FINAL REPORT

In-flight Engine Fire Incident

Northwest Airlines
Boeing 747-200F Registration N617US

On 24 July 2002

AIB/AAI/CAS.013

Ministry of Transport
Singapore

1 June 2004

Introduction

The Singapore Ministry of Transport (MOT) is responsible for the investigation of air accidents and serious incidents to Singapore and foreign civil aircraft in Singapore. The MOT also participates in overseas investigations of accidents and serious incidents involving Singapore aircraft or aircraft operated by a Singapore air operator.

The mission of the MOT is to promote aviation safety through the conduct of independent and objective investigations into air accidents and incidents consistent with Annex 13 to the Convention on International Civil Aviation.

The MOT conducts the investigations in accordance with the Singapore Air Navigation (Investigation of Accident) Regulations and Annex 13 to the Convention on International Civil Aviation, which governs how member States of the International Civil Aviation Organization (ICAO) conduct aircraft accident investigations internationally.

In carrying out the investigations, MOT will adhere to ICAO's stated objective, which is as follows:

> "The sole objective of the investigation of an accident or incident shall be the prevention of accidents and incidents. It is not the purpose of this activity to apportion blame or liability."

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GLOSSARY OF ABBREVIATIONS

ANC	Anchorage
CSD	Constant Speed Drive
EGT	Exhaust Gas Temperature
EIDS	Engine Instrument Display System
EPR	Engine Pressure Ratio
EVC	Engine Vane Control
FCU	Fuel Control Unit
FDR	flight data recorder
FOC	Fuel/Oil Cooler
FT-IR	Fourier Transform Infrared
GC/MS	Gas Chromatograph/Mass Spectrometer
HRC	Rockwell C Hardness
ICAO	International Civil Aviation Organization
LPT	Low Pressure Turbine
NRT	Narita
N1	Speed of Low pressure Compressor
N2	Speed of High Pressure Compressor
PIC	Pilot in Command
P & D	Pressure and Differential
PN	Part number
psi	Pounds per square inch
SEM/EDS.	Scanning electron microscopy with energy dispersive spectroscopy
SN	Serial number
SOAP	Spectrographic Oil Analysis Program
SOP	Standard Operating Procedures
TGA	Thermogravimetric Analysis
TPE	Taipei
TT2	Total Temperature Sensor 2
UTC	Coordinated Universal Time

PREAMBLE

On 24 July 2002, Northwest Airlines (NWA) B747-200 cargo aircraft, registration N617US, operating as flight NW 908 from Singapore to Bangkok, experienced a flame-out of its No.4 engine during climb at 28,000 feet. The flame-out was followed by a fire indication. Both engine fire bottles were discharged but the fire indication remained on. The aircraft returned to Singapore for an uneventful landing. After landing, fire was seen coming out from the No.4 engine and was put out by the airport fire and rescue personnel.

Substantial external damage to the No.4 engine was found, including extensive damage to the gearbox and nacelle along the bottom of the engine which resulted in some of the engine components being lost overboard.

The engine was returned to the NWA overhaul facility in Minneapolis for teardown investigation. A team of representatives from Pratt & Whitney (P&W), National Transportation Safety Board (NTSB), Singapore Ministry of Transport (MOT), Federal Aviation Administration (FAA), NWA and Boeing participated in the engine teardown.

The main gearbox and the angle gearbox were removed from the engine and shipped to Pratt & Whitney in October 2002 for evaluation. A team from United Technologies Corporation participated in the examination of the gearboxes.

This report has been prepared based on the investigations carried out by the Investigator-in-charge (from the Singapore Ministry of Transport - MOT) and the investigations performed at the NWA and P&W facilities. The investigation was carried out in accordance with Annex 13 to the Convention on International Civil Aviation and the Singapore Air Navigation (Investigation of Accident) Regulations.

The MOT was notified of the serious incident on 24 July 2002 at 0820 hours. The MOT notified the National Transportation Safety Board (NTSB) of the United States and the International Civil Aviation Organisation (ICAO).

All times used in this report are based on Singapore local time, which is 8 hours ahead of Coordinated Universal Time (UTC).

MINISTRY OF TRANSPORT
SINGAPORE

1 AIRCRAFT INFORMATION

1.1 **General information**

1.1.1

Aircraft type	:	Boeing 747-251F
Serial number	:	21121
Aircraft registration	:	N617US
Operator	:	Northwest Airlines
State of the Operator	:	United States of America
Type of flight	:	Scheduled Freighter Flight
Date and time of incident	:	24 July 2002, at about 0730 hours
Phase of flight	:	Climb
Persons on board	:	3

1.1.2 The details of the No.4 are as follows:

1.1.2.1

Engine model	:	P & W JT9D-7J
Serial No	:	662502
Total Time/Total Cycles	:	83,704 hours/19,364 cycles
Time/Cycles Since Overhaul	:	2,456 hours/520 cycles
Installed on aircraft	:	13 October 2001

2 DAMAGE TO AIRCRAFT

2.1 There was no damage to the aircraft other than the damage to the No.4 engine and the associated cowling and nacelle.

2.2 The No.4 engine experienced a fire in the vicinity of the gearbox, which caused extensive damage to the gearbox and nacelle along the bottom of the engine. The severity of the fire led to a hole in the bottom of the nacelle and the following components were lost overboard:

a) N2 tachometer
b) Main oil pump
c) Deoiler drive gear, bearings and seals
d) Main scavenge pump
e) Idler gearshaft
f) Starter, starter valve and a section of the starter air duct
g) Compressor stator control fuel supply filter assembly

(See **Appendix 1** for summary of damage to the engine.)

3 FIRE

3.1 Fire broke out at the No.4 engine and was confined to the engine. Two fire extinguishers were discharged into the engine. Fire was seen by the airport fire and rescue service personnel to be coming from the underside of the turbine section of the engine after the aircraft landed at Singapore Changi Airport at 0748 hours. The fire was put out by the airport fire and rescue service personnel using a hand-held fire extinguisher.

4 ENGINE GEARBOX MAINTENANCE HISTORY

4.1 Hours/Cycles of Main and Angle Gearboxes

Main Gearbox

Time/Cycles Since Overhaul	: 10,038 hours / 2,018 cycles
Full overhaul	: 12 March 1999

Angle Gearbox

Time/Cycles Since Overhaul	: 10,028 hours / 2,019 cycles
Full overhaul	: 20 February 1999

4.2 Recent Maintenance History

4.2.1 Filter Check/Chip Detectors Inspection

The previous 1A line check was accomplished on 15 July 2001. The chip detectors (Angle, #3, #4) were checked 350 hours before the incident. The main chip detector was checked 164 hours before the incident. The oil filter was checked 822 hours before the incident. There was no evidence of contamination found on the filter and the magnetic chip detector.

4.2.2 Oil Consumption Rate

The average oil consumption of the No.4 engine was 0.22 quarts/hour (in the 213 hours before the incident) and 0.25 quarts/hour (in the 50 hours before the incident).

4.2.3 Recent Shop Visit

4.2.3.1 Main Gearbox : The last shop visit was 8 October 2001.
Parts replaced : Main Oil Pump Bearing, Main Oil Pump Gear, Main Gearbox Centre Lug and Main Gearbox Front Housing.
The module was a repair level module.
No non-routine maintenance was performed.

4.2.3.3 Angle Gearbox : The last shop visit was on 10 October 2001
Parts Replaced: Support pins, two bearings.
The module was a repair level module.
No non-routine maintenance was performed.

4.2.4 **Review of the Aircraft Maintenance Log**

4.2.4.1 A review of the aircraft maintenance log showed the following:

a) On 11 July 2002, (departing from NRT for ANC), the No.4 engine (SN 662502) had an EGT exceedance of 991˚C for 4 seconds during take-off.
b) On 15 July 2002, (departing from NRT for TPE), No.4 engine had an EGT exceedance of 986˚C for 10 seconds during take-off (max take-off EGT is 985˚C).
c) On 19 July 2002, (departing from NRT for ANC), the No.4 EGT indication reads high, at approximately 30 to 50 degrees higher than other engines at the same EPR. EIDS exceedance – on take-off roll at an EGT of 963˚C. But shortly after lift off, the EGT reached 984˚C at 1.53 EPR.

5 MAINTENANCE BY SIA ENGINEERING COMPANY

5.1 The NWA aircraft N617US arrived at Singapore Changi Airport on 21 July 2002 at about 1810 hours. An overnight check was carried out by SIA Engineering Company (SIAEC). The check included a work package on the No.2 engine and two scheduled maintenance tasks on the No.4 engine. The two scheduled maintenance tasks for the No. 4 engine were for general inspection of the No.4 engine and pylon for obvious damage and to service the engine oil. The overnight check, the work package and the two scheduled maintenance tasks for the No.2 and No.4 engines were carried out satisfactorily.

5.2 On 22 July 2002, prior to the departure, an idle engine ground run was performed on all four engines in accordance with NWA requirements. The No.4 engine had two impending hot starts. Air was found to be leaking from the welded joint of the pre-cooler assembly. The pre-cooler duct was found to have a crack at the outlet of the high stage valve connection. After the pre-cooler was removed, a pneumatic tube was found chafed at the 11 o'clock position and the bracket fitting for the pre-cooler support link (Part No. 65B93007-1) was also found broken.

5.3 The pre-cooler support link bracket fitting was sent for fusion welding repair per DWG 65B93007 by SIAEC with the approval of NWA Maintenance Control in Minneapolis. The repaired fitting was reinstalled on the aircraft.

5.4 A permaswage repair was carried out on the pneumatic tube by SIAEC in accordance with Aircraft Maintenance Manual (AMM) 20-11-05 with the approval of NWA Maintenance Control in Minneapolis. The repaired tube was reinstalled on the aircraft.

5.5 A serviceable pre-cooler assembly (PN: 189680-3, SN: 16-874) provided by NWA was installed in accordance with AMM 36-12-01.

5.6 On 23 July 2002 (at 2300 hours), following the installation of the pre-cooler, the electrical plug of the start valve of the No.4 engine was disconnected to perform a reverse flow leak check. There was no leakage from the pre-cooler assembly and its associated ducting. The electrical plug of the start valve was reconnected.

5.7 A ground run of the No.4 engine was attempted in the presence of a NWA representative. However, the engine start was not successful as there were no N1 and N2 indications.

5.8 At 0045 hours (on 24 July 2003), the N1 blades of the engine was rotated manually. There was no binding. The N2 rotor was manually cranked and there was also no binding. A serviceable starter assembly (NWA spare, PN: 60B00015-2, SN: 28916) was installed. However when a start was attempted, there was no N2 indication.

5.9 The starter drive gearbox-coupling shaft was found sheared. The sheared coupling was removed with a coupling puller. The gearbox housing was inspected and no damage was found. A new starter coupling shaft and the starter provided by NWA together with the original starter shut off valve were installed. There were no problems encountered during the coupling shaft installation and starter replacement.

5.10 The engine ground run was performed with two NWA representatives present and all the engine parameters were normal. Following the ground run, the cowlings were opened for oil leak check. There were no leaks found and the aircraft was declared serviceable at 0500 hours.

5.11 At about 0712 hours, the aircraft, flight number NW908, took off for Bangkok.

6 GENERAL INSPECTION OF ENGINE

6.1 <u>General</u>

6.1.1 Following the incident, the engine was shipped to the Northwest Airlines (NWA) overhaul facility in Minneapolis for teardown inspection. The teardown was carried out with the participation of representatives of Pratt & Whitney (P&W), National Transportation Safety Board (NTSB), Singapore Ministry of Transport (MOT), Federal Aviation Administration

(FAA), NWA and Boeing.

6.1.2 The main and angle gearbox hardware was removed from the engine and shipped to Pratt & Whitney in October 2002 for examination by a team from United Technologies Corporation.

6.2 General Observations of the Fire/Thermal Damage

6.2.1 Fire and heat damage, along with sooting was observed from the rear end of the angle gearbox back to the tailpipe from approximately the 1:00 to 9:00 o'clock positions with the greatest amount of fire damage and distress localized between the 5:00 and 7:00 o'clock positions. The fire and heat damage outside the primary fire damage area (5:00 to 7:00 o'clock) consisted mainly of burned/damage wire bundles; burned, blackened, and melted tube and wire clamps, melted thrust reverser diaphragm-to-core cowl seal and general soot deposits. The heat/fire damage was most pronounced on the right side of the engine and forward of the race way.

6.2.2 The right hand hold-open core cowl rod was melted into two pieces but still attached to the thrust reverser inner diaphragm. Metallic spray was observed all along the bottom of the engine from just aft of where the main gearbox is normally installed back to the internal skin of the turbine exhaust sleeve. The metallic spray was easily peeled off the engine cases and the turbine exhaust sleeve by hand. The external skin of the turbine exhaust sleeve was burn through from approximately the 5:00 – 7:00 o'clock positions.

6.2.3 Metallic splatter was noted on the suction side of the LPT sixth stage blade airfoils and on the convex side of the radial support struts between the 4:00 and 6:00 o'clock positions.

6.2.4 A section of the starter air duct at the 6:00 – 6:30 o'clock position was missing. The exposed end (damaged) of the duct appeared to have experienced heavy fire and thermal damage. The starter and starter valve were not recovered.

6.2.5 The compressor stator control fuel supply (PH) filter assembly was missing. Both the inlet and outlet tubes were intact and covered in white residue. The fuel supply filter assembly attachment bolts (2) were still secure to the attachment bracket on the intermediate case.

6.3 Rotor Rotation

6.3.1 When the engine was received at the NWA facility, the fan could not be hand rotated. After the main gearbox was removed, the N2 was able to be hand rotated through the angle gearbox horizontal shaft forward gear. After the low pressure turbine (LPT) rotor assembly and fan were removed, the LPC turned easily by hand. With the high pressure turbine (HPT) rotor assembly now exposed after the removal of the LPT assembly, the HPT was easily rotated by hand. No visible damage was observed on any of the third or sixth stage LPT blades or on the LPT shaft.

6.4 <u>**Miscellaneous**</u>

6.4.1 The oil tank drain plug was removed and no oil was found in the tank. The oil filter was still installed and was removed after the event.

6.5 <u>**Condition of the Various Components**</u>

6.5.1 **Appendix 1** provides details of the condition of the various components after the fire.

7 DETAILED EXAMINATION

7.1 <u>**Main and Angle Gearbox Examination**</u>

7.1.1 General

A substantial number of components were lost overboard and thus are unavailable for review (Figure1). The condition of the available hardware is discussed below in detail. In general, damage was concentrated around the centre of the main gearbox. Many components were covered with a white fire retardant residue (white deposits).

7.1.2 Main Gearbox Housing & Front Cover

The main gearbox housing suffered extensive damage as a result of the magnesium fire (the gearbox housing is made of magnesium), with the middle half of the main gearbox housing either consumed by fire or lost overboard. The left and right side fragments of gearbox housing were visually examined, as described below.

7.1. 2.1 Left Side Fragment (Aft Looking Forward)

The exposed edges of the left side gearbox fragment exhibited areas of melted and re-solidified metal consistent with fire damage, as shown in Figure 2, as well as areas of cracking. In particular, melting and damage from the magnesium fire was typically found along the upper areas of the housing and cover, while bottom areas exhibited fracture surfaces suggestive of cracking or rubbed surfaces suggestive of wear damage. The oil passages cast into this housing that were associated with the missing oil pump were still oil wetted and contained areas of black deposits (probably oil coke). The left side gearbox housing also had the oil filter housing still attached (the oil tank had been removed), which was intact and undamaged.

7.1.2.2 Right Side Fragment

The exposed edges of the right side exhibited areas of melted and re-solidified metal consistent with fire damage as well as cracking, as shown in Figure 3. Similar to the other gearbox housing fragment, fire damage (melting) was typically found along the upper areas of the housing and cover, while the bottom areas exhibited fracture surfaces suggestive of cracking, as shown in Figure 4*.*

7.1.3 CSD/Generator Drive Gear, Bearings & Seals

The Constant Speed Drive (CSD) gear was found within the left side gearbox fragment, and appeared to be intact although it was coated with a layer of deposits from the fire. The gear shaft was subsequently disassembled from the gearbox housing and subject to cleaning treatment to remove the deposits. The gear shaft was completely disassembled including removal of the roller bearings. Subsequent visual examination did not find any damage to the gear teeth, roller bearings or sealing surfaces (for the carbon seals). Visual examination of the carbon seals themselves, still contained within the gearbox fragment, revealed that they were intact and in good condition.

7.1.4 Deoiler Drive Gear, Deoiler, Bearings & Seals (Not Recovered)

The deoiler drive gear and its associated bearings and seals were missing and presumed to be lost overboard during the course of the fire. Visual examination of the left side gearbox housing fragment did reveal pieces of the deoiler impeller. In addition, deposits or puddles of re-solidified aluminium were found along the bottom of the gearbox housing, adjacent to the main oil pump location and directly below where the impeller was located.

7.1.5 Breather Pressure Valve

The breather pressure valve assembly appeared to have been reduced to its steel components, i.e. the valve stem and valve seat. The rest of the assembly was presumed to have been consumed by the fire. The remnants of the valve exhibited red and white deposits. Three of the six bolts were missing, and two of these bolt hole flanges were bent. One flange contained a bolt, bracket and loop clamp, from which this valve was suspended after the event (by the fuel line 769469). The other two bolts were in place and had nuts and housing fragments attached to them, suggesting this valve might have been broken off sometime during the fire event.

7.1.6 N2 Tachometer (Not Recovered)

The N2 Tachometer and its associated driveshaft, bearings and seals were missing and presumed to be lost overboard during the course of the fire.

7.1.7 **Main Oil Pump (Not Recovered)**

The main oil pump was missing and presumed to be lost overboard during the course of the fire.

7.1.8 **Starter Drive Gearshaft, Bearings, Seal & Layshaft**

The majority of this hardware was recovered, as shown in Figure 5, with the exception of the aft bearing outer race and aft carbon seal.

7.1.8.1 Horizontal Drive Shaft or Layshaft

This shaft was fractured adjacent to the forward spline, as shown in Figure 5. The fracture surface exhibited necking consistent with an overstress mode of fracture. The shaft was also bent, with more pronounced bending along the aft end near aft spline. There were also splinelike indentations along the outside of shaft adjacent to aft spline, as shown in Figure 6, suggesting this shaft had shifted axially out of mesh at some time during the fire event and rode on the inside surface of the Ring-Lock Spline. Areas of impact damage and scoring were found along the middle of the horizontal drive shaft. The scoring damage was circumferential and appeared to be in the area of the slip joint in the layshaft housing. Also an indentation was found along the shaft exterior surface that matched the shape of the castellated nut attached to the bolt in the lower bearing of the layshaft link (Figure 7).

7.1.8.2 Ring-Lock Spline

This ring contained a spline on both its inside surface and outside surface and is assembled between the layshaft and the layshaft coupling (Figure 5). This ring was heavily and uniformly deformed around its circumference (Figure 8), indicating it had experienced an unusual radial load or displacement while it was still rotating. The aft end of the inside spline exhibited damage attributed to clashing with the layshaft spline after these two components were disengaged.

7.1.8.3 Layshaft Coupling, Attachment Nut and Key Washer

The main drive coupling was coated with a layer of white deposits. Visual examination of the coupling revealed it was bent, while examination of the spline areas did not reveal unusual contact patterns. Also, a circumferential rub pattern was found inside the forward end of the coupling, due to contact with the aft end of the layshaft. This coupling was otherwise intact, as were the attachment nut and key washer.

7.1.8.4 Starter Drive Gear

This gearshaft was covered with a layer of white deposits, as shown in Figure 9 which was presumed to be from the fire. Visual examination of the gearshaft after cleaning revealed both axial and circumferential scoring along the aft bore (Figure 10). This was the bore where the starter coupling was installed. Visual examination of the gear teeth revealed impact damage, nicks and dents, as well as faint gear contact patterns, as shown in Figure 11. The impact damage to the gear teeth was also smeared, which suggested that much of this impact damage had occurred while the gear was still rotating. Visual examination along the aft end of the shaft, where the aft carbon seal would run, revealed that surface appeared normal. The associated carbon seal was not recovered.

7.1.8.5 Starter Drive Gear Bearings

The forward starter drive roller bearing was covered with white deposits, as shown in Figure 12, presumed to be from the fire. After cleaning to remove these deposits, it was found that there was no silver plate left on the cage and the cage was deformed. The rollers exhibited heavy end wear, while both the inner and outer races were deformed, as shown in Figure 13. Otherwise, the radial bearing surfaces of both the inner and outer races were not cracked or spalled. Further destructive examination of the forward bearing inner race revealed hardness values that ranged from 22 to 24.5 HRC (converted Vickers), compared to the minimum hardness of HRC 58 specified by the part specification indicating that substantial softening had occurred as a result of the fire.

The aft starter drive roller bearing had only a light covering of the white deposits. Overall the cage appeared to be in good shape including the silver plate, except for several areas of impact damage which had dislodged several rollers and distorted and locally overstressed the cage, as shown in Figure 14. The rollers were intact. The inner race was intact. The outer race was missing and presumed to be lost overboard during the fire. There was no sign of prior distress on available hardware. Further destructive examination of the aft bearing inner race revealed hardness values that ranged from 40 to 49 HRC (converted Vickers), compared to the range of 58 to 62 HRC specified by the part specifications.

7.1.8.6 Starter Coupling

The starter coupling was found to be frozen inside the starter drive gear, and had to be forcibly removed during teardown. The outside surface of the coupling exhibited areas of deep axial scoring, suggesting an interference with the starter drive gear, as shown in Figures 15. Further examination of the layshaft coupling suggested the starter coupling had not been fully seated into the starter drive gear, as shown in Figure 16. The pattern of this damage suggested the starter coupling had been at least 0.150” too far aft.

Further visual examination of the starter coupling did not reveal unusual contact patterns along the outside spline. However, forward of the inside spline, a circumferential contact pattern was observed. Visual examination of the ouside spline did not reveal evidence of unusual contact patterns. Finally, the aft end of the coupling exhibited impact damage, similar to that of the aft starter drive roller bearing. The nut used to assemble the starter coupling to the starter drive gear was found to have white deposits on the threads at the aft end of the nut confirming the coupling was not fully seated into the starter drive gear.

7.1.9 **Layshaft Housing & Support Link**

The layshaft housing consisted of two halves. The forward half was attached to the angle gearbox as shown in Figure 1. The aft half of the layshaft housing was bolted to the main gearbox housing, and was missing (either lost overboard or consumed by the fire).

7.1.9.1 Layshaft Housing. Forward Half

This forward layshaft housing exhibited red deposits, as well as white deposits from the fire. This housing had a tube and bracket hanging off its four-bolt flange. Also, it appeared that the housing had rotated during the event, since the cut-out in the flange was now facing the engine right side (the normal installation direction of the layshaft housing flange cut out is facing the left). This suggested that the layshaft was still spinning at the time the cover plate on the angle gearbox was broken. This housing was also bent and exhibited cracking or structural damage. The inside surface of the housing aft end exhibited deposits from the fire.

7.1.9.2 Rear Drive Shaft Housing (Layshaft Housing) Support Link

The support link attached to the aft layshaft housing was not hanging vertically but tilted aft slightly and bent left by almost 90 degrees, as shown in Figure 1. The bolt and nut were present in the lower link bearing, but the layshaft housing lugs appeared to have been consumed by the fire (as was the entire aft layshaft housing). Examination of the link, lower bolt and nut did not reveal impact damage to explain the deformation, however there were impact marks on the layshaft that were similar in size and shape to the link nut.

7.1.10 **Main Scavenge Pump (Not Recovered)**

The scavenge pump was missing and presumed to be lost overboard during the course of the fire.

7.1.11 Idler Gearshaft (Not Recovered)

The idler gearshaft and related bearings and seals were missing and presumed to be lost overboard during the course of the fire.

7.1.12 Fuel Pump & Control Drive Gearshaft, Bearings & Seal

The fuel pump drive gear shaft was found contained within the right side gearbox housing fragment, as shown in Figure 3. The gearshaft was intact and except for a coating of external deposits from the fire appeared undamaged. The gearshaft was subsequently disassembled from the gearbox housing and cleaned to remove these deposits. The gearshaft was fully disassembled including removal of the roller and ball bearings. The bearing cages (both ball and roller) still exhibited a layer of silver plate. Looking at visible areas of the balls and rollers, these bearings appeared to be in good shape. The forward carbon seal and seal face areas were intact and did not exhibit damage. Visual and binocular examination of the gear teeth after cleaning did not find unusual contact patterns.

7.1.13 Hydraulic Pump Drive Gearshaft

The hydraulic pump drive gearshaft was also contained within the right side gearbox housing fragment, as shown in Figure 3. The gearshaft was intact and except for a coating of external deposits from the fire appeared undamaged. The gearshaft was fully disassembled to remove the roller and ball bearings. Visual examination of the shaft bearings did not reveal signs of distress.

7.1.14 Angle Gearbox Housing & Geartrain

7.1.14.1 Angle Gearbox Housing

The majority of the angle gearbox was in good condition except for the aft end and the aft cover. The aft corner of the housing had fractured along the right side and also along the top side in particular around the mount lugs that were partially torn out. This damage suggested that the aft part of the housing might have been shaken violently, probably just prior to the fracture of the horizontal main drive shaft (layshaft). The aft angle gearbox housing cover was fractured in many pieces.

7.1.14.2 Angle Gearbox Geartrain

The angle gearbox gears were all intact and did not exhibit any signs of distress. There was no visible damage to any of the gears or gear teeth, and each gear turned freely on its bearings. The bearings that were visible without further disassembly (beyond removal of the housing covers) appeared normal with no evidence of distress. The forward compartment of the angle gearbox was oil wetted, and did not exhibit deposit build-up from the fire.

7.1.14.3 Towershaft

The towershaft was intact and did not exhibit any signs of distress.

7.2 **Gearbox Mounted Engine Accessories**

7.2.1 Generator (Non Destructive Testing Only)

The generator sheet metal outer shield had burst, i.e. it had ruptured from the inside out. The burst was located on the right side of the generator, i.e. it was facing the outboard breather and layshaft housing. After the cover was removed, no damage was found to the generator housing. The generator shaft was found to spin freely.

7.2.2 CSD (Non Destructive Testing Only)

The CSD housing exhibited a dent and a small hole. Along the bottom of the dent area was the impression of a tooth and 2 bolt heads, which matched the tooth and bolt pattern along the outside surface of the starter output shaft. The hole was reportedly not present during the engine teardown, and exhibited fresh fracture surfaces. The hole was located in the middle of an outward bulge in the housing, an area that also exhibited numerous axial and circumferential housing cracks. The hole was actually at the intersection of several of these housing cracks. Because it was unclear whether the hole might not have been a puncture due to the sudden exit of some internal hardware, further borescopic inspection was conducted through the hole. This inspection found an internal cavity just inside the hole, but no gears or gearshafts were visible (this cavity was reportedly identified as an oil reservoir). An inspection of the internal cavity did not reveal any evidence of damage, holes or cracking.

7.2.3 Starter (Not Recovered)

Although the starter was not recovered and presumed lost overboard, the damage to the CSD housing suggested that an impact occurred between the starter output shaft and the CSD housing. Based on review of the starter cross-section, for impact to occur much of the starter housing and geartrain would have to already be gone prior to impact. This suggested that the starter had sustained damage during the course of the fire, possibly quite early in the fire, the cause and sequence of which is unknown.

7.2.4 Fuel Control

Extensive fire damage was noted to the left side of both pump and control modules, i.e. the side facing the layshaft housing, as shown in Figure 17. The exposed surfaces of these cast aluminium housings exhibited localized melting and areas of re-solidified metal due to the heat of the fire. Comparing the extent of the fire damage, the fuel control had experienced much more damage to its housing than the adjacent fuel pump. The fuel control exhibited extensive melting of the housing on its left and forward (i.e. dome) sides exposing the upper linkage bracket assembly, thus exposing the insides of the control. The fuel outlet boss, which mated to the fuel out manifold, was fractured, although part of the fracture surface was fresh. This area was not fractured on the engine, but had a large crack, which could have spilled a considerable amount of fuel into this area during the course of the fire.

Figure 18 shows the condition of the fuel control parts. The speed servo cam was visible through the missing section of the main cover, and the position of the cam was measured in its final position. It was determined that the cam was at 0.565 inch from a 0-speed reference point, thus from design curves it was determined that the control was operating at approximately 3870 RPM control speed. This correlates to idle speed on the JT9D-7 engine indicating the fuel control did not freeze at a high fuel flow during the flameout event.

7.2.5 Fuel Pump

Other than the fuel filter area which was partially missing (broken/melted away), the fuel pump experienced only areas of metal spatter and white deposits on the surface.

7.2.6 Hydraulic Pump (Non Destructive Testing Only)

The hydraulic pump did not show any obvious signs of distress.

7.3 **External Hardware**

7.3.1 No.3 Bearing Breather Tubes. Internal

The internal breather tubes appeared clean and undamaged by fire.

7.3.2 No.3 Bearing Scavenge tubes. Internal and External

The No. 3 bearing scavenge tube was melted at the gearbox end, and about half of the tube was missing, as shown in Figure 19. This tube connected to the scavenge pump on the front of the gearbox at a boss to the right of the layshaft housing. At the diffuser case end, the external No.3 scavenge tube was bent suggesting it had taken an impact. Included in the hardware was the mating internal No.3 scavenge tube, which was bent and deformed at its outboard end, further evidence of a substantial impact.

7.3.3 Pressurization and Dump Valve (P&D)

The P&D valve housing exhibited numerous areas of white deposits from the fire and melting damage along the secondary fuel pressure port. About half of this port was melted away and missing (this port is located on the right side). This unit was otherwise intact and did not exhibit other signs of melting damage. The fuel inlet port was intact and exhibited a layer of black deposits along sealing surface. Likewise the primary fuel pressure port was intact and exhibited a layer of black deposits along the sealing surface.

7.3.4 Secondary Fuel Supply Manifold

The tube was intact with no evidence of cracking. The packing at the inlet end was decomposed and charred. At the manifold outlet end, the four tube connections were frozen together, i.e. even though the B-nuts were backed off the cone seat joints did not come apart. There also appeared to be balls of material along one of the braze joints, possibly an indication that the braze had re-melted. White deposits (fire residue) were noted, in particular near inlet end.

7.3.5 Fuel Out Manifold From FCU to Fuel Transmitter

The Fuel Control Unit (FCU) housing section was still attached at manifold connector end. The tube was intact with no evidence of cracking. The tube inlet end fitting was loose suggesting packing material had been damaged by fire. Attached to the tube inlet end was also the tube-to-boss adapter to which was still bolted a section of the fuel control flange, which appeared fractured off (mixture of old and fresh fracture). The tube inlet area exhibited white deposits and areas of metal spatter. The tube-to-boss adapter exhibited white deposits, metal spatter deposits and an area of possible melting along the plugged end.

7.3.6 Fuel Heat Return Line to Fuel Filter Pressure Switch (Mounted on Fuel Pump)

Two tubes (P/N 769472 and 769469), were still connected at the Tee fitting.

7.3.7 Tube P/N 769472 (Manifold Assembly of, Hydraulic Return, Fuel Pump Inlet Rear")

This tube exhibited impact damage a the fuel pump end. The tube to boss adapter from fuel pump was still attached to the B-nut joint. Heavy impact damage was found along the tube, about 2 inches from the fuel pump end. The tube clamp was still attached to the tube at this location, which appeared partially fractured. The tee fitting in middle of this tube still had a tube attached to it, which was frozen in place, i.e. even though the B-nut was unscrewed, the 37-degree cone seat joint would not separate.

7.3.8 Tube 769469 (‘Tube. Assembly of, Fuel Signal, Delta P Switch”)

This tube exhibited yielding or bending, and the ferrule and B-nut at the switch end was missing. The tube at the switch end seemed to terminate in mid-air, but the tube surface was coated with deposits and it could not be determined if the tube had fractured or experienced braze melting and tube pull out. This is the tube which had the breather pressure valve remnant hanging off it from a loop clamp, and may have had more mass hanging there during the event which was consumed or melted later on in the fire. Visual examination inside this tube at the fractured end revealed that it was blocked by a meniscus of metal, which was determined to be stainless steel (and not braze material) by Energy Dispersive Spectrometry (EDS) analysis. Further destructive examination of the blockage found a dendritic structure, and a layer of dendritic material coating the inside surface of the tube. The fracture surface of the tube wall itself exhibited necking and a shear lip which indicated an overstress mode of fracture. This finding suggested that melting had occurred prior to the overstress fracture, or after the fire was well underway.

7.3.9 No.4 Oil Scavenge Line

The forward end of the No.4 oil scavenge tube exhibited impact damage, from multiple impacts several inches aft of the flanged connection (where it had been attached to the main gearbox). This forward flange also exposed the nuts, studs and heli-coils from the gearbox boss, indicating the fire had consumed the magnesium of the boss, but had not been locally hot enough to melt the studs.

7.3.10 PH Filter to Engine Vane Control (EVC) Connecting Line

The tube was intact and exhibited a coating of white deposits probably from the fire. On the EVC end, the fitting associated with the fuel filter still contained the tube adapter. This fitting was still tight. Overall the tube did not appear to be bent, deformed or damaged as others were. This was the fuel filter where the filter housing had been melted away, likely a result and not a cause of the fire.

7.3.11 Engine Vane Control (EVC)

The EVC, located on the right side of the engine just forward and above the location of the fuel control, was also examined for signs of fire damage. Visual examination revealed a fractured drain tap and the other half of the melted fuel filter fitting.

7.4. <u>**Starter Axial Stack Analysis**</u>

7.4.1 An analysis of the starter axial stack showed an axial clearance of at least 0.237 inch was available. This clearance would have precluded an interference with the starter.

7.5 **Analysis of Oil Samples and Oil Filter Element**

7.5.1 An oil filter element and three oil samples were analysed by Pratt & Whitney. The three oil samples were from:

- Fuel/Oil Cooler (FOC) - Oil sample No.1
- No.1/2 Bearing Area - Oil sample No.2
- No. 4 Bearing Area - Oil sample No. 3

7.5.2 The following chemical analysis was performed on the oil filter and three fluid samples:

Oil Filter	:	Flush Oil Filter, perform TGA and FT-IR
Oil Sample No.1 (FOC)	:	SOAP, Total Acid Number, Viscosity and GC/MS
Oil Sample No.2 (1/2 Bearing)	:	GC/MS Only*
Oil Sample No.3 (No.4 Bearing)	:	SOAP, Total Acid Number and GC/MS*

* Samples 2 and 3 were limited in their volume so we could not do as much analysis as we were able to with Oil Sample No. 1.

7.5.3 The results of the analyses were as follows:

Sample	**Analysis**	**Result**
Fuel/Oil Cooler	GC/MS	No contamination/high acid content
No.1/2 Bearing Area	GC/MS	~0.002 w/o hydraulic fluid/high acid content
No.4 Bearing Area	GC/MS	No contamination/high acid content
Oil Filter	FTIR/TGA	Oil coke; <5% ash

7.5.4 **SOAP SAMPLE DATA RECORD**

Element concentrations given in whole parts per million (PPM)

										Total Acid Number	Viscosity At 100F
RN43787	Fe	Ag	Al	Cr	Cu	Mg	Ni	Si	Ti	(mg KOH/g)	(cSt)
Fuel/Oil Cooler	6	1	<1	<1	8	2	<1	7	1	15.4	37.2
#4Bearing Area	45	<1	1	<1	1	6	<1	19	1	25.8	NA

All three oil samples were evaluated for signs of hydraulic fluid contamination via GC/MS. Only the results of the No.1/2 bearing area oil sample indicated the presence of hydraulic fluid at 0.002weight %. The SOAP results are shown in the table above.

7.5.5 Although the majority of the oil filter deposits consisted of organic phase materials that appeared consistent with coke, further analysis of the oil filter debris was conducted to locate and identify any metallic debris. As a result, the debris was solvent cleaned and sorted with a magnet, which revealed a dozen or so metal flakes which were subsequently analyzed by scanning electron microscopy with energy dispersive spectroscopy (SEM/EDS). The analysis found the chemical composition of the flakes were all similar to AISJ 52100 bearing steel. In some cases, silver was also found, a possible indication of silver plated bearing cage material or of an impact with same.

8 INVESTIGATION FINDINGS AND DISCUSSIONS

8.1 The root cause of the fire could not be determined due to the extent of the fire damage and loss of numerous components. However, based upon the investigation of available hardware, there were a number of notable findings:

8.1.1 The fire originated in and was confined to the main gearbox and accessory components. The most significant damage and the majority of the lost hardware occurred in the vicinity of the starter drivetrain system. Angle gearbox damage was limited to housing fracture only - the internal geartrain turned freely.

8.1.2 Oil filter analysis revealed the presence of a small quantity of metal flakes of composition AISJ 52100 bearing steel. The fact that the residue was reported as flake-like and not fine ground indicates that the metal particles most likely did not circulate in the oil system for a long period of time. However, it could not be determined whether the flakes developed prior to or after the fire event. Also, note that AISJ 52100 is an optional bearing material for nearly all gearbox bearings, so this information does not point to a specific location.

8.1.3 Difficulty with starting the engine the day prior to the event, including the need to replace the starter and shearing a starter drive coupling during one of the attempts, led to careful review of available starter system hardware.

8.1.4 Axial scoring indications were present on the outside surface of the starter drive coupling recovered from the event. Corresponding damage was found on the mating starter drive gear internal bore as well as circumferential score indications possibly associated with the starter coupling shear event reported. However, whether the axial scoring had occurred prior to or after the event cannot be determined.

8.1.5 The forward starter drive roller bearing inner and outer races were deformed, including an axial groove on the inner race. A hardness check on this area indicated 22.0 - 24.5 HRC versus a B/P minimum of 58 HRC, indicating a substantial softening had occurred as a result of the fire. According to the tempering curves for bearing steel, the temperature would have had to exceed 1200 degrees F for several minutes. Also, this bearing was obviously hot rolled, that is, the deformation occurred after the steel was very hot. Since it would not be possible for the bearing to reach that temperature while the oil was cooling it, this damage occurred at the end of the incident after the oil was eliminated.

8.1.6 Nevertheless, some amount of axial load had to be present to generate the axial distress and probably was induced by thermal distortion of the housing or by flailing of the layshaft. The hot rolling deformation could occur under fairly low thrust loading.

8.1.7 Deposits on the threaded end of the starter drive gearshaft indicate that the starter drive coupling was not fully seated axially by approximately 0.150 inch, providing a possible interference with the starter assembly. However, an axial stack analysis showed a minimum axial clearance of 0.237 inch which would preclude an interference with the starter.

8.1.8 The impression along the CSD housing was made by the starter output shaft. In order for the impression to be made, part of the starter housing and geartrain would have to be missing to allow the output shaft to be out of position and to strike the CSD. The normal operation of the starter, after cutoff speed, would allow the output shaft to continue to be rotated by the engine. The rotating and out-of-position output shaft would have sufficient energy to make such an impression on the CSD housing. This finding suggests that the main gearbox housing was burned away and the starter housing was not present when the starter output shaft made an impression on the CSD housing from high rotor windmill.

8.1.9 The fire damage (melting) sustained by the fuel control, fuel pump and P&D valve suggests that a fuel fire also occurred during the overall engine event. No obvious external leak sources were found on the fuel control unit and several features on the external of the control were heavily damaged and missing. Therefore it cannot be determined whether the fuel control had a fuel leak that would have caused the reported nacelle fire.

8.1.10 One area was found where the fire had burned hot enough to melt steel (i.e. the No.3 bearing scavenge tube, differential pressure switch sense tube, etc...) which was located in front of the gearbox housing at the idler gear / oil scavenge pump location.

8.1.11 The fuel pump did not contain electric/electronic components, which could become sources of ignition. The idea that the bearings heated up with lack of fuel and ignited the fuel vapour is not an option since fuel was running through the pump up until the pylon shutoff valve was closed in response to the fire. That fuel pump was running can be evidenced by the shear section that connected to the gearbox which was intact indicating fuel flow through the unit.

9 CONCLUSION

9.1 The findings of this investigation determined that the fire was due to ignition of the magnesium gearbox housing. A root cause for the ignition cannot be identified due to secondary damage and parts not recovered.

9.2 The examination of the forward starter gearshaft bearing revealed evidence of distress due to forward axial thrust load, which could have contributed to ignition of an oil fire. However, the source of the axial thrust load could not be determined.

9.3 The examination of the starter coupling revealed deep axial scoring that suggested this coupling had not been fully seated inside the Starter Drive Gear by about 0.150 inch. This should not have caused the starter output shaft to bottom out inside the starter coupling as the axial stack analysis showed that there is an axial clearance of at least 0.237 inch.

9.4 There were numerous indications that the layshaft including the starter drive gear and the starter output shaft became disengaged while still spinning and violently whipped around causing numerous impacts to adjacent hardware. This damage was considered secondary to the fire since it could only occur after the gearbox fire.

9.5 The impression of the starter output shaft along the CSD housing also suggested that the starter was damaged. Since the starter was not recovered, it was not possible to determine if this occurred after the fire (i.e. due to impact(s) from the layshaft whipping around) or prior to the fire (due to unknown circumstances).

9.6 There was evidence of a fuel fire in the area of the fuel control, fuel pump and P&D valve. However, there were no obvious external leak sources in the area, and with several features on the external of the fuel control heavily damaged and missing, it cannot be determined whether the fuel control had a fuel leak that would have caused the reported nacelle fire.

APPENDIX 1

SUMMARY OF DAMAGE TO THE ENGINE

The engine was shipped to the Northwest Airlines (NWA) overhaul facility in Minneapolis for teardown inspection by representatives of Pratt & Whitney (P&W), National Transportation Safety Board (NTSB), Singapore Ministry of Transport (MOT), Federal Aviation Administration (FAA), NWA and Boeing. Details of the condition of the various components of the engine after the fire are provided below.

1 Fuel Control (FC)

The entire fuel control (FC) exhibited varying degrees of fire and heat damage but the most significant damage was on the left side on the FC housing (inboard) and the front cover. The entire left side of the FC was either burned or fractured and the front cover was completely melted and missing, thus exposing internal components. The left side of the FC housing exposed the TT2 side of the housing where the TT2 assembly had been detached; however, it was recovered. A portion of the minimum fuel pressure shutoff valve housing and internal components was also missing from the left side of the FC. The minimum fuel shutoff valve was not recovered.

The fuel control outlet housing-to-fuel flow transmitter flange was fractured and heat damaged; however, the fuel control-to-fuel flow transmitter fuel line appeared to be intact.

The FC was separated during disassembly from the fuel pump and the FC drive shaft was exposed. The FC drive shaft appeared to be intact and the external threads exhibited no signs of significant spline wear. The fuel pump drive gear (located within the fuel pump) internal splines which mates with the FC drive shaft did not revealed any significant spline wear.

2 Angle Gearbox/Horizontal Driveshaft Housings

Approximately half of the angle gearbox rear cover was missing, thus exposing the coupling and the aft end of the bevel gear, key washer & nut unit. The edges of the rear cover appeared to be fire/heat damaged, charred, burned, melted and fractured. The inner housing assembly (top cover) and the outer housing assembly (forward cover) were intact with no significant fire/heat damage. The upper aft mount clevis was found nearly broken off from the cover.

The front horizontal driveshaft housing was intact separate from the angle gearbox; however, a piece of the angle gearbox rear cover was still attached. The front horizontal driveshaft housing had a rusted appearance. The rear horizontal driveshaft housing was missing and not recovered. The rear horizontal driveshaft housing support link was found bent almost 90^o clockwise but the bolts that secure the housing to the link and the link to the combustion case front flange were intact. The No. 3 bearing scavenge line which was located in the vicinity of the support link was also bent about 90^o and pushed towards the combustion case.

3 Fuel Pump

The entire fuel pump housing exhibited fire and heat damage. The left side of the housing (inboard) experienced the most damage with approximately half of the fuel filter housing missing, along with the fuel filter itself, and half of the fuel pump pressurizing valve housing missing, along with the pressurizing valve itself.

The fuel pump appeared to be intact and no visual damage was noted to the external splines. Visual examination of the internal splines on the fuel pump drive spur gear located within the gearbox did not revealed signs of significant spline wear. The splines did have a rust-like covering and the o-ring seal was charred and brittle but much of the seal was still in place.

4 Generator

The generator appeared to be intact except for a hole in the generator cooling duct that surrounded it. The hole was located at approximately 4:00 o'clock position (inboard) with the edges of the hole flared outwards. The generator itself did not exhibit any visual damage. After removal from the engine, the generator rotated freely by hand. The cooling duct exhibited a dent from in the inside outwards.

5 Main Gearbox

Both the front and rear main gearbox housing and all the internal components were missing from the centrifugal filter location (filter was missing) on one side to the constant speed drive (CSD) mount pad on the other. The remaining sections of front and rear main gearbox housing exhibited fire and heat damage, and fracture damage.

The right side of the main gearbox still had attached the fuel control, fuel pump, the fuel heater, and outboard hydraulic pump. The hydraulic pump drive bevel gear, bevel gear support bearing, the spur gearshaft, spur gear and bevel gear unit, and bevel gear bearings were still installed. All the gear teeth were intact and none of the gear teeth exhibited any significant visual wear.

The left side of the main gearbox still had attached the CSD and the generator. The CSD drive gear was still installed within the gearbox and the gear teeth appeared to be intact and no apparent wear was noted.

All other gearbox gears than those listed above were missing and not recovered.

The rear main bearing breather tube elbow was missing except for a piece of the rear flange which was still attached to the breather tube. The breather tube appeared to be intact.

6 <u>Gearbox Starter/Horizontal Driveshaft Unit</u>

The gearbox starter coupling, rear inner race, cage, and roller elements (outer race missing), starter gear, forward bearing, main drive coupling, spline lock ring and part of the horizontal driveshaft were connected as a single unit (parts listed aft to forward). The gearbox starter gear was located axial aft of its normal operating position (towards air starter motor) and the teeth were all intact but exhibited some teeth damage, dents to the tops of the teeth. The rear end of the gearbox coupling exhibited three significant inward dents.

The rear bearing outer race was missing along with 4 roller elements. The cage is damaged in the area where the 4 roller elements were missing and the entire bearing was seized. The inner race was no longer seated against its bearing shoulder and was slightly axial aft of its normal operating position.

The forward bearing was free to rotate and all the roller elements were present. The aft rails were distorted (wavy). The forward bearing outer race was still installed. Similar to the rear bearing, the forward was also found not completely seated against its bearing shoulder. Unlike the rear bearing, the forward bearing was slightly cocked as that part of the bearing was seated but the majority of the bearing was not.

The starter coupling internal splines appeared to be intact with no significant damage. The starter coupling was slightly aft of its normal operating position. The horizontal driveshaft, along with the spline lock ring was pushed aft into the main drive coupling. The horizontal driveshaft and spline lock ring were loose within the main drive coupling but they could not be disengaged. The nut that secured the main drive coupling and the gearbox starter coupling was not found attached to the threads on the main drive coupling. A circular impression was observed on the inside of the gearbox starter coupling in the area where the missing nut would have normally been installed. The Singapore Ministry of Transport stated that the nut was installed at the time of the event but was removed prior to shipping of the parts for teardown and evaluation to attempt to remove the starter coupling.

The horizontal drive shaft was fractured just aft of the transition radius of the forward spline and the shaft itself was slightly bent. The fracture surface was dark and the fracture angle was approximately 45^{o}. The overall length of the fractured horizontal driveshaft was approximately 17 inches. The main drive coupling internal splines exhibited flattening on the tops of the teeth and the horizontal driveshaft exhibited corresponding impact damage on its outside surface.

The horizontal driveshaft and the spline lock ring were separated from the rest of the gearbox starter coupling/main drive coupling unit. The splines on the spline lock ring did not exhibit any significant wear. Both the forward and rear ends of the spline lock ring were flared (cupped) outward, essentially increasing the radial diameter of both ends. However, the forward end (facing the angle gearbox) exhibited the greatest amount of distortion. The gearbox starter coupling could not be removed.

7 Constant Speed Drive

The constant speed drive was still attached to the gearbox and appeared to be intact but the outer housing exhibited heavy sooting. A round bottom dent approximately 3 inches long x 0.5 inch deep was noted on the outside of the CSD around the 2:00 o'clock position (inboard) but the housing was not breached. Within the dent were several impressions. Two of the impressions were consistent with a static six-sided nut or bolt and the other impression was a straight-line crease with an accompanying scrape mark. After removal from the engine, the CSD rotated freely by hand.

8 Lower thermal radiation engine accessory heat shield assembly

The lower thermal radiation engine accessory heat shield assembly exhibited an impact dent approximately 13 inches circumferentially at the 6:00 o'clock position but the shield was not breached in this area. The dent was located just aft of where the gearbox was normally installed and the centre of the dent was in contact against the diffuser case. Based on dimensional examination of a similar engine, the dent was axially in-line with the air starter quick attach detach (QAD) clamp. This is approximately 8 ¾ inches forward of the combustion chamber drain line cut-out in the heat shield. The No. 4 bearing scavenge line that ran along the bottom of the engine was flattened in-line with the dent in the radiation heat shield.

The heat shield exhibited severe fire and heat damage but stayed relatively intact except for the rear quarter of the outer skin at the 5:30 – 6:30 o'clock position where the heat shield was melted and missing.

9 Turbine Exhaust Case

The front (R flange) and rear (S flange) engine mount flanges were distorted in the area around the 6:00 o'clock position. Three front flange webs, all located around the 6:00 o'clock position, were noted to be fractured.

10 Main Bearing Breather Tube

Main bearing breather tube was intact with no visible signs of internal or external heat discoloration. Internally, no visible signs of sooting were noted in the upper elbow. The lower part of the tube still had a piece of the flange from the lower elbow attached. However, the rest of the magnesium elbow was missing.

11 No. 3 Bearing

The No.3 bearing compartment was examined using a borescope which revealed no abnormal distress of signs or heat discoloration or damage. The bearing compartment appeared to be wetted with oil. The bearing was visually inspected and it appeared satisfactory with no signs of heat damage or distress. Coke was noted on the intermediate rear air seal; however, this is typical for this engine model. The rear housing and the intermediate rear seal were removed to expose the bearing support and bearing. The scavenge pick-up and screen were visible with no signs of coking. The bearing appeared intact with all the roller present and no signs of distress. The roller elements were slightly oil wetted.

12 No.4 Bearing

Visual inspection of the No.4 bearing compartment revealed that the bearing was satisfactory with no signs of any damage or distress. Oil was puddled at the bottom of the bearing compartment.

13 Pressure and Dump Valve

The secondary fuel nozzle manifold elbow was missing and the remaining surface appears melted.

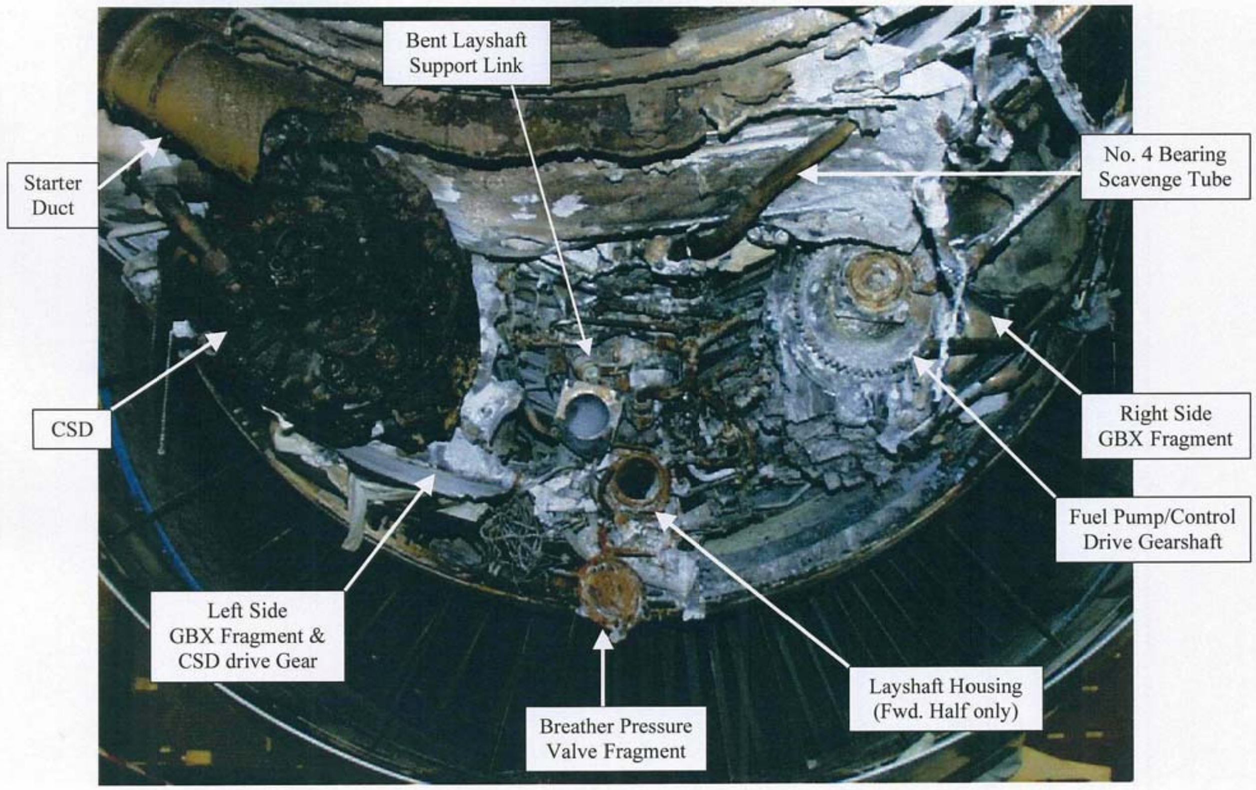


Figure 1: - Photo from engine teardown (view is aft looking forward)
Showing the general condition of the gearbox area during engine teardown. Note that the layshaft and starter drive gear were removed prior to this photo; these shafts were found hanging out of the layshaft housing.

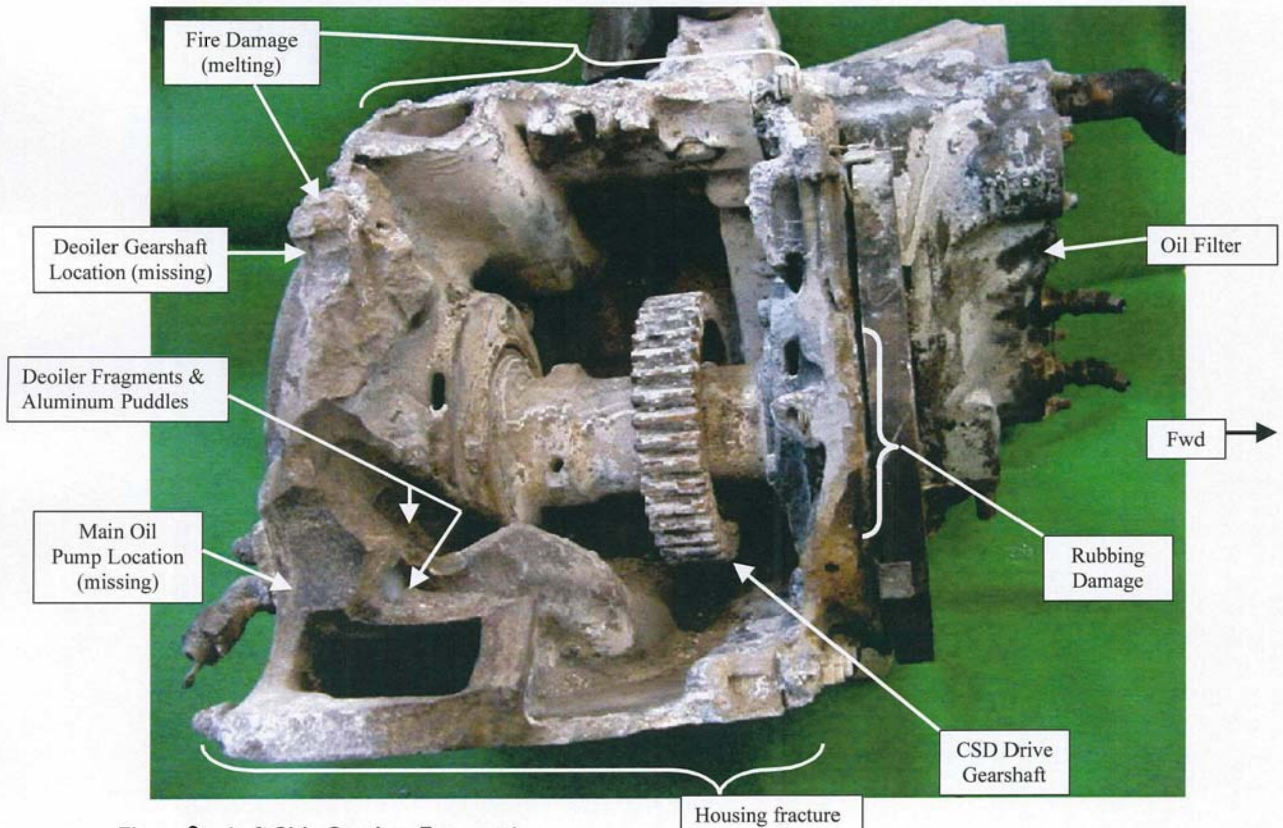
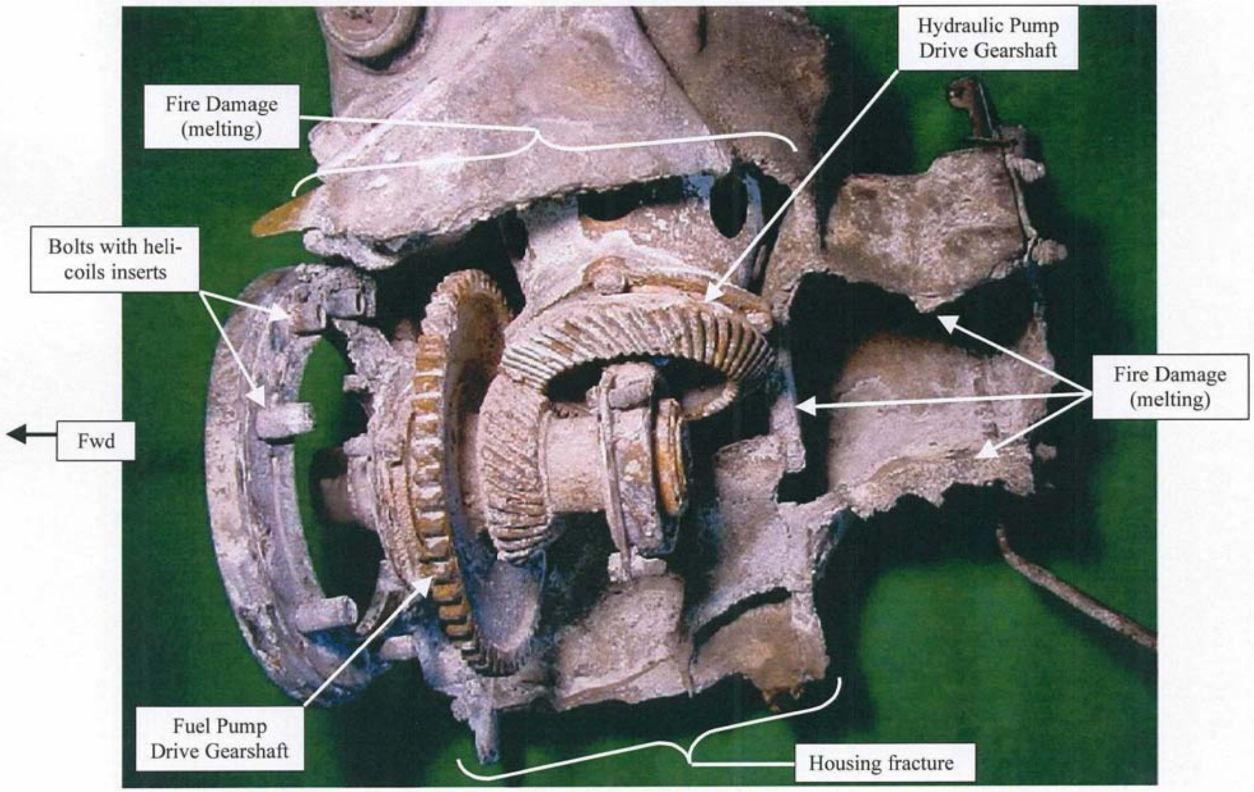
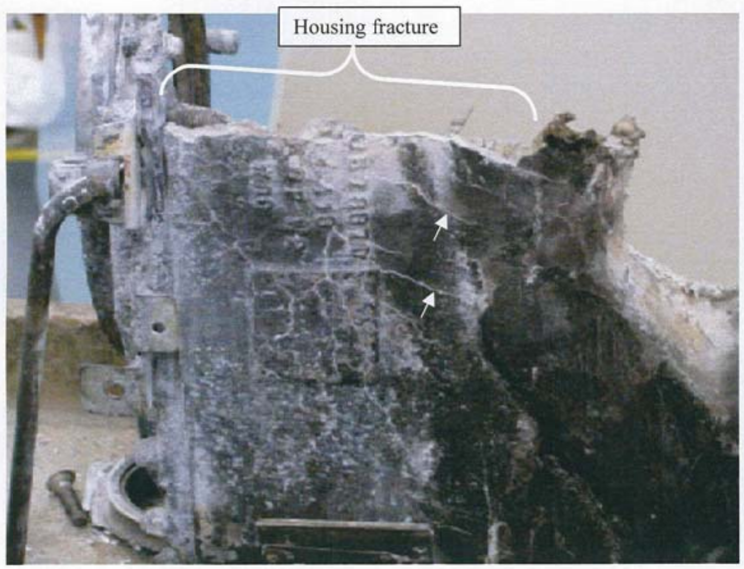


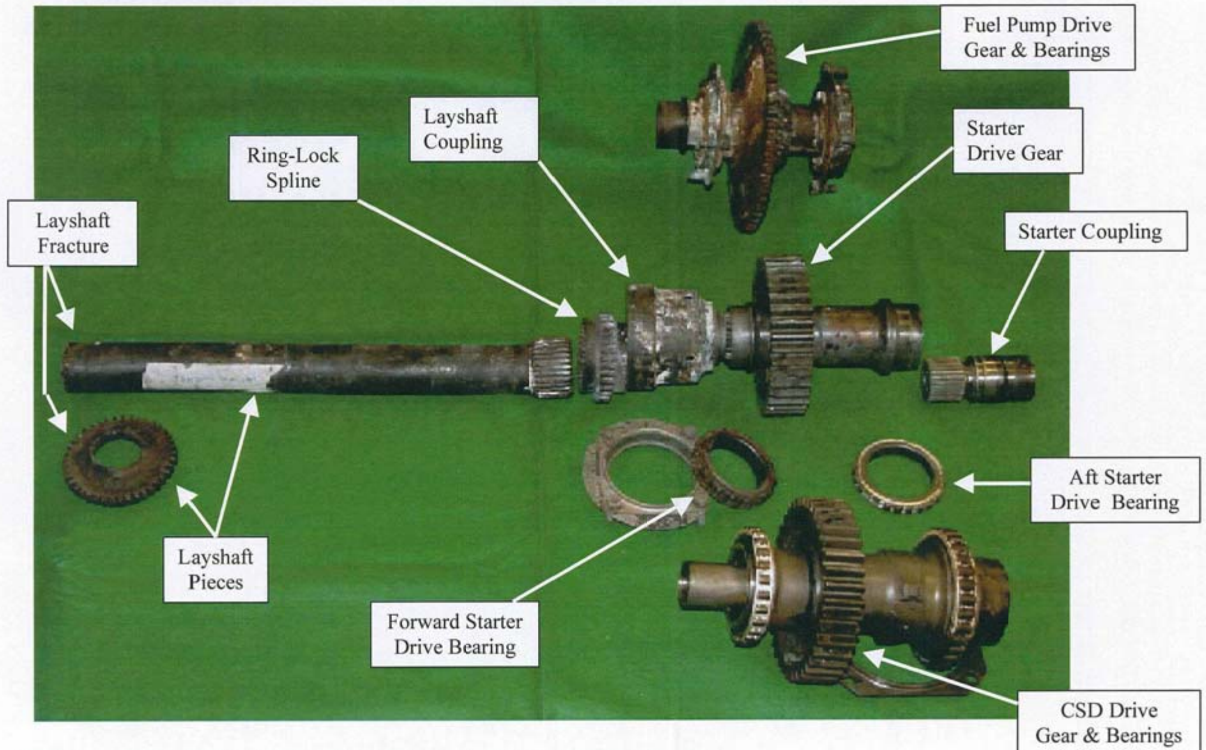
Figure 2: - Left Side Gearbox Fragment
Showing the condition of the left gearbox fragment. Note that the deoiler gearshaft and main oil pump were not recovered. The visual examination found fire damage was more prevalent naer the top, while cracking was more prevalent near the bottom.



<u>Figure 3:</u> - Right Side Gearbox Fragment
Showing the condition of the right side gearbox fragment. The visual examination found fire damage was more prevalent near the top, while cracking was more prevalent near the bottom. Note how steel components, gears & bolts, etc, were not melted.

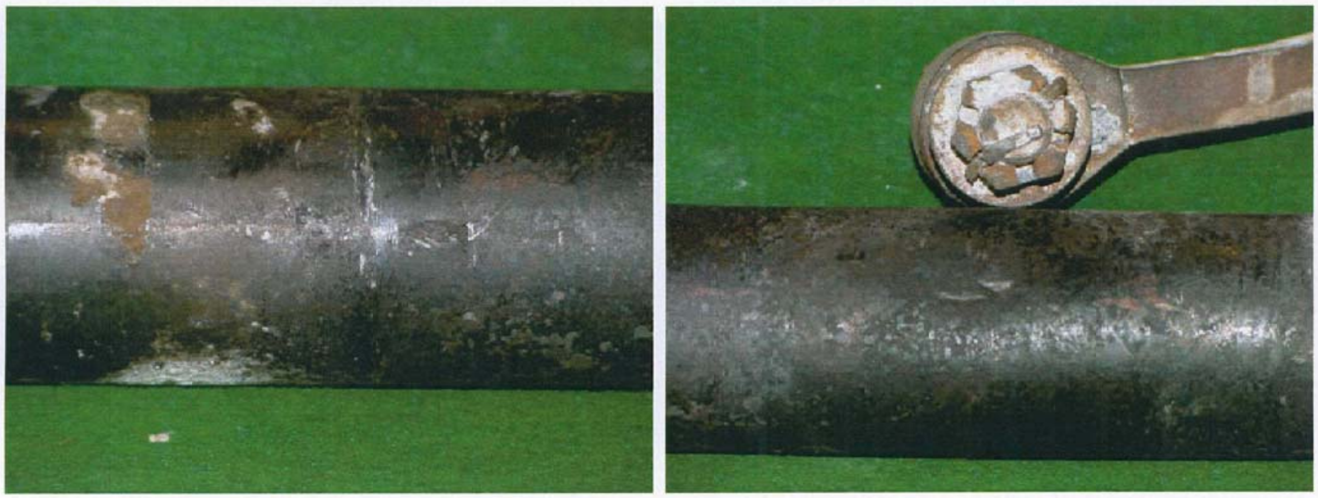


<u>Figure 4 :</u> - Right Side Gearbox Fragment
Showing additional views of the different types of damage visible along the right side gearbox housing fragment.



<u>Figure 5 :</u> - Gearshafts and Related Hardware recovered from Gearbox
Showing the layshaft, starter drive gear, CSD drive gear, fuel pump drive gear and associated couplings and bearings, after these components had undergone the cleaning treatment to remove deposits from the fire.

Figure 6 : - Layshaft and Ring-Lock Spline
Showing spline impressions on the layshaft indicating it had come out of mesh with the Ring-Lock Spline.



<u>Figure 7 :</u> - Layshaft and Layshaft Housing Support Link
Showing circumferential scoring damage along the layshaft (left) and (right) one of several indentations in the layshaft OD that was similar to the castellated nut on the nearby support link.

Figure 8 – Ring-Lock Spline
Showing the condition of the ring lock spline, which was deformed uniformly around its circumference (shown at right compared to a new spline).

Figure 9 : - Starter Drive Gear
Showing the condition of the gear during engine teardown (left) and (right) after disassembly.

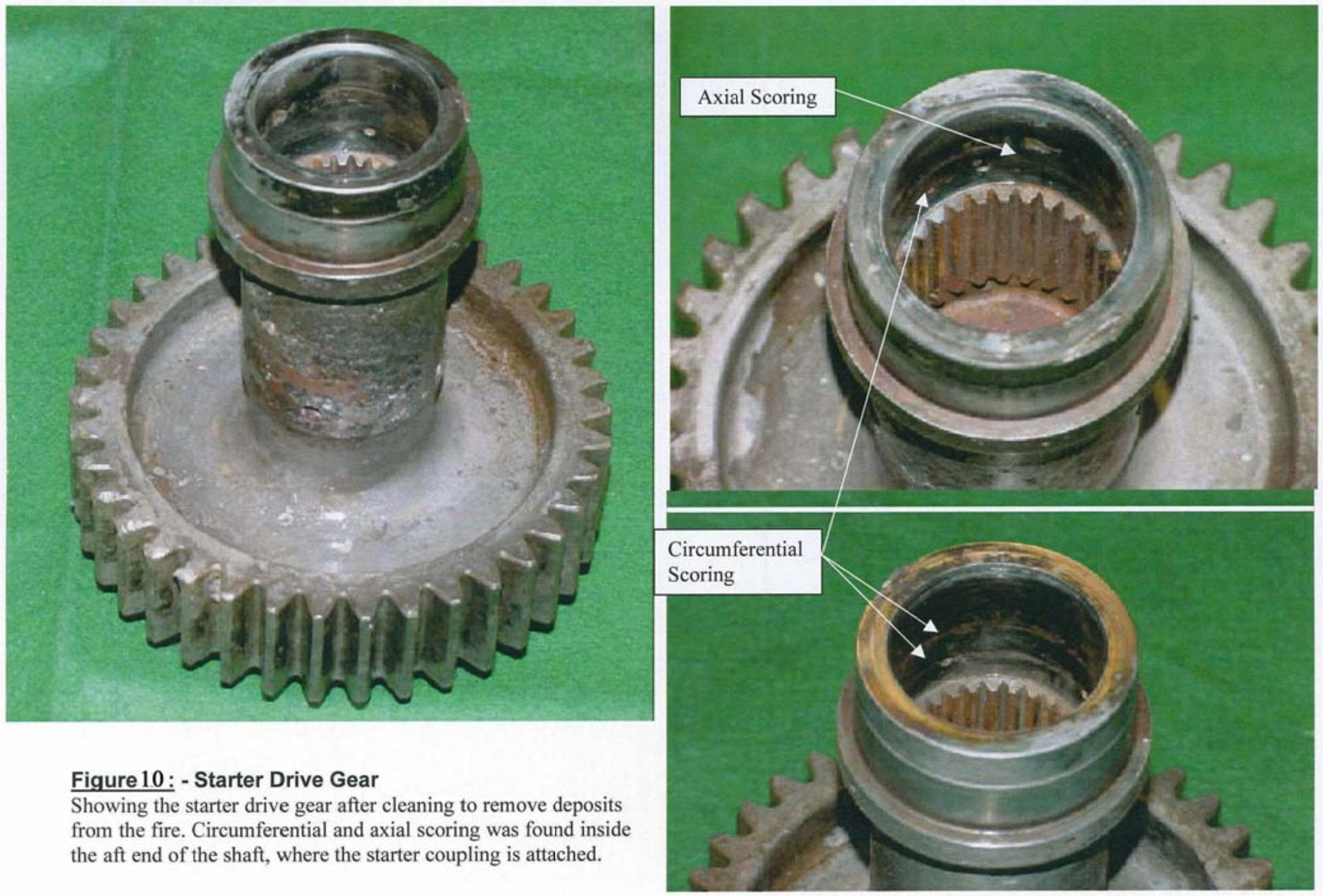
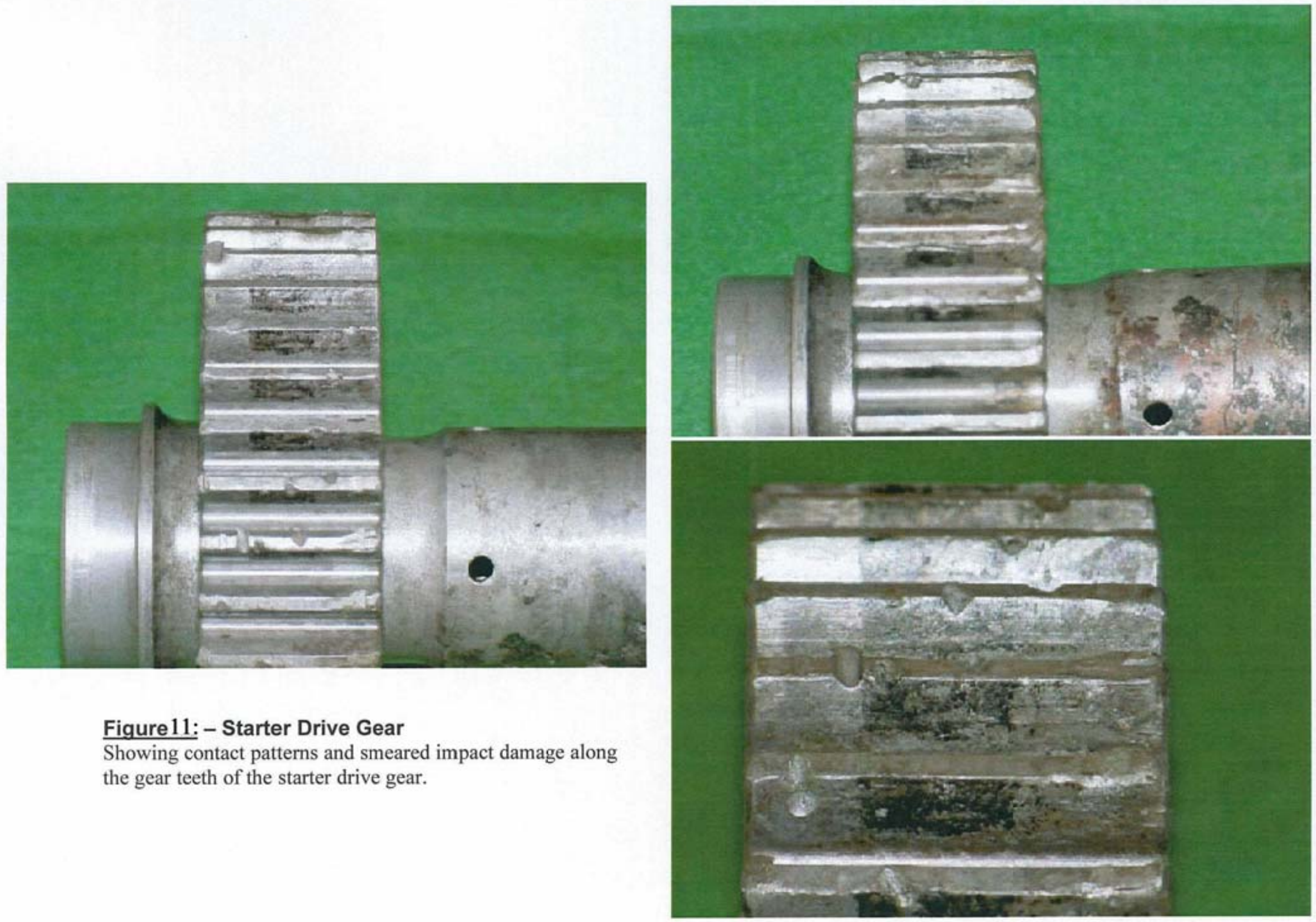


Figure 10 : - Starter Drive Gear
Showing the starter drive gear after cleaning to remove deposits from the fire. Circumferential and axial scoring was found inside the aft end of the shaft, where the starter coupling is attached.



<u>Figure 11:</u> – Starter Drive Gear
Showing contact patterns and smeared impact damage along the gear teeth of the starter drive gear.

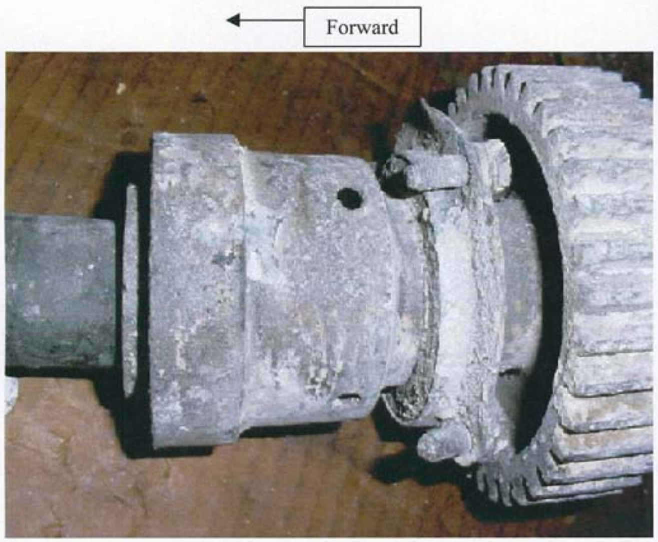
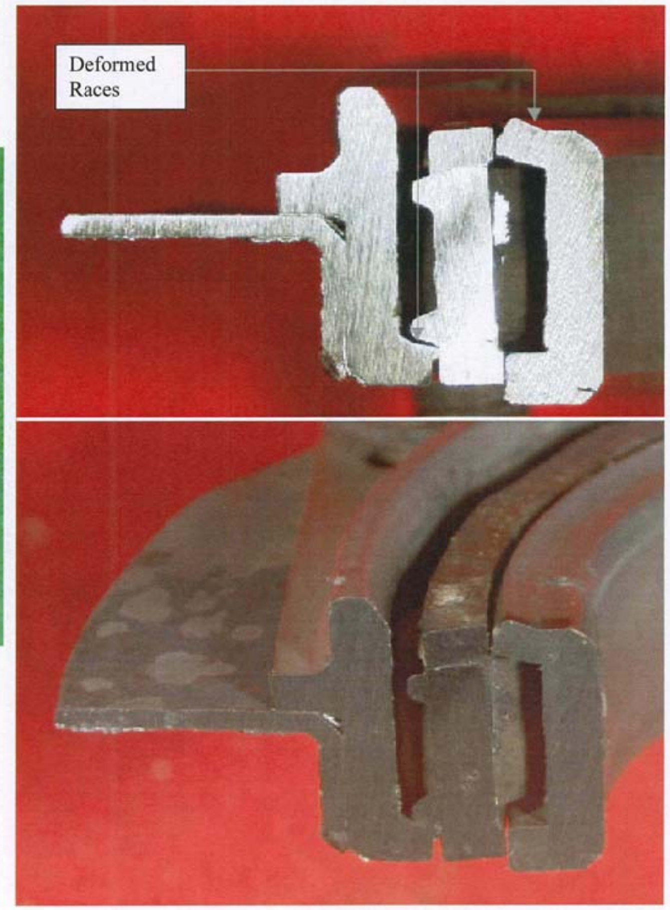


Figure 12 : - Forward Starter Drive Bearing
Showing the condition of the bearing during engine teardown. Note the cage is deformed at each roller.



<u>Figure 13</u> – Forward Starter Drive Bearing
Showing the condition of the bearing after cleaning.
Note the deformed areas of the inner and outer races.

Figure 14: - Rear Starter Drive Bearing
Showing the condition of the bearing, which exhibited heavy impact damage.

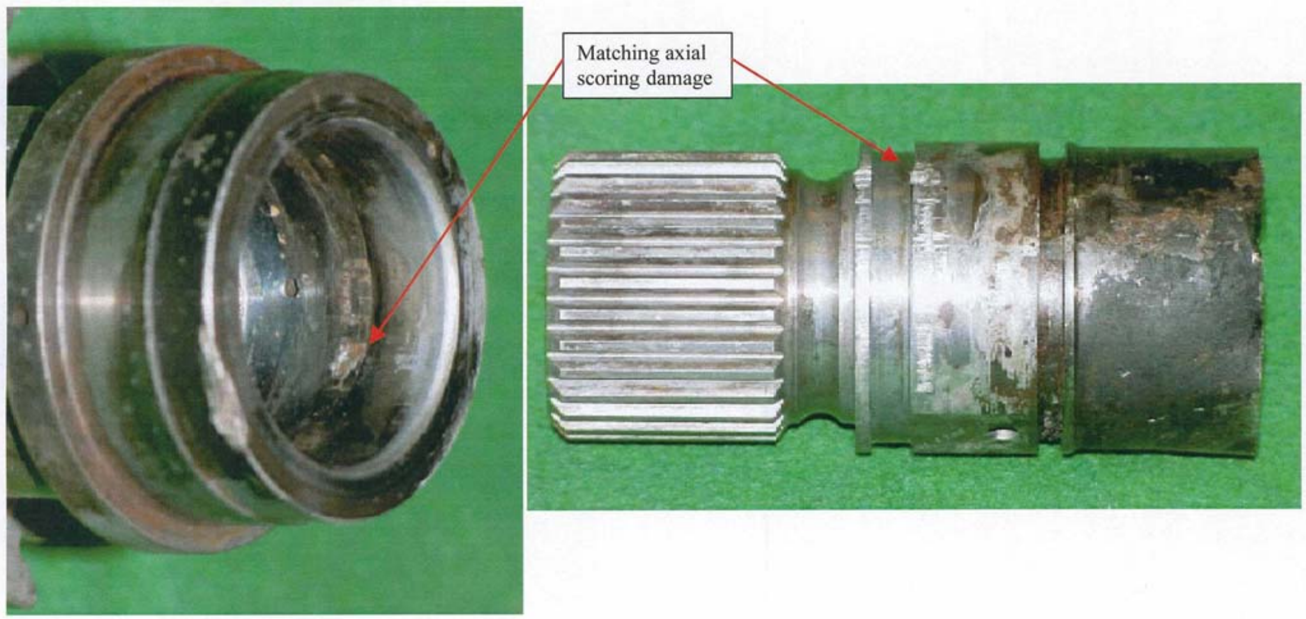


Figure 15 : - Starter Coupling
Showing matching areas of axial scoring damage on the starter coupling as well as inside the starter drive gear. This damage suggested the coupling was not fully seated inside the starter drive gear. See also Figure 21.

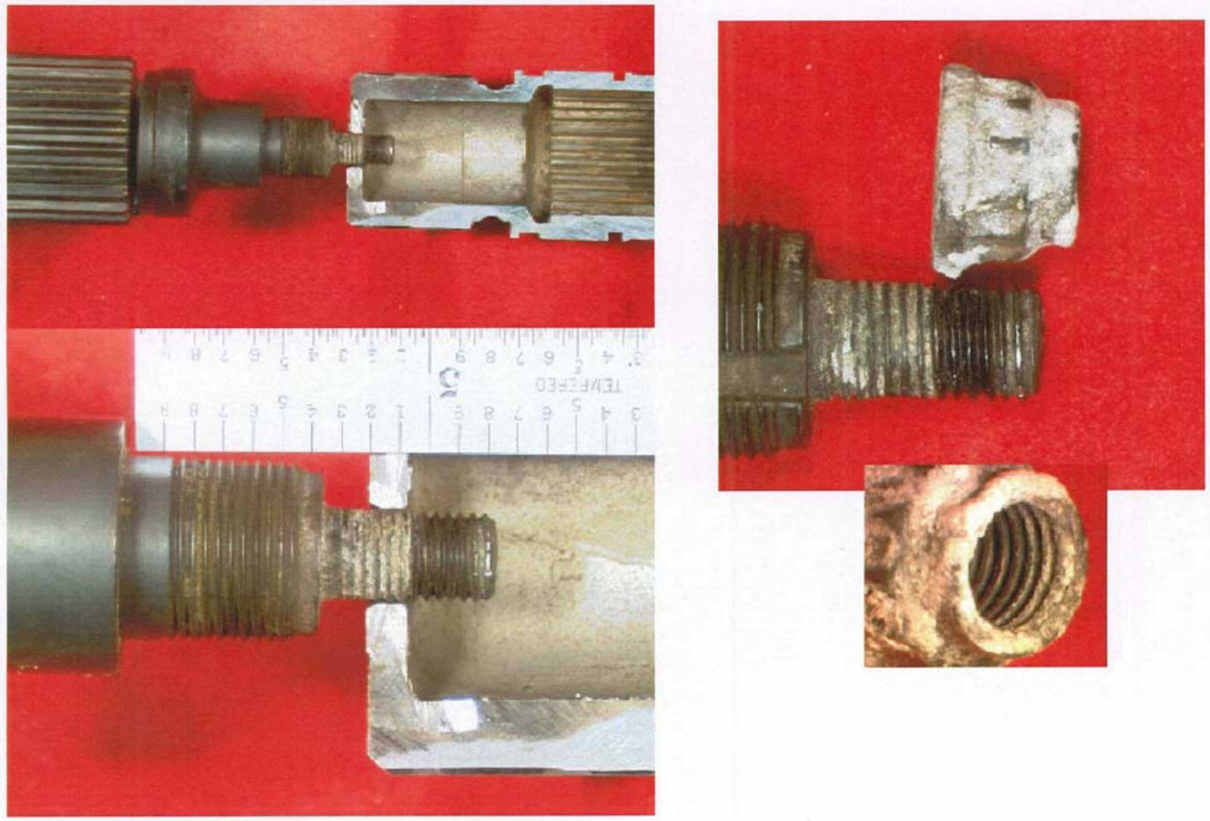


Figure 16: - Starter Coupling
Showing deposits along the threaded end of the layshaft coupling, which suggested the starter coupling was not fully seated inside the starter drive gear and was too far aft by more than 0.1".

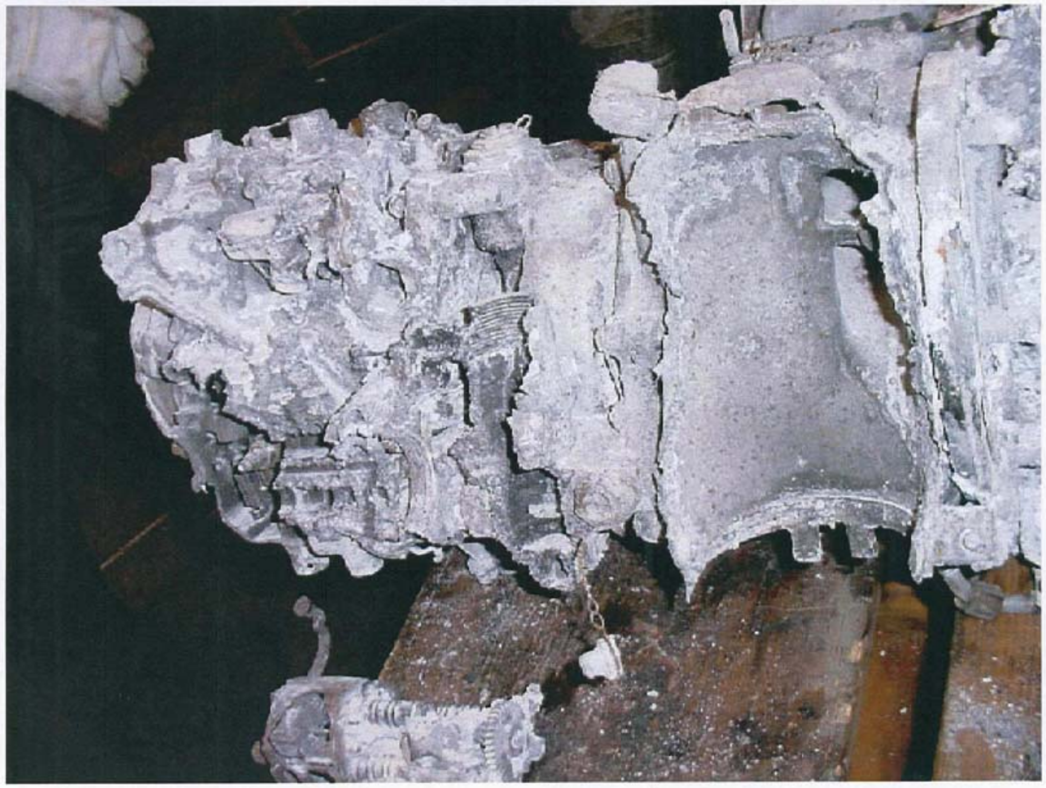
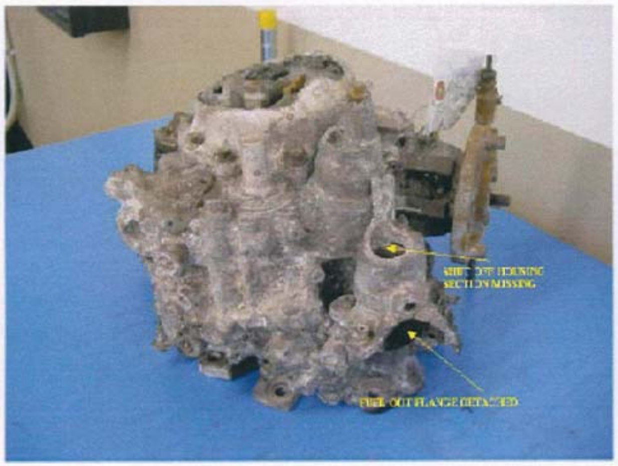


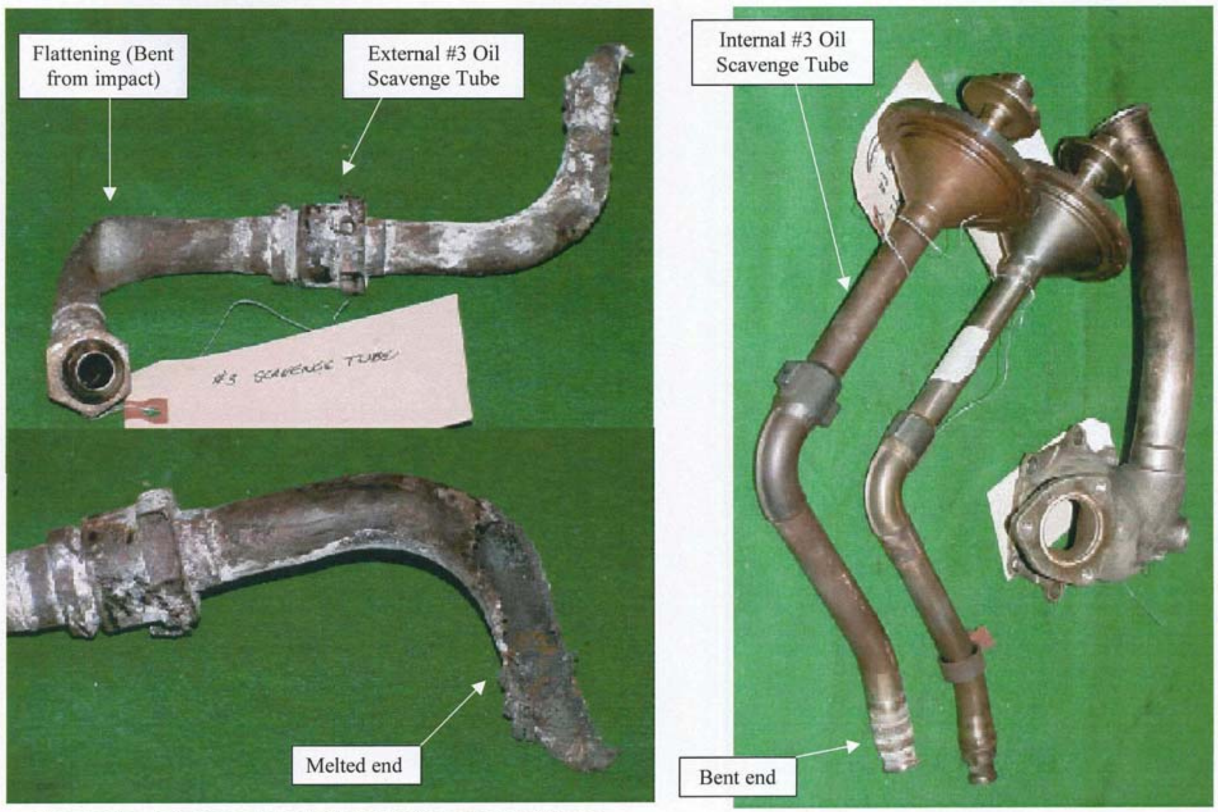
Figure17 : - Fuel Control and Fuel Pump
Showing the condition of these units at engine teardown. These housings exhibited numerous areas of localized melting, which had resulted in the severe distress to these units.



NWA GEARBOX FIRE INCIDENT
JFC68-3 SHOWING SHUT OFF VALVE HOUSING FUEL CUT FLANGE MISSING

NWA GEARBOX FIRE INCIDENT
JFC68-3 SHOWING MAIN COVER DOME MISSING

<u>Figure 18:</u> - Fuel Control at Hamilton Sundstrand



<u>Figure19:</u> - Internal and external #3 Oil scavenge tubes
Showing distortion due to impact along both the internal and external #3 scavenge tubes. The external tube was also partially melted away.