Statens haverikommission
Swedish Accident Investigation Board

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Report RL 2006:08e

Aircraft accident to SE-LTF at Gråbo, O county, Sweden on 15 February 2005

Case L-03/05

SHK investigates accidents and incidents with regard to safety. The sole objective of the investigations is the prevention similar occurrences in the future. It is not the purpose of this activity to apportion blame or liability.

Translated by CBG Konsult AB from the original Swedish at the request of the Swedish Accident Investigation Board.

In case of discrepancies between the English and the Swedish texts, the Swedish text is considered the authoritative version.

The report is also available on our Web site: www.havkom.se

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Statens haverikommission
Swedish Accident Investigation Board

2006-04-18 L-03/05

Swedish Civil Aviation Authority

601 73 NORRKÖPING

Report RL 2006:08e

The Swedish Accident Investigation Board (Statens haverikommission, SHK) has investigated an aircraft accident that occurred on 15 February 2005 at Gråbo, O county, involving an aircraft with registration SE-LTF.

In accordance with §14 of the Ordinance on the Investigation of Accidents (1990:717), the Board herewith submits a final report of the investigation.

The Board will be grateful to receive, by 20 October 2006 at the latest, particulars on how the recommendation included in this report is being followed up.

Åsa Kastman Heuman Dan Åkerman

Appendix 1

1 Extracts from Register of Licenses regarding the pilot (to the Swedish Civil Aviation Authority only)
2 TAE Preliminary report issue OIR-02-01-05-02-2005

Report RL 2006:08e

L-03/05
Report finalized 2006-04-18

Aircraft: registration and type	SE-LTF, Diamond DA-40 D
Class / airworthiness	Normal / Valid Certificate of Airworthiness
Owner/operator	Östflyg AB/Svensk Pilotutbildning AB
Time of occurrence	2005-02-15, 16:49 hours, day *Note: All times are given in Swedish standard time (UTC + 1 hour)*
Place	E. of Bergum church, Gråbo, O county, (pos 57.49N 012.09E; ca. 60 m above sea level)
Type of flight	Training flight
Weather	According to SMHI[1] analysis: wind NE 10-15 kt, good visibility, 8/8 stratocumulus with base 2000 feet, temp/dewpoint -2/-6 °C, QNH 1023 mbar (hPa)
Persons on board:	
crew members	2
passengers	0
Injuries to persons	None
Damage to aircraft	Substantially damaged
Other damage	None
Instructor:	
Sex, age, certificate	Male, 58 years, CPL
Total flying time	2 595 hours, of which 35 hours on type
Flying hours previous 90 days	21 hours, all on type
Number of landings previous 90 days	40
Student:	
Sex, age, certificate	Male, 37 years, student rating
Total flying time	13 hours, of which 13 hours on type
Flying hours previous 90 days	13 hours, of which 13 hours on type
Number of landings previous 90 days	85

The Swedish Accident Investigation Board (SHK) was informed on 15 February 2005 that an aircraft with registration SE-LTF had an accident east of Bergum church, Gråbo, O county, at 16:49 hours on the same day.

The accident was investigated by SHK, represented by Åsa Kastman Heuman, chairperson, and Dan Åkerman, Chief Investigator.

The investigation was followed by the Swedish Civil Aviation Authority, represented by Magnus Axelsson.

History of the flight

The flight departed Göteborg City Airport (Säve) with the object of practicing takeoffs and landings. For various reasons, this could not be done immediately after takeoff so the flight proceeded NE to practice emergency landings. This was done by having the instructor close the throttle, after which the student had to perform the items on the emergency checklist and

[1] SMHI = Swedish Meteorological and Hydrological Institute

prepare for landing in a suitable open field. The first practice was performed in a normal manner and was terminated when the instructor applied full throttle and the aircraft climbed to 1200 feet.

The next practice started in a similar way but when the instructor applied full throttle again the engine wound up at high RPM without any noticeable thrust being produced. The instructor then took over the aircraft while the student sent an emergency radio message saying that they planned an emergency landing. The aircraft landed on a plowed, partially snow-covered field. Because of the frozen uneven surface, the propeller, wings and landing gear were damaged. Those on board were not injured and could leave the aircraft, which remained upright with its nose resting on the ground.

The Diamond DA-40 D is a low-wing four-seater composite aircraft powered by a turbo-charged Thielert diesel engine. The engine, originally designed for an automobile, produces power at too high an RPM to drive a propeller directly, so a 1:1.69 gearbox is installed between the engine and the propeller.

The pilot's engine instrumentation consists of a combined instrument that indicates propeller RPM and engine load in percent. The propeller shaft does not have a RPM transducer, which means that the RPM indicated is actually the engine RPM divided by 1.69.

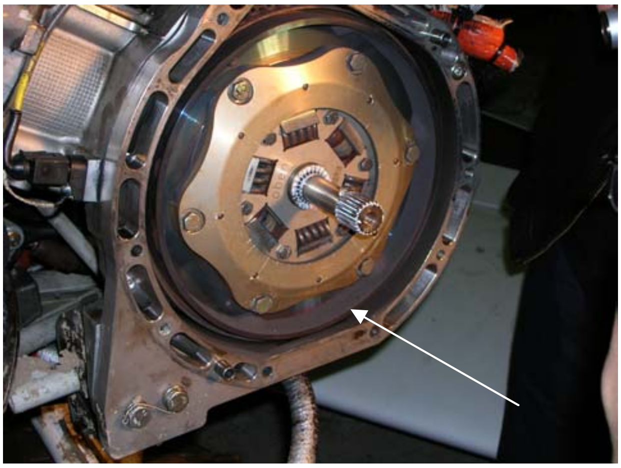
During engine startup and shutdown, stresses occur in the gearbox that could damage it. In order to prevent this a slipping-clutch is installed between the engine and the gearbox, consisting of a clutch basket with a friction plate and a pressure plate mounted on the flywheel. The clutch is adjusted so that it slips at a torque about 20 % higher than the engine's maximum.

Engine power and RPM are controlled by two parallel computers called FADEC (Full Authority Digital Engine Control) A and B. These receive commands from the pilot's throttle lever and control the engine's fuel injection system and the propeller pitch. In essence, the propeller pitch controls the RPM while the amount of fuel injected determines the power. The computers record operating data that can be downloaded to a PC for analysis.

Data from the flight in question was sent to the engine manufacturer the day after the incident. From this it could be determined that engine startup, taxiing and takeoff from Säve took place at normal engine values (see Attachment 2). At engine power-up at the end of the first practice emergency landing, it can be seen that the increase in engine RPM did not take place smoothly, but rather with oscillations. Engine RPM stabilized thereafter at normal full-throttle level. After almost 1 minute the power was again reduced and the second practice emergency landing began. When the throttle was pushed forward again the engine RPM increased beyond normal and did not stabilize until the engine's own overspeed protection cut back the amount of fuel injected at about 4800 engine RPM.

The engine manufacturer's analysis of the cause of the incident was that the clutch discussed above probably slipped.

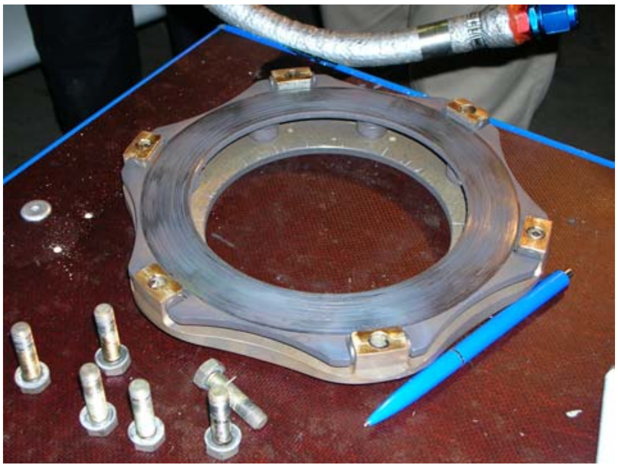
The engineering investigation was performed after the aircraft had been brought to a facility on the airfield and concentrated on the engine assembly.



The figure above shows the flywheel and clutch basket after the gearbox was removed.

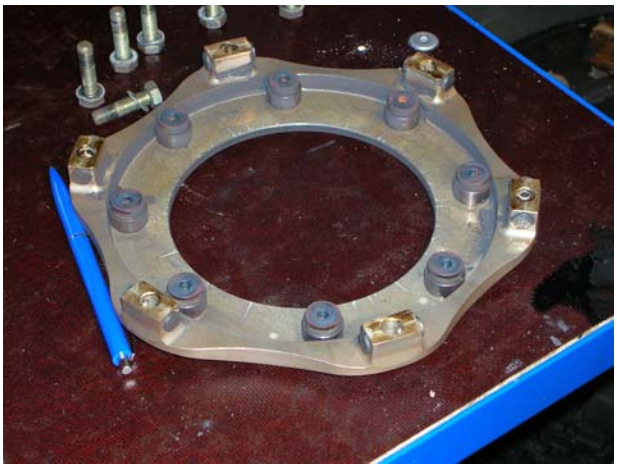
At the center of the clutch basket is the plate center with a shaft to the gearbox. The shaft is connected to the plate center via a splined coupling. It could be seen immediately that the flywheel was discolored blue and that the lower part of the flywheel was filled with dust (see arrow). The six bolts visible in the figure fasten the clutch basket to the flywheel and were flush with the clutch basket but could be loosened without any measurable torque being required.

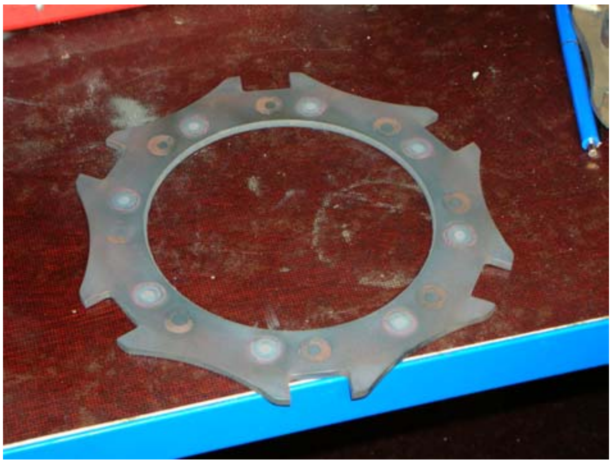
The plate (above) showed signs of overheating and the friction coating was practically entirely worn away.



The figure above shows the clutch basket with the pressure plate on top. The spring stacks can be seen between them. Each of these consists of a number of disc springs (Bellville washers) arranged so as to give the clutch a slipping torque of 290 Nm.

The two figures below show the clutch basket with its eight spring stacks and the rear side of the pressure plate. Note the six mounting pads on the clutch basket, with their holes for the mounting bolts.





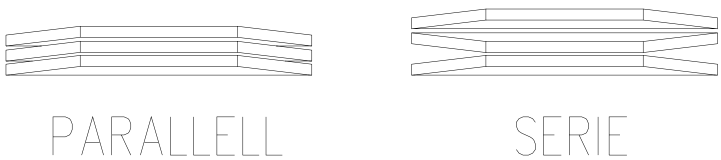
The rear side of the pressure plate showed clear marks from the spring stacks, but with an extra set of marks, probably from a previous assembly.

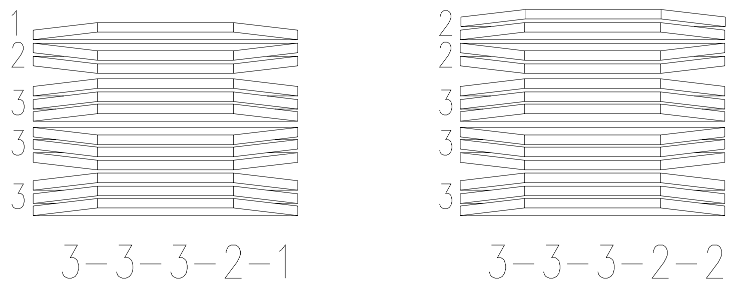
Each spring stack consists of 12-13 disc springs mounted in a two-part holder. See figure on next page.

Disc springs are cupped, hardened steel washers that are used as springs in many applications. They are characterized by strong spring power over a small displacement. Several disc springs can be assembled in either series or parallel. In series assembly the spring displacements are additive and if they are assembled in parallel, the spring forces are additive. Because of the friction between disc springs assembled in parallel, these have considerable hysteresis, that is, the spring force is significantly higher under increasing load than under decreasing load.

In the assembly in question the disc springs were assembled in parallel and series alternately. The diagrams below show three parallel disc springs and three assembled in series as well as how the assembly orders 3-3-3-2-1 and 3-3-3-2-2 are arranged. According to a factory documentation, the disc springs should be assembled 3-3-3-2-2. The assembly order 3-3-3-2-1 was also mentioned verbally.

This latter assembly order had also been used in the clutch in question.





In order for the clutch to slip at a torque of approximately 290 Nm, as discussed above, the spring stack must be compressed during assembly to the proper height and thereby to the proper preload. This is achieved by inserting shims under the spring stack. The shims are manufactured with thicknesses from 2.20 to 3.20 mm in steps of 0.05 mm. The slipping torque is then checked with a torque wrench. According to manufacturer's assembly instructions AFO 08-40, the spring assembly order can be changed or shims can be swapped until the proper torque value is obtained.

The six bolts that hold the pressure-plate to the flywheel should be tightened to a torque of 25 Nm. The bolts are locked with a locking fluid, Loctite 243, to keep them from vibrating loose. The locking fluid is a dimethyl acrylate ester that hardens in the absence of air. The strength of the bond can vary and depends upon several factors such as cleanliness of the parts to be locked and what materials are involved. For example, the locking strength on stainless steel is only about 25 % of the strength on carbon steel. In addition, the strength decreases with increasing temperature so that at 100 °C only about 50 % of the strength at room temperature remains.

The flywheel in question is made from 1.7225 steel, a hardening stainless steel with good tensile properties.

Close-up of the flywheel and one of the bolt holes in the clutch basket. Remnants of hardened locking fluid can be seen in the hole. Note that the blue discoloration that resulted when the clutch slipped and overheated is nearly entirely missing around the hole where the clutch basket had been in contact with the flywheel. In the picture there can also be discerned a line that cuts through in the bolt hole. This actually is a change in level, so that the clutch basket pad had complete contact with the flywheel only on the outer portion, the portion where the blue discoloration is missing. SHK studied several other flywheels and found that this difference in level is not uniform, but rather can vary in size.

The clutch was sent to the engine manufacturer for further investigation. The report is found in Attachment 2.

In the report it was determined that the clutch plate was completely worn down, that there was no indication that oil had penetrated into the clutch housing, and that several of the disc springs were permanently flattened, which indicates that the temperature in the spring stack was higher than about 130°C. The engine manufacturer also discusses tests that were made in order to clarify the relationship between the tightening torque of the bolts and the slipping torque of the clutch. According to these tests, a tightening torque greater than about 12 Nm is needed for the clutch to transmit the design torque, about 280 Nm. Theoretically and without friction, a torque of only about 1.6 Nm per screw is required to pre-load the spring stack so that the pressure-plate pads contact the flywheel.

Several new clutches were also assembled with the same assembly order of the disc springs and the same shims under the spring stack and a slipping torque of about 140 Nm was noted.

The manufacturer's conclusion concerning the cause of the clutch slipping is that either:

1. the bolts were not tightened to the prescribed torque, or
2. the technician who installed the clutch on SE-LTF rearranged the disc springs for some reason, or that
3. the flywheel was not replaced and the original one was allowed to remain, thereby spoiling the slipping torque adjustment.

Special investigations

The disc springs

Disc springs have been on the market since the mid-1800s. Dimensional tables and design documentation are easy to obtain on the Internet. Estimates can be made on the basis of these documents to get a clearer picture of how the springs function in the installation in question.

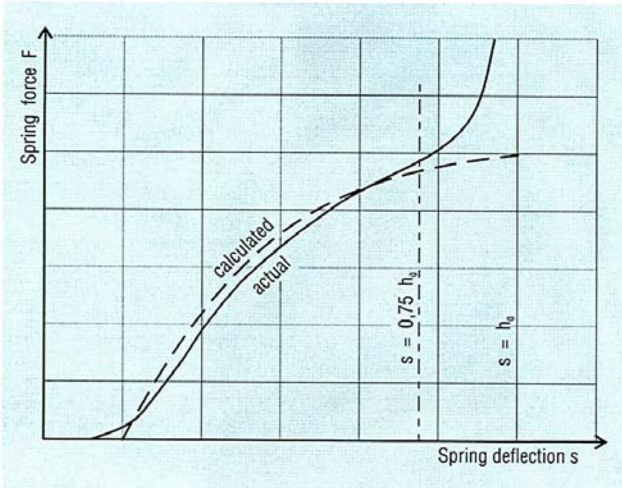
Input values:
The mean radius of the friction coating is 78.5 mm.
The coefficient of friction μ is assumed to be 0.5.

The usual calculations with these values show a requirement for a normal force on the clutch plate of about 7390 N at a torque of 290 Nm. Divided among eight spring stacks, this gives about 924 N/stack.

The individual disc springs appear to meet DIN 2093, type D147205 (D=14, d=7.2 and t=0.5 mm). Total height including material thickness = 0.9 mm. The springs can thus compress a maximum of 0.4 mm before they bottom out and become flat. Note that the springs normally are not damaged by static flattening.

As discussed previously, the springs were arranged 3-3-3-2-1, which can be illustrated either as >>><<<>>><<> or <<<>>><<<>><. The two assemblies are equivalent in this context. The spring stack is subjected to a force of about 924 N. In each subgroup of three springs (>>>) the force is divided among the springs so that each of them takes 924/3 = 308 N. In the subgroups with two springs (>>) 924 N is divided by two and each spring thus takes 462 N. The single spring (>) takes the entire force of 924 N.

Most disc springs have a relatively linear relationship between load and compression and the literature recommends calculations that are reliable up to a compression of about 75 % of maximum. At compressions above 75 %, the spring becomes increasingly progressive and the spring force increases very rapidly with compression. It should be noted that this also implies that the force decreases very rapidly with decreased compression. See diagram below.



The forces that were previously calculated indicate a compression in the springs assembled three-and-three in parallel of about 0.35 mm, that is, 87 % of the maximal compression. Compression of the other springs is 100 %, that is, they are completely flat.

Summary
The assembly order chosen resulted in several springs in the spring stack being compressed together completely and flattened, which resulted in the spring force decreasing very rapidly when the compression decreased; in this case, with the wearing of the clutch plate.

The clutch plate
On 13 June 2005, four months after the incident in question, the engine manufacturer issued a service bulletin, TAE125-0011 rev 3. In this bulletin it is stated that 105 clutches, including the one in question, should be returned to the factory for exchange. The reason for this is not stated in the bulletin, but SHK, in correspondence with the manufacturer, received information that these clutches were assembled with used plates after overhaul. These used plates were within thickness tolerance for new plates, but nevertheless some of them have slipped.

Following this and the event in question, the properties of the clutch plate have been studied by the engine manufacturer. These studies, which were carried out together with the manufacturer of the clutch plate, have shown that the slipping torque of the clutch, which is set at approximately 290 Nm at assembly, increases to approximately 410 Nm during the first 50 or so operating cycles. This is explained by the formation of a surface layer on the friction coating of the plate that acts to increase the coefficient of friction. The recycled clutch plates that slipped had all been cleaned before delivery by the engine manufacturer and this surface layer had been washed off. Tests made with cleaned plates show that after cleaning, the slipping torque increased to as much as approximately 390 Nm and that after two cleanings to as much as 340 Nm after 120 cycles but with a fairly stable value of approximately 300 Nm between 25 and 110 cycles.

SHK was present at a planned clutch change on another aircraft and there noted that the thickness of the new clutch plate was approximately 0.18 mm greater than the thickness of the plate being replaced, which had been in service for about 300 hours.

Engine roughness
All piston engines are characterized in that the torque from the crankshaft varies in phase with the explosions in the combustion chamber. The engine in question, a four-cylinder, four-stroke diesel engine, delivers two power pulses per crankshaft revolution. The amplitude of these power pulses, together with the inertial mass of the driven object, in this case the moment of inertia of the propeller, determine the loading on the transmission over and above the maximum stated torque of the engine, which can be said to constitute an average.

In the installation in question there are six spring stacks installed tangentially in the center of the clutch plate to isolate the propeller and gearbox from these variations in torque.

Conclusion

The engineering investigation of the aircraft's engine installation and analysis of engine data show that the cause of the loss of power is that the clutch slipped. It has not been possible to establish the reason for this with certainty.

It cannot be ruled out that the technician who assembled the clutch on SE-LTF rearranged the disc springs for an unknown reason, that he did not change the flywheel or that he did not tighten the bolts to the proper torque.

SHK has interviewed the technician involved but finds none of the alternatives probable.

As previously discussed, the factory tested several clutches with assembly order 3-3-3-2-1 and in all cases noted a slipping torque of 140 Nm. Because this torque is only about 57 % of what the engine can deliver at a maximum, it is not likely that SE-LTF could get into the air at all if the clutch in question had an equivalent slipping torque, let alone have flown about 25 hours without this being noticed.

The fact that recycled clutch plates slipped despite apparently having a slipping torque greater than 290 Nm can be interpreted as indicating that a new plate installed at 290 Nm does not slip only on engine startup and shutdown during the first few operations. Instead, some of the torque pulses are absorbed during operation when the clutch slips slightly, but that a wearing layer is rapidly built up which acts to increase the coefficient of friction.

A recycled plate does not build up any layer, so it continues to slip during operation. In a short time the plate then becomes so thin that the force from the disc springs decreases to the point at which the clutch slips continuously and fails.

SHK finds that the design of the clutch contains several dubious points.

1. *Torque-tightening of the clutch basket mounting bolts.*
According to the manufacturer's own investigations, approximately 7.5 times more tightening torque is required than what SHK calculated as a theoretical value for preloading the spring stacks. This indicates that there can be significant friction in the threads and/or that the clutch basket does not have proper contact with the flywheel. The difference in level on the flywheel, as previously discussed, can indicate the latter.

2. *Locking the clutch basket mounting bolts.*
Locking fluid is a fast and cheap method of locking bolts so that they do not loosen from vibration. However, locking fluid has several disadvantages that were discussed previously, and it appears as though several of these unfavorable factors were present in this case.

3. *Dimensioning of the disc springs.*
Installing spring groups in series with different numbers of springs in parallel means that the compression is proportional to the number of springs in the group. In the present case it means that the springs that were assembled in parallel and fewer than three-and-three became completely flat, which is attested to by the fact that many of the springs were permanently flattened after the incident. If this is the case, it is probable that the disc springs that are flat considerably decreased the preload, which increases the risk for slippage in the clutch. If the preload has decreased so much that the clutch slips not only during startup and shutdown, but also during operation, the process probably accelerates and the clutch fails after a short time.

In summary, SHK sees the following weaknesses in the design and installation documentation of the clutch in question.

- Secure locking for the clutch basket mounting bolts is lacking. Locking with a locking fluid cannot be considered to be reliable in the environment in question.
- The assembly instructions do not require that the mounting bolts be torqued with lubricated threads. This can mean that the preload in the screws varies despite proper tightening torque.
- The difference in level on the flywheel means that it was not possible to be certain that the clutch basket was correctly installed.
- The assembly order for the disc springs means that more than 75 % of the spring displacement of some of the washers was used up, which can cause a rapid decrease in spring force when the clutch plate wears.
- According to the assembly instructions, the assembly order of the disc springs can be changed arbitrarily by the mechanic as long as the correct slipping torque is achieved. This can lead to different clutches having different properties when the clutch plate decreases in thickness as it wears.

The accident was caused by recycling a clutch plate and by a number of shortcomings in the design and the installation documents of the clutch.

Recommendations

It is recommended that the Civil Aviation Authority and EASA:

- *Take action to correct the above-mentioned weaknesses in the design and the installation documents of the clutch (RL 2006:08 R1).*

SE-LTF
Loss of power event

February 17, 2005

Status: closed

Summary

The occurrence is related to clutch failure. Since this clutch was checked twice before it left the company it assumed that the failure was caused by maintenance.

There are two possibilities:

First possibility: The clutch could have fallen down and the maintenance mechanic rearranged the spring plate layer arrangement according to the clutch he exchanged.

Second possibility: The flywheel mass was not exchanged during the clutch exchange. The friction torque is a result of the displacement of the disk springs which is adjusted in the assembly. As soon as one part related to the displacement is exchanged the adjustment must be renewed. This is also the fact if the clutch cage is fitted to the old flywheel.

Prepared by:	Checked by:	Approved:
E. Bollen		

Index:

1 Introduction

On February 15th, 2005 a DA40 D with TAE 125-01 engine installed had a loss of power during a training flight in Sweden. The aircraft was exercising emergency landings. The two POB were unharmed. The aircraft damage is described in the Diamond investigation report IR-DA4-043

2 Facts

2.1 Pilots report

Report emergency landing Diamond DA40 TDI S/N D4.007 SE-LTF, Engine S/N 0063.

"*Yesterday 15th of February at 16.30. A teacher and his student were practicing emergency landings. At the second simulated motorstop the power were set to idle at 1000 ft. At 700 ft the teacher set the power to maximum again intending to climb. The engine did accelerate 100% but they could not feel the power and was not able to climb or keep the*
altitude. The teacher decided to make an emergency landing for real. The aircraft were landing on a field, the two onboard were unharmed.
The RH main landing legs and nose leg and propeller was broken.
Diamond Aircraft Scandinavia, Öst-Flyg AB, Hans Nilsson"

2.2 Initial inspection

2.2.1 Airplane Data:

Type:	DA 40 D
Serial-No.:	D4.007
Year of Manufacture:	2003
Call Sign:	SE-LTF
Engine Type:	Thielert TAE 125-01
Serial-No.:	0063
Propeller Type:	MTV-6-A/187-129
Serial-No.:	n.e.

2.2.2 FADEC Data

The Event log:

FADEC-A Events in chronological order:
2005-01-20 13:55:45 - Info only: Warnings cleared
2005-02-15 16:36:54 - Info only: High RPM: up to 4758 rpm for 8,4 seconds
2005-02-15 16:37:06 - Info only: High RPM: up to 4759 rpm for 10,0 seconds
2005-02-15 16:37:42 - Info only: High RPM: up to 4886 rpm for 45,9 seconds
2005-02-15 16:37:55 - Info only: High RPM: up to 4935 rpm for 2,0 seconds

The complete eventlog can be found in Appendix 5.1

2.2.3 History and maintenance program

Based on the maintenance parts, which were ordered at TAE, the clutch of the aircraft was exchanged shortly before the occurrence. According to the Diamond investigation report IR-DA4-043 the clutch was installed for less than 20 hours of operation.

2.2.4 Initial tear down inspection

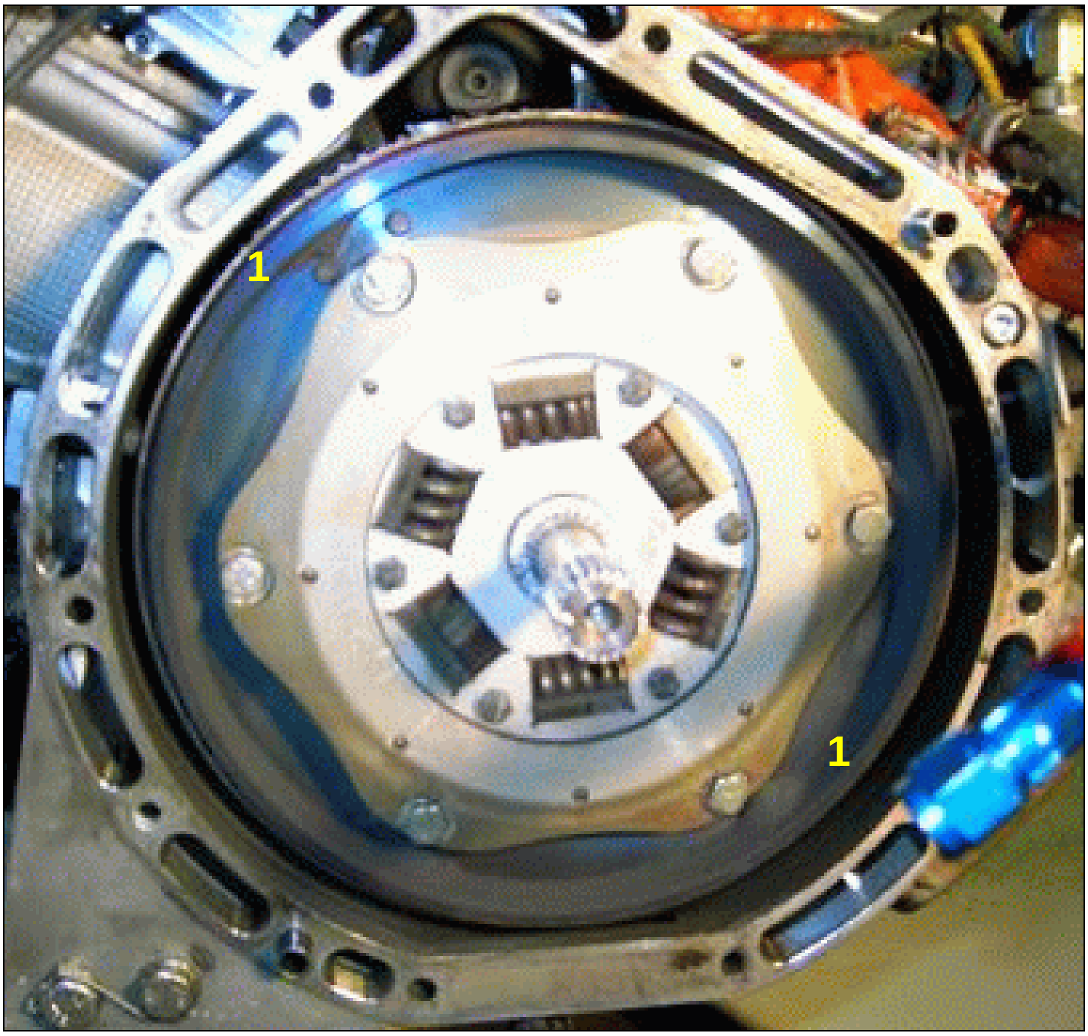
The initial tear down inspection was carried through on 22.02.05 in Götenborg by DAI and TAE with the following attendants:

Mr. Akerman	Swedish Accident Investigation Board
Mr. Östlund	Airworthiness Inspector, Aviation Safety Department of Sweden
Mr. Axelsson	CAA Sweden
Mr. Mikosch	Thielert Aircraft Engines
Mr. Nilsson	DAI Scandinavia
Mr. Ströman	Flight school
Mr. Eriksson	Mechanic

In this tear down it was detected that the screws of the clutch were not tightened with the required torque according Repair Manual RM-02-01.

Extracts of the Diamond investigation report IR-DA4-043:

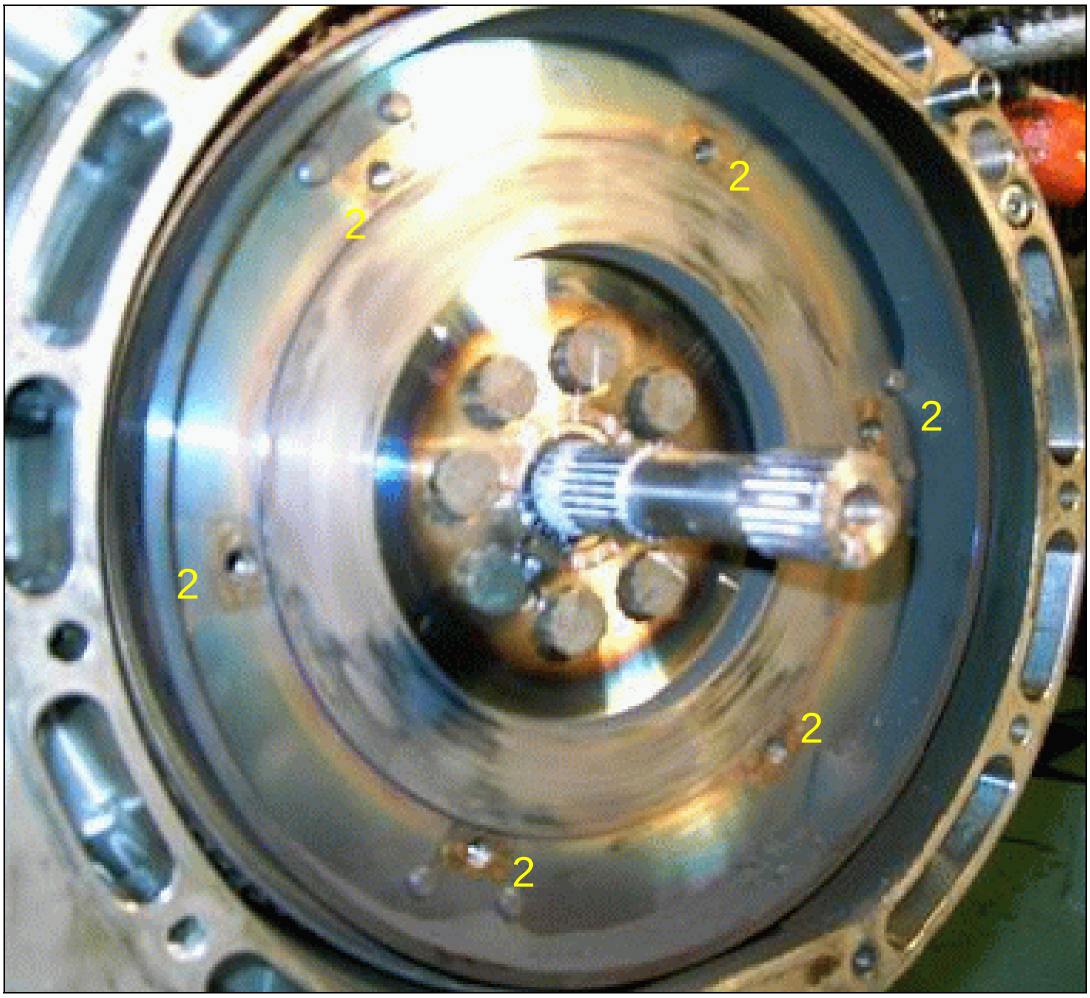
Before removing the gearbox the oil level of the gear was checked. It was enough oil inside. No leakage of the gearbox was found. After removing the gearbox the clutch was found as follows:



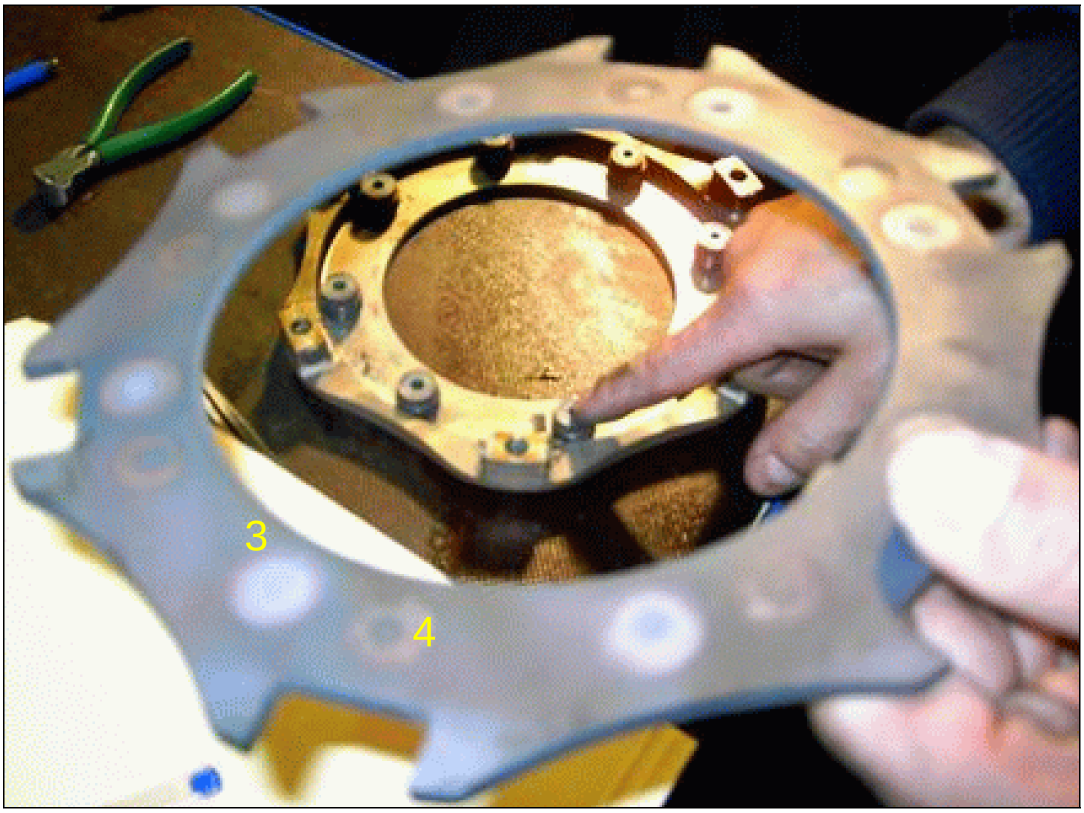
The metal of the clutch cage, the screws to fit the clutch cage, the flywheel mass disk and flywheel mass have different colours (yellow, blue and gray) as a result of thermal load. The zinc coating of the screws to fit the clutch cage was flaking off as a result of the high temperatures. Inside of the flywheel mass grouted (sintered) metal dust near the positions of the screws (1) was accumulated. All components were dry, no oil was found on the surfaces.

It was found that the torque of the screws that fit the clutch cage was less than 8 NM. However all screws were tightened so far that the clutch cage seemed to have contact to the flywheel mass. This could be seen on the pressure points of the clutch cage on the fly wheel (2).

Unlike stated in the Diamond Investigation Report, the tightening torque of the screws that fit the clutch cage has influence to the friction torque of the clutch.



At the screws that fit the clutch cage could be recognized traces of Loctite rests that looked blue and black, located at the base of the thread.



On the back side of the flywheel mass disk were found 16 marks of the spring packages that push the flywheel mass disk against the friction plate. 8 of them from the actual installation (3), 8 of them with red-brown traces of corrosion (4).
The clutch was installed only one time, and for less than 20 hours of operation, so the corrosion marks can only be from a previous installation, before this clutch was delivered from Thielert to Sweden.

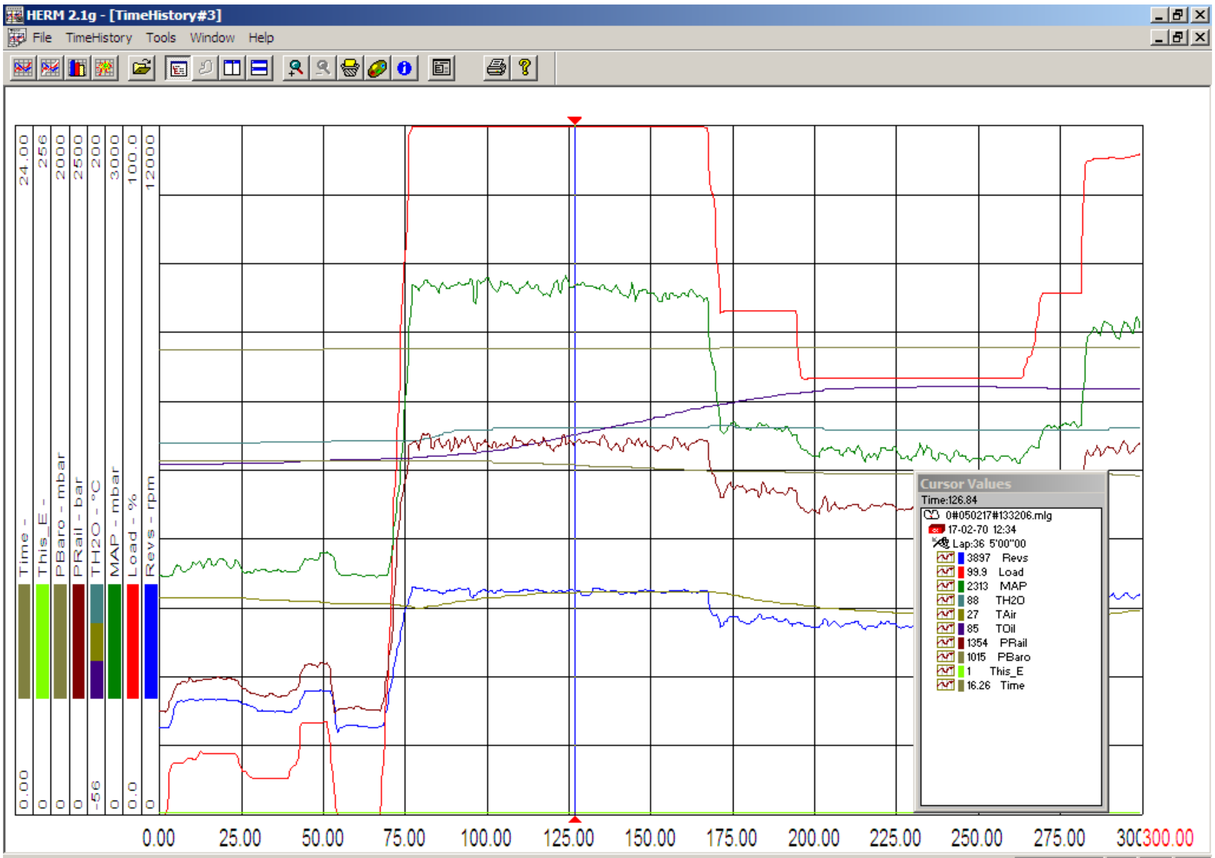
The pressure plate showed gray colour as a result of the high temperatures (> 500°C) in the clutch.

The friction plate had no friction lining left, the thickness on the measured point of the plate was 1.83 mm. It also showed evidence of the thermal load.

3 Analysis

3.1 Analysis of the FADEC data

The FADEC Logger data were downloaded on the 17th of February 2005. The engine was started at 16:14 hour (local time). The run up check was carried out successfully. Graph 1 showsthe take off at 16.25 hour. All parameters were within the limits at that point of time.



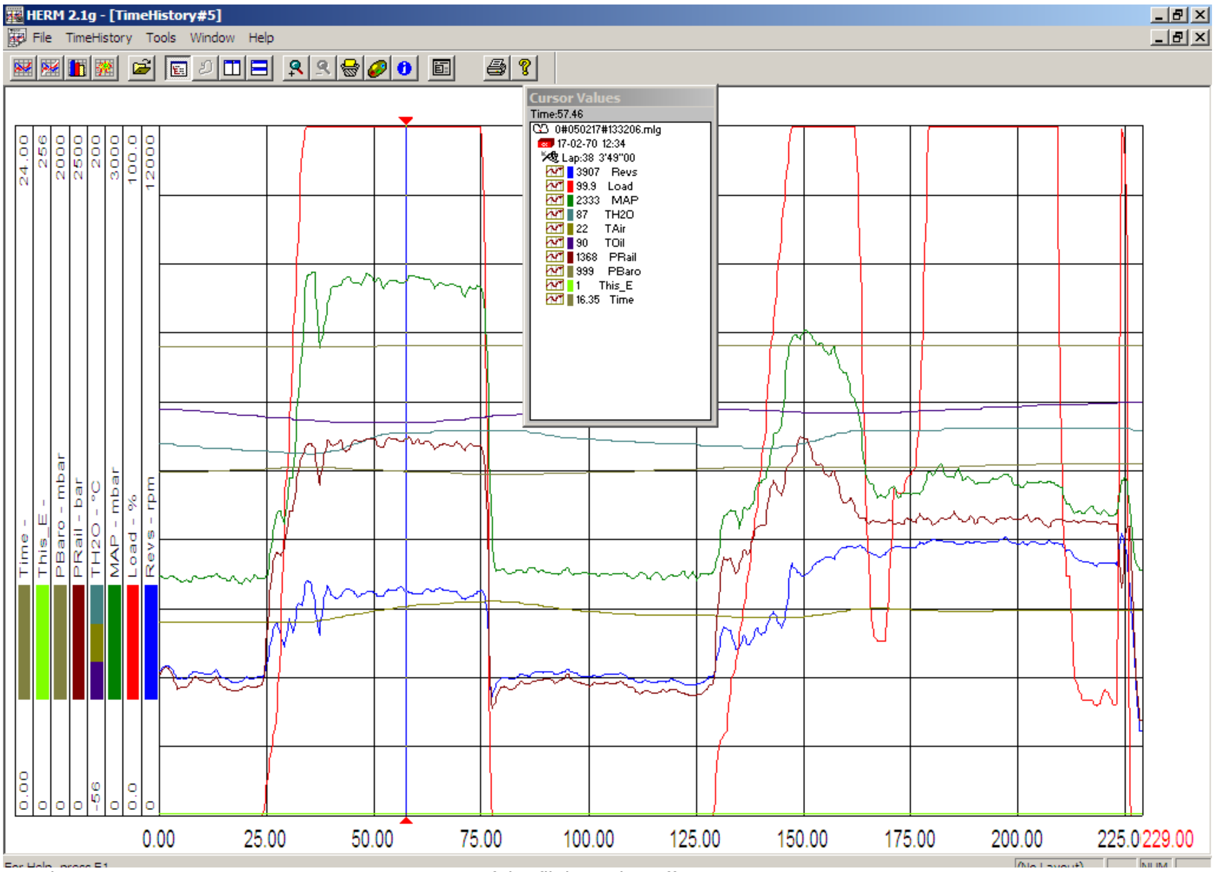
Graph 1: Motor 02-01-0408-SL01-104-0063, Start of the flight, Take Off

After Take-off, the aircraft climbed and began with idle decent stages. Graph 2 shows the first and the second full power stage. The aircraft descended with idle power setting at second 25 of graph 2. After that stage, the pilot put the throttle lever to 100 %. During this acceleration, the engine was running with an engine speed up to 4077 (2410 Prop RPM). In the next second, the engine speed broke down to 3300 RPM. This breakdown is probably caused by the propeller regulator. As soon as a high engine speed is detected, the propeller control system starts with reducing the propeller speed by changing the pitch angle. Graph 3 shows a zoom-in of the first acceleration.
The increase (Revs above 3900 engine RPM) can be caused by a slipping clutch.

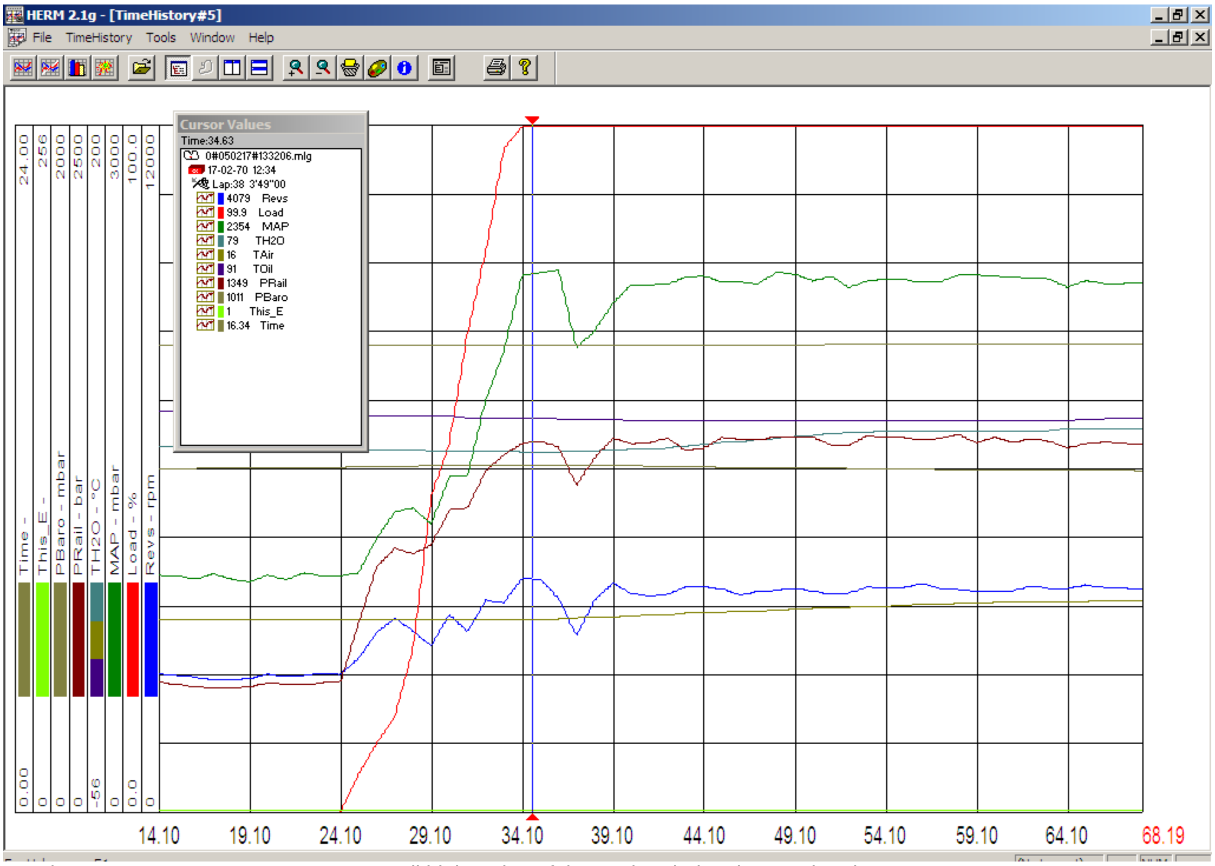
After the decent the pilot moved the throttle back to 100%. The “zoom-in” of this acceleration is visualised in graph 4. During the acceleration the engine is running at very high engine speeds up to 4780 engine RPM (2830 Prop RPM). At this point the RPM limiter is liming the power by reducing the injection volume to avoid further overspeed. The RPM limiter of the FADEC of the engine generally reduces the injection volume based on the actual RPM. The higher the engine speed is, the less fuel is injected.

The data shows a very high engine speed of approximately 4780 engine RPM, the remaining injection volume is 20% of the total desired injection volume at full power. The power reduction due to overspeed is not indicated in the CED instrument. The FADEC Software Version 2,7 will have this function integrated. During overspeed stages, the power reduction caused by the overspeed will then be indicated.

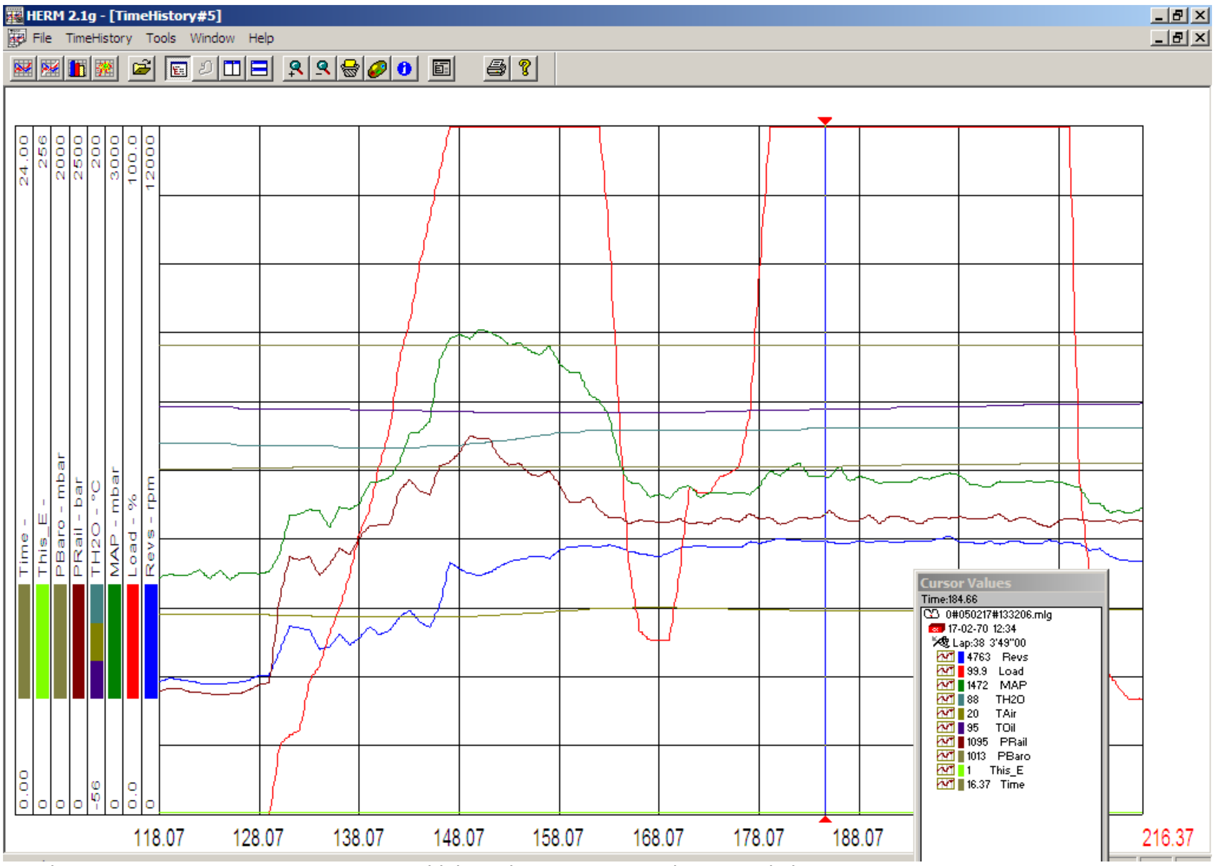
This overspeed behaviour of the engine is caused by a problem with the clutch. At the point where the power increases (and the load on the clutch increases, the clutch starts slipping. The speed at the propeller will be less than the engine speed divided by the gearbox ratio. The propeller control will push the propeller from low to high pitch.



Graph 2: Motor 02-01-0408-SL01-104-0063, Start of the flight, Take Off



Graph 3: 02-01-0408-SL01-104-0063, Small high reving of the engine during the acceleration stage



Graph 4: Motor 02-01-0408-SL01-104-0063, high engine RPMs, up to the RPM-Limiter

3.2 Analysis of the clutch

3.2.1 History of the affected clutch

The clutch was initially assembled with the engine 02-01-0311-SL01-004-0153 and delivered in March 2004. After 290 operating hours reached in November 2004, the clutch was exchanged and sent back to TAE for scheduled 300h-inspection.
In this inspection all springs, both driven plate and the friction disk (Assembly, Contact plate) were exchanged.
The clutch was inspected by the mechanic after assembly and by the inspector before delivery. Measuring equipment used is calibrated until November 2005. A recalibration check showed no deviations.
The clutch was delivered with a time since new of 304 hours on January 11th with Form One IP2162/2005.

In conclusion the overall run time of the clutch was approximately 324 hours, except parts exchanged in the 300h inspection.

3.2.2 Visual inspection of the affected clutch

Results of the visual inspection at TAE facility:

The friction pad of the friction disk (Assembly, Contact plate) is worn out totally down to the blank disk. This disk is colored dark blue to black. Partially, there are thin remains of the friction pad.

The torsional damper of the friction disk (Assembly, Contact plate) is undamaged and shows no signs of wear and tear.

The flywheel mass is colored blue due to heat influence. Due to the color the temperature must have been approximately 300°C. There is a large amount of settled dust on the flywheel mass, especially accumulated at the screws. There are no visual impurities due to other materials or other substances like oil.

Apart from the mentioned dust the clutch is clean.

The disk springs are also colored due to heat influence. Furthermore, many of these springs are completely flat like a washer and have no spring characteristic any more. The layered arrangement of all disk spring packages were similar 3-3-3-2-1.

The driven plate is colored as well. The pressure distribution plate, the flywheel mass and the friction disk (Assembly, Contact plate) show significant grooves.
The screws which fit the clutch against the flywheel mass show no signs of lengthening either to thermal or mechanical load.

3.2.3 Conclusions based on the visual inspection of the clutch

The clutch must have slipped for a longer time. The friction pad of the friction disk (Assembly, Contact plate) is totally destroyed due to heat influence caused by the slipping.
Since there are no signs of fluids like oil found in the clutch or at parts of the clutch, the slipping seemed not to be caused by oil. Otherwise there would have been signs of coked oil.

Above temperatures of 130°C the disk springs loose their spring characteristics and become flat.

The layered arrangement of the disk springs vary from clutch to clutch due to the tolerances of the single parts. In the assembly process the layered arrangement is selected in regard to the actual dimensions. The passing criteria is the friction torque, which has to be above 280Nm.

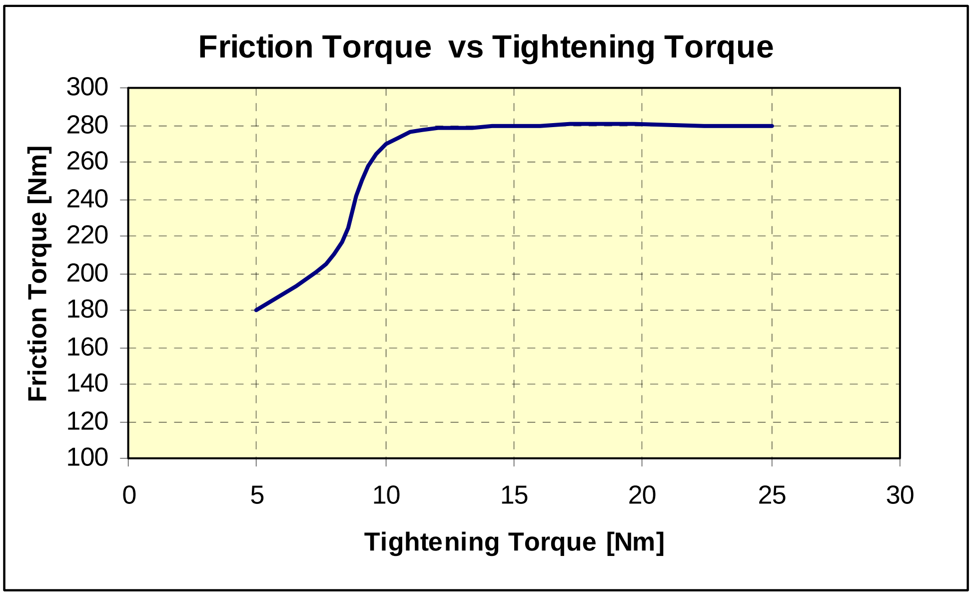
3.2.4 Special tests of the clutch to isolate the root cause of failure

Since this is the first occurrence related to a slipping clutch in more than 60.000 hours fleet operation, TAE carried out several tests to identify the root cause for this occurrence.

In the first test the friction torque was measured in relation to the tightening torque of the screws, which fits the clutch to flywheel mass. According to assembly instructions as well as regarding to the repair manual the tightening torque of these screws must be 25 Nm. The friction torque has to be between 280 and 290 Nm. The test was performed with a new clutch and confirmed with an inspected clutch.

There are the following results:

Tightening Torque	Friction torque
25 Nm	280 Nm
15 Nm	280 Nm
10 Nm	270 Nm
8 Nm	210 Nm
5 Nm	180 Nm
Tightenend by hand	160 Nm



In conclusion, the test shows that the friction torque is depending on the tightening torque.

Since the clutch left company checked by the mechanic and the inspector, it is assured that the friction torque was correct at the time of delivery. A further test was performed to get information if the spring plate layered arrangement found was acceptable before the occurrence. Therefore the friction disk (Assembly, Contact plate) and all disk springs of the affected clutch were exchanged by new parts. The disk spring layered arrangement was similar to the affected clutch layered; 3-3-3-2-1. This test was performed with 5 different friction disk (Assembly, Contact plate) to assure to be representative. The friction torque found at 25Nm tightening torque was 140 Nm. A visual comparison of the flywheel mass of the affected clutch with the flywheel mass which was installed in that aircraft before showed no significant deviations.

In the next test we exchanged the driven plate of the affected clutch against a new part. This test has been also performed with 5 different sets of pressure distribution plates. Also in this case, the friction torque found at 25Nm tightening torque was 140 Nm. So, deviations due to wear and tear of the driven plate could not be detected.

For a tightening torque of 25Nm the screw has a pretensioning force of 19,3 kN. Due to plastic deformation after assembly there is a loss of 2,3kN. Under the same conditions a screw tightened with 8Nm has a pretensioning force of 6,2KN

A loss in pretensioning force of approximately 11 KN due to plastic deformation is extremely improbable.

3.2.5 Influence of the surface roughness and its potential effects

The specified surface roughness (average roughness height Rz) of the flywheel mass is Rz 16, which means that in an average of 5 measurements there is a difference of 16µm between the deepest and the highest point of the measuring distance. Experience of the production showed, that the Rz value reached for the flywheel mass by turning is less than 10 (equivalent 10µm).

However, according the VDI (German Engineer Association) Guidance 2230 an embedding of 1µm is assumed for a decrease in surface roughness from Rz 40 down to Rz 10, which is a decrease of 30µm average roughness height.

In comparison to the difference from the actual Rz value to a grinded surface with a typical Rz value of 0,4 the embedding is assumed to be less than 0,35µm.

A loss in pretensioning force of approximately 11 KN due to an embedding of 1µm is extremely improbable.

4 Conclusion

Based on the FADEC data and the inspections, the loss of power was caused by the clutch.

The engine delivers a torque of 245Nm at max take-off power. The clutch is designed to damp overtorque of 35-40Nm, which occur during engine starting and turning-off the engine. If the torque where the clutch starts slipping is below the engine torque, the clutch slips and gets hot. The wear and tear increases.

According to the maintenance schedule, a new clutch was mounted on the aircraft short before the incident occured. In the tear down inspection at Göteborg-Säve the technician found a break away torque of less than 8Nm at all screws, which fits the clutch to the flywheel mass. The screws show no signs of lengthening either to thermal or mechanical load. This is a sign that the screws were not tightened with the specified torque. On the other hand the flywheel mass shows corrosion marks where the clutch cage usually fits. This is a sign that there was a connection between both the flywheel mass and the clutch cage. However, there is still the possibility that there was a small gap, because corrosion only occurs in contact with air.
The surface roughness of the flywheel mass is specified as R_z=16, which means 16µm between highest and lowest surface point. Due to the production process a R_z value of 10 is reached, equivalent 10µm. The embedding for these class of surface roughness is assumed with less than 1µm. The loss in pretensioning force with 11kN is too high to be related to an embedding of 1µm.

Further tests have shown, that the specified friction torque can not be reached with the disk springs layered arrangement which was found in the affected clutch. For that test all parts except the clutch cage, the distance plates and the flywheel mass have been replaced by new ones.
Since this clutch was checked after assembly by the mechanic and before delivery by the inspector it is improbable that the friction torque was below 280 Nm at the time of delivery.

For this deviation there are at least two possibilities which could not be checked by TAE.

First possibility: The clutch could has fallen down and the maintenance mechanic rearranged the spring plate layered arrangement according to the clutch he exchanged.

Second possibility: The flywheel mass was not exchanged during the clutch exchange. The friction torque is a result of the displacement of the disk springs which is adjusted in the assembly. As soon as one part related to the displacement will be exchanged the adjustment have to be renewed. This is also the fact if the clutch cage is fitted to the old flywheel.

5 Attachments

5.1 Eventlog

FADECDATA#18031af102bd207b3eb40fdd#

Event Log read 2005-02-17 13:32:34 from FADEC #1068
FADEC-A Events in chronological order:
2004-08-17 10:58:02 - Info only: Warnings cleared
2004-08-17 10:58:23 - Info only: Warnings cleared
2004-09-02 17:44:14 - Info only: Injector shorted: #1
2004-09-02 17:44:14 - Info only: InjectorPower0 shorted
2004-09-23 18:34:55 - Info only: Injector shorted: #1
2004-09-23 18:34:55 - Info only: InjectorPower0 shorted
2005-01-18 12:45:18 - Info only: ECU switchover due to RPM [9]
2005-01-18 12:46:14 - Info only: ECU switchover due to RPM [9]
2005-01-18 12:47:58 - Info only: ECU switchover due to RPM [9]
2005-01-19 10:34:00 - Info only: Warnings cleared
2005-01-19 11:23:33 - Info only: ECU switchover due to RPM [9]
2005-01-19 11:31:36 - Info only: Warnings cleared
2005-01-19 11:54:41 - Info only: ECU switchover due to RPM [9]
2005-01-19 12:03:42 - Info only: Warnings cleared
2005-01-19 12:04:47 - Info only: Warnings cleared
2005-01-19 12:05:28 - Info only: ECU switchover due to RPM [9]
2005-01-19 12:07:28 - Info only: ECU switchover due to RPM [9]
2005-01-19 12:08:58 - Info only: Warnings cleared
2005-01-19 12:09:32 - Info only: ECU switchover due to RPM [9]
2005-01-19 12:22:10 - Info only: Warnings cleared
2005-01-19 12:22:39 - Info only: ECU switchover due to RPM [9]
2005-01-19 12:24:10 - Info only: Warnings cleared
2005-01-19 12:41:58 - Info only: ECU switchover due to RPM [9]
2005-01-19 12:45:54 - Info only: Warnings cleared
2005-01-19 12:48:09 - Info only: ECU switchover due to RPM [9]
2005-01-19 12:48:47 - Info only: Warnings cleared
2005-01-19 12:50:30 - Info only: ECU switchover due to RPM [9]
2005-01-19 12:55:17 - Info only: Warnings cleared
2005-01-19 12:57:14 - Info only: ECU switchover due to RPM [9]
2005-01-19 13:00:35 - Info only: Warnings cleared
2005-01-19 13:01:47 - Info only: ECU switchover due to RPM [9]
2005-01-20 13:55:45 - Info only: Warnings cleared
2005-02-15 16:36:54 - Info only: High RPM: up to 4758 rpm for 8,4 seconds
2005-02-15 16:37:06 - Info only: High RPM: up to 4759 rpm for 10,0 seconds
2005-02-15 16:37:42 - Info only: High RPM: up to 4886 rpm for 45,9 seconds
2005-02-15 16:37:55 - Info only: High RPM: up to 4935 rpm for 2,0 seconds

FADEC-A statistics:

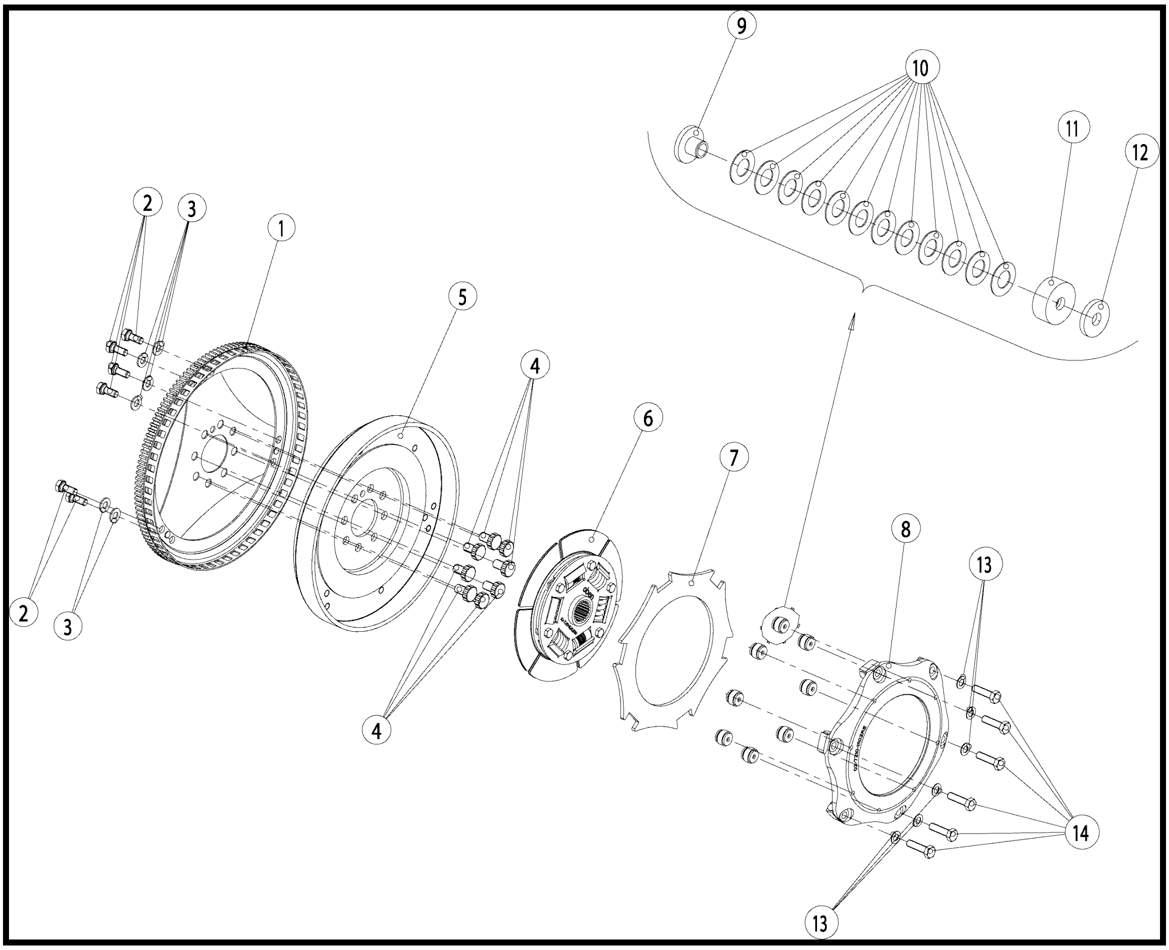
ECU Uptime: 0,01h
Total ECU Uptime: 221,83h
Total Engine Runtime: 219,95h
Engine Runtime in Load steps:A: 36,50 / B: 32,56 / C: 12,76 / D: 12,40 / E: 13,51 / F: 78,97 / G: 3,88 / H: 29,37
Engine Runtime in TH2O steps:A: 10,47 / B: 10,46 / C: 196,08 / D: 2,94 / E: 0,00 / F: 0,00 / G: 0,00 / : 0,00
Engine Runtime in TOil steps:A: 15,71 / B: 11,82 / C: 18,59 / D: 45,14 / E: 123,12 / F: 5,24 / G: 0,33 / H: 0,00
Engine Runtime in TGear steps:A: 215,72 / B: 3,99 / C: 0,22 / D: 0,01 / E: 0,00 / F: 0,00 / G: 0,00 / H: 0,00
Engine Runtime in PBaro steps:A: 0,04 / B: 0,00 / C: 3,08 / D: 6,81 / E: 2,90 / F: 26,47 / G: 110,88 / H: 69,78
Engine Runtime in POil steps:A: 0,20 / B: 0,10 / C: 26,65 / D: 38,14 / E: 154,74 / F: 0,13 / G: 0,00 / H: 0,00
Engine Runtime in RPM steps:A: 47,42 / B: 23,54 / C: 22,37 / D: 60,33 / E: 36,09 / F: 29,65 / G: 0,54 / H: 0,01
Engine Runtime in VBatt steps:A: 0,07 / B: 0,10 / C: 0,12 / D: 0,08 / E: 0,05 / F: 218,39 / G: 1,14 / H: 0,00

FADEC-B Events in chronological order:
2004-08-17 10:58:04 - Info only: Warnings cleared
2004-08-17 10:58:23 - Info only: Warnings cleared
2005-01-18 12:50:41 - High A/B diff Propspeed: up to 1219 rpm for 10,0 seconds
2005-01-18 12:55:03 - High A/B diff Propspeed: up to 1361 rpm for 271,8 seconds
2005-01-18 12:55:15 - High A/B diff Propspeed: up to 2414 rpm for 10,0 seconds
2005-01-18 12:55:25 - High A/B diff Propspeed: up to 2414 rpm for 20,2 seconds

2005-01-18 12:55:47 - High A/B diff Propspeed: up to 2349 rpm for 6,5 seconds
2005-01-18 12:55:55 - High A/B diff Propspeed: up to 2298 rpm for 5,8 seconds
2005-01-19 10:34:09 - Info only: Warnings cleared
2005-01-19 11:23:42 - Info only: Injector shorted: #1
2005-01-19 11:23:42 - Info only: InjectorPower0 shorted
2005-01-19 11:28:08 - High A/B diff Propspeed: up to 1355 rpm for 10,0 seconds
2005-01-19 11:28:26 - High A/B diff Propspeed: up to 1356 rpm for 28,4 seconds
2005-01-19 11:31:45 - Info only: Warnings cleared
2005-01-19 11:57:49 - High A/B diff Propspeed: up to 1250 rpm for 10,0 seconds
2005-01-19 12:00:34 - High A/B diff Propspeed: up to 1317 rpm for 174,9 seconds
2005-01-19 12:00:57 - High A/B diff Propspeed: up to 2363 rpm for 10,0 seconds
2005-01-19 12:01:09 - High A/B diff Propspeed: up to 2363 rpm for 22,7 seconds
2005-01-19 12:01:26 - High A/B diff Propspeed: up to 2336 rpm for 10,0 seconds
2005-01-19 12:01:42 - High A/B diff Propspeed: up to 2336 rpm for 25,7 seconds
2005-01-19 12:03:50 - Info only: Warnings cleared
2005-01-19 12:04:55 - Info only: Warnings cleared
2005-01-19 12:08:18 - High A/B diff Propspeed: up to 1981 rpm for 6,2 seconds
2005-01-19 12:09:06 - Info only: Warnings cleared
2005-01-19 12:10:09 - High A/B diff Propspeed: up to 2239 rpm for 6,7 seconds
2005-01-19 12:22:19 - Info only: Warnings cleared
2005-01-19 12:23:21 - High A/B diff Propspeed: up to 1162 rpm for 4,4 seconds
2005-01-19 12:24:18 - Info only: Warnings cleared
2005-01-19 12:42:54 - High A/B diff Propspeed: up to 1031 rpm for 5,1 seconds
2005-01-19 12:42:59 - High A/B diff Propspeed: up to 1034 rpm for 4,7 seconds
2005-01-19 12:46:02 - Info only: Warnings cleared
2005-01-19 12:48:55 - Info only: Warnings cleared
2005-01-19 12:53:11 - High A/B diff Propspeed: up to 1254 rpm for 3,8 seconds
2005-01-19 12:55:25 - Info only: Warnings cleared
2005-01-19 12:57:56 - High A/B diff Propspeed: up to 1239 rpm for 4,7 seconds
2005-01-19 13:00:43 - Info only: Warnings cleared
2005-01-19 13:02:36 - High A/B diff Propspeed: up to 1118 rpm for 3,7 seconds
2005-01-20 13:55:53 - Info only: Warnings cleared
2005-02-15 16:37:04 - Info only: High RPM: up to 4796 rpm for 8,1 seconds
2005-02-15 16:37:07 - Info only: High RPM: up to 4613 rpm for 1,3 seconds
2005-02-15 16:37:17 - Info only: High RPM: up to 4784 rpm for 10,0 seconds
2005-02-15 16:37:51 - Info only: High RPM: up to 4899 rpm for 44,1 seconds
2005-02-15 16:38:05 - Info only: High RPM: up to 4920 rpm for 2,0 seconds

FADEC-B statistics:
ECU Uptime: 0,01h
Total ECU Uptime: 222,71h
Total Engine Runtime: 220,31h
Engine Runtime in Load steps:A: 32,82 / B: 34,87 / C: 14,14 / D: 10,06 / E: 15,27 / F: 79,00 / G: 4,58 / H: 29,57
Engine Runtime in TH2O steps:A: 10,98 / B: 10,96 / C: 196,30 / D: 2,07 / E: 0,00 / F: 0,00 / G: 0,00 / H: 0,00
Engine Runtime in TOil steps:A: 16,38 / B: 12,07 / C: 18,93 / D: 47,64 / E: 120,97 / F: 4,03 / G: 0,29 / H: 0,00
Engine Runtime in TGear steps:A: 216,40 / B: 3,68 / C: 0,22 / D: 0,01 / E: 0,00 / F: 0,00 / G: 0,00 / H: 0,00
Engine Runtime in PBaro steps:A: 0,04 / B: 0,00 / C: 4,46 / D: 5,61 / E: 3,14 / F: 33,47 / G: 115,51 / H: 58,07
Engine Runtime in POil steps:A: 0,21 / B: 0,09 / C: 26,03 / D: 34,35 / E: 159,23 / F: 0,39 / G: 0,00 / H: 0,00
Engine Runtime in RPM steps:A: 47,72 / B: 23,64 / C: 22,43 / D: 60,54 / E: 35,80 / F: 29,61 / G: 0,55 / H: 0,01
Engine Runtime in VBatt steps:A: 0,07 / B: 0,11 / C: 0,12 / D: 0,09 / E: 0,05 / F: 211,84 / G: 8,02 / H: 0,00

5.2 Drawing



Nr. / Fig. No	Teile Nummer / Part Number	Beschreibung / Description	Menge / Quantity
		Kupplung / Clutch	
1	02-7220-11001R2	ZSB Anlasserzahnkranz / Assembly, Starter ring gear	1
2	02-7220-11103R1	Schrauben / Bolt M8x20	6
3	02-7220-11104R1	Scheiben / Washer A8,4	6
4	02-7220-11102R1	Schrauben / Bolt fly wheel M10x1x17	8
5	02-7210-11113R3	Schwungscheibe TAE 125 / Flywheel mass	1
6	02-7210-11002R13	ZSB Reibscheibe / Assembly, Contact plate	1
7	02-7210-11101R2	Druckplatte / Driven plate	1
8	02-7210-11102R6	Kupplungskorb / Clutch cage	1
9	02-7210-11104R2	Federführungshülse / Spring guide sleeve	8
10	02-7210-11107R1	Tellerfedern / Disk spring	96
11	02-7210-11105R2	Federführungstasse / Spring guide tappet	8
12	02-7210-11124R1 02-7210-11125R1 02-7210-11126R1 02-7210-11127R1 02-7210-11128R1	Distanzscheibe / Spacer 2,4mm Distanzscheibe / Spacer 2,5mm Distanzscheibe / Spacer 2,6mm Distanzscheibe / Spacer 2,7mm Distanzscheibe / Spacer 2,8mm	8
13	02-7210-11112R1	Wellscheiben / Corrugatet washer B8	6
14	02-7210-11108R1	Schrauben / Bolt M8x30x1	6