I ANALYSIS

1.0 Accident Synopsis

1.1 The subject engine was removed from an Agusta A119 Aircraft Registration No.N403CF following an aircraft mishap.

1.2 It was reported that the aircraft was found substantially damaged when it impacted terrain while approaching to land to a remote landing zone (LZ) approximately 8 miles northeast of Mancos, Colorado. The pilot, nurse, and paramedic were fatally injured.

1.3 As reported by the NTSB: "The flight originated from Durango, Colorado, at 12:42 where visual meteorological conditions prevailed. A company VFR flight plan was filed and activated for the local medical flight. The aircraft was dispatched in search for a drowning victim in the Animas River near Farmington, New Mexico and eventually located. While the aircraft was returning to Durango, it was diverted to the Red Arrow Mines area near Mancos to medivac an injured logger."

1.4 As reported by the NTSB: "According to a volunteer fireman, the aircraft made a low pass to assess the LZ, and then circled around to make his landing approach. The fireman advised the pilot that the winds were calm and he acknowledged. On approach, the aircraft was noted to be above tree level and suddenly dropped straight down. The fireman did not see the aircraft impact the terrain but reported no unusual engine sounds. The on-scene examination disclosed a ground scar, aligned on an easterly heading, containing slash marks and a separated left skid. The aircraft was at the end and next to the ground scar, and was aligned on a northerly heading. All four (4) rotor-blades were attached to the hub. There were no contact marks to the hydraulic actuators. The swash and pitch link rods were all intact and attached. The tail boom was severed just aft of the engine and was to the right of the aircraft. The tail rotor was separated at the gearbox."

2.0 Summary of Findings and Analysis

2.1 The engine externals examination revealed no signs of fire damage. The externals displayed impact damage predominantly on the lower portion of the engine. All major engine structural casings displayed no impact deformation.

2.2 The externals examination revealed an opening (gap) at the lower section of the fuel control unit (FCU) flow and drive body mating flanges with disengagement of the bottom left side retention-bolt (identified in this report as bolt and location No. 3). The bolt installed at location No. 3 was shorter than specified for that location and thread engagement within the flow body was approximately 2 full threads The fuel bypass passage (Po) preformed packing was partially extruded at the flange opening. The FCU power lever quadrant protractor needle and manual override linkage shield were impact damaged.

The FCU drive body flange mating with the flow body was found to have an irregular surface flatness. The drive body boltholes had markings matching the bolt thread spacing. Raised material was observed in boltholes No. 3 and No. 4. Furthermore, the raised material was flattened and rubbed in bolthole No. 3. The rubbing marks and flattening in bolthole No. 3 was consistent with relative movement between the drive body and the bolt.

The No. 3 flow body bolthole fractured threads showed three types of surface features. Some areas were consistent with a shear fracture surface resulting from a force pulling on the bolt (either from over-torque or excessive axial stress) and other areas exhibited features consistent with rubbing. The rubbing occurred after the shearing and is a consequence of the fracture. Consequently, the markings observed are consistent with a two step mechanism: the first step is the fracturing of the threads by shear, the second step is rubbing damage consistent with a movement of the drive body relative to the flow body.

A third area exhibiting a different mode of fracture had contaminants on its fracture surface. The absence of such contaminants on the adjacent rubbed area is indicative that this portion of fracture surface was pre-existing. This contaminated surface exhibited a topography showing evidence of striations consistent with a fatigue mechanism. A portion of the shear overload fracture initiated from this portion of the fracture surface.

Additionally, the fractured threads revealed evidence of deformation not consistent with a shear fracture along the root of the fractured thread. This deformation and its orientation are consistent with a contact along this edge after the fracture. Furthermore, evidence of a partial shearing of the threads occurring during a prior event was also observed.

2.3 Review of the EEC fault codes and cockpit switches confirmed that the engine was operating in electronic mode (EEC Mode) at the time of impact. Therefore the Mechanical Power Turbine Governor (MPTG) governing anomaly observed during bench testing would not have affected engine operation since the MPTG is used for the mechanical governing back-up mode (MEC mode).

3.0 Conclusions

3.1 There were no engine anomalies that would have prevented the engine from producing power prior to impact.

3.2 Based on the information available and the analysis conducted, it could not be established when the stripping of the flow body threads and the opening of the flanges between the FCU flow and drive FCU bodies occurred.

II FACTUAL INFORMATION

1.0 INVESTIGATION PARTICIPANTS

1.1 The engine investigation was performed on August 30, 2005 at the Pratt & Whitney Canada (P&WC) facilities. The individuals who participated in all or part of the Engine Investigation at P&WC as representatives of their respective organizations are as follows:

Paul Fréchette - Transport Safety Board of Canada (TSBC)
Luigi Candiani - Agusta, Accident/Incident Investigation Manager
Paolo Ferreri - Agusta, Product Support
Jim Stothers - P&WC Turboshaft Customer Support Manager
Laurent Azancot - P&WC Turboshaft Customer Support
David Barnard - P&WC Accessory Components Investigation
Marc Hemmings - P&WC Service Investigation

1.2 The Fuel Control Unit (FCU) S/N C68008 and the Mechanical Power Turbine Governor (MPTG) S/N C74004 investigations were performed on August 31, 2005 at the Honeywell Montreal (MTL) Facility. The individuals who participated in all or part of the Accessories Component Investigation at the Honeywell MTL Facility as representatives of their respective organizations are as follows:

Paul Fréchette - TSBC
Luigi Candiani - Agusta, Accident/Incident Investigation Manager
Paolo Ferreri - Agusta, Product Support
Ken Miller – Honeywell South Bend (SB), Engine Systems & Accessories Controls Engineering
Hytham Mokhtar – Honeywell MTL, Engine Systems & Accessories Controls Engineering
Sylvie Robin – Honeywell MTL, Engine Systems & Accessories Controls Quality Manager
David Barnard - P&WC Accessory Components Investigation
Marc Hemmings - P&WC Service Investigation

1.3 Further evaluation of the FCU S/N C68008 was performed on September 7 to 9, 2005 at the Honeywell SB Facility. The individuals who participated in all or part the Accessories Component Investigation at the Honeywell SB Facility as representatives of their respective organizations are as follows:

Ken Miller – Honeywell SB, Engine Systems & Accessories Controls Engineering
Alison Dekoschak – Honeywell SB, Engine Systems & Accessories Controls Engineering
Randy Griffith – Honeywell SB, Metallurgist Manager
Michael A. Swartz - Honeywell SB, Systems & Accessories Customer Service Engineering
Lee G. Fisher – Honeywell SB, Engines, Systems & Services, Product Integrity
Claude Lincourt - P&WC Mechanical & Electrical Clinic
Marc Hemmings - P&WC Service Investigation

Photo no. 9	Bottom LH view (intake area) shows the impact damage to the central fireseal with the P3 pneumatic and main oil pressure lines.
Photo no. 10	Bottom LH view (gas generator case side) shows the impact damage to the central fireseal with the P3 pneumatic and main oil pressure lines Bottom LH view (gas generator case side) shows the impact damage to the central fireseal with the P3 pneumatic and main oil pressure lines
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Photo no.12	Bottom LH view shows the damage to the rear fireseal, and the aircraft main rotor coupling (A) still attached on the RGB output coupling/clutch gearshaft.
Photo no. 13	Engine bottom view shows impact damage.
Photo no. 14	Engine LH front view shows the aircraft FCU PLA RVDT (arrow), as received
Photo no. 15	FCU RH view - The circle indicates the area of the opening of the mating flange of the drive/flow bodies (see photo no. 16 below for close-up).
Photo no. 16	The circle shows the opening at the mating flange of the FCU drive/flow bodies.
Photo no. 17	FCU LH view - The circle indicates the opening area with the extruded Po packing and the bottom left flange retention bolt No. 3 disengaged (see photo no. 18 below for close-up).
Photo no. 18	The large circle shows the opened mating flange of the drive/flow bodies with the extruded Po fuel packing. Arrow points to the disengaged bolt No. 3. The small circle shows the fractured flow body threads coiled on the bolt threads.
Photo no. 19	FCU bottom view - The circle shows the opened mating flange of the drive/flow bodies. The arrows point to the Py & Px air passages. See photo no. 20 below.
Photo no. 20	After removal & alternate bottom view shows the opened (circle) mating flange of the FCU bodies. The FCU Teflon drive coupling was intact.
Photo no. 21	Close up LH view of the opening & the extruded Po packing of the mating flange of the drive/flow bodies. Arrows point to the disengaged bottom left retention bolt No. 3.
Photo no. 22	FCU back view shows the drive body pad and the drive shaft teflon coupling. Arrows point to the retention bolts of the drive body to the flow body. The circle shows the extruded Po packing. A blue stain (blue arrow) noted on the drive bearing cover. Bolt No. 3 (bottom left): disengaged short bolt not in specified location Bolt No. 2 (top right): long bolt not installed in specified location Bolts No. 1 (top left) & No. 4 (bottom right): short bolts installed in proper locations

Photo no. 23	Arrow points to the bent FCU PLA protractor needle and the circle area indicates the indent on the sheet metal cover of the manual override linkage.
Photo no. 24	Engine top view at the exhaust case area shows the dented pneumatic line (arrow).
Photo no. 25	A blue stained residue (arrow) noted in the vicinity of the drive cavity of the fuel pump drive pad.
Photo no. 26	Removal of the MEC from the drive pad of the RGB shows an intact Teflon drive coupling
Photo no. 27	View of the P3 filter & the inside of the filter bowl being dry and clean
Photo no. 28	View of the assembly of the AGB housing/gears/bearings
Photo no. 29	View of the assembly of the AGB diaphragm/gears/bearings
Photo no. 30	Downstream view of the intact CT disc assembly and combustion liner
Photo no. 31	Trailing edge view of several CT blades shows no evidence of tip rubs
Photo no. 32	Leading edge view of the CT disc assembly
Photo no. 33	General view of the intact components of the compressor assembly
Photo no. 34	1st stage compressor stator shows no evidence of rubbing damage to the shroud.
Photo no. 35	Leading edge view of the intact 1st stage compressor rotor
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Photo no. 37	View of the compressor impeller with its shroud housing shows no evidence of rubbing damage.
Photo no. 38	View of the compressor rotor spacers shows no impact and rubbing damage to their OD's. Note that the wetness seen on the spacers (O.D) was introduced during the disassembly handling.
Photo no. 39	View of the compressor rotor air seals shows no impact rubbing damage to the OD's.
Photo no. 40	Leading edge view of the intact PT stator assembly
Photo no. 41	PS module LH view of the intact PT stator & housing, the T5 harness & the TED
Photo no. 42	PS module RH view of the intact PT stator & housing, the T5 harness & the TED
Photo no. 43	View of the intact PT disc assembly
Photo no. 44	View of the PT blade shrouded tips show light rubs.
Photo no. 45	View of the PT shroud shows the rubbed seal knives between the arrows.
Photo no. 46	Another section view of the PT shroud shows the light rubs to the seal knives referred in photo no. 43 above.
Photo no. 47	A section view of the PT shroud shows the seal knives being intact.
Photo no. 48	RGB module shows the intact input-drive coupling shaft linking with the PS module. Arrow points to the RGB output drive.
Photo no. 49	Closer view of the intact output-drive coupling shaft

Photo no. 50	View of the intact RGB output shaft, sprag clutch & No. 14 duplex bearings
Photo no. 51	Closer view of the intact sprag clutch
Photo no. 52	Inside view of the idler gear shows the intact runner (arrow) for the sprag clutch & the intact No. 15 roller bearing.
Photo no. 53	View of the intact assembly of the idler and torquemeter gearshafts and roller bearings (#10 & #15)
Photo no. 54	RGB internal view shows the intact outer ring flange of the No. 9 roller bearing and the four bolted fragments of the No. 12 ball bearing outer ring (see photo no's 54 & 55 below).
Photo no. 55	View of the No. 12 ball bearing attached to the idler gearshaft, which shows all four (4) fractures of the flanged outer ring.
Photo no. 56	View of the four (4) fractured areas of the flanged No. 12 bearing outer ring
Photo no. 57	Detail view of the fracture surface of one of a fractured No. 12 bearing outer ring lug
Photo no. 58	Leak test of FCU S/N C68008 drive body S/N 0005 shows the spray of fuel due to fuel and air leaks at the mating flange of the drive and flow bodies.

8.0 Reference Listing

8.1 Honeywell Teardown & Testing Report of One model DP-F2 Part Number 3244896-9 Serial Number C68008

9.0 Appendix:

Appendix:	Description:
I	P&WC Accessories Incident Factual Notes Job 05009190
II	P&WC Mechanical & Electrical Clinic Evaluation
III	P&WC Materials Investigation Laboratory Evaluations
IV	PWC Chemical Laboratory, Tabulated Results of the Analyzed Samples

Photo no. 1
As received, engine S/N PU0006 container with a cardboard box attached above the container.

Photo no. 2
As received, various aircraft instruments

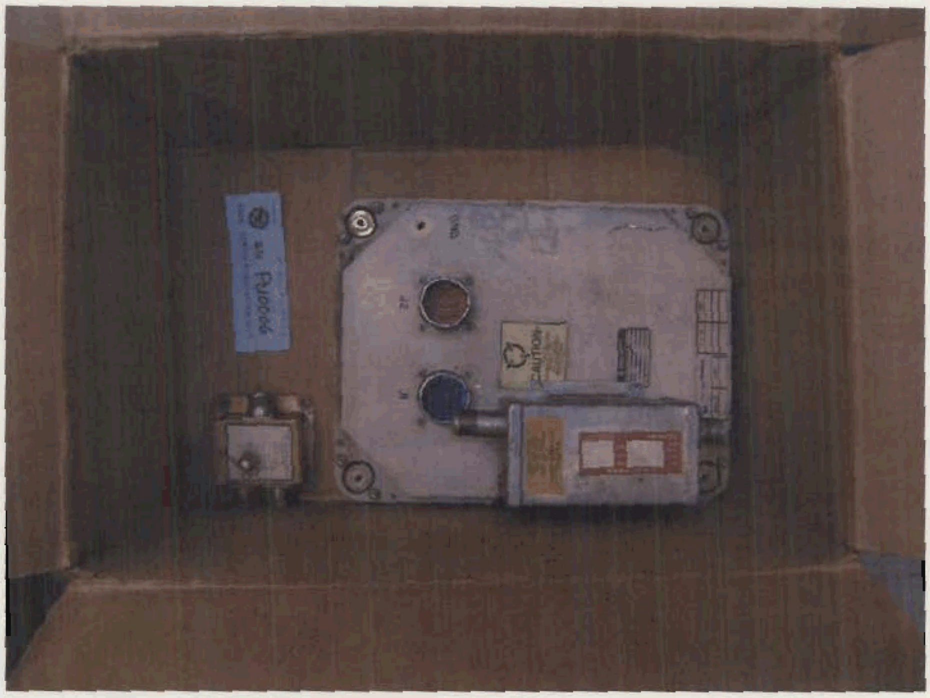

Photo no. 3
As received, trim compensator, EEC and igniter box

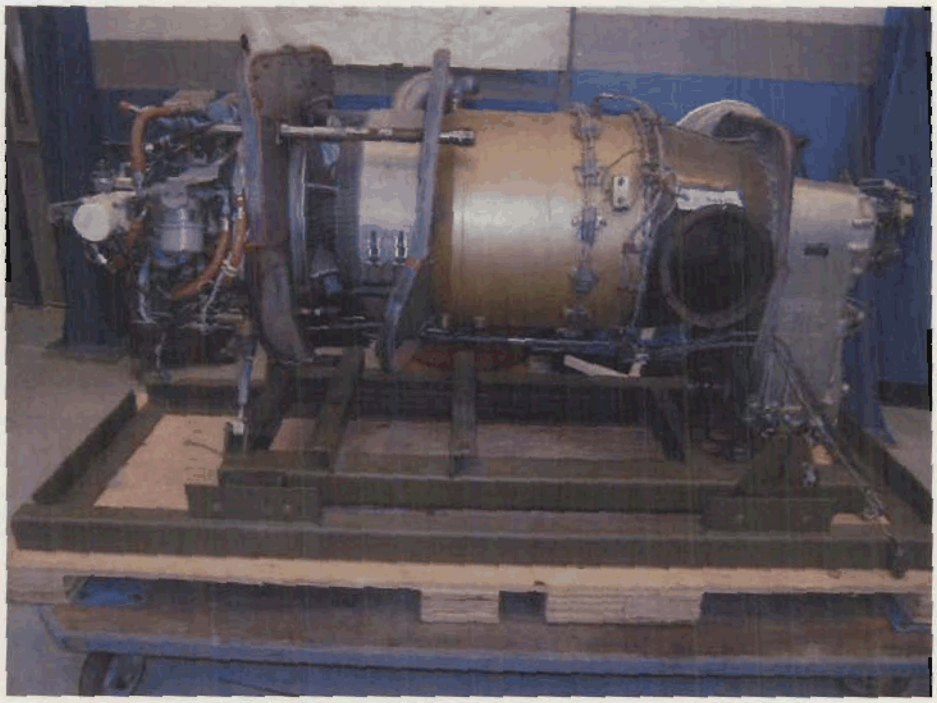

Photo no. 4
As received, the engine left hand (LH) view

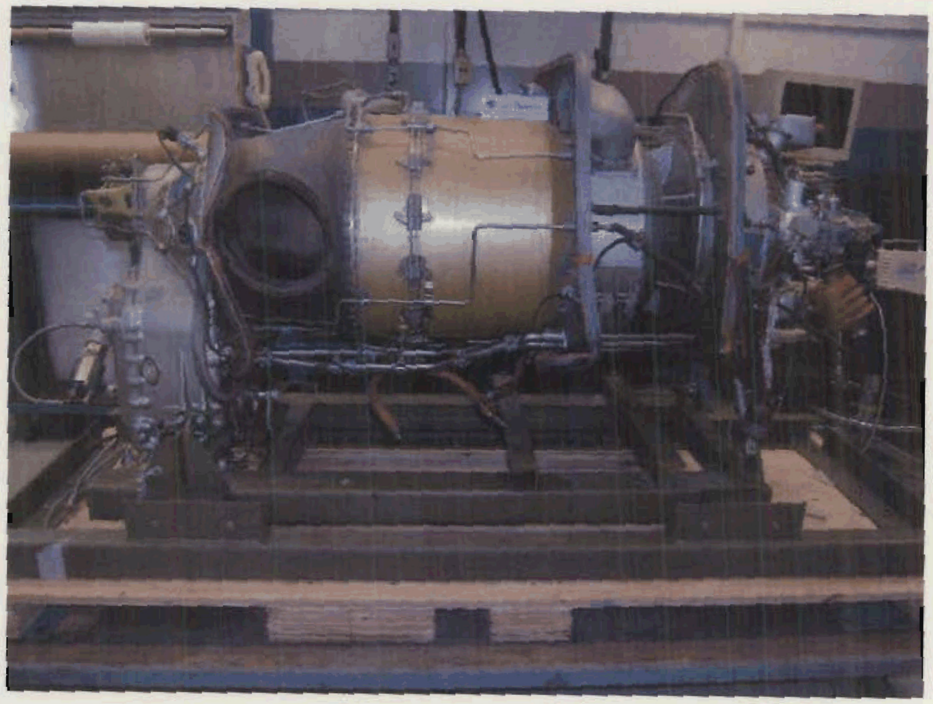

Photo no. 5
As received, the engine right hand (RH) view

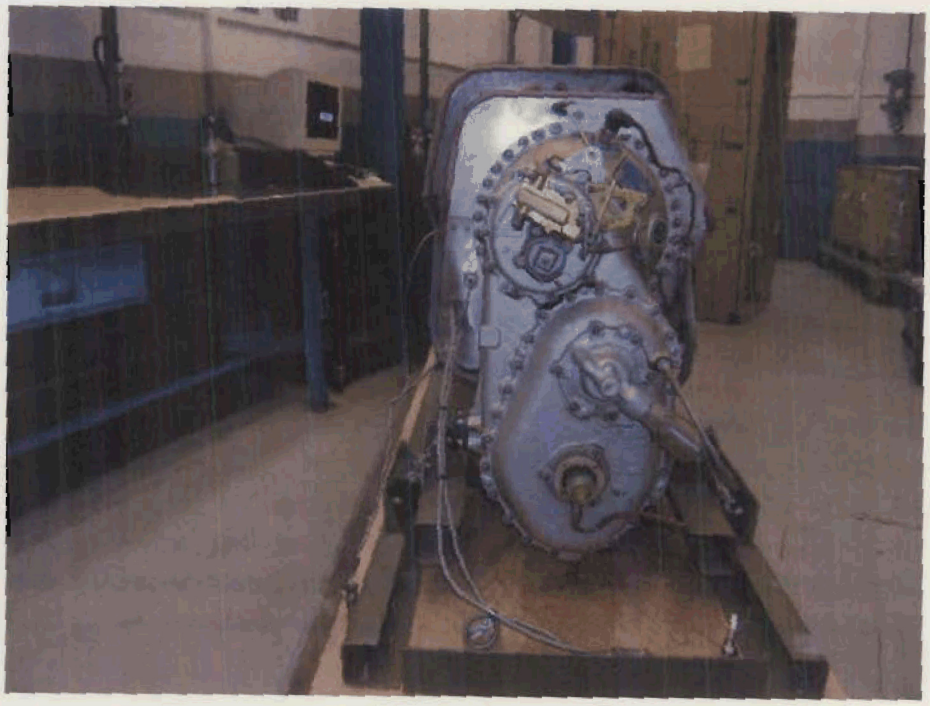

Photo no. 6
As received, the engine rear view (reduction gearbox side)

Photo no. 7
As received, the engine front view (accessory gearbox side)

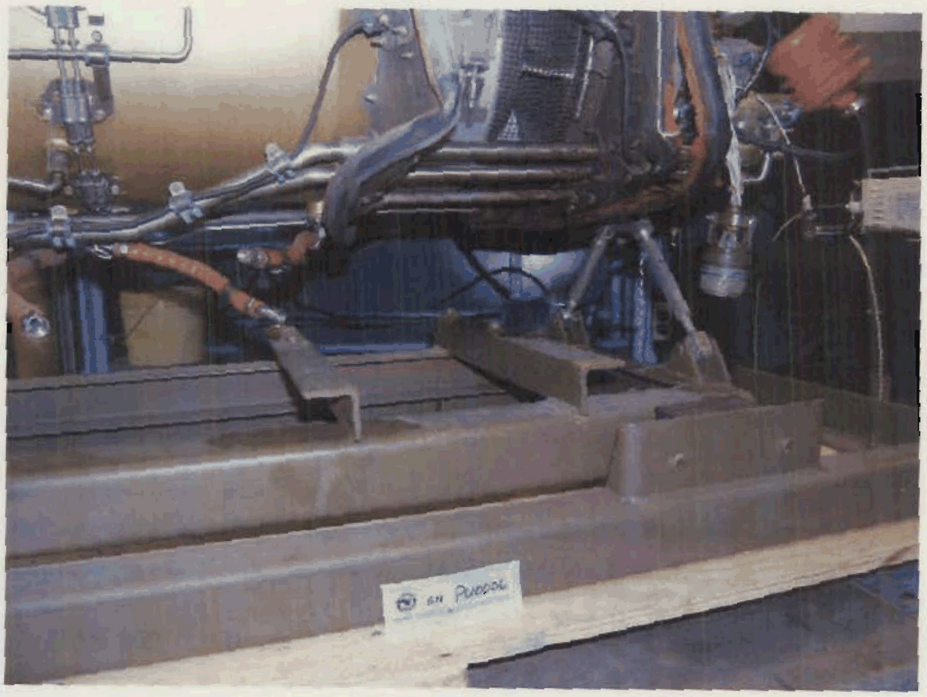

Photo no. 8
RH bottom view (intake area) showing the damage to the front & central fireseals and oil scavenge lines

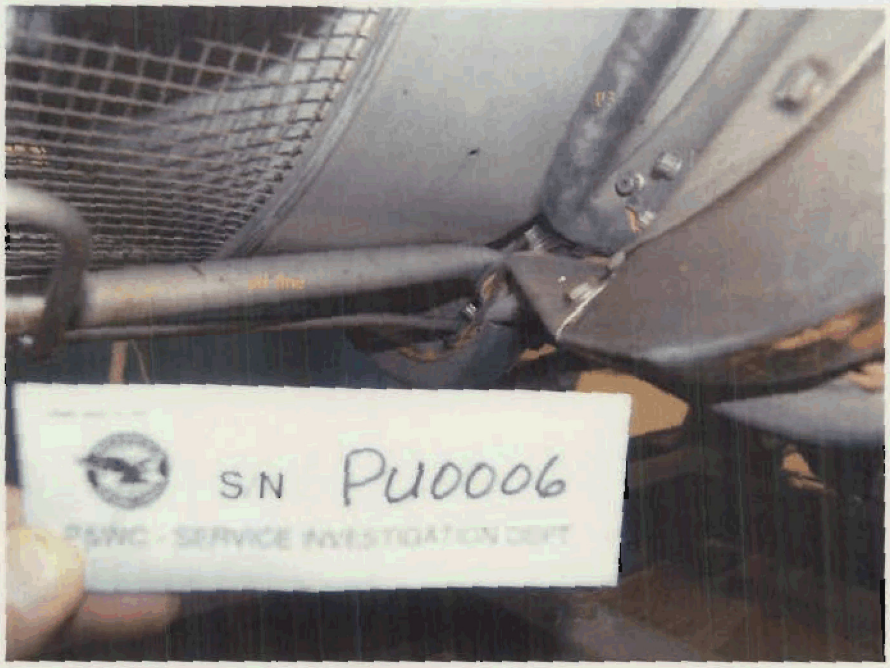

Photo no. 9
Bottom LH view (intake area) shows the impact damage to the central fireseal with the P3 pneumatic and main oil pressure lines.

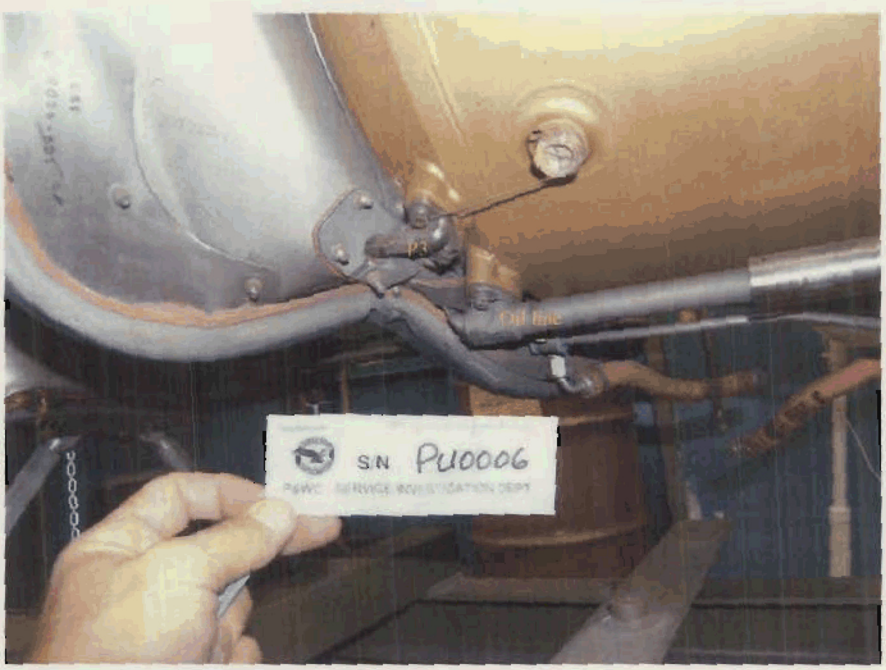

Photo no. 10
Bottom LH view (gas generator case side) shows the impact damage to the central fireseal with the P3 pneumatic and main oil pressure lines

Photo no. 11
Closer view of photo no. 10 shows the damage to the central fireseal with the main oil pressure line.

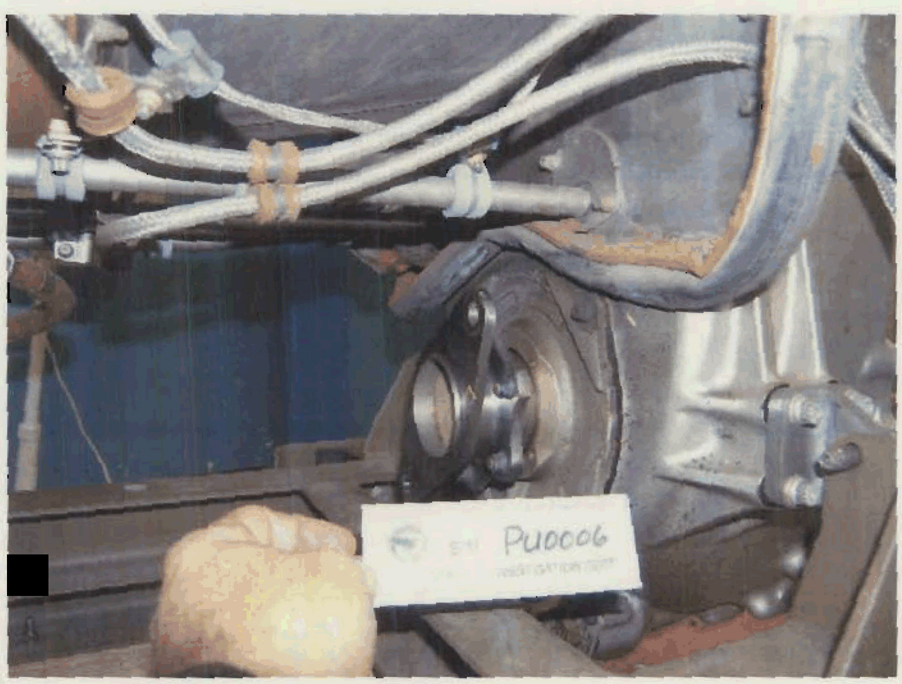

Photo no. 12
Bottom LH view shows the damage to the rear fireseal, and the aircraft main rotor coupling (A) still attached on the RGB output coupling/clutch gearshaft.

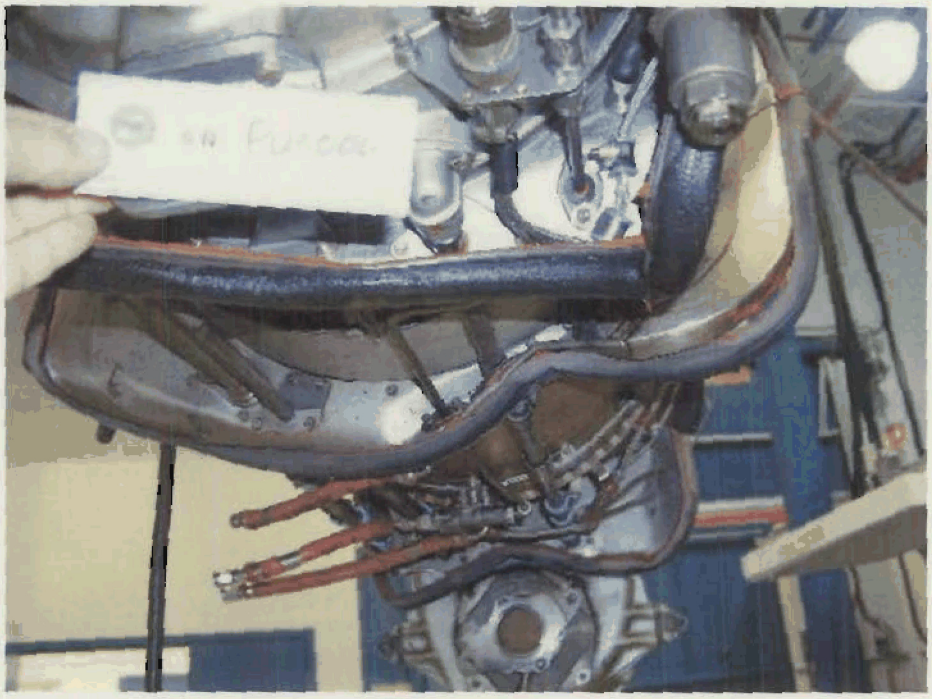

Photo no. 13
Engine bottom view shows the impact damage.

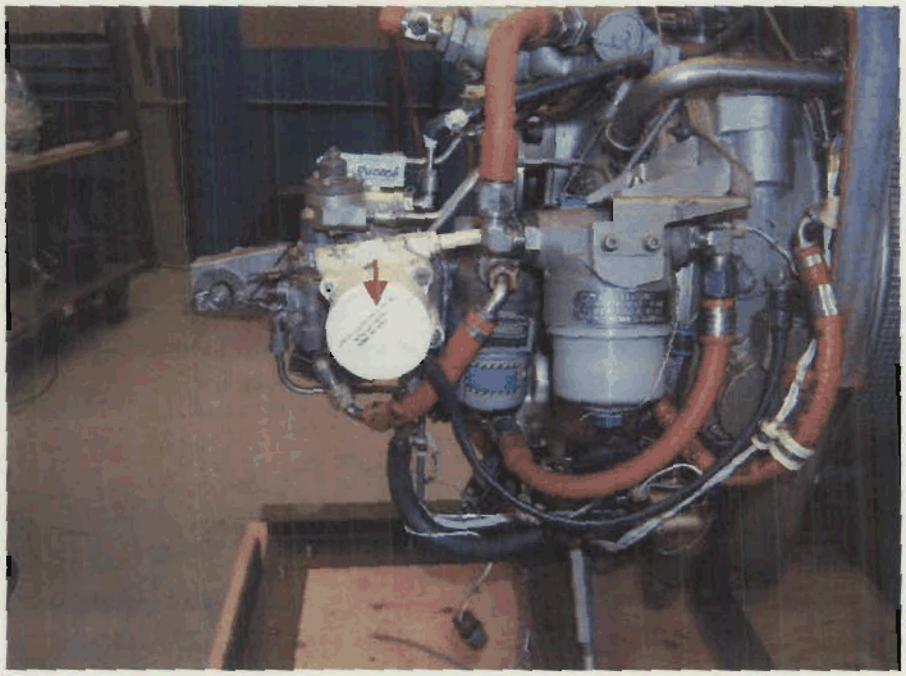

Photo no. 14
Engine LH front view shows the aircraft FCU PLA RVDT (arrow), as received

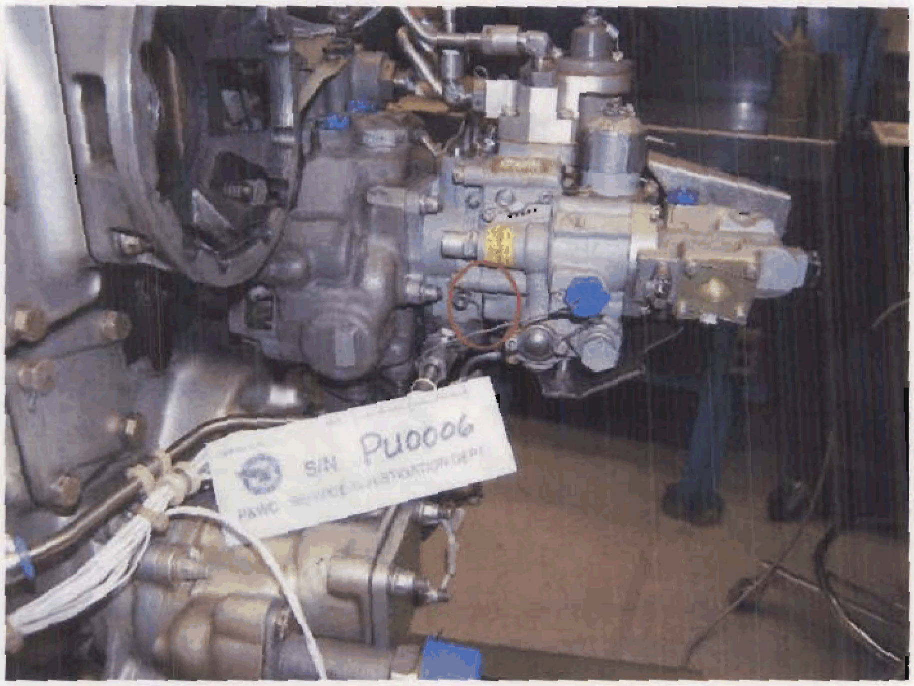

Photo no. 15
FCU RH view - The circle indicates the area of the opening of the mating flange of the drive/flow bodies (see photo no. 16 below for close-up).

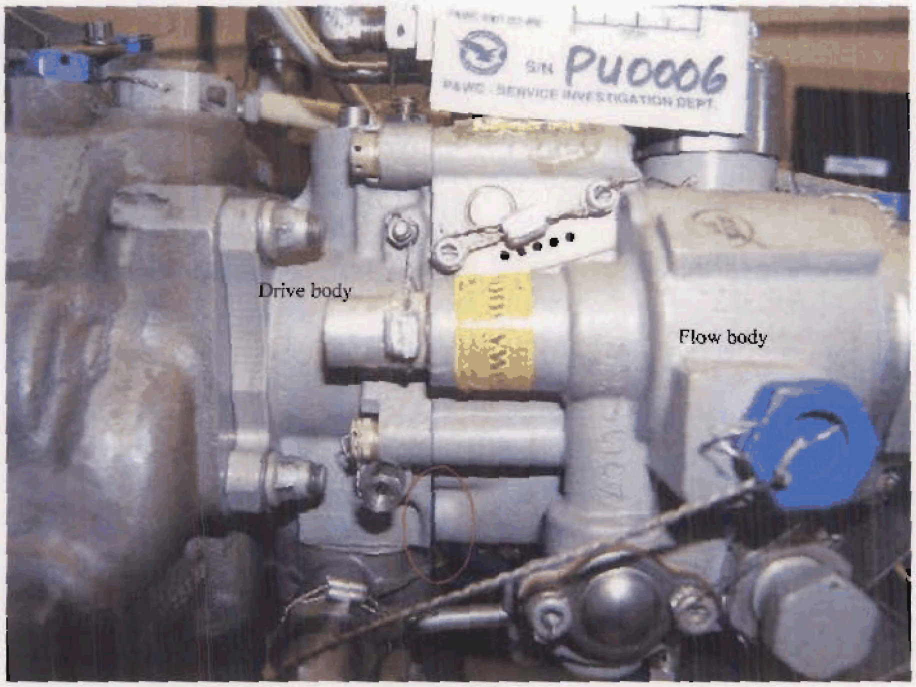

Photo no. 16
The circle shows the opening at the mating flange of the FCU drive/flow bodies.

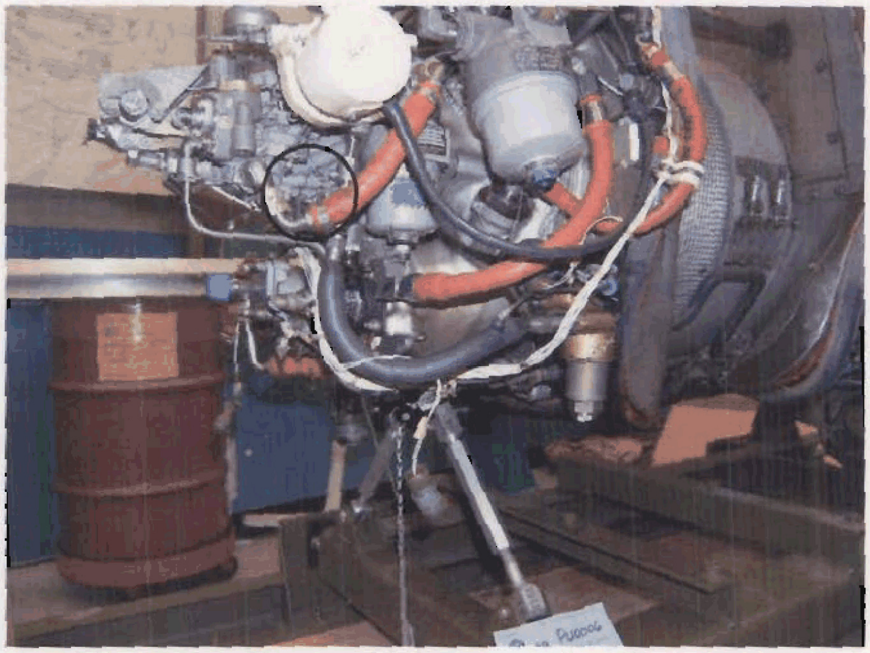

Photo no. 17
FCU LH view - The circle indicates the opening area with the extruded Po packing and the bottom left flange retention bolt No. 3 disengaged (see photo no. 18 below for close-up).

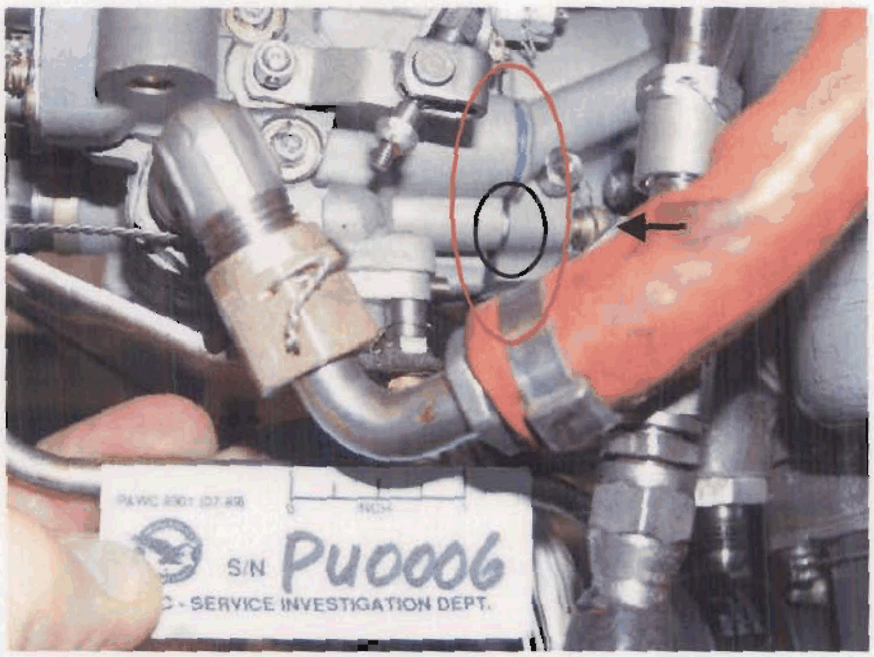

Photo no. 18
The large circle shows the opened mating flange of the drive/flow bodies with the extruded Po fuel packing. Arrow points to the disengaged bottom left bolt No. 3. The small circle shows the fractured flow body threads coiled on the bolt threads.

Photo no. 19
FCU bottom view - The circle shows the opened mating flange of the drive/flow bodies. The arrows point to the Py & Px air passages. See photo no. 20 below.

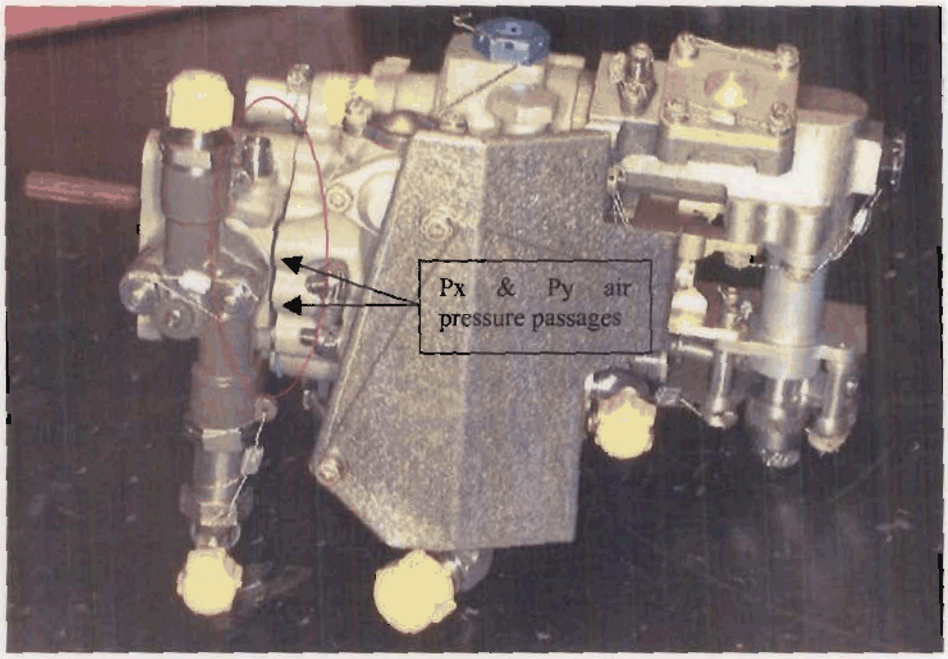

Photo no. 20
After removal & alternate bottom view shows the opened (circle) mating flange of the FCU bodies. The FCU Teflon drive coupling was intact.

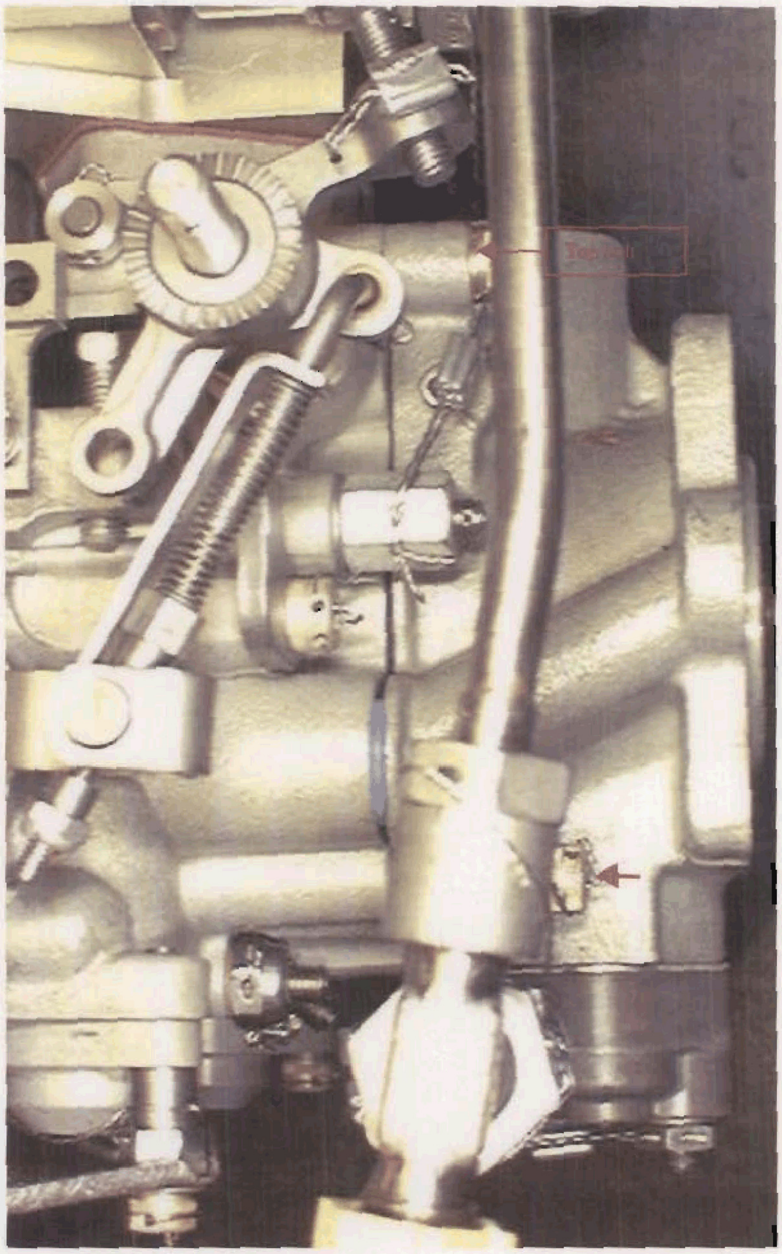

Photo no. 21
Close up LH view of the opening & the extruded Po packing of the mating flange of the drive/flow bodies. Arrows point to the disengaged bottom left retention bolt No. 3.

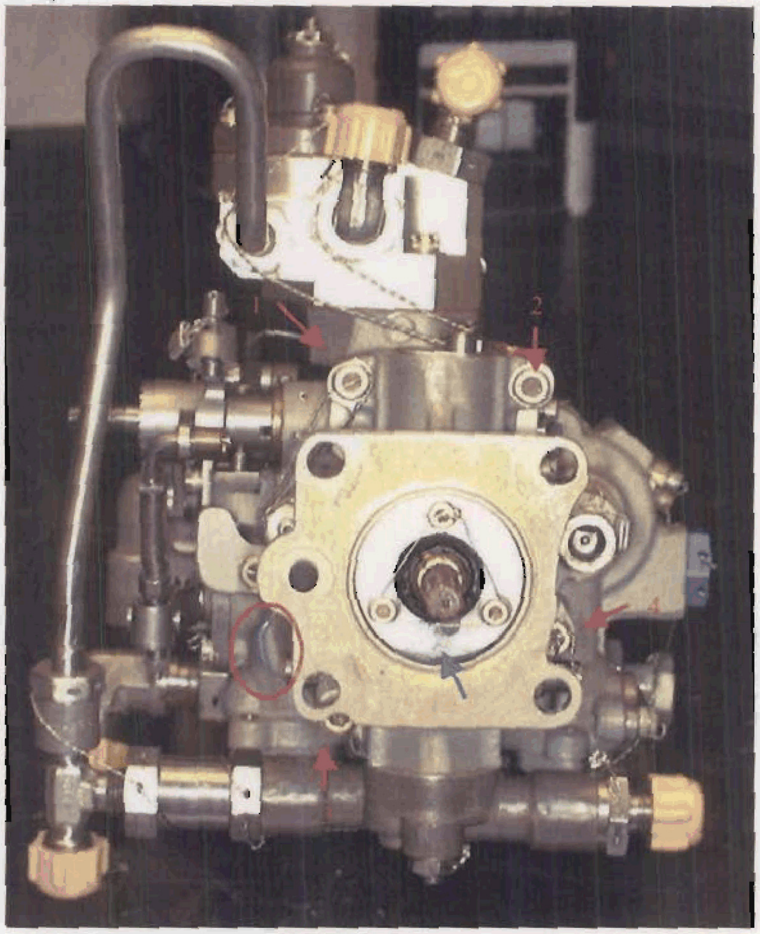

Photo no. 22
FCU back view shows the drive body pad and the drive shaft Teflon coupling. Arrows point to the retention bolts of the drive body to the flow body. The circle shows the extruded Po packing. A blue stain (blue arrow) noted on the drive bearing cover.
Bolt No. 3 (bottom left): disengaged short bolt not installed in specified location
Bolt No. 2 (top right): long bolt not installed in specified location
Bolts No. 1 (top left) & No. 4 (bottom right): short bolts installed in proper locations

Photo no. 23
Arrow points to the bent FCU PLA protractor needle and the circle area indicates the indent on the sheet metal cover of the manual override linkage.

Photo no. 24
Engine top view at the exhaust case area shows the dented pneumatic line (arrow).

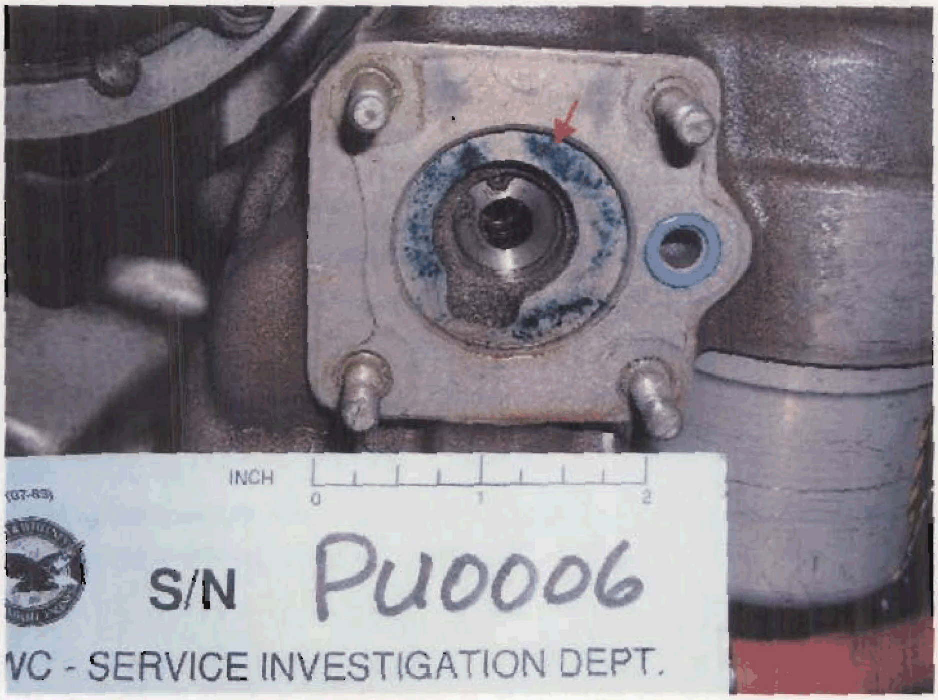

Photo no. 25
A blue stained residue (arrow) noted in the vicinity of the drive cavity of the fuel pump drive pad.

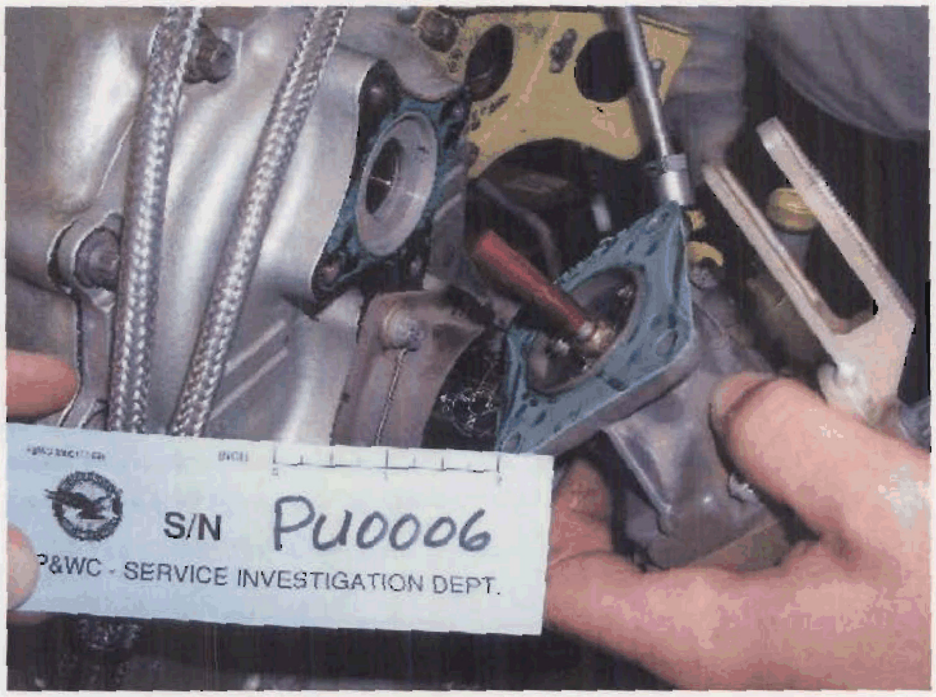

Photo no. 26
Removal of the MEC from the drive pad of the RGB shows an intact Teflon drive coupling.

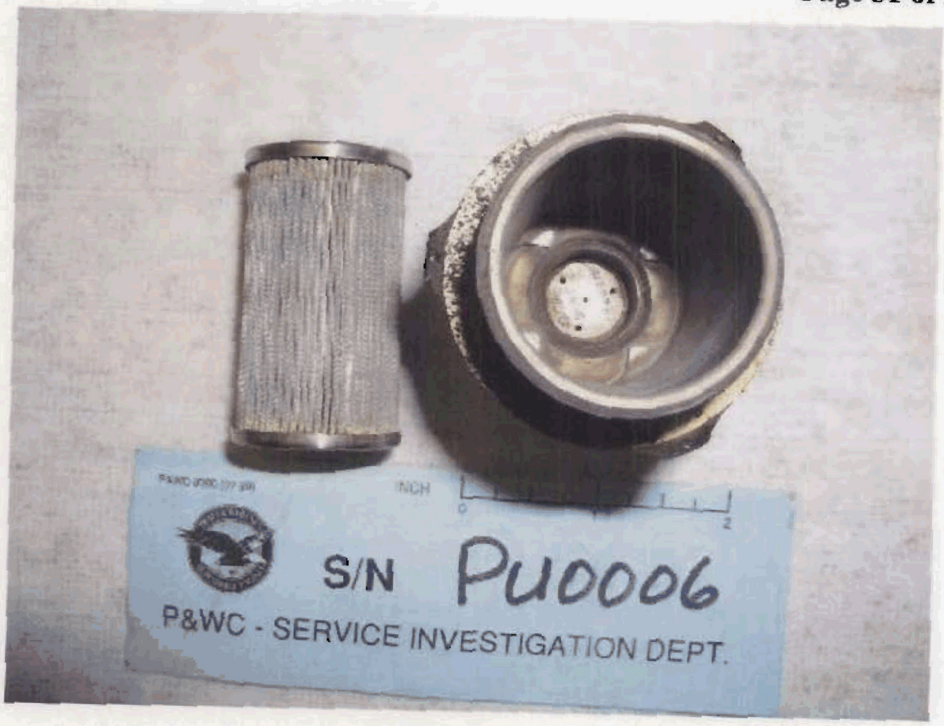

Photo no. 27
View of the P3 filter & the inside of the filter bowl being dry and clean

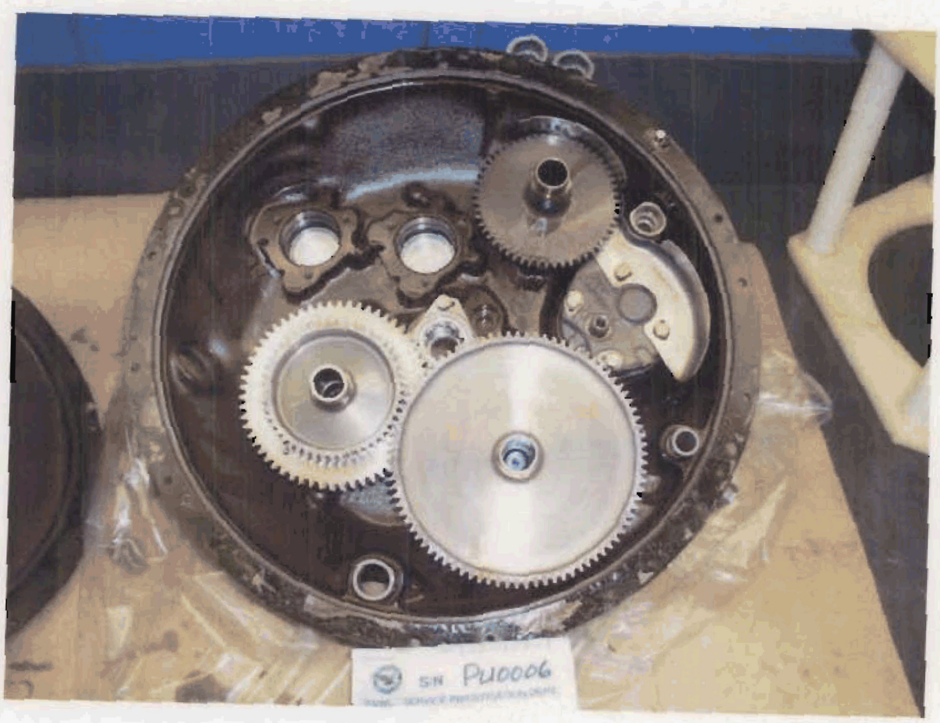

Photo no. 28
View of the assembly of the AGB housing/gears/bearings

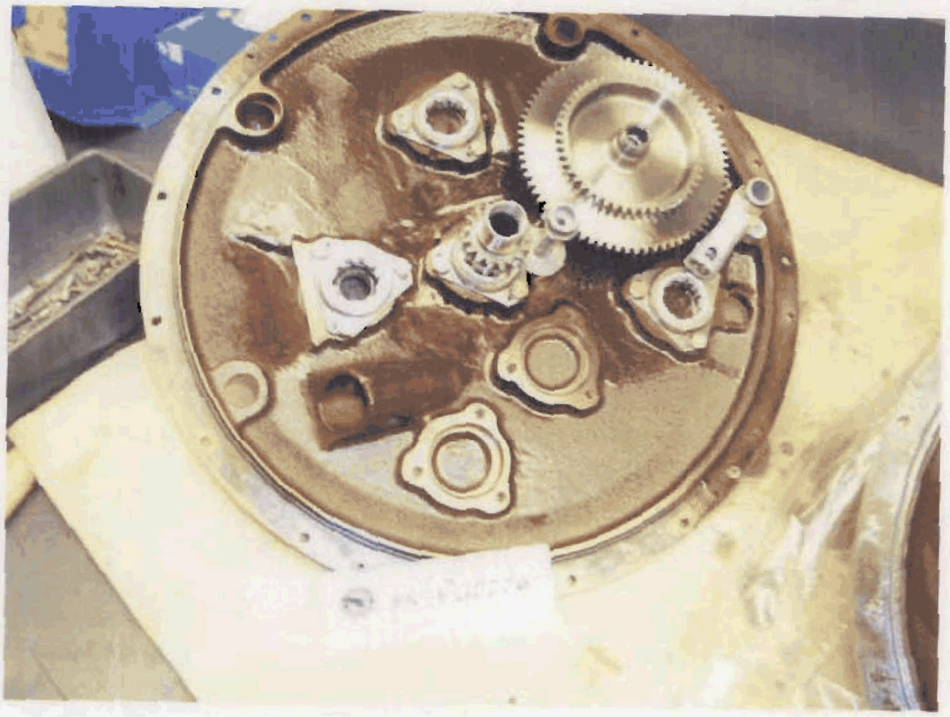

Photo no. 29
View of the assembly of the AGB diaphragm/gears/bearings

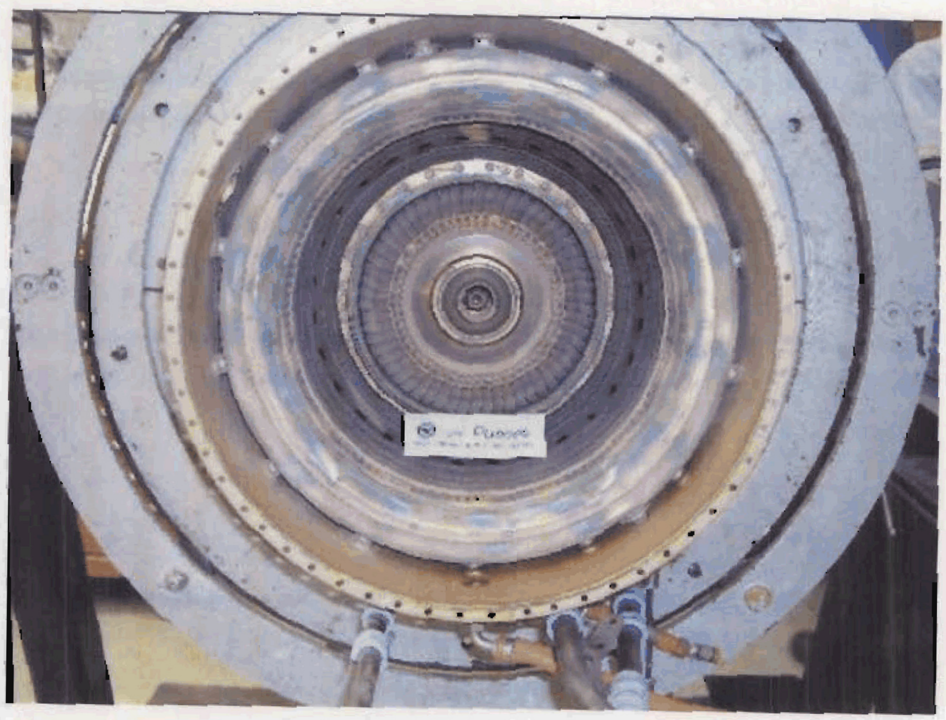

Photo no. 30
Downstream view of the intact CT disc assembly and combustion liner

Photo no. 31
Trailing edge view of several CT blades shows no evidence of tip rubs

Photo no. 32
Leading edge view of the CT disc assembly

Photo no. 33
General view of the intact components of the compressor assembly being intact

Photo no. 34
1st stage compressor stator shows no evidence of rubbing damage to the shroud.

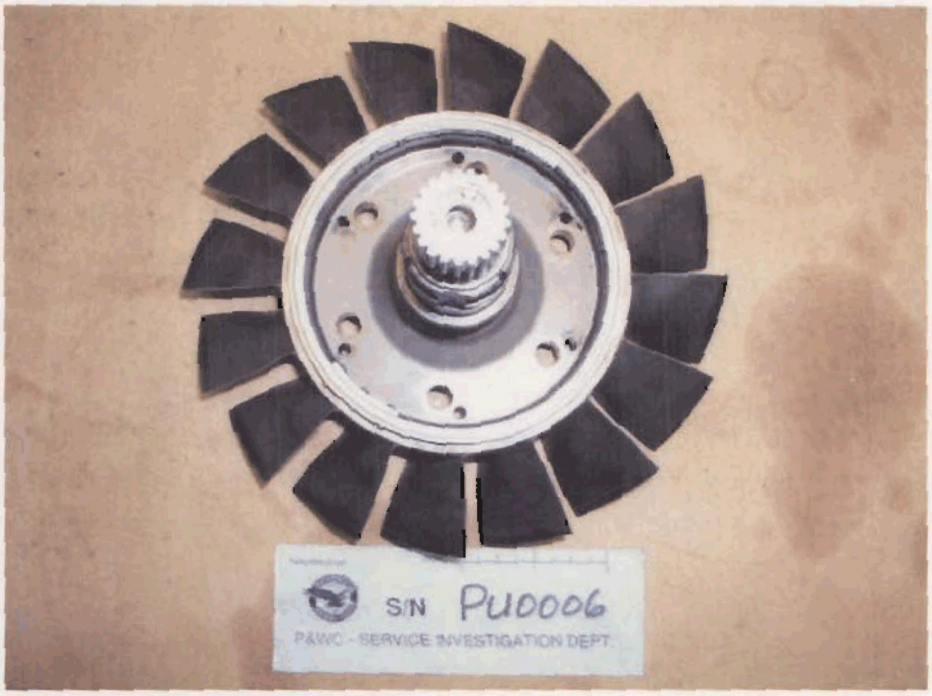

Photo no. 35
Leading edge view of the intact 1st stage compressor rotor

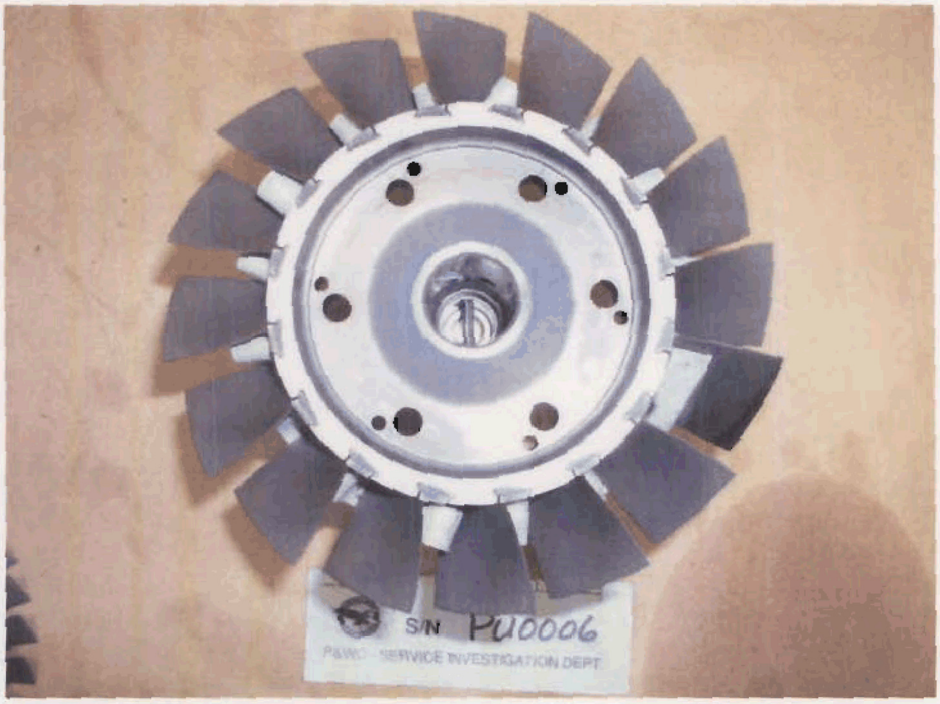

Photo no. 36
Trailing edge view of the intact 1st stage compressor rotor

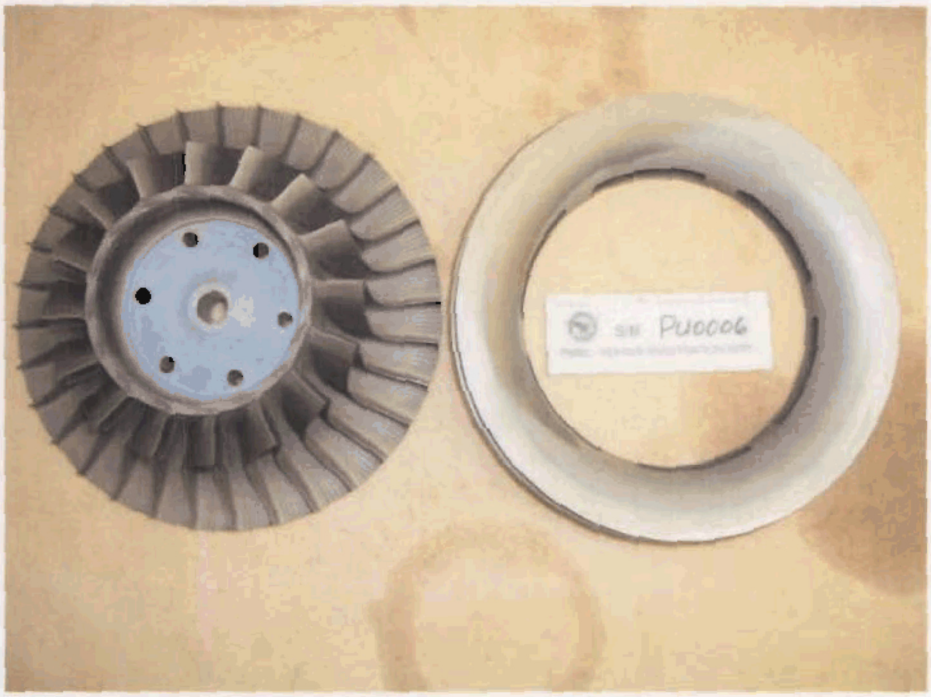

Photo no. 37
View of the compressor impeller with its shroud housing shows no evidence of rubbing damage.

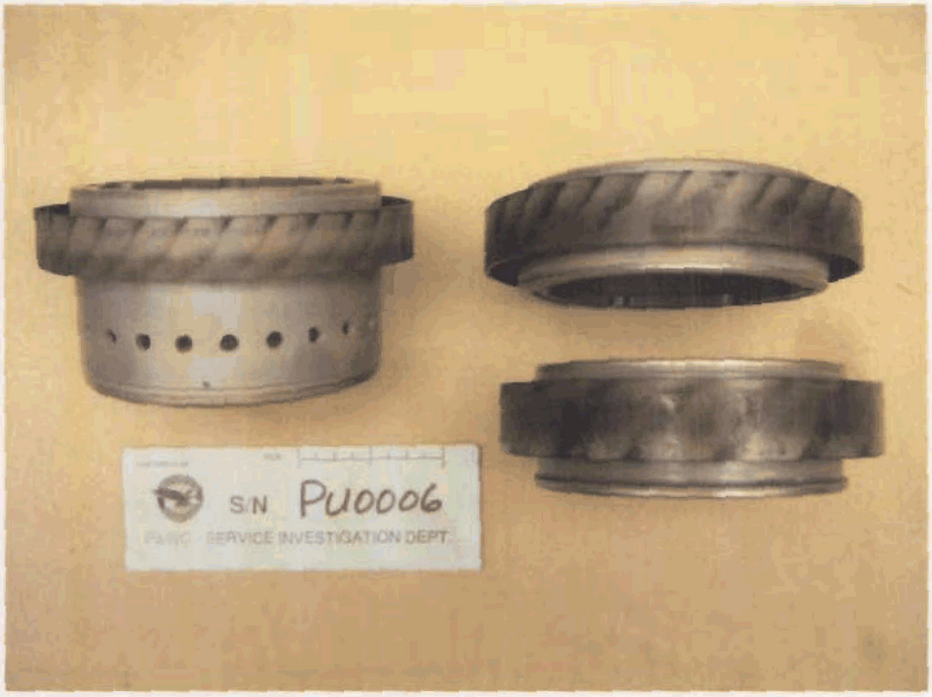

Photo no. 38
View of the compressor rotor spacers shows no impact and rubbing damage to their OD's
Note that the wetness seen on the spacers (O.D) was introduced during the disassembly handling.

Photo no. 39
View of the compressor rotor air seals shows no impact rubbing damage to the OD's.

Photo no. 40
Leading edge view of the intact PT stator assembly

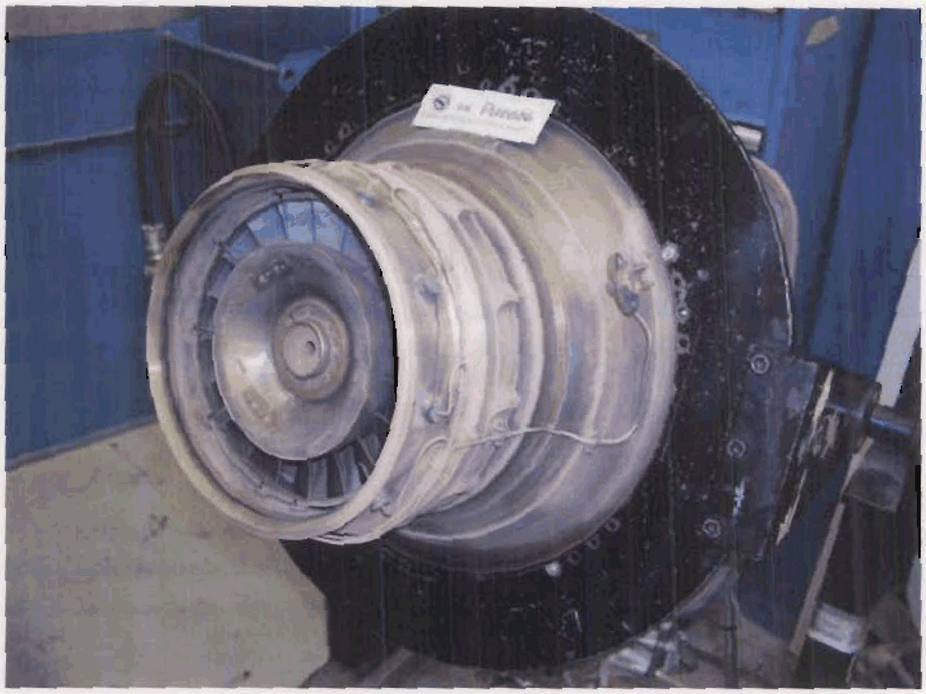

Photo no. 41
PS module LH view of the intact PT stator & housing, the temperature harness (T5) & the TED

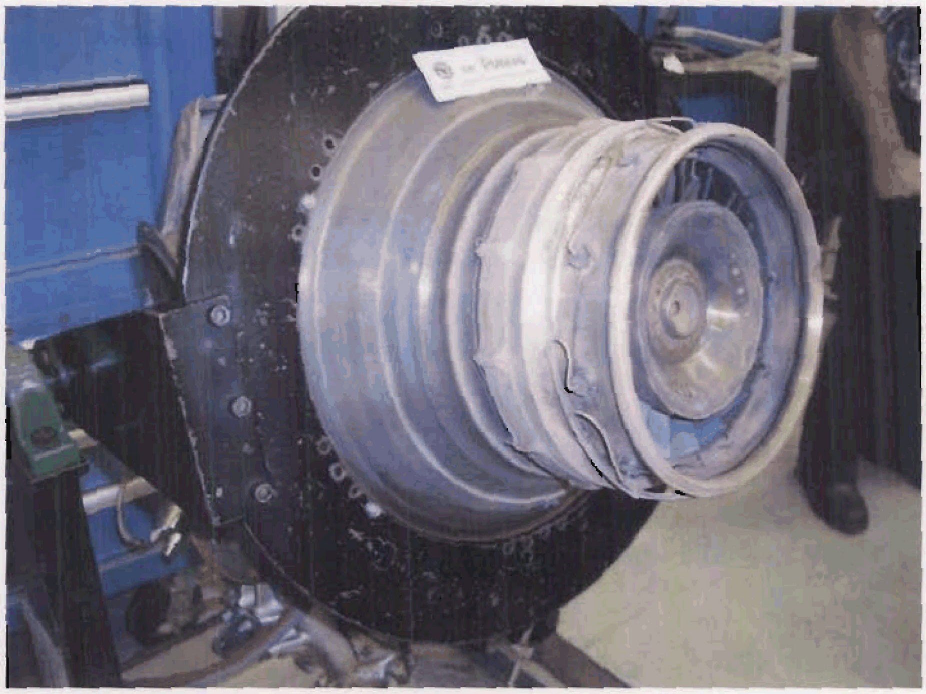

Photo no. 42
PS module RH view of the intact PT stator & housing, the temperature harness (T5) & the TED

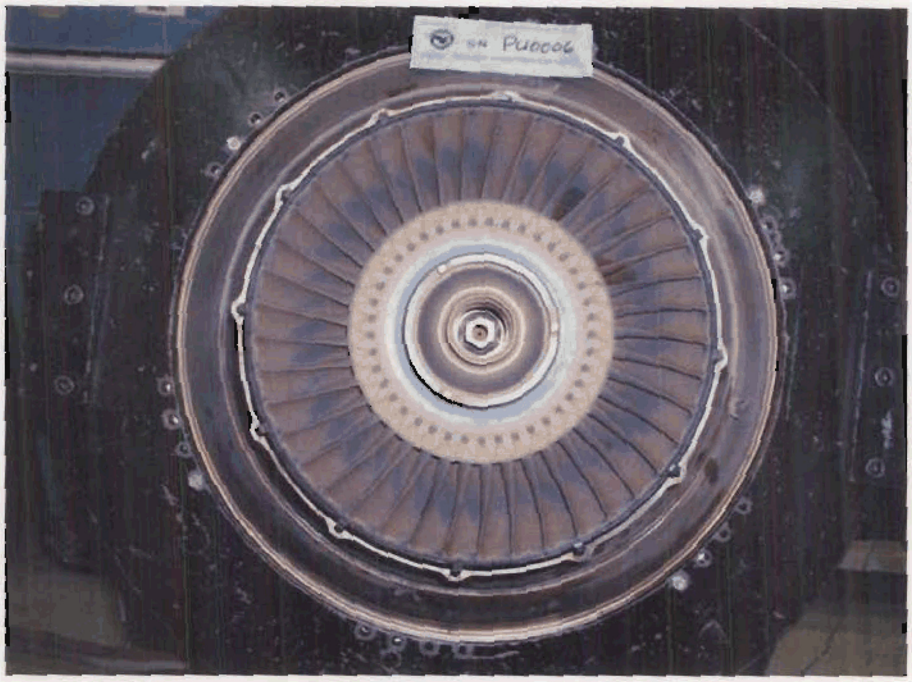

Photo no. 43
View of the intact PT disc assembly

Photo no. 44
View of the PT blade shrouded tips show light rubs.

Photo no. 45
View of the PT shroud shows the rubbed seal knives between the arrows.

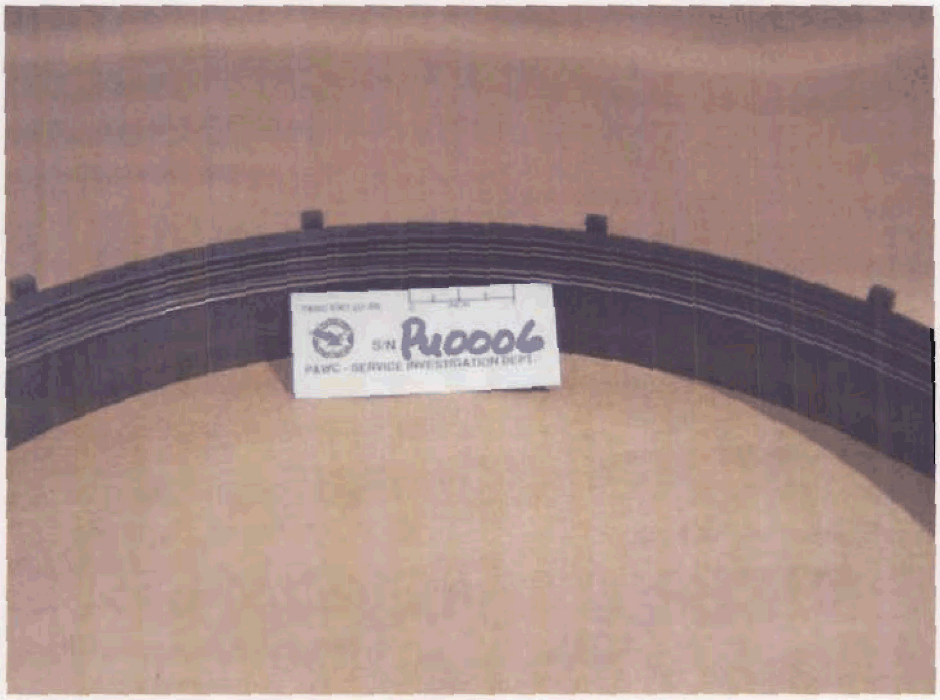

Photo no. 46
Another section view of the PT shroud shows the light rubs to the seal knives referred in photo no. 43 above.

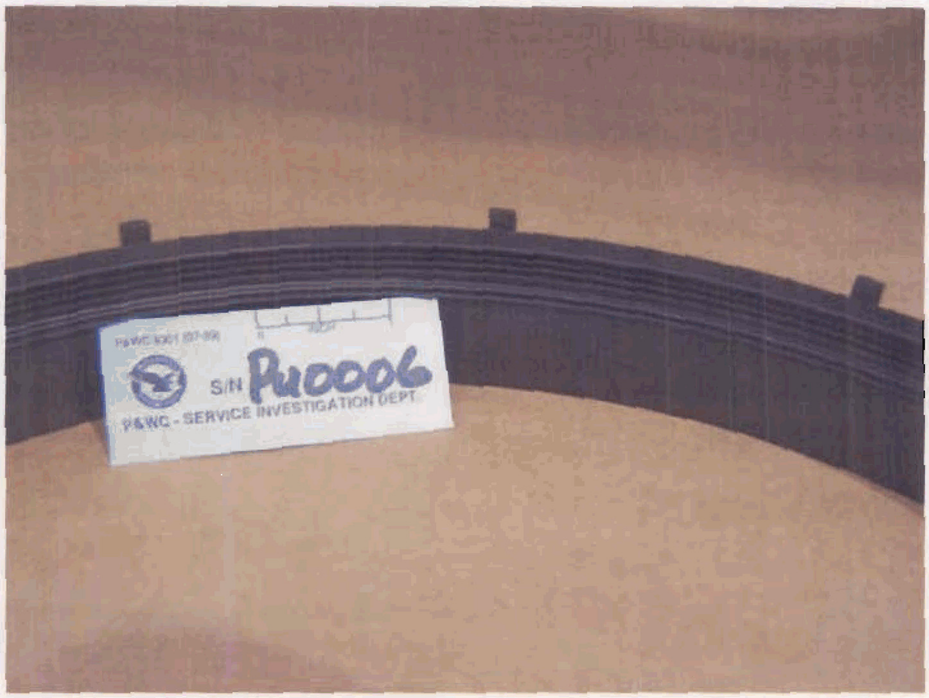

Photo no. 47
A section view of the PT shroud shows the seal knives being intact.

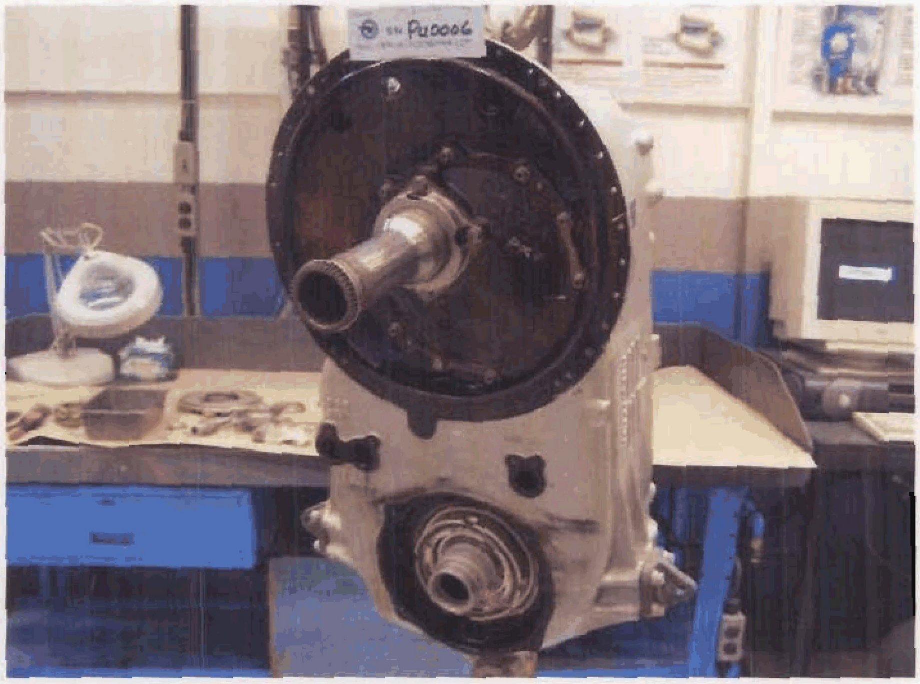

Photo no. 48
RGB module shows the intact input-drive coupling shaft linking with the PS module. Arrow points to the RGB output drive.

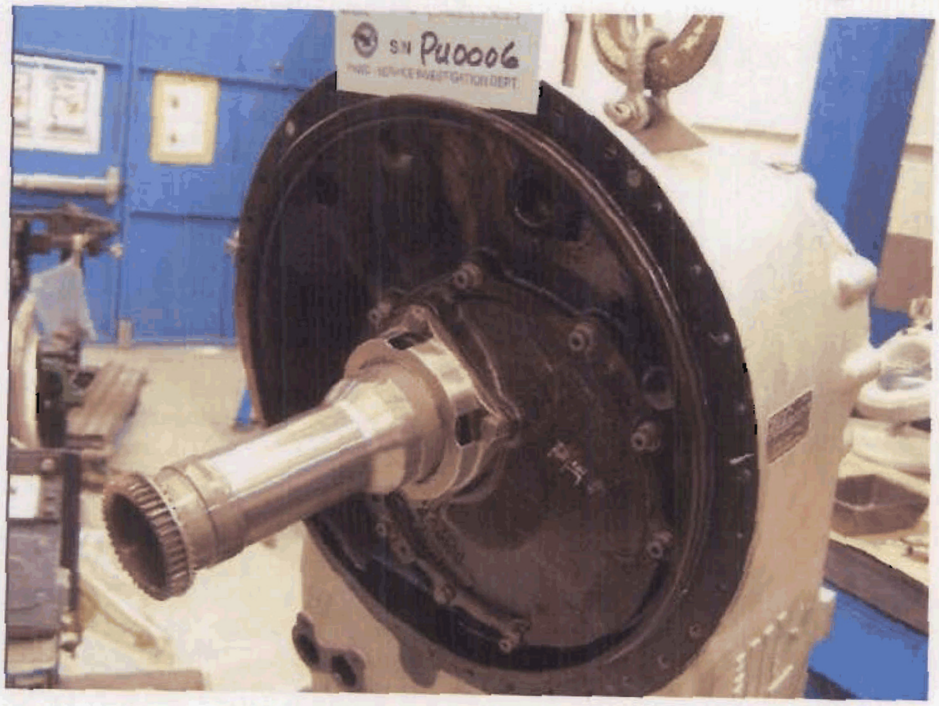

Photo no. 49
Closer view of the intact output-drive coupling shaft

Photo no. 50
View of the intact RGB output shaft, sprag clutch & No. 14 duplex bearings

Photo no. 51
Closer view of the intact sprag clutch

Photo no. 52
Inside view of the idler gear shows the intact runner (arrow) for the sprag clutch & the intact No. 15 roller bearing.

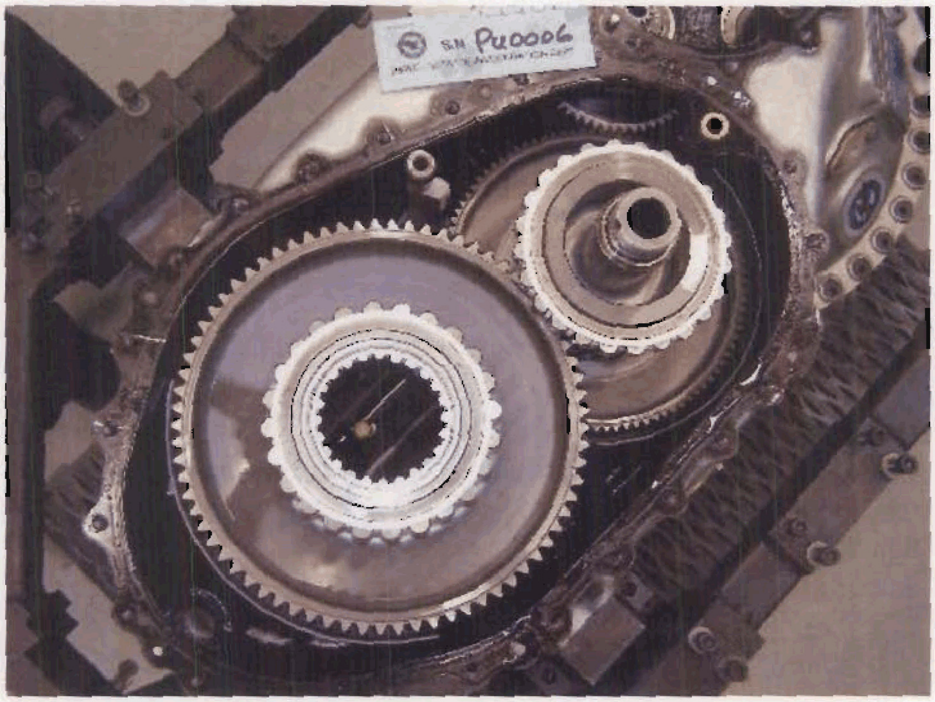

Photo no. 53
View of the intact assembly of the idler and torquemeter gearshafts and roller bearings (#10 & #15)

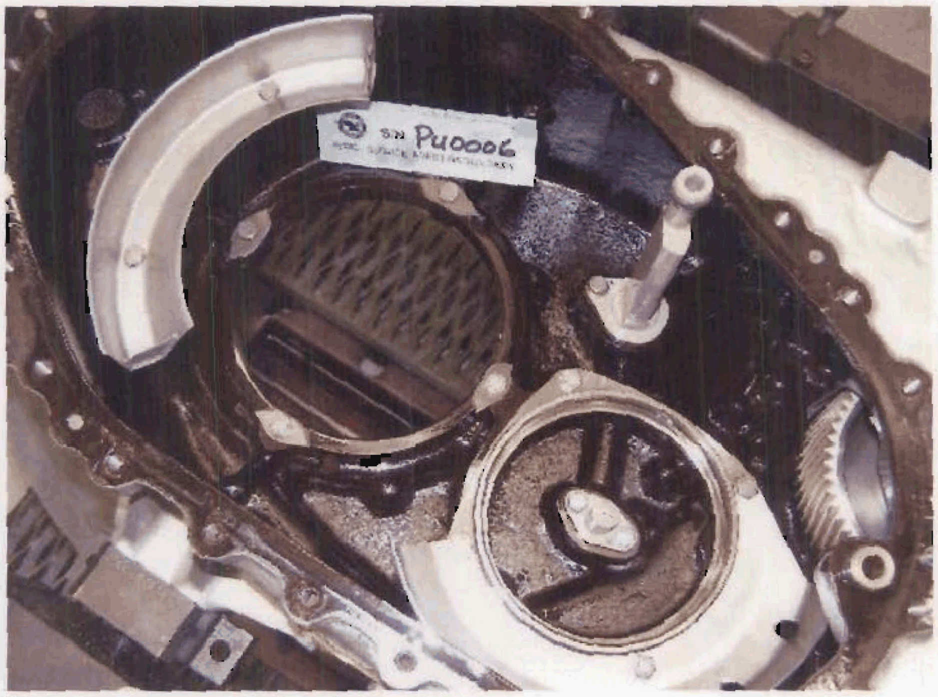

Photo no. 54
RGB internal view shows the intact outer ring flange of the No. 9 roller bearing and the four bolted fragments of the No. 12 ball bearing outer ring (see photo no's 54 & 55 below).

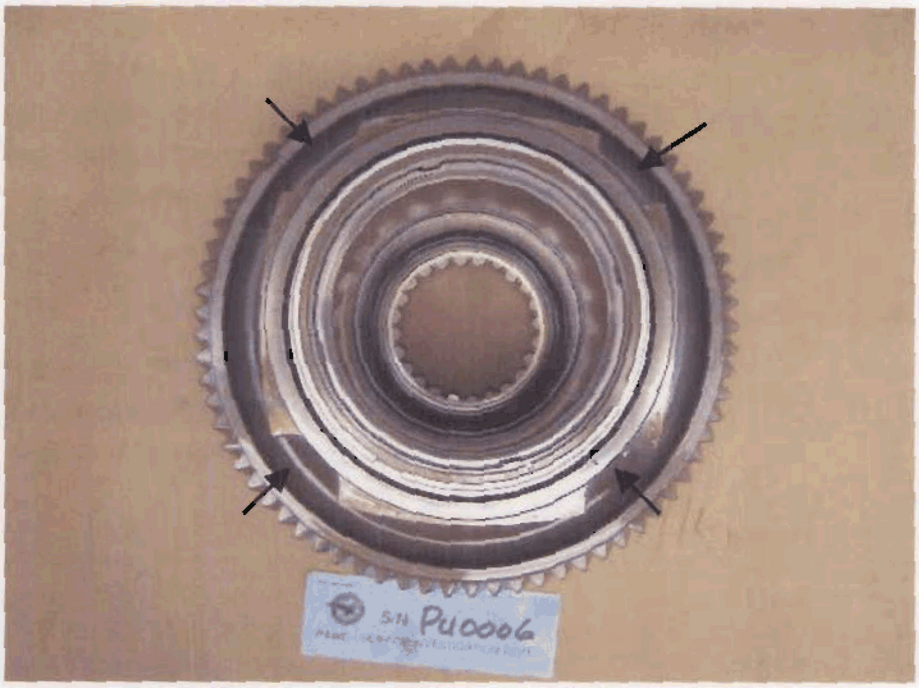

Photo no. 55
View of the No. 12 ball bearing attached to the idler gearshaft, which shows all four (4) fractures of the flanged outer ring.

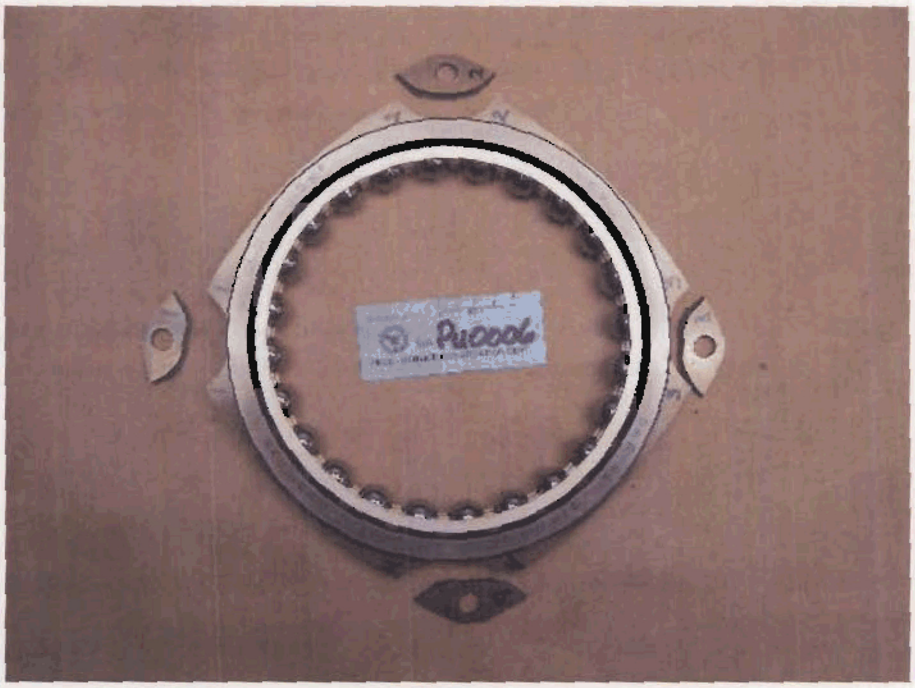

Photo no. 56
View of the four (4) fractured areas of the flanged No. 12 bearing outer ring

Photo no. 57
Detail view of the fracture surface of one of a fractured No. 12 bearing outer ring lug

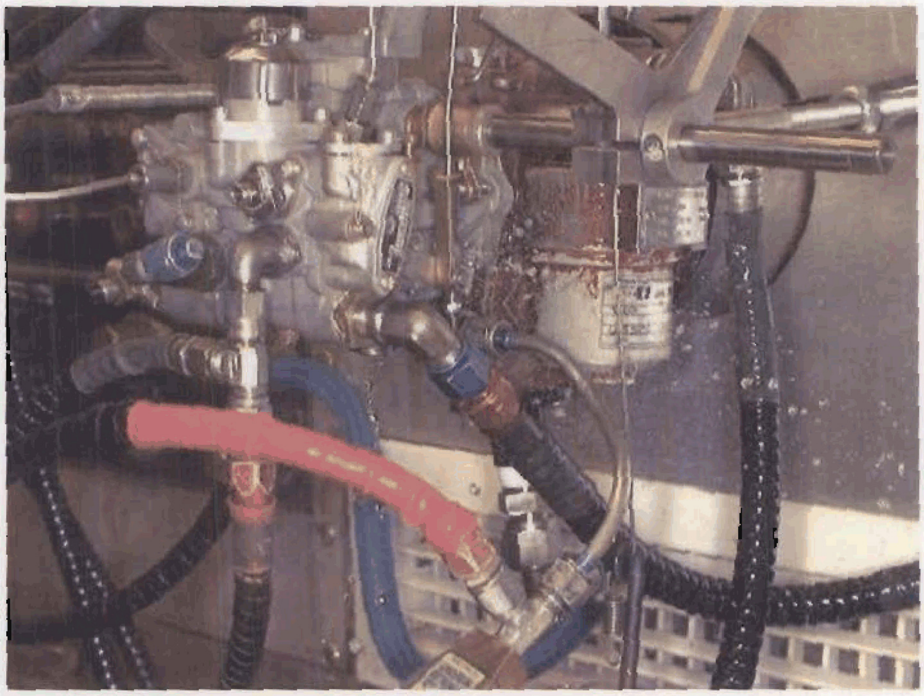

Photo no. 58
Leak test of FCU S/N C68008 drive body S/N 0005 shows the spray of fuel due to fuel and air leaks at the mating flange of the drive and flow bodies.

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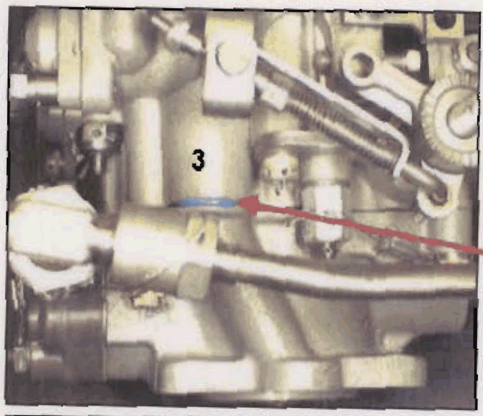

FIGURE 1
View of the Po packing from the fuel return line of FCU drive to flow body interface. The packing shows no evident damage except for faint permanent compression lines (black arrows). These lines likely correspond to position of the packing after extrusion (red arrow).

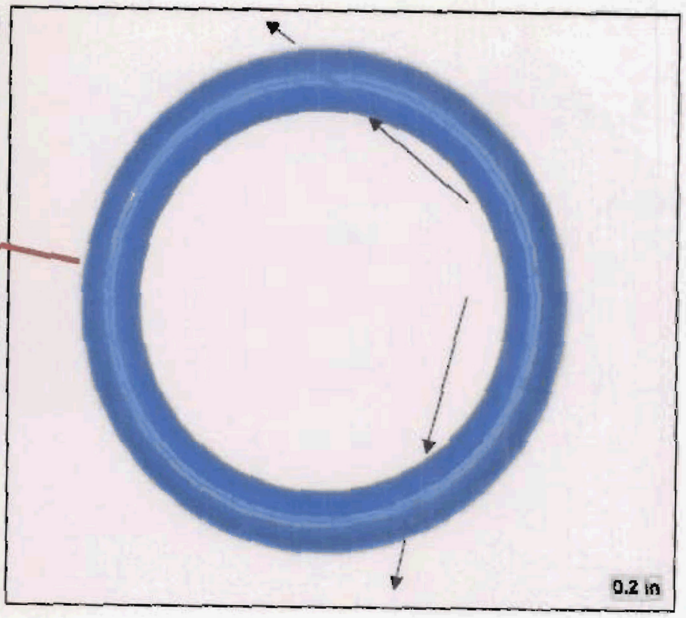

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FIGURE 2
This figure is showing the planarity measurement results obtained on the drive body casting mating surface. We can see that the surface shows a deviation of 0.0157" around hole #2. The drawing requires a maximum deviation of ±0.002".

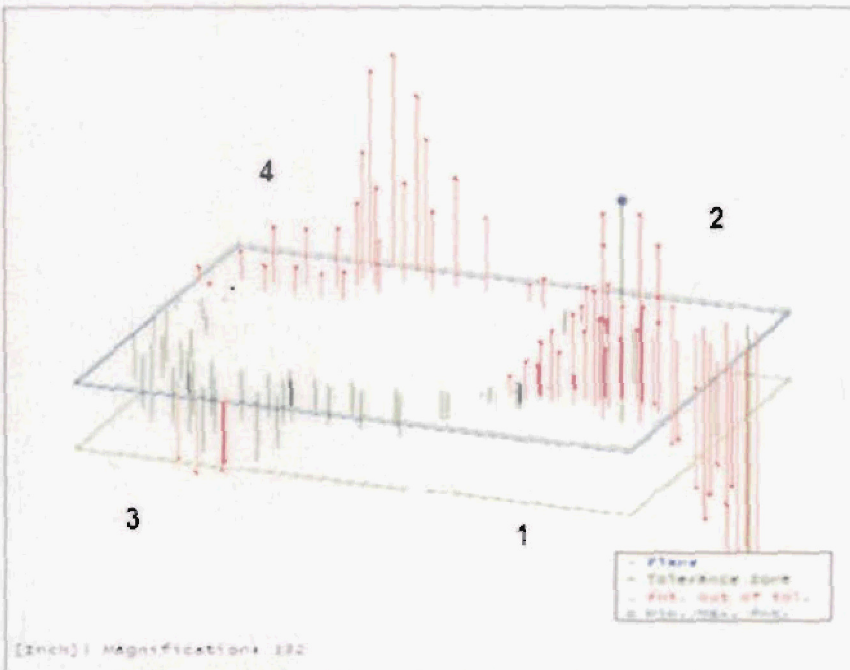

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FIGURE 3
This figure shows the tomography 3D reverse engineering image of the drive body casting. The variation in surface profile of the mating surface with the flow body shows an irregular pattern. What appear in blue indicates the area where there is a depression on the mating surface. The pattern is not symmetric.

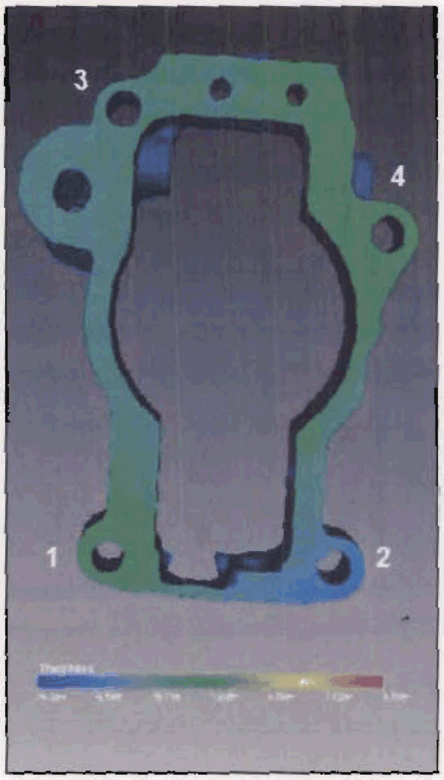

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FIGURE 4
This figure shows that the machining lines around hole #1 are not parallel. This likely suggests that the machining operation was performed in two stages.

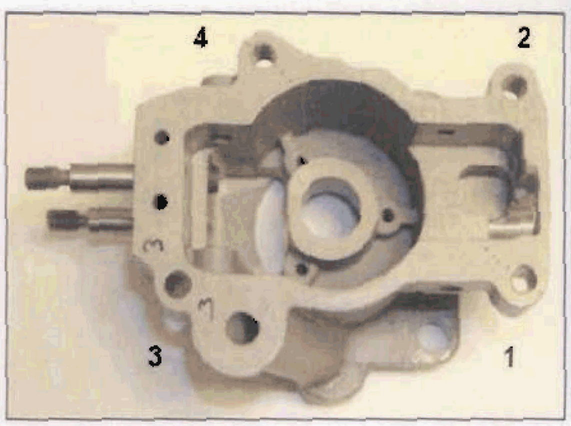

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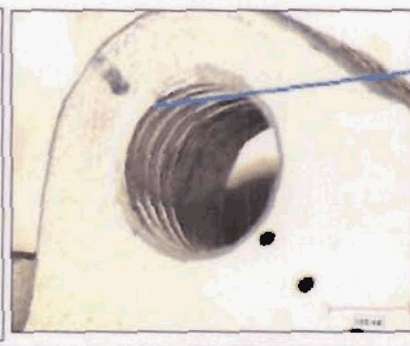
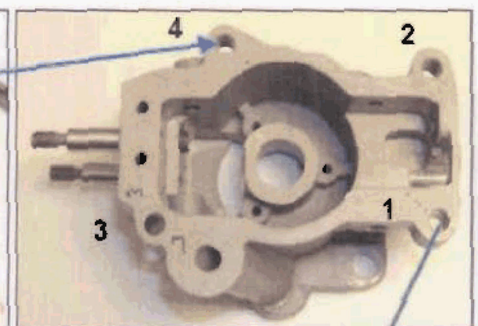
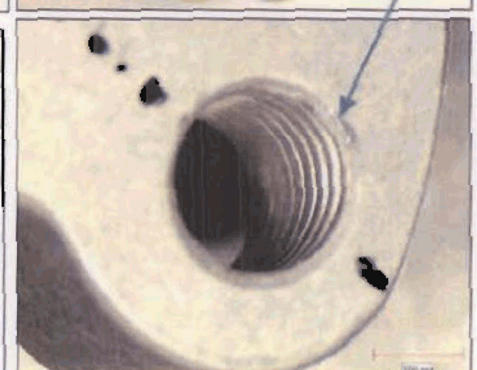
FIGURE 5
The figure shows threaded marks in holes 1 & 4. We can see that these marks are opposed. The dimensional analysis shows that the holes are not in true position according to the requirement. This offset likely contributed the threading marks seen in holes 1 & 4.







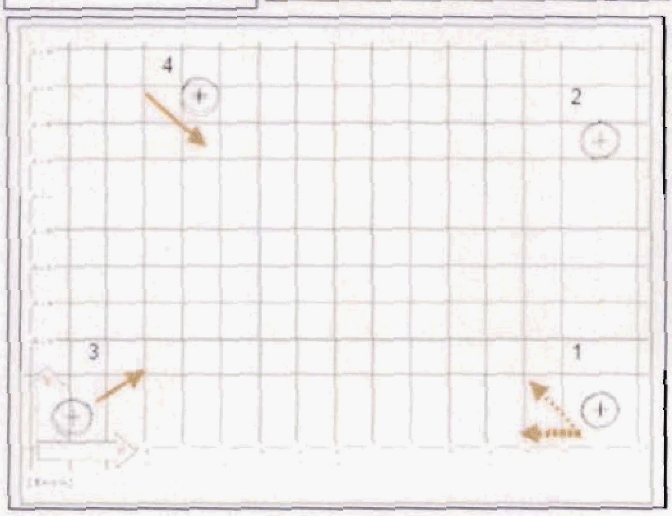


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FIGURE 6
The figure is showing evidence of rubbing left in hole #3. Thread marks are evident.

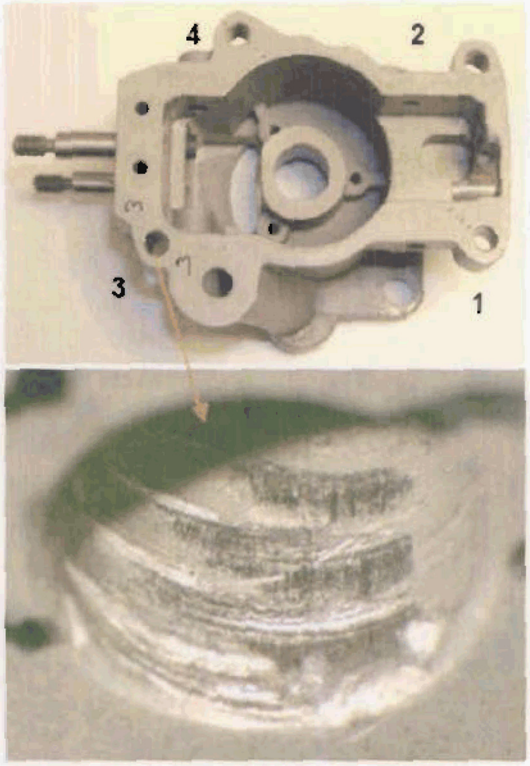

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FIGURE 7
This figure is showing evidence of light contact fretting left around holes #1 and 3 on the flow body-mating surface.

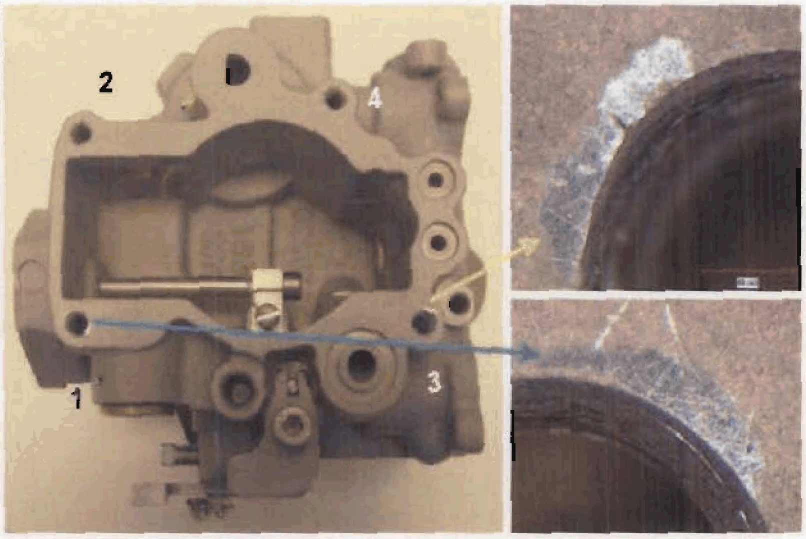

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FIGURE 8
This figure is showing evidence of light contact fretting left around holes #3 on the drive body-mating surface.

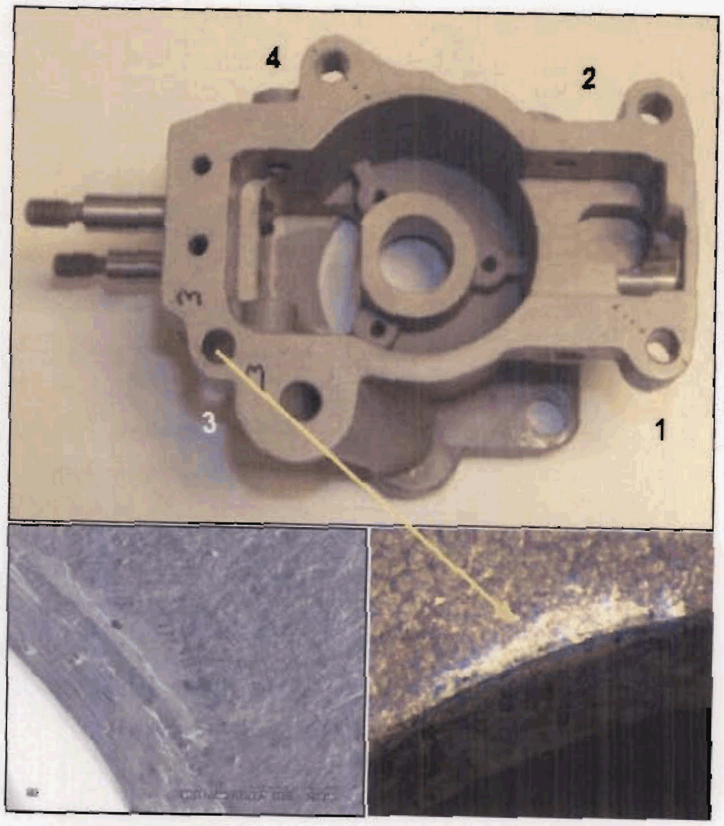

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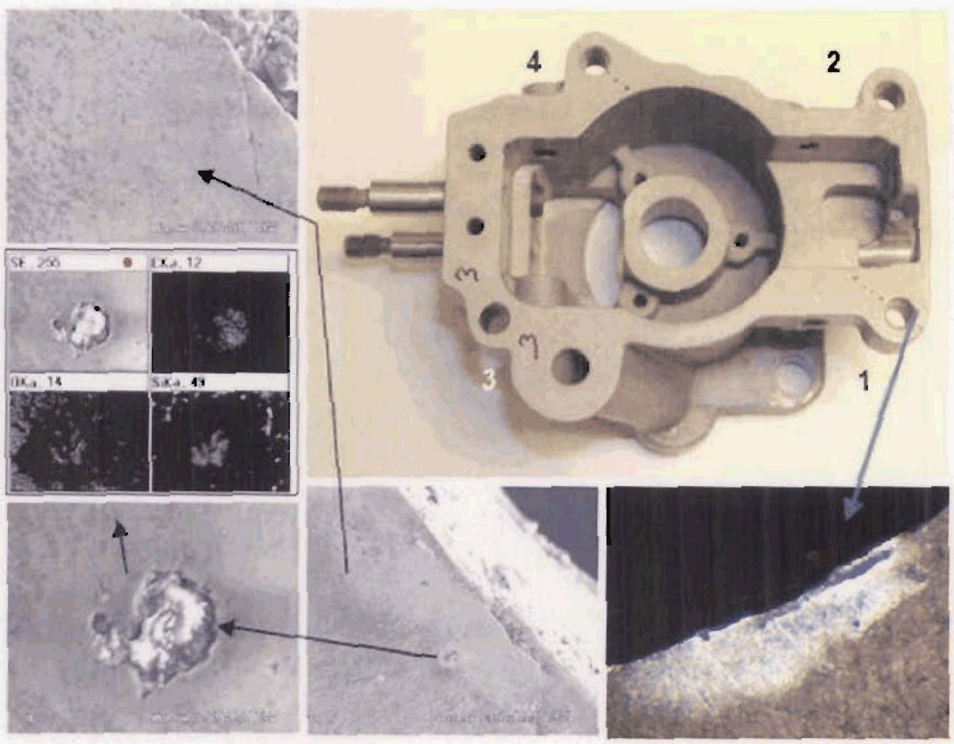
FIGURE 9
This figure is showing evidence of light fretting left around holes #1 on the drive body-mating surface. The SEM analysis indicates the presence of fretting. An embedded silicon oxide particle was observed in the fretting area of hole #1. The lower right figure, we can observe the shiny rubbing marks observed with the SEM



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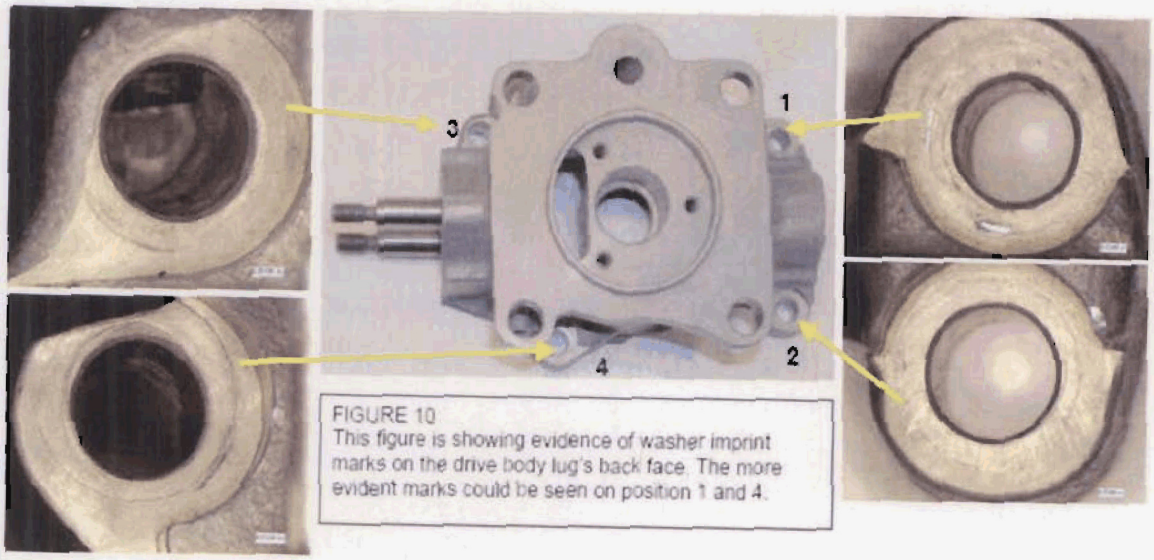

FIGURE 10
This figure is showing evidence of washer imprint marks on the drive body lug's back face. The more evident marks could be seen on position 1 and 4.

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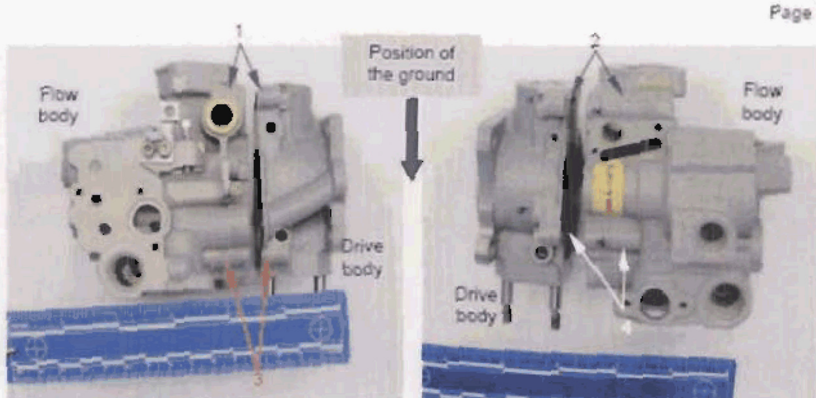

Figure 1a Figure 1b

Figure 1

Figure 1a and 1b) General aspect of the FCU showing the location of the bolts in relation to the ground.

Figure 1c) Aspect of the flange of the drive body in contact with the flow body. The bolts numbers are identified next to the hole. The bolt at location 3 was stripped from the flow body. The location of the ground when the unit is installed on the engine is downwards.

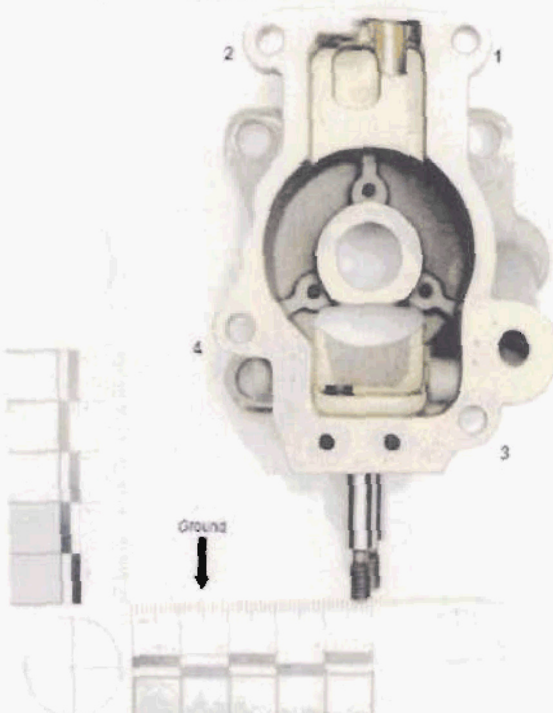

Figure 1c

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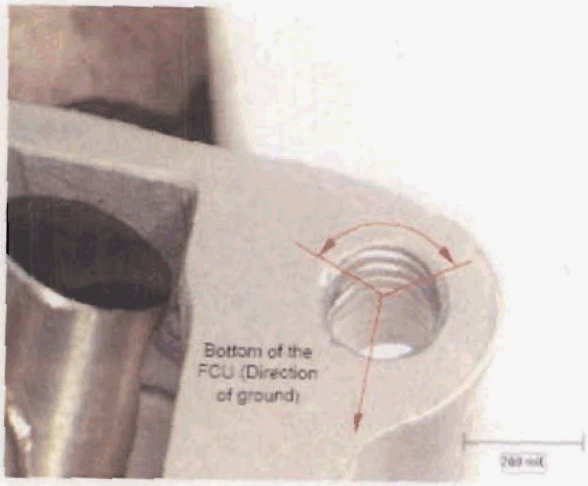
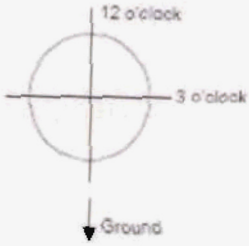


Figure 2

General aspect of the inner surface of bolt hole No. 1 in the drive body showing a circumferential marking suggesting that the surface was damaged by a threaded component. The damage is located approximately between 9 and 1 o'clock position.

The convention used for the location of the damage in all the bolt holes is as follow:



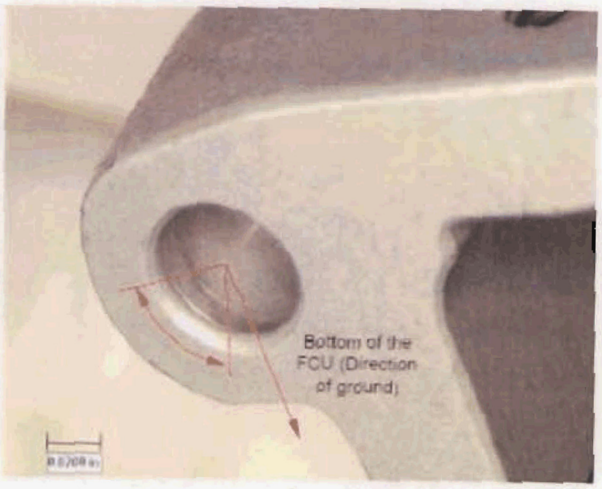


Figure 3

General aspect of the inner surface of bolt hole No. 2 showing a slight evidence of circumferential markings. Those markings are located between 7 and 9 o'clock position.

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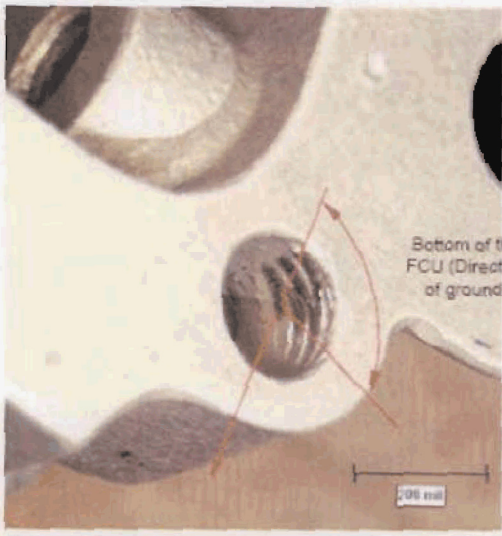

Figure 4

General aspect of the inner surface of bolt hole No. 3 showing pronounced circumferential markings. The damage is mainly located between 12 and 4 o'clock in the hole and next to the interface between the drive and the flow body.

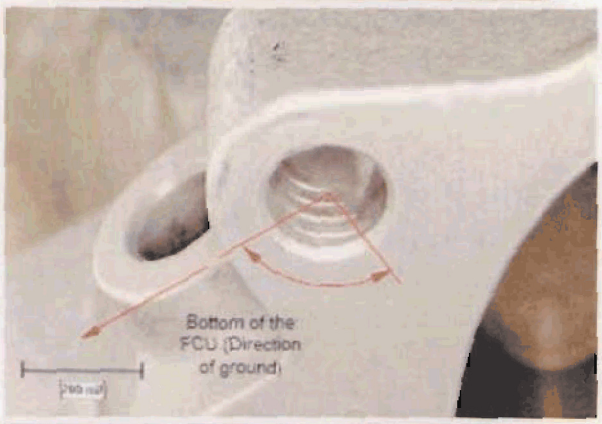

Figure 5

General aspect of the inner surface of bolt hole No. 4 showing deep circumferential markings. The markings are similar to thread-like features observed in other bolt holes. The damage is located approximately between 3 and 6 o'clock.

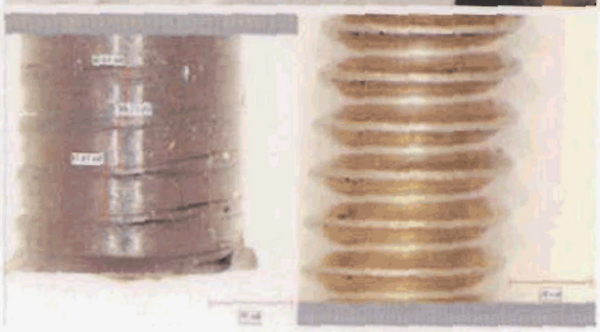

Figure 6

Silicon rubber replica of bolthole No. 4 and bolt No. 3 showing that the thread-like feature in the hole matches the thread spacing of the bolt and is approximately 0.041 in.

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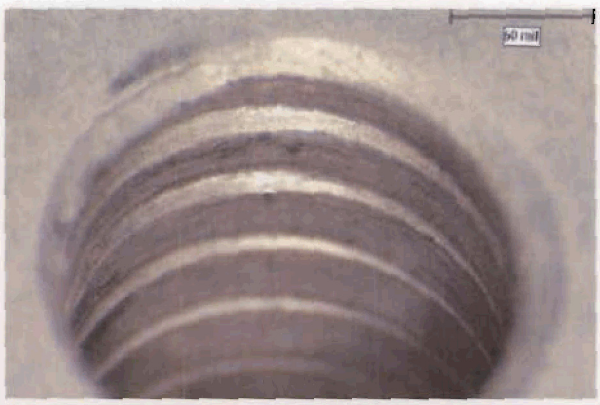

Figure 7

Examination of the circumferential threadlike pattern in bolt hole No. 1. The groove associated with the threading pattern is consistent with what was observed in bolt hole No. 4. However, there is no evidence of raised material associated with the threads.

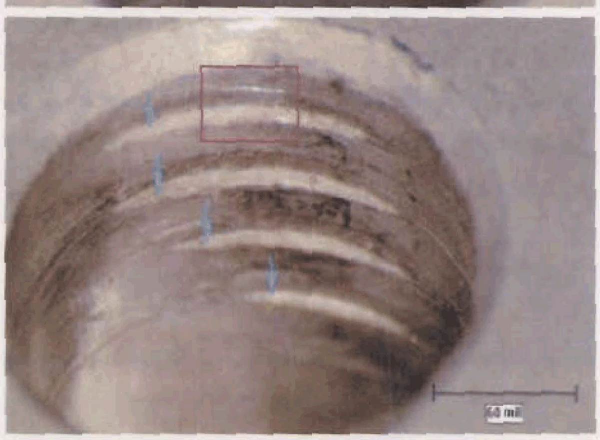

Figure 8

View of the damage in bolthole No. 4 at higher magnification showing that from the flange side, there is evidence of raised material in the bolt hole (arrows) associated with each thread.

Figure 9

Aspect of the damage at higher magnification showing that in this area the threads of the bolt are grooved in the material of the drive body. The raised features are material from the drive body. Note that the surfaces of the raised features area that are facing the flange are smooth and flat (arrow heads).

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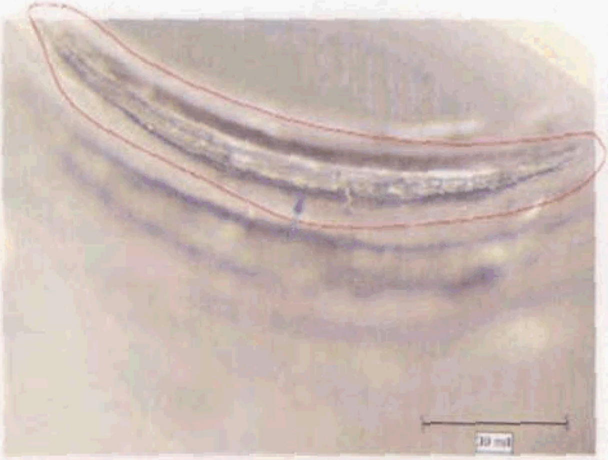

Figure 10

View of the raised features from the other side (bolting face). The feature highlighted here is the first area shown next to the interface in Figure 8 (outlined area in Figure 8). On this side, the raised feature is rough and exhibits evidence of deformation. There is a gap between the feature and the inner wall of the hole (arrow), indicating that this raised feature is a lap.

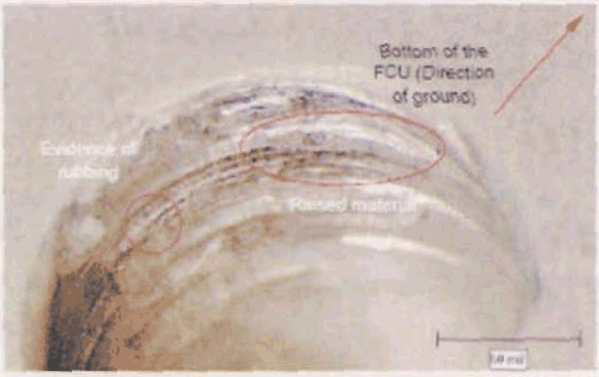

Figure 11

Damage in bolthole No. 3 on the drive body side, next to the flange. Evidence of raised material and of rubbing within the hole is also observed.

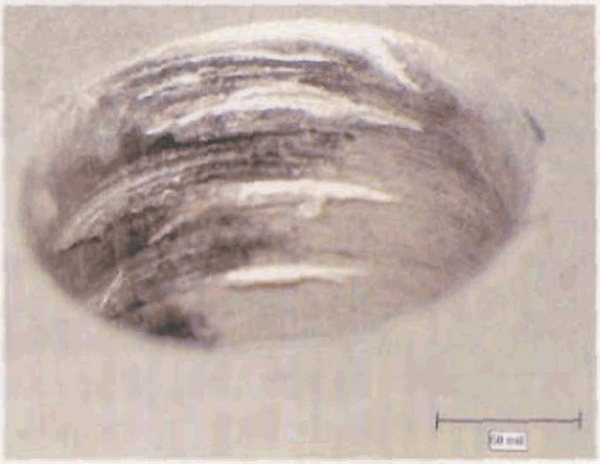

Figure 12

Evidence showing that the areas of raised material was most likely similar to what was observed in bolt hole No. 4. However these features appear to have been flattened while this was not observed in bolthole 4.

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Figure 13

Presence of a tongue just beneath a thread mark along with lines indicating that the feature was rubbed. These features are consistent with a relative movement between the drive body and the bolt. This damage could have been done while the bolt is moving away from the flow body or while the drive body moves towards the flow body while the bolt remains stationary. The origin of the flattening could not be determined.

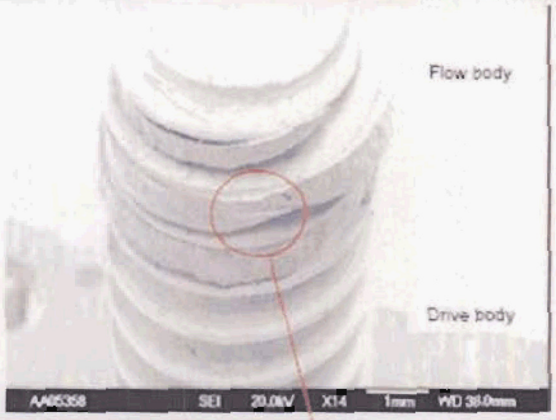

Figure 14

Figure 9A from Honeywell's South Bend Materials Technology Center report No. AA05358 and titled "Investigation of B-37 fuel Control, S/N 68008", dated 11/11/05.

This Figure was used to find the orientation of the sample of stripped material removed from the bolt, using a specific feature.

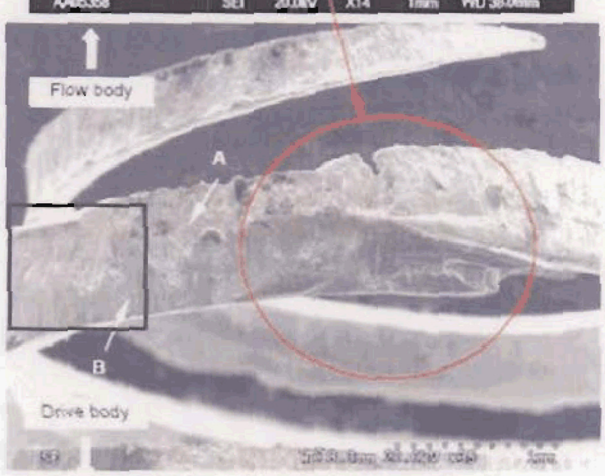

Figure 15

General aspect of the fragment stripped from the flow body and removed from the threads of the bolt. Using a specific feature of the fracture surface, the orientation of the sample was established. In the orientation presented, the top of the picture is towards the flow body and corresponds to the tip of the bolt while the lower part is closer to the bolt's head. The fracture surface of the stripped material exhibited three different surface aspects. In areas of type A, features characteristic of an overload shear fracture were observed (see Figure 16). In areas of type B the surface features were indicative of rubbing and smearing (see Figure 16). The area presenting the third fractographic aspect is located at approximately 90 degrees from the location shown and is presented in Figure 29.

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Figure 16a

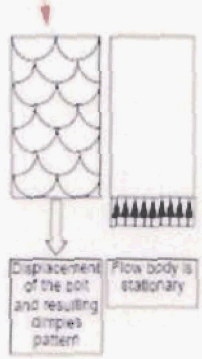

Figure 16b

Figure 16

General aspect in a region where surfaces A and B are visible. The orientation of the sample is the same as in Figures 14 and 15. Dimples are visible (red circled area) in region of type A. The orientation of the dimples is consistent with a shear moment resulting from a relative motion between the bolt and the flow body with the bolt moving out of the flow body (see Figure 16b).

Areas of type B are not consistent with a fracture surface and exhibit evidence of smearing over regions of type A (green arrows). The lines in area B are consistent with rubbing. Regions of type B are consequently subsequent to the shear fracture. The lines are also clearly defined and no evidence of fretting was observed indicating that the rubbing damage was produced in a single event.

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Figure 17

Aspect of the fracture surface of the stripped material at higher magnification showing the extent of the area exhibiting features A and B (black outlined area in Figure 15). An area of deformed material not consistent with the shear fracture is also visible along the root (circled area).

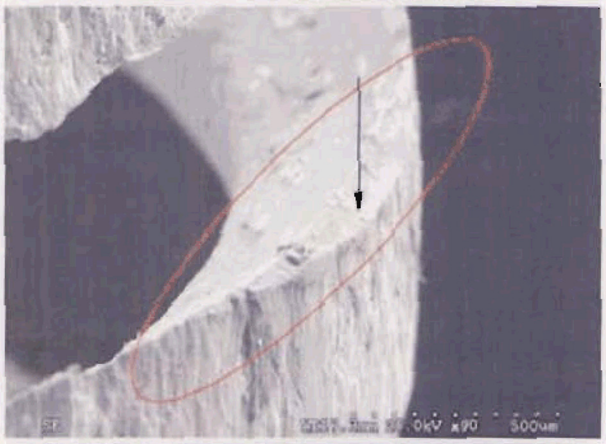

Figure 18

Same as Figure 17 showing the deformed area from the inwards portion of the thread. The deformation observed along the edge is consistent with the application of a force in the direction of the deformation, which is in agreement with a damage resulting from a contact at the location shown.

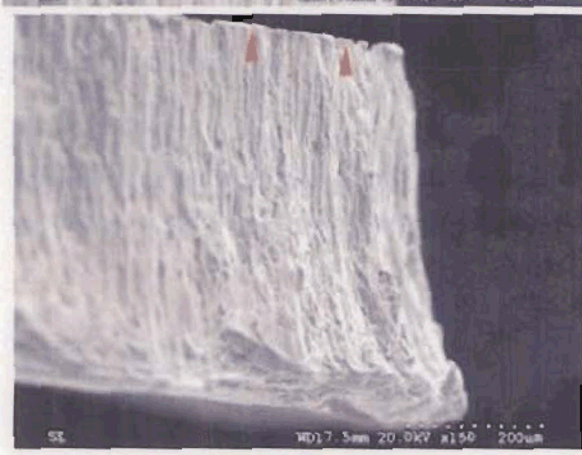

Figure 19

Typical aspect (lateral view) of a specimen fractured in pure shear (pull test sample) showing that there is no evidence of deformation along the edge of the flank facing inwards (arrow heads) previously reported for bolt hole No. 3 in Figure 17. This reinforces the notion that there was some contact between the stripped material and the bolt hole in the other direction.

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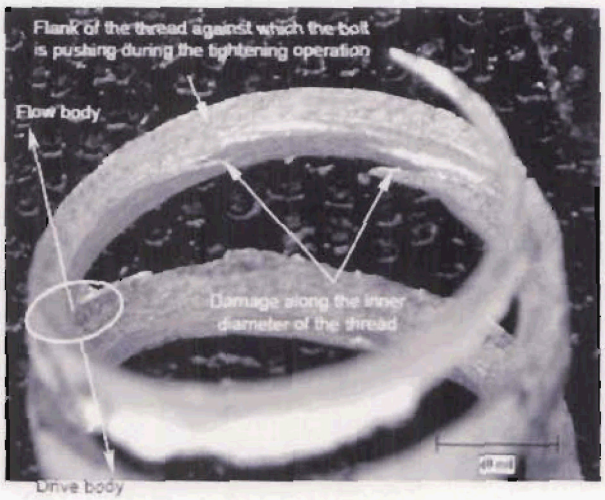


Figure 20

Damage along the inner surface of the thread fragment stripped from bolt hole No. 3 in the flow body. The damage is located along the flank of the thread facing into the tapped hole and consequently it is the surface on which the torquing load is applied. The damage visible on the right hand side corresponds to the feature seen in Figure 15 on the fracture surface.

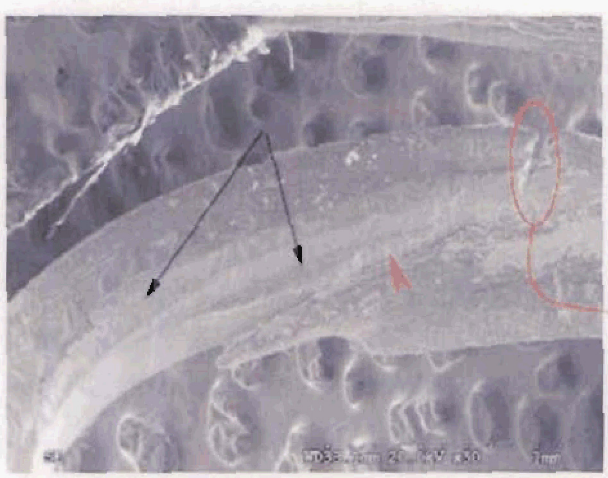
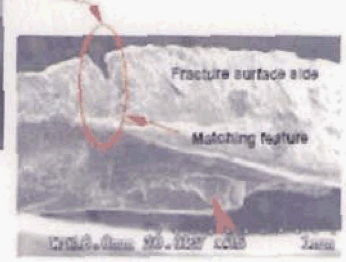


Figure 21

Damage to the inner surface of the stripped material shown in Figure 20 at higher magnification. This shows that the thread is partially sheared in this area (red arrow head). There is also evidence of rubbing on the thread indicating that the crest of the thread was damaged in this area (black arrows). Shearing was also observed from the fracture surface side (red arrow head in the inset).



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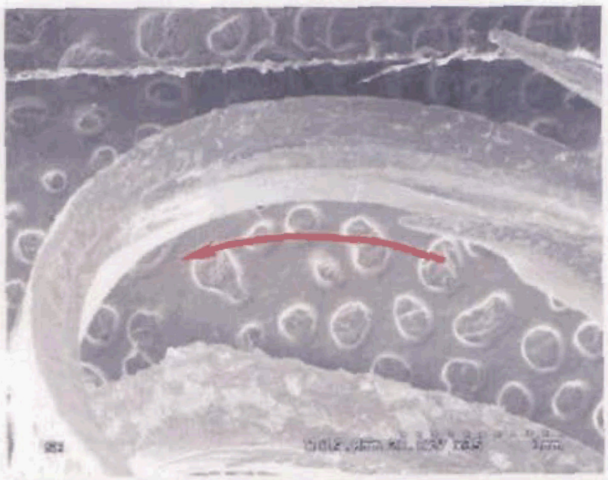

Figure 22

Damage to the inner surface of the stripped material shown in Figures 20 and 21. There is evidence of damage on the left hand side of the sheared area consistent with a damage that would be produced by the bolt that is being screwed in.

Figure 23

Damage similar to the one observed on the previous thread (Figure 22) are also visible along the crest of the last engaged thread (circled area). Grooving of the outer portion of the thread is also visible (arrow heads).

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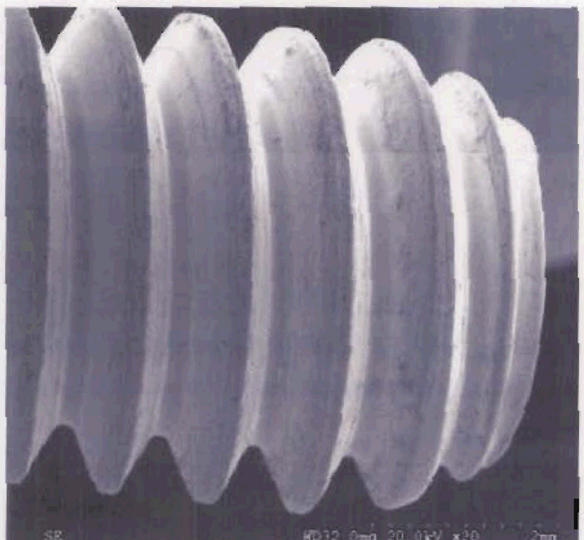

Electronic reconstruction using two photos of the tip

Figure 24

Bolt No. 3 showing the evidence of a taper at the end leading to threads with a smaller outer diameter.

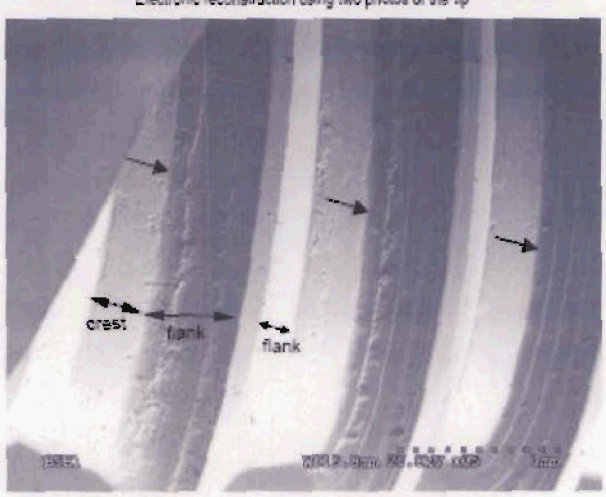

Figure 25

Replica of bolthole No.2 of the flow body showing the aspect of the surface finish of the flank in contact with the bolt. No evidence of damage to the crest or grooving was observed (arrows). Evidence of rubbing was observed on the flank of the threads.

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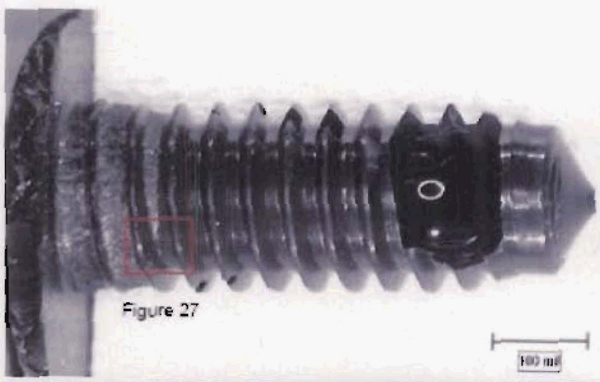
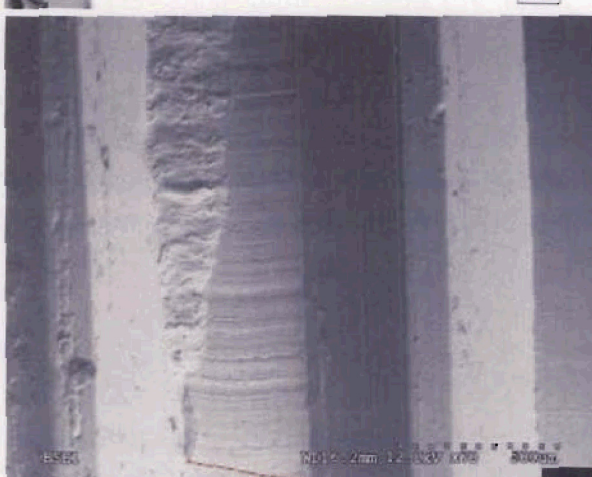


Figure 26

General aspect of the replica extracted from bolthole No. 3 of the flow body showing the area of damaged threads. The extremity of the stripped area showed longitudinal lines along the crest of the aluminium threads (red outlined area).

Please take note that the filling of the bolt hole cavity was incomplete and that an air bubble was trapped at the bottom (right hand side of the picture) leading to a very reflective surface were parasitic reflections of the lighting apparatus is visible.



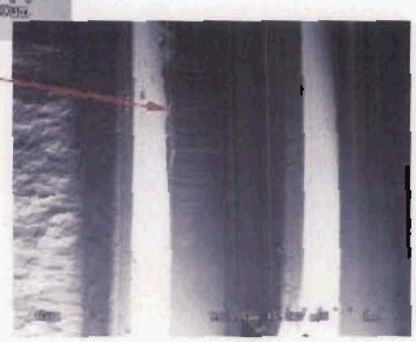


Figure 27

Replica from bolthole No. 3 of the flow body. Longitudinal lines at the tip of the region of stripped material are visible. In order to establish the source of the lines, the piece of stripped material was examined to determine if the grooves observed on one face could be matched to asperities on the other. Note that the axial lines continue beyond the photograph (inset) along an approximate distance of 0.30 inch and are still associated with fracture damage of the crest that is however significantly less discernible and located at the edge of the crest.

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Figure 28

Tip of the fragment of stripped material matching the location of the replica in Figure 27. No features on the fracture surface matching the features observed on the replica were found. The fact that the lines on the crest are in the axial direction of the bolt hole indicates that the damage resulted from a rubbing in the axial direction. The lines are also well defined indicating that there was no wear and consequently no subsequent rubbing between the fracture surface and the crest of the thread in the bolt hole.

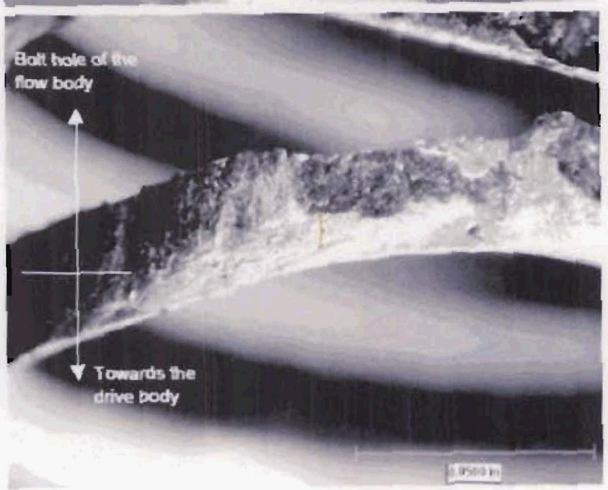

Figure 29

Area of the first thread of the fragment of stripped material exhibiting a different topography. Small parallel lines are visible (bracket). This feature is unique to the stripped material from the crash. A similar feature was not observed on the fragment produced in the overtorque or the pull tests performed by Honeywell. The fracture surface is approximately at a 45-degree angle to the axis of the bolt hole. This area is not associated with an area of partially sheared thread like the area shown in Figure 21.

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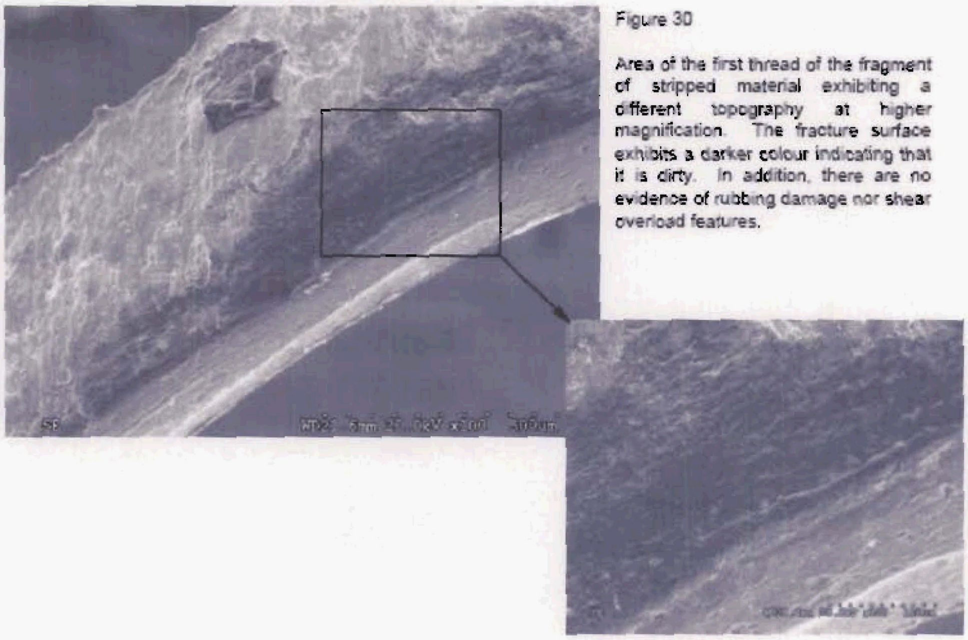

Figure 30

Area of the first thread of the fragment of stripped material exhibiting a different topography at higher magnification. The fracture surface exhibits a darker colour indicating that it is dirty. In addition, there are no evidence of rubbing damage nor shear overload features.

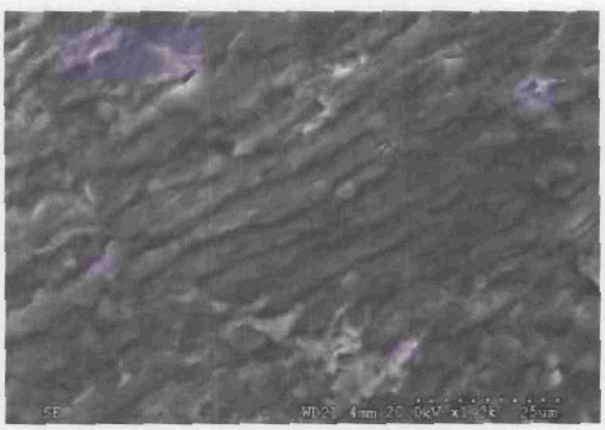

Figure 31

Evidence of large parallel striation-like features at higher magnification in the area of the fracture surface next to the root of the thread facing outwards. The presence of striation-like features is indicative of a fatigue crack propagation. However, the striations are not typical of a fatigue crack in Mode I (tensile) but are more consistent with a mixed Mode I-Mode II (tensile and shear).

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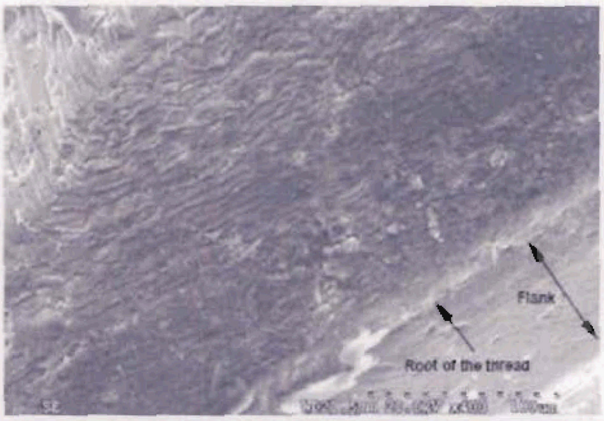

Figure 32

Area next to the root of the threads exhibiting striation-like features. The size and the spacing of these features are increasing from the root towards the sheared area. This is in agreement with a sub-critical crack growth under cyclic loading. Increasing striations spacing indicates that the fatigue crack was accelerating.

Figure 33

Aspect of the fracture surface next to the root of the thread (inset) at high magnification showing evidence of striations characteristic of fatigue crack propagation. The presence of these striations confirms a fatigue mechanism.

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Figure 34

Transition between the fatigue crack and the overload shear fracture surface. There is no evidence of a sudden increase in the applied load that would have resulted in the shear overload fracture of the thread. The evidences show that the overload shear fracture initiated from the fatigue crack and consequently from a crack that existed prior to the final shear fracture.

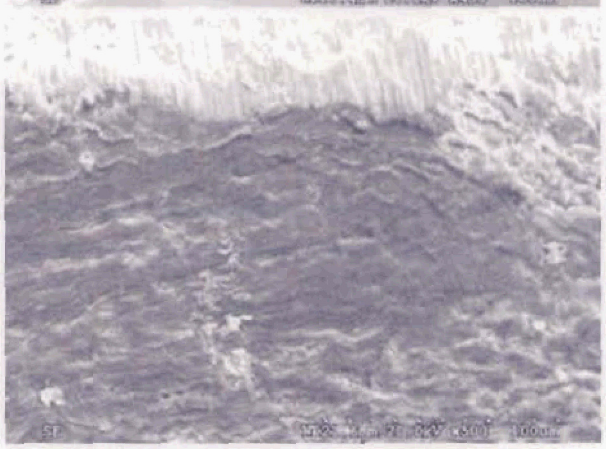

Figure 35

Other area showing the transition between the fatigue crack and the prior shear overload fracture subsequently damaged. Fatigue striations are visible on the fracture surface preceding the final overload fracture.

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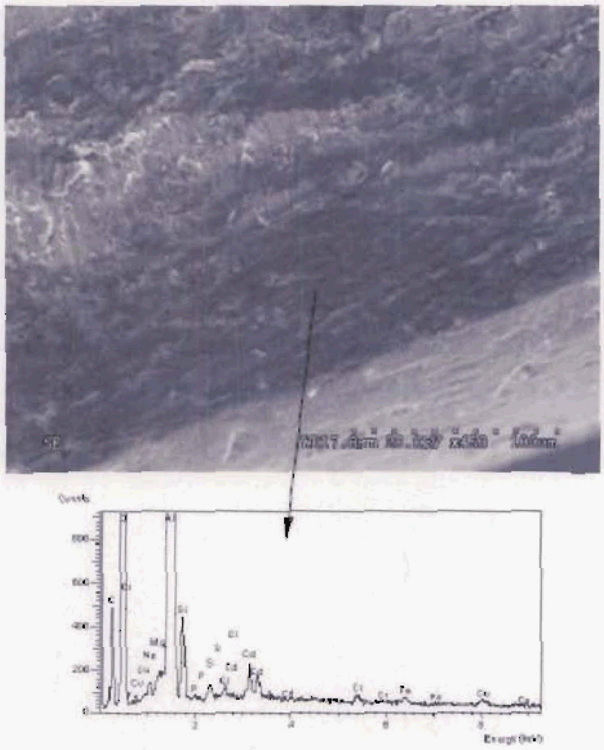

Figure 36

Chemical analysis of the greyish area exhibiting striation-like features on the fragement of stripped material. The Energy-Dispersive X-ray analysis showed the presence of elements such as cadmium indicating a contamination of the fracture surface. Cadmium is associated with the coating of the bolts used to fasten the drive body onto the flow body. Because the fracture surface shows evidence characteristic of fatigue crack propagation, the presence of chromium as well as mud cracks on the fracture surface cannot be attributed to the anodizing process since such a crack can only initiate during operation.

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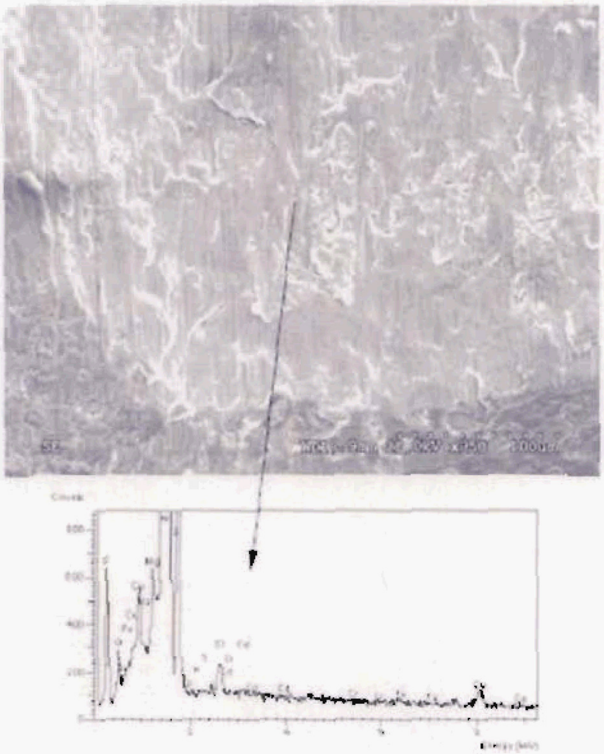

Figure 37

Chemical analysis performed on the sheared fracture surface on the fragment of stripped material. No evidence of cadmium was found indicating that the portion of the fracture surface next to the root of the thread where contaminants were found has most likely been present for some time and prior to the overload fracture.

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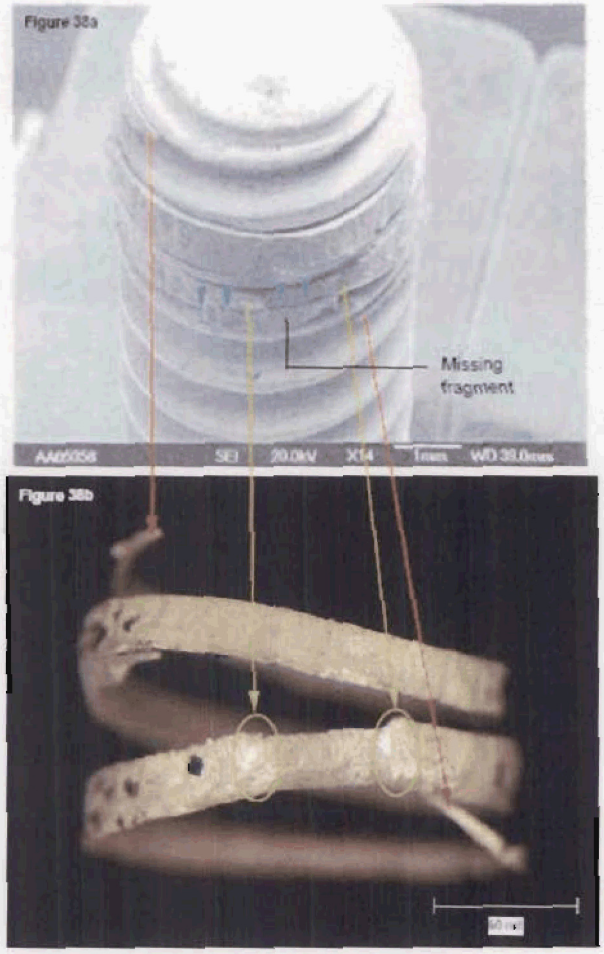

Figure 38

Figure 38a) Figure 9B from Honeywell's South Bend Materials Technology Center report No. AA05358 and titled "Investigation of B-37 fuel Control, S/N 68008", dated 11/11/05, showing the presence of a crack on the fragment of stripped material when it was still attached to bolt No. 3 (blue arrow heads).

Figure 38b) Area of the stripped material matching the area where evidence of fatigue crack propagation was observed on the as removed bolt No. 3. The details of the fracture surface are provided in photographs 29 to 37. This shows that there was a pre-existing crack at the time of the final fracture. The fragment containing the matching fracture surface was not submitted to the lab for examination.