ACCIDENT INVESTIGATION COMMISSION

FINAL REPORT
AIC 18-1002

Air Vanuatu Operations Limited

YJ-AV71

ATR 72-500

Loss of directional control during landing roll

Bauerfield International Airport, Port Vila

REPUBLIC OF VANUATU

28 July 2018

FOREWORD

The Accident Investigation Commission (AIC) is an independent statutory agency of Papua New Guinea (PNG). The AIC is governed by a Commission and is entirely separate from the judicial authorities, transport regulators, policy makers and service providers.

The AIC's function is to improve safety and public confidence in the aviation mode of transport through excellence in: independent investigation of aviation accidents and other safety occurrences within the aviation system; safety data recording and analysis; and fostering safety awareness, knowledge and action.

The AIC is responsible for investigating accidents and other transport safety matters involving civil aviation in PNG, as well as participating in overseas investigations involving PNG registered aircraft. The Commission's primary concern is the safety of commercial air transport, with particular regard to fare-paying passenger operations.

The AIC conducts investigations in accordance with the provisions of the *PNG Civil Aviation Act 2000 (As Amended)*, *Commissions of Inquiry Act 1951*, and *Annex 13* to the Convention on International Civil Aviation.

In meeting its international obligations under ICAO Annex 13 Standards, the AIC seeks to cooperate with and assist other States in the Region. *Annex 13 Chapter 5, Paragraph 5.1* and *Note 2* state:

> 5.1 The State of Occurrence shall institute an investigation into the circumstances of the accident and be responsible for the conduct of the investigation, but it may delegate the whole or any part of the conducting of such investigation to another State or a regional accident and incident investigation organization (RAIO) by mutual arrangement and consent. In any event, the State of Occurrence shall use every means to facilitate the investigation.
>
> *Note 2. — When the whole investigation is delegated to another State or a regional accident and incident investigation organization, such a State is expected to be responsible for the conduct of the investigation, including the issuance of the Final Report and the ADREP reporting. When a part of the investigation is delegated, the State of Occurrence usually retains the responsibility for the conduct of the investigation.*

The object of a safety investigation is to identify and reduce safety-related risk. AIC investigations determine and communicate the safety factors related to the transport safety matter being investigated and any other safety concerns identified during the course of the investigation even if not causal to the occurrence being investigated.

It is not a function of the AIC to apportion blame or determine liability. At the same time, an investigation report must include factual material of sufficient weight to support the analysis and findings.

At all times the AIC endeavors to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why it happened, in a fair and unbiased manner.

About this report

This occurrence was formally notified to the AIC on 28 July 2018 with the request from the Director Civil Aviation Authority of Vanuatu (CAAV) for the PNG AIC to provide investigation assistance.

Investigators arrived at the accident site on Sunday afternoon 29 July 2018 and immediately commenced assisting the CAAV on-site investigation.

On 29 July, the CAAV delegated the whole of the investigation to the PNG AIC in accordance with *Paragraph 5.1* of *Annex 13*.

The PNG Minister for Civil Aviation approved the Commission to accept the delegated investigation and the AIC Board endorsed and accepted the delegation.

The on-site investigation was fully supported by AIC staff in Port Moresby and the resources of the AIC's flight recorder laboratory.

The Director of the CAAV undertook to provide guidance on applicable *Republic of Vanuatu Civil Aviation Legislation*. However, where possible the conduct of the investigation was in accordance with the PNG legislation, the AIC Policy and Procedures, and at all times in accordance with *ICAO Annex 13*.

This *Final Report* was produced by the PNG AIC, PO Box 1709, Boroko 111, NCD, Papua New Guinea and the Commission has made it publicly available in accordance with *ICAO Annex 13, Chapter 3, paragraph 6.5.* It will be published on the PNG AIC website.

The report is based on the investigation carried out by the AIC in accordance with *Annex 13*. It contains factual information, analysis of that information, findings, and *Safety Recommendations*.

Readers are advised that in accordance with *Annex 13* to the *Convention on International Civil Aviation*, it is not the purpose of an AIC aircraft accident investigation to apportion blame or liability. The sole objective of the investigation and the final report is the prevention of accidents and incidents. (Reference: *ICAO Annex 13, Chapter 3, paragraph 3.1*). Consequently, AIC reports are confined to matters of safety significance and may be misleading if used for any other purpose.

> When the AIC makes recommendations as a result of its investigations or research, safety is its primary consideration. However, the AIC fully recognizes that the implementation of recommendations arising from its investigations will in some cases incur a cost to the industry.
>
> Readers should note that the information in AIC reports and recommendations is provided to promote aviation safety. In no case is it intended to imply blame or liability.

Hubert Namani, LLB

Chief Commissioner

29th October 2019

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GLOSSARY OF ABBREVIATION

ACAS	:	Airborne Collision Avoidance System
ACW	:	Alternating Current Wild
ADC	:	Air Data Computer
AEP	:	Airport Emergency Plan
AMM	:	Aircraft Maintenance Manual
AMSL	:	Above Mean Sea Level
AOA	:	Angle of Attack
AOC	:	Air Operator Certificate
ARFFS	:	Aviation Rescue and Fire-Fighting Service
ATC	:	Air Traffic Control
ATPCS	:	Automatic Take-off Power Control System
ATPL	:	Airline Transport Pilot License
ATR	:	Avions de Transport Régional
ATS	:	Air Traffic Services
AVL	:	Airport Vanuatu Limited
AVN	:	Air Vanuatu
BEA	:	Bureau d’Enquêtes et d’Analyses
BN-2	:	Britten-Norman Islander Aircraft
BTC	:	Bus Tie Contactor
CAAV	:	Civil Aviation Authority of Vanuatu
CAM	:	Cockpit Area Microphone
CAP	:	Crew Alert Panel
CCAS	:	Centralised Crew Alerting System
CC	:	Cabin Crew
CCOM	:	Cabin Crew Operating Manual
CCPTM	:	Cabin Crew Procedures and Training Manual
C of A	:	Certificate of Airworthiness
C of R	:	Certificate of Registration
CPL	:	Commercial Pilot License
CRC	:	Continuous Repetitive Chime
CRM	:	Crew Resource Management
CSN	:	Cycles Since New
CVR	:	Cockpit Voice Recorder
DC	:	Direct Current
DFDR	:	Digital Flight Data Recorder
EASA	:	European Union Aviation Safety Agency
EGPWS	:	Enhanced Ground Proximity Warning System
EGR	:	Engine Ground Run
EXT PWR	:	External Power
FAA	:	Federal Aviation Administration
FAP	:	Flight Attendant Panel
FCOC	:	Fuel Cooled Oil Cooler
FCOM	:	Flight Crew Operating Manual
FDR	:	Flight Data Recorder
FO	:	First Officer
FOD	:	Foreign Object Damage

FOM	:	Flight Operations Manual
ft	:	Feet
FL	:	Flight Level
GND	:	Ground
GPWS	:	Ground Proximity Warning System
GXC	:	Generator Transfer Contactor
HP	:	High Pressure
IAS	:	Indicated Airspeed
ICAO	:	International Civil Aviation Organisation
ITT	:	Interstage Turbine Temperature
kts	:	Knots
LAME	:	Licensed Aircraft Maintenance Engineer
LP	:	Low-Pressure
LTAA	:	Lufthansa Technik Aero Alzey
MC	:	Master Caution
MCD	:	Metal Chip Detector
MoU	:	Memorandum of Understanding
MW	:	Master Warning
NAC	:	Nordic Aviation Capital
NM	:	Nautical Mile
OEM	:	Original Equipment Manufacturer
PA	:	Public Address
PASO	:	Pacific Aviation Safety Organization
pb	:	push button
PBE	:	Protective Breathing Equipment
PF	:	Pilot Flying
PIC	:	Pilot in Command
PL	:	Power Levers
PM	:	Pilot Monitoring
PNG AIC	:	Papua New Guinea Accident Investigation Commission
PT	:	Power Turbine
PT6A	:	Pratt and Whitney engine type model
PW100	:	Pratt and Whitney engine type model
QAR	:	Quick Access Recorder
QRH	:	Quick Reference Handbook
RAIO	:	Regional Accident and Incident Investigation Organization
RCU	:	Rudder Control Unit
RIC	:	Rear Inlet Case
RGB	:	Reduction Gearbox
RTO	:	Reserve Take Off
SCC	:	Senior Cabin Crew
SD Card	:	Secure Digital Card
SHP MAX	:	Shaft Horsepower Maximum
SME	:	Subject Matter Expert
SOP	:	Standard Operating Procedures
SSCVR	:	Solid State Cockpit Voice Recorder
SSFDR	:	Solid State Flight Data Recorder
TAWS	:	Terrain Awareness Warning System
TCAS	:	Traffic Alert and Collision Avoidance System

TLU	:	Travel Limitation Unit
TM	:	Turbo Machinery
TSBC	:	Transportation Safety Board Canada
TSN	:	Time Since New
UTC	:	Universal Time Coordinated

INTRODUCTION

SYNOPSIS

On 28 July 2018, at 23:33 UTC (10:33 local time) an Avions de Transport Regional, ATR72-500 registered YJ-AV71, operated by Air Vanuatu Operations Limited was on a scheduled flight from Whitegrass Airport, Tanna to Bauerfield International Airport, Port Vila when during its landing roll, the aircraft lost directional control and veered off the runway towards the left of runway 29, and collided with two unoccupied Britten-Norman BN-2 Islander aircraft. The ATR had 39 passengers and four crew; two pilots and two Cabin Crew. There were no reported injuries.

While enroute at 16,000 ft and about 60 nm from Port Vila, the flight crew noticed the *No. 2 engine Interstage Turbine Temperature (ITT 2)* gauge reading increase rapidly and subsequently exceed its normal operating limits causing the *Master Caution* visual and aural warnings to activate.

The crew and passengers reported hearing loud banging noises from the right side of the aircraft. Some passengers reported seeing white flashes in the cabin. The Pilot in Command (PIC) stated that the noises sounded like the engine compressor stalling.

The PIC immediately took control of the aircraft from the copilot and retarded the *power levers*, causing the engine temperature to stabilise. The PIC then instructed the copilot to refer to the *'ATR Quick Reference Handbook (QRH) 'Abnormal Engine Parameters in Flight' checklist.*

The Senior Cabin Crew (SCC) was being briefed about the engine abnormality by the PIC via the crew interphone system when she informed the flight crew that there was smoke entering the cabin from the right side of the cabin. The PIC broadcast a *'Mayday'* and notified Vila Air Traffic Control (ATC) of their descent intentions. The flight crew commenced descent and proceeded to complete the checklist.

The smoke intensified in the cabin and travelled through other compartments. The flight crew donned their oxygen masks when they noticed smoke entering the flight deck.

About 2 minutes after the *'Mayday'* call, as the PIC was completing an announcement to the passengers the electrical smoke warning activated in the cockpit.

About 11 minutes prior to landing, the PIC instructed the copilot to refer to the *QRH 'ELECTRICAL SMOKE'* emergency checklist. That checklist required both of the Generators, termed *Alternating Current Wild (ACW)*, to be switched off, which was actioned in accordance with the checklist. As a result, the aircraft's main hydraulic pumps were no longer available resulting in the main-wheel brakes and nose-wheel steering no longer being available.

Just over 6 minutes after the first abnormal engine event, the *No. 2 engine* oil low pressure warning activated. The crew then referred to the *QRH 'ENG 1(2) OIL LO PR'* checklist and subsequently shut down the *No. 2 engine*. The rest of the descent and the landing were conducted with one engine inoperative.

The rudder *Travel Limitation Unit (TLU)* remained locked in the high-speed mode when the engine was shut down and was not checked and manually operated during the landing approach. The *QRH 'Before Landing'* checklist contained a *TLU* check action item, but the checklist was not consulted resulting in the *TLU* remaining locked in the high-speed mode, which significantly restricted rudder deflection. The aircraft had significantly limited rudder authority at low speed.

Analysis of the recorded Flight Data showed that 1 second after touchdown both power levers were set to maximum reverse and then advanced back to ground idle. The aircraft momentarily turned left with the initial application of reverse thrust. That was followed by a right turn when the thrust was set to ground idle and the aircraft again lined up with the runway direction. About 200 metres further along the landing roll, when maximum reverse thrust was again applied, the aircraft veered left off the runway and rolled across the taxiway, slowing to 45 kts before it impacted the two Britten-Norman BN-2 Islander aircraft. Impact damage was more prevalent on the starboard side of the ATR.

The emergency brake was available but the investigation found no evidence to show that emergency brakes were applied. The flight crew reported that they could neither control, nor stop the aircraft during the ground roll.

After the aircraft came to a stop, the PIC issued the evacuation command and the cabin crew conducted an orderly expedited evacuation of the passengers. None of the passengers and crew were injured during the evacuation.

Aviation Rescue and Firefighting services were standing by at the aerodrome before the landing. They assisted with the evacuation process.

The engine malfunction resulted in the generation of smoke, which activated the *Electrical Smoke Warning*, and prompted the declaration of a *'Mayday'* and an immediate descent. The investigation found that the engine malfunction, while contributing to the generation of smoke and subsequent crew checklist actions, did not cause the accident. Flight crews are trained to land multi-engine aircraft with an engine inoperative.

As a result of the investigation into the accident the Papua New Guinea Accident Investigation Commission issued the three *Safety Recommendations* to ATR for the enhancement of the *ATR Quick Reference Handbook* checklists. The recommendations are to ensure checklists are ergonomically able to draw the attention of flight crews to take appropriate safety action and ensure that the appropriate *'Before landing'* checklist is used.

The AIC also issued two *Safety Recommendations* to Air Vanuatu Operations Limited to ensure flight crews are adequately trained, current and competent in the execution of smoke emergency procedures and that Cabin Crew are adequately trained on cabin safety duties in relation to smoke emergency procedures.

At the time of issuing the *Final Aircraft Accident Investigation Report*, ATR and Air Vanuatu Operations Limited had not informed the PNG AIC of safety action proposed or taken to address the safety concerns identified during the investigation.

1 FACTUAL INFORMATION

1.1 History of the flight

On 28 July 2018, at about 23:33 UTC[1] (10:33 local time) an ATR 72-500 aircraft, registered YJ- AV71 (AV71), operated by Air Vanuatu Operations Limited, veered off the left of runway 29 during its landing roll at Bauerfield International Airport, Port Vila, Vanuatu, and collided with two unoccupied Britten-Norman BN-2 Islander (BN-2) aircraft in the airport apron area.

The aircraft was being operated on a scheduled passenger service flight from Whitegrass Airport, Tanna to Bauerfield Airport, Port Vila. The copilot was the designated pilot flying (PF) for that sector. The Pilot in Command (PIC) was the support/monitoring pilot. There were 39 passengers and four crew members onboard; two pilots and two cabin crew. None of the aircraft's occupants were injured.

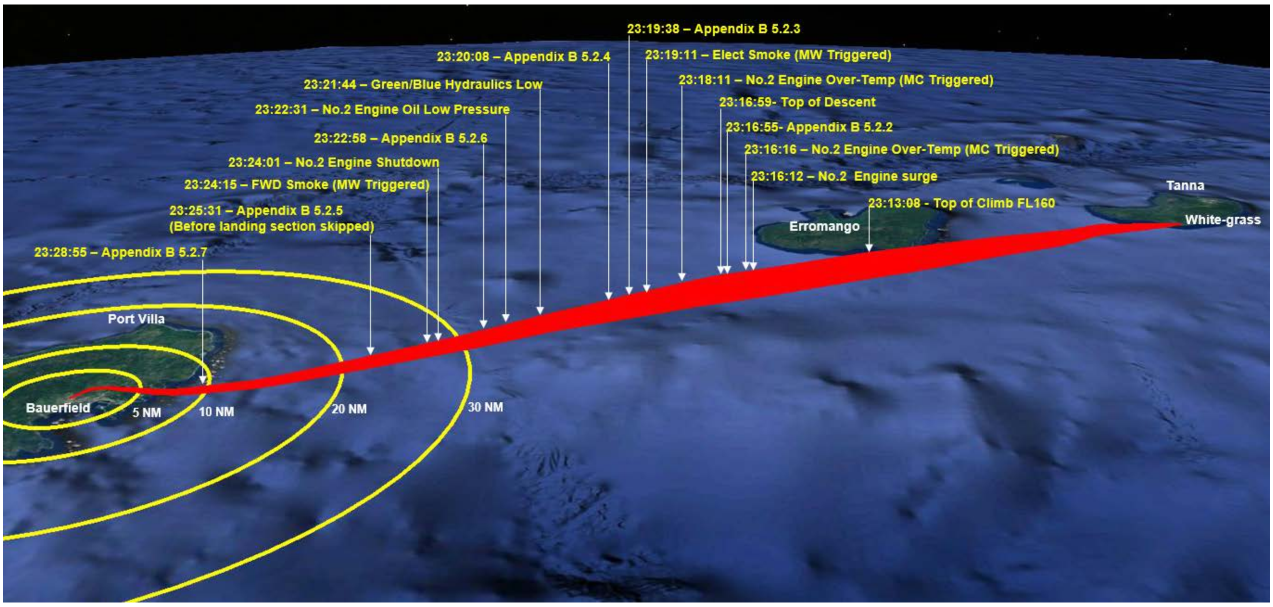


Figure 1: AV71 Flight Path from Tanna to Port Vila derived from the Flight Data Recorder

While enroute at 16,000 ft and about 60 nm from Port Vila, the crew and passengers reported hearing loud bangs from the right side of the aircraft. Some passengers reported seeing white flashes in the cabin. The PIC stated that the noises they heard sounded like surges and that the *No. 2*[2] *engine* was stalling[3].

The flight crew noticed the *No. 2 engine Interstage Turbine Temperature (ITT) gauge* reading rise rapidly and exceed its limit. A Master Caution[4] (MC) alert instantly followed the exceedance at 23:16:18.

The PIC immediately took control of the aircraft and retarded both *power levers (PL)* to reduce the *ITT* and stabilise the engine.

At 23:16:37, the PIC instructed the copilot to refer to the *ATR Quick Reference Handbook (QRH) 'ABNORMAL ENG PARAMETERS IN FLIGHT, A70.13'* checklist *(see Appendix B, 5.2.2).*

1 The 24-hour clock, in Coordinated Universal Time (UTC), is used in this report to describe the local time as specific events occurred. Local time in the area of the accident, Vanuatu Time (VUT) is UTC + 11 hours.
2 No. 2 engine: right engine.
3 Engine stall - commonly refers to an engine **compressor stall** where there is a *local disruption of the airflow* in the compressor of an engine while it is in operation. A stall that results in the complete disruption of the airflow through the compressor is referred to as a **compressor surge**. *Local disruption of airflow* in this case is when the flow of air is not all in the same direction and results in loud banging noises and/or vibration.
4 Master Caution – These are amber flashing lights used as ATTENTION GETTERS. Together with aural signals, they enable the flight crew to detect failures which require urgent crew action.

The PIC subsequently called on the interphone and notified the Senior Cabin Crew (SCC) about the abnormality. The SCC informed the PIC that there was smoke entering the cabin from the right side of the aircraft. The PIC exclaimed, *"Smoke!"*, and immediately broadcast a *'MAYDAY*[5].'

PIC to Vila ATC*[6]*:	*Vila, Victor 71, Mayday, Mayday, Mayday, we got cabin smoke*
Copilot to PIC:	*Engine parameters in flight. Ah 70.131*
Vila ATC to AV71:	*Victor 71, villa say again?*
PIC to Vila ATC:	*Victor 71 ah mayday, mayday, mayday, engine smoke and we got an engine problem, we might have to shut it down*

At 23:16:59, the PIC notified Vila Air Traffic Control (ATC) that they were commencing descent. Vila ATC acknowledged and asked if they would need fire truck assistance on standby at the airport. The PIC replied, "not required at this stage, we'll get back to you".

At 23:17:51, the flight crew donned their oxygen masks and recommenced the *QRH 'A70.13'* checklist. They had only completed the first item on the checklist when the PIC interrupted the copilot by calling the SCC again for cabin a smoke status update. The SCC confirmed that smoke was still entering the cabin.

At 23:18:37, the PIC called and instructed the SCC to don her *Protective Breathing Equipment*[7] *(PBE)* and carry out the cabin smoke procedures as required. The PIC then made a *public address (PA)* announcement to all passengers to remain seated and await further instructions.

At 23:19:11, while the PIC was making the public announcement, the red Master Warning[8] (MW) alert activated accompanied by the *'ELEC SMK'* warning message on the *Crew Alert Panel (CAP)*. The PIC immediately instructed the copilot to refer to the *QRH 'ELECTRICAL SMOKE, E26.05'* emergency checklist *(see Appendix B, 5.2.3).*

At 23:19:34, the PIC made a request to Vila ATC for fire services to be on standby as the smoke situation would require them to stop on the runway to evacuate passengers.

At 23:20:02, the copilot began reading from the *QRH 'ELECTRICAL SMOKE'* checklist. The first action item referred the crew to the *QRH 'SMOKE, E26.01'* emergency checklist *(see Appendix B, 5.2.4)*. The copilot started the *QRH 'SMOKE'* checklist and half way through the *'memory items*[9]*'* of that checklist, the PIC interrupted and instructed the copilot to go back to the *QRH 'E26.05'* emergency checklist and complete that first, but quickly corrected himself and asked the copilot to continue with the *'SMOKE'* checklist. The crew hastily completed the memory items and returned to continue with the *QRH 'ELECTRICAL'* checklist. The crew actioned that checklist up to action item nine, which referred them to the *QRH 'ACW GEN 1+2 LOSS, A24.07'*checklist *(see Appendix B, 5.2.5)*, but they did not refer to that checklist.

At 23:22:21, the SCC called the PIC and exclaimed that smoke was still present in the cabin and was intensifying. The PIC subsequently told the SCC that they would need to be ready for an evacuation of the passengers on the runway.

At 23:22:31, while communicating with Vila ATC during the descent about 33 nm from Bauerfield, the MW activated, along with the red *'OIL'* message on the *CAP* and red local alert[10] warning light on the *No. 2 engine oil pressure gauge.* As soon as the PIC finished, he instructed the copilot to refer to the *QRH 'ENG 1(2) OIL LO PR, A70.14'* checklist, *(see Appendix B, 5.2.6).*

5 ***MAYDAY:*** International call for urgent assistance, from French "m'aidez!" Hence, to declare a *, to go *; usually sent on 121.5 MHz. (Source Cambridge Aerospace Dictionary.)

6 Vila ATC refers to Port Vila Air Traffic Control.

7 Refer to *Appendix E, 5.5.2 for ATR CCOM information on PBE.*

8 Master Warning – These are red flashing lights used as ATTENTION GETTERS. Together with aural signals, they enable the flight crew to detect failures which require immediate crew action.

9 Memory items - framed with double-lines in the ATR QRH. Pilots action memory items of a particular checklist before referring to that checklist to confirm appropriate actions have been taken.

10 Local Alert: See *Section 1.6.2.1* and *Appendix A, 5.1.*

The checklist had several sub-checklists (conditional), but the copilot could not determine which sub-checklist was appropriate to action. Therefore, the PIC handed control of the aircraft to the copilot and took the *QRH* to read and selected the most appropriate one for the condition. The PIC then handed the *QRH* back to the copilot and resumed control. The crew completed the checklist and shut down the *No. 2 engine*. The checklist then referred them to the *QRH 'SINGLE ENG OPERATION, A70.12'* checklist *(see Appendix B, 5.2.7)*. However, the crew did not refer to that checklist at that time.

The PIC then instructed the copilot to check and confirm if they had completed the *QRH 'ELECTRICAL SMOKE, E26.05'* checklist.

The copilot pointed out that the next action item on that checklist that they had to continue from would require them to refer to the *QRH 'ACW GEN 1+2 LOSS'* checklist.

At 23:25:31, the crew commenced the *QRH 'ACW GEN 1+2 LOSS, A24.07'* checklist. As the copilot continued to the *'Before Landing'* section of the checklist, the PIC intervened and instructed him to reserve that section and continue with the rest of the checklist. The copilot complied and skipped the *'Before Landing'* section to continue with the rest of the checklist. However, before he could finish the PIC told him to start again from the top. The copilot restarted the checklist, but before he could finish reading the first item, the PIC interrupted again by saying that they needed to complete the *QRH 'SINGLE ENGINE OPERATION'* checklist.

At 23:28:31, the copilot referred to the *QRH 'SINGLE ENGINE OPERATION'* checklist. As he read out the title, the PIC called the SCC and informed her that he would be announcing the 'brace' call before touchdown. The crew then continued with the checklist and completed it.

At 23:31:12, when the aircraft was within 5 nm of the aerodrome, the PIC instructed the copilot to refer back to the *QRH 'ACW GEN 1+2 LOSS, A24.07'* checklist and continue with the *'Before Landing'* section *(see Appendix B, 5.2.5)*. At about 1,900 ft, on descent, the crew selected the *landing gear lever* down and extended the *flap* to 15° and subsequently to 30° at about 1,400 ft. For the landing gear extension[11], the PIC handed aircraft control over to the copilot while he performed the manual landing gear extension procedure from memory and successfully extended the landing gear. After confirming *landing gear* extension, the PIC resumed control of the aircraft.

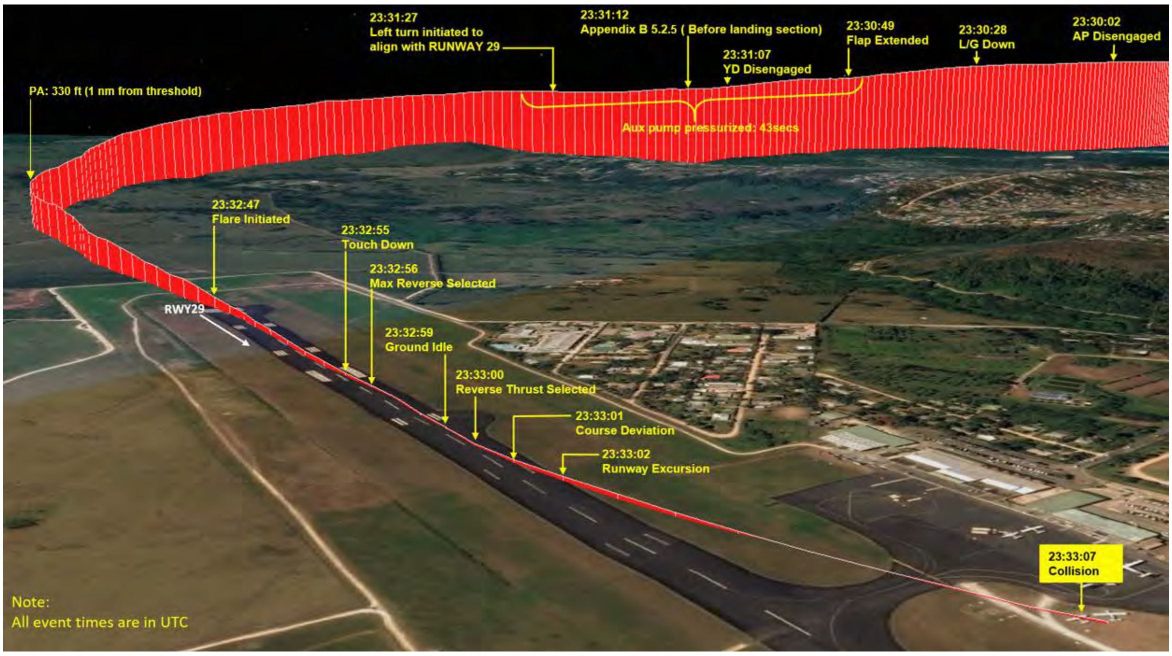


Figure 2: AV71 Approach and Landing

11 With the loss of the *'ACW GEN 1+2'* the landing gear was extended using manual gravity extension procedure in accordance with the *QRH 'A32.03'* checklist.

The *QRH* '*Before Landing, 4.2'* checklist, *(see Appendix B, 5.2.13)* was not consulted during the descent to land.

The PIC continued the descent and completed the final turn to line up with runway 29 at about 330 ft and 1 nm from the runway threshold. The final approach was maintained on profile. The PIC made a PA brace call at about 330 ft. At about 20 ft, the PIC initiated the flare. The final approach descent was recorded at 500 ft/min and decreasing as the aircraft passed the threshold. The *power levers* were retarded to flight idle when the aircraft was about 6 ft above the runway. The rudder was recorded to have deflected from +6° (left) to -1° (right) 1 second before touchdown.

At 23:32:55, the aircraft touched down about 400 m past the runway 29 threshold near the runway touchdown zone *(see Figure 2)*. The *power levers* were pulled into the maximum reverse thrust setting 1 second after touchdown.

The power levers remained in maximum reverse for 1 second before they were advanced back to ground idle. The speed started to decrease from 98 kts as the aircraft rolled down the runway. About 200 m further along the runway, at a speed of 65 kts, the *power levers* were pulled back into the reverse setting. The aircraft subsequently veered to the left and ran off the left of the runway and tracked 320 m over the grass field and across the taxiway before colliding with two parked, unoccupied, BN-2 aircraft *(see Figure 2)*.

The PIC stated that they had no directional control or brakes and could not stop the aircraft's runway excursion and subsequent collision. The aircraft came to an abrupt stop after the collision with the BN-2 aircraft.

As soon as the aircraft came to rest, the PIC gave the command to evacuate. The cabin crew conducted an orderly, expedited evacuation. The passengers and crew safely egressed without injury.

1.2 Injuries to persons

Injuries	Flight crew	Passengers	Total in Aircraft	Others
Fatal	-	-	-	-
Serious	-	-	-	-
Minor	-	-	-	Not applicable
Nil Injuries	4	39	43	Not applicable
TOTAL	4	39	43	-

Table 1: Injuries to persons

1.3 Damage to aircraft

The ATR sustained significant damage to the right side of the *fuselage, propeller assembly, right-main landing gear nacelle* and *nose landing gear door* structure. The *No. 2 engine* was substantially damaged *(see Section 1.6.1.4)*.

Figure 3: AV71 Right fuselage impact damage

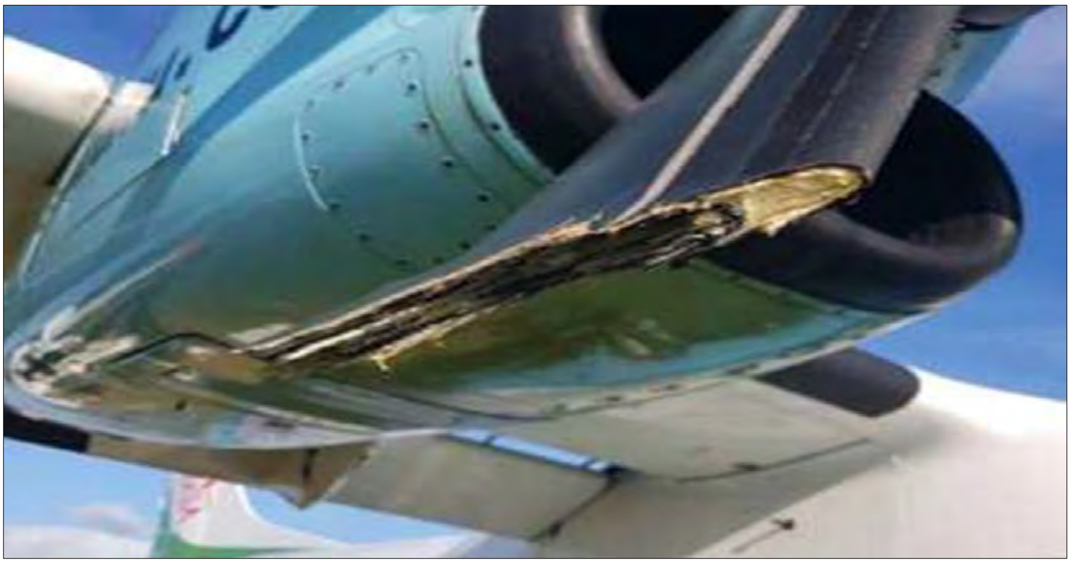


Figure 4: Fractured right propeller blade

1.4 Other damage

Two BN-2 Islander aircraft, YJ-OO9 and YJ-AL2 were substantially damaged when they were impacted by AV71. The forward fuselage of YJ-OO9 was impacted by the right side of AV71 and was destroyed.

The outboard section of the left wing (YJ-OO9) was substantially damaged and the rudder and vertical stabiliser were sheared off the aircraft (see Figure 5).

Figure 5: BN-2 Islander, YJ-OO9 destroyed by the starboard-side of AV71

YJ-AL2, also sustained vertical stabiliser and rudder damage from impact with the left side of AV71. The upper hinge of the rudder was dislodged *(see Figure 6)*.

Figure 6: BN-2 Islander damaged by the left side of AV71

1.5 Personnel information

1.5.1 Pilot in command

Age	: 34 years
Gender	: Male
Nationality	: France
Position	: Training Captain / ATR Fleet Manager
Type of license	: ATPL Vanuatu
Route	: Endorsed
Type rating	: ATR 72-500
Total flying time	: 7,205.4 hours
Total on ATR 72-500	: 3,870.2 hours
Total hours last 30 days	: 35.9 hours
Total hours last 7 days	: 1.6 hours
Total hours last 24 hours	: 1.6 hours
Medical class	: One
Valid to	: 2 July 2019
Medical limitation	: Prescription lenses to be worn[12]

The PIC completed his operational competency training and assessment for transition to the ATR 72-500 on 8 November 2014. He was not assessed for smoke control and removal during the transition assessment. The PIC subsequently completed six ATR 72-500 Simulator Competency tests. He was only assessed twice for smoke control and removal emergency procedures.

His most recent simulator smoke training and assessment was done on 11 May 2015.

He was conducting a line training flight for the copilot on the day of the accident.

1.5.2 Copilot

Age	: 27 years
Gender	: Male
Nationality	: Vanuatu
Position	: Line pilot
Type of license	: CPL Vanuatu
Route	: Endorsed
Type ratings	: ATR 72-500 (Co-Pilot), DHC-6
Total flying time	: 1,629.7 hours
Total on ATR 72-500	: 55.0 hours
Total hours last 30 days	: 26.8 hours
Total hours last 7 days	: 3.1 hours
Total hours last 24 hours	: 1.6 hours

On the day of the accident the copilot was undergoing line training.

12 The prescribed lenses were worn at the time of the accident.

His initial type rating and subsequent line training records listed task sharing as pilot monitoring, Crew Resource Management (CRM) and system knowledge as areas of deficiency that needed to be improved.

1.5.3 Senior Cabin Crew (SCC)

Age	: 40 years
Gender	: Female
Nationality	: Vanuatu
Type of certificate	: ATR 72-500/600 and Boeing737-800
Competency ATR 72-500 Type Rating	: 05 July 2018
Total flying time	: 515.46 hours[13]
Total on ATR	: 466.11 hours

The SCC was qualified and had 21 years of experience as a cabin crew. She held a current ATR 72-500/600 Emergency Procedures Training Certificate, which was revalidated on 5 July 2018.

On the accident flight, the SCC occupied the rear cabin crew station *(see Figure 28)*.

1.5.4 Other Cabin Crew (CC)

Age	: 24 years
Gender	: Male
Nationality	: Vanuatu
Type of certificate	: ATR 72-500/600 and Boeing 737-800
Competency ATR 72-500 Type Rating	: 10 April 2018
Total flying time	: 258.15 hours
Total on ATR 500/600	: 244.48 hours

The other CC had 3 years' experience as a cabin crew member. He held a valid ATR 72-500/600 Emergency Procedures Training Certificate which was revalidated on 10 April 2018.

On the accident flight, the CC member occupied the forward cabin crew station *(see Figure 28)*.

1.5.5 LAME 1

Age	: 45 years
Gender	: Male
Nationality	: Solomon Islands
Position	: LAME
Type of license	: Group 3 and 6 (Airframe and Powerplant)
Type ratings	: ATR42/72-500
Issuing Authority	: New Zealand CAA & CAAV Validation Certificate
Competency ATR 72-500 Type Rating	: 4 Feb 2019

Note: LAME 1 was not on the aircraft at the time of the accident, but was responsible for maintenance of the aircraft.

13 Total flying time for the period from 2014 to the date of occurrence. Flight Scheduling & Crew Management system adopted by Air Vanuatu in 2014.

1.5.6 LAME 2

Age	: 33 years
Gender	: Male
Nationality	: Vanuatu
Position	: LAME
Type of license	: Group 6 (Airframe and Powerplant)
Type ratings	: ATR42/72-500
Issuing Authority	: CAAV
Competency ATR 72-500 Type Rating	: 30 Mar 2018

Note: LAME 2 was not on the aircraft at the time of the accident, but was responsible for maintenance of the aircraft.

1.6 Aircraft Information

1.6.1 Aircraft data

Aircraft manufacturer	: Avion's de Transport Regionale (ATR)
Model	: ATR 72-500
Serial number	: 720
Year of manufacture	: 2005
Registration	: YJ-AV71
Name of the owner	: Nordic Aviation Capital (NAC) Aviation 8 Limited
Name of the operator	: Air Vanuatu Operations Limited
Certificate of Airworthiness number	: 285
Certificate of Airworthiness issued	: 28 April 2018
Valid to	: 3 April 2019
Certificate of Registration number	: 285
Certificate of Registration issued	: 5 April 2017
Certificate of Registration valid to	: Non-terminating
Total airframe hours	: 19,887 hours 39 minutes

1.6.1.1 Engine data

Engine type	: Turbo-propeller
Manufacturer	: Pratt and Whitney Canada (P&WC)
Type	: PWC 127M

No. 1 engine (Left)

Part number	: PW127M
Serial number	: PCE-ED0192

Note: No defects with No. 1 engine therefore further details not relevant.

No. 2 engine (Right)

Part number	: PW127M
Serial number	: PCE-ED0190
Date of Manufacture	: April 2009
Total time	: 10,042.92
Total Cycles	: 12,280
Cycles since last Overhaul	: 161
Previous Overhaul	: Lufthansa Technik AERO Alzey (LTAA)

1.6.1.2 Engine History

The *No. 2 engine*, serial number ED0190, was removed on 20 January 2016 from an Air Vanuatu ATR aircraft, registered YJ-AV72 after it was reported to have sustained an engine failure and subsequent shutdown in-flight. According to the operator, the engine was removed due to a suspected *2nd stage Power-Turbine (PT)* fracture. The engine was removed and preserved for more than 2 years. It was subsequently sent to the LTAA headquarters in Germany to be overhauled.

LTAA conducted a teardown inspection on 20 April 2018. A number of findings and repair actions were reported. Many components were repaired and replaced during the overhaul exercise.

Note: For the purpose of this investigation, the LTAA findings and actions have been limited to the compressor section.

- The ***Rear Inlet Case*** was found with damaged coating in an assembled condition. LTAA attributed this damage to environmental factors. It was sent to Budney Overhaul and Repair LTD, an FAA and EASA approved repair station. The component was overhauled and sent back to LTAA where it was refitted to the engine.
- The ***Low-Pressure Diffuser Case*** was also found with its aluminium coating missing. It was sent to the OEM[14] (P&WC) where coating repair was conducted. It was then sent to LTAA where it was inspected as required and refitted to the engine.
- The ***Low-Pressure Impeller Housing*** was found corroded.
- Heavy rubbing was witnessed on the ***Low-Pressure Impeller.*** The damage was due to imbalance caused by the *2nd stage PT blade* fracture.
- ***The No. 1, 2, 3, 6 & 7 Bearings*** were scrapped due to the failure mode and replaced with new bearings.
- The ***No. 3 Bearing Air Seal*** was found worn and replaced with a new seal.
- The ***Low-Pressure Impeller Nuts*** were found worn and replaced with new nuts.
- The ***Low-Pressure Rotor Shaft*** was found damaged and replaced.

LTAA recommended further investigation to be performed on the *2nd stage PT blades* by the OEM as an independent evaluation process and to determine the root cause of the failure.

On 5 June 2018, the engine repair (and overhaul) was completed by LTAA and certified serviceable.

The engine was shipped to an approved Maintenance facility in Nadi, Fiji where it was installed to the *right wing* of YJ-AV71 on 15 July 2018. The engine ground run and test flight were carried out and the engine reportedly performed normally. The aircraft was then released to service and began commercial operations.

14 Original Equipment Manufacturer. In this reference, the OEM is Pratt & Whitney Canada.

On 22 July 2018, during taxi, at Santo, Vanuatu, the aircraft sustained a *No. 2 engine* oil low pressure indication and was subsequently shut down by the crew. LAME 1 was tasked to investigate the event on site. He traced the cause of the pressure drop back to the *rear inlet to accessory gearbox oil pressure tube*, where a leak was found.

The Air Vanuatu engineers, under the supervision of LAME 1, replaced the *O-ring seals* on the tube and refitted the tube to the engine. An engine ground test was conducted, but the leak persisted. The engine was shut down and LAME 1 ordered a replacement tube.

The aircraft remained in Santo overnight pending a new tube installation to the engine. The new tube was received and fitted the next day, 23 July. The engine was ground tested by LAME 1 and no leaks were observed. The aircraft was certified serviceable and then released to service.

On 25 July 2018, at top of descent, while on the repositioning flight from Santo to Bauerfield, the flight crew noticed a drop in the *No. 2 engine* oil pressure to 42 psi[15]. They informed LAME 1 who was onboard at the time and requested for him to verify the indication by visually observing the *engine cowling* for leaks.

During his interview with the AIC investigators, LAME 1 stated that he looked out through the passenger windows adjacent to the *No.2 engine* and did not witness any oil leaks. The flight crew opted to monitor the *oil pressure gauge* while continuing their normal descent.

On touchdown and during the landing roll, LAME 1 observed that there was oil dripping from the *No. 2 engine cowling*. He then advised the crew who immediately shut down the *No. 2 engine*.

The aircraft was taxied to the parking bay using the *No. 1 engine*. After the *No. 1 engine* was shut down, the *No. 2 engine* was inspected again and the leak was traced back to the same tube. Another oil tube was requested and was subsequently installed on 27 July 2018 by LAME 1 and his engineering team. They also conducted a weekly/400 hourly routine-check at that time.

The ground test run and checks were completed successfully, but the aircraft's release to service was recorded as conditional on a mandatory verification flight imposed by LAME 1.

The verification flight was conducted successfully on 28 July 2018, the day of the accident, with LAME 2 onboard, who released the aircraft to service after the test flight.

During the accident flight, the engine sustained a rapid *ITT* rise and subsequent normal operating exceedance.

Loud bangs, similar to those that would be heard during an engine seizure, were heard as the compressor stalled. The engine was shut down just under 8 minutes after the engine seizure.

1.6.1.3 Propeller data

Manufacturer	: Hamilton Standard
Propeller type	: Six blade, full feathering, electronically controlled
Propeller number one (Left)	
Part number	: 815500-3
Serial Number	: FR20061250
Propeller number two (Right)	
Part number	: 815500-3
Serial Number	: FR991153

15 The oil pressure readings on the oil pressure gauge are divided as follows: **Green** sector – 55 to 65 psi, **Amber** Sector – 40 to 55 psi, and a **Red** mark at 40 psi.

1.6.1.4 Defects

No. 2 engine (Post-accident examination conducted by P&WC).

On 29 July 2019, a P&WC field engineer arrived at the accident site and conducted a borescope examination of the engine under the supervision of PNG AIC investigators. The engineer recommended that the engine should be shipped to the P&WC facility in Canada for a detailed disassembly investigation. The request was accepted by the investigation and the engine was subsequently shipped to Canada.

The engine was received at P&WC Service Centre St-Hubert, Quebec, and placed in quarantine. The engine disassembly investigation was performed between 9 and 11 October 2018, under the supervision of the Transportation Safety Board of Canada (TSBC) Accredited Representative to the investigation.

A *disassembly investigation report* was provided to the AIC to complement the investigation.

NOTE: The AIC determined that the engine malfunction, in isolation, did not cause the accident. The AIC report focuses only on findings and analysis from the P&WC reports that were identified as being relevant to the root cause of the engine malfunction, and the subsequent smoke event. The P&WC report investigation section is discussed below while the *Material Laboratory* section can be found in Appendix F, 5.6.

The P&WC findings were as follows:

The power turbine rotor rotated freely while the *low-pressure* and *high-pressure rotors* were seized. The *turbo machinery (TM)* and the *reduction gearbox (RGB) magnetic chip detectors (MCD)* had collected ferrous debris to a different extent *(see Figure 7)*. The debris on the *MCD's* was collected and sent to the chemical laboratory for analysis and revealed metallic particles similar to M50 and similar to 400 series stainless steel.

Metallic particles were also found in the *TM* and *RGB oil filters* and *cover (see Figure 8)*. The particles in the oil filter cover were collected and sent to the chemical laboratory for analysis and revealed metallic particles similar to M50 and similar to 400 series stainless steel.

Impact damage was observed on the *power turbine disc assembly*. When the *low-pressure turbine disc assembly* was removed, evidence of rubbing with the *low-pressure vane assembly* was observed. The *interstage turbine baffle* of the *low-pressure vane assemblies* was torn as a result of rubbing with the *low-pressure turbine disc assembly*. The upstream side of the *low-pressure turbine disc assembly* showed a groove at the bottom portion of the blade leading edge and rubbing at various location of the disc face. These indications showed that the *low-pressure turbine disc assembly* moved forward into the *low-pressure turbine stator*.

Rubbing was observed at the *high-pressure turbine disc assembly* at the blade tips. The *rear inlet to accessory gearbox oil pressure tube* was inspected and found to be in normal condition. A non-destructive test inspection was performed and did not reveal any cracks.

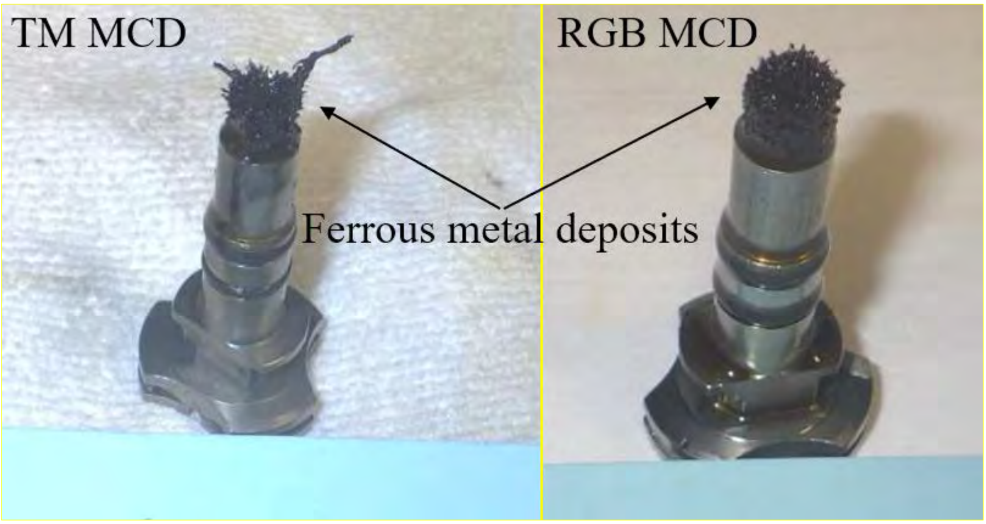


Figure 7: AV71 *No. 2 engine* magnetic chip detectors

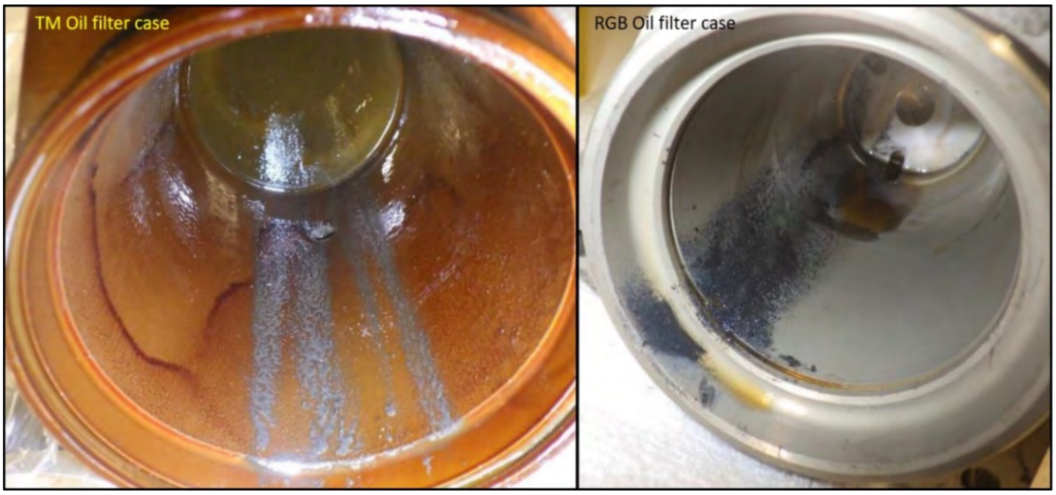


Figure 8: Oil filter cases

When the *combustion chamber* was removed, evidence of an internal oil leak was observed.

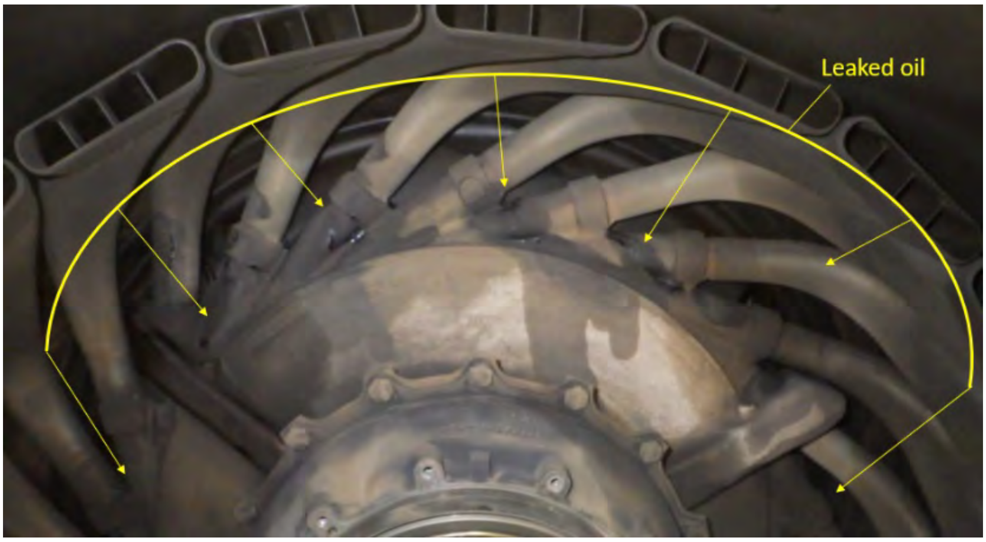


Figure 9: Evidence of oil leak

When the *rear inlet case* was removed, evidence of rubbing at the *impeller shroud housing* and three large perforation areas was observed *(see Figure 10)*. The *No. 2 bearing housing* was circumferentially fractured adjacent to the *No. 2 bearing outer race* location as a result of rubbing against the *low-pressure impeller blade profile*, the *bore*, and *forward face (see Figure 10 &11)*. These indicated that the *low-pressure impeller* moved forward into its *low-pressure impeller housing*. Engine oil and rubbing marks were observed on the back face of the *impeller (see Figure 12)*.

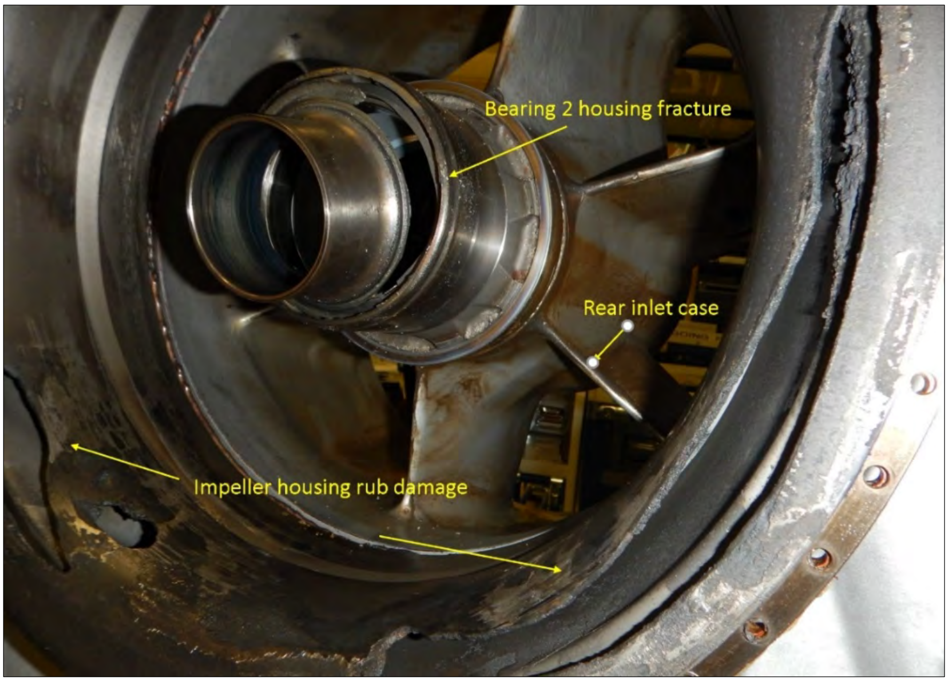


Figure 10: Rear inlet case and impeller housing

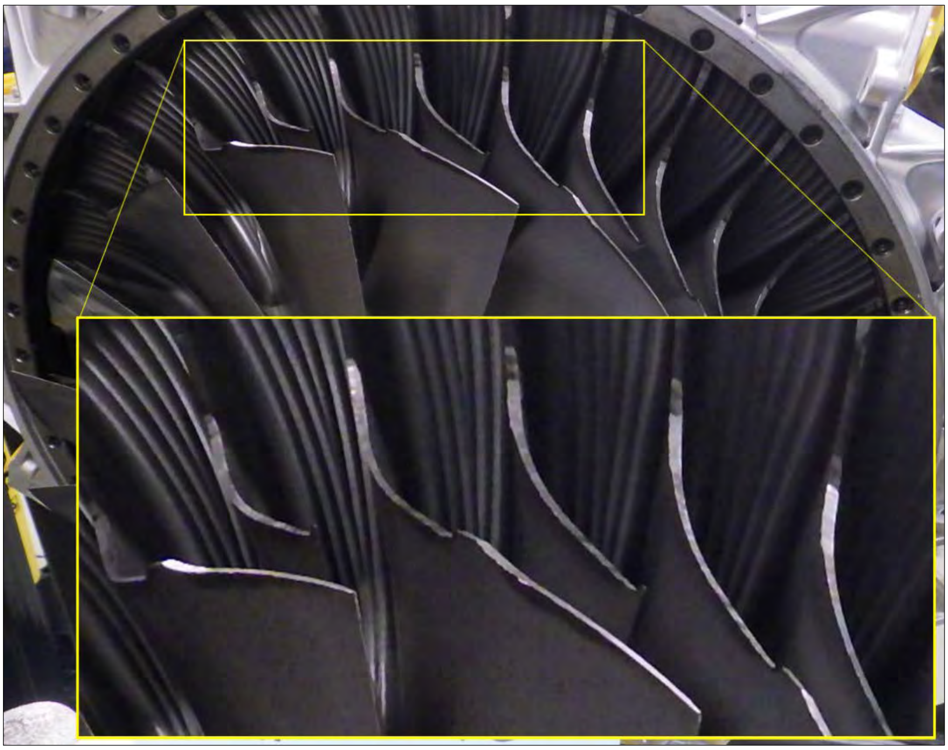


Figure 11: Low-Pressure Impeller blade wear

Figure 12: Impeller back surface

When the *diffuser case* was removed and examined, fractures were observed at several locations. Circumferential rubbing marks were also noticed on the *low-pressure diffuser,* which were consistent with *low-pressure impeller* contact *(see Figure 13)*.

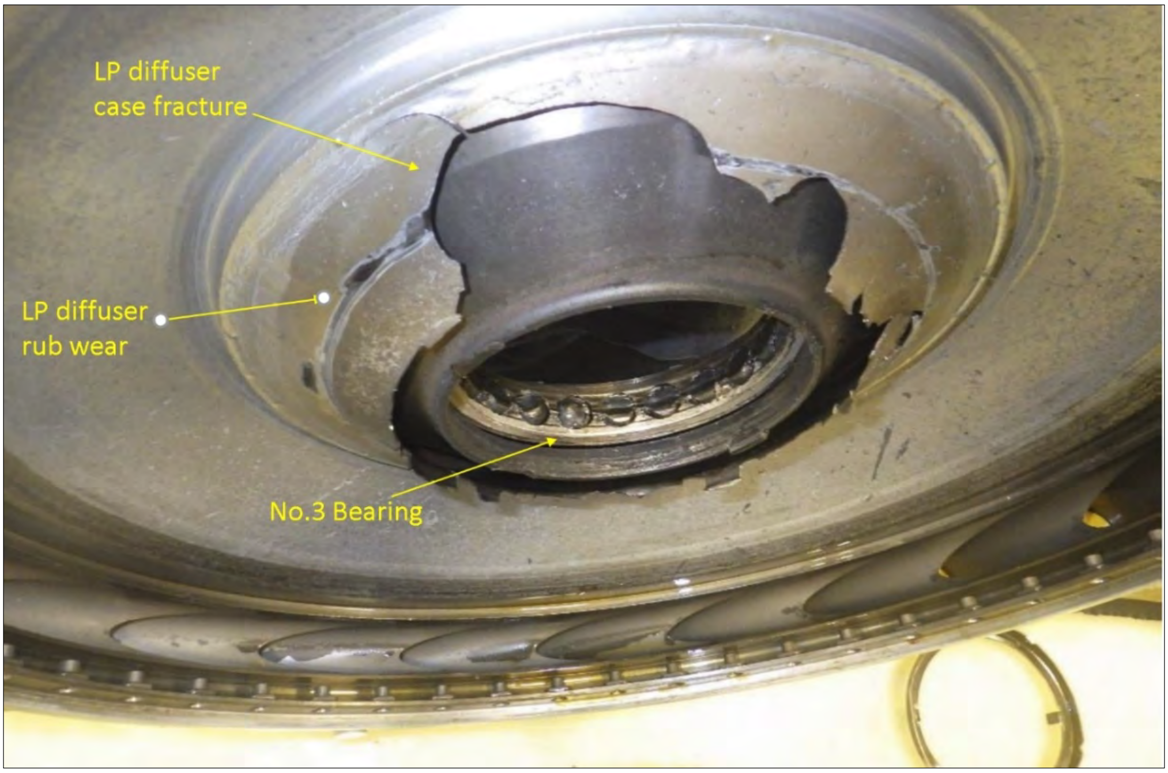


Figure 13: Low-Pressure diffuser case

The *low-pressure diffuser case* had four fracture surfaces at the *No. 3 bearing stator seal web*. Three of fracture surfaces were completely obliterated during the event. One could only be observed through the microscope and showed fractographic features.

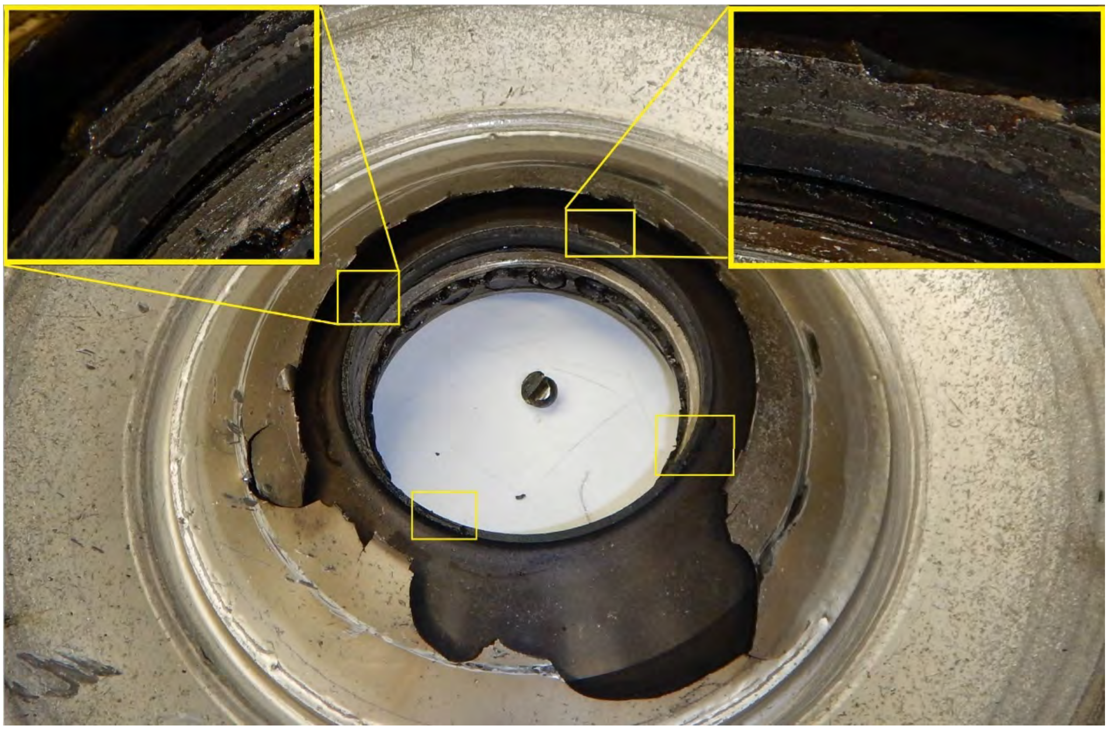


Figure 14: Low-Pressure diffuser case fracture surfaces stator seal web

Rubbing wear was observed on the *low-pressure shaft* outside diameter at the *high-pressure impeller seal* area. The *No. 3 bearing inner race* was found fractured. The *No. 3 bearing rear spacer* was found underneath the *No. 3 bearing inner race (see Figure 15)*.

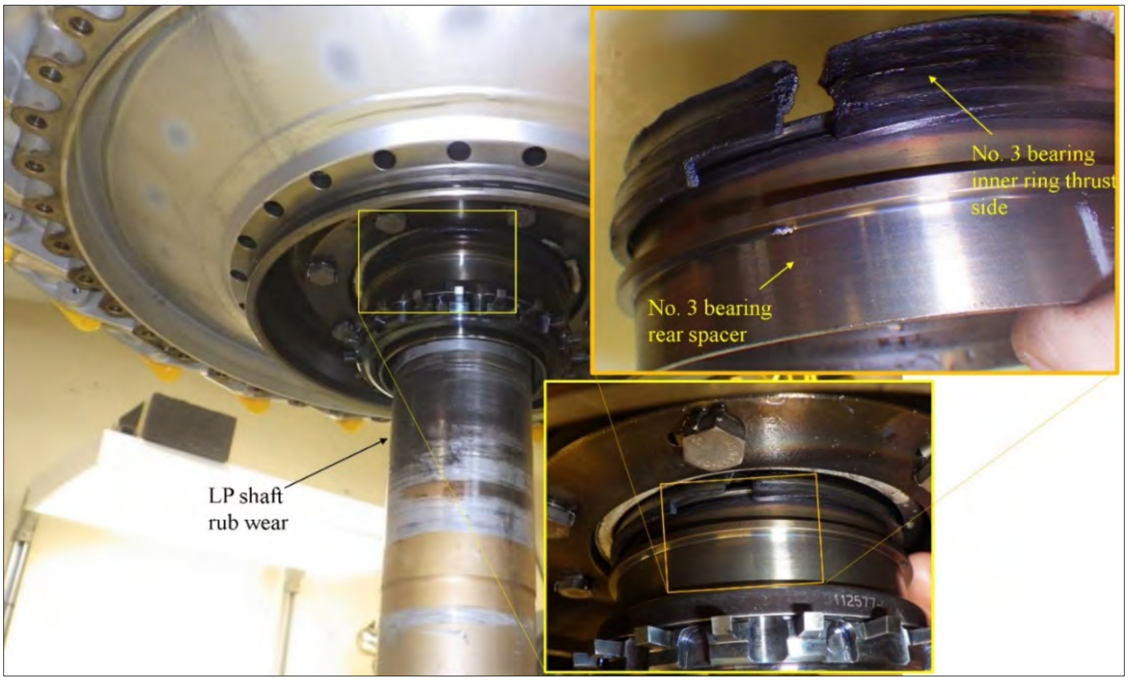


Figure 15: No. 3 bearing inner ring & rear spacer

After de-crimping the *key washer*, the technician was able to rotate and remove the *pulse pick-up runner* by hand.

The *key washer* remaining crimped with the *inner anti-rotation tangs* still engaged in the *impeller shaft* indicated that the *pulse pick-up runner* did not move. The *No. 3 bearing rear spacer* was wedged into the fractured *No. 3 bearing inner race* thrust side.

Wear marks were observed on the outer diameter of the *No. 3 bearing spacer (fwd)*. Fractures were observed on the *No. 3 bearing air seal* at several locations *(see Figure 16)*.

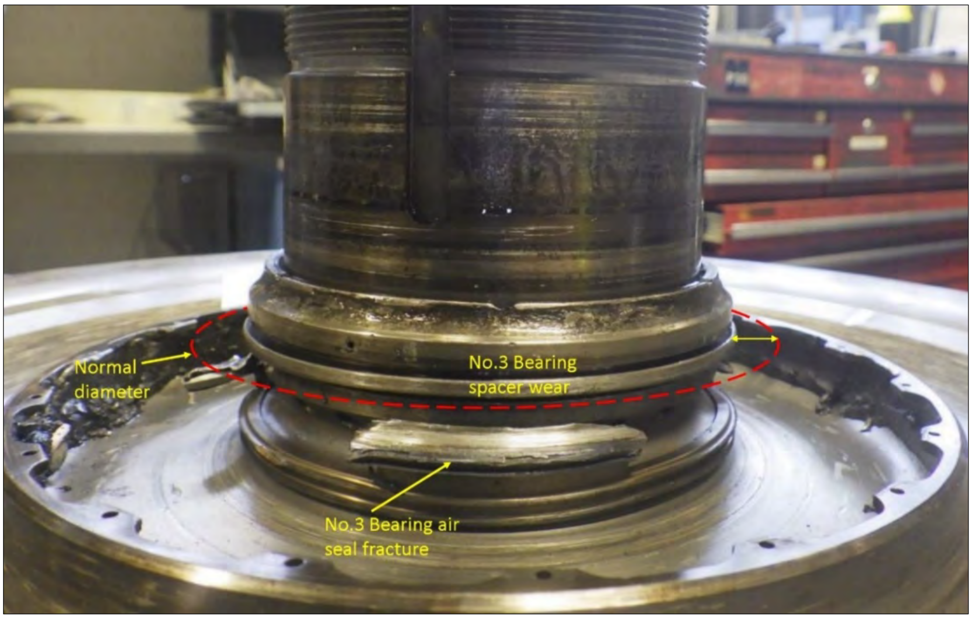


Figure 16: No. 3 bearing spacer and air seal

All the *No. 3 bearing balls* were seized inside the cage and showed heavy wear from rubbing against the *No. 3 bearing inner ring* thrust side. Rubbing wear was also observed on the *bearing cage*. The *bearing cage* was fractured at three locations, but did not show evidence characteristic of a ball bearing primary distress *(see Figure 17)*.

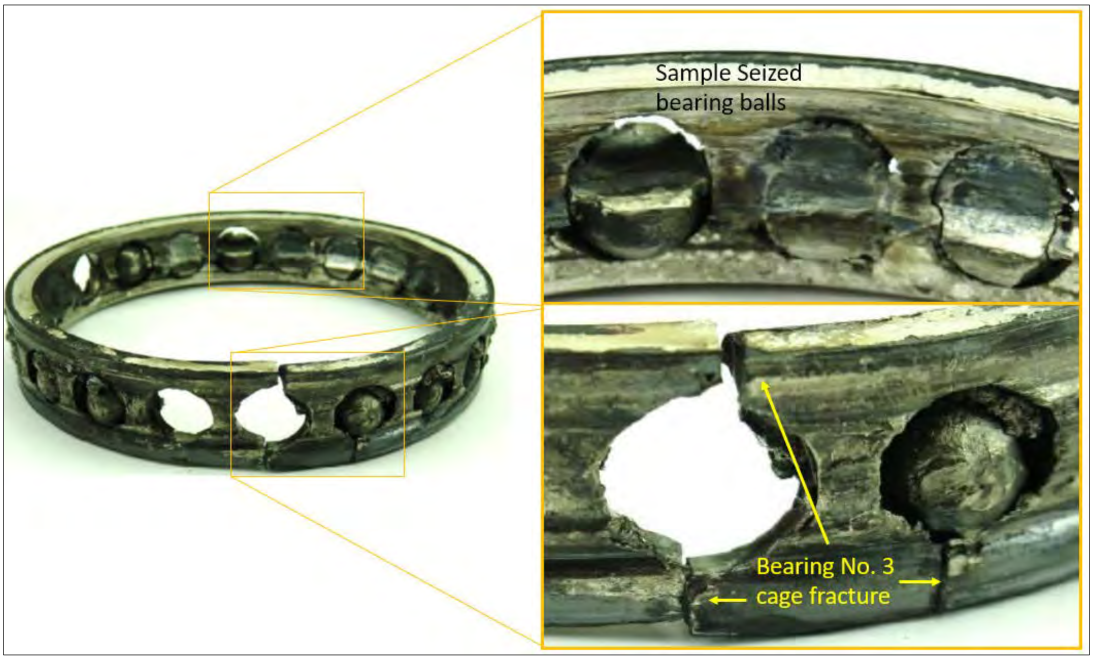


Figure 17: No. 3 Bearing cage

Rubbing wear was noticeable on the complete circumference of the split face of the *No. 3 bearing inner race* non-thrust side and there was no evidence to suggest that it was rotating.

The *No. 3 bearing inner race* thrust side sustained a fracture near one of its internal oil passages. Deformation was also observed next to the fracture. The inner surface of the *No. 3 bearing inner race* thrust side had rotational wear marks along the whole surface except for the area adjacent to the deformation. This suggested that the fracture occurred prior to the rotational wear.

The *No. 3 bearing rear spacer* was determined to have been subjected to rotational wear and discoloration on the mating face with the *No. 3 bearing inner race* thrust side and adjacent to the outer diameter surface. A circumferential wear line was observed at the inner diameter of the *No. 3 bearing rear spacer* (*see Figure 15)*.

During the examination the *pulse pick-up runner*, the *key washer* and the *No. 3 bearing rear spacer* were mated together by the technician to identify the source of the circumferential wear observed at the inner diameter of the *No. 3 bearing rear spacer*. The *tang* of the *key washer* was believed to have induced the wear at the inner diameter of the *No. 3 bearing rear spacer (see Figure 18)*.

Figure 18: No. 3 bearing rear spacer wear induced by the tang of the key washer

1.6.1.5 Minimum Equipment List

At the time of the accident the aircraft was certified as airworthy and the requirements of the *Minimum Equipment List (MEL)* were met.

1.6.1.6 Fuel information

The fuel type used was JET-A1 (AVTUR). Total fuel on board was 3,400 L (2650 kg). Fuel was not a contributing factor in this accident.

1.6.2 Systems

1.6.2.1 Centralised crew alerting system (CCAS)

According to the *ATR 72 Flight Crew Operating Manual (FCOM)*, the *CCAS* consists of **three** types of visual device *(see Figure 19)*:

- **Master Warning (MW)** and **Master Caution (MC)** lights. These flashing lights are used as ATTENTION GETTERS. Together with aural signals, they enable the flight crew to detect a failure and identify its degree of urgency.

- **Crew Alerting Panel (CAP)** lights. Regrouped on a centrally located panel, these lights are used to identify the origin of a failure. They provide condensed information of system faults or aircraft abnormal configuration.
- **Local alert** lights. These lights are generally integrated in the system central panels. They give detailed information on the failure and also direct the corrective action, being as much as possible combined with, or adjacent to, the corrective action control *(see Appendix D, 5.4)*. A limited number of aural alerts call flight crew attention through two loudspeakers.

The *CCAS* continuously monitors all aircraft systems in order to provide the following functions:

- Alert the flight crew to the existence of a system malfunction or aircraft hazardous configuration with a clear indication of the urgency of the situation.
- Identify the malfunction or situation without ambiguity.
- Direct the appropriate corrective action without confusion.

The first *CCAS* alert was a MC with an amber '*ENG'* message on the *CAP* and a *No. 2 engine* ITT exceedance, ITT caution light *'local alert'* on the engine panel.

About 3 minutes later, the MW and red *'ELEC SMK'* message illuminated on the *CAP*. There was no *'local alert'* associated with those warnings at that particular time. The ambiguous warning caused the crew to refer to the 'Electrical Smoke' checklist which, under the circumstances apparent at the time, was the incorrect checklist.

When the *No. 2 engine* low oil pressure warning activated, the MW, a red *'OIL'* message on the *CAP*, and oil warning light '*local alert'* illuminated on the *engine panel (oil pressure gauge)*, prompting the crew without ambiguity to refer to the appropriate *QRH* checklist.

Many *CCAS* alerts were activated during the flight as a result of crew checklist actions *(see Appendix A, 5.1)*. The investigation was unable to conclusively determine some of the alerts because the flight recorders were not configured to record them.

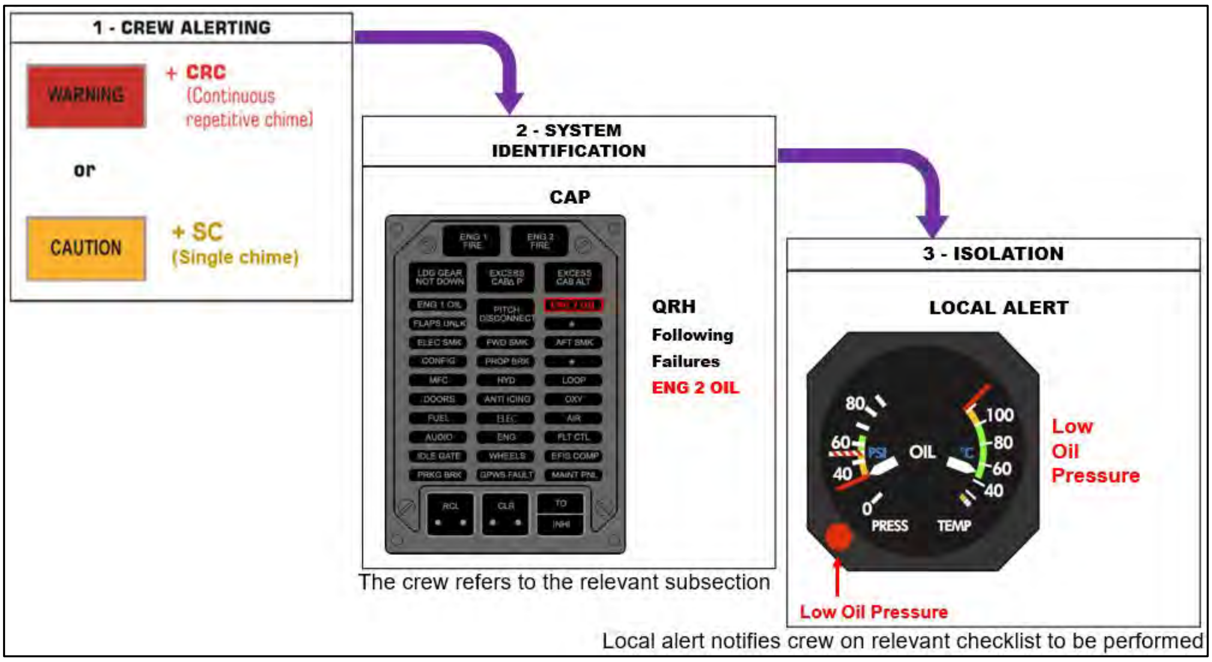


Figure 19: Example of a CCAS ALERT

1.6.2.2 Rudder

The rudder is used to control the aircraft along its lateral plane (Yaw). Yaw control consists of rudder pedals, *travel limitation unit (TLU)*, *rudder control unit (RCU)*, *rudder damper*, and *trim*. The *rudder pedals* mechanically act on a spring tab and through associated cables and on the rudder itself.

The *flight data recorder (FDR)* data showed that rudder position was recorded between -24.4° and +27.5° during the taxi controls' check prior to takeoff. The maximum travel range is +/- 27.0° *(see Appendix C, 5.3.1).*

The FDR data also showed that rudder travel remained consistent with *TLU high-speed (HI-SPD)* range throughout the approach and landing (*see Appendix C*, *5.3.2*).

Travel Limitation Unit (TLU)

The function of the *TLU* is to limit *rudder pedal* travel in order to prevent any damaging *rudder* deflections when flying at high speed. When the *TLU* is in AUTO control mode, the *HI-SPD* mode is selected automatically through *air data computers (ADC) 1* or *2* when the aircraft speed exceeds 185 kts during an acceleration, and *low-speed* (*LO-SPD)* when reaching 180 kts during a deceleration. The *TLU* power for the AUTO control is provided through *DC Bus 2*. AUTO control mode is the normal position in flight. The *TLU* is selected to this mode before each flight, during cockpit preparation.

The *TLU* power for manual control and indication are supplied by the *DC Emergency Bus* and is usually available after an AUTO mode fault. To operate the *TLU* in manual mode, the crew have to monitor the *Indicated Airspeed (IAS)* and manually select the *TLU* mode based on the aircraft's airspeed.

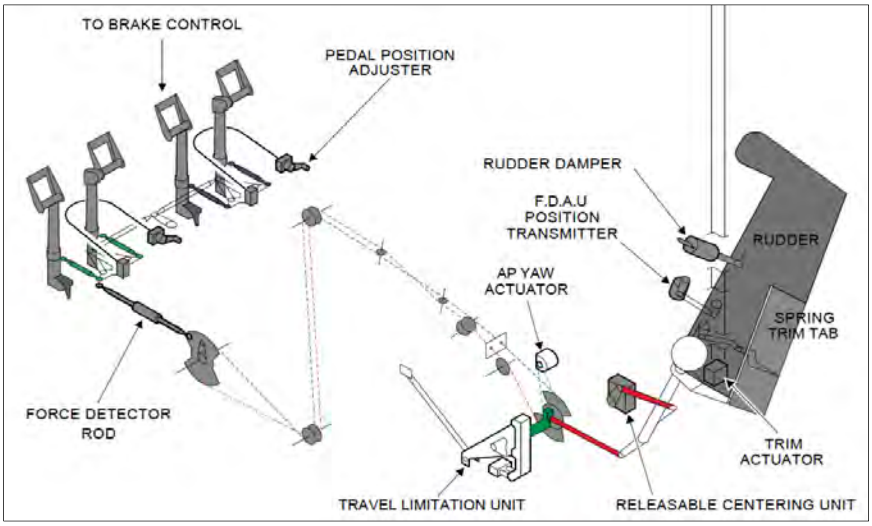


Figure 20: Rudder Schematic

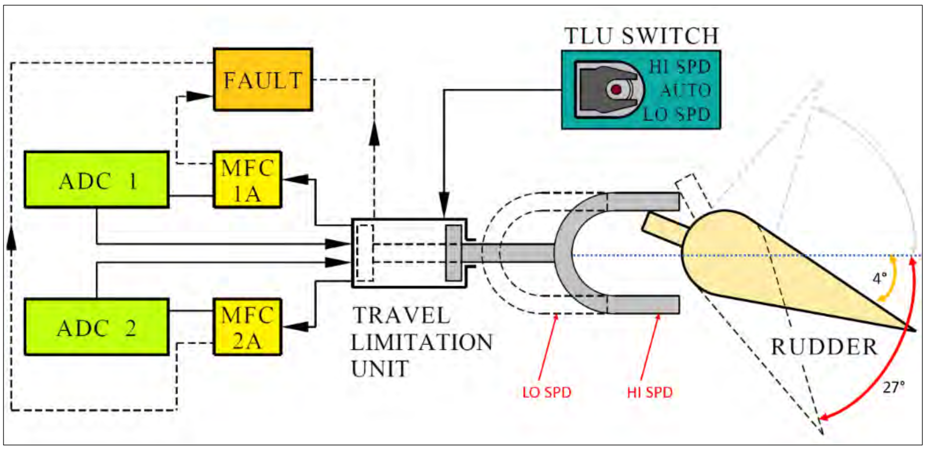


Figure 21: TLU function

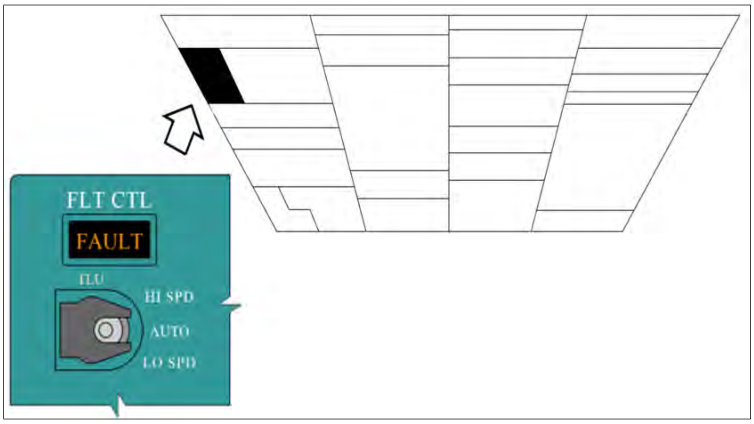


Figure 22: TLU FLT CTL and Fault Indicator (overhead panel)

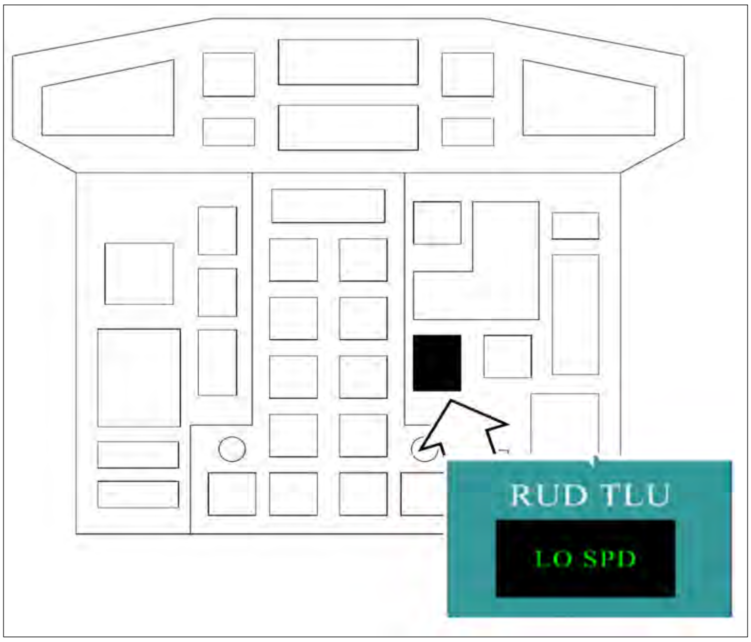


Figure 23: Rudder Travel Limited Unit *LO SPD* indicator

With the *DC BTC* already isolated during the *QRH 'ELECTRICAL SMOKE'* checklist action when the *No. 2 engine* was shut down, the *TLU's* AUTO control function was lost. A fault light appeared next to the *TLU switch* on the overhead panel *(see Figure 22)*. The *TLU* remained in the *HI-SPD* mode throughout the approach and landing. When the airspeed decreased below 180 kts, the crew were required to manually switch over to the *LO-SPD* setting to enable full rudder authority.

FDR data showed that the aircraft's calibrated airspeed was 201 kts when the *TLU* AUTO function was lost. The *TLU* locked the rudder pedals in the high-speed configuration. The investigation found that due to an uncorrected rudder centre calibration error, *rudder* travel was +7°/- 1° throughout the approach and landing.

The *TLU LO-SPD* indicator is designed to only illuminate when the TLU is in the correct, *LO-SPD* configuration and the airspeed is below 185 kts. The indicator remains blank when the *TLU* is in the incorrect configuration. Generally, flight crew are required by the *QRH 'Before Landing 4.2'* checklist to ensure that the *TLU* is in the *LO-SPD* mode *(see Appendix B, 5.2.13)*.

The crew did not consult the *QRH 'Before Landing 4.2'* checklist, which would have drawn their attention to the *TLU LO-SPD* light.

1.6.2.3 Ailerons and Spoilers

The two interconnected pilot control wheels operate the two ailerons and two spoilers. The ailerons are controlled mechanically, while the spoilers are hydraulically controlled through the **blue** hydraulic system. The two aerodynamic surfaces complement each other to provide the roll function of the aircraft.

The Ailerons were determined to have been fully operational throughout the emergency phase of the flight and landing.

The spoilers were operating normally while the **blue** hydraulic system was pressurised. After the flap extension and when the **blue** pressure was unavailable, both spoilers remained extended for the remainder of the flight and landing (*see Appendix C 5.3.4*).

Roll control became less effective due to the unavailability of the spoilers. However, with fully functional ailerons, control was still available.

1.6.2.4 Air conditioning and pressurisation system

Air for the air conditioning and pressurisation systems is bled from the *engine low-pressure compressor*.

At low engine speed, if pressure from *low-pressure compressor* is not sufficient, the air source is automatically switched to the *high-pressure compressor* (This may occur on the ground and during descent at flight idle). The aircraft uses external air to supply the air conditioning, pressurisation, and the de-icing systems respectively.

When the *No. 2 engine low-pressure diffuser case* sustained fractures, predominantly due to engine vibrations, and oil began to leak from the *No. 3 bearing* cavities, through the cracks and into the air system. The smoke-contaminated bleed air was processed through the right-side air-conditioning system and carried into the aircraft cabin, cargo compartment, flight deck and subsequently through the avionics compartment (*see Figure 24*).

The smoke in the aircraft was first noticed in the cabin and reported to the PIC by the SCC.

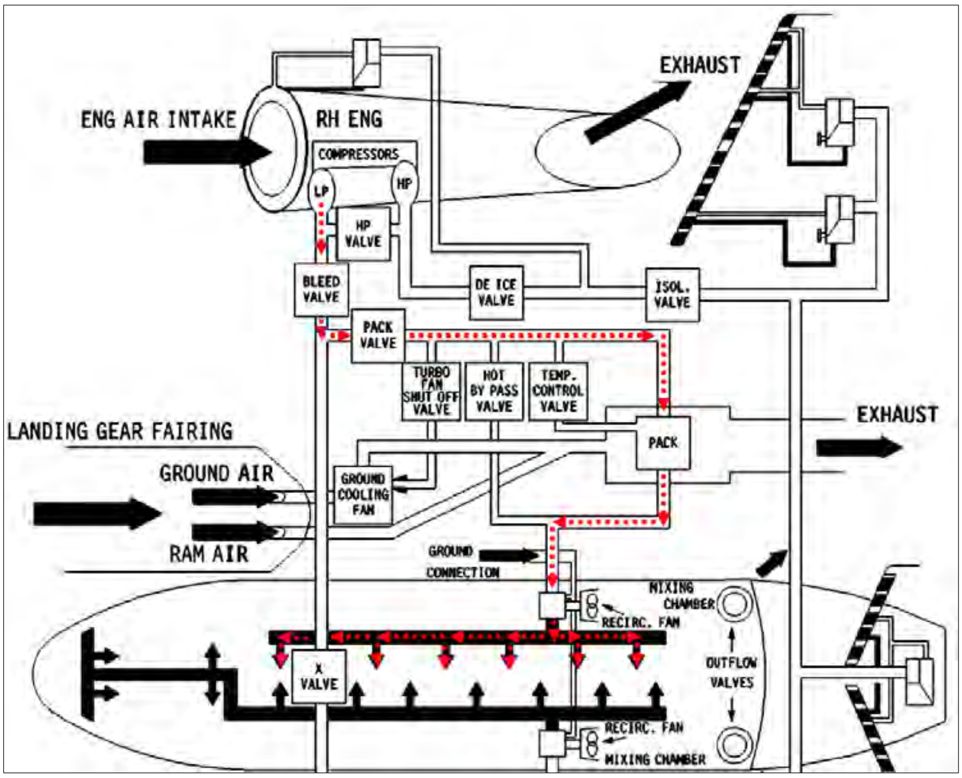


Figure 24: Air conditioning and Pressurisation System

1.6.2.5 Smoke Detection

There can be many sources of smoke that could lead to an in-flight emergency. Some of the common sources of smoke are cargo, avionics/electrical systems, galley ovens, pneumatics, and the engines. Crew are trained to diagnose and identify smoke sources whenever they occur. Aircraft manufacturers provide alerting systems and documentation to guide pilots to manage smoke events.

The *ATR QRH* contains five smoke emergency checklists[16]. When there is an indication of smoke in the aircraft, wherever the source is, flight crews are required to start with the *QRH 'SMOKE, E26.01'* checklist. The first five items on the *QRH 'SMOKE'* checklist are memory items.

The next item requires the crew to identify the smoke source. When pilots refer to any other smoke origin related checklist, they are referred back to the *QRH 'SMOKE'* checklist by the first action item.

During the accident flight, the smoke was noticed in the cabin and reported by the SCC to the flight crew.

The colour and odour of the smoke were not conveyed, nor did the PIC ask for this information. In his interview with the AIC, the PIC stated that smoke started entering the cockpit soon after the SCC alerted him about the cabin smoke. Less than 3 minutes after the SCC notified the PIC about the smoke, the '*ELEC SMK*' warning activated.

16 *Refer to Appendix B, 5.2.3, 5.2.4, 5.2.9, 5.2.10* and *5.2.11* for *Air Vanuatu ATR FCOM* smoke checklists. All smoke checklists in the QRH refer to *QRH 'SMOKE E26.01'* checklist.

The *avionics extract air duct* (outlet) includes a *smoke detector* connected with the *CCAS*[17] *(see Figure 25)*. Smoke detection between the *avionics compartment* and the *extract fan* activates the MW and the '*ELEC SMK*' red alert on the *CAP*. The '*ELEC SMK*' warning is activated when the *avionics compartment smoke detector* detects smoke.

When there is an *'ELEC SMK'* warning, the crew may not receive a '*local alert*'. In an attempt to avoid ambiguity, a **'Note'** has been provided in the *QRH 'SMOKE'* checklist to make the crew aware that an *'ELEC SMK'* warning may be activated by air conditioning smoke. The **'Note'** is positioned under the sub-checklist (conditional) that follows the action item requiring crew to identify the smoke source *(see Appendix B 5.2.1)*. The *QRH 'ELECTRICAL SMOKE, E26.05'* checklist does not contain similar guidance information such as a **'Note'** or ***'CAUTION'*** to provide crew awareness and guidance relating to the *'ELEC SMK'* ambiguity.

The '*ELEC SMK*' warning illuminated on the *CAP* and the MW activated while the PIC was making an announcement to the passengers. The PIC instructed the copilot to refer to the *QRH 'ELECTRICAL SMOKE'* checklist.

The '*ELEC SMK'* warning activated at 23:19:11 while the crew were dealing with the *No. 2 engine* and what the PIC announced as engine smoke. This was the first panel warning alert the crew received and their immediate priority became to deal with that warning. No other warning was triggered until after 23:22:31, when the *No. 2 engine* low pressure warning activated. The *'FWD SMK'* alert activated at 23:24:17.

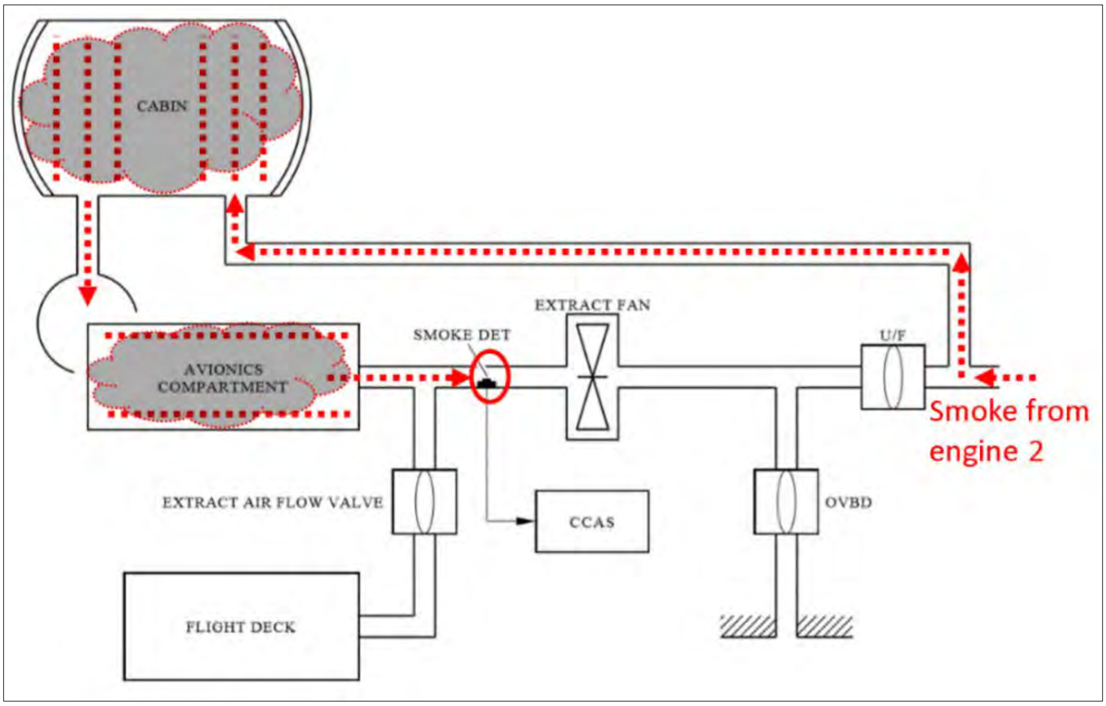


Figure 25: Avionics Smoke Detection System

1.6.2.6 Engine Fire Protection System

Passengers reported seeing flashes from the *No. 2 engine*. However, the engine's fire warning did not activate. The investigation determined that the flashes witnessed were momentary sparks from the engine. The engine examination did not reveal any evidence of an engine fire.

17 Centralised Crew Alerting System.

1.6.2.7 Electrical Systems (Power supply)

Alternating Current Wild (ACW) Generators

The *ACW generators* are located in the *propeller reduction gearbox of each engine*. The *ACW* power generation system consists of two *propeller-driven three-phase generators*. The aircraft *ACW* distribution network consists of three busses; the main *ACW busses 1* and *2*, and the *ACW service bus*. The *ACW bus 1* is normally supplied by the left generator (generator 1) and the *ACW bus 2* by the right generator (generator 2). The *ACW service bus* supplies power in flight and on ground during aircraft servicing operations. If one of the generators fails, the *Bus Tie Contactor* (*BTC*) will automatically close allowing the serviceable *generator* to supply power to the other *bus*.

These generators produce variable frequency alternating current to supply systems that do not require constant alternating current to function.

Some aircraft AC powered systems do not require constant frequency. However abnormal frequency fluctuation can cause load shedding and even cause supplied systems to overheat.

Both *ACW generators 1* and *2* were switched off by the crew during the *QRH 'ELECTRICAL SMOKE'* checklist actions about 11 minutes prior to landing. Several systems, including both *hydraulic systems*, were lost when the generators were switched off *(see Appendices B, 5.2.3 and 5.2.5)*.

Direct Current (DC) Generators

The *DC generators* are driven by the *engine accessory gear boxes*. They supply power to the *main DC busses* through which power gets distributed to their respective DC powered systems. When one generator fails, power for the DC powered systems is supplied through the *DC BTC* by the other *DC generator*.

DC Generator 2 was lost when *No. 2 engine* was shut down by the flight crew at 23:24:01 during the *QRH 'ENG 1 (2) OIL LO PR, A70.14'* checklist action *(see Appendix B, 5.2.6)*.

The *flap indicator* power is supplied by *DC bus 2*. When flap was extended, there was no indication because *DC bus 2* was off.

DC Bus Tie Contactors (DC BTC)

The two *DC bus* networks operate independently. However, when one of the *DC Generators* fails, the supply bus for the respective generator can be supplied by the other generator through the *BTC*.

The *DC BTC* had been isolated during the *QRH 'ELECTRICAL SMOKE'* checklist actions *(see Appendix B, 5.2.3)*. Hence, when *DC generator 2* was lost, the *DC bus 2* network power supply was completely lost.

1.6.2.8 Hydraulic System

The aircraft has two *hydraulic systems*; the ***blue*** and ***green***, with a common *hydraulic tank* in the *hydraulic bay (landing gear fairing)*. An *ACW electric motor driven pump* is included in each system to supply pressure for its operation. The ***blue*** *system* also has an *auxiliary pump* powered by a *DC motor*. Each system has a *0.2 ltr power accumulator* installed in the *hydraulic bay*. They reduce pump jerks and pressure surges, and also compensate for response time of the pump in case of high output demands.

The **blue** system supplies pressure for the following:

- ***wing flaps*** extension/retraction;
- ***spoilers***;
- ***nose-wheel steering***; and
- ***propeller brake*** for the right engine.

The **green** system supplies pressure for:

- ***landing gear*** extension/retraction; and
- ***Normal brakes*** for the four wheels of the main landing gear.

If one of the hydraulic systems fails, the other pump can supply the associated systems through the cross-feed valve.

The *emergency/parking brakes* are also supplied through the ***blue*** *hydraulic system accumulator*. When all the pumps stop operating, the *hydraulic accumulator* is available for emergency braking on the four wheels of the *main landing gear*. There is a separate indicator in the cockpit for accumulator pressure.

Both the ***green*** and ***blue*** *hydraulic system pumps* stopped operating when the *ACW Generators* were switched off by the flight crew as part of the *QRH 'ELECTRICAL SMOKE'* checklist actions, resulting in the loss of certain critical aircraft systems (*see Appendix B, 5.2.12).*

The emergency/parking brakes for the main landing gear were available through the ***blue*** *system accumulator*, which would have allowed six emergency braking applications.

The *auxiliary pump* power and AUTO control mode is supplied by DC bus 2. It automatically pressurises the ***blue*** *hydraulic system* when the *ACW* ***blue*** *system pump* is not working.

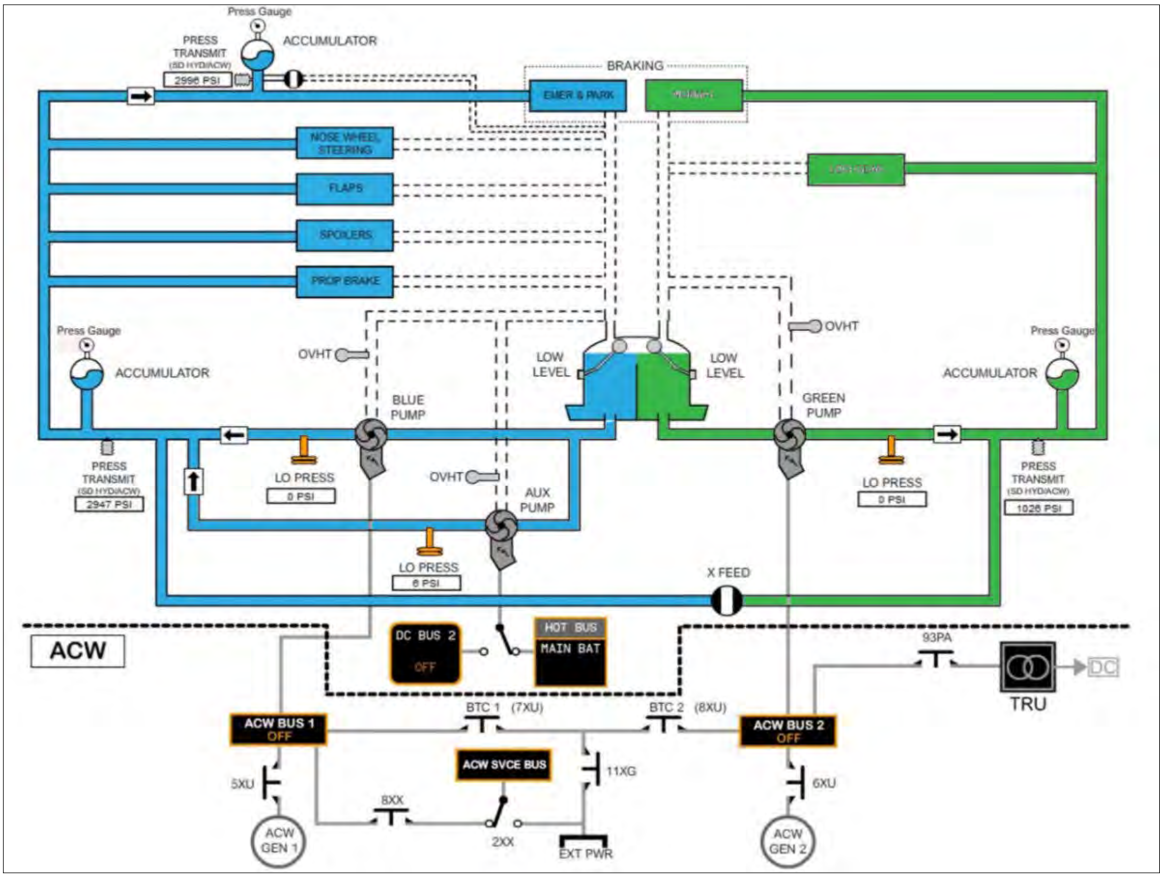


Figure 26: ATR 72 ACW and hydraulic system

When the push button *(pb)* is pressed in (AUTO) the *auxiliary pump* starts running as soon as:

- Pressure of *ACW* ***blue*** *pump* is below 1 500 psi –
- *Propeller brake* is released - *Gear handle* is selected DOWN –
- At least one engine is running.

When the push button is released (OFF), the auxiliary pump is deactivated.

If *DC bus 2* power is lost, the *auxiliary pump* AUTO mode is also lost. The *'hot main battery bus'*[18] will supply power for the auxiliary pump. However, in this instance, the crew would have to push the ground *'HYD AUX PUMP'* button to manually activate the *auxiliary pump*.

FDR data showed that during the approach, the aux pump was activated at 23:30:48, for 43 seconds during which the flap (15 and subsequently 30) were extended.

1.6.3 Collision Avoidance Systems

The aircraft was equipped with a *Mode S transponder*, *Traffic Alert and Collision Avoidance System (TCAS)* and *Enhanced Ground Proximity Warning System (EGPWS).*

The *TCAS* is supplied power from *DC bus 2*. The *TCAS* was lost subsequent to the shutdown of the *No. 2 engine*. The unavailability of the *TCAS* did not affect the flight or have any bearing on the occurrence.

1.7 Meteorological information

There was no significant weather reported for the approach and landing at Bauerfield International Airport, Port Vila.

1.8 Aids to navigation

Ground-based navigation aids, on-board navigation aids, and aerodrome visual ground aids and their serviceability were not a factor in this accident.

1.9 Communications

The aircraft's V*HF 2 transceiver* became inoperative when the *No. 2 engine* was shut down. *VHF 1* was available and was selected by default. Transmissions between the crew and Vila ATC were normal.

The PIC maintained radio communication with Vila ATC during the emergency phase while he was flying the aircraft.

Communication systems pilot to pilot communication, flight crew to cabin crew, and flight crew to passengers were functioning normally.

The CVR revealed continuous use of non-standard phraseology between the flight crew and the cabin crew.

A number of the flight crew's checklists were interrupted to facilitate communication with ATC and the cabin crew.

About 20 minutes before landing at Bauerfield International Airport the PIC broadcast a *'Mayday'* call. The PIC requested Vila ATC to arrange rescue and fire services to be on standby. The air traffic controller called Aviation Rescue and Fire-Fighting Services (ARFFS) and requested for them to stand by at the aerodrome.

18 Hot main battery bus is connected directly to the battery and is constantly energised.

1.10 Aerodrome information

Bauerfield International Airport, Port Vila, Republic of Vanuatu.

- Airport Operator: Airports Vanuatu Limited
- Longitude: 168° 19' 11" E
- Latitude: 17° 41' 57" S
- Elevation: 70 feet (21.3 metres)
- Runways: 11/29 (110°/290°M)
- Length: 2,600 metres (8,530 feet)
- Surface: Asphalt

The airport infrastructure did not contribute to this accident.

1.10.1 Rescue and fire fighting

The Aviation Rescue and Fire-Fighting Service (ARFFS) services personnel were alerted by Vila ATC about AV71's distress call. They responded by dispatching their vehicles to the airport, and were on standby prior to the arrival of the aircraft.

1.11 Flight recorder

The aircraft was fitted with a *Solid-State Cockpit Voice Recorder (SSCVR)*, a separate *Solid-State Flight Data Recorder (SSFDR)* and a *Quick Access Recorder (QAR)*.

The *CVR* was capable of recording at least 2 hours of 4-channel high quality cockpit audio. The channels included the PIC and the copilot microphones, the *cockpit area microphone (CAM)*, and the *public address (PA) system*. The *CVR's* identifying information:

- **Manufacturer** : L-3 Communications
- **Model** : FA2100
- **Part Number** : 2100-1220-02
- **Serial Number** : 000931323

The FDR met the minimum recording duration requirement of 25 hours. The programmed data recording rate was 128 words per second. The FDR's identifying information:

- **Manufacturer** : L-3 Communications
- **Model** : FA2100
- **Part Number** : 2100-4043-00
- **Serial Number** : 01416

The aircraft had a *SAGEM Digital Flight Data Acquisition Unit (DFDAU)*, part number ED34A340. The DFDAU was programmed in accordance with ATR's Data Frame[19] Version *V2b Config.1* with mods 04017[20],04262[21] and 04263[22] incorporated. This configuration along with the subsequent mods did not comply with the requirements of *FAR 121.344*[23].

19 Provides the recorded parameters, allocations and the equations used to convert recorded raw data into engineering unit.

20 Indicating & recording systems - FDAU - modify wiring of "ICING AOA" discrete. AOA (Angle of Attack).

21 Indicating/Recording system - FDAU - Provide acquisition of discretes of icing conditions.

22 Indicating/Recording system - FDAU - Provide acquisition of discretes for electronic regulation.

23 Digital flight data recorders for transport category airplanes.

The data recording system of AV71 (aircraft manufactured in 2005) was not capable of recording some of the *FAR* specified parameters such as hydraulic pressure, brake pedals, trim command, brake pressure, etc.

Following the accident, both recorders were recovered from the accident site and transported to the AIC Flight Recorder Laboratory in Port Moresby under the control of the AIC for download and readout.

The *QAR's Personal Computer Memory International Association (PCMCIA)* card was also recovered from the aircraft. Data from the card was downloaded and readout by the Operator under the supervision of the AIC Investigators.

None of the recorders sustained any damage during the occurrence.

The AIC's readouts from the recorders were analysed by the Investigation Team *(see Appendix C, 5.3).*

1.12 Wreckage and impact information

The aircraft touched down approximately 400 metres after the runway 29 threshold, at a speed of 98 kts IAS.

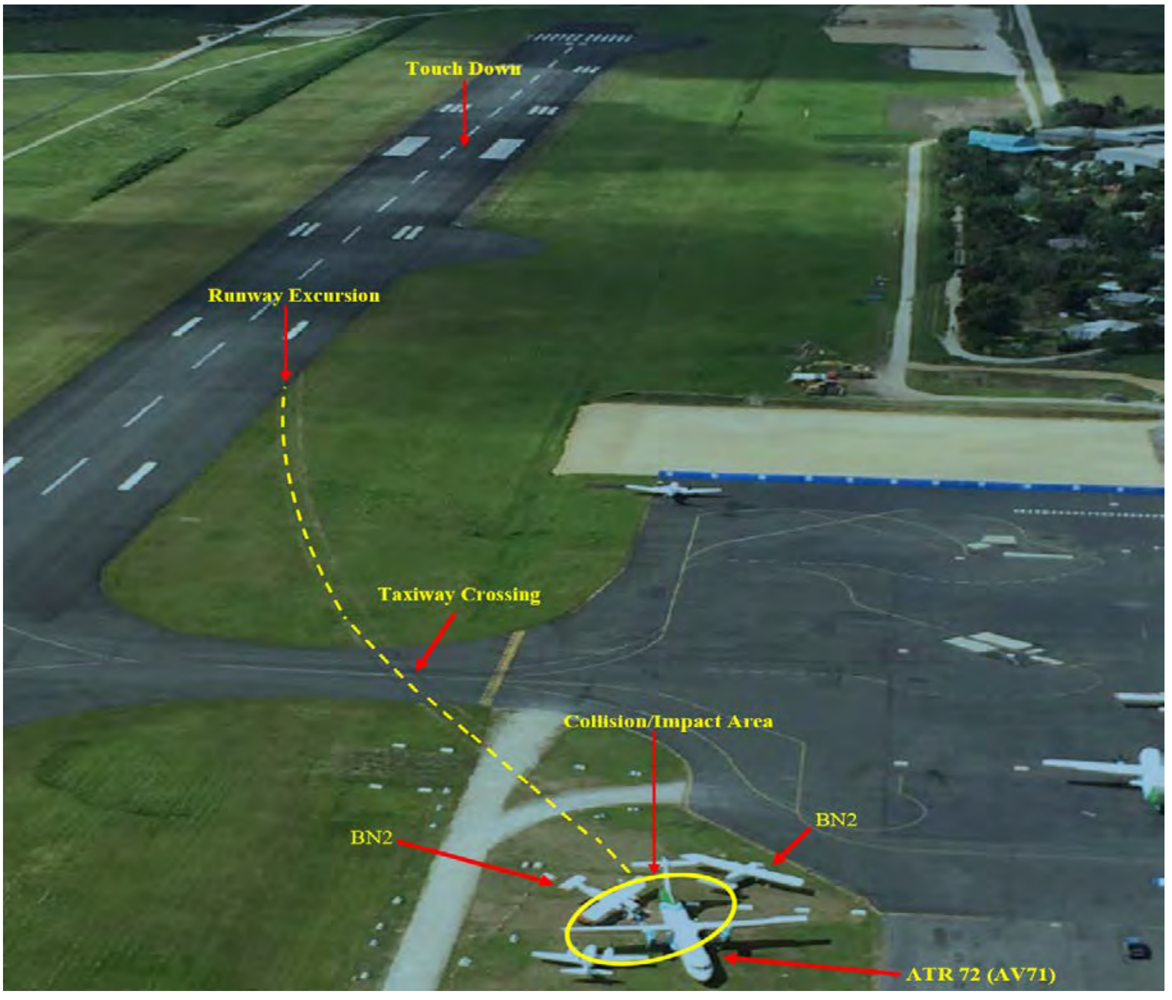


Figure 27: AV71 Runway Excursion

The aircraft touched down on runway 29 (290° M[24]) near the landing zone, on its left main landing gear, followed by the right main and nose landing gear. It momentarily turned left with the initial application of reverse thrust for 1 second. That was followed by a right turn when the thrust was set to ground idle and the aircraft again lined up with the runway direction. About 200 metres further along the landing roll, approximately 8 seconds after the touchdown when maximum reverse thrust was applied, the aircraft veered left off the runway and rolled across the taxiway, slowing to 45 kts before it impacted the two Britten-Norman BN-2 Islander aircraft. Impact damage was more prevalent on the starboard side of AV71.

1.13 Medical and pathological information

After the evacuation, the operator did not arrange for medical checks to be conducted after the accident. Post-accident Carbon Monoxide tests were not conducted on the crew and passengers. The investigation has not been informed of any passenger or crew suffering adverse effects.

1.14 Fire

There was no evidence of pre- or post-impact fire.

1.15 Survival aspects

During their respective interviews, both cabin crew stated that during the cabin smoke emergency, they continuously instructed the passengers to keep their heads down and stay low. Some passengers reported that they were running out of air and inhaling a lot of smoke that they asked the CC at the forward crew station for oxygen, however he advised them to cover their nose and mouth and to keep their heads down and stay low.

Both cabin crew also stated that the operator did not have a smoke procedure. However, they had been taught during training to instruct passengers to keep their *'heads down and stay low'*.

A review of the operator's *ATR Cabin Crew Operating Manual (CCOM)* revealed that the operator did have a *'Cabin Smoke Contamination'* procedure (*see Appendix E, 5.5.1*). However, the cabin crew were neither aware of its existence, nor trained to action all required actions of the procedure.

During the smoke emergency, the PIC instructed the SCC to don Protective Breathing Equipment[25] (PBE) and action the smoke procedure. The cabin crew did not don their PBE and also did not carry out any standard procedures such as handing out wet towels to passengers to help with their breathing.

The *ATR CCOM Section 10.03.4* also stated that in their role as a communicator, cabin crew are required to inform the flight crew about the *'Severity/density of fire and/or smoke (colour/odour)'* and *'Identify the location/source'*. The SCC did not inform the flight crew about the colour and odour of the smoke, nor did she attempt to identify the source of the smoke. The PIC did not ask the SCC for this information.

During interviews, the cabin crew also stated that they remained seated from the time the PIC switched on the fasten seatbelt sign until the aircraft came to a complete stop following the impact. The SCC stated that as an operational requirement, cabin crew were required to be seated whenever the seat belt sign was on during the flight.

24 Magnetic declination, or magnetic variation, is the angle on the horizontal plane between magnetic north and true north. This angle varies depending on position on the Earth's surface and changes over time.

25 *See Appendix E, 5.5.2 for Air Vanuatu CCOM* for description of *PBE*.

The investigation found that except for the *'take-off and climb'* and *'landing'* phases[26] of the flight, the *ATR CCOM Section 9.03* requires cabin crew to complete all safety related duties before taking up their seats. After the PIC declared a planned emergency evacuation, the cabin crew did not execute the *ATR CCOM 'Cabin preparation'* procedures *(see Appendix E, 5.5.4)*.

The fasten seatbelt signs went off when the *No. 2 Engine* was shut down. Video footage taken by passengers confirmed that the fasten seatbelt signs in the cabin were off during the smoke event. However, passengers remained seated.

The SCC instructed the passengers to fasten their seatbelts about 3 minutes before touchdown.

1.15.1 Emergency service notification

At 23:16:41, the SCC notified in the flight crew about the cabin smoke and the PIC immediately made a '*MAYDAY*' broadcast.

At 23:17:20, 15 minutes prior to landing, Vila ATC asked the crew if they needed fire trucks at the airport. The PIC stated that they did not require them at that stage.

At 23:17:57, Vila ATC called the ARFSS and declared an emergency and provided details.

At 23:19:44, the PIC requested for fire services to be on standby.

At 23:20:24, Vila ATC called Vila ARFFS on Ground Frequency and requested for them to stand by at the airport for the emergency landing on runway 29.

By 23:29:50, the Vila ARFFS trucks confirmed on standby at the aerodrome during for the AV71 to land.

1.15.2 Emergency lighting

The investigation was unable to determine the status of the cabin emergency lights during the evacuation.

1.15.3 Emergency exits

After the aircraft stopped, and following the PIC's subsequent command to evacuate the aircraft, the cabin crew conducted an orderly expedited evacuation through the aft left primary door, L2.

Door, L2 was opened by the SCC. Upon exiting the flight deck, the flight crew discovered that both L1 and R1 emergency exits were open. The flight crew evacuated through the forward exits. The investigation was unable to confirm who opened those emergency exits and whether or not they were used for exit by any passenger.

26 *See Appendix E, 5.5.3 for Air Vanuatu CCOM* for definition of *take-off* and *landing of the flight.*

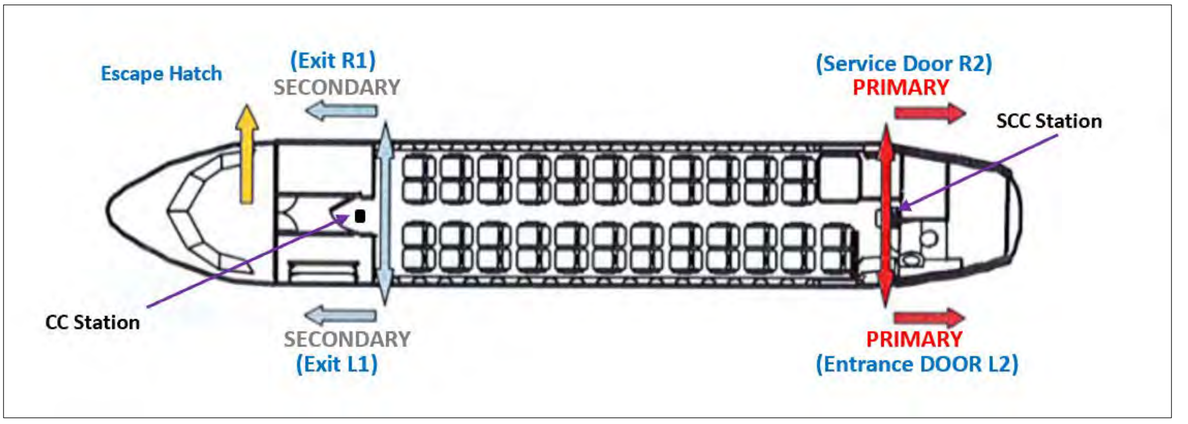


Figure 28: ATR door/exits classification for ground evacuation and Cabin Crew stations

The evacuation procedures were carried out by the cabin crew in accordance with the *ATR CCOM* requirement for ground evacuation *(see Appendix E,5.5.5).*

1.15.4 Injuries sustained during the evacuation

There were no reported injuries sustained by the crew or passengers during the evacuation.

1.15.5 Post-evacuation events

The SCC reported that after all passengers had evacuated, she assisted the last passenger, an elderly person, to evacuate the aircraft while the other CC conducted the cabin checks to ensure there was no passenger left behind in the cabin. Both cabin crew stated that in their haste to evacuate the aircraft, they forgot to collect any relevant emergency equipment[27] as required in the operator's evacuation procedure.

1.16 Tests and research

No tests and research were conducted as result of this occurrence. For the engine examination by Pratt and Whitney Canada (P&WC), refer to *Section 1.6.1.4* and *Appendix F, 5.6.*

1.17 Organisational and management information

1.17.1 The Operator

Air Vanuatu is the national flag carrier of the Republic of Vanuatu with its head office in Port Vila, Vanuatu. The airline operates scheduled passenger services within Vanuatu and internationally to Australia, New Zealand and destinations in the South Pacific. Its main base is Bauerfield International Airport, Port Vila.

Air Vanuatu's maintenance base is also located at the Bauerfield International Airport.

CAAV had approved the Air Vanuatu's CAR 119 compliant exposition. Air Vanuatu had adopted the *ATR QRH, AFM, FCOM, CCOM* and other operational documents under their operational exposition.

According to the *Air Vanuatu Check & Training Manual (AVCTM), Section 2.16*, flight crew members are required to are undergo a Flight Crew Operational Competency assessment every 6 months, and CRM recurrent/renewal course every 12 months.

27 *Air Vanuatu ATR CCOM Section 10.06.3.5* **Relevant Equipment**: Emergency locator transmitter (if available), megaphone, first aid kit and flashlight.

The Air Vanuatu policy is for all Part 121 aircraft competency assessments to be conducted in a flight simulator. The simulator training is conducted under a service agreement with Air New Zealand.

The training records of the PIC showed, inconsistency in some of the simulator training, with the smoke emergency procedure being out of currency by about 3 years.

The *(AVCTM)* does not contain any specific recurrent training requirements for smoke emergencies.

The operator's Cabin Crew *Safety and Emergency Procedures (SEP)* training syllabus, as outlined in the *Cabin Crew Procedures and Training Manual (CCPTM),* contained the: 'smoke and fumes', 'normal' and 'emergency' procedures.

Although the training records showed that both cabin crew held valid *Safety Emergency Procedure* (SEP) certificates at the time of the occurrence, the investigation found that the cabin crew had not been adequately trained on the smoke emergency procedure and safety duties and responsibilities for normal and emergency situations.

At the time of the occurrence, the cabin crew were unaware of the smoke emergency procedure. They had not been trained to execute all actions required by this procedure. The cabin preparation procedure was not carried out. The cabin crew remained seated throughout the smoke emergency phase.

1.17.2 Lufthansa Technik Aero Alzey (LTAA)

LTAA is an aircraft engine maintenance repair and overhaul service company that has, for more than 30 years, been an Original Equipment Manufacturer (OEM) approved company specialising in repair and overhaul of PW100 series engines.

The No. 2 engine (SN: ED0190) was repaired and overhauled by LTAA in mid-2018 prior to the accident.

1.17.3 Civil Aviation Authority of Vanuatu (CAAV)

The CAAV is the State Agency responsible for safety and regulatory oversight of the Aviation System in Vanuatu. The head office is located in Port Vila, Vanuatu.

The Republic of Vanuatu Government has adopted the New Zealand *Civil Aviation Rules* for the purpose of ensuring regulatory oversight.

The CAAV does not have qualified inspectors to conduct audits. For this reason, a Subject Matter Expert (SME) qualified to conduct audits, regulatory and safety inspections was seconded to the CAAV.

The Air Vanuatu Operations Limited *Standard Operating Procedures (SOPs)* were audited by a qualified Flight Operations Inspector seconded to the CAAV. Based on the inspector's recommendation, the CAAV Director approved the *SOP's*.

CAAV's Audit records were not provided to the investigation. However, the deficiencies existing in the Air Vanuatu operational staff training and standard operating procedure, knowledge and skill suggests that the auditors audits on compliance with operational documentation and *Rules* was not effective.

The *Civil Aviation Rules Part 121*; *Air Operations — Large Aeroplanes* states:

121.555 Syllabus for crew member training programme

(a) A holder of an air operator certificate must ensure that each segment of the training programme for flight crews and flight attendants includes a syllabus that is applicable to the certificate holder's operations and is

acceptable to the Director.

(b) Each syllabus required by paragraph (a) must include at least the following elements as applicable to—

(3) the crew member assignments, functions, responsibilities, and the relationship of these to the assignments, functions and responsibilities of other crew members, particularly in regard to abnormal or emergency procedures:

*(4) training in **all** types of emergency and abnormal situations or procedures caused by power plant, airframe or system malfunctions, fire or other abnormalities:*

121.607 Flight crew competency assessments

A holder of an air operator certificate must ensure that—

(2) each pilot acting as a flight crew member of an aeroplane conducting an air operation under VFR has, within the immediately preceding 12 months, successfully completed a competency assessment administered by a flight examiner that covers—

(i) procedures, including emergency procedures; or

(ii) the pilot's flying skills in an aeroplane type normally used by the pilot in an air operation; and

(iii) human factors and crew resource management; and

*(3) each pilot acting as a flight crew member of an aeroplane conducting an air operation under IFR has, within the immediately preceding **6 months**, successfully completed a competency assessment administered by a flight examiner that—*

*(i) covers procedures, including **emergency procedures**, appropriate to the equipment fitted to the aeroplane and to the type of operations to which the pilot is assigned by the certificate holder; and*

(ii) includes human factors and crew resource management;

1.18 Additional information

Although not a contributing factor to this accident, there is an ongoing hazardous environment presented by Mt. Yasur (1,184 ft amsl), to aircraft flying to and from Tanna, and within the vicinity of the Volcano. The volcanic activity is strombolian or sometimes vulcanian in nature. Ejection of ash, cinder or lava from the volcano has been known to occur several times an hour and occasionally rising to as high as a several hundred feet.

With predominant north-westerly winds, volcanic ash from Mt. Yasur is blown over Tanna, Whitegrass airport. Aircraft operating to and from Tanna are subjected to this hazard. The flight crew requested company personnel on the ground at Tanna to give them the status of the volcano.

Figure 29: Mt. Yasur on Tanna island

Airborne weather radar systems are not designed to detect volcanic ash or dust. The effects of volcanic emissions on an aircraft may cause multiple engine malfunctions such as stalls, increased ITT, torching from the tailpipe, flameout etc.

1.19 Useful or effective investigation techniques

1.19.1 Pratt & Whitney Canada (P&WC) Engine Investigation Report

The engine was received at P&WC Service Centre St-Hubert, Quebec, where a disassembly investigation was performed between 9 and 11 October 2018, under the direct supervision of the Accredited Representative for Canada reporting to the AIC.

The engine's components were subjected to several examination and testing methods which included visual, bench testing and microscopic etc.

An engine disassembly investigation report from P&WC was sent to the AIC through the Accredited Representative.

1.19.2 Flight Data Analysis

The FDR and CVR data were downloaded and readout at the PNG AIC Flight Recorder Laboratory. A separate copy of the raw file was sent to ATR through the Bureau d'Enquêtes et d'Analyses (BEA) Accredited Representative to the investigation. Although all recorded data was identical, there was a minor discrepancy of the data record time of about 4:12 seconds.

The *FDR's* readout also showed that the recorded latitude, longitude, groundspeed and drift angle parameters were not available because the *GPS* parameters were not valid. The AIC derived the estimated flight path of the aircraft from takeoff at Whitegrass Airport, Tanna to collision at Bauerfield International Airport, Port Vila using other recorded parameters from the FDR.

2 ANALYSIS

2.1 General

This section contains investigation analysis pertinent to the major events.

After an engine-oil low-pressure indication activated in the cockpit of the ATR 72-500, the *No. 2 engine* was shut down more than 8 minutes after the engine surge event. Shutting down the engine caused more fault lights to illuminate. The *Direct Current Bus Tie Connector (DC BTC)* had been isolated during the crew actioning of the incorrect checklist; *QRH 'ELECTRICAL SMOKE'* checklist, *(see Appendix B, 5.2.3)*. When the *No. 2 engine* was shut down, the No. 1 engine generator could not provide backup power to the *bus 2* supply network. Power to its supply network was lost completely.

The investigation determined that all aircraft systems discussed in this report, apart from the *No. 2 engine*, were functioning correctly and were unavailable due to crew checklist action.

The ATR *QRH* checklists discussed in this report met the manufacturers specifications and technical requirements for the operation of the aircraft. However, the intent of those checklists is solely for pilot reference and use for the safe operation of the aircraft. In analysing the checklist's, the investigation considered the ergonomic effectiveness of the flight crew-checklist interface relating to human factors.

2.2 Flight operations

2.2.1 Crew qualifications and training

The PIC was qualified and had significant experience in command of ATR 72-500 aircraft. His recurrent simulator training records showed that smoke control and removal techniques had not been tested since May 2015. It is likely that along with the ambiguous warning, in a time critical situation, the lack of recent experience on smoke control and removal training contributed to the confirmation bias and uncertainty that he experienced during the accident flight.

The copilot had an ATR 72-500 type rating. However, he was inexperienced and had minimal hours on ATR type aircraft. He was undergoing line training at the time of the accident. His on-going training records also showed evidence of inadequate systems knowledge and this was apparent during the accident flight. This contributed to his degraded level of assertiveness and affected his ability to be an effective flight crew member. This was also an area of deficiency that he was advised to address during training flights prior to the accident.

The investigation determined that the flight crew did not have adequate systems knowledge, particularly with regard to a smoke emergency. This contributed to the mis-diagnosis of the smoke source, and the subsequent selection and actioning of the incorrect checklist.

2.2.2 Operational procedures

2.2.2.1 Checklists

Procedures in the *ATR Quick Reference Handbook (QRH)* are classified in three parts: Emergency, Normal, and Abnormal parameters in flight.

The Centralised Crew Alerting System (CCAS) automatically generates alerts (Warnings & Cautions) when an abnormal system condition is detected. Warnings and cautions are displayed and sorted according to a specifically designed hierarchy. The crew must respect this hierarchy.

When using the *QRH*, the crew are required to comply with the following hierarchy:

− EMERGENCY

− NORMAL

− FOLLOWING FAILURES (ABNORMAL)

When an emergency checklist references another checklist as an action item, that checklist becomes part of the emergency checklist as it is a necessary checklist to complete in order to complete the emergency checklist. For instance, the '*ACW 1+2 loss*' checklist is an abnormal situation checklist. However, the '*ELECTRICAL SMOKE'* emergency checklist refers to the *'ACW Gen 1+2 loss'* checklist making it a necessary checklist for the completion of the emergency checklist. It would therefore be perceived as a higher priority checklist than a normal checklist. There is not enough guidance provided for crew to understand the prioritization scheme.

The crew started the *QRH 'ABNORMAL ENG PARAMETERS IN FLIGHT'* checklist *(see Appendix B, 5.2.2),* when they received the *No. 2 engine ITT gauge* caution, which would have likely led them to shut down *No. 2 engine*. However, continued interruptions from the PIC communicating with the cabin crew and Vila ATC created a distraction that prevented them from completing the checklist.

As the PIC ended a radio transmission to Vila ATC, the '*ELEC SMK*' warning activated. The crew did not return to the *QRH 'ABNORMAL ENG PARAMETERS IN FLIGHT'* checklist. However, they referred to and actioned the *QRH 'ELECTRICAL SMOKE'* checklist.

The investigation determined that the smoke originated from the *No. 2 engine*. If the crew had completed the *QRH 'ABNORMAL ENG PARAMETERS IN FLIGHT'* checklist and shut down the *No. 2 engine*, the smoke source would have been isolated. The investigation also determined that, even after abandoning the *QRH ABNORMAL ENG PARAMETERS IN FLIGHT'* checklist, had the crew correctly diagnosed the smoke source and completed the appropriate smoke checklist, *'AIR COND SMOKE, E26.03'* checklist *(see Appendix B, 5.2.4)*, the No. 2 engine would have eventually been shut down isolating the smoke source.

The flight crew used the *ATR QRH* for respective emergency procedures throughout the emergency. They did not action checklists in accordance with *Air Vanuatu SOP*, which states:

'If a checklist is interrupted, reading must be resumed one step before the last read item'.

Normal checklists were not completed during the emergency phase of flight.

It was evident that aspects such as cognitive saturation, lack of situational awareness, time pressures, inadequate systems knowledge, checklist ambiguity, and confirmation bias influenced the crew's decision making, which led to incorrect checklist selection, prioritisation and action.

One such instance was the *QRH 'Before Landing'* checklist, *(see Appendix B, 5.2.13)*. The crew actioned the before landing section of the *QRH 'ACW GEN 1+2 LOSS'* checklist *(see Appendix B, 5.2.5),* in place of the normal *QRH 'Before Landing'* checklist. This resulted in the crew not recognising that the rudder *Travel Limitation Unit (TLU)* was locked in the *HI-SPD* mode. Had they completed the normal *QRH 'Before landing'* checklist, they would have been directed to check the *TLU* setting and ensured that it was selected manually to the *LO-SPD* mode and full rudder authority would have been available.

However, the shutdown of the *ACW generators* through incorrect checklist selection caused the unavailability of the hydraulic system. The *Air Vanuatu SOP* permits reverse thrust to be used by flight crew as required during single-engine operations. However, the investigation determined that the use of reverse thrust under the prevailing circumstances was inappropriate.

The aircraft sustained a *No. 2 engine* failure, which historically, is a manageable event. However, the uncommon association of smoke from the engine into the avionics/electrical compartment likely led to the flight crew's confirmation bias and misdiagnosis.

The added ambiguous '*ELEC SMK'* warning confirmation bias and mis-diagnosis led to the subsequent shutdown of several essential systems.

The crew's inability to identify the ambiguity in the *'ELEC SMK'* warning was attributed to the lack of appropriate recurrent training, systems knowledge and situational awareness.

There is a **'Note'** contained in the *QRH 'SMOKE'* checklist to make the crew aware of the ambiguity that exists when an '*ELEC SMK'* warning is activated. The investigation determined that the **'Note'** was not consulted and did not grab the attention of the crew as intended.

<u>Note:</u> The investigation found that the engine malfunction, and the subsequent one-engine inoperative landing did not cause the accident. Flight crews are trained to land multi-engine aircraft with an engine inoperative.

2.3 Aircraft

2.3.1 Engine

The *No. 2 engine* oil low-pressure event that occurred on previous flights was caused by an external oil leak from the *rear inlet to accessory gearbox oil pressure tube*. When oil pressure is lost, components such as the bearings would not receive adequate lubrication and cooling as required. Bearing material may be exposed to high temperatures throughout such events. This may cause irreversible softening of the near-surface material which could remain latent for some time.

The investigation could not determine whether the previous low oil pressure events contributed in any way to the seizure of the *No. 3 bearing*. The Pratt and Whitney Canada (P&WC) engine investigation report did not attribute any internal engine damage to those events (oil pressure loss).

From the investigation of the engine, P&WC engineers observed wearing marks on the *split-ring mating faces* of both *inner races* and determined that it may have been caused by a fracture at the *inner race* thrust side. The fracture of the *inner race* thrust side released the fit with the *low-pressure shaft*, which subsequently permitted its relative rotation. The absence of fretting observed around the deformation on the *inner race* thrust side suggested that the relative rotation occurred subsequent to the ring fracture. The circumferential wear of the *No. 3 bearing rear spacer*, produced by the tang of the cup washer indicated that the *No. 3 bearing rear spacer* rotated relative to the *low-pressure shaft*. The wear observed on the *No. 3 bearing inner race* thrust side shoulder was consistent with the *No. 3 bearing rear spacer*, and was induced by their relative rotation.

The relative rotation between the *No. 3 bearing rear spacer* and the *No. 3 bearing inner race* thrust side contributed to the wear damage on the *No. 3 bearing inner race thrust side shoulder*. The missing material on the *No. 3 bearing inner race* thrust side induced by the wear damage, forced the inner ring out of symmetry and created additional hoop stresses[28]. The additional hoop stress would have reduced the ball rolling clearance, which led to skidding/rubbing.

The combination of the additional hoop stresses with the reduced wall thickness of the *No. 3 bearing inner race* thrust side resulted in the overload fracture of the bearing cage. The fatigue features observed on the *No. 3 bearing cage* and the *low-pressure diffuser* may likely have occurred when the seized balls started skidding/rubbing against the distressed *inner ring*.

High temperature exposure was evident at the *M50 bearing* rolling-sliding contacts under heavy load and high speed. This caused thermal softening and deformation near the surface of the bearing balls. *No. 3 bearing balls* had martensite deposits on their surfaces which may have come from its inner ring and *rear spacer*. The results show that the surface damage of M50 steel at rolling-sliding contacts is basically caused by thermal softening of the near-surface material.

28 Hoop Stress –The circumferential stress on the shaft mounted bearing inner ring structure.

Smoke was liberated from the fractured *diffuser case* around the *No. 3 bearing*. The fractures were likely the result of excessive vibration of the bearing when it started to skid and rub against the inner and outer ring following the engine surges.

2.3.2 Aircraft performance

The aircraft's *No. 2 engine* failed, which deteriorated the thrust performance significantly. However, when one engine fails, the aircraft is designed to be flown and landed safely on one engine.

The operational engine, *No.1 (left) engine*, was brought into flight idle as the copilot retarded the *power levers* during the flare. As soon as one of the landing gear absorbers was compressed, the weight-on-wheels switch allowed the *power levers* to be brought back past the ground idle detent to the maximum reverse position.

Full rudder authority was not available for the approach and landing due to the high-speed lockout of the *TLU* during engine shutdown. The crew only had +/- 4° rudder deflection available on either side of centre. Without the full 27° available, the aircraft's aerodynamic lateral control was significantly limited.

The hydraulic system was not available during the approach and landing. This resulted in the loss of the main braking system, and nose-wheel steering.

The *hydraulic accumulator* allows six braking applications for emergency brake usage. However, recorded data analysis and PIC statements confirm that emergency brakes were not applied.

2.3.3 Aircraft instrumentation

The loss of *DC generator 2*, through the shutdown of the *No. 2 engine*, resulted in the loss of power to several aircraft instruments *(see Appendix B, 5.2.7 and 5.2.8)*. However, most of the instruments that became unavailable were dual display systems allowing one system to remain operational.

2.3.4 Aircraft systems

The investigation determined that none of the aircraft's systems were defective. All system failures and faults were induced through crew checklist action or inaction.

Furthermore, apart from the *No. 2 engine* malfunction related cautions and warnings, all other cautions and warnings followed crew checklist action or inaction.

The smoke travelled from the *No. 2 engine compressor* section through the air-conditioning ducts into the cabin, flight deck and subsequently through the avionics/electrical compartment causing the activation of the '*ELEC SMK*' warning. The avionics/electrical systems were operating normally and had no relation to the smoke event in-flight. However, the warning in isolation presented an ambiguity that significantly contributed to the crews' confirmation bias.

The hydraulic system was not available when the aircraft landed. The ***blue*** *hydraulic system* can act as a backup of the ***green*** *hydraulic system* when it fails and vice versa. However, both systems became unavailable when the *ACW generators* were shutdown. The aircraft at that point had no brakes or ground control capability. Only the hydraulic auxiliary pump was available for 43 seconds through battery power and was pressurised to extend flap.

The *TLU* AUTO selection capability was not available due to *DC generator No. 2* shutdown and *DC BTC* isolation. The manual selection of speed modes was available, but was not operated by the crew. The system fault occurred while it was in the HI SPD mode and therefore remained in that mode throughout the approach and landing. The crew did not switch over to the LO SPD mode when it was appropriate.

2.3.4.1 Electrical smoke warning system

It is important to note the sequence of smoke detection for the purpose of logically making sense of the smoke event. The smoke travelled from the engine through the air conditioning system, into the passenger cabin, forward cargo compartment, flight deck and eventually into the avionics/electrical compartment, and activated the electrical smoke detector at the outlet of the avionics/electrical compartment.

The investigation determined that if the smoke had originated in the avionics/electrical compartment, the electrical smoke detector would have been activated before the smoke could get into the cabin.

Smoke was first detected in the cabin by the SCC who notified the PIC. The *'ELEC SMK'* warning was the first to be activated on the *Crew Alert Panel (CAP)* along with the MW, about 3 minutes after the first detection of smoke in the cabin. This was caused when the engine smoke reached the electrical smoke detector. This smoke detector is located at the outlet duct of the avionics compartment to ensure that if smoke originates from the avionics compartment, the first smoke detector that will unambiguously activate is the electrical smoke detector.

The mis-diagnosis of the origin of the smoke due predominantly to the *ELEC SMK* warning, resulted in the crew's decision to action the *QRH 'ELECTRICAL SMOKE'* checklist. It was apparent that the crew did not see the '**Note**' in the *QRH 'SMOKE'* checklist. This may have been due to a number of factors. Firstly, the '**Note**' that is intended to be an attention grabber is not ergonomically positioned relative to the rest of the checklist text. If pilots read down the checklist, the checklist would draw their attention away from the checklist and to the cockpit instruments and systems before reaching the **'Note'**. There is a risk of not seeing the **'Note'** if the crew have a biased perception of the smoke source. This was the case with the accident flight. As soon as they completed the *QRH 'SMOKE'* checklist memory action items, they immediately referred to the *QRH 'ELECTRICAL SMOKE'* checklist.

The investigation determined that the crew's confirmation bias with regard to the diagnosis of the smoke source, led them to select and action the incorrect checklist.

The investigation determined that the absence of an appropriate 'attention grabbing' ***'CAUTION'*** note in the *QRH 'ELECTRICAL SMOKE'* checklist to highlight the ambiguity, aided and strengthened the crew's confirmation bias

The investigation also determined that the content of the **'Note'** in the *QRH 'SMOKE'* checklist meets the criteria for a ***'CAUTION'***. It requires the crew to note that an '*ELEC SMK'* warning is ambiguous could lead to incorrect crew action. The investigation determined that the **'Note'** did not grab the attention of the copilot because;

1. It was a '**Note'** in plain black text and blended in with other text and was not appropriately highlighted to attract the attention of flight crew.
2. It is positioned after the checklist item that requires crew attention to be diverted away from the checklist. A Note is not as high in the prioritisation thought process as a CAUTION or WARNING. Therefore, in high stress and time critical conditions, it is easy to disregard 'Notes' in pursuit of timely checklist completion.
3. The '**Note**' from the *QRH 'SMOKE'* checklist is next in line after the 'SMOKE SOURCE…. IDENTIFY' action item. This item would draw the crew's attention away from the checklist to diagnose the smoke source before coming back to continue the checklist.

The investigation determined that the content of the '**Note'** on the *QRH 'SMOKE'* checklist is intended to tell the crew that care needs to be exercised to avoid danger or mistakes. This is typically a *caution*.

2.3.4.2 Ground control systems

When both *ACW Generators* were shut down during the *QRH 'ELECTRICAL SMOKE'* checklist action, the *main hydraulic pumps* were lost. As a result, the *main brakes* and *nose-wheel steering* were not available. The *hydraulic auxiliary pump* primary power and AUTO mode were not available following the *No. 2 engine* shutdown. The *auxiliary pump* was powered for 43 seconds to extend the *flap*.

The only systems that were available to the crew were the rudder for aerodynamic steering, and the emergency brakes through the hydraulic accumulator.

However, rudder control was rendered ineffective when the *TLU* was not switched to the *TLU LO-SPD* mode.

With the AUTO mode unavailable, the crew were required to manually select the speed modes. Neither pilot was able to recognise the fault. The *No. 2 engine* was shut down while the aircraft airspeed was about 200 kts.

The fault light illuminated when the aircraft speed decreased below 185 knots with the *TLU* locked in the *HI-SPD* mode. The aircraft landed with this mode resulting in negligible rudder control available.

The fault light is on the overhead panel above the left seat. With the overwhelming number of faults, alerts and lights active in the cockpit, it would have been difficult to detect. Furthermore, the *TLU LO-SPD* is designed in a manner that it would only attract crew attention if the *TLU* is correctly in the *LO-SPD mode.* The indicator remains blank when it is correctly in the *HI-SPD* mode and if there is *TLU* fault of any kind.

The crew were not drawn by the alerting system of the aircraft to the fault. Under the prevailing circumstances the existing fault message was ineffective.

The crew also did not consult the *QRH 'Before Landing'* checklist because they had completed the *'before landing'* section of the *ACW Gen 1+2 Loss* checklist. The Before Landing checklist would have drawn their attention to the *TLU LO-SPD indicator* and *switch* and the crew would have been able to notice that it was not in the correct mode. They would have had the opportunity to manually switch to the *LO-SPD* mode and full rudder authority would have been available for ground control during the landing roll.

Flight data analysis showed that the *No.1 engine* thrust reverser was momentarily deployed upon touchdown and again a few seconds later. The selection of asymmetric reverse thrust during the landing roll with nose-wheel steering, brakes and rudder authority were unavailable caused the aircraft to veer off the runway.

2.4 Human factors

2.4.1 Psychological and physiological factors

The investigation determined that a number of human factors affected crew decision-making and action. The following are some of the common and obvious human factors observed during the investigation.

- ***Steep cockpit authority gradient***
- ***Aircraft systems knowledge inadequacies***
- ***Inadequate CRM***
- ***Cognitive saturation (overwhelming workload)***
- ***Time pressures***
- ***Stress***
- ***Lack of familiarity (Non-compliance with recurrent training requirements)***
- ***Crew lack of situational awareness***
- ***Confirmation bias***
- ***Ergonomics***
- ***Vigilance decrement***

The investigation determined through the CVR data analysis of the day's flights, that the *Crew Authority Gradient* was generally steep. This is naturally the case when the Captain is a highly experienced, well respected pilot and holds a position of high regard. The PIC was the ATR Fleet Manager. The copilot was new to the aircraft and was still undergoing line training at the time of the accident. CVR data analysis led to the determination that the copilot was very reserved and lacked assertiveness throughout the flight, and even more so during the emergency phase. He did not raise any concerns or question any actions throughout the flight.

The copilot accepted every action by the PIC. An example of this behaviour was clearly displayed when the crew was actioning the memory items of the *'SMOKE'* checklist. The copilot immediately switched to and started reading the *'ELECTRICAL SMOKE'* checklist before completing the memory items of the *'SMOKE'* checklist when the PIC said go back to the other one [translated].

The investigation determined that the relative difference in levels of experience and knowledge between the flight crew contributed to the PIC's sense of increased responsibility and workload.

The lack of appropriate *crew resource management (CRM)* was evident and the investigation found that some of the contributing factors were the difference in crew experience levels and inadequacies in the copilot's ATR systems knowledge. The crew's technique for the application of the *QRH* checklists was unorthodox, rushed, and not in accordance with the established standard operational requirements.

The crew continued the approach and did not give themselves enough time to properly implement appropriate actions. This was influenced by the *'ELECTRICAL SMOKE'* checklist requiring that the aircraft be landed as soon as possible if the smoke source within the perceived originating area could not identified.

The PIC took on most of the tasks that would, in such emergencies, normally be shared. The checklist actions were not conducted in a timely manner due to conflicting tasks and the level of urgency. The PIC's initial perception caused by the *'ELEC SMK'* warning would have contributed to the less than effective use of available time.

The operator had not fully complied with their approved operational competency and recurrent training requirements established under the Civil Aviation Rules (CAR's). The PIC's training records showed that the smoke training and CRM were only assessed in the simulator at irregular intervals and not annually. The last time he had been assessed in the simulator for smoke training in the sim was more than 3 years before the accident flight. Familiarity and decision making relating to a smoke event were inadequate.

The activation of multiple system fault messages, cautions and warnings that appeared on the *CAP* and throughout the cockpit was perceived by the crew as a mass aircraft system malfunction and failures and created confusion and raised stress levels. In fact, most of those messages and alerts were induced by crew action and/or inaction. The crew did not anticipate the adverse effects of shutting down the ACW generators and shutting down the *No. 2 engine* with the *DC BTC* isolated. The investigation determined that because of the complexity of some of these systems and their simultaneous activation, the crew was not able to regain full situational awareness within the limited time available. The crew also did not consult any of the lost equipment lists provided in the QRH which complement some of the checklists. The unexpected activation of numerous faults and failures along with the existing emergency workload led to cognitive saturation and increased stress levels. This also caused the crews unintended division of attention and vigilance decrement, which directly affected the crew's decision-making.

When the *No. 2 engine ITT* exceedance indication was noticed by the PIC, he took control of the aircraft. The crew identified that event as an abnormal engine parameter and immediately referred to the appropriate checklist. The PIC notified the SCC of the engine abnormality. He was surprised when the SCC informed him that there was smoke entering the cabin.

The cabin crew did not inform the flight crew about the colour and odour of the smoke which are key identifying features smoke, nor did the PIC ask for that information. These details usually help crew with their diagnosis during smoke emergencies.

The PIC immediately broadcast a '*MAYDAY*' and provided details of the abnormality to Vila ATC. The *CVR* showed that during the radio transmission, the PIC associated the smoke with the *No. 2 engine* abnormality.

The PIC appeared to have acknowledged the concurrent events and therefore resolved that the smoke was being produced by the engine. As a result, he decided to continue with the *ABNORMAL ENGINE PARAMETERS IN FLIGHT* checklist instead of referring to the *'SMOKE'* checklist.

The radio transmission of the *'Mayday'* was due to the smoke. If the engine malfunction had occurred in isolation without any smoke event, the broadcast would normally have been a *'Pan Pan'*.

Towards the end of a PA announcement made subsequent to the '*Mayday*' broadcast, the *'ELEC SMK'* warning activated and the attention of the PIC was immediately drawn away from the engine towards the warning. From that point on, the PIC's declining situational awareness and inductive reasoning was apparent as the warning was managed with no consideration given to the likelihood of the smoke being produced by the malfunctioning engine. The *'ELEC SMK'* warning was perceived by the PIC as an indisputable identifying feature of the smoke originating from the Avionics/Electrical compartment. The PIC's confirmation bias caused by the *'ELEC SMK'* warning led to the misdiagnosis of the smoke origin that subsequently led to the selection and action of the 'ELECTRICAL SMOKE' checklist which was, under that situation, not the appropriate checklist.

The crew had donned their oxygen masks and goggles prior to the *'ELEC SMK'* warning when the smoke started entering the flight deck.

When the *QRH 'ELECTRICAL SMOKE'* checklist referred them to the *QRH 'SMOKE'* checklist, they actioned the *'memory items'* in a hurried and disjointed manner. Immediately following that, the crew returned to the *QRH 'ELECTRICAL SMOKE'* checklist.

During the investigation review of the *QRH 'SMOKE'* checklist together with the CVR, it was determined that the crew returned to the *QRH 'ELECTRICAL SMOKE'* checklist because the PIC was adamant that he had already identified the origin of the smoke and there was an urgency to diagnose the actual source.

The action item that follows after the *'memory item'* on the *QRH 'SMOKE'* checklist requires the crew to identify the source of the smoke, and following that action was the **'Note'** regarding the ambiguity associated with the *'ELEC SMK'* warning. It was evident from the CVR that the copilot did not observe the **'Note'.** Confirmation bias coupled with time pressures and inadequate checklist ergonomics were determined to be contributing factors to the oversight of this important note.

If the **'Note'** on the *QRH 'SMOKE'* checklist had attracted the attention of the copilot, he and the PIC would have been appropriately cautioned about the ambiguity associated with the *'ELEC SMK'* warning and aided in the crew's decision-making process. This did not eventuate, which led them to continue without ambivalence.

The consequences of the use of an incorrect checklist can cause additional and unnecessary workload and confusion for pilots, especially when the end result does not turn out as expected. When the *QRH 'ELECTRICAL SMOKE'* checklist was actioned, the smoke continued to intensify. This was the opposite effect of the checklists intended outcome. However, the crew did not re-assess the situation to ensure that they had made the correct diagnosis and taken the appropriate actions. If there was any chance of re-assessing the situation, it is likely that it would have been exacerbated by unmethodical approach towards the situation and time constraints imposed by the intensifying smoke.

When the crew were later faced with a *No. 2 engine* oil low-pressure warning, they took appropriate actions and shut down the engine. The smoke source was subsequently isolated.

However, by that time the smoke would have been too intense and its discontinued emission or subsidence would have been difficult to identify. Therefore, at that point, the crew would not have been able to realise that their earlier checklist selection was incorrect.

The investigation determined that the '**Note'** on the *QRH 'SMOKE'* checklist was not ergonomically positioned to attract the attention of the crew. Furthermore, The AIC believes that the content of that **'Note'** warrants its classification as a 'CAUTION' with a strong amber colour. Further, the *QRH 'ELECTRICAL SMOKE'* checklist does not contain any cautions or, at the very least, a note to provide awareness to pilots that there is an ambiguity associated with the *CAP 'ELEC SMK'* warning.

In general, if smoke is first suspected, crew are required to action the *'SMOKE'* checklist. The *'SMOKE'* checklist would subsequently require the crew to refer to the *'ELECTRICAL SMOKE'* checklist if either electrical smoke is suspected, or if the smoke source has not been identified. The interpretation would be that if pilots do not know where the smoke is emanating from, action the *'ELECTRICAL SMOKE'* checklist. This in turn would mean that ATR have determined that the likelihood of unidentified smoke sources being electrical in nature is higher than all other aircraft smoke sources.

This also means that if the crew has to 'guess' and decide which checklist to implement, the primary checklist becomes the *'ELECTRICAL SMOKE'* checklist.

When crew are actioning the *'ELECTRICAL SMOKE'* checklist, and get to the item that condition 'If smoke source not identified', the crew are required to 'land as soon as possible' and action the *'ACW Gen 1+2 Loss procedures*'. At this point, crew would have completed actions in support of their diagnosis and arrived at the condition where either the electrical smoke source has been identified or not.

When the existing condition is that the smoke source has not been identified through the '*ELECTRICAL SMOKE'* checklist actions, no information or clarification is provided to the crew to inform or caution them that it may be because the earlier *QRH*-influenced-decision to action the *'ELECTRICAL SMOKE'* checklist may have been incorrect. Crew should be prompted to at least reconsider the *QRH*-influenced-checklist decision and re-evaluate the broader scope of possible smoke originating areas before being required to move on to the *'ACW Gen 1+2 Loss'* checklist. Moving on to the *'ACW Gen 1+2 Loss'* checklist would signify that although the source of smoke has not been identified by that point, the crew will have to commit to accept and proceed with all systems switched off during the *'ELECTRICAL SMOKE'* checklist.

The crew did not consult the '*Before Landing'* checklist. While they were actioning the *QRH 'ACW Gen 1+2 Loss'* checklist, the PIC instructed the copilot to skip the 'Before landing' section of the *QRH 'ACW Gen 1+2 Loss'* checklist because the aircraft was not yet within the speed range and appropriate position for landing gear and flap extension, and that they would complete it later. They later revisited and completed that section when it was appropriate to configure the aircraft for landing, where the normal *QRH* '*Before Landing'* checklist is usually actioned. This is why the TLU was not checked for correct configuration.

During touchdown and the landing roll the aircraft had one engine inoperative and its landing and ground control systems, including brakes and steering, were not available. According to the FDR data, reverse thrust was applied three times. Selecting reverse thrust while landing with an engine inoperative is permissible by the manufacturer's operating procedures for the aircraft. However, it is advised that care must be taken.

However, for the landing of AV71, the inoperative engine was not the only system not available. The hydraulics and rudder also were not available. Any application of reverse would therefore be deemed inappropriate under those circumstances. This was a further indicator that the crew lacked situational awareness during the landing.

The investigation determined that the crew's inadequate aircraft systems knowledge, skill level and the lack of situational awareness contributed to the runway excursion.

2.5 Survivability

2.5.1 Rescue fire service response

ARFFS were requested by the PIC, minutes prior to landing. The fire and rescue trucks were on standby at the airport before the aircraft landed.

2.5.2 Survival aspects

The SCC notified the PIC of the smoke in the cabin when he initially called to advise her of the engine problem. However, the SCC did not inform the PIC about the colour and odour of the smoke, nor did the PIC ask for this information. The cabin crew did not attempt to identify the source of smoke/fire. These actions would have assisted the PIC assessment of the situation. The flight crew donned their masks when they saw smoke start to enter the flight deck.

Both cabin crew remained seated during the emergency phase. They were complying with what they believed was the company policy; when the fasten seatbelt sign is on, cabin crew are to remain seated and fasten their seatbelts fastened. Contrary to that belief, the *ATR CCOM* instructs cabin crew to carry out safety duties and responsibilities as required before taking up their seats during emergency situations. In this case, the safety duties included the '*cabin smoke contamination procedure*' and 'cabin preparation' procedures.

The cabin crew did not don their PBE at the onset of smoke in the cabin and throughout the event. If they had donned PBE, they would have had 15 minutes of clean oxygen, which would have enabled them to move through the cabin and assist passengers.

The cabin crew were unaware that Air Vanuatu Operations Limited had a cabin smoke emergency procedure. This was determined by investigators to be due to the lack of appropriate training by Air Vanuatu Operations Limited.

The fact that they did not hand out wet towels to the passengers increased the probability of the passengers choking and suffocation.

During the smoke emergency, the cabin crew members continuously instructed the passengers to keep their 'heads down and stay down.' Some passengers reported asking the cabin crew member in the forward crew seat for oxygen, however, he instructed them to keep their heads down and stay low and breathe through clothing.

Although the fasten seatbelt signs went out when the 'DC SVC' and 'UTLY BUS' were switched off, passengers remained seated as instructed by the PIC during his PA announcement. The cabin crew also remained seated.

After the PIC declared the emergency evacuation, the cabin preparation procedure was not executed as required by the *CCOM*. The cabin preparation procedure is to ensure passengers and cabin crew are secured for survivability during the impact and a subsequent safe egress after the aircraft comes to a stop. It is also a safety responsibility of the cabin crew for all known emergency evacuations. The SCC advised passengers to fasten their seatbelts 3 minutes before impact.

The investigation was unable to determine why the cabin crew did not execute the cabin preparation actions as required in the *CCOM*.

2.6 Operator

2.6.1 Air Vanuatu Operations Limited Standard Operating Procedures

Air Vanuatu's operational manuals are established to meet the New Zealand Civil Aviation Rules (CAR's) adopted by the Vanuatu Government. For the ATR fleet, Air Vanuatu had adopted the ATR the type specific operational documents.

The investigation found that the Operator did not comply with the CAAV approved *Air Vanuatu Check and Training Manual* with regard to training and recurrency. The PIC’s training records showed that he had not done smoke training since 11 May 2015. The training requirements under the Air Vanuatu Training Manual did not provide adequate guidance and emphasis on smoke emergencies.

There were many other training areas that were reviewed and found non-compliant with the Air Vanuatu Operations Manual approved and certified by CAAV to be compliant with the New Zealand CAA adopted Civil Aviation Rules (CAR’s). The lack of appropriate and regulated training was a contributed to the PIC’s decision-making.

The investigation determined that cabin crew training was inadequate. The actions and inactions of the cabin crew during the emergency phase of the flight were not adherent to the *ATR CCOM* and *CCTM* adopted by Air Vanuatu Limited. This was seen as a matter of concern as the smoke event lasted about almost 20 minutes and the cabin crew did not don their PBE’s and provide wet towels to the passengers to help ease the inhalation of smoke. the appropriate care to the passengers was not given.

Furthermore, the investigation found that the passengers and crew were not medically tested for carbon monoxide poisoning after the accident.

3 CONCLUSIONS

3.1 Findings

3.1.1 Aircraft

a) The aircraft was certified, equipped and maintained in accordance with existing Civil Aviation Rules and approved procedures.

b) The aircraft was certified as being airworthy when dispatched for the flight.

c) The mass and the centre of gravity of the aircraft were within the prescribed limits.

d) The bang noise and compressor stall were as a result of the *No.3 bearing* distress in the *No. 2 engine.*

e) The reported smoke in the cabin was attributed to the fracture of the low-pressure diffuser case in the *No. 2 Engine* that allowed oil from the No. 3 bearing cavity into the air system.

f) The root cause of the *No. 3 bearing* distress was attributed to relative rotation between the *No. 3 bearing* inner race thrust side and the *No.3 bearing rear spacer*.

g) The relative rotation between the No.3 bearing inner race thrust side and the *No. 3 bearing* rear spacer was believed to have been caused by a problem with the *stack-up* of the various components around the *No. 3 bearing* induced at the last engine overhaul.

h) Apart from the engine, none of the aircraft systems, including electrical and hydraulic systems, malfunctioned in-flight. The loss and unavailability of these systems, was induced by flight crew action.

i) The aircraft alerting systems were adequate and provided warnings in an appropriate manner.

j) The aircraft landed without the main brakes and nose-wheel steering.

k) The TLU was locked in the HI-SPD mode resulting in the significant limitation of the rudder.

l) The aircraft's heading and course change during the landing roll occurred because the crew applied reverse thrust to the *No.1 engine*.

m) The sudden change in course resulting in a significant runway excursion that could not be corrected due to the unavailability of nose-wheel steering, differential braking (main brakes) and rudder.

n) Rudder travel was limited to +/-4° and rudder was offset due to incorrect calibration and operated between -1 and +7 due to incorrect TLU setting.

o) Nose-wheel steering and main landing gear brakes were not available during landing due to hydraulic pump loss.

p) The aircraft could not be stopped from impacting the parked aircraft because of the unavailability of the main brakes and the crew not applying the emergency brakes.

q) The emergency brakes were available but were not applied by the crew.

3.1.2 Crew / pilots

a) The PIC was licensed and qualified for the flight in accordance with existing Civil Aviation Rules.

b) The copilot was licensed and qualified for the flight in accordance with existing Civil Aviation Rules.

c) The flight crew were medically fit and adequately rested to operate the flight.

d) The flight and cabin crew were in compliance with the flight and duty time rules.

e) The flight crew's actions and statements indicated that their knowledge and understanding of the aircraft systems was inadequate.

f) The PIC was not current with smoke control and removal procedures

3.1.3 Flight operations

a) The flight was conducted in accordance with the *Air Vanuatu Operations Manual*.

b) The PIC carried out normal radio communications with the relevant ATC units.

c) The co-pilot's limited experience flying the ATR, and deficient systems and checklist knowledge contributed to the inadequacies CRM, crew coordination, and steep cockpit authority gradient.

d) The flight crew did not communicate efficiently or effectively with each other.

e) The flight crew did not fully comply with *Air Vanuatu Company Standard Operating Procedures.*

f) The PIC's training on smoke removal and control techniques was not current and was determined to be inadequate during the smoke emergency.

g) The ***'Note'*** in the *QRH 'SMOKE'* checklist was not adequately featured to effectively attract the attention of the crew.

h) Generally, the *'SMOKE'* checklist condition, *'If source not identified or electrical smoke suspected'* lead crew to the Electrical Smoke checklist when smoke is not identified.

i) The *QRH 'ELECTRICAL SMOKE'* checklist does not contain an attention-grabbing **'CAUTION'** to ensure crew are aware of the ambiguity presented by the *'ELEC SMK'* warning.

j) The QRH *'ELECTRICAL SMOKE'* checklist does not provide guidance for crew to return and reassess other possible smoke sources (non-electrical) when the condition *'smoke source not identified'* exists.

3.1.4 Operator

a) The *Air Vanuatu Training Manual* did not fully comply with the requirements of the *New Zealand CAR 121* adopted by CAAV.

b) The cabin crew were not trained to the appropriate standard for smoke emergencies in accordance with the adopted *ATR CCOM*.

c) The Air Vanuatu smoke emergency training requirements for flight crew were found to be inadequate.

d) Little emphasis is available for crew regarding smoke control and removal in the Air Vanuatu Operational documentation.

e) The Crew Resource Management displayed by the crew did not promote good flight deck communication and coordination.

f) The Cabin crew were not aware of the smoke emergency procedure contained in the *ATR Cabin Crew Operating Manual*, and had not been trained to execute all actions required by this procedure.

3.1.5 Air Traffic Services and airport facilities

a) The air traffic controllers' workload was assessed as moderate with normal complexity.

b) Villa ATC provided prompt and effective assistance to the flight crew.

c) All aerodrome approach aids and lighting facilities were operating normally at the time of the accident.

d) The airport was not equipped with a facility to record the Secondary Surveillance Radar.

3.1.6 Civil Aviation Authority of Vanuatu

The safety and regulatory oversight of the operator's training and operational compliance was found to be inadequate.

3.1.7 Flight recorders

a) The FDR did not record, and was not capable of recording, some of the relevant parameters required by FAR specifications.

b) The dataframe version for the aircraft's data recording system did not meet the requirements of *FAR 121.344*.

3.1.8 Medical

a) There was no evidence that incapacitation or physiological factors affected the flight crew performance.

b) There was no evidence that the pilots suffered any sudden illness or incapacity which might have affected his ability to control the aircraft.

c) A post-accident medical check was not conducted on the crew and passengers.

3.1.9 Survivability

a) The SCC informed the PIC of the smoke when he initially called to advise her of the engine abnormality.

b) The SCC did not advise the PIC of the colour / odour /density of the smoke, nor did she attempt to identify the source of smoke/fire. The PIC did not ask for this information.

c) The cabin crew did not execute the required procedure for cabin smoke emergency due to the lack of inadequate training.

d) Although the seat-belt signs were off, the passengers remained seated as instructed by the PIC.

e) Both cabin crew were seated when the PIC switched on the seatbelt sign. They remained seated with their seatbelts fastened throughout the remainder of the flight and until the aircraft came to a stop after impact, compliance with the operational requirement for cabin crew to be seated whenever the seat belt sign was illuminated**.**

f) After the PIC declared a planned emergency evacuation, the cabin crew did not execute the cabin preparation procedure as required in the *ATR Cabin Crew Operating Manual*.

g) The SCC made a Public Announcement advising passengers to fasten their seatbelts 3 minutes before impact.

h) The crew and passengers survived the accident.

i) After the aircraft came to a stop and the PIC commanded the evacuation, the cabin crew and passengers egressed safely from the aircraft with no injuries.

j) Emergency evacuation procedures were followed during *egress* from the aircraft.

k) The SCC assisted an elderly passenger to egress the aircraft while the CC conducted a cabin check before evacuating.

l) ARFFS were present at the airport during the emergency landing of the aircraft.

3.2 Causes [Contributing factors]

The engine malfunction, although not directly causal to the accident, caused the generation of smoke, which prompted the declaration of a *'Mayday'* and an immediate descent.

The smoke detection by the electrical smoke detector caused the ambiguous *'ELEC SMK'* warning to activate in the cockpit causing the PIC's confirmation bias and subsequent diversion of the attention away from the engine issue.

The confirmation bias created by the ambiguous *'ELEC SMK'* warning led to the selection and action of the 'Electrical Smoke' checklist

The copilot's lack of aircraft systems knowledge and introverted behaviour increased the workload on the PIC and contributed to the steep cockpit authority gradient. This significantly contributed to the degraded CRM.

The oversight of the 'Note' in the *QRH 'SMOKE'* checklist and the absence of similar information in the *QRH 'ELECTRICAL SMOKE'* checklist encouraged the crew to continue the checklist without other consideration.

The ACW generators were switched off and the DC BTC was isolated through compliance with the *QRH 'ELECTRICAL SMOKE'* checklist by the flight crew resulting in the loss of hydraulic system pump power and the illumination of several fault lights.

The crew were referred by the *QRH 'ELECTRICAL SMOKE'* checklist action of the *QRH 'ACW GEN 1+2 LOSS'* checklist and completed the 'before landing' section in place of the normal *QRH 'Before Landing'* checklist. This caused the crew not to check the *TLU* setting.

With the DC BTC isolated, the shutdown of the *No. 2 engine* caused all *DC bus 2* supplied systems to lose power. This resulted in a number of system faults, failures and cautions.

The activation of numerous fault and failure messages as a result of the *QRH 'ELECTRICAL SMOKE'* checklist and the shutdown of the *No. 2 engine,* significantly contributed to crew cognitive saturation and reduced situational awareness and crew vigilance.

The lack of situational awareness caused the crew to select reverse thrust with ground control and braking systems unavailable.

The selection of reverse thrust caused the aircraft to turn to the left and exit the runway.

The absence of hydraulic control, brakes, and aerodynamic control prevented the crew from correcting the undesired course change, runway excursion, and subsequent collision with the parked aircraft.

4 RECOMMENDATIONS

4.1 Recommendations

As a result of the investigation into the accident involving ATR 72 aircraft registered YJ-AV71 at Bauerfield International Airport Port Vila, Vanuatu on the 28 July 2018. The Papua New Guinea Accident Investigation Commission issued the following recommendations to address concerns identified in this report.

4.1.1 Recommendation number AIC 19-R19/18-1002 to Avions de Transport Regional (ATR) Limited

Date Issued: 27 July 2019

***'SMOKE'* checklist**

The PNG Accident Investigation Commission (AIC) recommends that ATR should ensure that the word '**Note**' on the *QRH 'SMOKE'* checklist is reclassified to, and represented by, an amber **'CAUTION'** that is ergonomically able to draw the attention of flight crews to the ambiguity presented by the electrical smoke warning.

Action requested

The AIC requests that ATR note recommendation *AIC 19-R19/18-1002*, and provide a response to the AIC within 90 days of the issue date, and explain (including with evidence) how ATR has addressed the safety deficiency identified in the safety recommendation. **STATUS: ACTIVE.**

4.1.2 Recommendation number AIC 19-R20/18-1002 to Avions de Transport Regional (ATR) Limited

Date Issued: 27 July 2019

***'ELECTRICAL SMOKE'* checklist**

The PNG Accident Investigation Commission (AIC) recommends that ATR should ensure that a **'CAUTION'** statement with content similar to the content of the **'Note'** in the *QRH 'SMOKE'* checklist is included in the *QRH 'ELECTRICAL SMOKE'* checklist.

Action requested

The AIC requests that ATR note recommendation *AIC 19-R20/18-1002*, and provide a response to the AIC within 90 days of the issue date, and explain (including evidence) how ATR has addressed the safety deficiency identified in the safety recommendation. **STATUS: ACTIVE.**

4.1.3 Recommendation number AIC 19-21/18-1002 to Avions de Transport Regional (ATR) Limited

Date Issued: 27 July 2019

The PNG Accident Investigation Commission recommends that ATR should ensure that the either:

1. The rudder Travel Limitation Unit (TLU) Low-Speed check, along with other essential check and action items, is included in the before landing section of the *QRH 'ACW GEN 1+2 LOSS'* checklist, and every abnormality and emergency checklist that has gear and flap extension procedures; or

2. The *Quick Reference Handbook (QRH)* contains appropriate information that informs the crew that the *'before landing'* sections of the *'ACW GEN 1+2 LOSS'* checklist and other abnormality and emergency checklist is not a substitute for the normal *'Before landing'* checklist.

Action requested

The AIC requests that ATR note recommendation *AIC 19-R21/18-1002*, and provide a response to the AIC within 90 days of the issue date, and explain (including evidence) how ATR has addressed the safety deficiency identified in the safety recommendation. **STATUS: ACTIVE.**

4.1.4 Recommendation number AIC 19-22/18-1002 to Air Vanuatu Operations Limited

Date Issued: 27 July 2019

The PNG Accident Investigation Commission (AIC) recommends that Air Vanuatu Operations Limited should ensure that the Cabin Crew are adequately trained on cabin safety duties in relation to smoke emergency procedures.

Action requested

The AIC requests that Air Vanuatu note recommendation *AIC 19-R22/18-1002*, and provide a response to the AIC within 90 days of the issue date, and explain (including with evidence) how Air Vanuatu has addressed the safety deficiency identified in the safety recommendation. **STATUS: ACTIVE.**

4.1.5 Recommendation number AIC 19-R23/18-1002 to Air Vanuatu Operations Limited

Date Issued: 06 August 2019

The PNG Accident Investigation Commission recommends that Air Vanuatu Operations Limited should ensure that its Flight Crew are adequately trained, current and competent in the execution of smoke emergency procedures.

Action requested

The AIC requests that Air Vanuatu note recommendation *AIC 19-R23/18-1002*, and provide a response to the AIC within 90 days of the issue date, and explain (including evidence) how Air Vanuatu has addressed the safety deficiency identified in the safety recommendation.

STATUS: ACTIVE.

5 APPENDICES

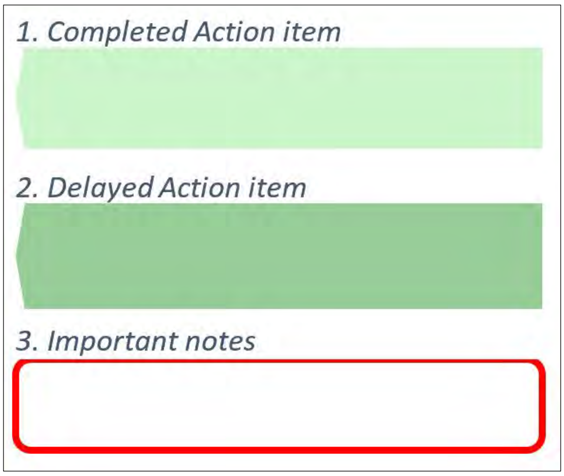
5.1 Appendix A: CCAS Alerts during accident flight

Time (UTC)	MC/MW	CAP	Local Alert	Remark
23:16:16	MC	ENG	Eng 2 overtemp on ITT gauge	Engine overtemp
23:18:11	MC	ENG	Eng 2 overtemp on ITT gauge	Engine overtemp
23:19:11	MW	ELEC SMK		Electrical Smoke Detector activated by smoke
23:20:53	MW	ELEC SMK		Electrical Smoke Detector activated by smoke
	MC	AIR	Cabin/Cargo recirc fan – FAULT	Switched off by crew during SMOKE checklist memory items
	MC	AIR	Flight comp't recirc fan - FAULT	Switched off by crew during SMOKE checklist memory items
23:21:26	MW	ELEC SMK		Smoke still passing over ELEC SMK detector
	MC	AIR	Avionics vent exhaust mode – FAULT	Remained off
	MC	AIR	Cabin/cargo recirc fan - FAULT	Remained off
	MC	AIR	Flight Comp't recirc fan - FAULT	Remained off
23:21:43	MW	ELEC SMK		Smoke still passing over ELEC SMK detector
	MC	AIR	Avionics vent exhaust mode – FAULT	Switched off by crew during ELEC SMK checklist.
	MC	AIR	Cabin/cargo recirc fan - FAULT	Remained off
	MC	AIR	Flight Comp't recirc fan - FAULT	Remained off
	MC	ELEC	ACW bus 1 OFF	Off as a result of ACW Gen 1 switch off by crew
	MC	ELEC	ACW bus 2 OFF	Off as a result of ACW Gen 2 switch off by crew
	MC	ELEC	ACW gen 1 FAULT	Switched off by crew during ELEC SMK checklist
	MC	ELEC	ACW gen 2 FAULT	Switched off by crew during ELEC SMK checklist

	MC	ELEC	Utility bus SHED	switched of by crew during ELEC SMK checklist
	MC	HYD	Hyd blue pressure LO	Pump pressure lost when ACW Gen 2 switched off
23:22:30	MW	ELEC SMK		Smoke still passing across ELEC SMK detector
	MC	AIR	Avionics vent exhaust mode – FAULT	Remained off
	MC	AIR	Cabin/cargo recirc fan - FAULT	Remained off
	MC	AIR	Flight Comp't recirc fan – FAULT	Remained off
	MC	ELEC	ACW bus 1 OFF	Remained off
	MC	ELEC	ACW bus 2 OFF	Remained off
	MC	ELEC	ACW gen 1 FAULT	Remained off
	MC	ELEC	ACW gen 2 FAULT	Remained off
	MC	ELEC	Utility bus SHED	Remained off
	MC	HYD	Hyd blue pressure LO	Remained off
	MC	ELEC	ACW bus 1 OFF	Remained off
23:22:33	MW	ELEC SMK		Smoke still passing across ELEC SMK detector
	MC	AIR	Avionics vent exhaust mode – FAULT	Remained off
	MC	AIR	Cabin/cargo recirc fan - FAULT	Remained off
	MC	AIR	Flight Comp't recirc fan – FAULT	Remained off

5.2 Appendix B: ATR QRH Abnormal/Emergency Checklists

5.2.1 Key



5.2.2 Abnormal Engine Parameters in Flight (Abnormal)

_e7495818-8165-47cd-a97a-0af8692c6f2e — 1.2 — ALL

A70.13 ABNORMAL ENG PARAMETERS IN FLIGHT

23:16:55 → 23:17:54

- ■ **If Intermittent fluctuations or unrealistic steady indication**
  - ▶ ATPCS .... OFF
- ● **When flight conditions permit**
  - ▶ PL (affected ENG).. FI
  - ▶ EEC (affected ENG).. OFF
  - ■ **If successful**
    - ▶ EEC 1(2) FAULT procedure (A70.03) .... APPLY
  - ■ **If not successful**

    - OR -

  - ■ **If TQ = 0 % and NP < 77 %**
    - ▶ PL (affected ENG).. FI
    - ▶ CL (affected ENG).. FUEL S.O.
    - ▶ **LAND ASAP**
    - ▶ SINGLE ENG OPERATION procedure (A70.12) .... APPLY
- ■ **If "---" indication on the torque digital counter**
  - ▶ PL (affected ENG).. MOVE WITH CARE

5.2.3 **Electrical Smoke (Emergency)**

_50eded2b-d359-4f7f-b1eb-1f4e07b3d10e — 2.1 ALL

E26.05 — ELECTRICAL SMOKE

23:19:38

- ► SMOKE procedure (E26.01) .... APPLY
- ► AVIONICS VENT EXHAUST MODE...... ...... OVBD
- ► AIR FLOW...HIGH
- ► DC SVCE & UTLY BUS.................................OFF
- ► DC BTC .... ISOL
- ► ACW GEN 1 + 2.......................................OFF
- ► SUSPECTED EQUIPMENT............................OFF

23:21:55

■ If smoke source not identified

- ► **LAND ASAP**
- ► ACW GEN 1+2 LOSS procedure (A24.07) .... APPLY

■ If smoke source identified

- ► OPERATING EQUIPMENT........ .... RESTORE

• When ΔP below 1 psi

- ► OVBD VALVE .... FULL OPEN
- ► AVIONICS VENT EXHAUST MODE.......... NORM

5.2.4 **Smoke (Emergency)**

_7d2c74a9-e6e1-4855-8fb5-15c18e9b8b95 — 3.2 ALL

SMOKE — E26.01

23:20:08

■ If smoke/fumes in the cockpit

- ► CREW OXY MASKS........... .... DON / 100 %
- ► GOGGLES... SET
- ► CREW COMMUNICATIONS...... ...... ESTABLISH

► RECIRC FANS 1+2.................. .... OFF

► AP.. ON

23:20:20

► SMOKE SOURCE................ .... IDENTIFY

■ If source not identified or electrical smoke suspected

> **Note**
>
> *ELEC SMK may be activated by an air conditioning smoke source*

- ► ELECTRICAL SMOKE procedure (E26.05) .... APPLY

■ If air conditioning smoke identified

- ► AIR COND SMOKE procedure (E26.03) .... APPLY

■ If FWD SMK comes on or smoke in FWD zone of aircraft

- ► FWD SMOKE procedure (E26.06) .... APPLY

■ If AFT SMK comes on or smoke in aft zone of aircraft

- ► AFT SMOKE procedure (E26.02) ....APPLY

5.2.5 ACW Generator 1+2 Loss

_c858266e-b1b6-4aec-b623-1a40c9700866 — 2.4 ALL

ACW GEN 1+2 LOSS	A24.07

23:25:31 → 23:27:00

- ▶ ICING CONDITIONS : LEAVE AND AVOID
- ▶ ICE ACCRETION : VISUALLY MONITOR
- ▶ STBY ALT & IAS ....USE AS REFERENCE
- ▶ IAS & ALT : PERIODICALLY COMPARE WITH STBY INST
- ▶ ACW GEN 1 + 2.. .... OFF
- ▶ HYD X FEED ....CHECK OFF
- ▶ ACW GEN 1+2 FAULT LOST EQUIPMENT LIST................. .... CHECK
- ▶ AFFECTED EQUIPMENT FAULT procedure.......................................APPLY
- ▶ HYD GREEN AND BLUE PUMPS.............................. ....OFF
- ▶ LDG DIST (Refer to Landing Distance)................ .... MULTIPLY BY 1.5

23:31:12 → 23:31:48

- **Before landing**

  LDG GEAR NORMAL OPERATION LOST

  - ▶ LDG GEAR lever ....DOWN
  - ▶ BLUE PRESSURE................................ .... CHECK
  - ▶ FLAPS 15..AS RQRD
  - ▶ LDG GEAR GRAVITY EXTENSION procedure (A32.03) .... APPLY
  - ▶ FLAPS 30...AS RQRD

23:27:20 → 23:27:00

- **After touchdown**

  NORMAL BRAKE OPERATION LOST.

  - ▶ REVERSE.. .... AS RQRD
  - ▶ BRAKE HANDLE...EMER/AS RQRD
  - ▶ TAXI : ON ENG 1+2

_dd66512e-d4f5-4ae4-85bc-5d05e0a49ba9 — 1.3 ALL

Lost Equipment List

Cabin	Lights
- TOILETS SYS (If supplied by ACW)	- Integrated Normal INST & PANELS Lights
Hydraulic	- TAXI & TO Lights
- HYD GREEN AND BLUE PUMP	- LAND Lights
Ice and Rain Protection	
- F/O PITOT STAT HTG	
- F/O TAT ALPHA HTG	
- WINDSHIELD HTG	
- ANTI ICING HORNS	
- ANTI ICING PROP 1+2	
- ICE DETECTOR	

5.2.6 **ENG 1(2) OIL LO PR**

_610b79eb-4bb4-48bd-9405-ac68a9992fa5 | **0.6** ALL

A70.14 | **ENG 1(2) OIL LO PR**

23:22:58 → 23:24:51

- ▶ PL (affected ENG)..FI
- ■ **If both OIL LO PR alert on CAP and local alert are activated**
  - ▶ CL (affected ENG)........................ FTR THEN FUEL S.O.
  - ▶ **LAND ASAP**
  - ▶ SINGLE ENG OPERATION procedure (A70.12) .... APPLY

23:28:55 → 23:30:52

- ■ **If only local alert is activated**
  - ▶ CL (affected ENG)........................ FTR THEN FUEL S.O.
  - ● **After engine shut down**
    - ▶ CL (affected ENG)..FTR
    - ■ **If CCAS activated after 30 s (normal warning delay)**
      - ▶ CL (affected ENG)........................ FUEL S.O.
      - ▶ ENG RESTART IN FLIGHT procedure (A70.09) .... APPLY
    - ■ **If CCAS not activated after 30 s**
      - ▶ CL (affected ENG)........................ FUEL S.O.
      - ▶ **LAND ASAP**
      - ▶ SINGLE ENG OPERATION procedure (A70.12) .... APPLY
- ■ **If OIL LO PR alert only activated on CAP**
  - ▶ ALERT : DISREGARD

    MAINTENANCE ACTION REQUIRED
  - ▶ OIL PRESS LOCAL ALERT : MONITOR
- ■ **If single engine operation**
  - ▶ NP (feathered ENG) : MONITOR
  - ■ **If NP (feathered ENG) above 10 %**
    - ▶ IAS : LIMIT NOT TO EXCEED NP 101 %
    - ▶ VAPP..INCREASE BY 10 kt

5.2.7 Single Engine Operation (Abnormal)

23:28:55

_29e7dd35-f992-4ef6-94b6-79003640c91e — REV 2.0 — ALL

SINGLE ENG OPERATION — A70.12

- LAND ASAP
- PWR MGT .... TO if necessary then MCT
- FUEL PUMP (affected eng)..OFF
- DC GEN (affected side)..OFF
- ACW GEN (affected side)..OFF
- PACK VALVE (affected side)..OFF
- BLEED VALVE (affected side)..OFF
- APM ....OFF
- TCAS .... TA ONLY
- OIL PRESS (affected eng) : MONITOR
- FUEL BALANCE : MONITOR

MAXIMUM RECOMMENDED FUEL UNBALANCE IS 200 kg (440 lb).

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.*
- *Refer to Single Engine Gross Ceiling to determine single engine gross ceiling.*

■ **If icing conditions**

- FLAPS..15

TO IMPROVE DRIFT DOWN PERFORMANCES & SINGLE ENGINE CEILING.

• **When FUEL X FEED is required**

- FUEL PUMP (affected eng)..ON
- FUEL X FEED..ON
- FUEL PUMP (operating eng)..OFF

• **For approach**

Note

Refer to STEEP SLOPE APPROACH to check steep slope approach limitation applicable to your aircraft.

- BLEED VALVE (operating side)..OFF
- CL (operating eng).. 100 % OVRD
- V_{APP} .... NOT LESS THAN V_{GA}

■ **If affected engine NP above 10 %**

- V_{APP} .... NOT LESS THAN V_{REF} + 10 kt

• **When V_{APP} is increased**

- LDG DISTANCE.. MULTIPLY BY 1.15

23:30:52

• **At touchdown, before nosewheel is on the ground**

- PL : MAINTAIN AT OR ABOVE FI

5.2.8 DC Bus 2 off (Abnormal) & Lost Equipment List

_f11fd1f8-4711-4c04-8b8c-7b8ae1884bad | 2.3 ALL

A24.10	DC BUS 2 OFF

- ► DC GEN 2 .... OFF
- ► PF .... CAPT
- ► ADC sw .... SELECT ADC 1
- ► VHF .... SELECT SYS 1
- ► ATC .... SELECT SYS 1
- ► DC BUS 2 LOST EQUIPMENT LIST .... CHECK
- ► AFFECTED EQUIPMENT FAULT procedure .... APPLY
- ► PAX INSTRUCTIONS .... USE PA
- **After touchdown**
  - ► TAXI : ON ENG 1+2

_d43f1ee9-c34a-40ba-ac29-7d2aed1ea9a7 | 1.2 ALL

Lost Equipment List

Air
- LANDING ELEVATION indicator

Doors
- DOORS UNLK Lights
- CDLS

Fire Protection
- NAC OVHT

Flight controls
- STBY PITCH TRIM CTL
- F/O STICK SHAKER
- TLU AUTO CONTROL

Hydraulic Power
- HYD PWR AUX PUMP IND
- HYD PWR AUX PUMP AUTO MODE

Ice and Rain protection
- F/O STATIC PORTS ANTI ICING
- F/O SIDE WINDOWS ANTI ICING
- F/O WINDSHIELD HTG indicator
- F/O PROBES indicator
- F/O WIPER

Indicating - Recording Systems
- CAP AMBER ALERT (except MAINT PNL, PRKG BRK, MFC)

Landing Gear
- SECONDARY indicator

Lights
- F/O CHARTHOLDER
- F/O READING Lights
- INTEGRATED INSTRUMENTS Lights
- INTEGRATED PANELS Lights
- TAXI & T.O Lights
- WING Lights
- PAX SIGNS Lights

Navigation
- F/O EADI/EHSI
- SGU #2
- VOR #2
- ILS #2
- DME #2
- ADF #2
- CAPT RMI
- VHF #2
- ATC #2
- ADC #2
- ALT ALERT #2
- F/O CLOCK
- TCAS or T2CAS (if installed)
- GPS KLN90 (if installed)

Power Plant
- FF/FU #2
- FUEL TEMP #2
- FUEL CLOG #2
- OIL PRESS #2
- OIL TEMP #2
- IDLE GATE CAUTION

5.2.9 **Aft Smoke (Emergency)**

_0af7a442-901d-41b5-bbfa-0c5b1f3bb452 | 2.2 ALL

E26.02 **AFT SMOKE**

► SMOKE procedure (E26.01) .... APPLY

■ **If passenger configuration**

► CABIN CREW (PA)..... ..... ADVISE FOR ACTION

► AIR FLOW.. HIGH

► **LAND ASAP**

■ **If cargo configuration**

► CAB PRESS MODE SEL .... MAN

► CAB ALT .... MAX INCREASE

■ **If dual bleed operation**

► BLEED VALVE 2.................................. OFF

■ **If dual pack operation**

► PACK VALVE 2.................................... OFF

► CAB VENT AIR FLOW............... .... OFF

► FLT COMPT TEMP SEL .... HOT

► **LAND ASAP**

■ **If immediate landing is not possible**

► FL : 160/HIGHER (FL 200 is recommended)

● **When EXCESS CAB ALT warning is triggered**

► CAB ALT .... MAINTAIN MAX INCREASE

Note

Other smoke detection alarms maybe triggered during smoke evacuation process. Disregard them.

5.2.10 **Air Conditioning Smoke (Emergency)**

_e10128ed-55e0-4062-ba90-de025e1cd54c	3.2 ALL

AIR COND SMOKE E26.03

► SMOKE procedure (E26.01) .... APPLY
► PACK VALVE 1.................... .... OFF
► MAX FL : 200/MEA

CAUTION

Air conditioning smoke evacuation may trigger electrical smoke. Disregard it.

■ **If smoke persists**
- ► PACK VALVE 1.................... .... ON
- ► PACK VALVE 2.................. .... OFF
- ► ENG PARAMETERS : CARREFULLY MONITOR

■ **If ENG amber on CAP associated to local ITT alert**

- OR -

■ **Total loss of NL indication**

- OR -

■ **Engine abnormality clearly identified (NH, NL, ITT indications, noise, surge...)**

CAUTION

Identify the engine that shows signs of abnormal operation in order to avoid shutting down the safe engine.

- ► PL (affected ENG).................. .... FI
- ► CL (affected ENG)........... FTR THEN FUEL S.O.
- ► **LAND ASAP**
- ► SINGLE ENG OPERATION procedure (A70.12) .... APPLY

5.2.11 **Forward Smoke (Emergency)**

057ea1a6-e8c4-4158-a983-ef79edf9da04 — 2.3 ALL

FWD SMOKE — E26.06

► SMOKE procedure (E26.01) .... APPLY

■ **If passenger configuration**

► CABIN CREW (PA)..... ..... ADVISE FOR ACTION

► AVIONICS VENT EXHAUST MODE .... OVBD

► AIR FLOW...HIGH

► EXTRACT AIR FLOW lever ....CLOSED

► **LAND ASAP**

● **When ΔP below 1 psi**

► OVBD VALVE ....FULL OPEN

► AVIONICS VENT EXHAUST MODE ...... NORM

■ **If cargo configuration**

► CAB PRESS MODE SEL .... MAN

► CAB ALT .... MAX INCREASE

■ **If dual bleed operation**

► BLEED VALVE 2......................................OFF

■ **If dual pack operation**

► PACK VALVE 2..OFF

► CAB VENT AIR FLOW............... ....OFF

► FLT COMPT TEMP SEL .... HOT

► **LAND ASAP**

■ **If immediate landing is not possible**

► FL : 160/HIGHER (FL 200 is recommended)

■ **When EXCESS CAB ALT warning is triggered**

► CAB ALT .... MAINTAIN MAX INCREASE

Note

Other smoke detection alarms maybe triggered during smoke evacuation process. Disregard them.

5.2.12 Hydraulic Blue or Green Low Level (Abnormal) & Lost Equipment List

_191238a6-7ad4-4456-835d-666ea6668cd8 — 3.3 ALL

HYD BLUE (GREEN) LO LVL	A29.01

- **If blue hydraulic system affected**
  - ► HYD BLUE PUMP .... OFF
  - ► HYD AUX PUMP .... CONFIRM OFF
  - ► HYD BLUE SYS LOST EQUIPMENT LIST .... CHECK
  - **For approach**
    - ► REDUCED FLAPS LANDING procedure (A27.05) .... APPLY
  - **At landing**
    - N/W STEERING LOST
    - ► DIFFERENTIAL BRAKING : USE
    - ► TAXI : ON ENG 1+2
- **If green hydraulic system affected**
  - ► HYD GREEN PUMP .... OFF
  - ► LDG DIST (Refer to OPSDATA) .... MULTIPLY BY 1.5
  - ► HYD GREEN SYS LOST EQUIPMENT LIST .... CHECK
  - **Before landing**
    - NORMAL BRAKING LOST
    - ► LDG GEAR GRAVITY EXTENSION procedure (A32.03) .... APPLY
  - **After touchdown**
    - ► REVERSE .... AS RQRD
    - ► BRAKE HANDLE .... EMER/AS RQRD
    - ► TAXI : ON ENG 1+2

_7d62bcad-a994-4250-b37d-b75af802d7e7 — 2.1 ALL

HYD BLUE SYS LOST EQUIPMENT LIST

Flight Controls	Landing Gear
- FLAPS	- PARKING BRAKE
- SPOILERS	- EMER BRAKE (accumulator allows at least 6 applications of braking force at full braking pressure)
- N/W STEERING	
Propellers	
- PROP BRAKE	

5.2.13 **Before Landing (Normal)**

16 Before Landing

_eab6f18c-1073-423a-956c-a6c68f46b435 **4.2**

ALL

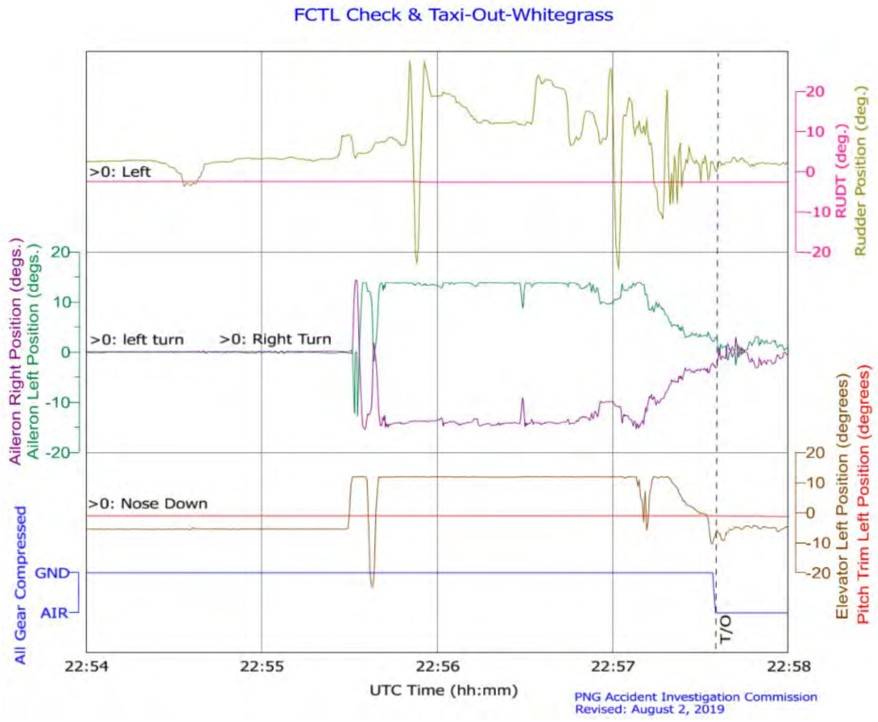
PF	PM
When Passing Deceleration Point	
▶ PL 1+2........ .... RETARD AS RQRD	
At Appropriate Speed	
▶ FLAPS 15..............................ORDER	
	▶ FLAPS.................. .... 15°
At Appropriate Speed	
▶ LDG GEAR DOWN........ .... ORDER	
	▶ LDG GEAR ....DOWN
	▶ TLU LO SPEED........ ....CHECK ON
	▶ PWR MGT................................ ....TO
	▶ TAXI & T.O lights ....ON
	▶ LDG GEAR ....MONITOR
	Announce Gear when locked.
	▶ ICING AOA ....AS RQRD
	Note
	Icing AOA must remain ON for a landing under icing conditions. Make sure that the aircraft is clean and out of icing conditions before resetting icing AOA for a landing under normal conditions. Refer to ADVERSE WEATHER.

CAPT	F/O
▶ CABIN CREW REPORT..........OBTAIN	

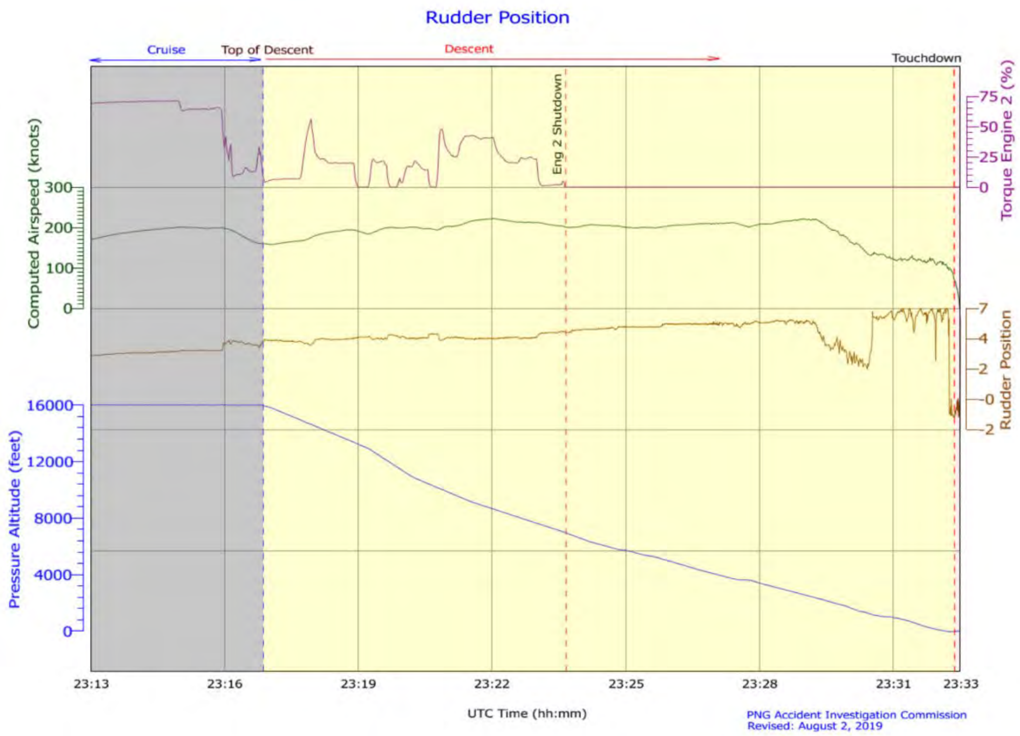
PF	PM
At Appropriate Speed	
▶ FLAPS 30..............................ORDER	
	▶ FLAPS.................. .... 30°
▶ BEFORE LDG C/L .... ORDER	▶ BEFORE LDG C/L .... PERFORM
Note	**Note**
In the case of turbulence CL must be set to 100% OVRD to help maintain approach speed.	*In the case of turbulence CL must be set to 100% OVRD to help maintain approach speed.*

5.3 Appendix C: Flight Data Recorder - Engineering Readout

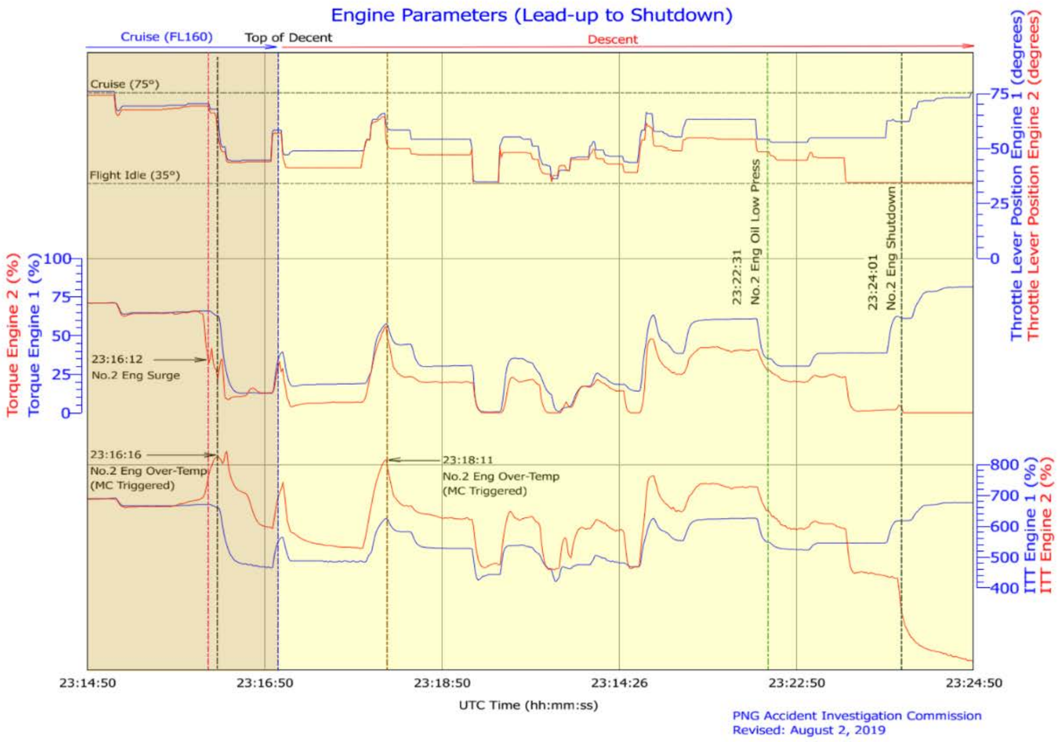
5.3.1 Flight controls check during taxi White grass Airport Tanna to Bauerfield Airport Port Vila



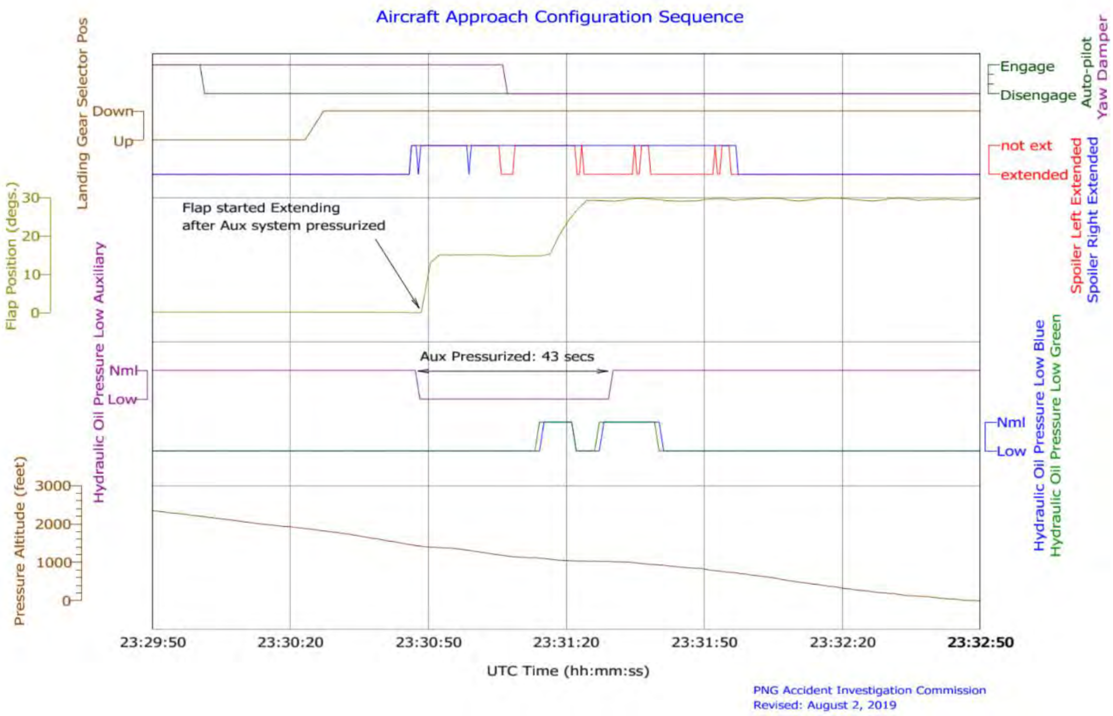
5.3.2 Rudder position throughout the flight



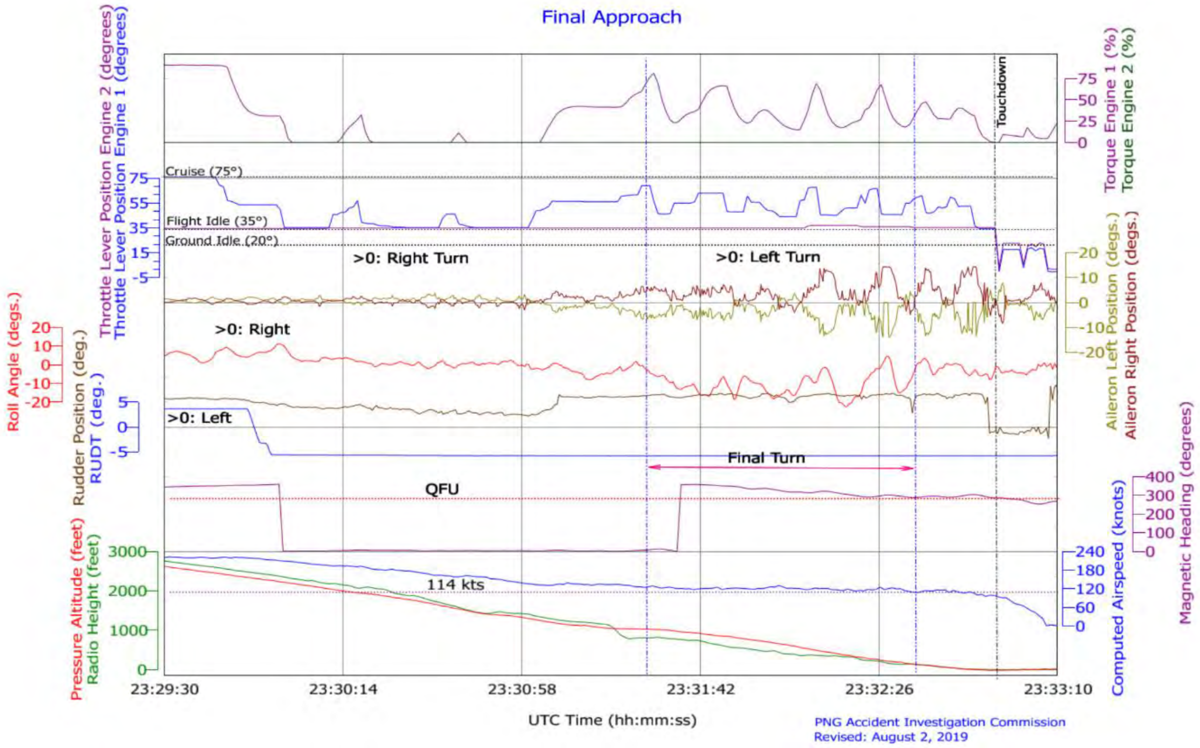
5.3.3 Engine Parameters Lead up to Shutdown



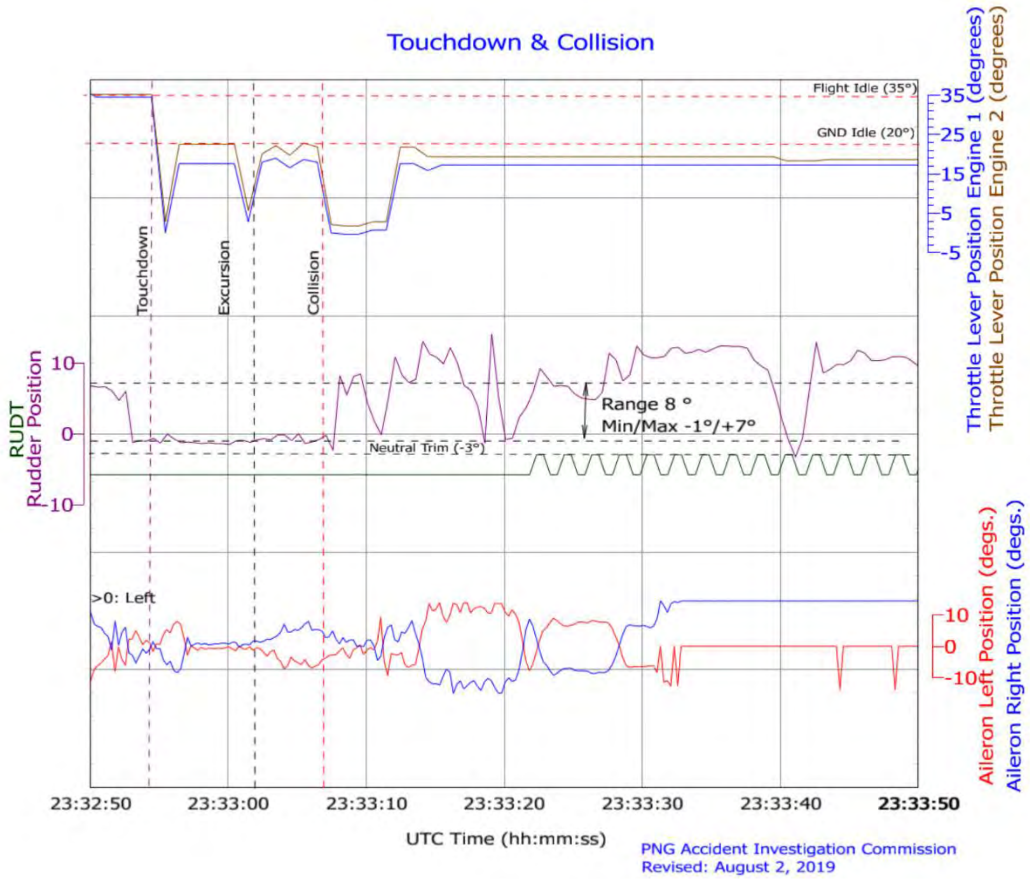
5.3.4 Aircraft Approach Configuration Sequence of Events



5.3.5 Final Approach



5.3.6 Touchdown and Collision



5.4 Appendix D: CCAS indicating and recording system

NF / 75 FCOM	DESCRIPTION INDICATING AND RECORDING SYSTEMS CCAS	DSC.31.4 Page n°13

3.1.4 With Aircraft System Failure

e9bcd5ea-3876-4297-b76a-a8d5df20aefc 0.1 ALL

LEVEL 3	LEVEL 2
Failure detection	
Aural alert : CRC	Aural alert : SC
MW light flashing red	MC light flashing amber
Red warning light on the CAP identifying the failure	Amber caution light on the CAP identifying the failure
For some cases, a red light on the affected system control panel	Local alert light on the affected system control panel
Acknowledgement of the failure by the crew	
Press MW light - MW light turns off - Aural alert is cancelled.	Press MC light - MC light turns off.
Corrective action	
If the failure disappears, associated local alert light and CAP light turn off. If the failure does not disappear, associated local alert light and CAP light remain turned on.	
Press CLR pb on CAP (after check list application)	
CAP light does not turn off.	CAP light turns off Before starting descent, press RCL pb on CAP CAP light turns on, associated with systems where a failure persists or with a white light on the associated control panel. If necessary, take into account the failure consequences for the landing Press CLR pb on CAP.

Note

The local alert lights always reflect directly the system status: they never are inhibited nor cleared by any other means than restoring normal functioning. When a local alert light disappears, the other alert sequence elements (MW/MC light, CAP, aurals) also disappear.

5.5 Appendix E: ATR Cabin Crew Operational Manual

5.5.1 Cabin Smoke Contamination procedure for cabin crew

ATR C.C.O.M	CABIN CREW OPERATING MANUAL	10.03
	EMERGENCY PROCEDURES	P 8
	FIRE	JUN 13

Fire type	*Cabin Crew Action(s)*
Aft Cargo Compartment	PBE........DON CURTAIN........CLOSED HALON EXTINGUISHER........IN EXTINGUISHER CONNECTOR FLIGHT CREW........INFORMED

10.03.7 CABIN SMOKE CONTAMINATION

It is important that cabin crew are aware of any smoke indications and report it to the flight crew members immediately. The source of smoke should be immediately identified in order to take the appropriate actions.

Note: Cabin crew should not discharge the fire extinguisher randomly into an enclosed area if the source of fire has not been located.

Materials that are used in the cabin release toxic fumes when smouldering.

The cabin crew action should be:

- Switch off the DC & ACW GND service bus located on the FAP (Flight Attendant Panel) refer to chapter 1.09 p1&2
- Report to flight crew member "Cabin smoke"

The cabin crew must protect themselves as well as the flight crew and passengers from the negative effects and consequences of smoke inhalation by:

- Donning the Protective Breathing Equipment (PBEs)
- Keeping the flight crew compartment door closed at all times
- Encouraging passengers to remain at a low level and breathe through their clothing
- Distributing wet towels and instructing passengers to breathe through it

Fire type	*Cabin Crew Action(s)*
Smoke contamination	FLIGHT CREW........INFORMED DC & AC GND service BUS........SHED PBE........DON WET TOWELS........DISTRIBUTED

5.5.2 Air Vanuatu ATR CCOM, Section 7.02.6; Protecting Breathing Equipment (PBE)

ATR C.C.O.M	CABIN CREW OPERATING MANUAL	7.02
	EMERGENCY EQUIPMENT	P 8
	PORTABLE EQUIPMENT	JAN 12

7.02.6 PROTECTIVE BREATHING EQUIPMENT (PBE)

The PBE, "Puritan-Bennett BE Aerospace PN 119003", ensures protection of the eyes and respiratory system against heat, smoke and/or noxious gases.
The device supplies 15 minutes of oxygen and enables crew members being protected when performing relevant safety duties in case of smoke or fire.

DESCRIPTION:

The PBE is a device that completely encloses the head of the wearer and seals around the neck with an elastic membrane. The unit is vacuum sealed in a bag and installed in a protective stowage box within the aeroplane cabin.

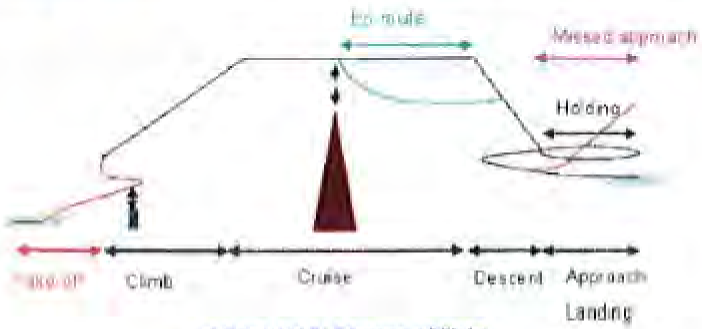
The PBE can be worn with spectacles (eyeglasses).

F7.02_P8A: PBE stowage box

F7.02_P8B: PBE deployed

5.5.3 **Air Vanuatu ATR CCOM, Section 9.03; Phases of the flight**

ATR C.C.O.M	CABIN CREW OPERATING MANUAL	9.03
	NORMAL PROCEDURES	P 1
	PHASES OF THE FLIGHT	JAN 12



F9.03_P1A: Phases of flight

The related flight phases are applicable to the cabin operation.

__Phase 1: Preflight, Push Back, Taxiing.__
This phase begins at the preflight check and ends at take off. The aeroplane might require a pushback from the parking to a position where engines can safely be started.

__Phase 2: Take-off and climb__
During this phase, the aeroplane takes off and climbs until reaching the cruising altitude.

__Phase 3: Cruising__
This phase involves the part of the flight on which the aeroplane is steady at a flight planned altitude and ends at the descent.

__Phase 4: Descent and approach__
This phase begins when the aeroplane starts descending and ends before the landing phase.

__Phase 5: Landing__
This phase begins at the landing gear touchdown and ends when the aeroplane has vacated the runway.

__Phase 6: Taxiing and arrival.__
This phase begins when the aeroplane has vacated the runway and ends when it reaches the final stand.

The most critical phases of the flight are:

- Take off and climbing
- Landing

Statistically, 90% of unplanned evacuations were the results of events that occurred during those phases.

5.5.4 Air Vanuatu ATR CCOM, Section 10.06.3.2; Cabin Preparation

ATR C.C.O.M	CABIN CREW OPERATING MANUAL	10.06
	EMERGENCY PROCEDURES	P 7
	EMERGENCY EVACUATION	JAN 12

10.06.3.2 CABIN PREPARATION

Public announcement

An emergency PA should be made to inform the passengers of the situation and obtain their complete attention (PA might vary according to different operators).

When reading the announcement, the cabin crew should speak slowly and distinctly.

Cabin crew will coordinate some of the following demonstrations with the announcement:

- Exits to use
- Brace positions to adopt

Cabin preparation

After the passenger has been briefed over the PA, cabin crew should ensure that the cabin is properly secured with:

- Seat belts fastened
- Seat backs in the upright position
- Tray tables closed and latched
- Armrests down
- Hand baggage stowed in the proper compartment
- Overhead compartments closed
- Exits and aisles clear of all obstructions
- Window blinds up (If available)
- Service items cleared
- Cabin doors and curtains opened and secured
- Lavatory vacated and locked
- Galley equipment secured
- Rear cargo compartment secured with safety net
- Video screens up (if applicable)

Additionally, high-heeled shoes and sharp objects must be removed (Ex: false teeth, eyeglasses, neck ties, pens...) since they may cause injuries during impact and/or during the evacuation process.

Cabin crew should also remove items such as pens, badges and wing pins from their uniforms.

5.5.5 Exits to be used in case of Ground Evacuation

ATR C.C.O.M	CABIN CREW OPERATING MANUAL	10.06
	EMERGENCY PROCEDURES	P 17
	EMERGENCY EVACUATION	JAN 12

10.06.5 EXITS TO USE IN CASE OF EVACUATION

This is a classification of exits to use in case of evacuation. Cabin crew members will use their own judgment on which door/exit to use according to factors such as outside conditions, position of the aeroplane, structure damage, possible threat etc…

	Ground Evacuation	**Ditching**
Primary exits	Aft doors	Fwd emergency exits
Secondary exits	Fwd emergency exits	Aft doors
Auxiliary exits	Flight crew compartment hatch	Flight crew compartment hatch

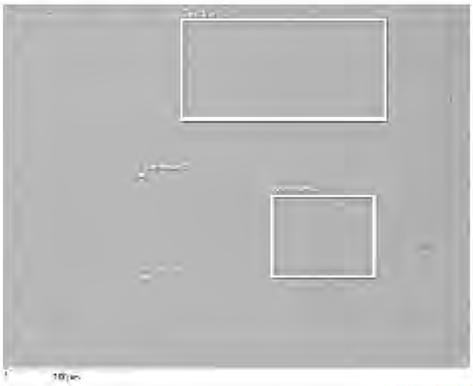
T10.06_P17A: Doors/exits classification for evacuation

5.6 Appendix F: P&WC, Engine disassembly investigation report (Laboratory analysis section only)

3.0 Material Laboratory

3.1 Visual examination of the No. 3 bearing rear spacer showed discoloration resulting from a high temperature exposure most probably created by the friction of within the No. 3 bearing inner race thrust side (Red bracket, Photo No. 51). Scanning electron microscope (SEM) of the cross section taken through the No. 3 bearing rear spacer using energy dispersive spectrum (EDS), semi-quantitative and standardless method showed the proportions of the major elements to be consistent with the drawing requirement (Photo No. 52).

Photo No. 51



Spectrum Label	Spectrum 1	Spectrum 2	Spectrum 3	Spectrum 4
C	7.29	7.4	6.55	7.57
O		25.27	22.5	
Mg		1.02	1.72	
Al		14.81	15.77	
Si	0.23		0.25	0.23
Ti		0.71	0.64	
Cr	11.97	15.16	10.82	11.69
Mn		15.9	18.79	
Fe	80.51	19.32	25.09	80.31
Total	100	100	100	100

Photo No. 52

3.2 Magnified views of the cross section through the No. 3 bearing rear spacer showed the discoloration adjacent to the wear marks (red oval, Photo No. 53).The microstructure in the material and their relative hardness vary into the material. The material of the spacer hardened in the portion that was heated by friction transforming the tempered martensite into a re-hardened slightly tempered martensite and into an untempered as white martensite (Photos No. 54 to 58). The original microstructure in the non-affected zone revealed martensite as per drawing requirement. The hardness observed in the non-affected zone is as per drawing requirement. The hardness of the No. 3 bearing spacer becomes harder on the section that was heated.

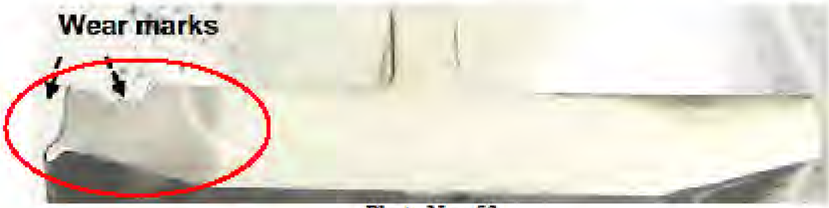


Photo No. 53

Photo No. 54

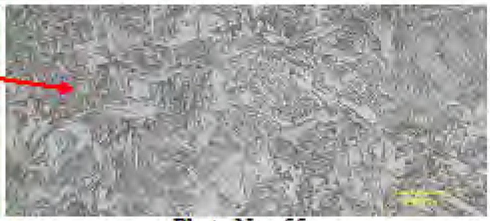


Photo No. 55

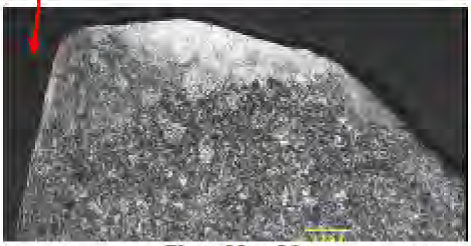


Photo No. 56

Photo No. 57

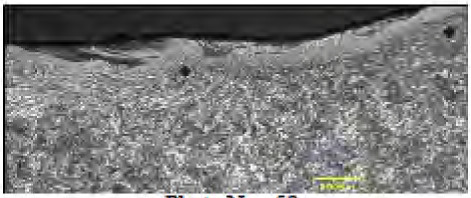


Photo No. 58

Hardness	HV_{mm}	HRC
Base Metal	205	–
Modified martensite / transition zone	415	42.1
White martensite	506	49.3
Cold work microstructure under wear groove	463	46.1

3.3 Visual examination of the No. 3 bearing air seal showed 6 fracture surfaces (yellow ovals, Photo No. 59). Magnified view of the fracture surfaces showed the extent of the damage on each of them. Almost all of the fractographic features have been obliterated by rubbing during the event (Photos No. 60 to 63).

Photo No. 59

Photo No. 60

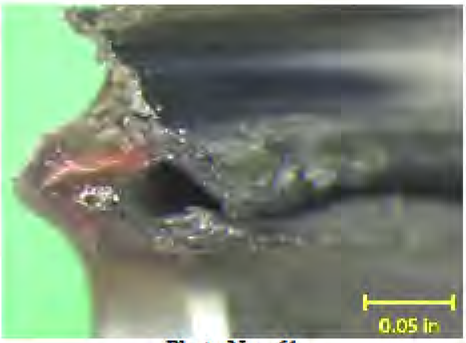


Photo No. 61

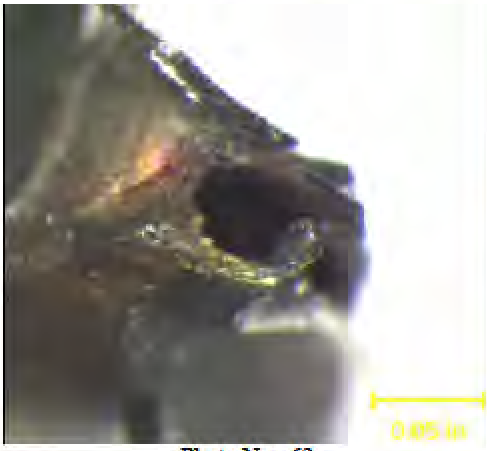


Photo No. 62

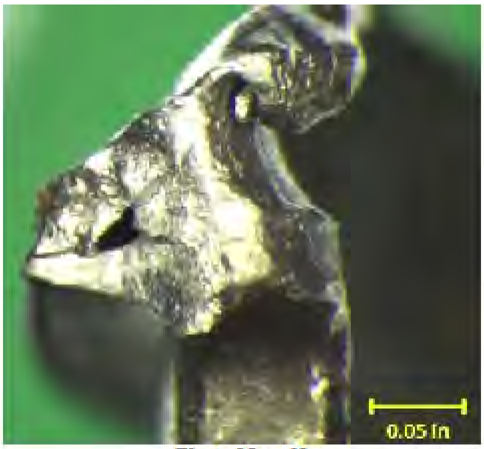


Photo No. 63

3.4 SEM view of two different fracture surfaces from the No. 3 bearing air seal showed dimples and no fractographic evidence of fatigue or any other progressive failure. These fractured surfaces suggest that they occur in overload and are secondary damage (Photos No. 64 to 67). The hardness of the No. 3 bearing air seal was within drawing limits.

\

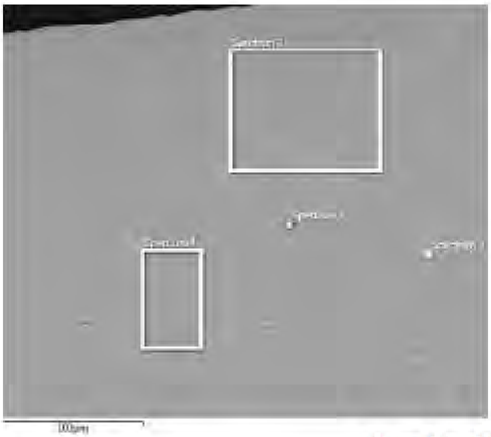
Photo No. 64

Photo No. 65

Photo No. 66

Photo No. 67

3.5 SEM magnified of the cross section taken through the No. 3 bearing air seal using EDS semi quantitative method showed that the proportions of the major alloying elements were as per drawing requirements (Photo No. 68).



Spectrum Label	Spectrum 1	Spectrum 2	Spectrum 3	Spectrum 4
C	11.79	13.5	10.78	8.29
O		18.76	1.34	
Mg		0.4		
Al		2.72		
Si	0.39	3.57	0.54	0.36
S		0.12		
Ca		1.68		
Ti		0.86		
Cr	10.91	7.3	10.77	11.23
Mn		5.48		
Fe	76.9	39.65	76.58	80.12
Total	100	100	100	100

Photo No. 68

3.6 General views of the LP diffuser case showing the four fracture surfaces (Photo No. 69) at the No. 3 bearing stator seal web. Magnified view of the 4 fracture surfaces of interest showed that only one fracture surface revealed fractographic features (Photo No. 70). The other 3 fracture surfaces were completely obliterated during the event (Photos No. 71 to 73).

Photo No. 69

Photo No. 70

Photo No. 71

Photo No. 72

Photo No. 73

3.7 Magnified view of the LP diffuser case fracture surface No. 1 showed semi-elliptic crack progression marks (white arrows) indicative of fatigue crack propagation originating from the external surface of the fixing (yellow arrow, Photo No. 74).

Photo No. 74

3.8 SEM view of the fracture surface No.1 showing the progression marks (white dotted line, Photo No. 76) and the suggested direction of the propagation which pointed to the origin at the external surface (Photo No. 75). SEM magnified view next to the origin revealed no material anomalies next to the origin. SEM magnified view of fracture surface on the opposite site revealed river lines, characteristic of final propagation of the fatigue crack (black arrow, Photo No. 77). The fracture surface suggests low nominal and cyclic stresses consistent with high cycle fatigue (HCF) typical of vibrations.

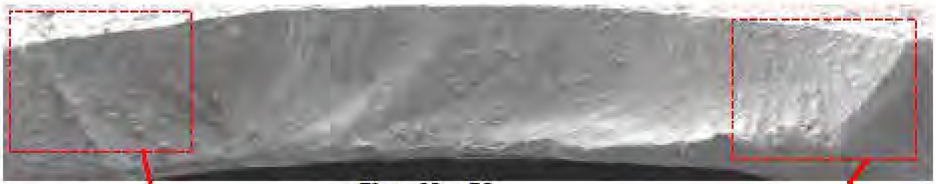


Photo No. 75

Photo No. 76

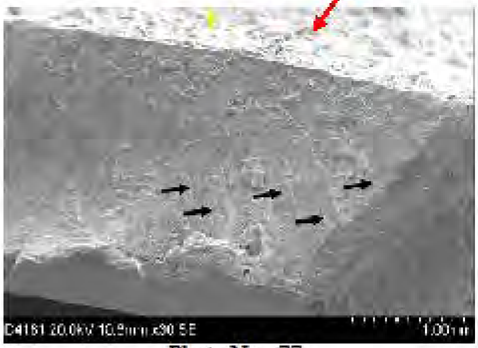


Photo No. 77

3.9 Microstructure view of the cross section through the suspected origin of the fatigue crack showed a tempered martensite (Photos No. 78 & 79) Micro hardness measurement taken is higher than the drawing requirement. Results of the SEM revealed that the proportions of the major alloying elements were consistent with the drawing requirements.

Photo No. 78

Photo No. 79

3.10 Visual examination of the No. 3 bearing outer ring showed transferred material on the raceway and discoloration on the flange most likely due to high temperature exposure (Photo No. 80). No evidence of crack was observed on the No. 3 bearing outer ring. Magnified view of the cross section taken through the outer race showing the microstructure modification due to high temperature exposure and rapid cooling near the track. The micro hardness measured in the modified microstructure is higher than the original tempered martensite (Photos No. 81 to 85). The transition zone exhibited the lowest hardness measured.

Photo No. 80

Photo No. 81

Hardness	HV_{500}	HRC
Base Metal	689	58.6
Modified martensite / transition zone	583	53.2
White martensite	744	61.8

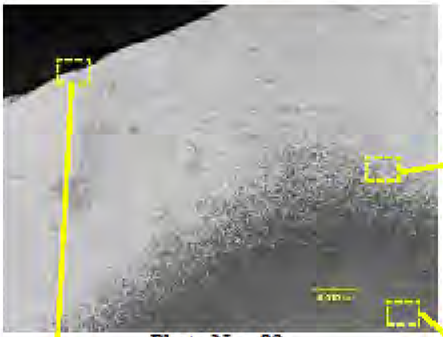


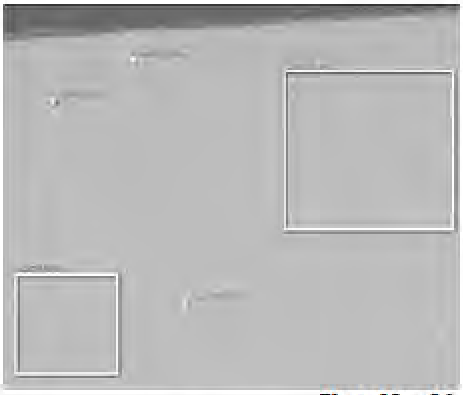
Photo No. 82


Photo No. 83 Transition zone


Photo No. 84


Photo No. 85

3.11 SEM magnified view of the cross section taken through the No. 3 bearing outer ring showing the analysed region using EDS semi quantitative and standardless method revealed that the major alloying material elements were consistent with the drawing requirements (Photo No. 86).



Spectrum Label	Spectrum 1	Spectrum 2	Spectrum 3	Spectrum 4	Spectrum 5
C	10.29	23.65	[illegible]	[illegible]	[illegible]
O		2.25	1.34	1.17	
Si	0.18		0.12		
V	1	8.13	4.47	[illegible]	[illegible]
Cr	5.89	8.45	[illegible]	[illegible]	4.17
Fe	81.24	15.47	47.79	19.37	82.06
Mo	3.39	42.04	23.45	[illegible]	[illegible]
Total	100	100	100	100	100

Photo No. 86

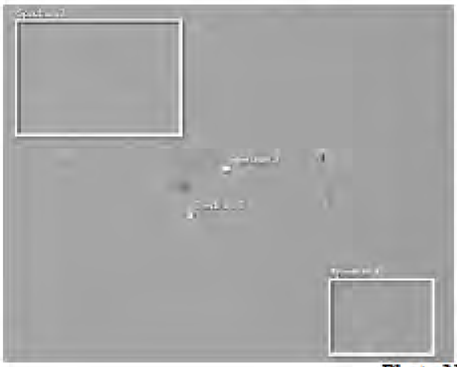
3.12 Visual examination of the No. 3 bearing inner rings showed damage on the raceway and discoloration most likely due to high temperature exposure. The No. 3 bearing inner ring thrust side was fractured and distorted next to the fracture (Photo No. 87). Magnified view of the fracture surfaces on the No. 3 bearing inner race thrust side showed overload fracture characteristic. Missing material (yellow ovals) and groove (red arrows) were noticeable on the inner diameter of the No. 3 bearing inner ring thrust side shoulder (Photos No. 88 to 89).

Photo No. 87

Photo No. 88 View A

Photo No. 89 View B

3.13 SEM-EDS using semi-quantitative and standardless method showed that the major alloying elements were consistent with the drawing requirements (Photo No. 90).



Spectrum Label	Spectrum 1	Spectrum 2	Spectrum 3	Spectrum 4
C	6.24	11.7	10.48	9.79
O		0.51		0.54
Si	0.19	0.16	0.16	0.17
V	0.95	2.48	2.24	0.85
Cr	4.1	7.43	7.71	3.98
Fe	84.52	59.68	65.76	81.43
Mn	3.97	17.64	13.65	3.24
Total	100	100	100	100

Photo No. 90

3.14 SEM view of the fracture surface of the inner ring (Photo No. 91) showing that the surface is mostly covered by splattered material covering the microfractographic features (Photo No. 92). A small section exhibited dimples characteristic of an overload fracture (Photo No. 93).

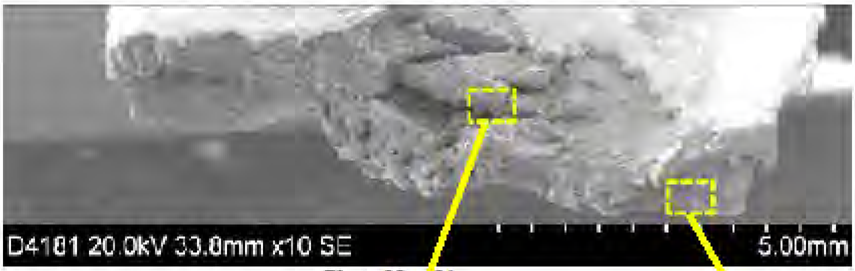


Photo No. 91

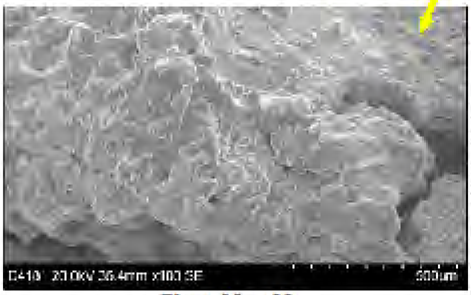


Photo No. 92

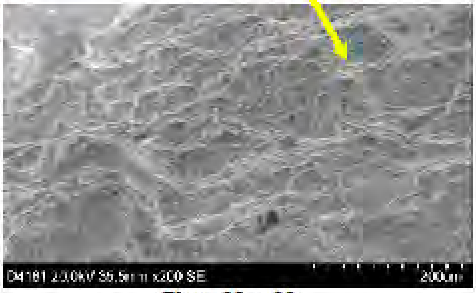


Photo No. 93

3.15 Cross section of the No. 3 bearing rear spacer and the No. 3 bearing inner ring thrust side showing that the grooving and the missing material on the No. 3 bearing inner ring thrust side interlocks with the wear pattern observed which is confirming interaction between the two components in operation (Photo No. 94).

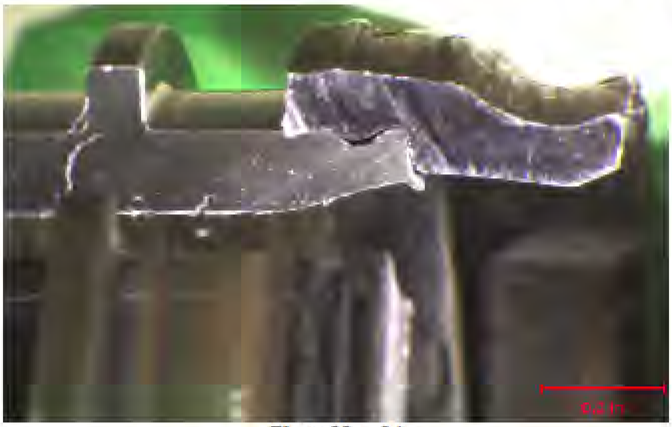


Photo No. 94

3.16 Magnified view of the cross section of the No. 3 bearing inner ring non-thrust side showing microstructure alteration due to high temperature and rapid cooling underneath the raceway and most probably due to the rubbing of the seized bearing balls (Photo No. 95). The micro hardness results showed that the microstructure in the transition zone or far from the raceway exhibited hardness lower than the drawing requirement indicating tempering as a result of an exposure to high temperature (Photos No. 96 & 98) The altered microstructure of white martensite showed a higher hardness than the rest of the cross section consistent with an as-quencher condition (Photo No. 97).

Photo No. 95

Hardness	HV[illegible]	HRC
Base Metal	538	51.6
Modified martensite / transition zone	609	55.7
White martensite	778	63.1

Photo No. 96

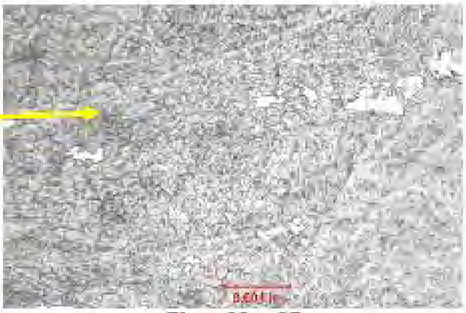


Photo No. 97

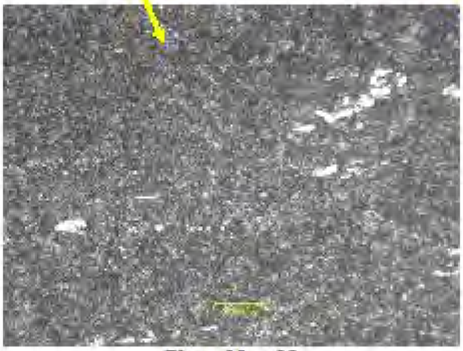


Photo No. 98

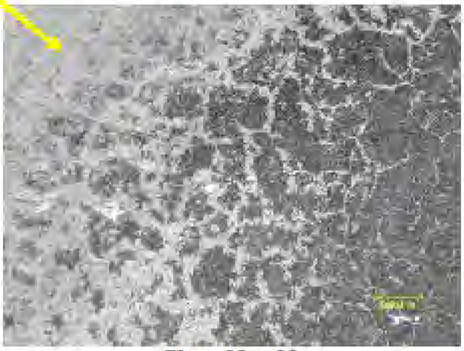


Photo No. 99

3.17 Visual examination of the No. 3 bearing cage showed the extent of the damage (Photo No. 100). The No. 3 bearing cage was fractured at 3 locations (Photo No. 101). The No. 3 bearing balls have been seized in the No. 3 bearing cage's pocket and worn down by the No. 3 bearing inner race thrust side (Photo No. 102).

Photo No. 100

Photo No. 101

Photo No. 102

3.18 SEM magnified view of a No. 3 bearing cage fracture surface showing progression marks (white arrows) suggesting fatigue crack propagation initiated at the surface at the internal diameter of the cage (red arrows) and propagated toward the external diameter (Photos No. 103 to 105).

Photo No. 103

Photo No. 104

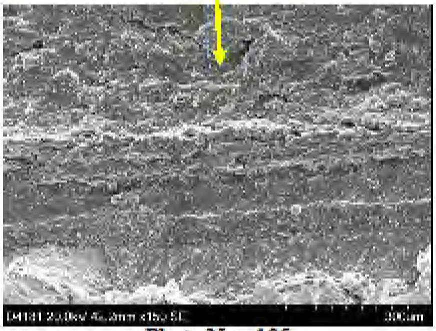


Photo No. 105

3.19 SEM magnified view of a cross section through the No. 3 bearing cage bearing showed a microstructure of martensite and the remnants of silver plating at the external surface (white layer, Photos No. 106 & 107). The average hardness of the No. 3 bearing cage is higher than the drawing requirements.

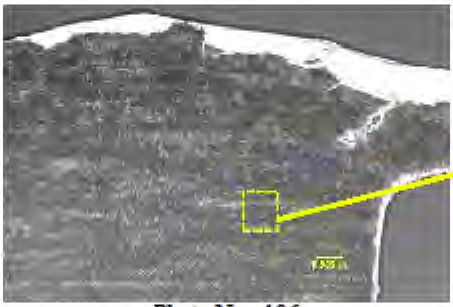


Photo No. 106

Photo No. 107

3.20 SEM-EDS using semi-quantitative and standardless method magnified view of the cross section through the cage pocket showing that the proportions of the major alloying elements were consistent with the drawing requirements (Photo No. 108).

Spectrum Label	Spectrum 1	Spectrum 2	Spectrum 3	Spectrum 4	Spectrum 5
C	9.26	0.12	18.8	21.49	7.28
[illegible]		3.59	1.40	2.13	
Si	0.76				0.37
V			0.67	0.48	
Cr	[illegible]		[illegible]	[illegible]	0.91
Fe	87.4	0.44	63.95	61.15	99.55
Ni	1.62				1.58
Mn			8.44	2.50	
Ag	0.38	80.86	8.09	4.92	0.43
Total	100	100	100	100	100

Photo No. 108

3.21 Visual examination of the No. 3 bearing balls showed the extent of the damage. The No. 3 bearing balls have been worn down by the No. 3 bearing inner ring thrust side and most of them have been seized within the No. 3 bearing cage's pocket (Photos No. 109 & 110).

Photo No. 109

Photo No. 110

3.22 Magnified view of the cross section of a ball showing a microstructure consisting exclusively of untempered white martensite (Photos No. 111 & 112). The white martensite exhibited by the No. 3 bearing balls most likely resulted from high temperature exposure. Hardness measurement taken at the center of the balls were within the drawing requirement while the hardness measurement taken near the damage was lower than the drawing requirements.

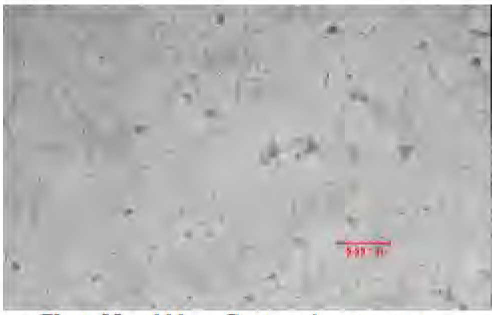


Photo No. 111 Center microstructure

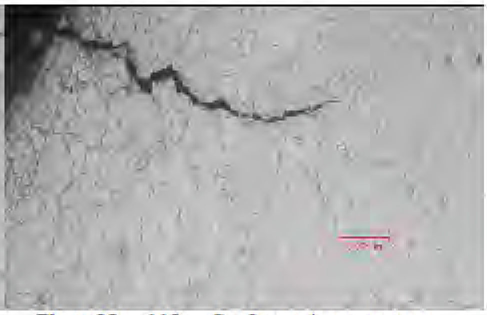


Photo No. 112 Surface microstructure

3.23 SEM EDS by semi-quantitative and standardless method of the cross section through a ball showed that the proportions of the major alloying elements to be consistent with the drawing requirements (Photo No. 113).