ANNEXURE C

Turbomeca Africa
SAFRAN Group

Report No.	001-2005-TMA
Date:	23-Oct-05
Page:	1 of 11

Investigation Report

1. Material P/N	2. Material S/N	3. Material Description
0292005270	16077	ENGINE

4. Engine / Component Type	5. Aircraft Type	6. Customer
Arriel 1k1	Agusta 109 K2	Acher Aviation

7. Customer Complaint Yes [ ] No [X] Number: N/A

8. Customer Reference N/A

9. Reported Material Condition

During a winching operation, the helicopter crashed into the sea on 03-Sept-2005.

10. Investigation Findings & Conclusions

From the investigation findings it is concluded that the engine was most probably in a serviceable condition and producing sufficient power at the time of the accident.

11. Material Condition Reported Confirmed Yes [ ] No [ ]

12. Corrective Actions Yes [ ] No [X] Reference: N/A

13. Recommendations/Actions taken

NIL

14. Report Distribution

TMF
SACAA

15. Signature

Investigator

SCHRÖDER	[signature]	31 OCTOBER 2005.
Name	Signature	Date

16. Customer Representative

N/A	N/A	N/A
Name	Signature	Date

1 REPORTED CONDITION

1.1 During a winching operation, the helicopter crashed into the sea on 03-Sept-2005.

1.2 At the time of the accident the wind was blowing in a North-easterly direction at approximately 25 knots and the day temperature was 22°C.

1.3 At this point no report has been received from the pilot.

2 HISTORY

2.1 MODULAR COMPOSITION

	MO 1	MO 2	MO 3	MO 4	MO 5	FCU
S/No	16078	16030	16030	16091	16026	606M
TSN	4321,4	4819,0	4819,0	4666,21	1504,5	2266,57
TSO	N/A	N/A	2004,0	N/A	N/A	N/A

2.2 SERVICING

On 12-Aug 2005 the Module 2 and 3 were replaced and on 02-Sept-2005 the 100hr MPI service was completed. On 03-Sept-2005 (5hrs after the said MPI the accident happened).

2.3 POWER CHECK

The last recorded power check was done during the ground test run performed after the MPI servicing on 03-Oct-2005 and for this engine + 6% was recorded.

3 INTRODUCTION

3.1 After having been submerged in approximately 10 meters of water for two days, after the accident, the helicopter was recovered and transported to the operational hanger for initiation of the investigation.

3.2 At this stage the engines were not suspected of having contributed to the accident, so a Turbomeca engine investigator was only engaged in the preliminary investigation on the 12-Sept-2005.

3.3 During this exercise the following observations were made with reference to the visible condition of the engines.

3.3.1 ENGINE SERIAL NUMBER 16077 (number 1 Engine PORT side)

- No obvious external accident impact damage to engine
- Slight evidence of surface corrosion on various engine parts
- The free turbine could not be rotated by hand
- No blade damage (temperature or impact) on free turbine
- Compressor bleed valve in "open" position
- Throttle positively connected to FCU
- No fuel or oil filter blockage indicators "on"
- Gas Generator, no rotation with slight ingestion damage on rotor blades leading edges
- Magnetic plugs not checked, will action at TMA site
- Drive shaft from engine to transmission ruptured

4 INVESTIGATION (TMA site)

4.1 For this part of the investigation, the work done was limited to:

- Receipt inspection
- Boroscopic inspection
- Strip down (Removal of the FCU and Module 05 to facilitate inspection of the drive gear and retaining nut index marks)

4.1.1 Receipt inspection

- Receipt inspection confirmed, no accident impact damage to engine, see figures I and 2.

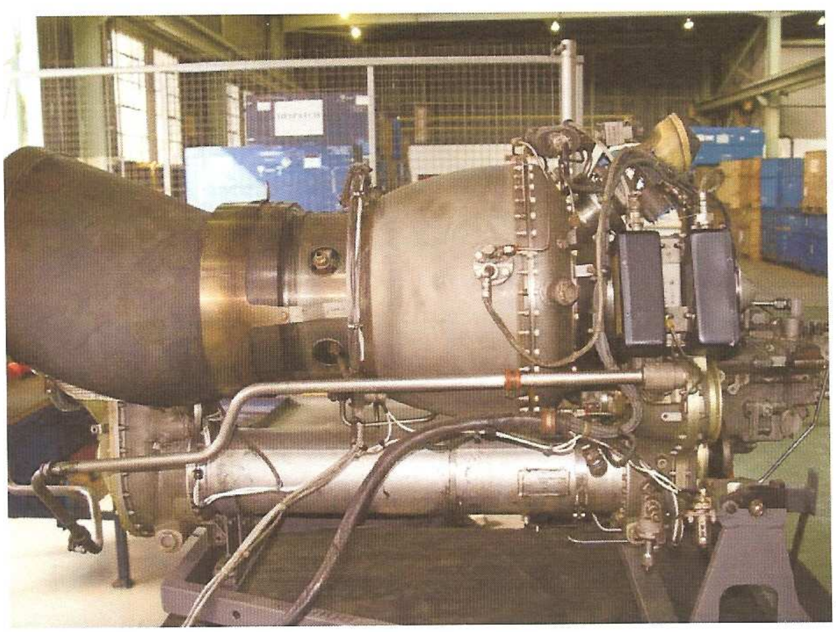


FIGURE 1

FIGURE 2

- Apart from showing evidence of progressing corrosion, all external components and items were intact and properly secured.
- The free turbine and gas generator were not free to rotate radially by hand.
- The engine to airframe gearbox drive shaft had ruptured, but the engine side flange was still intact, although severely corroded, see figure 3 and 4. It was noted that this drive shaft was fitted with the "engine side" attached to the main rotor gearbox flange.

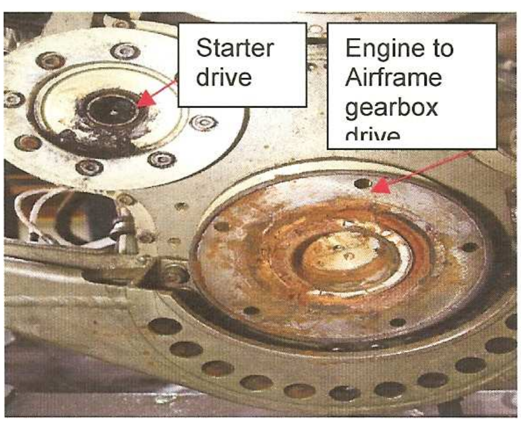


FIGURE 3

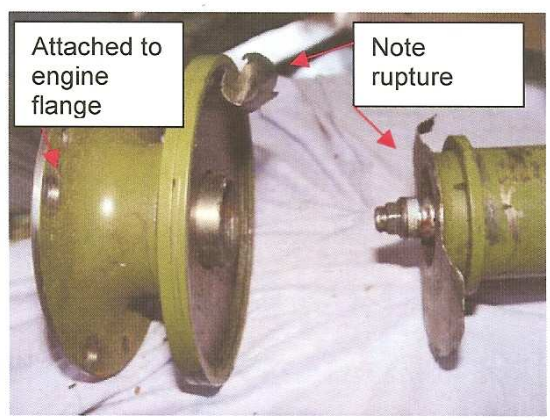


FIGURE 4

- The cooler drive shaft splines were in a satisfactory condition although showing signs of slight corrosion see figure 5.

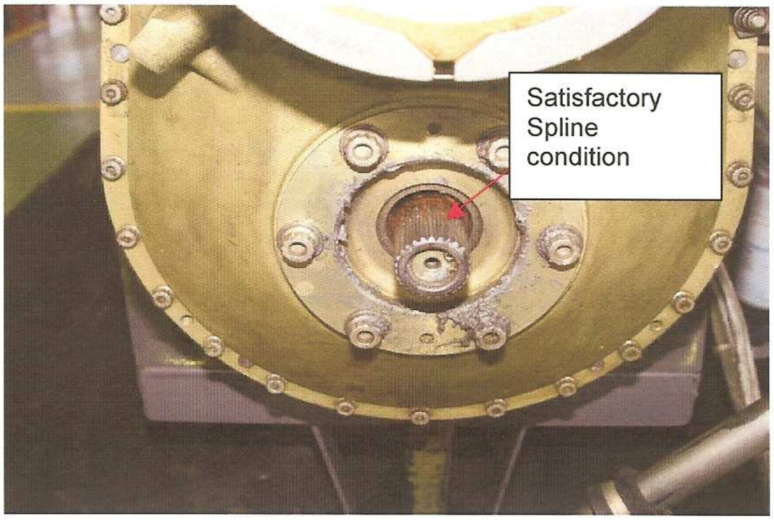


FIGURE 5

- Inspection of the axial compressor blades did not reveal significant erosion to the leading edges or any blade distortion due to accident impact. However, small ingestion damage could be seen on the leading edges of various blades, see figures 6 and 7.

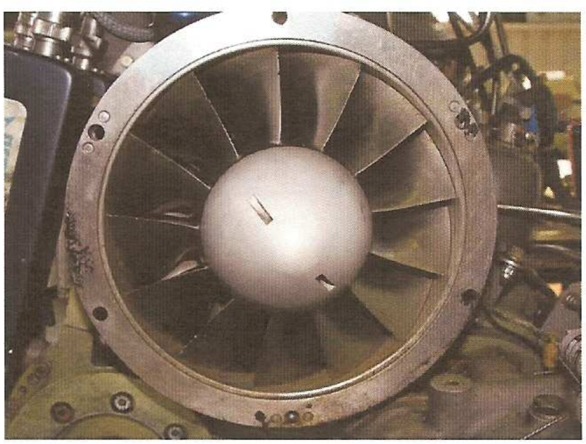


FIGURE 6

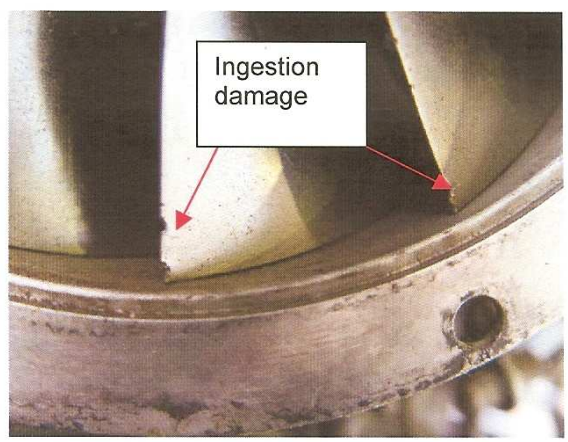


FIGURE 7

- Examination of the compressor bleed valve confirmed the valve to be in the "OPEN" position

- Removal and inspection of the oil filter showed the filter to be free from any contamination, see figure 8

FIGURE 8

- Visual examination of the magnetic plugs fitted to the oil scavenge system from the gas generator rear bearing, the module 1, the module 5 and oil supply line showed no evidence of Ferrous material collection. Only oil/water sludge could be seen on the items, see figures 9 to12 (oil sample taken from MO5 severely contaminated with water).

FIGURE 9

FIGURE 10

FIGURE 11

FIGURE 12

- Removal and inspection showed the accessory gearbox strainer and the gas generator strainer to be free from metallic contamination although polluted with oil/water sludge, see figures 13 and 14.

FIGURE 13

FIGURE 14

- Permeability test performed on the injection wheel showed the flow to be satisfactory at between 5.4 and 5.7 seconds (limit is equal to or less than 8 seconds).

4.2.1 **Boroscopic inspection:**

- The combustion chamber showed carbon formation associated with normal combustion and did not disclose any evidence to suspect over-temperature operation.

- The gas generator turbine (T1) did not show any blade growth (no blade tip rub) or mechanical degradation.

- The centrifugal compressor showed corrosion pitting on the majority of the vane surfaces together with slight ingestion damage being visible on some of the vane leading edges, no rotational rubbing could however be noted.

4.2.2 Strip down (FCU and Module 5 removal)

- Removal of the FCU was initiated with fuel sampling collection and removal inspection of the filter. This operation showed the fuel sample and filter to be free from contamination, see figure 15.

FIGURE 15

- The FCU and free turbine governor drive shafts were intact, see figure 16 and although the free turbine could not be rotated by hand to verify a positive drive connection to the FCU, shaft condition was such to suggest satisfactory drive connection.

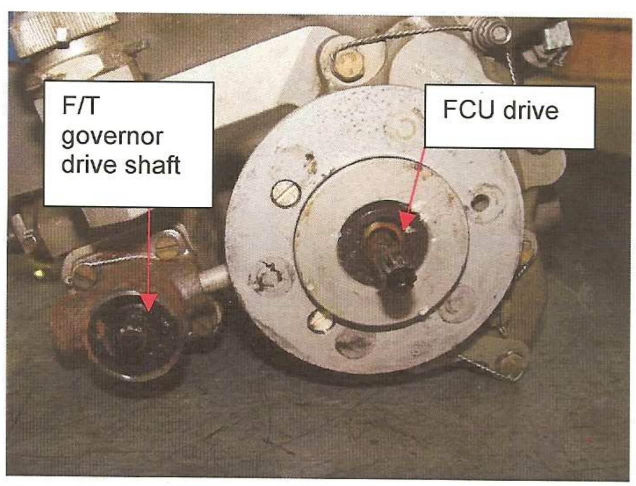


FIGURE 16

- Removal of the module 5 showed severe corrosion damage to the bearings and drive train assembly, however no significant condition with regards to the integrity of this assembly could be established, see figures 17 and 18 on page 9 (rotation of module 5 still not possible).

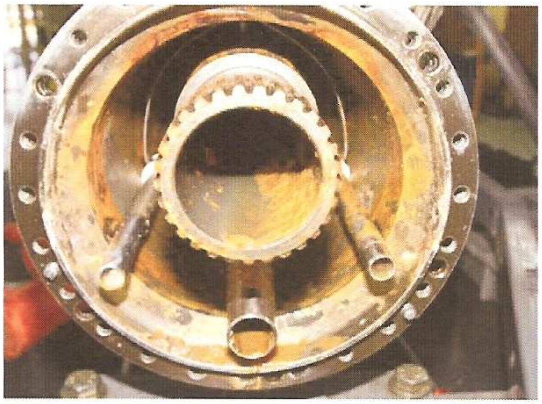


FIGURE17

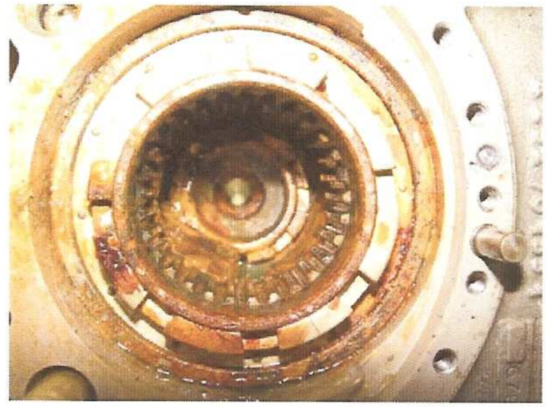


FIGURE 18

- Close inspection of the reduction gearbox drive gear and securing nut showed severe corrosion contamination on the face adjacent to the index marks. Clean-up with abrasive paper had to be performed to facilitate inspection of the said marks. By reference to figure 19 the index marks in position on the shaft and nut can be observed. No mark displacement could be confirmed.

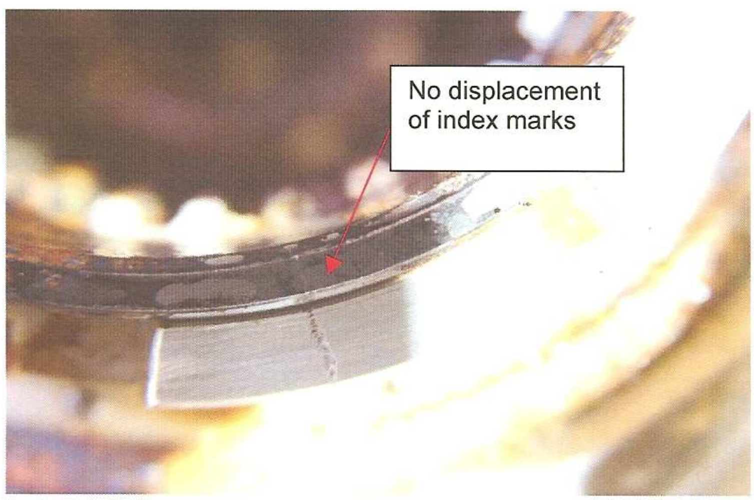


FIGURE 19

- As no displacement could be confirmed on the drive gear and nut, it was decided to remove the module to facilitate inspection of the gas generator second stage turbine (T2), the free turbine NGV and turbine wheel. By reference to figures 20, 21 and 22 it can be noted that these assemblies are all free from any evidence to indicate a possible over-temperature operation or mechanical deterioration that could have impaired satisfactory engine operation.

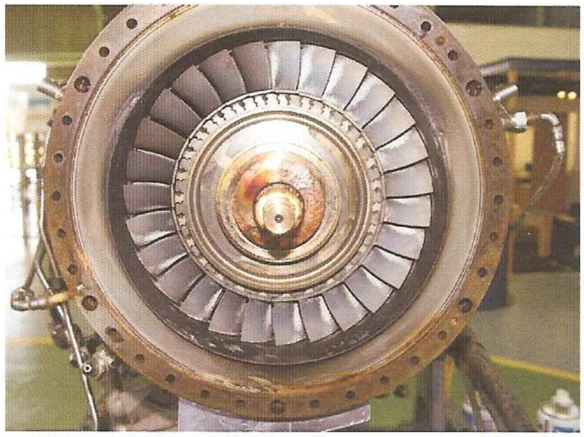


FIGURE 20 (gas generator – T2)

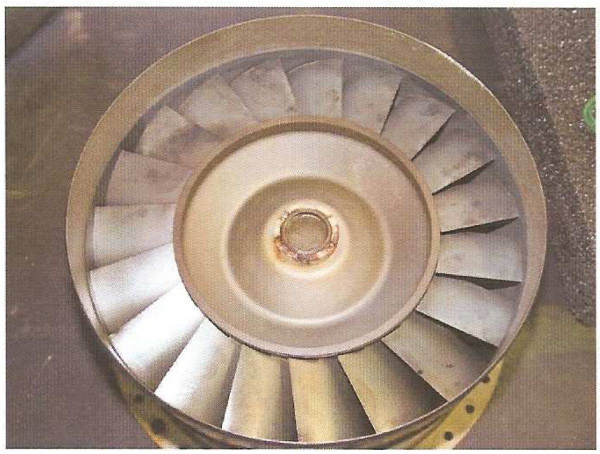


FIGURE 21 (F/T NGV)

FIGURE 22 (Free turbine wheel)

5 ANALYSIS

5.1 Displacement between the drive gear and nut is a guide to confirm engine operation during main-rotor contact with solid objects. However, with a two engine aircraft configuration, experience has shown that displacement may not occur on both engines, in fact displacement may not occur at all. This being so, displacement between the drive gear and nut should not be evaluated in isolation or be seen as the only indicator to verify engine operation. The condition of the engine combustion chamber, the gas generator hot end components and the free turbine assemblies together with the main line bearings (magnetic plugs and strainers/filters) and gearbox drive train assemblies and gearbox connecting flanges should also be considered.

5.2 Strip inspection performed on this engine showed no displacement of the drive gear and nut assembly. However, detailed examination of the various engine systems as described in paragraph 5.1 showed no significant evidence to suspect that engine operation was other than normal at the time of the mishap.

6 CONCLUSION

6.1 From the investigation findings it is concluded that the engine was most probably in a serviceable condition and producing sufficient power at the time of the accident.

6.2 The non rotation of the gas generator, the free turbine and gearboxes assemblies were due to corrosion progression as a result of engine water submersion after the accident.

Turbomeca Africa
SAFRAN Group

Investigation Report

1. Material P/N	2. Material S/N	3. Material Description
0292005270	16079	ENGINE

4. Engine / Component Type	5. Aircraft Type	6. Customer
Arriel 1k1	Agusta 109 K2	Acher Aviation

7. Customer Complaint Yes [ ] No [X] Number: N/A

8. Customer Reference N/A

9. Reported Material Condition

During a winching operation, the helicopter crashed into the sea on 03-Sept-2005.

10. Investigation Findings & Conclusions

From the investigation findings it is concluded that the engine was most probably in a serviceable condition and producing sufficient power at the time of the accident.

11. Material Condition Reported Confirmed Yes [ ] No [ ]

12. Corrective Actions Yes [ ] No [X] Reference: N/A

13. Recommendations/Actions taken

NIL

14. Report Distribution

TMF
SACAA

15. Signature

Investigator		
SCHRÖDER	[signature]	31 OCTOBER 2005.
Name	Signature	Date

16. Customer Representative

N/A	N/A	N/A
Name	Signature	Date

1 REPORTED CONDITION

1.1 During a winching operation, the helicopter crashed into the sea on 03-Sept-2005.

1.2 At the time of the accident the wind was blowing in a North-easterly direction at approximately 25 knots and the day temperature was 22°C.

1.3 At this point no report has been received from the pilot.

2 HISTORY

2.1 MODULAR COMPOSITION

	MO 1	MO 2	MO 3	MO 4	MO 5	FCU
S/No	16080	16065	16044	16079	16084	826B
TSN	5811,4	4063,07	4910,1	511,23	2812,07	2843,29
TSO	N/A	N/A	1908,1	N/A	N/A	N/A

NOTE: The data plate for the MO5 was missing and the recorded serial number was only copied from the Log card.

2.2 SERVICING

On 12-Aug 2005 the Module 2 and 3 were replaced and on 02-Sept-2005 the 100hr MPI service was completed. On 03-Sept-2005 (5hrs after the said MPI the accident happened).

2.3 POWER CHECK

The last recorded power check was done during the ground test run performed after the MPI servicing on 03-Oct-2005 and for this engine + 2% was recorded.

3 INTRODUCTION

3.1 After having been submerged in approximately 10 meters of water for two days, after the accident, the helicopter was recovered and transported to the operational hanger for initiation of the investigation.

3.2 At this stage the engines were not suspected of having contributed to the accident, so a Turbomeca engine investigator was only engaged in the preliminary investigation on the 12-Sept-2005.

3.3 During this exercise the following observations were made with reference to the visible condition of the engines.

3.3.1 ENGINE SERIAL NUMBER 16079 (number 2 Engine STB side)

- No obvious external accident impact damage to engine
- Slight evidence of surface corrosion on various engine parts
- The free turbine could not be rotated by hand
- No blade damage (temperature or impact) on free turbine
- Compressor bleed valve in "open" position
- Throttle positively connected to FCU
- No fuel or oil filter blockage indicators "on"
- Gas Generator, could be rotated by hand, although with some friction and slight ingestion damage could be seen on the leading edges of some rotor blades.
- Magnetic plugs not checked, will action at TMA site
- Drive shaft from engine to transmission ruptured

4 INVESTIGATION (TMA site)

4.1 For this part of the investigation, the work done was limited to:

- Receipt inspection
- Boroscopic inspection
- Strip down (Removal of the FCU and Module 05 to facilitate inspection of the drive gear and retaining nut index marks)

4.1.1 Receipt inspection

- Receipt inspection confirmed, no accident impact damage to engine, see figures I and 2.

Figure 1

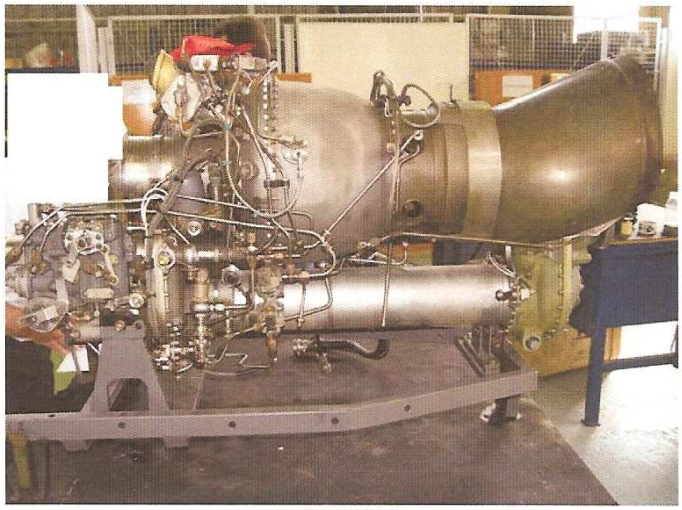


FIGURE 2

- Apart from showing evidence of progressing corrosion, all external components and items were intact and properly secured.

- Although the gas generator could be rotated by hand during the initial investigation done on 12 September 2005, no rotation was now possible. The free turbine was also not free to be rotated radially by hand.

- The engine to airframe gearbox drive shaft had ruptured at the gear box side, but the engine side flange was still intact, although severely corroded, see figures 3 and 4.

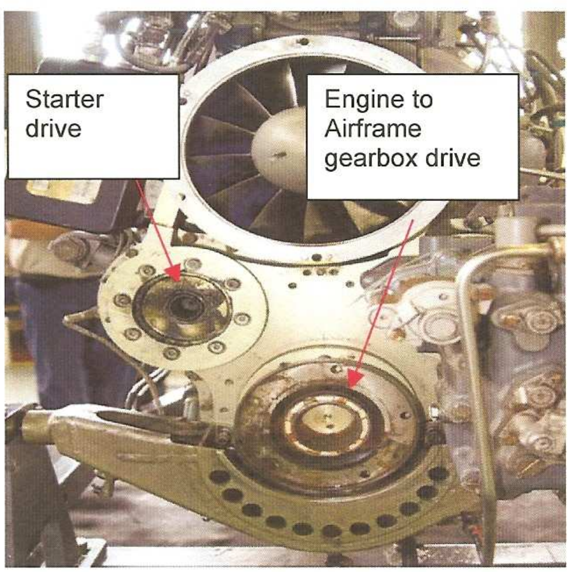


FIGURE 3

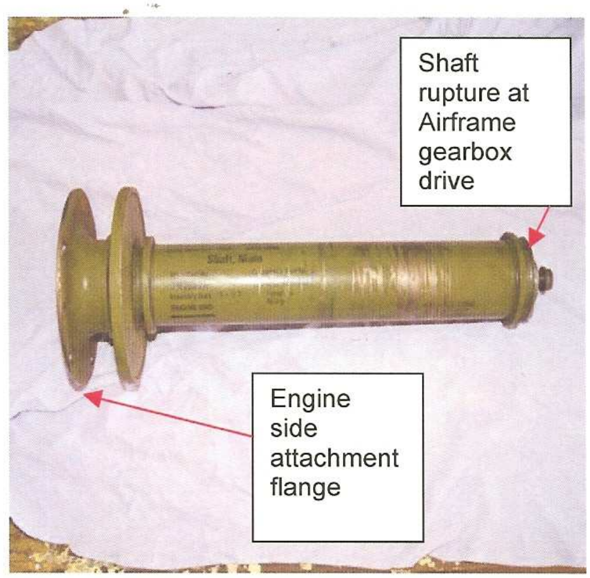


FIGURE 4

- The cooler drive shaft splines were in a satisfactory condition although the shaft end showed signs of slight corrosion see figure 5.

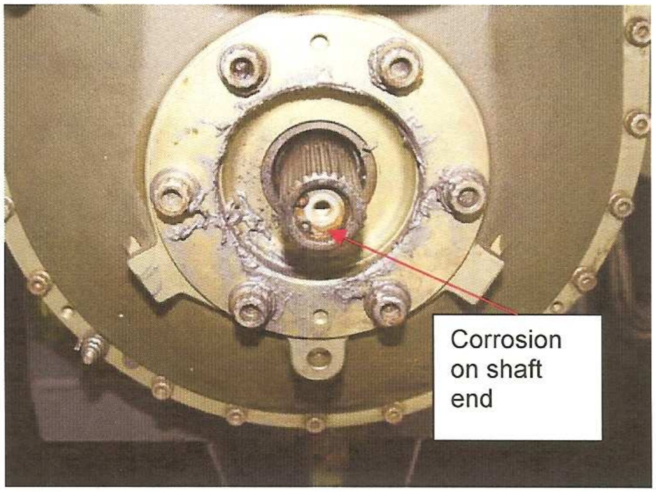


FIGURE 5

- Inspection of the axial compressor blades revealed no significant blade erosion to the leading edges (less than 1mm was the average recorded as opposed to the limit of 3mm maximum) see figure 6. Small ingestion damage could be seen on the leading edges of various blades, but no blade distortion due to accident impact could be found, see figure 7.

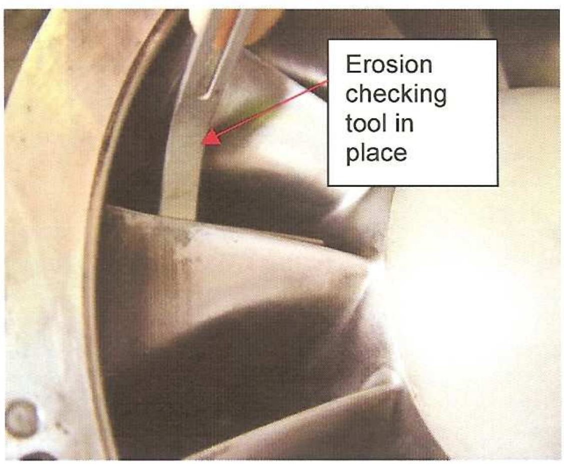


FIGURE 6

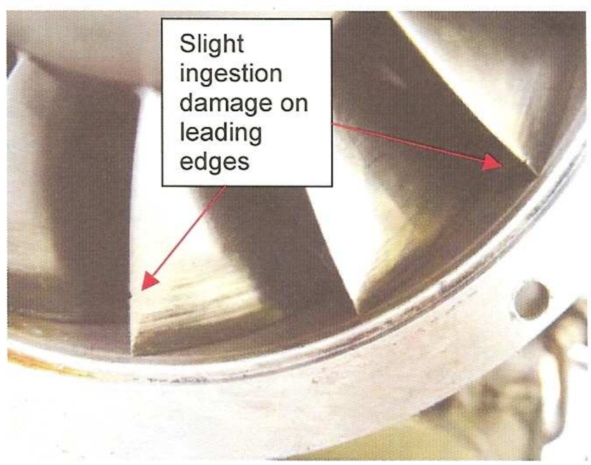


FIGURE 7

- Examination of the compressor bleed valve confirmed the valve to be in the "OPEN" position

- Removal and inspection of the oil filter showed the filter to be free from any contamination, see figure 8

FIGURE 8

- Visual examination of the magnetic plugs fitted to the oil scavenge system from the gas generator rear bearing, the module 1, the module 5 and oil supply line showed no evidence of Ferrous material collection. Only oil/water sludge could be seen on the items, see figures 9 to12 (oil sample taken from MO5 severely contaminated with water).

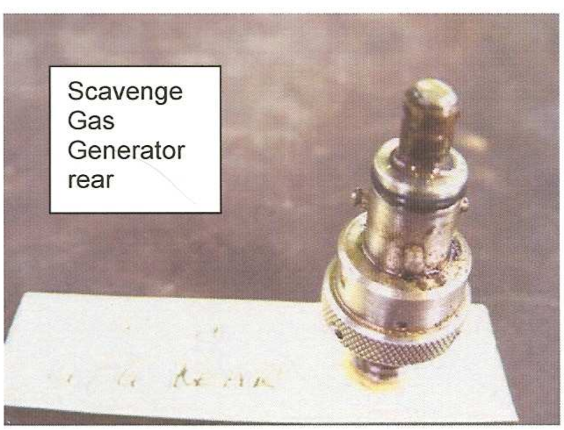


FIGURE 9

FIGURE 10

FIGURE 11

FIGURE 12

- Removal and inspection showed the accessory gearbox strainer and the gas generator strainer to be free from metallic contamination although polluted with oil/water sludge, see figures 13 and 14.

FIGURE 13

FIGURE 14

- Permeability test performed on the injection wheel showed the flow to be satisfactory at between 5.0 and 5.1 seconds (limit is equal to or less than 8 seconds).

4.2.1 **Boroscopic inspection:**

- The combustion chamber showed carbon formation associated with normal combustion and did not disclose any evidence to suspect over-temperature operation.

- The gas generator turbine (T1) did not show any blade growth (no blade tip rub) or mechanical degradation.

- The centrifugal compressor showed corrosion pitting on the majority of the vane surfaces together with slight ingestion damage being visible on some of the vane leading edges, no rotational rubbing could however be noted.

4.2.2 Strip down (FCU and Module 5 removal)

- Removal of the FCU was initiated with fuel sampling collection and removal inspection of the filter. This operation showed the fuel sample and filter to be free from contamination, see figure 15.

FIGURE 15

- The FCU and free turbine governor drive shafts were intact, see figure 16 and although the free turbine could not be rotated by hand to verify a positive drive connection to the FCU, shaft condition was such to suggest satisfactory drive connection.

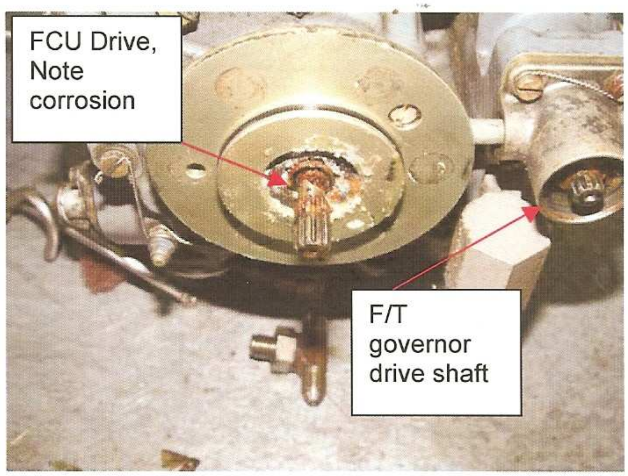


FIGURE 16

- Removal of the module 5 showed severe corrosion damage to the bearings and drive train assembly, however no significant condition with regards to the integrity of this assembly could be established, see figures 17 and 18 on page 9 (rotation of module 5 still not possible).

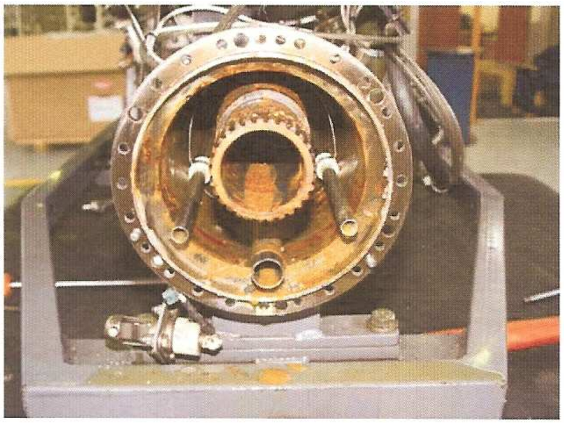


FIGURE17

FIGURE 18

- Close inspection of the reduction gearbox drive gear and securing nut showed severe corrosion contamination on the face adjacent to the index marks. Clean-up with abrasive paper had to be performed to facilitate inspection of the said marks. By reference to figure 19 the index marks in position on the shaft and nut can be observed. Slight mark displacement could be confirmed.

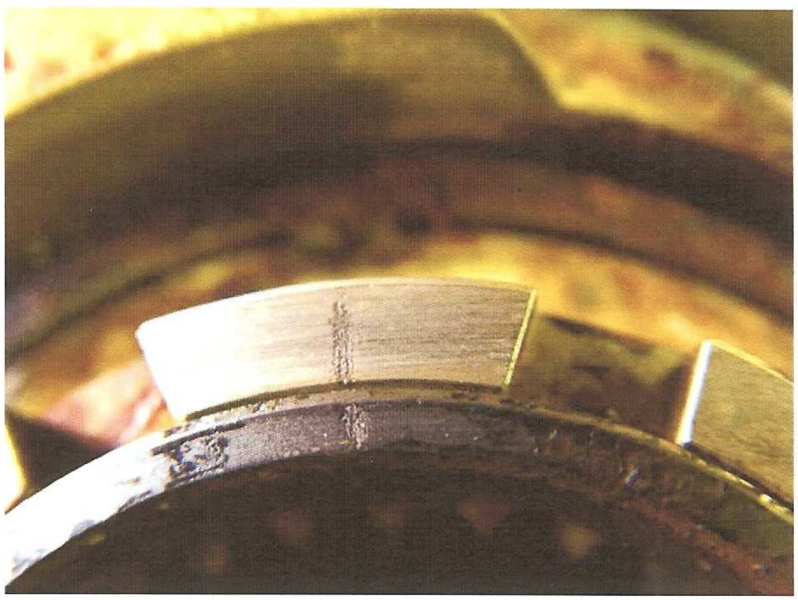


FIGURE 19

- Although displacement was confirmed on the drive gear and nut, it was decided to remove the module to facilitate inspection of the gas generator second stage turbine (T2), the free turbine NGV and turbine wheel. By reference to figures 20, 21 and 22 it can be noted that these assemblies are all free from any evidence to indicate a possible over-temperature operation or mechanical deterioration that could have impaired satisfactory engine operation.

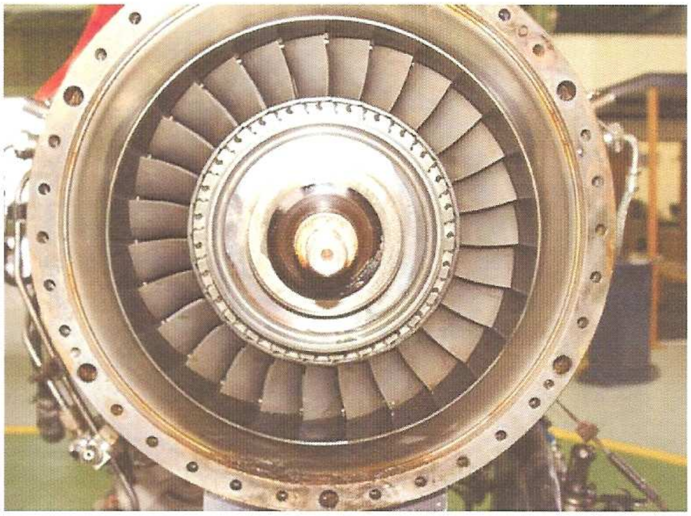


FIGURE 20 (gas generator – T2)


FIGURE 21 (F/T NGV)

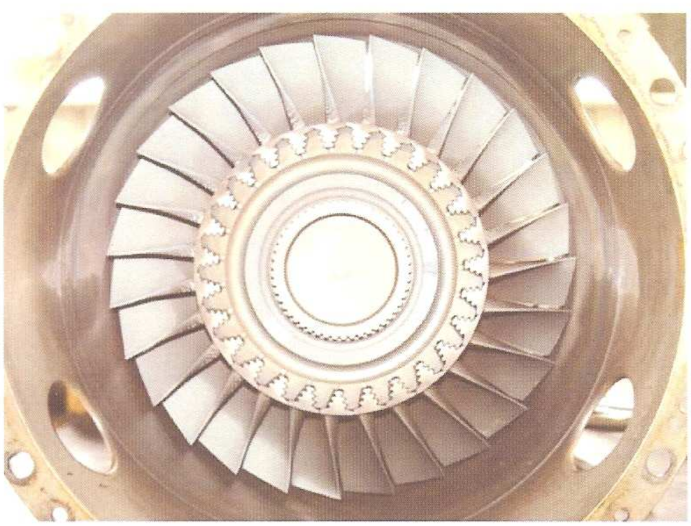


FIGURE 22 (Free turbine wheel)

5 **ANALYSIS**

5.1 Displacement between the drive gear and nut is a guide to confirm engine operation during main-rotor contact with solid objects. However, with a two engine aircraft configuration, experience has shown that displacement may not occur on both engines, in fact displacement may not occur at all. This being so, displacement between the drive gear and nut should not be evaluated in isolation or be seen as the only indicator to verify engine operation. The condition of the engine combustion chamber, the gas generator hot end components and the free turbine assemblies together with the main line bearings (magnetic plugs and strainers/filters) and gearbox drive train assemblies and gearbox connecting flanges should also be considered.

5.2 Strip inspection performed on this engine showed slight displacement of the drive gear and nut assembly. This evidence together with the condition of the various engine systems as described in paragraph 5.1 would suggest that engine operation was normal at the time of the mishap.

6 **CONCLUSION**

6.1 From the investigation findings it is concluded that the engine was most probably in a serviceable condition and producing sufficient power at the time of the accident.

6.2 The non-rotation of the gas generator, the free turbine and gearboxes assemblies as noted during the investigation were due to corrosion progression as a result of engine water submersion after the accident.

303 Galway Avenue
Bronberrik
CENTURION, 0157
Tel: (012) 654 5270 (after hours)
Cell: 082 577 7282

Department of Materials Science and Metallurgical Engineering
University of Pretoria
PRETORIA, 0002
Tel: (012) 420 3185 (office hours)
Fax: (012) 362 5304
e-mail: mtoit@postino.up.ac.za

Your reference: Purchase order number: 01111
Our reference: 2006/01

EXAMINATION OF FRACTURED COMPONENTS FROM A SALVAGED HELICOPTER (Registration number: ZS-RRB)

Madeleine du Toit

27 February 2006

1. BACKGROUND

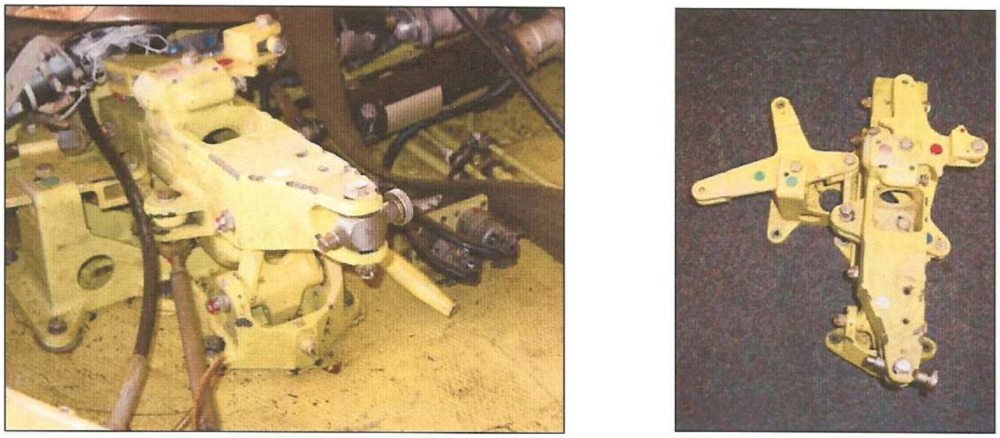
Prof M du Toit of FACET CONSULTING cc was approached by Mr Jacques Grobbelaar of the SOUTH AFRICAN CIVIL AVIATION AUTHORITY to examine a number of fractured metal components removed from the wreck of a helicopter (registration number: ZS-RRB) salvaged from the Richards Bay harbour following an accident that occurred in September 2005. The components described in this report were removed from the wreck in the presence of Mr Grobbelaar and Prof Du Toit. Prof Du Toit was requested to comment on the possible failure modes of the components, and to determine whether the presence of any pre-existing defects in the components may have hastened failure. The material and design specifications of the components were not supplied. The observations made during this investigation are described below.

2. INVESTIGATION

2.1 Mixing unit:

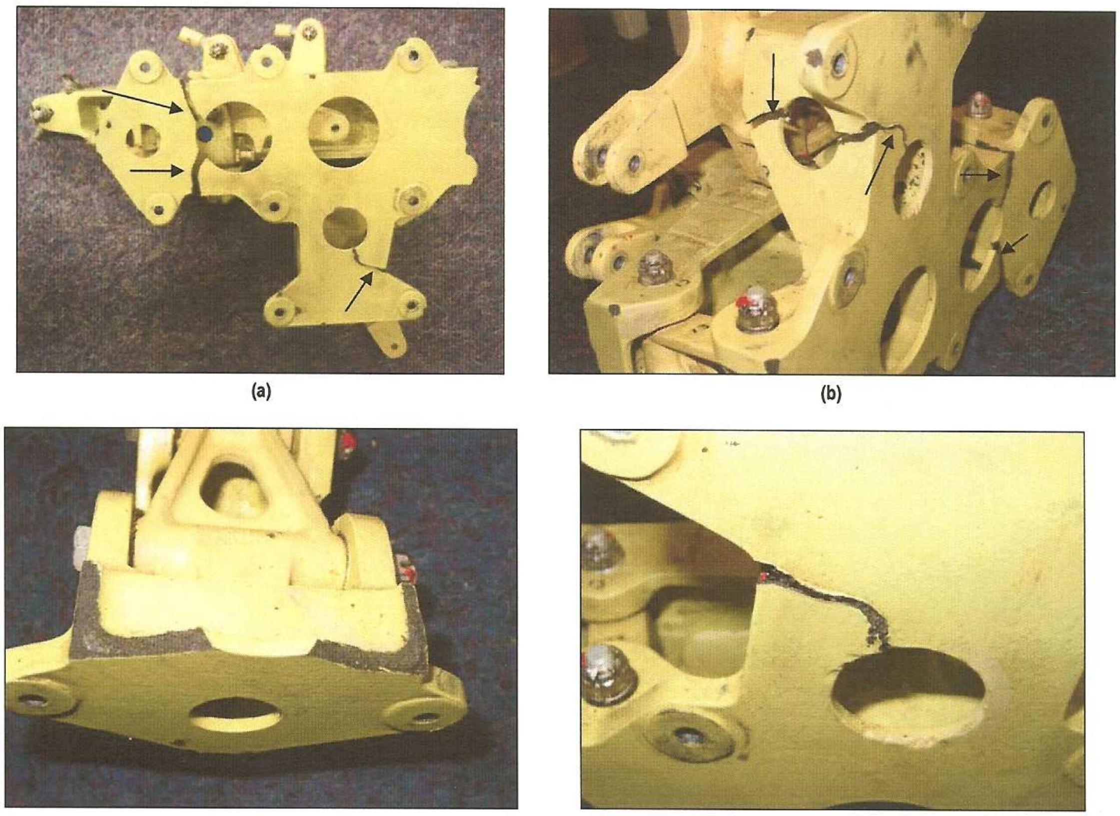
Photographs of the damaged mixing unit *in-situ* in the wreck of the helicopter and after removal are shown in Figures 1(a) and (b), respectively. Visual examination of the mixing unit revealed four separate cracks (highlighted by the arrows in Figures 2(a) and (b)). Enlarged views of these cracks are shown in Figures 2(c) and (d). All the cracks are associated with the inherent stress concentrations caused by integral holes in the mixing unit. The fracture surfaces of these cracks were examined visually and at low magnification and were found to be similar in appearance, with coarse, granular surfaces, uniform dark gray colouration and well-defined chevron markings. Significant plastic deformation did not occur prior to final fracture. The appearance of the fractures is therefore consistent with rapid, brittle failure under impact loading conditions. No evidence of any pre-existing cracks, that may have caused or accelerated failure, was observed during the examination of the cracks in the mixing unit.

More superficial damage to the surface of the mixing unit was observed in the form of a number of single or overlapping chips, examples of which are shown in Figures 3(a) to (d). The fracture surfaces of these defects are in all cases similar to those of the cracks observed in the same unit, and display the typical features characteristic of brittle failure caused by impact loading (i.e. a coarse granular appearance with little plastic deformation). The majority of these defects were observed on the top surface of the unit, suggesting an impact or impacts originating from above the mixing unit.



(a) (b)

Figure 1. Photographs of the damaged mixing unit: (a) *in-situ* in the wreck of the helicopter (magnification: approximately 0,22x), and (b) after removal (magnification: 0,15x).



(a) (b) (c) (d)

Figure 2. Cracks observed in the mixing unit: (a) magnification: 0,23x; (b) magnification: approximately 0,37x; (c) magnification: 0,7x; and (d) magnification: 0,8x.

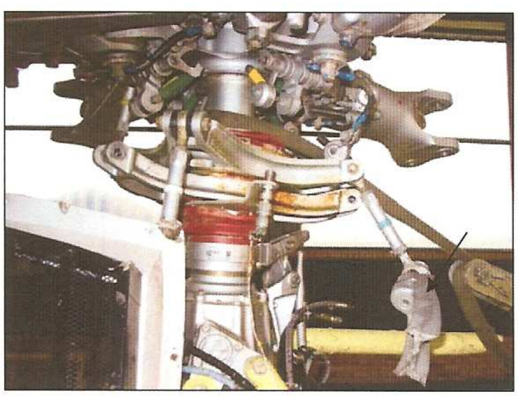

(a) (b)


(c) (d)

Figure 3. Damage to the surface of the mixing unit: (a) magnification: 0,9x; (b) magnification: 0,5x; (c) magnification: 1x; and (d) magnification: 0,6x.

2.2 <u>Main rotor blade horn</u>:

Photographs of the fractured main rotor blade horn *in-situ* in the helicopter wreck, and after removal, are shown in Figures 5(a) and (b), respectively.




(a) (b)

Figure 5. The fractured main rotor blade horn: (a) *in–situ* in the helicopter wreck (magnification: approximately 0,01x); and (b) after removal (magnification: 0,25x).

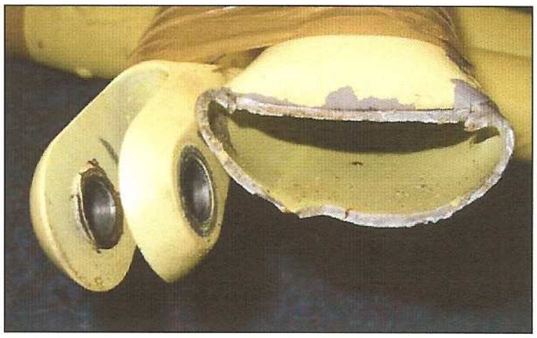
An enlarged view of the fracture surface of the blade horn is shown in Figure 6. The fracture surface is coarse and uneven, with a uniform gray colour, shallow 45° shear lips and distinct chevron markings. Little evidence of plastic deformation prior to failure was observed and no pre-existing cracks could be identified. These features of the fracture surface are consistent with a predominantly brittle failure mode under impact loading conditions. This conclusion is corroborated by the absence of any visible plastic deformation in the vicinity of the fracture site.

Figure 6. Fracture surface of the fractured blade horn (magnification: 1,2x).

2.3 <u>Main rotor gear box supports</u>:

As shown in Figure 7, the two main rotor gear box supports are tubular aluminium components with diameters of approximately 51 mm, and wall thicknesses of about 2,4 mm. Both the left and right supports fractured approximately halfway along the length of each component. Enlarged views of the fractures surfaces of both supports are shown in Figures 8(a) and (b). Significant plastic deformation is evident in the vicinity of the fracture sites, with both supports being flattened into roughly oval shapes. When the two halves of the fractured supports are lined up (as illustrated in Figure 9), it is clear that significant bending occurred prior to final failure. Bending appears to be localised, with damage limited to the central region of the supports. Initial fracture apparently occurred as a result of an excessive bending stress, which resulted in an overload shear failure at an angle of approximately 45° to the wall thickness of the tube (hemispherical part of the fracture surface). The remainder of the fracture surface of each support displays predominantly brittle failure. No evidence of any pre-existing defects, that may have contributed to the failure of the supports, was observed.

Figure 7. The main rotor gear box supports after removal from the salvaged wreck (top: left hand support; bottom: right hand support) (magnification: 0,16x).



(a) (b)

Figure 8. Enlarged views of the fracture surfaces of the (a) left hand support; and (b) right hand support (magnification: approximately 0,7x).

Figure 9. The two parts of the fractured left hand support lined up to illustrate that significant bending occurred prior to final failure (magnification: 0,47x).

2.4 Control rods:

Three damaged control rods were removed from the helicopter wreck and examined. The control rods supplied for examination are thin walled tubular aluminium components, approximately 16 or 25 mm in diameter with wall thicknesses of about 1 mm, as shown in Figures 10(a) and (b). Enlarged views of the fracture surfaces of these control rods are shown in Figures 11(a), (b) and (c).

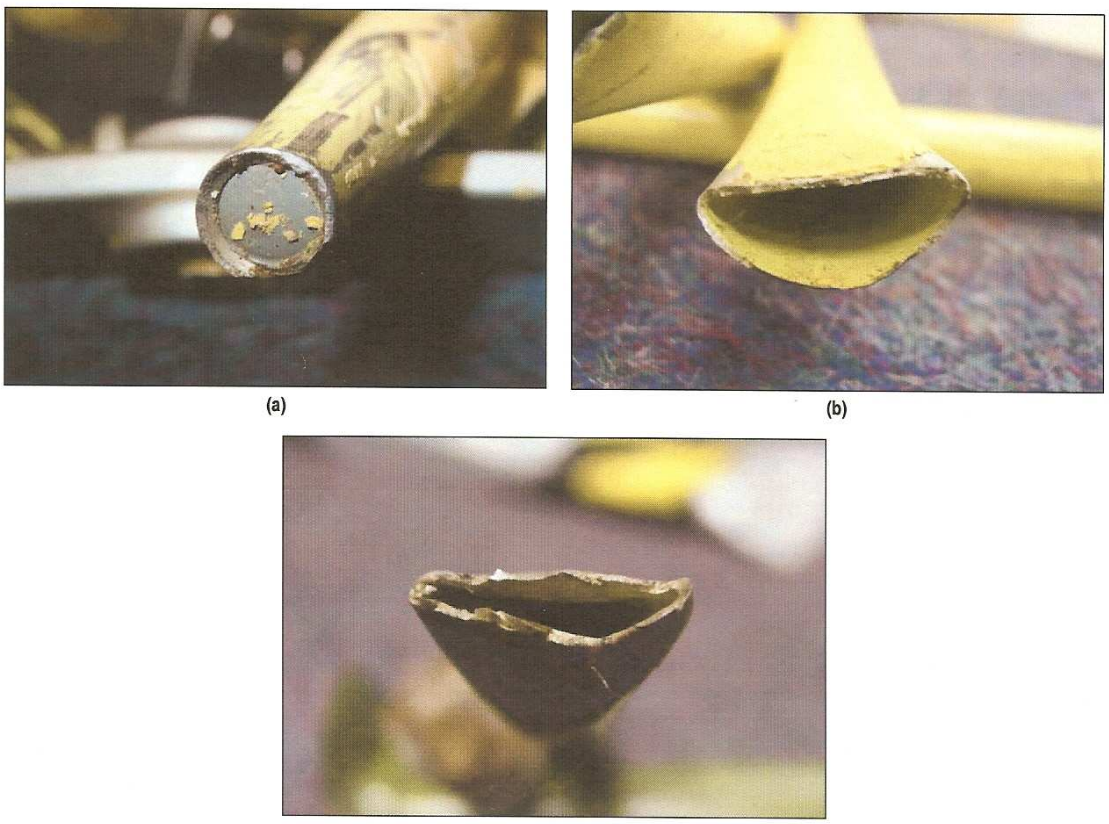
The first control rod (top of Figure 10(a)) exhibits damage along its length consistent with localised bending and compression. Fracture occurred at one of the reduced diameter ends of the control rod, resulting in the fracture surface shown in Figure 11(a). Failure occurred at an angle of approximately 45° to the wall thickness of the rod over most of the circumference, which signifies that the rod cracked as a result of overloading, resulting in an overload shear stress in the thin walled component. Scratches and damaged paint are visible on the surface of the rod adjacent to the fracture site. It is not clear whether this damage was caused during removal of the rod from the wreck, or from an object that may have contributed to the failure.

The second control rod, the two sections of which are shown in Figure 10(a), fractured at a location approximately two thirds along the length of the rod. The fracture surface is shown in Figure 11(b), and appears similar to the fracture surfaces of the gear box supports shown in Figures 8(a) and (b). Considerable plastic deformation occurred in the vicinity of the fracture surface and the available evidence suggests that failure was caused by localised bending, which resulted in predominantly shear failure of the control rod.

(a)

(b)

Figure 10. The fractured control rods supplied for examination: (a) magnification: 0,13x; and (b) magnification: 0,34x.



(a) (b)

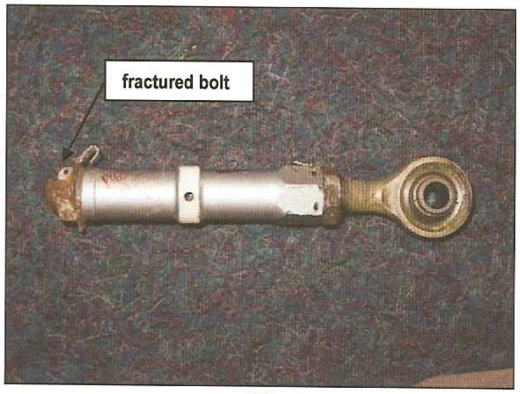
(c)

Figure 11. Enlarged views of the connecting rod fracture surfaces: (a) magnification: 2x; (b) magnification: 1x; and (c) magnification: 1,9x.

The third control rod supplied for examination is shown in Figure 10(b). Evidence of bending and compression is visible along the length of this component, and the fracture surface, shown in Figure 11(c), is similar in appearance to the fracture surface shown in Figure 11(b). The appearance of the rod and the fracture surface implies that fracture of this control rod was caused by bending, which resulted in predominantly overload shear failure.

2.5 Pitch change link:

The main rotor pitch change link is a steel component, and contained a fractured steel bolt on one side in the as-supplied condition (Figure 12(a)). An enlarged view of the bolt fracture surface is shown in Figure 12(b).



(a)

(b)

Figure 12. (a) The main rotor pitch change link in the as-supplied condition (magnification: 0,4x); and (b) an enlarged view of the fracture surface of the fractured pitch change link bolt (magnification: 1,5x).

Immersion in sea water after the accident resulted in corrosion of the uncoated steel parts of the pitch change link. One of the areas that suffered considerable corrosion damage is the fractured bolt. In the as-supplied condition, the rust deposit that formed on the cracked bolt obscured many of the underlying features of the fracture surface. In order to examine the fracture surface, the bolt was first cleaned using ethanol and a soft brush. This treatment dislodged loose rust particles, but did not remove all the corrosion product (see Figure 12(b)). The fracture surface of the bolt was observed to be largely flat and perpendicular to the shaft of the bolt, and contained a well-defined 45° shear lip on one side. The appearance of this fracture surface has some features in common with fatigue damage, and therefore the fracture surface was thoroughly cleaned using Hibatex™ solution to reveal more detail. Although this treatment removes all the corrosion product, it also damages the underlying metal and should be performed with care. The resulting fracture surface was shown to contain some linear features, but these features appeared to be chevron markings, rather than fatigue beach marks. Visual examination also revealed that the bolt apparently bent prior to failure (as shown in Figure 13), which precludes fatigue or a pre-existing defect as the primary cause of failure. The conclusion can therefore be drawn that the bolt failed as a result of overload bending stresses.

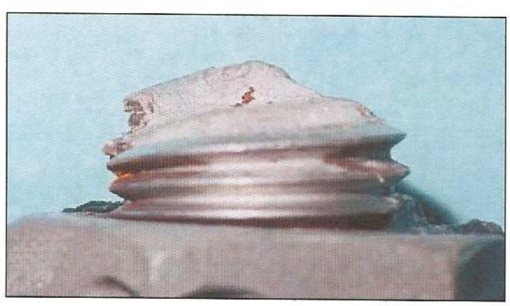


Figure 13. A side view of the pitch change link bolt, demonstrating that the bolt apparently bent prior to failure (magnification: 3,3x).

2.6 Main drive shaft couplings:

The damaged main drive shaft couplings are shown in Figures 14(a) to (d). Extensive plastic deformation is evident in the vicinity of the fracture surfaces. In all instances, the observed damage appears to be consistent with bending and tearing of the thin sheet metal under overload conditions, resulting in ductile shear failure. No evidence of any pre-existing defect that may have accelerated failure was observed on any of the fracture surfaces.

(a)

(b)

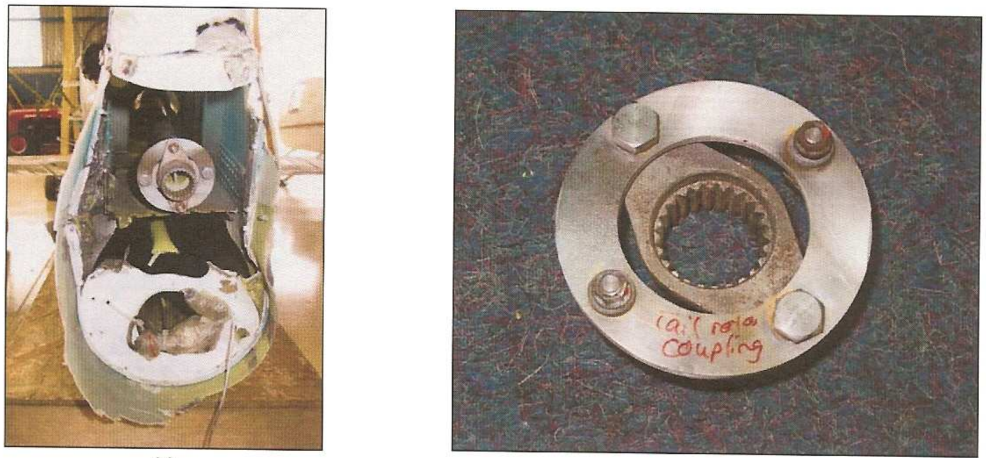
(c)

(d)

Figure 14. The damaged main drive shaft couplings in the as-supplied condition: (a) magnification: 0,35x; (b) magnification: 0,36x; (c) magnification: 1x; and (d) magnification: 0,5x.

2.7 Tail rotor coupling:

Photographs of the tail rotor coupling *in-situ* in the wreck and after removal are shown in Figures 15(a) and (b), respectively. The component appears to be largely undamaged, except for minor localised corrosive damage, probably sustained during the period in which the helicopter was submerged in sea water after the accident. Examination of the gear teeth inside the coupling revealed no evidence of overheating, excessive or uneven wear, contact fatigue damage or tooth chipping. The available evidence therefore suggests that insufficient lubrication during service, misalignment, excessive adhesive or abrasive wear, or contact fatigue damage of the tail rotor coupling gear did not cause or hasten the accident. The gear material appears to have performed well in the application. The tail rotor coupling supplied for examination also appears to have suffered very little damage during the accident itself. Since the tail rotor and a large piece of the tail section of the helicopter were not recovered during the salvage operation, further conclusions are not currently justified.



(a) (b)

Figure 15. The tail rotor coupling: (a) *in-situ* in the helicopter wreck (magnification: 0,15x); and (b) after removal (magnification: 0,6x).

2.8 Tail rotor gear box attachment:

Photographs of the tail rotor gear box attachment, *in-situ* in the wreck of the helicopter and after removal, are shown in Figures 15(a) and 16, respectively. The component was formed from aluminium alloy sheet, approximately 1,5 mm in thickness. It is normally rivetted to the tail section of the helicopter, and contains a number of holes and attachments, either rivetted or screwed to the sheet metal.

Figure 16. The damaged tail rotor gear box assembly in the as-supplied condition after removal from the wreck (magnification: approximately 0,2x).

Considerable plastic deformation is evident, resulting in bending in several areas. This damage was not caused during removal of the attachment from the wreck, as is evident from Figure 15(a) which shows the attachment in position in the helicopter prior to removal. Bending of the component resulted in the thin sheet metal tearing through the centre of one of the rivet holes, and caused damage to a threaded screw hole (as shown in Figure 17). Some of the rivets used to secure an attachment in this area also display evidence of bending.

The top section of the component had apparently been torn off (see Figure 15(a)), and was presumably not recovered during the salvage operation. The metal surrounding the fracture surfaces appears deformed and bent, and examination of the fracture sites suggests that failure was caused by tearing under the influence of an overload shear stress (see Figures 18(a) to (d)). This was confirmed by the appearance of the fracture surfaces, which displays predominantly ductile shear failure, with the fracture surfaces orientated at an angle of approximately 45° to the sheet metal surface. With the exception of the single fractured rivet hole shown in Figure 17 and very slight deformation to ovality in a number of cases, none of the rivet holes around the circumference of the attachment sustained significant damage. This implies that the rivets in the damaged section of the attachment (where the component was partly detached from the tail section) must have fractured, probably as a result of an impact load.

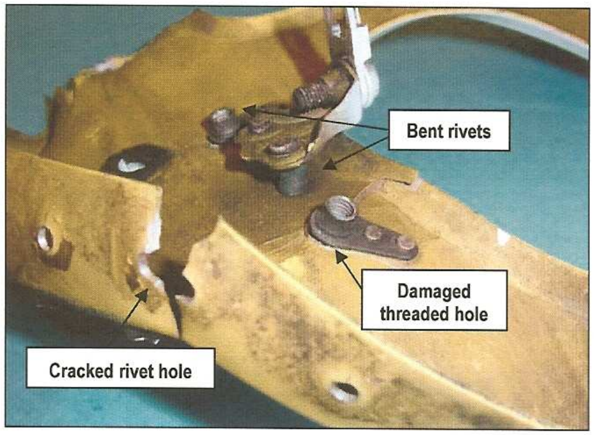


Figure 17. Damage observed in one area of the tail rotor gear box attachment (magnification: approximately 1x).

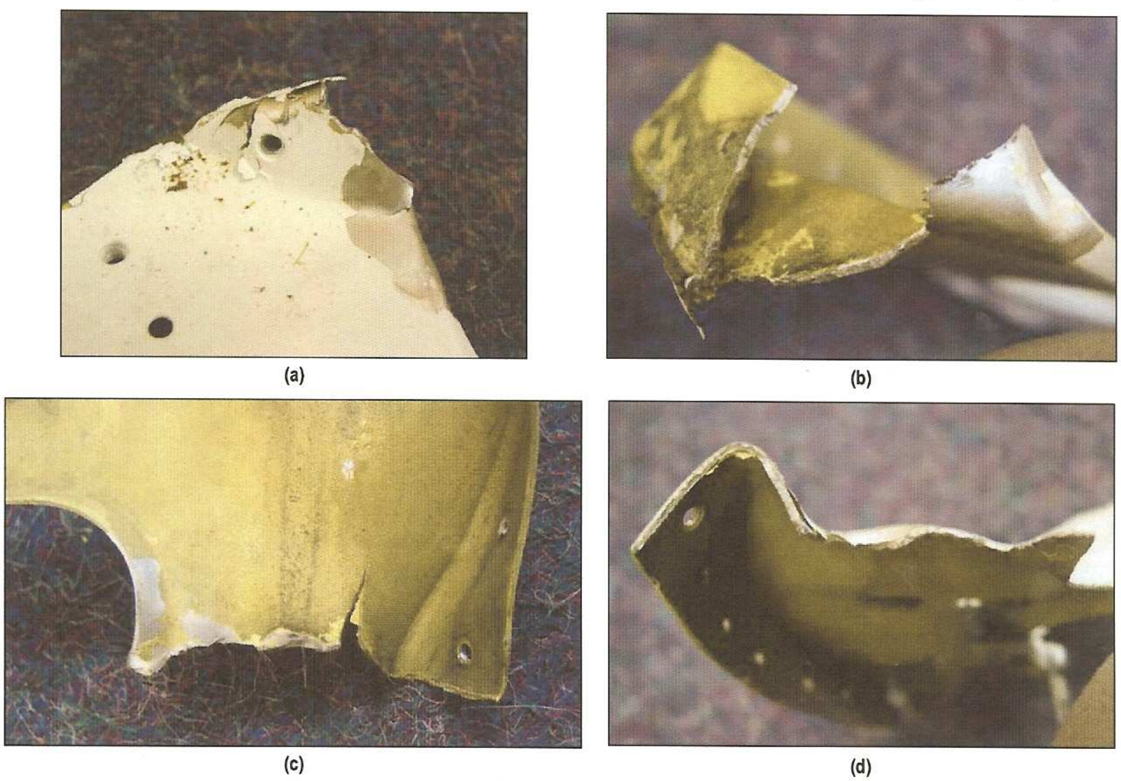


Figure 18. Views of the fracture surfaces of the tail rotor gear box attachment: (a) Left hand fracture surface as shown in Figure 16 (magnification: 0,9x); (b) left hand fracture surface as shown in Figure 16 (magnification: 1,3x); (c) right hand fracture surface as shown in Figure 16 (magnification: 0,76x); and (d) right hand fracture surface as shown in Figure 16 (magnification: 1x).

The available evidence therefore suggests that the tail rotor gear box attachment was torn when the missing tail section detached from the helicopter.

3. CONCLUSIONS

Eight components removed from the wreckage of a helicopter were supplied for examination. All the components studied during this investigation were found to have failed under the influence of overload stresses, either brittle failure caused by impact, or ductile failure caused by overload conditions. No evidence of any pre-existing defect, that may have caused or accelerated failure, was observed. The available evidence therefore suggests that failure of all the components examined was caused by the accident itself, and that none of these components directly resulted in the accident.

Signed on behalf of FACET CONSULTING cc: M du Toit

M du Toit Pr.Eng., Ph.D. (Metallurgical Engineering) (UP)