and flight animation.
[160] Discussion on aircraft controllability / certification aspects with ATR at BEA during November 2019.
[161] Certification process presentation by ATR provided an overview of risk assessment paradigm, and an understanding about possible consequences that could be related to hazardous flight conditions. These possible consequences included a large reduction in safety margins of aircraft functional capabilities and capabilities of flight crew; and may even lead to fatal injuries to few of the occupants.
[162] AAIB analysis.

additional drag due to complicated technical malfunctions of No 1 Engine propeller system).

2.4.2.5 This event highlights importance of adhering to the cardinal principle of ***Fly, Navigate, and Communicate***, especially in an unusual emergency situation. Top priority must always be accorded to the control of the aircraft first and then consume the remaining effort in effective management of cockpit resources for mitigation of hazards, and subsequent safe recovery of the aircraft. The crew actions indicated several events of incorrect prioritization. However, the event was unexpected and the cockpit crew was not trained for this specific sequence of event.

2.4.3 **Aircraft Controllability Aspects:** BEA provided an Aircraft Controllability / Drag Simulation / Engineering Simulation Report[163]. Salient aspects of the said report are as follows: -

2.4.3.1 **Simulation Results.**

(a) The objectives of the simulations were to determine the position and state of drag of the left side of the aircraft during the flight of the event, as well as to get more factual information on the management of the aircraft energy during the flight, the controllability margins (how much surface deflection would have been needed to bring the aircraft back into straight level flight) and on the overall aerodynamic state on the aircraft.

(b) In particular, the following questions were asked to the propeller and aircraft manufacturers: -

(i) Determine the drag of the left engine during the flight, especially from 11:11:18 to the end of the flight.

(ii) Estimate the blade pitch angle Beta ¾ of the left propeller for the entire flight.

(iii) Estimate the drag of the left engine and propeller from the estimated blade pitch position Beta ¾ (based on DFDR and ATR simulation results).

(iv) Estimate the necessary ailerons and rudder input to maintain straight flight, from 11:11:18 to the end of the flight.

(v) Assess the effort on control column to maintain the elevator position in the conditions of the event (altitude, SAT, IAS, and Pitch trim in particular), from 11:11:18 to the end of the flight.

(vi) Obtain information on the left elevator deflections, in relation with the control column effort threshold recorded.

(vii) Determine the minimum control speed for the configuration the aircraft was flying at, ie the minimum speed at which an engine failure (engine power loss) can be controlled in yaw through rudder inputs.

(c) Questions 1 to 3 were partially answered in relevant sections of Aircraft Controllability / Drag Simulation Report[164]. Unfortunately, due to limitation of recorded parameters, as well as due to the aircraft and propeller conditions being outside the conventional computing envelop, the computations were not made on the entire flight.

[163] BEA2016-0760_tec29 Report on ATR & UTAS simulations Part II – Simulation results dated 19 September 2018.
[164] Sections 3 -, 0 and 5 - of BEA2016-0760_tec29 Report on ATR & UTAS simulations Part II – Simulation results dated 19 September 2018.

(d) Question 4 was answered thanks to the load increment computation of ATR[165].

(e) Question 5 and 6 on the control column effort were answered by the longitudinal controllability simulation[166].

(f) Finally, question 7 on the minimum control speed for the configuration the aircraft was flying at was answered by ATR computation[167].

2.4.3.2 **Drag Estimation:** The simulation period was split into several time zones to ease the analysis: -

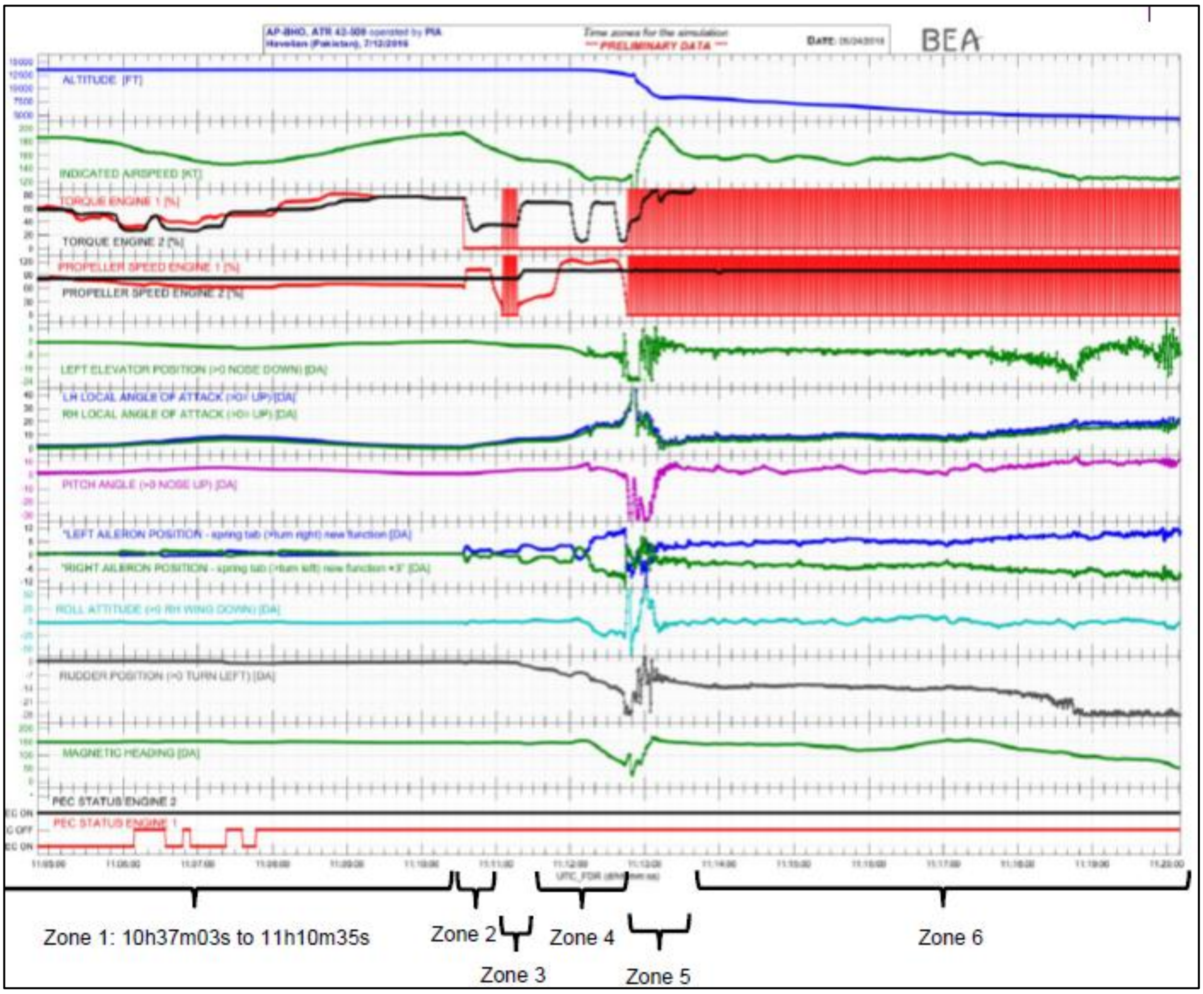


Figure 2-48: Drag Estimation

(a) **Zone 1: Beginning of the Flight (from 10:37:03 to 11:10:35)**

(i) The computation by ATR showed that for different flight conditions and engine powers, the load increments were constant. This difference is consistent and as expected. It represents the natural difference of the aircraft with the aerodynamic and engine models[168].

(ii) During the beginning of the cruise, the blade pitch angle was around 40°. When the propeller speed decreased below 82%, at the

[165] Section 6.3.1 of BEA2016-0760_tec29 Report on ATR & UTAS simulations Part II – Simulation results dated 19 September 2018.
[166] Section 6.4 of above report
[167] Section 6.3.4 of above report.
[168] Section 3.5.2 of above report.

same time as the PEC status changed, the blade pitch angle increased[169].

(iii) No comparison could be made between the traction estimations as the ATR estimation only started at 11:10:35.

(b) **Zone 2: 102% Np (from 11:10:35 to 11:11:05)**

(i) When the propeller speed increased to 102%, the load increments showed an increase of drag. This is consistent with the failure of No 1 Engine (engine power loss), and the wind milling of No 1 Propeller. Also the aircraft had a tendency to roll and yaw to the left. This tendency was counteracted by the auto-pilot, maintaining the desired track and flight path[170].

(ii) At 11:10:34, the propeller speed increased from 61.5% to 102%. The estimated blade pitch angle decreased from 43° to 30°. The blade pitch angle continued to decrease to a minimum of 26° as the propeller speed was around 102%[171].

(iii) From both results, it is possible to say that the traction force created by the No 1 Propeller speed turning at 102% was within the range [-1950, 680] lbf. UTAS simulation showed a drag force. Because the No 1 Engine torque dropped at 0% at 11:10:35, it is highly probable that the engine was dragging after 11:10:35 at it was not propelling the aircraft, even if the simulation computation showed that the traction force when the No 1 Propeller speed was 102% was within the range [-1950, 680] lbf.

(iv) This also correlated with results from Section 3.5 of Aircraft Controllability / Drag Simulation Report showing that it is likely that the aircraft was dragging more and more, and was more inclined to turn and yaw left than what can be predicted with the aero and feathered-engine models.

(v) Then when the propeller speed reduced before becoming NCD, the drag increment reduced and the tendency to roll left decreased. The estimation showed that blade pitch angle increased to a maximum estimated value of 59.3°. The rate of increase of the blade pitch angle was smaller than what can be observed on other ATR feathering sequence. It is not possible to determine from the blade pitch angle estimation if the propeller reached the feather position.

(vi) When the propeller speed reduced from 102% and became NCD, the traction force was less to drag. The traction force was within the range [- 1200, 720] lbf[2]. The blade pitch angle increased towards feather. When the propeller speed reduced, the drag should be lower than when the propeller speed was 102%, which is not highlighted by the simulation results.

(vii) It is not possible to conclude from the simulations whether or not the No 1 Propeller went up to feather. The increase of blade pitch angle associated with a traction force less to drag indicate that the blade pitch went towards feather.

[169] Section 4.4.2 of BEA2016-0760_tec29 Report on ATR & UTAS simulations Part II – Simulation results dated 19 September 2018.
[170] Section 3.5.3 of above report.
[171] Section 4.4.3 of above report.

(c) **Zone 3: Potential Feathering with Np NCD (from 11:11:05 to 11:11:18)**

(i) There was no UTAS computation during this period.

(ii) The ATR simulation showed that when the No 1 Propeller speed was NCD, the traction was within the range [-1300, 450] lbf and did not vary significantly. The zone 2 conclusion also applies during zone 3.

(iii) The simulation showed that the blade went towards feather but it is not possible to conclude if the blade went up to full feather position.

(d) **Zone 4: 120% Np (from 11:11:18 to 11:12:34)**

(i) During the first increase of propeller speed to 50.50%, the load increments showed a constant increase of drag and a constant tendency to roll left and yaw left. When the propeller speed was around 120%, the drag increment increased, as well as the tendency to roll left and yaw left. There was also an increase of the loss of lift[172].

(ii) The first blade pitch angle value estimated after the NCD period was 61.3°. The blade pitch angle decreased while the propeller speed increased[173].

(iii) When the propeller speed increased slowly towards 120%, from 11:11:18 to 11:11:46, the traction force was mainly negative, indicating drag. The traction force was almost constant and was contained in the range [-1500, 410] lbf[174].

(iv) Then when the propeller speed increased more rapidly to 120%, the drag increment increased, as well as the tendency to roll left and yaw left.

(v) The blade pitch angle continued to decrease, with a faster rate. The last valid blade pitch angle estimation with the strip analysis is 19°. According to the CFD, the blade pitch angle that would match a -100SHP power would be 15.3° at 11:12:08.

(vi) When the propeller speed increased more rapidly to 120%, the drag force increased. It is not possible to quantify with precision the drag force after 11:11:47 as the difference between the ATR and UTAS results became superior to 800 lbf.

(vii) When the propeller speed was constant around 120%, the comparison between the two simulations was made for only one point. At 11:12:08, when the propeller speed was constant around 120%, ATR and UTAS results showed that the estimated drag force was within the range [-2360, -960] lbf. This estimation of the drag force is higher than during zone 2 when the propeller speed was 102%. Also, for the three power assumptions, the UTAS showed that the blade pitch angle would have been around [15°, 16.5°] at 11:12:08.

---

[172] Section 3.5 of BEA2016-0760_tec29 Report on ATR & UTAS simulations Part II – Simulation results dated 19 September 2018.
[173] Section 4.4.5 of above report.
[174] Section 5.3 of above report.

(e) **Zone 5: Loss of Control (from 11:12:35 to 11:13:26)**

(i) No load increment computation was possible during the loss of control. But a comparison of the values before and after showed a reduction of the drag increment, a reduction of the loss of lift, less moment increment to nose up, less moment increment to turn left and less moment increment to yaw left.

(ii) There was no UTAS computation during this period.

(iii) It is not possible to conclude on the traction estimation during this period.

(f) **Zone 6: End of the Flight (from 11:13:26 to 11:20:17)**

(i) The load increment computation showed that between 11:13:26 and 11:15:50, the drag increment and the loss of lift increased while the other increments stayed constant[175] (still indicating a tendency to roll left and yaw left).

(ii) Then up to 11:17:07, the load increments stayed constant. Then from 11:17:07 to 11:18:43, the drag increment and loss of lift increased while the other increments stayed constant. Finally, the drag increment and loss of lift continued to increase while the moment increment increased to nose up.

(iii) The tendency to roll left was constant and the tendency to yaw left increased.

(iv) The only comparison between ATR and UTAS results could be made at 11:13:50.

(v) The results showed that the UTAS computation was outside the ATR uncertainty range. Thus, it is likely that the propeller was not in the low pitch stop position of 12.8° at a propeller speed of 10% as the difference between the two drag force estimations was about 1000 lbf[176].

(vi) Then from 11:15:50 and until 11:17:07, the ATR estimated drag increment did not vary significantly. The traction force was within the range [-3255, -680] lbf.

(vii) From 11:17:07 to 11:18:43, the ATR traction estimation showed a constant drag force within the range [-3630, -480] lbf.

(viii) From 11:18:43, the ATR traction estimation showed an increase of the drag force. The traction estimation was within the range [-3550, -710] lbf.

(ix) After 11:19:53, the results were not analyzed as the load increment values were varying very dynamically.

---

[175] Section 0 of BEA2016-0760_tec29 Report on ATR & UTAS simulations Part II – Simulation results dated 19 September 2018.

[176] Section 5.5 of above report.

2.4.3.3 Conclusions of the Drag Simulation Report About Controllability.

(a) ATR simulation showed that at 11:14:46, considering that the aircraft was represented by the load increments added to the aerodynamic model, the aircraft would have turned to the right, reached and maintained 220° (with a roll rate of 1°/s) with an additional aileron input of 0.6° to roll right and less than 1° of left elevator. The IAS would have been maintained and the altitude would have decreased.

(b) The altitude loss due to the turn was marginal in comparison to the loss of altitude due to aircraft residual energy. The turn radius of this maneuver was 3750m[177].

(c) ATR simulation showed that at 11:17:13, considering that the aircraft was represented by the load increments added to the aerodynamic model, the aircraft would have turned from 152° and maintained heading 270°, with a roll rate of 1°/ s with an additional aileron input of 0.6°. The turn radius to reach heading 270° was 3600m. In addition, an additional input of 1° of left elevator to nose up would have been necessary to maintain the IAS. The loss of altitude during the maneuver would have been around 1600ft AMSL[178].

(d) A comparison between the parameters recorded on the DFDR and the simulation parameters showed that the aileron deflections were of similar magnitude in the DFDR and in the simulation. The difference between the simulation results and the recorded behavior of the aircraft could be explained by the increase of the angle of attack, which increased the induced roll to bank left due to the engine asymmetry. The increase of recorded angle of attack was even more significant during simulation 2 period.

(e) In addition, the load increments computed showed that during the simulation period, globally the drag increased, the loss of lift increased, the tendency to yaw left increased. A difference between the DFDR and the simulation could come from the fact that the simulation considered the average dCi (aerodynamic load increment) during the initialization time period whereas the actual load increments the aircraft was subjected to during the flight of the event varied during this time period.

(f) Also, the simulations were performed with the objective to maintain the IAS. In the DFDR during simulation 2 period, the decrease of the altitude was smaller than in the simulation, but the IAS decreased from 158 knots to 125 knots. The use of elevator during the simulation to maintain the IAS in the simulation enabled to maintain the IAS. This could partially explain the difference between the observations of DFDR parameters and simulation parameters.

(g) Finally, the two simulations were run at approximately 2 minutes and 30 seconds time difference. The variations of the load increments in the time between the two simulations were relatively small. As a consequence, it is likely that the state of the aircraft in between the two simulations did not change significantly. The two simulations start on an equilibrium point. This means that for two equilibrium points separated by 2 minutes and 30 seconds, it is likely that the aircraft would have been able to turn to the right with an aileron increment inferior to 1° to roll right, while maintaining its IAS through elevator deflection.

---

[177] Section 6.3.1 of BEA2016-0760_tec29 Report on ATR & UTAS simulations Part II – Simulation results dated 19 September 2018.

[178] Section 6.3.2 of above report.

(h) The longitudinal controllability simulation showed that after the loss of control, with the assumption that the pitch uncoupling had activated, the estimated left control column efforts were coherent with the recorded control column effort parameters.

2.4.4 Advanced Discussion on Aircraft Controllability and Performance Margins[179].

2.4.4.1 The purpose of the advanced discussion on the aircraft controllability aspects was to quantify the additional drag and understand additional difficulty for pilots (of reasonable / usual capacity to understand and perform) to control the aircraft and undertake a possible landing. The additional drag reduced the performance margins and thus the aircraft single engine performance (as experienced during last phase of flight) was considerably lesser than the standard / designed performance.

2.4.4.2 During advanced discussions ATR provided a quantifiable comparison of drag values during a standard single engine flight envelope (feather / wind milling RPM), with the drag values during last phase of flight, where the unusual technical malfunctions had resulted in a stabilized blade pitch angle and corresponding stabilized degraded aircraft performance. The Drag Count (DC) used hereunder is considered by removing speed variable from typical drag calculation method[180].

2.4.4.3 These are as follows: -

(a) Engine in feather : 100 DC

(b) Normal wind-milling : 300 DC

(c) AP-BHO : 700 DC

2.4.4.4 It was established that it was not possible for the aircraft to sustain a level flight. The cockpit crew attempted to trade off altitude with speed but could not quantify the magnitude of disadvantage created because of the additional drag and could not judge whether they would be able to cross the mountains ahead or reach BBIAP (Islamabad), or not. Whenever there was an effort by the pilots to maintain a steady rate of descend they could maintain IAS, and conversely whenever the cockpit crew tried to reduce the rate of descend the IAS reduced as well. Figure hereunder describes aircraft performance margins during last phase of flight.

[179] During this process advance questions were forwarded to BEA for evolving better understanding about aircraft aerodynamic degradation. Additionally, teleconference was undertaken with ATR test pilot and BEA investigators. Furthermore these aspects were discussed among BEA, AAIB, ATR and EASA during November 2019 meeting at BEA.

[180] For the phase of flight after unusual un-feathering (ie Np-1 in the range around 120 and more with SLPS overridden) it was not possible to determine the drag count.

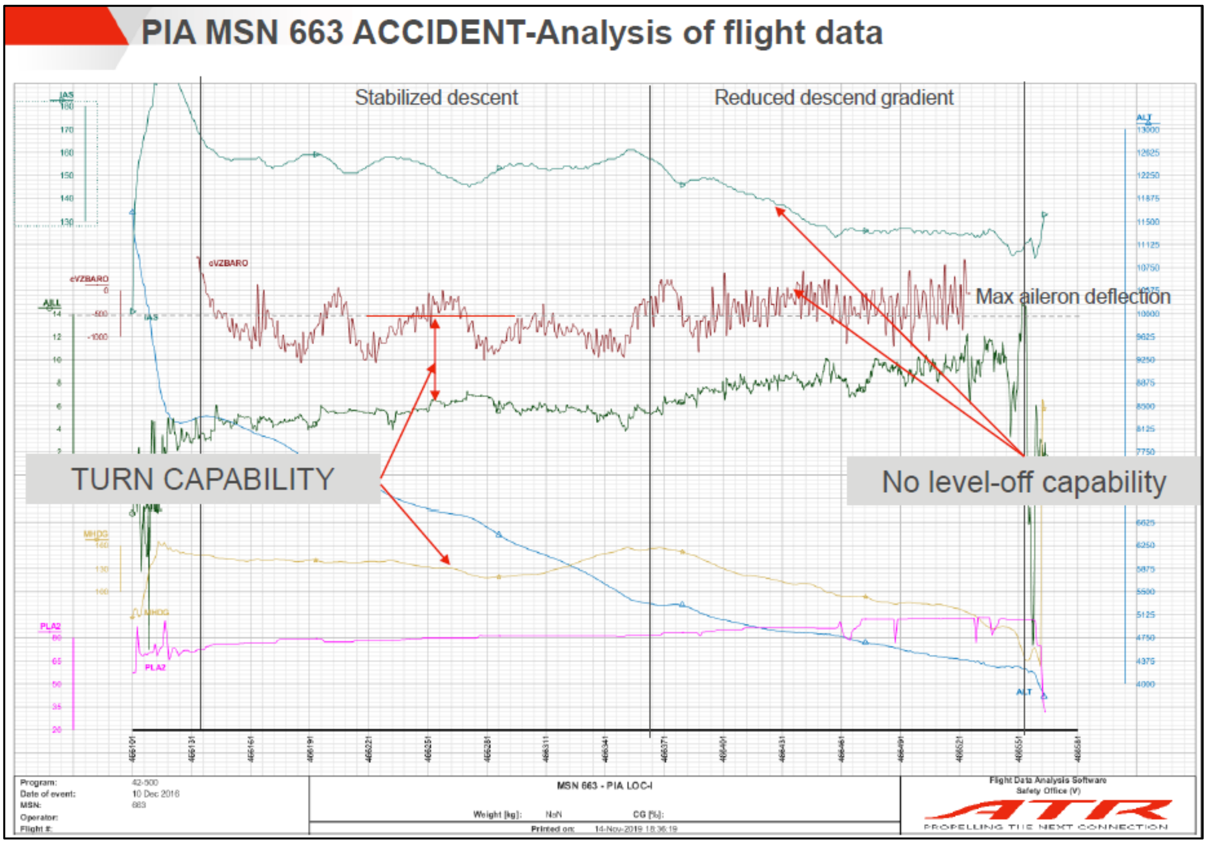


Figure 2-49: Aircraft Performance Margins During Last Phase of Flight

2.4.5 Aircraft Certification Aspects for Single Engine Performance and Landing Possibilities.

2.4.5.1 **Discussion on Certification Process:** ATR provided an overview about the aircraft certification process. Important steps are described in figures blow: -

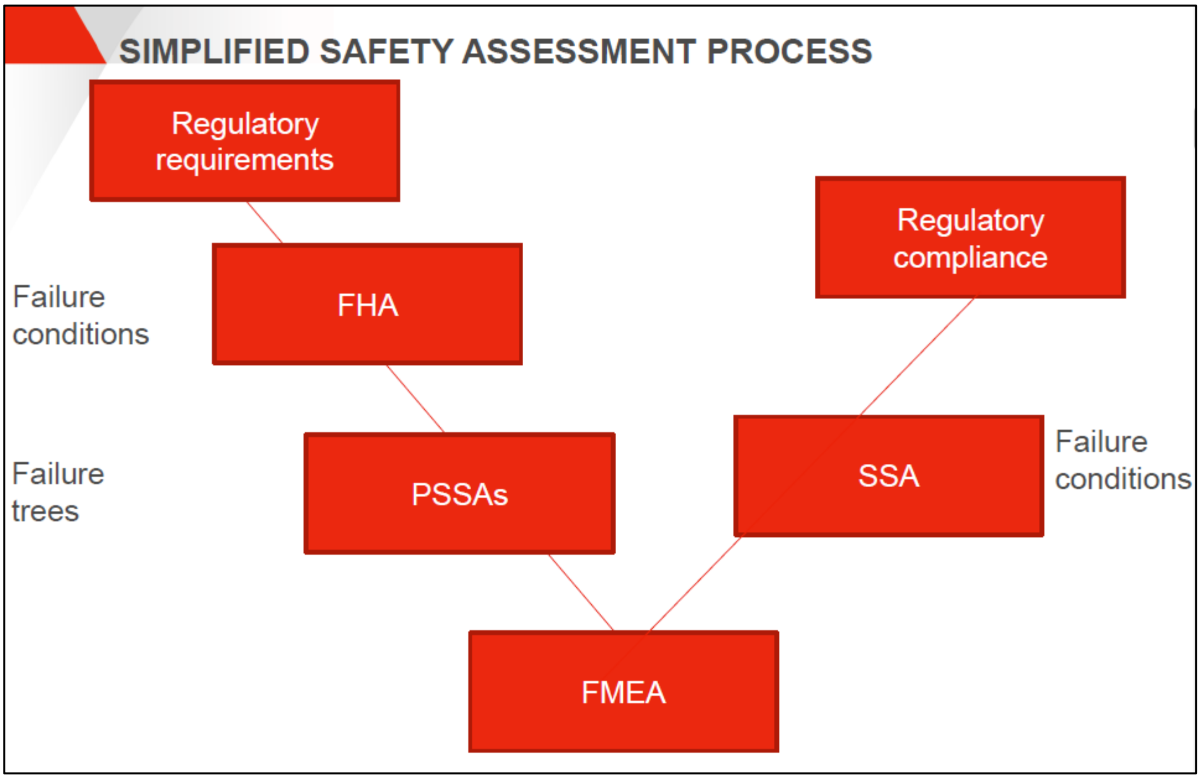


Figure 2-50: ATR Aircraft Certification Process

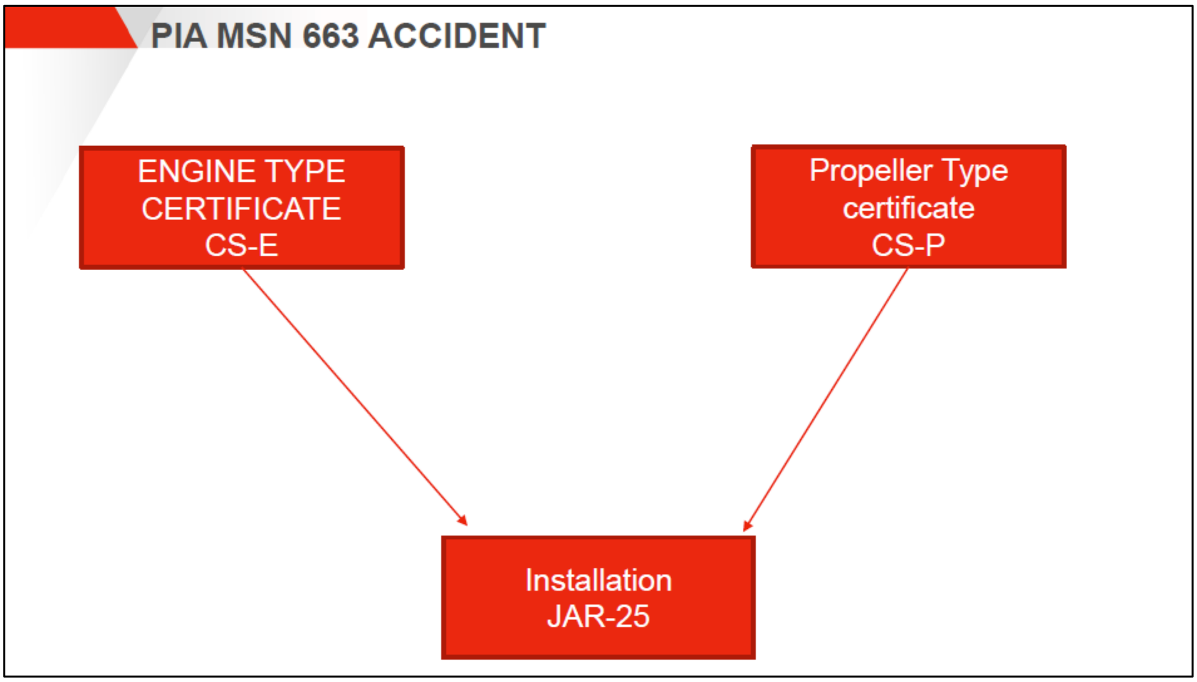


Figure 2-51: ATR Aircraft Certification Process

2.4.5.2 **Discussion on the Event Flight for Certification / Related Aspects:** The case of under investigation PIA flight was discussed. Salient discussion points are as follows: -

(a) Aircraft performance in cruise relative to Engine failure conditions are addressed in JAR 25 regulation through several certification items. All of them are referring to "most critical condition".

(b) JAR 25.149: Minimum control speed

"The minimum control speed during landing approach with one engine inoperative must be established with the aero-plane in the most critical condition […] trimmed as recommended for approach and landing with the critical engine inoperative."

(c) ATR aircraft performances were determined with one engine out with the propeller feathered because safety analysis has shown that the level of redundancy makes feathering function failure extremely improbable.

(d) ATR describes the failure condition (corresponding to un-feathering and not to subsequent phases) in risk factor / safety assessment paradigm as failure condition No 1.003 "engine failure in cruise without propeller feathering" (System Safety Analysis 42.0078/95 issue 5), as of "Hazardous Consequence", with further explanation about the possible results[181].

(e) It was further described that probability of having such failure per flight hour was lesser than 10^{-7} (which corresponds to the objective for hazardous consequence). Subsequently, as the situation under discussion (the final state of the degraded aircraft) was different from expected "engine failure in cruise without propeller feathering", therefore it was discussed that the probability of three independent failure sequence, as was experienced during this flight was even lesser than 10^{-9} (which corresponds to the objective for

[181] Certification process presentation by ATR provided an overview of risk assessment paradigm, and an understanding about possible consequences that could be related to hazardous flight conditions. These possible consequences included a large reduction in safety margins of aircraft functional capabilities and capabilities of flight crew; and may even lead to fatal injuries to few of the occupants.

catastrophic consequence). Figure hereunder describes the sequence of technical failures during this flight which was considered for this assessment.

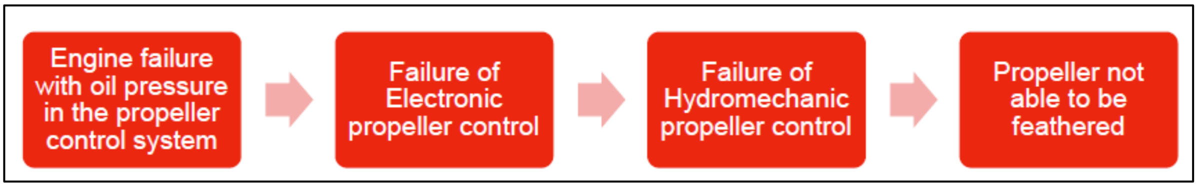


Figure No 2-52: Achieved Probability $<10^{-9}$

Note: As per the understanding of AAIB and discussion with BEA on the topic, the condition of failure of Electronic Propeller Control (referred in the remaining parts of the report as Propeller Electronic Control ie PEC) and the condition when it is turned off as a consequence of failure indication along with an unsuccessful reset attempt are consider similar.

(f) For assessment about minimum controllable speed, flight tests were performed with auto feather system inoperative (MMEL item No 61-22-02-01 and 61-22-02-03) and cover a potential subsequent failure. These flight tests were carried out in following configuration: -

(i) Landing gear extended.

(ii) Flaps 15º and flaps 30º.

(iii) Left hand (critical engine) propeller in wind milling: Propeller pitch controlled by the PEC at a propeller speed in accordance with power management position (82% or 100%).

(g) Test results showed that in such configuration, the effect on the speed would be as follow: -

(i) V_{mcg} (Minimum Control Speed on Ground) increased by 5 knots.

(ii) V_{mca} (Minimum Control Speed in the Air) increased by 3 knots.

(iii) V_{mcl} (Minimum Control Speed at Landing) increased by 3 knots.

(iv) Since the time of initial ATR42-500 type certification there was no amendment of the operational manuals or training related to this item.

Note: These values of minimum control speed do not reflect possible landing speed for AP-BHO.

2.4.5.3 **Discussion on Landing Possibilities AP-BHO:** This event highlights importance of adhering to the cardinal principle of ***Fly, Navigate, and Communicate***, especially in an unusual emergency situation. Top priority must always be accorded to the control of the aircraft first and then consume the remaining effort in effective management of cockpit resources for mitigation of hazards, and subsequent safe recovery of the aircraft. The crew actions indicated several events of incorrect prioritization. However, the event was unexpected and the cockpit crew was not trained for this specific sequence of event. Salient discussion points are as follows: -

(a) Landing possibilities for the event flight were discussed. The scenario was orchestrated on expectation from the cockpit crew to understand the nature and extent of degradation in the aircraft performance, and evolve an effective strategy to bring the aircraft for an approach to any airfield and land it successfully. However, this expectation was contrary to the details provided in ATR's risk factor / safety assessment paradigm (System Safety Analysis

42.0078/95 issue 5) as failure condition, of “Hazardous Consequence” which recognizes that in the presence of physical distress or excessive workload, the cockpit crew cannot be relied upon to perform their tasks accurately or completely[182]. It is also pertinent to mention that the distress condition covered in above referred document was much simpler than the conditions experienced by the cockpit crew of event flight.

(b) It was discussed that (subject to the conditions said above) provided the cockpit crew decides to maintain a speed of around 160 knots by trading off altitude (and avoided power modulation) and provided that the cockpit crew is able to judge the speed of the aircraft required to be maintained on final approach (latter estimated to be above 160 knots), the aircraft was able to descend to an airport located at 36NM radius (based on aircraft position and altitude before the loss of control). The proposed course of action[183] was: -

(i) Fly at 160 knots until landing.

(ii) No change in the configuration (flaps 0, landing gear extension only once sure of landing).

(iii) Landing distance would be 1030 meter (done with Max landing weight).

(c) This landing profile has numerous inherent risks (as the pilots were not aware of the nature and extent of degradation) with no margin for error available to the cockpit crew. The additional drag of landing gears (whenever lowered for landing) may result in speed depletion, causing difficulty in the directional control, further leading to stall / uncontrollable flight condition. Moreover, the profile had to be flown with the condition of Pitch Disconnect which was an additional factor and might have added to the aerodynamic degradation and limited the control authority.

(d) Keeping in view the discussed limitations it has been concluded that while average pilots (as far as possible) would try to fly (and consider a landing profile) as per the guidelines provided in QRH / FCOM / Company SOPs, and the training exposure usually provided in the simulations / training sessions, the conditions experienced by the aircrew during the event flight were well outside the published procedures and routine training(s).

(e) Furthermore, the possibility of selection of an alternate airfield was discussed. PIA SOPs do not provide detailed guidance for conditions requiring option for selection of military / disused / other airfields for emergency landing (except specified). This aspect is however considered an overboard expectation from the pilots especially when they were unable to understand and correct the situation, and had no method available to them to reach to the correct understanding about possible descend / landing profiles (on any nearby airfield or attempt ditching elsewhere), without any specific guidelines provided in any form. Figure hereunder provides a Google image of an area of 36 NM radius around the point (before encountering the first stall, at an altitude of around 13,500ft) where (as per the proposed profile) if the pilots had decided, they could reach (theoretically) the military airfield.

---

[182] ATR Presentation at BEA Nov 2019.

[183] Any of the aircraft publications, simulator training, and PIA SOPs does not provide any guidelines for the cockpit crew to reach to such conclusions enabling a flight profile proposed during the discussion.

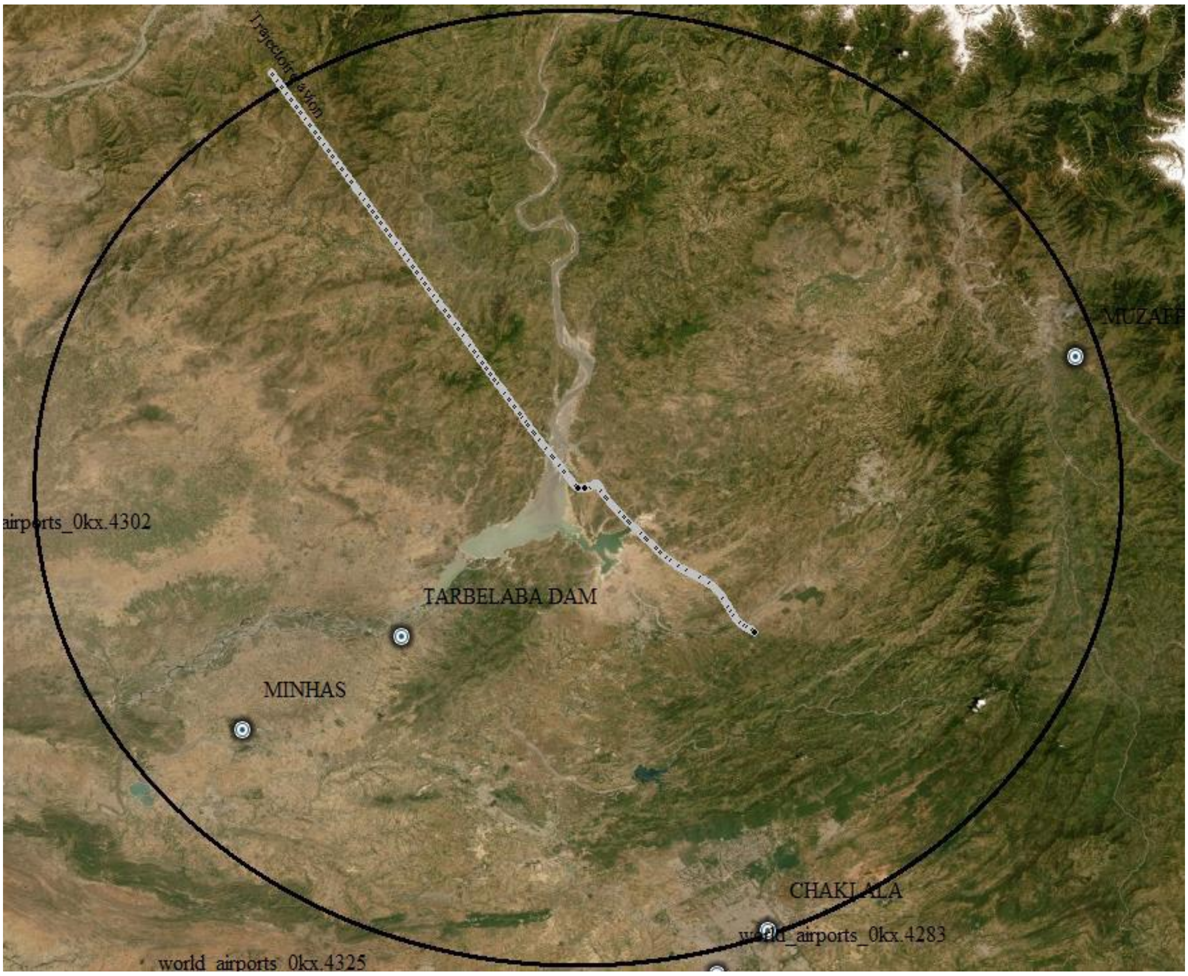


Figure 2-53: Google Image of an Area of 36 NM Radius
Around the Point (Before Encountering the First Stall)

SECTION 3 - CONCLUSIONS

SECTION 3 - CONCLUSIONS

3.1 **Introduction:** The findings have been organized, in a sequence, according to relevance to the cause of the crash (direct or indirect attribution). Several findings of general interest, that are considered important, however, may not have attribution to the cause, have also been included. All these findings have been based on the factual information; reports generated from time to time, and detailed analysis of failure events, actions and possibly related considerations known so far, till the time of completion of this report.

3.1.1 **Latent Pre-existing Technical Anomalies / Condition Before the Flight.**

3.1.1.1 The flight took off at 10:38 hrs (UTC) with two latent pre-existing technical anomalies inside the No 1 Engine and same side propeller system and one probable latent pre-existing condition[184]. One anomaly was a fractured Power Turbine Stage 1 (PT-1) blade, and the second anomaly was a fractured pin inside the Overspeed Governor (OSG) of the same side. The probable latent pre-existing condition was contamination (external from the engine) observed in Propeller Valve Module (PVM).

3.1.1.2 Most probably, the PT-1 blade had fractured during previous flight[185] (Peshawar to Chitral); however this defect is not observable during regular operations.

3.1.1.3 Fracture or distress of PT-1 blade may not essentially lead to an immediate IFSD, however, if it happens, (and if not combined with other independent failures) the aircraft can fly on the other engine and land.

3.1.1.4 It was determined that the pin inside the OSG was fractured due to improper re-assembly[186]. Metallurgical evaluation of the OSG pilot valve pin fracture surface, at Woodward USA determined that the pin had failed in overload resulting from the valve being forced together using an improper re-assembly method during some un-authorized / undocumented maintenance activity[187].

3.1.1.5 Analysis of complete records / history of OSG revealed that there was no reported unauthorized / un-documented maintenance activity[188]. Since manufacturing, this particular OSG was sent to its certified maintenance facility (Woodward / Honeywell) first time in 2011, then in 2012 and lastly in April, 2015[189].

3.1.1.6 It was not possible to ascertain when and where unauthorized / undocumented maintenance of OSG may have occurred[190].

3.1.1.7 OSG can continue to be functional without any problem detected with a sheared pin of the pilot valve, until further deterioration. Continued operation with a broken pin may possibly have weakened component(s) inside OSG (ie the flyweights at the toe location)[191].

3.1.1.8 Probable latent pre-existing contamination / debris found in PVM were most likely introduced when the propeller system LRU's were not installed on the

---

[184] Analysis / discussion during final concluding meeting in November 2018 at BEA, and review / analysis between AAIB and the ACCREPs.
[185] Analysis / discussion during final concluding meeting in November 2018 at BEA.
[186] Same as above.
[187] Maintenance Group Investigation Report, Service Review of Woodward Overspeed Governor P/N 8210-097, S/N 14967680 by NTSB, dated 02 October, 2020 attached as **Appendix-1**.
[188] Review of PIA maintenance records by AAIB.
[189] Same as above.
[190] Maintenance Group Investigation Report, Service Review of Woodward Overspeed Governor P/N 8210-097, S/N 14967680 by NTSB, dated 02 October, 2020 attached as **Appendix-1**.
[191] AAIB analysis / understanding on the issue.

gearbox. However it is not possible to ascertain when and where the contamination in the PVM was induced.

3.1.1.9 It has been established that any of the latent pre-existing technical anomalies and probable latent pre-existing condition (ie fractured PT-1 blade, or fractured pin inside OSG, or external contamination in PVM) alone may not lead to such a catastrophic / hazardous situation except in the presence of unusual combination and / or additional contributing factor(s)[192].

3.1.2 Sequence of Technical Failures and Crash.

3.1.2.1 The summarized sequence of the technical failures was as follows: -

<table>
<tr><th>Time</th><th colspan="2">Event</th></tr>
<tr><td>Before Event Flight</td><td colspan="2">• Engine Power Turbine Stage 1 (PT-1) Blade fractured / dislodged causing imbalanced rotation of PT shaft.
• OSG pin fractured.
• Probable contamination (external from the engine) in PVM.</td></tr>
<tr><td>Prior to 11:05:31</td><td colspan="2">Engine degraded and caused engine oil system contamination.</td></tr>
<tr><td rowspan="2">Subsequent to above</td><td rowspan="2">Propeller Control Fault indications and Power-plant malfunctions.</td><td>Left OSG caused un-commanded decrease in propeller speed. This was due to the fractured OSG pilot valve pin combined with oil contamination from the engine system.</td></tr>
<tr><td>PEC Fault triggered and crew reset and eventually permanently de-powered the PEC.</td></tr>
<tr><td>11:10:34</td><td colspan="2">No 1 Engine suffered power loss.</td></tr>
<tr><td>Subsequent to above</td><td colspan="2">Crew requested feathering, propeller speed decreased.</td></tr>
<tr><td>11:10:57</td><td colspan="2">Crew positioned CL in FSO position.</td></tr>
<tr><td>Subsequent to above</td><td>Continued technical malfunctions</td><td>OSG became non-functional due to loss of contact with broken flyweights.</td></tr>
<tr><td>11:11:18 to 11:11:53</td><td colspan="2">Propeller went out of feather (Np-1 over shoot to 120%) most probably due to contamination inside the overspeed line of the PVM. This caused the protection valve to leave the protected mode, resulting in propeller movement towards low pitch below low pitch value in flight.</td></tr>
<tr><td>~11:12:30 onwards</td><td colspan="2">Sharp decrease in Np-1, blade pitch angle most likely moved further beyond the previous position (ie below low pitch in flight) and settled with Np-1 below 5% (estimated) with a drag force of about 2,000 lbf (estimated).</td></tr>
</table>

[192] Analysis / discussion during meeting in November 2019 at BEA.

3.1.2.2 The aircraft crashed after 42 minutes of flight at 11:20 about 3.5 NM SSE of Havelian, and 24 NM North of BBIAP Islamabad. All 47 souls (42 passengers and 05 crew members) were fatally injured.

3.1.3 PIA Maintenance, Anomaly of PT-1 Blades, Latent Pre-Existing OSG Fractured Pin and PVM Contamination.

3.1.3.1 The distress mode of PT-1 blades was from a known issue on P&WC "PW127" series engines since 2007. To address this issue, the OEM undertook various improvements (in the management / design of the blades). As a final effort, in October 2015 (ie ~08 years since the trending failures in the industry were being observed), the OEM introduced a new design of the PT-1 blade, through a Service Bulletin No 21878. Subsequently, the OEM amended the Engine Maintenance Manual in May 2016 (ie ~06 months prior to the crash) by specifying replacement criteria for both new and old design blades[193].

3.1.3.2 Past maintenance records at PIA indicated that the No 1 Engine of the aircraft was removed from another ATR aircraft (AP-BHP) during the second week of November 2016 (ie ~26 days prior to the occurrence) on a defect of rubber FOD stuck inside engine LP impeller. This was an unscheduled activity[194].

3.1.3.3 During shop visit, the blades had accumulated 10004.1 hrs and the PT Assembly was removed (to take out the FOD stuck inside LP impeller). Pre-conditions to replace the PT-1 blades were met as per OEM's defined criteria given in the revised Engine Maintenance Manual Chapter-5. However, these blades were not replaced and PIA Engine Shop cleared the engine. This engine was later installed on 16 November 2016 at No 1 position on AP-BHO[195].

3.1.3.4 This engine after operating for another 93 hrs on AP-BHO, had one of its PT-1 blades fractured (from a known issue). This event triggered a sequence of technical malfunctions in the event flight[196]. However, it can be assumed that if this engine had not encountered a rubber FOD, the said PT-1 blade might have continued operating (as per OEM's instructions) and might have fractured around same time frame (ie 10004.1 + 93 hrs)[197].

3.1.3.5 Fractured pilot valve pin of OSG was present since it was last accessed during a maintenance activity. It was not possible to ascertain when and where this maintenance activity took place[198].

3.1.3.6 Probable pre-existing contamination / debris found in PVM were most likely introduced when the propeller system LRU's were not installed on the gearbox. It was not possible to ascertain when and where this contamination was introduced[199].

3.1.4 Nature of Technical Malfunctions and Degradation in Aircraft Performance.

3.1.4.1 In this particular single engine IFSD, coupled with a propeller possibly rotating at 5% (estimated) rpm and a blade pitch assumed to be near (or below) the low pitch stop, the pilots came across a situation which was neither experienced earlier, nor expected. Due to system redundancy and accumulated probability of

[193] Engine Maintenance Manual and relevant publications.
[194] Scrutiny / Analysis of PIA records at AAIB.
[195] Same as above.
[196] Discussion / Analysis during concluding meeting at BEA in November 2018.
[197] AAIB analysis.
[198] Maintenance Group Investigation Report, Service Review of Woodward Overspeed Governor P/N 8210-097, S/N 14967680, by NTSB, dated 02 October 2020 attached as **Appendix-1**.
[199] Analysis at AAIB.

independent failures, and since the probability meets and exceeds applicable safety regulations, it was not considered as a condition to be addressed, therefore, it was not explained in any operational publication by the aircraft OEM (ATR).

3.1.4.2 Due to this combined technical anomaly, during following parts of the flight[200], the conditions were exceptionally difficult (ie may be considered as conditions of hazardous consequence) and it was expected that the cockpit crew may not be able to cope with the situation, and therefore they may not be relied upon to undertake the required / expected actions correctly[201]. These are as follows: -

(i) **11:10:33 to ~11:10:56:** During this part at the time of No 1 Engine IFSD, Np-1 had increased (before engine shutdown) to about 102%.

(ii) **11:10:56 to ~11:11:45:** Np-1 decreased and became NCD. Its behavior looked like a feather request. Then, Np-1 unexpectedly increased again at an abnormal slow rate[202], corresponding to propeller un-feathering.

(iii) **11:11:45 to ~11:12:35:** During this part Np-1 increased to a very high value range of 120 to 125 %, gradually reduced to 116.5%, and then increased to 123% again. During this part of flight the left side of the aircraft produced high drag values, until the propeller speed began to rapidly decrease in an un-expected manner.

(iv) **11:12:45 to ~11:13:09:** During this part the aircraft entered an uncontrolled / stalled condition of flight where the aircraft lost about 5,100ft and rolled right by 360º and beyond[203]. This had immense psychological impact on the cockpit crew, and it impaired their capacity to perform normally[204].

(v) **11:12:36 to ~11:20:39:** During this last part of flight when there was no further technical degradation and the blade pitch angle and Np-1 had stabilized at a particular value. This new pitch angle was possibly beyond the low pitch in flight (ie in fine pitch range normally corresponding to ground operations). The aerodynamic drag of the left side of the aircraft was estimated to be seven times[205] more than the drag usually expected during single engine flight envelope (with the effected side propeller in feather position).

3.1.4.3 All flight parts subsequent to un-feathering (except first condition ie sub para (i) of para 3.1.4.2 above) are not covered in QRH / FCOM of ATR aircraft. ATR describes the failure condition (corresponding to un-feathering and not to subsequent phases) in risk factor / safety assessment paradigm as failure condition No 1.003 “engine failure in cruise without propeller feathering” (System Safety Analysis 42.0078/95 issue 5), as of “Hazardous Consequence”, with further explanation about the possible results[206].

3.1.4.4 All flight parts subsequent to un-feathering (ie sub para (i) of para 3.1.4.2 above) were understandably much more complicated and difficult to handle, than

[200] DFDR data analysis at AAIB.
[201] Discussion on aircraft controllability / certification aspects with ATR at BEA during November 2019.
[202] Confirmed by ATR flight test.
[203] DFDR data analysis at AAIB. The aircraft stalled at a speed of 120 knots indicating a significant aerodynamic degradation in the aircraft performance.
[204] AAIB analysis deduced from DFDR / CVR recordings and flight animation.
[205] Discussion on aircraft controllability / certification aspects with ATR at BEA during November 2019.
[206] Certification process presentation by ATR provided an overview of risk assessment paradigm, and an understanding about possible consequences that could be related to hazardous flight conditions. These possible consequences included a large reduction in safety margins of aircraft functional capabilities and capabilities of flight crew; and may even lead to fatal injuries to few of the occupants.

"engine failure in cruise without propeller feathering" (ie the first condition), and therefore are considered more severe for their possible consequence(s). Moreover, the aircraft was flying with Pitch Disconnect which probably brought in additional challenges for the aircrew in terms of aircraft handling and control authority[207].

3.1.4.5 The torque value of No 2 Engine during the flight conditions (sub para (v) of para 3.1.4.2 above) was sufficient enough to fly, cross over the mountains and land the aircraft with No 1 Engine IFSD (if the propeller was in feather condition, and there was no additional drag due to complicated technical malfunctions of No 1 Engine propeller system).

3.1.4.6 The event was unexpected and the cockpit crew was not trained for this specific sequence of event. This event highlights importance of adhering to the cardinal principle of ***Fly, Navigate, and Communicate***, especially in an unusual emergency situation. The crew actions indicated several events of incorrect prioritization. Top priority must always be accorded to the control of the aircraft first and then consume the remaining effort in effective management of cockpit resources for mitigation of hazards, and subsequent safe recovery of the aircraft. This aspect is however considered an overboard expectation from the pilots especially when they were unable to understand and correct the situation, and had no method available to them to reach to the correct understanding about possible descend / landing profiles (on any nearby airfield or attempt ditching elsewhere), without any specific guidelines provided in any form.

3.1.5 Crew Training, Qualification, Performance and Matter of Dubious Pilots' Licenses[208].

3.1.5.1 The Captain had a total of 11265:40 hrs of flying experience, with 1216:05 hrs (as Captain) on ATR aircraft. He held valid licenses, and ratings, and met the required training / regulatory prerequisites of PIA and CAA. During his career, in addition to ATR aircraft he flew (as a First Officer) Fokker F-27, Airbus 300, Airbus 310, Boeing 737, and Boeing 777 aircrafts. He had a family and led a normal family life. There were no social / psychological issues reported / documented by PIA / CAA Pakistan in their respective records.

3.1.5.2 The First Officer (A) had a total of 1742:30 hrs of flying experience with 1416:00 hrs (as First Officer) on ATR aircraft. He held valid licenses and ratings, and met the required training / regulatory prerequisites of PIA and CAA. During his career, in addition to ATR aircraft he flew (as First Officer) Twin Otter and Fokker F-27 aircrafts. He had a family and led a normal family life. There were no social / psychological issues reported / documented by PIA / CAA Pakistan in their respective records.

3.1.5.3 The First Officer (B) had a total of 570:00 hrs of flying experience with 369:15 hrs (as First Officer) on ATR aircraft. He held valid licenses and ratings, and met the required training / regulatory prerequisites of PIA and CAA. He was unmarried and lived with his mother and siblings. There were no social / psychological issues reported / documented by PIA / CAA Pakistan in their respective records.

3.1.5.4 During 2019 CAA Pakistan initiated scrutiny of licensing records of pilots. It was discovered that there were irregularities regarding the conduct of ground examinations by the licensing branch of CAA. This rendered a suspicion about

[207] AAIB analysis.
[208] In June 2020, the matter of dubious licenses by the pilots was made public during a formal joint session of the National Assembly of Pakistan by the Federal Minister of state for Aviation.

licenses of few of the pilots who appeared in the exams during a specified period of time, and their attendance / physical participation could not be verified from the records. CAA has reconciled the matter by seeking clarification from the individuals, and disposing off the cases by adopting a legal / formal procedure. Names of Captain and First Officer (B) appeared in the initial list of pilots whose licenses were considered suspicious. CAA has removed these names on the basis of criteria / standard being followed during the review process[209].

3.1.5.5 Career training records of the pilots highlighted few observations. Similar observations were also noted during the event flight. Based on the analysis of actual crew performance in comparison with the expected crew actions, AAIB has concluded that their performance was commensurate with their respective experience / training records etc. The matter of dubious licenses surfaced during the course of investigation therefore becomes irrelevant. However pilots' actions for attribution to the crash have been discussed in detail in analysis part of the investigation.

3.1.6 **CAA Pakistan Oversight and Safety Management System of PIA:** CAA Pakistan as a regulator is required to maintain an oversight of all the operators. The primary objective of airworthiness directorate regulatory oversight is the efficient maintenance management by the operators, which is in accordance with the OEM prescribed procedures (and is in light of purposes and objectives of relevant ICAO publications and applicable SARPs). CAA Pakistan conducts annual audits of all the operators at the time of renewal of AOC. Audit reports of PIA for the years 2014 to 2018 were examined[210] during the course of investigation. It was observed that there were gaps in the monitoring and evaluation in the domain of Airworthiness and Safety Oversight by CAA. Based on these audits or other oversight tools, CAA Pakistan was unable to demonstrate proportionate conclusions, identify the trends, and undertake proactive interventions. Furthermore, Safety and Quality Management of PIA is responsible to have a strong internal mechanism to ensure compliance to the required procedures and meet the expected safety standards. PIA Safety Management System did not identify and implement appropriate corrective measures. Some important observations are as follows: -

3.1.6.1 P&W Canada identified that the reliability of PIA PW127 series engines is lower than the entire fleet operating in rest of the world[211]. The oversight mechanism established by PIA / CAA Pakistan was found to be inadequate to identify and monitor performance indicators that can reflect such findings. Furthermore the mechanism for a proactive intervention upon such findings was in-effective.

3.1.6.2 PIA has established Maintenance Repair Overhaul (MRO) facility for the maintenance of PW127 engine series. Such setup is authorized for the maintenance in accordance with the conditions and requirements prescribed by the respective OEM. During a site survey of the said PIA MRO facility by P&WC in April 2017, few anomalies (deviations from requirements / procedures given by P&WC) were observed[212], which were not registered / documented by CAA Airworthiness during audits (or any activity related to the oversight). The oversight mechanism of CAA Pakistan (Directorate of Airworthiness) was inadequate / ineffective to identify such weak areas.

---

[209] AAIB letter to CAA for seeking clarification on the matter and CAA response.
[210] Annual audit / AOC renewal audit reports by CAA Pakistan of PIA for the years 2014 to 2018.
[211] P&WC provided classified data about ATR aircraft reliability the world over and a comparative analysis in the form of a presentation.
[212] P&WC Shop survey of Pakistan International Airlines MRO Facility, Karachi, Pakistan dated 01 May 2018.

3.1.6.3 Non implementation of SB-21878 (and related deviation from relevant engine maintenance manual) was neither identified by PIA Quality and Safety Management System nor by CAA Airworthiness oversight system.

3.1.6.4 A number of IFSD cases were recorded on ATR aircraft in PIA, from 2008 to 2016 (ie before the crash)[213]. These cases and all other occurrences / incidents are mandatorily reported to CAA Pakistan. PIA Quality and Safety Management System, and the CAA Pakistan were unable to identify the trend(s) and undertake any proactive intervention.

3.2 **Probable Causes of Occurrence.**

3.2.1 **Probable Primary Factors.**

3.2.1.1 The dislodging / fracture of one PT-1 blade of No 1 Engine triggered a chain of events. Unusual combination of fractured / dislodged PT-1 blade with two latent factors[214] caused off design performance of the aircraft and resulted into the accident[215].

3.2.1.2 The dislodging / fracture of PT-1 blade of No 1 Engine occurred after omission from the EMM (Non-Compliance of SB-21878) by PIA Engineering during an unscheduled maintenance performed on the engine in November 2016, in which the PT-1 blades had fulfilled the criteria for replacement, but were not replaced[216].

3.2.1.3 Fracture / dislodging of PT-1 blade in No 1 Engine, after accumulating a flying time slightly more than the soft life of 10,000 hrs (ie at about 10004.1 + 93 hrs) due to a known quality issue. This aspect has already been addressed by re-designing of PT-1 blades by P&WC [217].

3.2.2 **Probable Contributory Factors.**

3.2.2.1 A fractured pin (and contamination inside the OSG), contributed to a complex combination of technical malfunctions. The pin fractured because of improper re-assembly during some unauthorized / un-documented maintenance activity. It was not possible to ascertain exact time and place when and where this improper re-assembly may have occurred[218].

3.2.2.2 Contamination / debris found in overspeed line of PVM of No 1 Engine probably introduced when the propeller system LRU's were not installed on the gearbox, contributed to un-feathering of the propeller. It was not possible to ascertain exact time and place when and where this contamination was introduced.

3.3 **Important Observations.**

3.3.1 There were several findings discovered during the course of investigation, which did not have any direct contribution to the crash / causes. However, these findings were of significant importance, and have been included as observations. These are as follows: -

---

[213] AAIB data about ATR aircraft IFSD cases for the years 2008 to 2016.

[214] AAIB analysis - the two latent factors include broken pin inside OSG and probable contamination inside PVM.

[215] AAIB analysis - had any of these factors existed alone, or had these not been coupled with an IFSD of the same side engine (in the manner it was experienced during this event), it may have resulted in different and / or less serious consequences.

[216] If PIA during the said unscheduled maintenance had changed the blades, the said PT-1 blade fracture may not have occurred.

[217] Had there been no unscheduled repair (by PIA) on subject engine, PT blades would have continued in service passing 10,000 hrs soft life without being replaced. Probability of blade failure in such case (where the engine is not subjected to any scheduled / unscheduled maintenance enabling access to the relevant area) cannot be ruled out.

[218] Maintenance Group Investigation Report, Service Review of Woodward Overspeed Governor P/N 8210-097, S/N 14967680, by NTSB, dated 02 October 2020 attached as **Appendix-1**.

3.3.1.1 In February 2017 PIA Engineering reviewed the life of the old design PT-1 blades. PIA Engineering decided to change the soft life as a hard life of 10,000 hrs irrespective of the conditions given in the maintenance manual (an action overboard towards safe side). The enabling reasons for this review and details of participation of CAA Pakistan in this review were not recorded / provided.

3.3.1.2 After issue of First Immediate Safety Recommendation by AAIB in Jan 2019, both PIA Engineering and CAA Pakistan (Directorate of Airworthiness) maintained the stance that the SB-21878 was not important (non-mandatory / non-critical / optional etc), contrary to the related revision in Engine Maintenance Manual (which recommends to discard the blades on completion of 10,000 flight hours when the PT assembly or turbine disk is accessed).

3.3.1.3 CRM training of the cockpit crew is governed by CAA Pakistan ANO ANO-014-FSXX-2.0. The refresher sessions are undertaken at prescribed periodicity (two years), by the operators by designated / qualified CRM facilitators. These trainings, were not effective, and did not yield the expected improvement in the behaviors / responses by cockpit crew. Operators as well as CAA Pakistan (Directorate of Flight Standards) did not have an effective mechanism to gauge the efficacy of the CRM trainings.

3.3.1.4 Flight Data Monitoring (FDM) is useful tool for the operators to observe trends about the cockpit crew during regular flight operations. PIA has established an FDM analysis mechanism; however it was not being effectively utilized. In case if such systems are utilized effectively, detailed records of operational trends are established and used to feed the airline SOP and training program.

3.3.1.5 Flight inspectors from CAA Pakistan (Directorate of Flight Standards) supervise the periodic Simulator Sessions of the cockpit crew of all operators. During the conduct of these CAA supervised Simulator Sessions, response to exposure to different situations is formally evaluated and weak areas are identified. PIA needs to undertake necessary improvements and establish a continuous monitoring system (during regular flight operations) for the identified weak areas by using suitable tools (ie FDM analysis etc).

3.3.1.6 It was established that metal debris (small particles), likely from No 6 bearing seal of engine travelled inside OSG through contaminated engine oil. Same oil is used by Propeller Control System components (ie OSG, PVM, Feathering & SLPS solenoids etc). The OSG incorporates orifices and polyester screens protecting downstream components from contaminants too large to exit through the PVM solenoid hydraulic drain, whereas the protection valve inside PVM has wire mesh screens.

3.3.1.7 As a redundant design, PEC ‘ON’ is a secondary control for feathering as PEC commands to the PVM’s EHV. In the AP-BHO event (engine in flight shutdown with PEC ‘OFF’ (depowered) plus pre-existing independent conditions), normal feathering method using PEC command to PVM's EHV might have provided additional margin. However, an acceptable means of incorporating a specific operating procedure change, into the overall fault accommodation philosophy utilized on ATR aircraft systems, has not been identified by ATR.

3.3.1.8 CMM of OSG has been recently revised by OEM. AAIB understands that the revised CMM must essentially encompass all conditions to rule out possibility of incorrect assembly of the lower body of the OSG and consequent damage to the pin. Furthermore it is expected that once an OSG goes through any inspection at the MRO facility, it has no hidden / latent defect.

SECTION 4 –
SAFETY RECOMMENDATIONS

SECTION 4 - SAFETY RECOMMENDATIONS

4.1 **Introduction:** The Safety Recommendations have been divided into two parts. The first part provides overview of Immediate Safety Recommendations issued by AAIB during the course of investigation (implementation already in progress); while the second part provides recommendations having direct bearing / relationship with the probable cause(s) of occurrence along with additional safety recommendations which have been based on findings provided as important observations.

4.2 **Immediate Safety Recommendations:** As various findings were established progressively, AAIB issued two Immediate Safety Recommendations to PIA Engineering and CAA Pakistan Airworthiness Directorate: -

4.2.1 **The First Immediate Safety Recommendation[219]:** was issued on 09 January 2019. In that AAIB advised PIA to implement SB-21878 (incorporated as a revision in EMM Chapter 5 about six months prior to crash) for replacement of PT-1 blades on entire ATR fleet held at PIA according to the prescribed schedule / criteria. AAIB also advised CAA Pakistan (Airworthiness Directorate) to improve oversight function / mechanism accordingly.

4.2.2 **The Second Immediate Safety Recommendation[220]:** was issued on 20 August 2019 at the request of Collins and the NTSB, in order to identify and correct any pre-existing failure related to incorrect re-assembly of OSG. AAIB advised PIA to initiate recycling / inspection (in a phased manner) at an OEM facility (Collins USA), of all (Qty 48) OSGs, either installed on ATR aircraft in operation or held in inventory with PIA.

4.3 **PIA.**

4.3.1 **PIA** is to ensure replacement of PT-1 blades as per schedule given in EMM Chapter 5 in letter and spirit on the entire fleet of ATR aircrafts (in light of First Immediate Safety Recommendation)[221].

4.3.2 PIA is to ensure recycling of all the Qty-48 OSGs (currently held with PIA) from an OEM's certified MRO facility to verify and confirm that no other OSG is having any internal pre-existing anomaly (in light of Second Immediate Safety Recommendation)[222].

4.3.3 PIA is to ensure strict compliance of service information letter (SIL-568F-796)[223] issued by Collins Aerospace to maintain proper cleanliness and FOD prevention during engine and propeller storage and maintenance.

4.3.4 PIA is to undertake improvements (and ensure continued compliance) in all the areas identified in P&WC site survey report of the MRO facility established for the maintenance of PW127 series engines[224].

4.3.5 PIA Safety Management must identify critical performance indicators both in the domains of airworthiness as well as flight operations. The data is to be utilized

---

[219] First Immediate Safety Recommendation attached as **Appendix-2.**

[220] Second Immediate Safety Recommendation attached as **Appendix-3.**

[221] Refer para 11 (a), PIA Engineering has already decided to change the soft life as a hard life of 10,000 hrs irrespective of the conditions given in the maintenance manual (an action overboard towards safe side).

[222] Implementation of the said safety recommendation was initiated soon after its issue and is under process at the time of publication of this report.

[223] Collins Aerospace Service Information Letter SIL-568F-796 attached as **Appendix- 4.**

[224] P&WC Shop survey of Pakistan International Airlines MRO Facility, Karachi, Pakistan dated 01 May 2018.

for establishing trends and weak areas, further leading towards proactive corrective measures and corresponding improvements in SOPs / training programme.

4.3.6 PIA is to ensure effective utilization of FDM system, observations noted during the simulator check flights and training sessions to identify and maintain records of operational trends. This mechanism may also include continuous monitoring and must enable requisite / proportionate improvements in relevant SOPs and training program.

4.3.7 PIA is to revamp its CRM training system (in light of purposes and objectives of relevant ICAO publications and applicable SARPs) and evolve a purposeful internal assessment mechanism to gauge the effectiveness of CRM training.

4.4 CAA Pakistan.

4.4.1 CAA Pakistan (Directorate of Airworthiness, State Safety Programme Management and / or any other relevant departments), must identify relevant performance indicators and establish a mechanism of monitoring of such indicators (in light of purposes and objectives of relevant ICAO publications and applicable SARPs). P&WC data about comparison of reliability of PIA ATR fleet, and details of IFSD cases of ATR (as per records held with PIA / CAA), can be considered as a reference. The established mechanism must also include relevant management tools to identify trends and recognize weak areas, and execute proactive intervention(s), proportionate with the nature and extent of identified concerns.

4.4.2 CAA Pakistan (Directorate of Airworthiness), must undertake necessary improvements (in light of purposes and objectives of relevant ICAO publications and applicable SARPs) to ensure that appropriate management tools are evolved / adopted, and effective procedures are established to identify weak areas, related to the compliance with the OEM specified requirements / procedures etc. P&WC shop visit of PIA MRO for the maintenance of PW127 series Engines can be considered as a reference.

4.4.3 Keeping in view the actions by the cockpit crew regarding Energy State Management, Automation Management, Crew Resource Management (CRM) failure aspects, CAA Pakistan (Directorate of Flight Standards) is to consider following measures: -

4.4.3.1 Revamp the CRM training system (in light of purposes and objectives of relevant ICAO publications and applicable SARPs) and institute and implement regular / periodic CRM facilitator's interactive training workshops for emphasizing upon the objectives of CRM, sharing of experiences and knowledge from accident / incident investigations of aviation industry, and evaluating the positive outcomes of CRM.

4.4.3.2 Evolve a purposeful internal assessment mechanism (for the operators), to increase the effectiveness of CRM training by identifying tangible performance indicators, and may consider to develop a software module to accumulate database of CRM observations for analysis.

4.4.3.3 Institute and implement feedback and analysis tools for use by the operators along with necessary training / guidelines. It may include use of existing systems of FDM analysis, hazard reporting system, voluntary reporting of events, and self-assessment by the cockpit crew etc.

4.4.3.4 Institute and implement an elaborate mechanism for the operators, of separately recording the weak areas identified during CAA Flight Inspector's supervised flights / simulator tests, and continuous monitoring during regular training sessions, and FDM analysis. Ensure effective utilization by establishing detailed records of operational trends and utilize same to feed the airline SOP and training program etc.

4.5 **ATR:** ATR is to consider inclusion, as part of the training philosophy, of a procedure in the relevant aircraft publications to handle the aircraft in case of severe structural damage (to correlate an aerodynamic degradation similar to the event), to enable the cockpit crew to respond to such situations in a more appropriate manner.

4.6 **FAA:** Woodward has completed review and update to OSG CMM. Maintenance group review report[225] by NTSB summarizes the completion of this activity. FAA may re-evaluate that the revised CMM encompasses all conditions to rule out possibility of incorrect assembly of the lower body of the OSG and consequent damage to the pin.

4.7 **FAA / Collins Aerospace:** Collins Aerospace has issued a service information letter (SIL-568F-796) to remind operators to maintain proper cleanliness and FOD prevention during engine and propeller storage and maintenance. FAA and Collins Aerospace are to consider a system review and possible improvements to the oil system filtration inside the propeller control system to enhance existing protections against debris entering the PVM OSG line (including feather solenoid and SLPS solenoid) that could affect safety functions.

[225] Maintenance Group Investigation Report, Service Review of Woodward Overspeed Governor P/N 8210-097, S/N 14967680 by NTSB dated 02 October 2020 attached as **Appendix-1**.

NATIONAL TRANSPORTATION SAFETY BOARD
OFFICE OF AVIATION SAFETY
WASHINGTON, D.C. 20594

October 2, 2020

MAINTENANCE GROUP INVESTIGATION REPORT, SERVICE REVIEW OF WOODWARD OVERSPEED GOVERNOR P/N 8210-097, S/N 14967680

A. ACCIDENT

Location:	Havelian, Pakistan
Date:	December 7, 2016
Aircraft:	ATR 42-500, Reg. No. AP-BHO, Operated by Pakistan International Airlines

B. GROUP

Carol Horgan, National Transportation Safety Board, Washington, DC
Tim Maver, Collins Aerospace, Windsor Locks, CT
Chris Behling, Woodward Inc., Loves Park, IL
Lee Fisher, Honeywell, South Bend, IN

C. BACKGROUND

The overspeed governor (OSG) S/N 14967680 recovered from the No. 1 engine S/N EB0259 of accident airplane AP-BHO was sent to the manufacturer, Woodward Inc. in November 2017 for assessment of damage noted during a disassembly conducted under BEA supervision. [1]

Woodward's materials examination determined that the pilot valve pin (pin) was damaged when the lower body was assembled to the main body. This was supported by analysis of internal witness marks and materials. See Attachment A, *Woodward Report No. EN835035*.

The AAIB IIC approved the formation of a maintenance group to further investigate the OSG service and maintenance history. The Group's work was delayed by visa issues, and then limited by the Coronavirus health crisis. As a result, a full group could not participate as planned, and the shop where the OSG had been sent on three occasions, a Woodward-approved Honeywell repair facility at Prince Edward Island, Canada (PEI), was not visited.

[1] The BEA reported that the liberated pin section and other part fragments were not found inside the OSG. A 0.218-inch diameter drain bore that enlarges to a 0.312-inch diameter passage located at the bottom of the inner body housing cavity provides an exit path to the engine reduction gearbox. All the liberated pieces are small enough to have traveled the passage without further fragmentation. Woodward reports that on the two occasions where Woodward forcefully broke the pin and then ran the ATP, the liberated portion of the pin migrated to the drain bore. The dimensions of the liberated fragments are provided in Attachment A.

D. HARDWARE INDICATIONS

1.0 Direction of force

Metallurgical examination of the pin fracture surface found that the pin had sheared in overload. The direction of fracture was in line with the slots in the ballhead assembly[2] carrier that the pin engages during assembly and was inconsistent with operational loading, which is perpendicular to the slots. This ruled out an in-service pin failure. An overload fracture in line with the carrier slots indicated that the pin was sheared during assembly.

2.0 Multiple pilot valve block wear signatures

Wear marks found on the OSG pilot valve block were identified by Woodward as normal wear signatures created by light contact from the flyweight toe tips during operation. The marks can appear in two locations because the pin can be (correctly) installed in either of two ballhead carrier slots; the wear location shifts depending on which slot is used. The pilot valve block is often repositioned with respect to the ballhead carrier when assembled, which will shift the flyweight tip wear to the alternate location.

According to Woodward, a wear signature is created when the ballhead assembly operates with a sheared pin, but this wear occurs in a different location on the pilot valve block.

The OSG P/N 8210-097 pilot valve block displayed distinct wear marks at both of the normal locations. The marks were typical in size and radius for flyweight toe contact with an intact pilot valve pin. An atypical wear signature consistent with a sheared pin was not present.

2.1 An additional lower body removal

Because the lower body must be separated from the main body to change the pin location, the presence of two wear signatures on the pilot valve block means that the ballhead assembly was repositioned during a post-manufacture lower body disassembly after the OSG was operated long enough for a wear to be discernable.[3]

The pin was sheared by a second, incorrect lower body reassembly after operating enough hours to create the second wear signature. Following this access, the unit did not operate the minimum number of hours required to produce a third signature at the anomalous location.

The investigation identified three MRO shop visits to PEI.[4] Review of the PEI records found nothing detailing lower body access. However, Woodward advised that the lower body can be disassembled to inspect the main drive bearing and ballhead assembly. The lower body is retained by two screws. According to Woodward, such work can occur during shop visits without being specifically noted in the repair workscope.

---

[2] The ballhead assembly consists of the flyweights and a carrier.
[3] Woodward surveyed its repair organizations but was unable to estimate a minimum amount of service time required to produce the wear marks.
[4] See Attachment B, *Honeywell PEI/Collins Windsor Locks Shop Visit Records for OSG S/N 14967680.*

E. MAINTENANCE REVIEW

1.0 Limited records review

The investigation was limited because the Group did not participate in the investigation's formal airplane maintenance records review in 2017.

2.0 OSG S/N 14967680 service history

A service history was created from the available records to identify opportunities for the second lower body assembly access.[5] See Table 1.

Table 1. Timeline representation of OSG S/N 14967680 service data

date	location	record	notes	TSN	source
Dec 29 2006		New	First PIA record	0	PIA, mnfr sales record
Jan 26 2007		moved from A1 to 42	"RV42/0030"		PIA PAMMIS
not provided		Installed on ESN EB260			
Jan 31 2007	AP-BHJ	INSTALLED on AP-BHJ #2	Airplane installation		PIA PAMMIS
Sep 07 2008	AP-BHJ	REMOVED from AP-BHJ	Engine HSI		AAIB notes
Jan 01 2009		OSG removed to stores	removed from ESN EB260		PIA PAMMIS ESN: AAIB notes
Jun 21 2010		Parts control	placed in parts control (P/C)		PIA PAMMIS
Aug 11 2010	ABROAD 1	Shipped out for repair			PIA PAMMIS
Oct 11 2010	ABROAD 1	To engine shop		3,863	PIA PAMMIS
Feb 07 2011	ABROAD 1	Received at PEI*	PEI w/o# T343403 RAR** found pneumatic valve test was 4 RPM low out of limits-minor adj. Updated to P/N 8210-097 per SB83374-61-001 (Update Overspeed Governor Assembly with new filter & Replace seal)	3,863	Woodward/PEI records
May 10 2011	ABROAD 1	Shipped from PEI		3,863	PEI records
May 25 2011		Rcvd back in stores	Stores A1		PIA PAMMIS
Jul 19 2011		Installed on an engine			AAIB notes
Jul 19 2011	AP-BHO	INSTALLED on AP-BHO #1	Airplane installation		PIA PAMMIS
Sep 04 2011	AP-BHO	REMOVED from AP-BHO	Airplane removal EB0297, IFSD		AAIB notes
Sep 20 2011		OSG moved to P&PC			PIA PAMMIS
Jun 05 2012	ABROAD 2	Out for repair	for repair/shop check	4,225	PIA PAMMIS
Jul 09 2012	ABROAD 2	HS SHOP FINDINGS REPORT	HS: EP1206013-12 Prelim Findings Report	4,225	HS report
Jul 20 2012	ABROAD 2	Received at PEI	PEI w/o# 5005488277.RFR- IFSD Cable broken between 2/4 body retaining screws. RAR 30" on-speed run - unit passed all test points, NFF. Unit recertified. No disassembly	4,225	Woodward/PEI records
Aug 23 2012	ABROAD 2	Shipped from PEI		4,225	PEI records
Oct 30 2012		To PIA stores	Stockroom A1		PIA PAMMIS
Dec 24 2013		installed on an engine			PIA PAMMIS
Dec 24 2013	AP-BHO	INSTALLED on AP-BHO #2	Airplane installation		PIA PAMMIS
Jan 19 2015	AP-BHO	EB0259 REMOVED fr AP-BHO	FOD		AAIB notes
Feb 10 2015		Removed from engine	Moved to P&PC		PIA PAMMIS

[5] See Attachment E, *AAIB Synopsis of PIA service records for OSG S/N 14967680*. New records provided by the AAIB on September 11, 2020 are added to this report and to the Table.

Feb 11 2015		P&PC to Component Shop			PIA PAMMIS
Mar 13 2015	ABROAD 3	Shipped out for repair			PIA PAMMIS
Apr 22 2015	ABROAD 3	HS receiving inspection	HS: PO# EP1503017-12	6,648	HS report
Jun 01 2015	ABROAD 3	Received at PEI	PEI w/o# 500858822 Cust # 311302 Reason for return: REPAIR. RAR failed Reset solenoid replaced.	6,648	Woodward/PEI records
Jul 18 2015	ABROAD 3	Shipped from PEI		6,648	PEI records
Sep 5 2015		Installed on ESN EB0259			
Sep 15 2015		Received at PIA	Stock room A1		PIA PAMMIS
Nov 11 2015	AP-BHM	EB0259 removed from AP-BHM			AAIB
Nov 11 2015	AP-BHH	EB0259 installed on AP-BHH	Airplane installation		Instl log page + AAIB indicating the a/c
Nov 21, 2015	AP-BHM	EB 0259 removed from BHM			
Nov 23,2015		Installed on ESN EB0259	Airplane installation	6,648	Form 9-22-121, demand voucher
	AP-BHO	EB0259 installed on AP-BHO	Airplane installation		PIA PAMMIS
Sep 06 2016		Installed on ESN EB0259	OSG S/N not stated on paperwork		engine change sheet
Sep 21 2016	AP-BHO	ESN EB0259 rmvd fr AP-BHO			
	AP-BHP	EB0259 installed on AP-BHP			
Nov 11 2016	AP-BHP	Removed from AP-BHP	Shop repair for impeller seizure		Logbook entry
Nov 11 2016	AP-BHH	Installed on AP-BHH	Airplane installation		
Nov 18 2016		ESN EB1159 removed			AAIB notes
Nov 18 2016	AP-BHO	ESN EB0259 installed AP-BHO	Airplane installation		
Nov 20-30 '16	AP-BHO	63 flight hours			
Dec 07 2016	AP-BHO	Accident	Engine TSN 16,996	8,175	

*Honeywell MRO, Prince Edward Island, Canada
**Run as received, receiving test

Note that several OSG S/N 14967680 removals and the Sept 6, 2016 installation are unclear.

Review of the service history revealed several periods for which the OSG location was not established. Without removal/installation records it is unknown whether the OSG was operated in support of other aircraft, and possibly repaired. However, most of these gaps can be ruled out using the wear signature evidence (Section G).

F. WOODWARD ANALYSIS OF LOWER BODY ASSEMBLY PROCEDURE

Woodward identified and demonstrated three Possible Assembly Conditions that might result in a pin separation. A process failure modes and effects analysis (PFMEA) of the OSG design and CMM assembly instructions was also conducted to identify any improvements that could preclude the OSG S/N 14967680 lower body assembly error. See Attachments C, *Woodward Report 8210-097, Assembly Evaluations*, Jan 6, 2020 and F, *Woodward Report 8210-097 Assembly Review*, July 28, 2020.

1.0 First Possible Assembly Condition

All the Possible Assembly Conditions involve assembly of the lower body to the OSG main body with the pin lining up outside of its assembly slot. In the First Possible Assembly Condition, with the pin lying on top of a flyweight, the unit will not assemble using the CMM instructions. If the CMM instructions are not followed and considerable force is used, the obstruction can be overcome by shearing the pin. This is the assembly condition identified in OSG S/N 14967680.

The fracture surface of the pin broken during the demonstration exhibited the same fracture directionality as the event pin fracture. SEM/EDS analysis of a mark noted on the top surface of an OSG S/N 14967680 flyweight found sliding contact damage and pin material transfer that supports this condition. The First Possible Assembly Condition also involves attempting to insert the pin into the carrier slot with the ballhead assembly incorrectly installed in the base plate.

Tests of the First Assembly Condition unit demonstrated that an OSG with a non-functioning pin can pass functional acceptance testing and remain in operation undetected, because the pilot valve contacts the flyweights in the absence of the pin.

Woodward found that the CMM assembly procedure does not permit the First Possible Assembly Condition incorrect assembly. The PFMEA process assigned an “unable to assemble” status, due to the inability to seat the ballhead assembly in the main body. Any assembling in this condition would require disregard of assembly order (base plate installed after ballhead assembly is seated), which ignores a CMM Caution, and forcible seating of the ballhead assembly, which required excessive force.

2.0 Second and Third Possible Assembly Conditions

Woodward’s Second Possible Assembly Condition (pin misplaced between the carrier and a flyweight) and Third Possible Assembly Condition (pin misplaced on top of the carrier) result in units that will assemble but are non-functional. When assembled with the pin in either location, the pin remains intact but unseated ballhead assemblies exert high preload and side loads on the pilot valve. The driveshaft rotation is impaired, which should be caught at assembly. It was demonstrated that units in this condition will seize, rendering the OSG non-functional and preventing completion of the acceptance test procedure (ATP).

2.1 CMM revision

To prevent an untestable condition at product acceptance, a measurement was added to the CMM that checks for misplacement of the pin between the carrier and a flyweight or on top of the carrier instead of inside the slot.

The measurement will not detect the First Possible Assembly Condition (the pin installed on top of the flyweight) because that assembly either results in an inability to assemble, or in pin fracture, if the ballhead assembly is forcibly seated. Woodward found that this assembly condition was not due to inadequate assembly instructions.

G. WEAR SIGNATURE ANALYSIS

Given that two marks were created in 8,175 total operating hours, there would have been a distinct wear pattern at 3,863 TSN, the time of the first PEI visit. See Table 1. The lower body of OSG S/N 14967680 was likely accessed during this shop visit. Because creation of the second mark required an intact pin, the unit was properly assembled. The ballhead assembly happened to be repositioned in the alternate slot, beginning the second wear pattern.

Significant additional hours were not accumulated until OSG S/N 14967680 was installed on AP-BHO between Dec 24, 2013 and Jan 19, 2015. The operating hours during this period are consistent with the earlier installation periods.[6] The unit was removed Feb 10, 2015 and shipped out for the third shop visit on Mar 13, 2015 with 6,648 TSN, having accumulated an additional 2,785 hours. It is reasonable to assume that the second signature was present at this time.

Following the shop visit, OSG S/N 14967680 was operated 1,527 hours, between Sept 15, 2015 and Dec 07, 2016. This analysis narrowed the opportunity window for the second lower body reassembly by ruling out the service time prior to approximately March 13, 2015.

The OSG S/N 14967680 records are unclear for this period. It is possible that the unit became suspect sometime after the last shop visit, prompting a second lower body access that was locally performed.

Although a shop visit seems a more likely opportunity, the forcible assembly required to fracture the pin would be an anomaly at a certified repair facility, where supervised technicians repeatedly assemble the product with strong emphasis on the CMM assembly procedure. Woodward's review of MRO reliability data since 1994 found no reports of a unit received with a sheared pin. It also can be noted that assembly with the pin atop a flyweight is more difficult and does not save time, indicating that only an untrained mechanic would attempt this method. All of this makes it unlikely, but not impossible, that the improper assembly was performed by a certified OSG repair technician at the Woodward-approved repair facility.

Both possibilities have the OSG operating 1,527 hours or less with the broken pin, considerably fewer hours than the times assumed to have produced the two wear signatures.

The remaining window of opportunity for the second lower body access is enclosed by the blue box in Table 1.

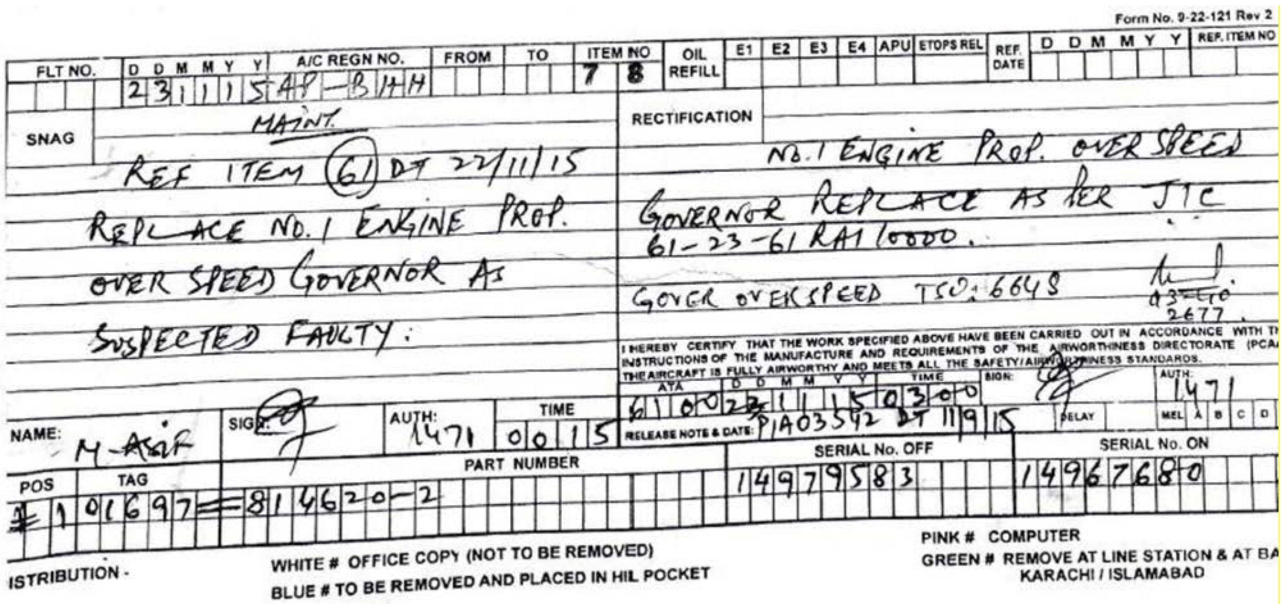
The additional operator records provided on Sept 11, 2020 follow.

H. ATTACHMENTS

A. OSG Woodward Report EN835035, OSG Examination Feb 22, 2018
B. Honeywell PEI – Collins OSG S/N 14967680 shop records – 8 files
C. Woodward Report 8210-097 Assembly Evaluations, Jan 6, 2020
D. Pertinent CMM pages (WG60258_R1 and _R2)
E. AAIB Synopsis of PIA service records for OSG S/N 14967680 - 3 files
F. Woodward Report 8210-097 Assembly Review, July 28, 2020

Carol M. Horgan
U.S. Accredited Representative

[6] Time on wing before the first shop visit averaged roughly 203 hours/month. Time on wing between Jul 19, 2011 and Sep 4, 2011 averaged roughly 238 hours/month. Time on wing between Dec 24, 2013 and Jan 19, 2015 averaged roughly 186 hours/month.



Form No. 9-22-121 Rev 2

FLT NO.	D D M M Y Y	A/C REGN NO.	FROM	TO	ITEM NO	OIL REFILL	E1	E2	E3	E4	APU	ETOPS REL	REF. DATE	REF. ITEM NO
	231115	AP-BHH			7 8									

SNAG

MAINT.
REF ITEM (61) DT 22/11/15
REPLACE NO. 1 ENGINE PROP.
OVER SPEED GOVERNOR AS
SUSPECTED FAULTY.

NAME: M-ASIF SIGN: AUTH: 1471 TIME: 0015

RECTIFICATION

NO. 1 ENGINE PROP. OVER SPEED
GOVERNOR REPLACE AS PER JIC
61-23-61 RAI 10000.
GOVER OVERSPEED TSO: 6648

2677

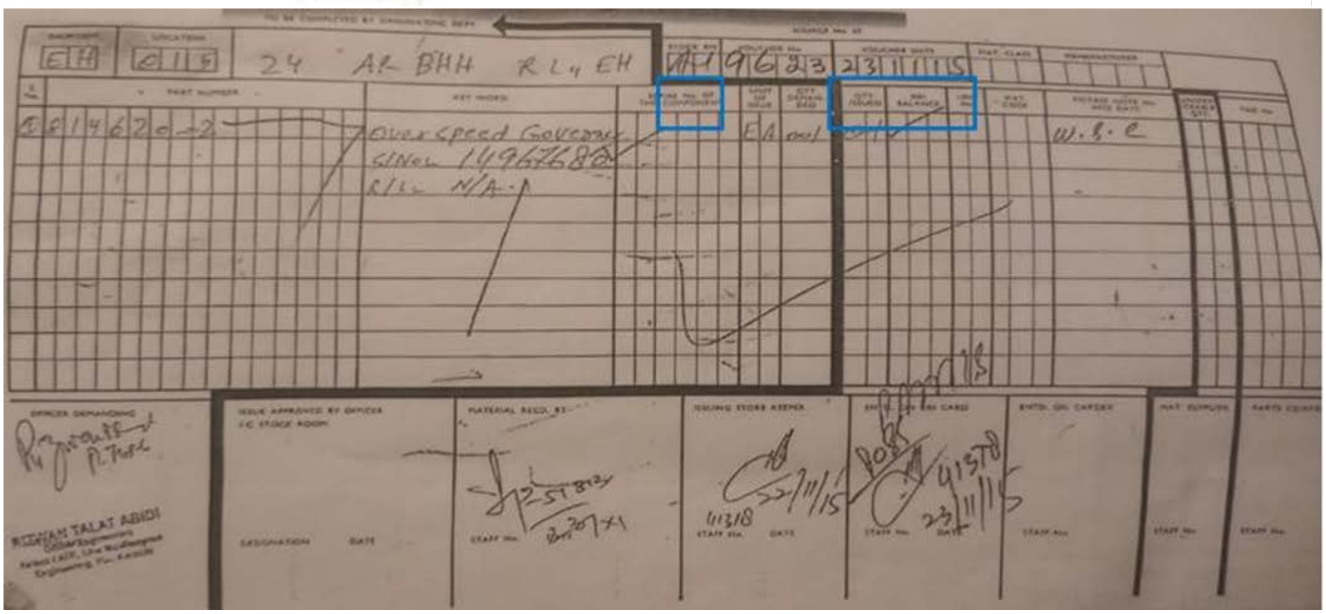
I HEREBY CERTIFY THAT THE WORK SPECIFIED ABOVE HAVE BEEN CARRIED OUT IN ACCORDANCE WITH THE INSTRUCTIONS OF THE MANUFACTURE AND REQUIREMENTS OF THE AIRWORTHINESS DIRECTORATE (PCAA) THE AIRCRAFT IS FULLY AIRWORTHY AND MEETS ALL THE SAFETY/AIRWORTHINESS STANDARDS.

ATA	D D M M Y Y	TIME	SIGN	AUTH
6100	231115	0300		1471

RELEASE NOTE & DATE: PIA03542 DT 11/9/15 DELAY MEL A B C D

POS	TAG	PART NUMBER	SERIAL No. OFF	SERIAL No. ON
#1	01697	814620-2	14979583	14967680

DISTRIBUTION - WHITE # OFFICE COPY (NOT TO BE REMOVED) BLUE # TO BE REMOVED AND PLACED IN HIL POCKET PINK # COMPUTER GREEN # REMOVE AT LINE STATION & AT BASE KARACHI / ISLAMABAD



EH 015 24 AP BHH RL4 EH AH 9623 231115

814620-2 Over Speed Governor S/No. 14967680 R/L N/A EA W.B.C

22/11/15 41318 23/11/15 41378

RIZWAN TALAT ABIDI

7	8
1. Particulars of all maintenance work done on the aircraft 2. Particulars of all overhauls replacement, repairs, modifications and mandatory to the aircraft or its equipment. 3. I hereby certify that the work specified in column 7 bellow has been carried out in accordance with the requirements of Civil Aviation Authority of Pakistan.	Signature Authority Date
S/A ENG INSTALLED ON AP-BHO #1 ENG POSN	AME [signature] AML 01471 18-11-16

19

7	8
1. Particulars of all maintenance work done on the aircraft 2. Particulars of all overhauls replacement, repairs, modifications and mandatory to the aircraft or its equipment. 3. I hereby certify that the work specified in column 7 bellow has been carried out in accordance with the requirements of Civil Aviation Authority of Pakistan.	Signature Authority Date
S/A ENG INSTALLED FROM (EX AP-BHM) ON #1 POSN	AME [signature] AML 0147? -11-15

Aircraft Type ATR-42-500 Nationality PAK

Registration AP-BHO Position #1 ENG SR-No-EB0259

(1)		(2)	(3)		(4)		(5)		(6)
Date	Number of Cycles	Cycles since New	Flight Time		Time Run Since New		Time Run Since Complete Overhaul		Time and / or Cycles *Run Since Last Statement of Life Used on Life Limited Parts.
			Hrs.	Min.	Hrs.	Min.	Hrs.	Min.	
Total Brought Forward		16582			16792	48			
20/11/16	05	16587	04	29	16797	17			
21-11-16	06	16593	06	00	16803	17			
22-11-16	06	16599	06	01	16809	18			
23-11-16	08	16607	07	06	16816	24			
24-11-16	07	16614	05	45	16822	09			
25-11-16	08	16622	07	45	16829	54			
26-11-16	06	16628	04	42	16834	36			
27-11-16	02	16630	02	45	16837	21			
28-11-16	06	16636	05	24	16842	45			
29-11-16	06	16642	07	08	16849	53			
30-11-16	05	16647	06	34	16856	27			
Total		16647			16856	27			

Cycles - See Constructor's Manuals for Definition.

18

Aircraft Type ATR 42-500 Nationality PAKISTANI

Registration AP-BHH Position #1 ENG EB0259

(1)		(2)	(3)		(4)		(5)		(6)
Date	Number of Cycles	Cycles since New	Flight Time		Time Run Since New		Time Run Since Complete Overhaul		Time and / or Cycles *Run Since Last Statement of Life Used on Life Limited Parts.
			Hrs.	Min.	Hrs.	Min.	Hrs.	Min.	
Total Brought Forward		15204			15363	43			
21-11-15	02	15206	01	57	15365	40			
26-11-15	02	15208	02	35	15368	15			
27-11-15	04	15212	04	07	15372	22			
28-11-15	02	15214	01	47	15374	09			
29-11-15	05	15219	05	31	15379	40			
30-11-15	04	15223	03	43	15383	23			
01-12-15	08	15231	06	17	15389	40			
02-12-15	08	15239	09	30	15399	10			
03-12-15	06	15245	06	35	15405	45			
04-12-15	06	15251	07	09	15412	54			
Total									

Cycles - See Constructor's Manuals for Definition.

APPENDIX - 2

SAFETY INVESTIGATION BOARD
PAKISTAN CIVIL AVIATION AUTHORITY
OFFICE COMPLEX, LEHTRAR ROAD
RAWALPINDI – PAKISTAN

پاکستان سول ایوی ایشن اتھارٹی

Tele	:	92 51 44 727 50
Cell	:	92 3235550111
Fax	:	92 51 44 727 54
Email	:	psib@caapakistan.com.pk

Ref. No. HQCAA/1901/386/SIB/010

Dated: 09 January 2019

IMMEDIATE SAFETY RECOMMENDATION
ACCIDENT OF PIAC FLIGHT PK-661, ATR42-500, AP-BHO
NEAR HAVELIAN ON 7TH DECEMBER, 2016

1. On 07 Dec 2016, a PIAC aircraft ATR (AP-BHO) flying from Chitral to Islamabad crashed near Havellian by killing all 47 souls on-board. Safety Investigation Board (SIB) of Pakistan was mandated by the Federal Govt to carry out detailed investigation into this unfortunate air crash. The investigation is towards a concluding stage, however, some important findings of technical nature require immediate attention / intervention. These are as follows: -

(a) Sequence of events was initiated with dislodging of one blade of Power Turbine Stage-1 (PT-1), inside Engine No 1 (left side engine) due to fatigue.

(b) This dislodging of one blade resulted in in-flight engine shut down, and it contributed towards erratic / abnormal behaviour of No 1 Propeller.

(c) According to a "Service Bulletin" these turbine blades were to be changed after completion of 10,000 hrs, on immediate next maintenance opportunity. The said engine was under maintenance on 11 Nov 2016, at that time these blades had completed 10004.1 hrs (due for a change). This activity should have been undertaken at that time, but it was missed out by the concerned.

(d) Aircraft flew approximately 93 hrs after the said maintenance activity, before it crashed on 07 Dec 2016.

(e) Missing out of such an activity highlights a lapse on the part of PIAC (Maintenance and Quality Assurance) as well as a possible in-adequacy / lack of oversight by PCAA.

2. In light of the above, following is recommended please: -

(a) PIAC is to ensure immediate implementation of the said Service Bulletin in letter and spirit on the entire fleet of ATR aircraft, undertake an audit of the related areas of maintenance practices, ascertain root cause(s) for the said lapse, and adopt appropriate corrective measures to avoid recurrence.

(b) PCAA is to evaluate its oversight mechanism for its adequacy to discover lapses and intervene in a proactive manner, ascertain shortfall(s) and undertake necessary improvements.

3. A feedback on the actions taken by M/s PIAC and PCAA may please be provided to the SIB.

(M USMAN GHANI)
Air Commodore
President SIB

To,

- **PSO to DG CAA,**
  HQCAA, Terminal-1,
  JIAP, Karachi

- **GM Safety & QA,**
  M/s. PIAC,
  JIAP, Karachi

Copy to:-

- SO to Secretary Aviation Division, Islamabad
- SSO to Chairman PIAC, M/s. PIAC JIAP, Karachi
- Secy to AD DG CAA, HQCAA

APPENDIX - 3

SAFETY INVESTIGATION BOARD
PAKISTAN CIVIL AVIATION AUTHORITY
CAA OFFICE COMPLEX, LEHTRAR ROAD
RAWALPINDI – PAKISTAN

Tele : +92 51 44 727 50
Fax : +92 51 44 727 54
Cell : +92-323 555 0111
Email : psib@caapakistan.com.pk

Ref . HQCAA/1901/386/SIB/

Dated: 20 August 2019

SECOND IMMEDIATE SAFETY RECOMMENDATION
M/S PIAC FLIGHT PK-661 ATR42-500 AP-BHO AT HAVELLIAN ON 07 DEC 2016

1. Refer investigations into subject air crash investigation.

2. During the course of investigation, the Overspeed Governor (OSG P/N 8210-097, S/N 14967680) was strip examined at the OEM facility (M/s Collins Aerospace, USA) in the presence of an accrep from NTSB. Complete details of the anomalies observed inside the accident OSG shall be covered in the final air crash investigation report. Based on the observations, all Qty-48 OSGs held on the inventory of PIAC are required to be recycled through an authorized facility for **disassembly**, **inspection**, **replacement of parts (packing, hardware)** and **re-assembly** followed by **functional test**. List of OSGs (held on PIAC inventory) along with priority (1 being most immediate) accorded by the OEM / NTSB is given in the attached email **(Appendix 'A')**. Correspondence / emails exchanged earlier on the subject are also attached as **Appendix 'B'** for details / context.

3. Aforesaid in view, kindly undertake recycling of all OSGs held at PIAC inventory as per recommendations / priorities assigned by the Propeller System's OEM / NTSB under intimation to this office.

(M USMAN GHANI)
Air Commodore
President SIB

To,

GM Safety & QA,
M/s PIAC,
JIAP, Karachi

Copy to:-

1. PS to Secretary Aviation Division, Islamabad
2. PSO to DG CAA , HQ CAA
3. Secy to AD DG CAA, HQ CAA
4. SO to Chairman & CEO PIAC, JIAP, Karachi
5. Director Airworthiness, HQ CAA

Collins Aerospace

SIL: 796

Service Information Letter 796

This Service Information Letter is prepared in support of ATA Specification No. 100. If any questions arise regarding this data, please contact your Collins Aerospace Representative or the Collins Aerospace Customer Response Center (CRC) at 1-877-808-7575.

APPLICATION:	All ATR 42 and all ATR 72
ATA CHAPTER:	61
TITLE:	Propeller Component Removal and Storage
REFERENCE:	P5188, P5196, P5202, P5204, P5206, and P5207
EXPIRATION DATE:	N/A
REVISION(S):	N/A

Hamilton Sundstrand, a part of Collins Aerospace, is releasing this Service Information Letter (SIL) to remind operators that when a propeller system component that is part of the engine and propeller oil system is removed, that the proper removal and storage practices are followed to ensure no foreign objects or debris are introduced into the component and subsequently into the engine and propeller system oil. This applies to the Propeller Control (Propeller Control Unit (PCU), Propeller Servo Valve (PSV), or Propeller Valve Module (PVM) as applicable), Overspeed Governor (OSG), Main Pump, Auxiliary Motor and Pump, Propeller Actuator, and Transfer Tube Assembly.

When possible all components should have the exterior surfaces cleaned prior to removal to prevent possible contamination as per the applicable maintenance manual. Cleaning of exterior surfaces can be continued after removal provided that the hydraulic ports are adequately protected. For the PSV and PVM, Maintenance Manuals P5202, P5207, and P5206 as applicable, section 61-22-00, Disassembly, details the protective caps that should be installed when the PSV or PVM is removed. For the Transfer Tube, in the applicable maintenance manual, section 61-10-00, Disassembly instructs to use storage container GS20401-1 or GS26224-1 as applicable. For the other components standard maintenance procedures (such as using a suitable container to preserve the component and to protect from debris entering the component) should be used when the component is removed from the aircraft.

U.S. Export Classification: NSR

This document does not contain any export controlled technical data.