COMANDO DA AERONÁUTICA

CENTRO DE INVESTIGAÇÃO E PREVENÇÃO DE ACIDENTES AERONÁUTICOS

FINAL REPORT
A-009/CENIPA/2014

OCCURRENCE:	**ACCIDENT**
AIRCRAFT:	**PT-YRE**
MODEL:	**AS 350 BA**
DATE:	**10 FEB 2010**

NOTICE

According to the Law nº 7565, dated 19 December 1986, the Aeronautical Accident Investigation and Prevention System – SIPAER – is responsible for the planning, guidance, coordination and execution of the activities of investigation and prevention of aeronautical accidents.

The elaboration of this Final Report was conducted taking into account the contributing factors and hypotheses raised. The report is, therefore, a technical document which reflects the result obtained by SIPAER regarding the circumstances that contributed or may have contributed to triggering this occurrence.

The document does not focus on quantifying the degree of contribution of the different factors, including the individual, psychosocial or organizational variables that conditioned the human performance and interacted to create a scenario favorable to the accident.

The exclusive objective of this work is to recommend the study and the adoption of provisions of preventative nature, and the decision as to whether they should be applied belongs to the President, Director, Chief or the one corresponding to the highest level in the hierarchy of the organization to which they are being forwarded.

This Report does not resort to any proof production procedure for the determination of civil or criminal liability, and is in accordance with item 3.1, Annex 13 to the 1944 Chicago Convention, which was incorporated in the Brazilian legal system by virtue of the Decree nº 21713, dated 27 August 1946.

Thus, it is worth highlighting the importance of protecting the persons who provide information regarding an aeronautical accident. The utilization of this report for punitive purposes maculates the principle of "non-self-incrimination" derived from the "right to remain silent" sheltered by the Federal Constitution.

Consequently, the use of this report for any purpose other than that of preventing future accidents, may induce to erroneous interpretations and conclusions.

N.B.: This English version of the report has been written and published by the CENIPA with the intention of making it easier to be read by English speaking people. Taking into account the nuances of a foreign language, no matter how accurate this translation may be, readers are advised that the original Portuguese version is the work of reference.

SYNOPSIS

This is the Final Report of the 10 February 2010 accident with the AS350 aircraft, registration PT-YRE. The accident was classified as “system or component failure”.

Approximately 30 minutes into the flight, the pilot had problems with the aircraft directional control.

Shortly afterwards, the aircraft was observed in a descending spiral until crashing into the ground.

The pilot perished in the crash, and the passenger suffered serious injuries.

The aircraft was substantially damaged.

An accredited representative of the French BEA (*Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile*) was designated for participation in the investigation.

CONTENTS

GLOSSARY OF TECHNICAL TERMS AND ABBREVIATIONS

ABRAPHE	Brazilian Helicopter Pilots Association
ANAC	National Civil Aviation Agency
APP	Approach Control
APP-SP	São Paulo Approach Control
APPA	Aircraft Pilots and Owners Association
ATS	Air Traffic Services
BEA	*Bureau d'Enquêtes et d'Analyses pour la securité de l'aviation civile*
CCF	Aeronautical Medical Certificate
CENIPA	Aeronautical Accident Investigation and Prevention Center
CHT	Technical Qualification Certificate
CIAA	Aeronautical Accident Investigation Committee
CIV	Piilot's Flight Logbook
CNPAA	National Aeronautical Accident Prevention Committee
DCTA	Department of Science and Airspace Technology
DST	Daylight Saving Time
ESA	Superior School of Aviation
FCU	Fuel Control Unit
HBV	Brazilian Daylight Saving Time
IAC	Civil Aviation Instruction
INSPAC	Civil Aviation Inspector
Lat	Latitude
Long	Longitude
PCH	Commercial Pilot (Helicopter category)
PPH	Private Pilot (Helicopter category)
RBHA	Brazilian Aeronautical Homologation Regulation
SBMT	ICAO location designator –Campo de Marte Aerodrome
SBSP	ICAO location designator – Congonhas Aerodrome
SERIPA	Regional Aeronautical Accident Investigation and Prevention Service
SIPAER	Aeronautical Accident Investigation and Prevention System
SOP	Standard Operating Procedures
TPP	Private Aircraft Register Category – Private Air Services
UTC	Coordinated Universal Time
VFR	Visual Flight Rules

1. FACTUAL INFORMATION.

Aircraft	**Model:** AS 350 BA **Registration:** PT-YRE **Manufacturer:** Eurocopter France	**Operator:** Rede Record S/A
Occurrence	**Date/time:** 10FEB2010 / 09:03 (UTC) **Location:** Jockey Club de São Paulo **Lat.** 23º34'33"S **Long.** 046º42'08"W **Municipality – State:** São Paulo – SP	**Type(s):** System or component failure

1.1 History of the flight.

The aircraft departed from SBMT at 06:33 DST, destined for the neighborhood of Morumbi on an aerial footage operation, with the pilot and a cameraman on board.

With the aircraft approximately 30 minutes into the flight, the pilot called São Paulo Approach Control (APP-SP) to inform that he was having difficulty controlling the aircraft on account of tail rotor problems. He also said that he was heading for the Jockey Club where he intended to make an emergency landing.

Shortly later, the aircraft entered a descending spiral until crashing into the ground.

1.2 Injuries to persons.

Injuries	Crew	Passengers	Others
Fatal	1	-	-
Serious	-	1	-
Minor	-	-	-
None	-	-	-

1.3 Damage to the aircraft.

The aircraft sustained substantial damage.

1.4 Other damage.

None.

1.5 Personnel information.

1.5.1 Crew's flight experience.

Hours Flown	
	Pilot
Total	8.541:10
Total in the last 30 days	33:20
Total in the last 24 hours	01:25
In this type of aircraft	Unknown
In this type in the last 30 days	33:20
In this type in the last 24 hours	01:25

N.B.: Data obtained from the Pilot's Flight Logbook.

1.5.2 Professional formation.

The pilot did his Private Pilot course (Helicopter category) at the Escola Superior de Aviação S/C – ESA – in the city of São Paulo in 1973.

1.5.3 Category of licenses and validity of certificates.

The pilot had a Commercial Pilot License (Helicopter). His H350 Technical Qualification Certificate (CHT) was valid.

1.5.4 Qualification and flight experience.

The pilot had qualification and enough experience for the flight in question.

1.5.5 Validity of medical certificate.

The pilot had a valid Aeronautical Medical Certificate (CCF).

1.6 Aircraft information.

The aircraft was manufactured by Eurocopter France in 1994 (SN 2832).

The aircraft airworthiness certificate (CA) was valid.

The airframe and engine records were out of date.

The aircraft logbook records were in discordance with the IAC 3151 (dated 2 June 2002), item 9.3, making it difficult to determine the exact number of hours flown by the aircraft.

Nevertheless, it is possible to affirm (with an approximate margin of error) that:

a) The airframe had a total flight-time of 8,018 hours and 55 minutes;

b) The last comprehensive overhaul (12 years, type C) was done in September 2007, and the helicopter had flown 610 hours ever since;

c) The last records concerning maintenance of the tail rotor dated from 21 December 2009, when the helicopter had 7,833 hours and 25 minutes of flight time. On the occasion, the tail rotor was disassembled for replacement of the command plateau hertalites.

d) Upon reassembly, the records indicated that the tail rotor had been balanced and was within the limits prescribed in the manufacturer's manual. From this intervention until the day of the accident, the helicopter flew 185 hours and 30 minutes; and

e) The last 100-hour inspection was completed on 21 January 2010, and the helicopter had a total of 7,942 houra and 10 minutes of flight time. After the aforementioned inspection until the accident, the helicopter flew 76 hours and 40 minutes.

There are no records of intermediate inspections (such as 7 days, 10 hours, 25 hours, 30 hours, and 50 hours). Such inspections used to be done in connection with the 100-hour inspection, and were entered in the records retroactively. On the day of the accident, the validity of all intermediate inspections had already expired.

There were no records concerning any preflight, interflight and post-flight inspections.

The engine maintenance manual prescribes that the engine has to be washed after the last flight of each day, but no records were found relative to this service.

The investigation commission verified that the validity of the tail rotor activation servo had expired 11 hours before the accident, within the margin of tolerance prescribed by the manufacturer.

1.7 Meteorological information.

Nil.

1.8 Aids to navigation.

Nil.

1.9 Communications.

All the communications were carried out on the frequency 118.35 MHz of the São Paulo Approach Control (APP-SP).

Information of the failure was given by the pilot two minutes before the crash, and during this period, he used the frequency 10 times, i.e., one call every 12 seconds on average. Below, there is a summary of the communications in the moments prior to the accident:

- at 09:21:18, the pilot called another aircraft flying in the vicinity to inform that the tail rotor had problems, and that he was flying toward the Jockey Club;
- at 09:21:19, the pilot called APP-SP to inform that the helicopter tail rotor was malfunctioning, and that he was heading for the Jockey Club, but was having difficulty maintaining direction.
- APP-SP instructed him to stand by on the frequency, and then asked whether he was in emergency. The pilot gave an affirmative answer;
- the ATCO informed that he would discontinue landings and departures in SBSP;
- at 09:21:43, the pilot informed that he was flying over the Jockey Club and would attempt to land. Then he called another aircraft, which advised him to proceed with tranquility;
- at 09:21:53, the pilot transmitted the following information to the other pilot (colloquial language): “I’ll tell you what..., I cannot depress the left pedal without causing lots of vibration, it is with … face way left, differently from a tail rotor failure, did you understand?”
- at 09:22:04, the pilot of the other aircraft inquired whether he would be able to perform a “run-on”, and he said that he would make an attempt to “run on” in the Jockey Club;

Note: the expression “run-on” refers to run-on landing.

- at 09:23:11, APP-SP called the distress traffic and received no answer; and
  the other pilot who was on the same frequency, and that was monitoring the aircraft in emergency, informed ATC that the helicopter had crashed in the Jockey Club area.

1.10 Aerodrome information.

Not applicable.

1.11 Flight recorders.

Neither required nor installed.

1.12 Wreckage and impact information.

Available video images showed that the aircraft flew a vertical path without any considerable speed forward.

Figure 1 – General view of the wreckage in the crash site.

The characteristics of the wreckage indicated that the collision of the aircraft with the ground had a high degree of energy. The cabin floor sank and the structure supporting the pilot seat was deformed.

1.13 Medical and pathological information.

1.13.1 Medical aspects.

The day before the accident, the pilot landed the helicopter at 20:00 DST, and left the hangar at about 20:30.

If one estimates the time spent by the pilot to get home and do his domestic chores, it is reasonable to think that he went to bed around 23:00.

On the day of the accident, the aircraft took off at 06:33 DST.

If one considers the time spent by the pilot with his morning activities, including breakfast and later riding to work, one may infer that he woke up around 05:00 DST.

Therefore, the real period of rest, if these hypotheses are accurate, was approximately six hours.

The Law no. 7183, dated 5 April 1984, which regulates the exercise of the aeronaut profession, prescribes (article 34, letter “a”) that the “rest period of an aeronaut shall be 12 hours following a workday of 12 hours.”

The Interministerial Ordinance no. 3016 of 5 February 1988 makes provisions for the compliance with the aforementioned Law, and defines in its article 23 that a workday is the elapsed time between the moment of reporting for work at the workplace (with a minimum advance of 30 minutes relative to the time of flight initiation) and the time at which the flight is terminated (termination time shall be considered 30 minutes after the engines are shut down, or the services on the ground are completed).

The pilot made use of a medication (Omeprazol) for treatment of a gastroesophagic reflux disease. Such medication may cause drowsiness and diminish one’s reflexes.

The pilot was not a smoker and did not make use of illicit drugs. There were no signs of alcohol in his blood, and he had no complaints related to the physical aspect on the day of the accident.

The pilot's causa mortis was brain injury caused by a blunt instrument related to the accident.

1.13.2 Ergonomic information.

Nil.

1.13.3 Psychological aspects.

Individual information

Pilot

The pilot was described as being a devoted father and a reserved person.

He started to fly at the age of 23 at the ESA School. Despite financial constraints, he managed to earn his wings out of personal effort. He did his Commercial Pilot course (Helicopter) at Helischool, and worked as a flight instructor, being responsible for the professional formation of many pilots, among them and especially, his two brothers.

After working for seven years with the accident aircraft operator, he left for one year and was hired again approximately one year before the accident.

Apparently, the pilot was happy with his employer, and had refused other employment offers.

In 2003, he experienced a real situation of engine failure with a Robinson helicopter, during a hovering flight outside of ground effect at a height of approximately 500 feet AGL. He managed to perform the prescribed autorotation, and made a landing on a terrain free of obstacles. The helicopter sustained minimal damage, and the occupants got out uninjured.

On the day before the accident, he told another pilot of the company that he had noticed an abnormal behavior of the helicopter on landing. Apparently, the information did not receive proper attention, and the fact was not reported to (or verified by) a qualified mechanic.

Mechanic

The mechanic who did the last assembly of the aircraft tail rotor was also a maintenance instructor. He had been working at the company for seven years, and had been two and a half years in the function.

He said that his intention was to remain working for the company until retirement. He affirmed that the company invested in the development of the personnel, and considered it to be an excellent place to work, in which he could talk to everyone, from the Manager to the CEO.

He said that he had done the assembly service of the AS 350 tail rotor six times, including the maintenance of the accident aircraft. He mentioned remembering the steps for assembling the tail rotor of the helicopter in question, and that he had applied torque on the fastening bolt in accordance with the prescriptions of the manual, which was open on the bench for consultation during the provision of service.

The action was supervised by a maintenance inspector, and watched by a trainee who was being instructed by him (the mechanic).

He also said that type of service was not frequent, and had been done carefully, while he explained every step of the assembly process to the trainee.

He affirmed that in his opinion it was impossible for him to have inserted the bolt in a wrong manner, since it would be a gross mistake, different from what is prescribed, and that if such an error had been committed, it would not go unnoticed by all the other professionals involved in the process.

In the opinion of the mechanic, the helicopter had not left the maintenance workshop with an incorrectly assembled tail rotor.

Maintenance inspector in charge

The inspector responsible for the aircraft tail rotor assembly had been working twelve years at the company.

He described himself as a demanding person, who had done all the courses pertinent to his profession, with qualification in all Eurocopter aircraft and engines. He had been working as an inspector for six years.

He said that in his opinion it was not possible that an error could have been committed at the assembly of the tail rotor during the 100-hour overhaul on 21 December 2009. He also said that it was unlikely that the tail rotor balance could have been executed after an incorrect assembly, and thought it was strange that the pilots had not sensed any vibration in the pedals in the period from the overhaul to the accident.

He stressed that no tail rotor problems had been notified. He also mentioned that, following the aircraft delivery on completion of the overhaul, he and the mechanic had participated in the test flight with the same pilot who would later be involved in the accident.

He reported that what he had seen in the tail rotor upon delivering the aircraft after the 100-hour overhaul was not the same thing he saw in the post-accident photographs of the aircraft.

Psychosocial information

The pilot did not have many friends, but was liked in the work environment. The company Director responsible for the air activity trusted him and sought his advice on several occasions.

The cameraman reported that his relationship with the accident pilot was good, and that they had frequently flown together.

At work, the company personnel had an informal way to discuss issues related to the air activity. The Coordinator and the Director had only limited knowledge of air operations and would normally consider the position of the captains in their decision making process.

An informal work culture existed, based on friendship, but deprived of operational standards set up by the management. The pilots would accept to fly the helicopter even if the intermediate inspections had been skipped, in discordance with the aircraft maintenance manual.

Organizational information

The use of the helicopter required the pilot to be agile, and fly with precision in limited airspace, under conditions of high concentration of people or buildings, at low speed or even hovering.

The processes within the operating company were informal, lacking logbook records and controls. The release of the flight was usually done via telephone, and the decision to comply with the mission belonged exclusively to the pilot. The role of the individuals within the group was not clearly defined.

The work schedule was informal, and changes in the schedule were made by the very pilots, without supervision or control. The writing of the hours flown by the aircraft in the aircraft logbook was not done in a standardized manner.

According to the Director of the air activity, the pilots had all the support from the management to abort or refuse a flight. They had no manuals to describe the procedures and limits to be complied with in the execution of the air activity.

The investigation commission observed failures in the planning of equipment maintenance, resulting in delays in the grounding of aircraft for overhauling purposes.

The company did not have appropriate control of crew training in relation to obligatoriness and frequency. The last training of the pilot involved in the accident had taken place in 2006. In 2008, he did a check ride, which was also considered a training flight.

The interviewees referred to the company as a “family”. The climate was one of comradeship and cooperation. The apparent lack of standardization was seen as a sign of confidence, both on the part of the management and on the part of the pilots.

1.14 Fire.

No signs of either inflight or post-impact fire.

1.15 Survival aspects.

The pilot perished in the crash on account of a traumatism in the region of his right eye. His head was violently whipped downward and hit his own knee. The sinking of the seat on the floor loosened the seat belt and rendered the suspenders ineffective.

A pilot who had witnessed the accident rescued the cameraman from the helicopter, and an ambulance of the Jockey Club took him to hospital. There, he stayed several days in a coma state.

Figure 2 – Aspect of the pilot’s seat belt after the impact.

The seat of the pilot was not one of the anti-crash type, and the points of attachment were located on the aircraft floor.

1.16 Tests and research.

Engine

The result of the analysis of the engine and its accessories at the Aerospace Technology and Science Department (DCTA) showed that nothing had been found that could explain the malfunctioning of the helicopter power plant. According to the characteristics observed, the engine had only residual rotation at the moment of the crash.

The accident was captured on film, and the images suggest that the pilot shut down the engine when the aircraft began rotating (around the vertical axis). A white smoke which got out of the engine was an indication of the exact moment at which the fuel was cut off.

Tail rotor

The tail rotor sustained only minor damage, and one of the blades was practically intact.

Figure 3 – Tail rotor blades.

The blade in worse condition had signs of earth and damage to the tips, a probable consequence of hitting the ground. This is corroborated by the absence of significant damage to the other blade.

Ninety-degree gearbox

The ninety-degree gearbox was opened in the premises of Helibras and Eurocopter.

No evidence of malfunctioning was observed in the component, and it maintained its operational characteristics during the bench tests.

Conical shaft, fastening bolt, and tail rotor blades support- fork

The conical shaft was analyzed at the DCTA and at Eurocopter. The results complement are complementary, and important information was obtained.

Description of the system

In order to make the result of the exams easier to understand, a brief description of the system is necessary. The conical shaft transmits the rotation from the engine to the tail rotor. It rotates at a high rate of more than 2,000 RPM. The aircraft design was conceived in such a way that, during the assembly, the tail rotor blades support-fork grasps the entire surface of the conical shaft. In addition, the torque applied to the fastening bolt, together with the actuation of the “tongue” (a projection on the conical shaft that fits in the fork groove) will ensure full connection of the tail rotor system.

The scheme below (cross-section view) shows how the fork is attached to the conical shaft. The distance between the fork fastening-bolt and the bolts which limit the flapping of the blades is 4mm.

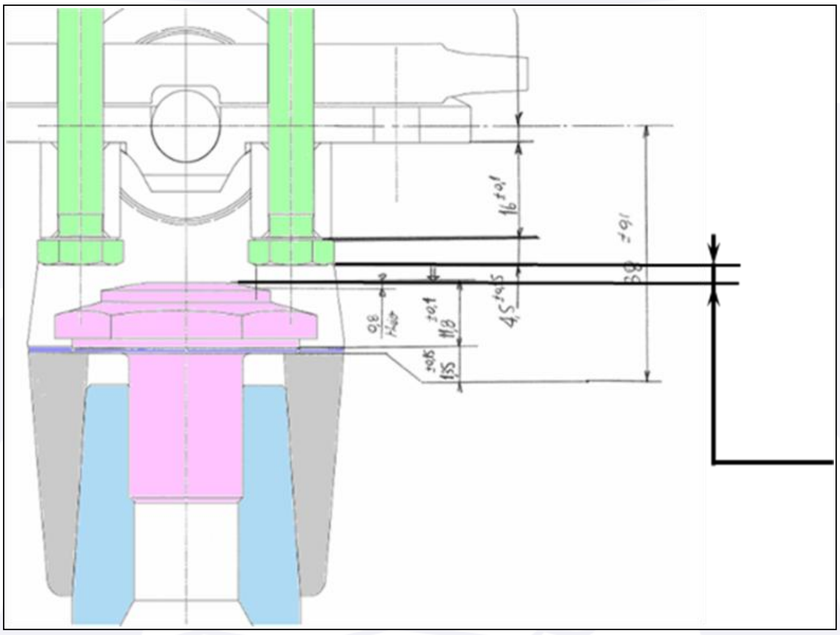

Figure 4 – Scheme of the fastening of the fork (which holds the tail rotor blades) to the conical shaft.

The bolt for fastening the fork to the conical shaft is represented in pink. The bolts which limit the flapping of the blades are shown in green. The fork is gray. The conical shaft is represented in blue. This shaft connects with the blade supporting-fork, ensuring that rotation is transmitted to the tail rotor system. The fork, in turn, has a groove, which the conical shaft ‘tongue’ has to match.

Figure 5 – Transmission shaft ready to be installed. In the highlight, the tongue on the surface of the shaft.

In figure 5, it is possible to observe the 'tongue' (in highlight), which serves two purposes: the first one is to assist in the task of fastening the tail rotor blades support-fork to the conical shaft and prevent relative movement between the conical shaft and the fork; the second one is to be an indicator in case of an abrupt stop of the tail rotor. These two purposes can only be accomplished if the 'tongue' is duly placed in the groove.

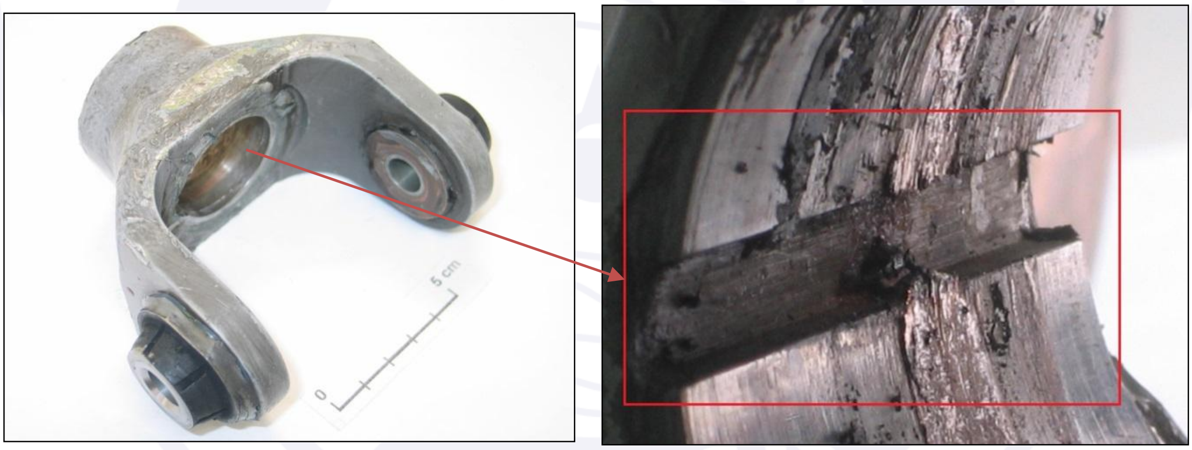

Figure 6 – Support fork of the PT-YRE blades (left). On the right, the inner surface of the fork, showing the groove for the 'tongue' in highlight.

When there is a sudden stop of the tail rotor, (resulting from a collision of the blades with the ground or obstacle, for example) the 'tongue' is broken, but the fork does not make a complete revolution around the conical shaft. In relation to the 'tongue', it is expected that the broken part will stay in the interior of the fork groove.

The system is assembled and fixed by means of a fastening bolt (shown in purple in Figure 4). In addition to this bolt, two other bolts (green color in figure 4) limit the flapping of the tail rotor blades.

During the analyses at the DCTA, the fastening bolt, the conical shaft and the support-fork of PT-YRE tail rotor blades showed strong evidence that there had been relative rotation between them (Figure 6).

System fastening-bolt

When the technicians analyzed the bolt that fastened the fork to the conical shaft, they found out that the lock washer was outside of its original position, and that the bolt had almost no torque. It is estimated that they needed only 2 kgf.m to remove the bolt. They found, also, circular blue color marks on the head of the bolt. These marks were caused by friction between this bolt and the bolts limiting the flapping of the tail rotor blades, as illustrated in Figures 7 and 8. They also found circular friction marks on the underside of the head of the fastening bolt (Figure 9). All this evidence indicated that the bolt rotated in relation to the fork.

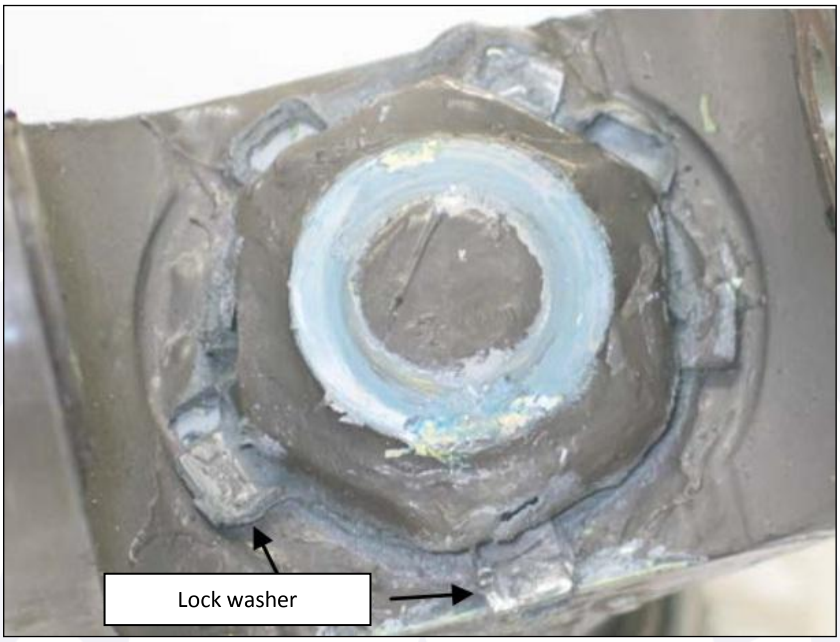

Figure 7 – Bolt for fastening the fork to the conical shaft. It is possible to observe that the lock washer is outside of its original position, and that there is a blue circular mark around the head of the bolt.

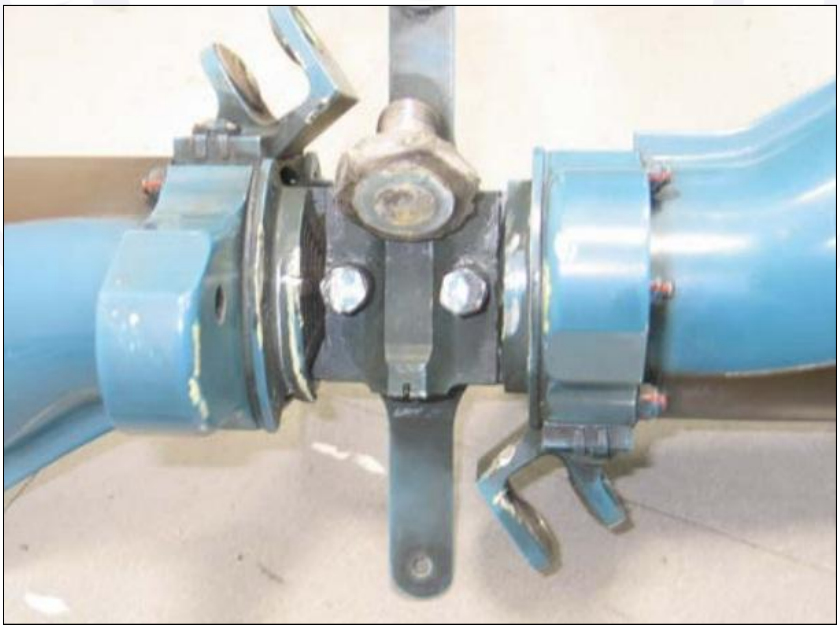

Figure 8 – Bolts for limiting the flapping of the tail rotor blades. The bluefish mark on the fastening bolt was caused by friction between the fastening bolt and the two bolts which limit the flapping.

Figure 9 – Mark of circular friction on the lower part of the fastening-bolt head.

<u>Tail rotor blades support-fork</u>

An analysis of the internal surface of the blade support-fork showed circumferential marks of friction at the point of connection with the conical shaft. In addition, the presence of worn down encrusted 'tongue' material was detected on the whole internal circumference of the fork. There were no signs of this material inside the groove. Finally, presence of the sealant material was also detected on the internal surface of the fork.

Figure 10 makes a comparison between the internal part of a fork with fracture of the 'tongue' caused by an abrupt stop (left picture), and the fork of the PT-YRE (right picture). In the left picture, it is possible to observe that a piece of the fractured 'tongue' remained in the groove, something that did not happen in the PT-YRE (on the right)

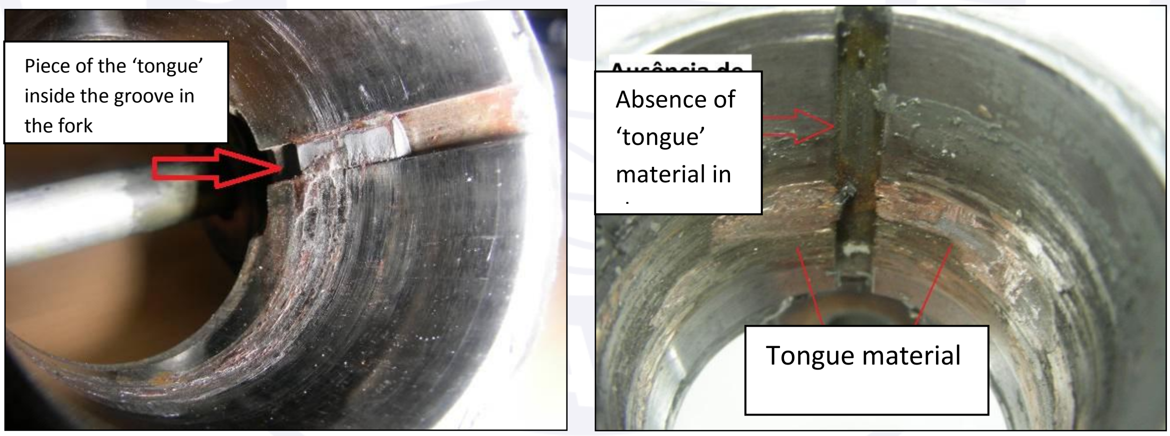

Figure 10 – Comparison between a fork with fracture of the 'tongue' on the left, and the fork of the PT-YRE on the right.

With participation of Eurocopter, a transversal cut was made in the fork, and the internal marks of the part were compared with the marks on the conical shaft. The purpose was to determine the relative position between the two parts when the failure occurred.

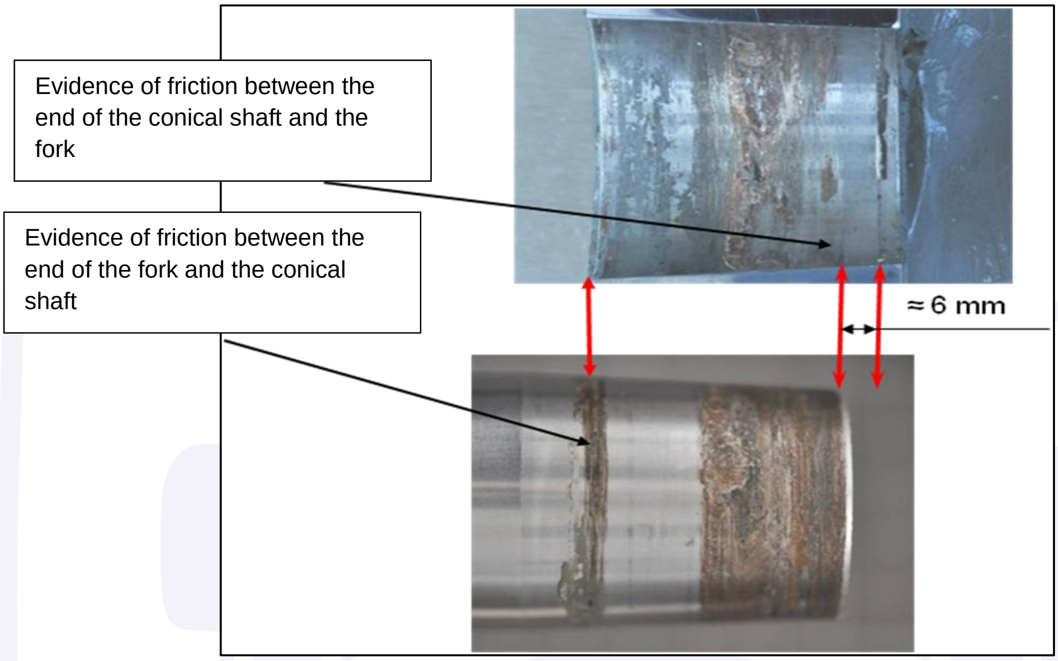

Figure 11 – Evidence of disconnection between the conical shaft and the fork.

All the pieces of evidence indicate that there was relative rotation between the conical shaft and the fork.

Conical shaft

Upon analyzing the conical shaft, the commission verified that there were circumferential marks of friction on its surface. The ‘tongue’ had sustained total wear, and there was ‘tongue’ and sealant material around the circumference of the shaft, as shown in the figure below.

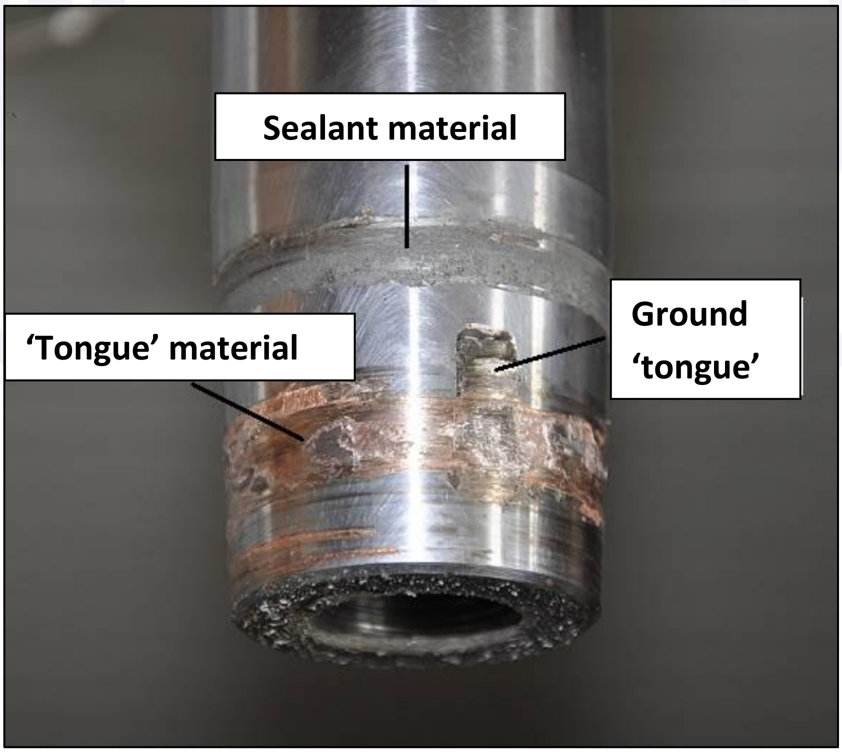

Figure 12 – Conical shaft of the PT-YRE, as seen after disassembly.

All pieces of evidence indicate that there was relative rotation between the conical shaft and the fork.

Rear transmission (short shaft, long shaft)

During the Initial Action in the crash site, it was observed that there was a breakage in the tail rotor transmission tree, and at the connection between the long and short shafts.

The short and long shafts, and the bearing that supports the connection between them were analyzed at the DCTA and Eurocopter. The following considerations are made in the technical report issued by the DCTA Materials Division (AMR).

There was failure of the long shaft in the region of the attachment bolts. The marks found correspond to a shear fracture in torsion due to overload, probably caused by blocking. Tests performed in the parts anterior to the tail rotor drive shaft did not show any problems capable of causing a blocking of the drive shaft.

Figure 13 – Rear transmission, as found at the Initial Action.

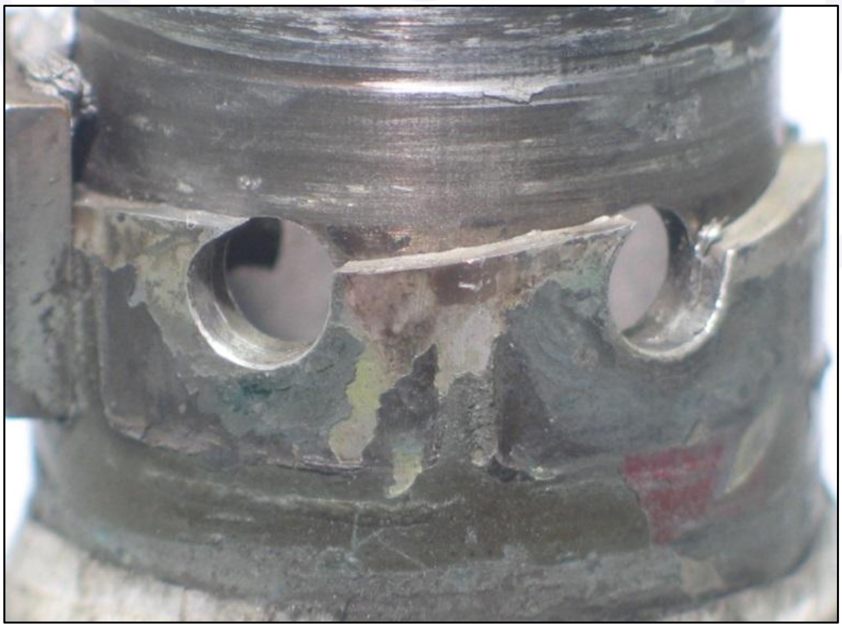

Figure 14 – Failure observed in the long shaft. The slope of the fracture indicates that there was overload due to torsion.

After the breakage, the shaft continued turning forcefully on the connection. Signs of friction and high temperatures were observed between the long shaft (external) and the short shaft (internal), resulting in fusion of the shaft material (Figure 16). This evidence suggests that the shafts remained concentrical, and that there was transmission of rotation for some time.

Figure 15 – End of long shaft broken at the point of connection with the short shaft.

Figure 16 – Molten metal (fusion) deposited in the connection between the shafts.

<u>Simulations conducted at Helibrás</u>

The absence of torque on the fastening bolt caught the attention of the investigator in charge and of Eurocopter. This type of evidence is not common, on account of the simplicity of the system installation and its robustness, as well as on account of the torque prescribed to be applied on the bolt.

After the necessary studies, the conclusion was that the absence of torque observed in the accident might occur in three situations:

- if the mechanic failed to apply torque on the bolt during the assembly;
- if the fork was installed with the 'tongue' outside its groove; and
- if the situations 1 and 2 occurred simultaneously.

In order to check the tail rotor system behavior in the situations described above, simulations were performed at the laboratory of Helibras, whose results are described below. Eurocopter performed the same tests in France, and reached the same conclusions.

The system and its components were studied, and then the steps prescribed in the manual for mounting the fork on the conical shaft were verified.

The procedure was considered very simple and easy to perform.

The complete sequence of the system assembly, as defined in the manual, is described below:

1 - Install the 'tongue' in the conical shaft (as a matter of fact, the 'tongue' is already installed in shaft when it comes from the manufacturer);

2 - mount the fork on the conical shaft, making sure that the 'tongue' is appropriately placed in the groove;

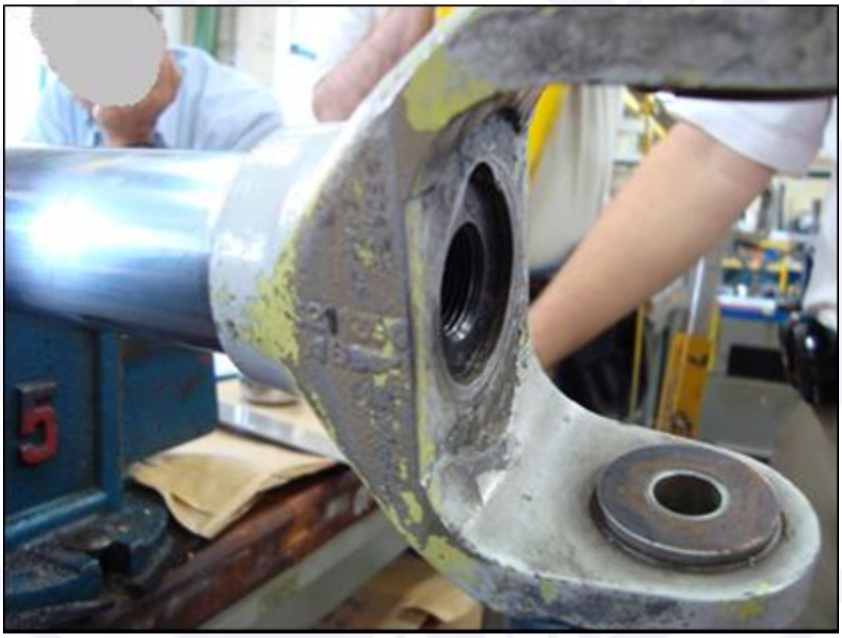

Figure 17 – Fork installed in the conical shaft.

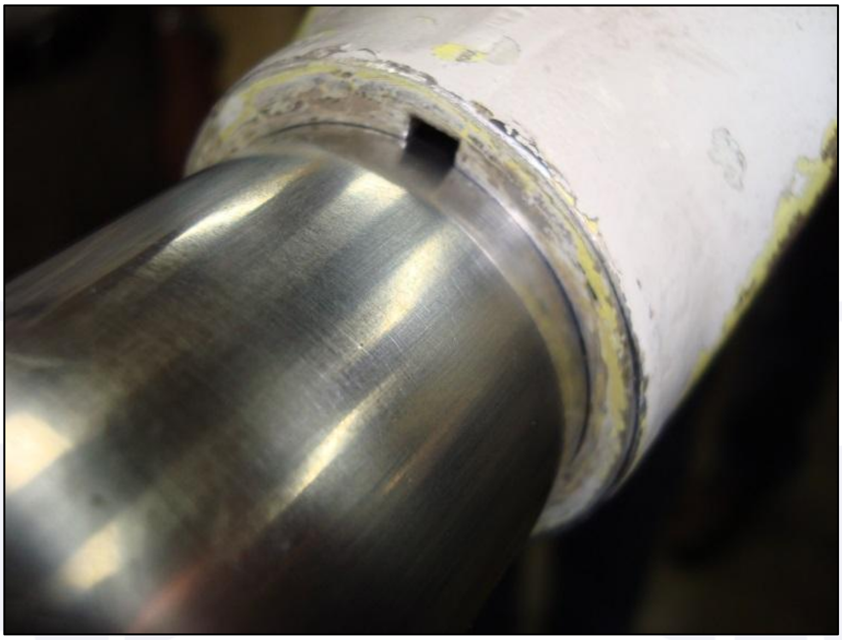

Figure 18 – Aspect of a correct installation, with the ‘tongue’ in the groove.

3- Place the washer and the bolt (Figures 19 and 20);

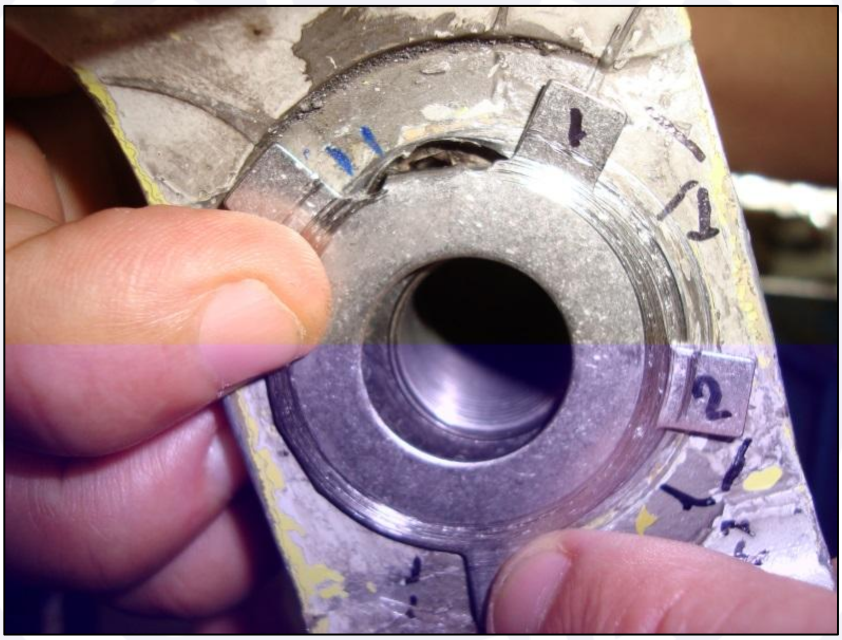

Figure 19 – Correct placement of the washer.

Figure 20 – Placement of the bolt.

4- Do not lubricate the conical shaft;

5- Apply 26 kgf.m torque on the bolt (such torque makes the fork perfectly match the conical shaft);

Figure 21 – Application of torque on the bolt by means of a torquemeter.

6- Remove the fastening bolt;

7- Remove the washer (at this moment, it was observed that the washer was deformed, and it was necessary to replaced it with a new one);

8- Apply Loctite 242 on the bolt (Figure 22);

Figure 22 – Application of *Loctite* on the bolt, before setting the final torque.

9- Apply polymer on the face of shaft with the fork, below the washer, to prevent penetration of moisture;

10- Install the washer and the bolt;

11- Apply the final torque, which must be between 12 and 13 kgf.m;

12- Make sure that the washer has not turned, leaving the notch;

13- Fold the locking tab of the washer so that it coincides with the perpendicular surface of the bolt head;

14- Apply the polymer on the bolt head and on the back of the fork; and

15- Wait approximately 24 hours before the first start-up of the aircraft engine (see Manual of Current Techniques).

Incorrect installation of the fork in the conical shaft

For removing the fork fastening-bolt at the DCTA laboratory, only 2kgf.m were necessary. As mentioned earlier, this would not be expected if the system had been assembled correctly. So, the investigation commission began to study how the system would behave in the case of an incorrect assembly.

The first possibility considered was that the fork might not have been appropriately mounted on the conical shaft. An incorrect assembly was simulated with the ‘tongue’ outside the groove. The figure below shows the appearance of the system in such situation.

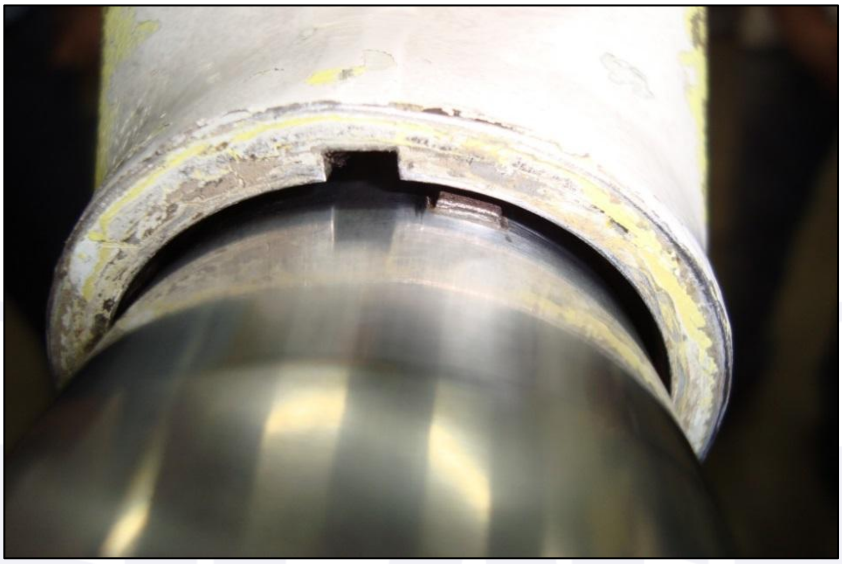

Figure 23 – Incorrect installation of the fork in the conical shaft.

It was observed that, despite the gross appearance, it is possible to follow all the steps for assembling the system, and the prescribed torque (26 kgf.m) is accepted.

In figure 23, it is possible to see that the system remains “superimposed”, and that the applied torque is absorbed by the ‘tongue’. It was observed that the fork does not perfectly match the conical shaft, with a space of .8 mm between the two parts.

When the system is assembled appropriately, approximately 37 to 38 mm of the conical shaft are inserted in the blade support-fork (figure 24), and on the front part, a space of 3 mm is left between the ends of the conical shaft and fork (figure 25).

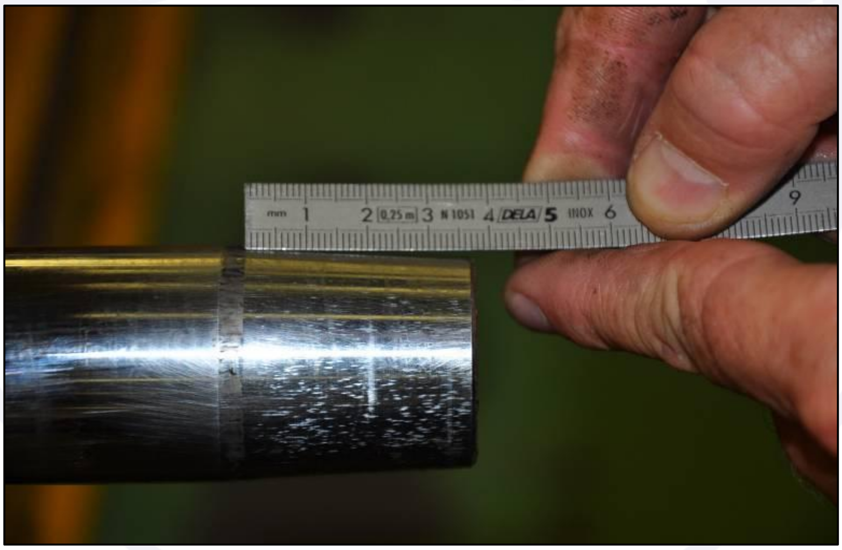

Figure 24 – The section of the conical shaft that remains inserted in the fork corresponds to 37-38 mm, when they are correctly assembled.

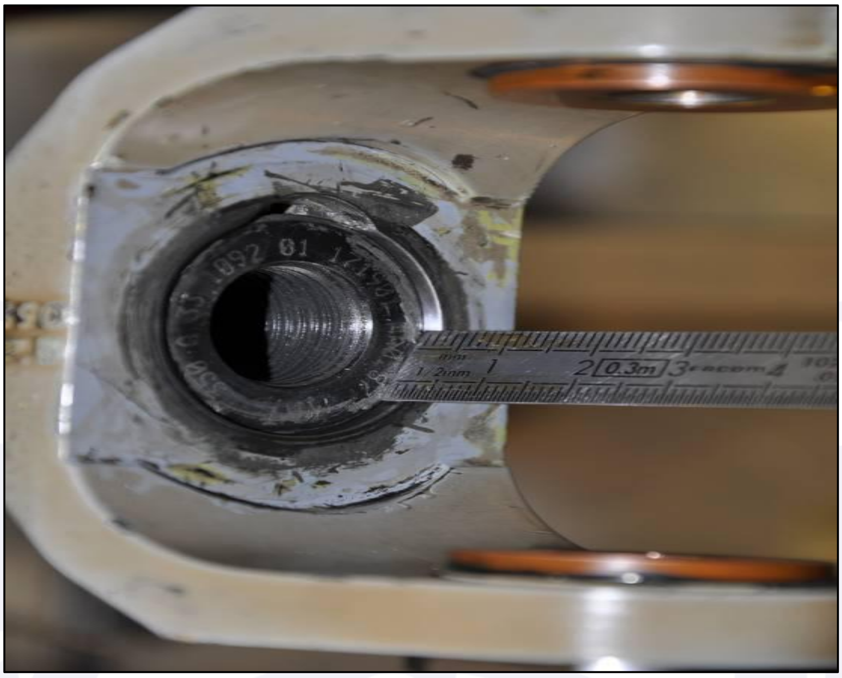

Figure 25 – Space of 3 mm between the ends of the fork and conical shaft, when the system is correctly assembled.

In the simulation, it was observed that the assembly becomes compromised when done incorrectly. The fork never ‘involves’ the conical shaft completely, and the torque applied is absorbed by the ‘tongue’.

In the incorrect assembly, it was observed that the section of the conical shaft inserted in the fork was approximately 27 mm (without application of torque), and 33 mm when the torque was applied in accordance with the prescriptions of the helicopter maintenance manual. The distance between the ends of the parts on the frontal surface was also different, corresponding to 7 mm. It is worth highlighting that the values found were significantly different from those obtained when the system is assembled in the correct manner (37 to 38 mm; and 3 mm).

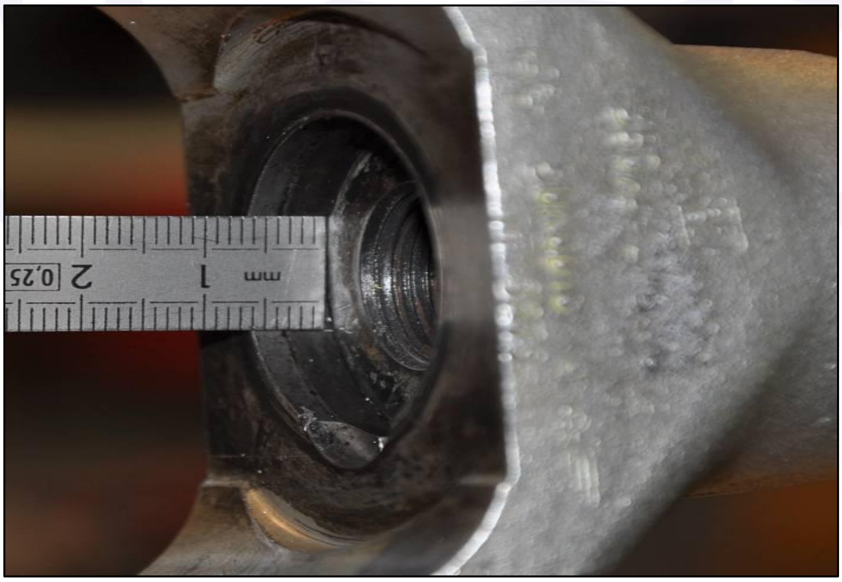

Figure 26 – Space of 7 mm between the ends of the fork and conical shaft when the system is assembled incorrectly.

After this work, the investigating in charge decided to verify which workload the tail rotor system would be able to stand if it had been assembled incorrectly. Therefore, after completion of all assembly steps, the drag the tail rotor was simulated on the bench.

The torque values (kgf.m) shown in the table below were those obtained at every 15 degrees of turn approximately.

TURN	TORQUE	TURN	TORQUE	TURN	TORQUE	TURN	TORQUE
1	40	10	60	19	65	28	10
2	50	11	60	**20**	**75**	29	10
3	55	12	55	21	40	30	10
4	58	13	60	22	30	31	10
5	60	14	58	23	40	32	10
6	50	15	60	24	60	33	10
7	50	16	60	25	10	34	10
8	55	17	70	26	12	35	10
9	60	18	70	27	15	36	10

Figure 27 – Table of the values obtained in the tail rotor tests.

During the test, it was observed that 60 kgf.m on average were necessary to move the fork. This pattern was modified after the turn number 20. This was the point at which the 'tongue' entered the groove, and the force necessary to move the set diminished considerably. After the event 27, the force necessary remained constant, in the order of 10 kgf.m.

The torque required for removing the bolt at the end of the test was 2 kgf.m, the same as the one of the accident aircraft.

During the simulation, a considerable loss of material was observed as a result of friction between the parts. The figures below illustrate the result of the grinding.

Figure 28 – 'Tongue' installed before the application of torque simulating turn.

Figure 29 – ‘Tongue’ showing loss of material, after application of torque simulating turn.

Loctite and polymer marks

The position of the fork when correctly mounted on the conical shaft is different from the one resulting of an incorrect assembly (“superimposed”).

There were some marks on the conical shaft coincidental with the values obtained in an incorrect assembly. Figure 30 shows that the polymer was distributed in a non-homogeneous manner on the conical shaft and gathered close to the ‘tongue’, precisely at the point where a space would exist in the ‘superimposed’ assembly. It is also possible to observe that opposite the ‘tongue’ there is practically no polymer, and there are marks of metal-metal rubbing.

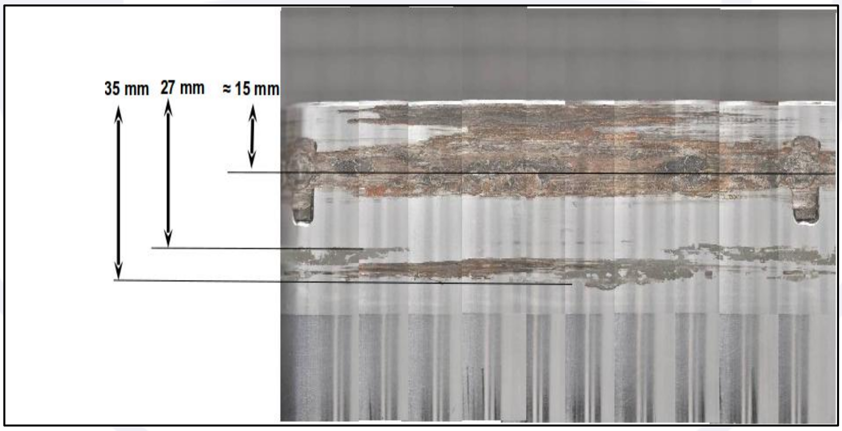

Figure 30 – Conical shaft made plane.

These pieces of evidence suggest that the fork was fastened incorrectly, with the ‘tongue’ outside of the groove, with penetration of polymer in the space existing between the fork and the conical shaft.

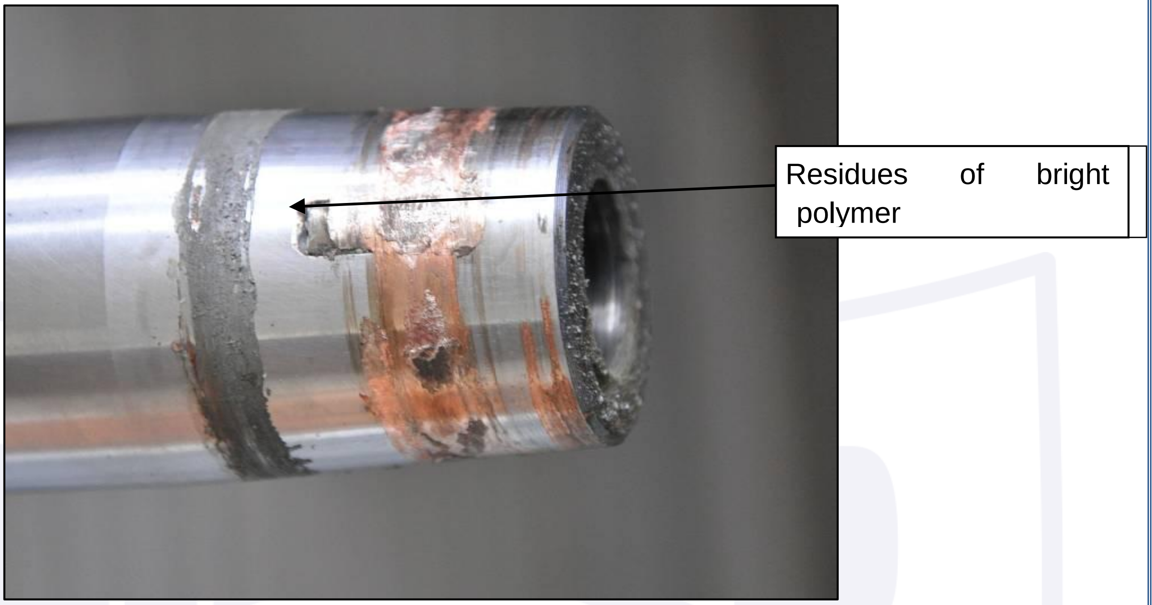

Figure 31 - Residues of bright polymer on the conical shaft.

The pulverized aspect of this polymer suggests that it was not dry when the failure occurred.

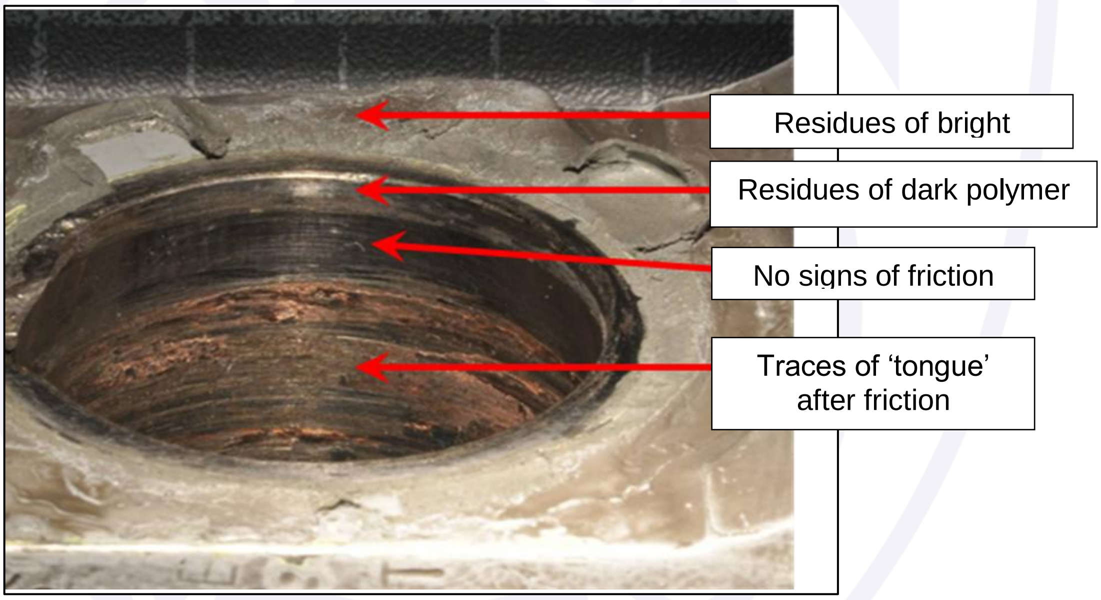

Figure 32 – Evidence of two different polymers.

The presence of residues from different polymers indicates that the polymers had been placed on different dates. The work at the laboratory with a spectrometer also suggests that there were two polymers on the conical shaft and fork, placed on different dates.

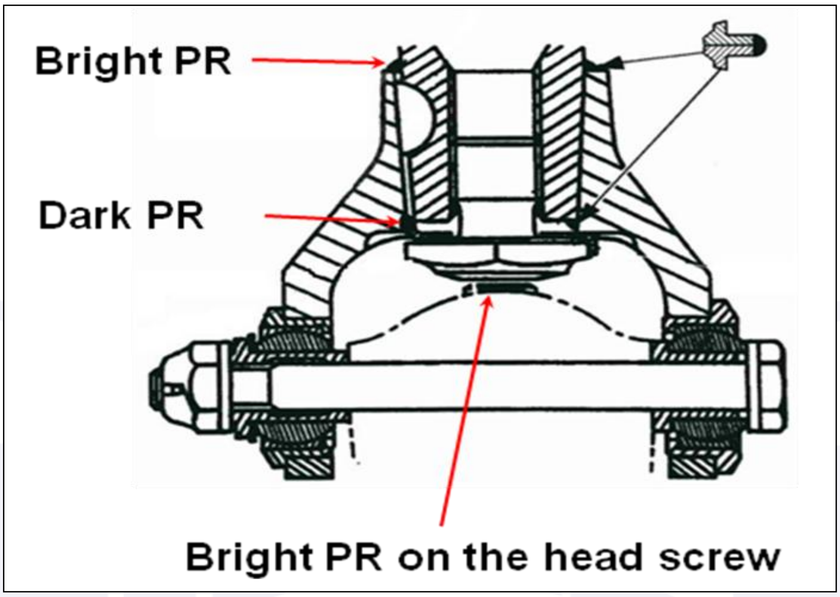

Figure 33 – Representation of the place in which the polymers were applied and how they were found.

The figures above are evidence that failures occurred during the last assembly and during the application of the polymer. With the assistance of Eurocopter, the following aspects were considered:

- the dark polymer had been applied on an earlier date in relation to the bright polymer, which was applied more recently;
- in the last assembly, there is evidence that the polymer was not applied on both sides of the connection, between the fork and the conical shaft. Apparently, it was not applied on the front part, which had residues of dark polymer; and
- The pulverized appearance of the polymer on the conical shaft suggests that the system rotated with the conical shaft not yet fully polymerized. It is worth stressing that an appropriate coupling between the conical shaft and the fork (correct assembly) would prevent such pulverization.

Exam of the Loctite on the fastening-bolt

The correct or incorrect position of the fork fastening-bolt at the moment of installation will affect the length of its penetration into the threaded hole. The Loctite applied for fastening the bolt during the installation of the fork may serve as evidence of the penetration length in the receptacle.

With participation of Eurocopter, the following values were obtained:

- for a correct system assembly, the bolt penetrated 19.65 mm + 1.8 mm; and
- for an incorrect system assembly, the bolt penetrated 13.55 mm + 1.8 mm.
- The bolt penetration difference between a correct/incorrect installation was 6 mm.

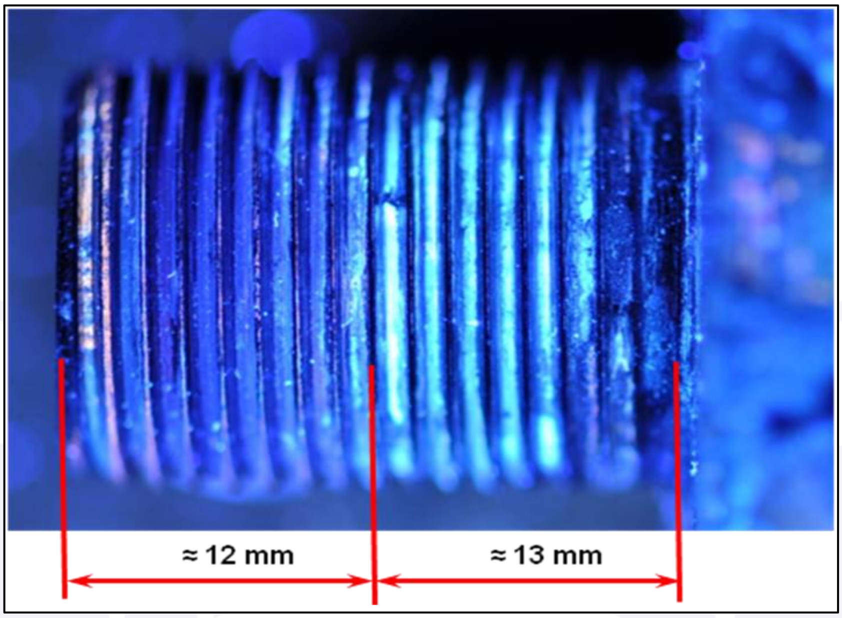

Figure 34 – Fork fastening-bolt.

The Loctite value found was approximately 12 mm, indicating that this was the final position of the bolt at the (incorrect) assembly of the system.

Tail rotor balance

Before accepting the hypothesis that the assembly of the tail rotor was done incorrectly on 21 December 2009, one must make sure that the system so assembled would accept balance, according to the records obtained from the company responsible for the maintenance services.

Thus, the following aspects were analyzed:

- the position of the fork when mounted with the 'tongue' outside the groove;
- the number of weights found on the tail rotor blades within the limits prescribed by the manufacturer; and
- the speed and aerodynamic forces to which the whole tail rotor assembly was subjected.

According to the manufacturer, the space between the fork and the conical shaft resulting from an incorrect assembly of the system corresponds to an imbalance of 6.4 mm.kg in the tail rotor. In order to correct such imbalance, it would be necessary to apply:

- a weight of 64 g on the *blade cord axis* (which accepts a maximum of 30 g according to the design of the helicopter); and
- a weight of 6.88 g on the *blade span axis* (which accepts a maximum of 5.35 g).

According to the maintenance records, at the last balance of the system, 18.6 g were used on the blade cord axis, with 2.07 g and 0.33 g being used on the blade span axis, i.e., all within the limits established by the maintenance manual.

Functioning of the tail rotor

The tail rotor has the function of counteracting the torque generated by the main rotor. For this function to be fulfilled, it is necessary that this system be mounted correctly. The rotation of tail rotor derives from the main transmission being passed along to the system by means of mutually interconnected shafts. The pilot is able to change, by means of the pedals, the pitch angle of the tail rotor blades by increasing or decreasing the tension provided by the rotor. This is the way the movement of the aircraft around its vertical axis is controlled (directional control). The rotation of the tail rotor, as well as the one of the main rotor, is constant throughout the flight. Similarly to what occurs with the main rotor, the tail rotor is also subject to various aerodynamic forces. Below, some system assembly possibilities are considered, along with their respective influences on the operation of the aircraft.

Without considering the 'tongue', when the torque of 26 kgf.m is properly applied to the fastening bolt, the system is able to transmit 190 + 7 kW in the conical shaft. The 7 kW correspond to the aerodynamic forces generated by the tail rotor in operation.

For a torque on the bolt of 12 to 13 kgf.m, without applying the pre-torque of 26 kgf.m and without considering the 'tongue', it is possible to transmit 95 + 7 kW in the tail rotor shaft.

If the 'tongue' is correctly installed (inside the groove), it is possible to transmit 178 + 7 kW in the conical shaft.

Without applying any value of torque on the fastening bolt, just considering that the 'tongue' is installed correctly, the system is able to transmit 83 + 7 kW to the conical shaft.

The 'tongue' is made of metal, and breaks upon receiving a torque of approximately 90 kW. Therefore, the value of 90 kW is considered the maximum torque made available by the system. However, the tail rotor works with 22 kW on average. This force is absorbed by the 'tongue' (without torque) for about 22,775,000 cycles (or approximately 180 flight hours), a point at which the curve of material fatigue shows that breakage may occur during normal operation of the rotor tail, i.e., with 22 kW or less. It is worth stressing that out of these 22 kW, 7 kW are provided by the very rotation of the tail rotor.

Considering the type of flight performed by the helicopter, another calculation is necessary. When filming, the helicopters remain hovering for extended periods of time or make small sideway movements. In relation to this type of flight, the manufacturer stated that the average torque in the tail rotor is around 31 kW, and it may reach 65 kW on flights with lateral movements. For these values, a failure of the 'tongue' due to fatigue will probably occur with 12.3 million cycles, corresponding to approximately 100 flight hours.

Pedal position influence

With an incorrect mounting of the fork, it was observed that it remains approximately 4 mm out of its axis. Since the tail rotor pitch drive rods are fixed in relation to the blades, it can be inferred that an incorrect assembly results in a pitch angle value different from the one specified by the design, in the direction of a negative angle. It is estimated that for the neutral pitch angle (centered pedal), pedals would be around 3 to 5 cm off center, in the direction of the left pedal.

In other words, the pilots would have to give less right pedal when hovering and more left pedal when flying forward. However, when asked about the subject, the other pilots of the aircraft reported that no abnormality in this sense had been perceived or reported.

Video of the accident

The sequence of the accident was filmed and widely publicized in the media. The video shows that the helicopter starts a downward spiral at a rate of one turn per second. Halfway through the third turn, smoke is seen coming out of the underside of the helicopter. During the fifth turn, a white smoke, thicker than the last, is emitted through the helicopter exhaust pipe.

Shutoff valve

The shutoff valve (a lever that blocks the fuel supply to the engine) was found activated in the middle of the wreckage. This valve is used in two situations: System testing (before releasing the aircraft for flight) or engine shutdown in an emergency (related to technical problems for which the check list so recommends).

Prior to releasing the aircraft for flight, a shutoff valve test must be carried out. With the helicopter on the ground, this procedure consists of the following: *under flight-idle regime, trigger the shut-off valve, and wait for the engine to shut down due to deprivation of fuel*. During such test, once the shutoff valve is activated, it is expected that the engine shutdown will occur in about 3 seconds. At the time of engine shutdown, it is normal that some smoke will be produced from the remaining fuel vaporized by the fuel drain of the combustion chamber.

1.17 Organizational and management information.

Maintenance company

The maintenance company was well structured, and had a set of documents clearly defining the personnel duties and responsibilities. It was certified for the types of services provided to the aircraft, and its maintenance records were considered appropriate.

The last records concerning the provision of maintenance services to the accident helicopter tail rotor indicate that the service was done by a mechanic (who was accompanied with a trainee), and monitored by the inspector responsible for the maintenance. Both the mechanic and the inspector had valid technical qualification certificates.

The mechanic said that he applied torque on the fastening bolt, and that he could remember having done the service with the manual open on the bench. In addition, he reported having completed all the steps planned for the task. Despite affirming that he applied torque on the bolt, the mechanic also said that, while he was performing this task, the inspector (who was monitoring the torque application procedure) had his attention directed to another helicopter.

The inspector said that shortly after the assembly of the system, he carried out a visual inspection, and found no irregularities in the procedure.

Operator

The aircraft operator used the helicopter as a platform for recording images that would be utilized on TV news broadcast or on releases throughout the day. Therefore, the helicopter was utilized three times a day on average (for news broadcast in the morning, afternoon and evening), and was also on the alert to take off at any time, upon request of the newspapers producers.

Three pilots and three cameramen would take turns among themselves in the period from 05:30 to 23:00 (local time), in order to keep the helicopter manned and ready for the missions.

In the hierarchical chain, there was a coordinator above the pilots, and a Director of Logistics above the coordinator. The coordinator was responsible for defining the needs, which would then be granted approval at the discretion of the Director of Logistics. Both the coordinator and the Director of Logistics had limited knowledge of aviation, and would quickly accept all the requests and/or suggestions made by the pilots.

With regard to air operations, the helicopter was registered for private use (TPP) in the National Civil Aviation Agency (ANAC), as was operated in accordance with the Brazilian Aeronautical Certification Regulation 91 (RBHA91).

1.18 Operational information.

It was an aerial footage flight for a TV broadcast station in the city of São Paulo.

In the vicinity, there was an aircraft of the same type which belonged to another television station. The pilots of the two aircraft were accustomed to flying near each other in a coordinated manner so as to maintain the safety of the operation and the spacing between the aircraft while, at the same time, they did the filming.

At a certain point, the pilot of the accident aircraft, on the APP-SP frequency, informed the other pilot that he was having difficulty with the tail rotor, and that he was heading for the Jockey Club. The other pilot followed him. The images of the outcome of this event were widely publicized on the TV channels.

The images show that the pilot managed to leave from the Morumbi neighborhood and keep directional control of his aircraft for a little over 7 minutes. During this period, the helicopter flew straight, made some turns to the left, and arrived on the vertical of the Jockey Club.

Suddenly, the pilot lost control of the helicopter, which yawed to left with high intensity, and crashed violently into the ground.

The AS-350 is maneuverable under conditions of tail rotor failure. The manufacturer affirms that the drift can perform anti-torque functions at speeds above 70 kt; however, at speeds below 50 kt, the drift loses efficiency, and loss of control is imminent.

Two types of emergencies are likely to occur in case of AS-350 tail rotor failure: loss of control or loss of tail rotor effectiveness.

In the first case, the manual prescribes a run-on landing, as described below:

7.2 Tail Rotor Control Failure

- Set IAS 70 kt (130 km/h), in level flight. R
- Press the hyd. push-button (this cuts off hydraulic power to the yaw servo-control and depressurizes the load-compensating servo accumulator). After 5 seconds, reset the test button to the normal position. R
- Make a shallow approach to a clear landing area with a slight side slip to the left. Perform a run-on landing ; the side slip will be reduced progressively as power is applied.

Figure 35 – Procedure for “Tail Rotor Control Failure”.

In the second case, the manual prescribes an autorotation. The recommended procedure is to "shut down the engine and made an autorotative landing" as described below:

7.1.2 Failure in Forward Flight

- In forward flight reduce the power as much as possible and maintain forward speed (weathercock effect), select a suitable landing area for a steep approach at a power enabling a reasonably coordinated flight.
- On final approach, shut down the engine and make an autorotative landing at the lowest possible speed.

Figure 36 – Procedure for “loss of tail rotor effectiveness”.

The pilot successfully completed the AS-350 emergency course at the specialized training center in March 2006. From the flight sheets and from conversations with the flight instructor responsible for the training, the investigation commission learned that, during the course, the pilot trained autorotation, run-on landing, and landing without pedals, with satisfactory performance in all maneuvers.

On 20 and 21 June 2008, at the same training center, the pilot did performance-evaluation flights. According to reports made by the person responsible for the evaluation, the main aircraft emergency procedures were contemplated. The sheets of these flights contain records of completion of autorotation and landing without pedals. The pilot’s performance was considered satisfactory, and he even passed the ANAC evaluation.

The investigator in charge was not shown any other records concerning the execution of AS-350 emergency training after that last evaluation of the pilot’s performance.

With regard to maintenance, all primary maintenance records were logged by the same company, which had certification for that type of aircraft. There were no records concerning malfunctioning, vibration or maintenance of the PT-YRE tail rotor.

It was observed that the company responsible for the maintenance received the helicopter with a number of overdue intermediate inspections, and just complied with the pertinent inspections. Little or nothing was done to prevent these errors in the future.

The operator did not have support from flight engineers. In this sense, there were no records concerning preflight/inflight/post flight inspections in the operational routine. The absence of flight engineers also had influence on the intermediate inspections. These inspections, which could be performed by a trained mechanic, were often disregarded in terms of deadline, and were done in conjunction with the 100-hour inspections.

The planning of air operations, the flight time logging, the control of maintenance services, and other important activities for the safe operation of the aircraft were done by the pilots themselves, without any interference on the part of the management, who proved technically unprepared to manage a helicopter.

No manuals or procedures were presented which standardized or limited the pilots’ conduct. The operational safety was under the exclusive responsibility of the pilots, and their decisions were always accepted by the management staff, as if they represented the best in terms of flight safety. It was observed that the operator had been flying around 100 hours per month with the aircraft later involved in the accident.

The day before the accident, after the landing of the helicopter, the pilot reported to a friend of his, who was also a pilot of the aircraft, that he had noticed a strange yaw behavior of the aircraft just before landing.

The issue was treated informally by both, and was not informed to a mechanic for a preventative inspection of the tail rotor.

The flights were not annotated in the logbooks as prescribed by the IAC 3151. The last entry in the logbook was on 4 February 2010. Apparently, technical problems were not duly annotated, since there was no reference to them in the aircraft logbook.

The pilots and cameramen's schedules were made informally, without being written or controlled, and duty hours would be exchanged between the pilots, without communication to the coordinator or to the person responsible for the operation of the helicopters.

The company Director of Logistics was ultimately responsible for air operations and for the helicopter. The air operations represented only a part of his duties. At an interview, it became clear that his knowledge of aviation was limited, and that he would promptly accept without questioning the requests and/or suggestions made by the pilots...

1.19 Additional information.

Operator and maintenance company

The aircraft operator declared that all the maintenance services to the helicopter were always done by the same workshop.

A contact was made with one of the PT-YRE pilots, who used to fly the aircraft prior to the accident. He said that did not know of any maintenance services to the tail rotor on the days preceding the accident, nor of any dynamic balance (Vibrex) in the referred system. Once again, the only company responsible for the aircraft maintenance services was the one whose records were in the logbooks.

Landing site

The collision with the ground occurred in the grass race-track of the São Paulo Jockey Club.

It was an area appropriate for run-on landings: flat terrain with no holes or obstacles, with a length of 1,070 meters.

Figure 37 – Landing area.

In the figure above, the yellow line represents the area chosen for landing. The white star shows the location where the aircraft crashed. The red arrow indicates the direction of the wind, with an estimated strength between 4 and 8kt.

1.20 Useful or effective investigation techniques.

Nil.

2. ANALYSIS.

Pilot

The pilot was very popular in the work environment, and was considered an experienced professional by his peers and superiors. He had valid certificates and licenses, and experience for the flight in question.

According to the information gathered in the medical aspect (item 1.13.1), the pilot's rest period was shorter than the one required by law. Therefore, under the circumstances, the pilot could not have accepted to fly the helicopter on the day of the accident.

The human factor, physiological aspect, referred to the consumption of a digestive system medication, which, according to medical doctors, may lead to drowsiness and decreased reflexes.

Pilot training

The tail rotor transmission failure is not a frequent one, and the corresponding training is done only in simulators, since it is not possible to disengage the transmission tree and/or to make a full stop of the tail rotor blades in flight.

The last records of training by the pilot referred to a date approximately one year and eight months before the accident. Prior to that date, there were records of a similar training in 2006. Such time interval between training sessions, if one considers the particulars of this crash, may have degraded the pilot’s ability to deal with the problem.

The tail rotor failure

Two possibilities of failure in the AS 350 tail rotor were analyzed. The first one occurs when tail rotor transmission fails, but the system keeps its normal rotation. In this situation, the tail rotor, although no longer having pitch-angle control by the pilot, continues to provide traction and, therefore, continues to play an important role in the directional control of the aircraft, assisting the drift in the task of maintaining the helicopter aligned.

The second possibility of failure in the AS 350 tail rotor relates to the loss of power in the system. In such situation, the tail rotor blades stop turning, and the system completely loses the ability to counteract the torque generated by the main rotor. The pilot must maintain an adequate minimum speed so that the drift is able to generate the aerodynamic forces necessary to provide the anti-torque function that was being provided by the tail rotor. Moreover, at the time of landing, the recommended procedure is to "shut down the engine and perform autorotative landing".

All the exams and tests indicated that there were two failures in the tail rotor system: the breaking of the transmission shaft, and the relative rotation between the conical shaft and the blade support-fork.

The breakage of the tail rotor transmission shaft was caused by overload, probably on account of locking. Exams of the parts anterior to the shaft ruled out any problems capable of causing the locking. Therefore, one may infer that the breakage of the transmission shaft occurred after the failure in the coupling between the conical shaft and the blade support-fork.

Regarding the relative rotation between the conical shaft and the fork, two hypotheses may be considered: the first is that the torque applied on the fastening bolt was smaller than required, allowing the 'tongue' to leave its groove, resulting in relative rotation between the conical shaft and the fork; the second is that the assembly was done incorrectly, and that the conical shaft 'tongue' never entered its groove, allowing relative rotation between the two parts.

Operational aspect

The helicopter was at low speed, very close to hovering, while the camera was focused on a stationary truck on the street. Suddenly, there was a brief change of heading to the right, followed by a yaw to the left. At this moment, the pilot did a go-around, increased the speed and maintained control of the aircraft until moments before the crash.

At that moment, the failure in the connection between the blade support-fork and the conical shaft was most likely already in progress. The reverse yaw to the left probably began due to the breakage of the tail rotor transmission tree in the connection between the long and short shafts. Signs of friction and heat observed on the shaft suggest that, in some way, both shafts remained concentrical for some time.

Thus, some degree of rotation continued to be transmitted to the tail rotor, and, therefore, directional control (however residual) could be maintained. This explains why it was possible for the pilot to do the go-around maneuver. Moreover, according to the communication transcripts, the pilot says that whenever he depressed the left pedal, there were lots of vibration. This is an indication that, until moments before the accident, the long and short shafts were still concentrical, and that the tail rotor still had some effectiveness.

A Eurocopter test-pilot was asked to talk about the total loss of the tail rotor. He said that, under the circumstances, speeds below 50kt are extremely dangerous, and can lead to loss of control of the helicopter, due to ineffectiveness of the drift in counteracting the forces resulting from the torque produced by the main rotor.

The images of the accident show that, over the area of the Jockey Club, the speed of the accident helicopter decreases considerably, contrary to what is recommended in the checklist in case of problems related to the tail rotor.

With a remarkably low speed, the aircraft loses directional control, and flies a downward spiral until crashing into the ground. The total disconnection between the long and short shafts probably occurred at this moment, causing the helicopter to yaw to the left under loss of control. The helicopter descends almost vertically at high sink rate and without horizontal speed.

The vertical descent may have been a result of a reduced collective pitch, an expected reaction from pilots with training of autorotation and recovery from tail rotor failures.

The shutoff valve was found activated in the wreckage. The video of the accident shows that the helicopter starts the downward spiral at a rate of a turn per second. Halfway through the third turn, it is possible to see smoke coming out from the underside of the helicopter. During the fifth turn, white smoke, thicker than the previous one, comes out from the helicopter exhaust.

After the images were analyzed, the following possibilities were raised:

a) after losing directional control, the pilot was likely to have commanded the collective downward in an attempt to reduce the effect of torque and restore directional stability. Such statement is consistent with the loss of height observed after the beginning of the tail turns;

b) the aircraft begins a sequence of turns around the vertical axis, at a rate of one turn per second;

c) if the action of lowering the collective control does not produce the expected effect, it is indeed likely that the pilot will shut down the engine in an emergency, as a last resort to suppress the torque and decrease the rate of turns around the vertical axis. These arguments are supported by the shutoff valve position (activated) when it was found in the wreckage;

d) the engine shutdown procedure by means of the shutoff valve takes about 3 seconds (which corresponds to three turns in this case);

e) when the engine is shut down, it is normal to see some smoke coming out from under the helicopter; and

f) considering the aforementioned, all these pieces of evidence suggest that the pilot activated the shutoff valve after losing directional control, and that the engine shutdown occurred effectively in the middle of the third turn of the downward spiral.

As for the thicker smoke observed during the fifth turn of the downward spiral, the following considerations can be raised:

a) Helibras and Eurocopter technicians suggest that the thicker smoke comes from burning engine oil after contact with hot parts, depending on the aerodynamic forces present, and on the very engine shutdown;

b) the smoke coming out of the engine passes through the main rotor. This is strong evidence that the collective control was in the downward postion at that moment, and that the direction of the air flow through the main rotor was upwards; and

c) shortly before the crash, the helicopter rate of turn around the vertical axis begins to decrease approximately 50% per turn. This corresponds to what is expected after engine shutdown, due to the decrease in the torque generated by it.

In view of the foregoing, it is coherent to affirm that, upon losing control, the pilot lowered the collective lever, and then shut down the engine in an attempt to stop the aircraft from turning around the vertical axis. It is possible to infer, too, that the position of the shutoff valve is consistent with the pilot's action in shutting down the engine in the emergency during the downward spiral.

<u>Helicopter</u>

The primary records in the aircraft logbooks were all done by the same workshop and the latest maintenance records concerning the tail rotor (which required to disassemble and subsequently assemble the whole conical shaft / fork assembly) were written during the inspection of 100 hours, in December 2009 (185 hours of flight hours before the accident).

From 18 to 21 January 2010, another inspection of 100 hours was done by the same maintenance company, when the aircraft had a total of 7,942 hours and 10 minutes of flight time. It was observed that the intermediate maintenance inspections (7 days, 10 hours, 25 hours 30 hours and 50 hours) were not being observed by the aircraft operator. Moreover, the helicopter flew 9 flight hours, after expiration of the 100-hour validity.

In the inspection of 100 hours, the tail rotor was not disassembled. The balancing of the tail rotor blades would only be made if requested by the operator. since this balancing was not performed, it is understood that the system was operating normally. Only the tail rotor transmission shaft was balanced, and no difficulties were reported.

It is estimated that on the day of the accident, the helicopter had 8,018 hours and 55 minutes of flight time, i.e., 73 hours and 25 minutes after the latest inspection. On that date, the intermediate inspections were no longer valid.

There are no records concerning prescribed daily inspections such as pre-flight-inflight/post-flight inspections. Nor were there any records of compressor washing, an action prescribed in the maintenance manual.

Despite all these errors in relation to keeping the aircraft airworthiness, there was no direct relationship between the lack of inspections and the failure of the tail rotor transmission shaft.

Hangarage of the aircraft

Hangarage of the helicopter was done in a private hangar in SBMT. Soon after the accident, the investigator in charge contacted the hangar administrator, and requested the images of the arrival of the PT-YRE the day before the accident (9 February 2010), and of the aircraft departure on the morning of 10 February 2010. This request was made verbally immediately after the accident, and formalized via an official document on 18 March 2010.

The images recorded on 10 February 2010 show just short sequences that preclude a deeper analysis. Neither was it possible to verify the extent of the yaw of the helicopter upon landing at night on 9 February 2010, nor any post-landing/hangarage procedures.

In the sequences, it is possible to see that the helicopter leaves the hangar at 06:04, and takes off at 06:33. During this period, no indication of preflight and/or external inspection is observed, nor any verification of the tail rotor on account of the problem experienced the day before.

According to the report made by of one of those responsible for taking the helicopter out of the hangar, the pilot went directly to his seat and started up the helicopter engine.

Company responsible for the aircraft maintenance

The maintenance company that did the last assembly of the tail rotor registered in the aircraft logbook had a well-defined corporate structure, in which each member knew his own duties and responsibilities.

All procedures were documented and apparently in accordance with the prescriptions of the Helicopter Maintenance Manual. The professionals involved in the maintenance were qualified and had the training necessary to perform the services.

Records and controls compatible with what can be expected from a maintenance company were presented. In the visit of the installations, it was possible to observe practices in accordance with flight safety precepts.

Training of employees was controlled, and courses were offered in consonance with the needs of the company and personal interest. Apparently, employees were satisfied with the work, and nobody showed interest in leaving the company.

Despite the positive aspects mentioned above, the fact is that the company received commercial and operational pressures, being part of a larger system. In this sense, some lenience with the operator was observed when the helicopter entered the workshop with a number of overdue inspections, and nothing was done to inform the operator on the irregularity.

Another factor observed relates to the inspector and the way he did his work. He reported feeling stressed and pressed for time in the completion of maintenance. According to him, being an inspector of different aircraft simultaneously generated a high workload that, in his opinion, was not always possible to manage. He also reported that he was monitoring the tail rotor assembly, when his attention was diverted to another service, and that was the reason why he was not present at the time the fork was mounted and torque was applied on the fastening bolt. This period without his supervision can be related to a weakening of procedures, and may have contributed to the accident.

It was observed that the mounting of the fork can not be performed by just one person. The investigation commission verified that a trainee helped the mechanic do the job. According to information gathered at the interviews, the service was fully guided by the mechanic. The trainee demonstrated knowledge about details of the ‘tongue’ placement in the groove of the fork, and application of torque on the fastening bolt, indicating that these actions were performed during the assembly of the tail rotor.

Operator

The use of the helicopter was aimed at recording images with quality and celerity to, opportunely, put them on the air in the form of journalism or information. Thus, the use of the helicopter demanded agility, accuracy, flying in restricted airspace at low speeds or even hovering, close to large numbers of people or buildings.

The operation of the helicopter was under full responsibility of the pilots. The management staff, almost exclusively, was responsible for supporting the decisions made by the aircraft captains, as well as for providing them with the financial and logistical means necessary for the operation of the aircraft. The Director responsible for the air activity also took care of ground vehicles and other equipment. His position in the company was defined as Director of Logistics.

Between this Director and the pilots, there was also a coordinator. It was not possible to determine his/her assignments and activities because there was no written document listing his/her duties.

The pilots, in turn, would report to the coordinator, but could also report to the Director. Both the coordinator and the Director had limited knowledge of the air activity, and would accept the considerations of the pilots as being correct. For both, flight safety was synonymous to trusting their pilots and doing what they requested, either operationally or in terms of the helicopter maintenance.

The entire flow of information related to air activity lacked systematization. There were no written procedures to legitimize the decisions made by the management or the pilots. Communication between the system components was informal and not logged.

The work environment was characterized by informal relationships and apparently defined as agreeable. Everyone involved with the air activity was very satisfied with the work, and considered the company as part of their families. No-one expressed interest in leaving the company.

The aircraft operator stated that all helicopter maintenance services were always provided by the same workshop, and that no one else would service their aircraft.

The commission contacted one of the operator’s pilots, who used to fly the aircraft later involved in the accident. He was asked if he knew whether any maintenance job had been done to the tail rotor on the days preceding the accident, and whether Vibrex had been performed in the tail rotor. His answer was negative.

Supervision of the helicopter operation

Several times during the investigation of this accident, it became clear that the supervision by the operator was inadequate. An example was the treatment given to a report made by the pilot on the day before the accident. The pilot reported having felt a strange yaw behavior moments before landing. The issue was treated informally, and the information was not passed to a mechanic or to the company management so that a preventive inspection of the tail rotor could be carried out. The fact is that there was not a mechanic who could receive this information and treat it accordingly.

There are no records to confirm the report of failure made by the pilot, and there are no records attesting the adoption of any preventative measures. The images of the hangar CCTV system did not show any inspections (not even pre-flight or external ones) performed by the pilot or the mechanic in the helicopter after the landing of the previous day and before the takeoff on the next day.

The flight records were also written incorrectly. The last entry in the logbook dated from 4 February 2010. Apparently, the records of technical issues were not entered as prescribed, either.

Another indication that the supervision was not appropriate was the treatment given to the intermediate inspections of the aircraft (7 days, 10 hours, 25 hours, 30 hours, and 50 hours). As a matter of fact, theses inspections were done jointly with every 100-hour inspection, when the helicopter would be grounded to undergo the periodical inspection.

It was also verified that, despite the prescription of maintenance manual that the engine compressor had to be washed with a certain frequency, such washing was not being done by the operator.

The helicopter operation was under full responsibility of the pilots. In addition to the fact that there was not a mechanic monitoring the operation, the ground support personnel were not knowledgeable of technical maintenance and did not have bonds with the operator. Their functions were merely restricted to placing the helicopter in the hangar after the flight, and taking it out from the hangar before the next flight.

The flight Coordinator and the Director responsible for the operation of the aircraft were apparently interested in operating the helicopter in accordance with highest levels of safety. However, their apparent short experience in the air activity made it difficult for them to supervise the pilots and the operation.

There were no manuals with operational procedures; the flight schedule was informal; the exchange of pilots scheduled for flights was done without participation of the supervisors; the pilots were summoned for flight in an informal way (via telephone), and the safety of operations was under the exclusive responsibility of the pilots.

Psychological aspect, organizational culture, and training

As for the psychological aspect, the pilot was described by all interviewees as knowledgeable of aviation and capable of good performance in emergency situations. Positive characteristics which, nevertheless, proved not sufficient for preventing the accident.

Unsafe conditions got aligned in a chain of actions and omissions in the day to day operation of the helicopter, with the persons involved unaware of the hazard. The informality, present in the organizational culture of the operator, created an unstable terrain for the construction of a structure of work capable of detecting and mitigating possible threats.

The collected data show that the structure lacked on the one hand a leader knowledgeable of aviation and, on the other hand, a support system (Standard Operating Procedures – SOP – manuals, among others) for documenting the procedures of the company, protecting the actions and decisions of the personnel, formally defining everyone’s responsibility with the air activity.

The informality with which the flight schedule was made, subject to exchanges without the knowledge or management on the part of someone in charge, led the pilot of the PT-YRE to disregard the prescriptions of the Aeronaut Law relative to the 12-hour rest period between workdays.

The continued training of the pilots did not follow an appropriate periodicity and was done without planning and supervision. The low frequency of the training may have degraded the pilot's performance in the operational context of the emergency.

The culture of informality within the organization was also present in the maintenance, with outdated maintenance logbooks, non-compliance with inspection deadlines, and lack of verification by a qualified mechanic of the abnormal behavior of the aircraft one day before the accident.

The maintenance workshop which did the last inspection noted down in the logbook had a well-defined enterprise structure, in which every employee was aware of their own obligations and responsibilities. All the procedures were documented, and complied with a standardization aimed at the continuous improvement of processes and results, as well as at the qualification of the personnel.

The work methodology relative to the inspector, however, proved inappropriate. He felt stressed and pressed for time because he had to supervise distinct maintenance actions simultaneously. Such demand generated an interval without his supervision concerning the maintenance of the accident aircraft, exactly at the time when the mechanic applied torque on the fastening bolt of the tail rotor system.

Tail rotor transmission shaft

The shaft was found broken at the point of connection between the long and short shafts. It is possible to affirm that the failure occurred in two distinct stages. In the first one, the breakage occurred, and the long shaft remained concentrical with the short shaft. The existing signs of friction and heat are evidence that this situation existed for some time.

The overload found in the fracture of the connection between the two shafts has the same direction of rotation of the tail rotor transmission shaft. Therefore, it may have been caused either by sudden acceleration or abrupt stop.

Tail rotor

The right-angle gearbox was opened, and showed preserved characteristics.

The parts anterior to the tail rotor transmission shaft did not present evidence of being capable to block the system. Likewise, there were no signs on the tail rotor blades indicative of impact with an obstacle that could lead to an abrupt stop.

In light of the foregoing, the investigation commission concluded that the blade supporting-fork rotated in relation to the conical shaft. The rotational speeds of the shaft and of the tail rotor were different. During the hovering, while the truck was being filmed, the fork and the conical shaft re-connected. The torque generated by the reconnection led to a failure of the tail rotor transmission tree, causing a breakage of the connection between the long and short shafts. The pilot did a go-around and proceeded to the Jockey Club. As the aircraft was flying over the area of intended landing, the shafts separated completely, and the pilot lost control of the tail rotor.

Conical shaft

The conical shaft was analyzed at the DCTA and Eurocopter. The result of the analyses shows that there was "relative motion" between this part and the fork, possibly on account of incorrect assembly.

'Tongue'

The 'tongue' is attached to the conical shaft meaning a special paste (structural paste, according to the manufacturer).

During the simulation of incorrect assembly, it was possible to verify a considerable loss of 'tongue' material, as a result of friction between the 'tongue' and the internal part of the fork.

Another important fact is that, if there is an abrupt stop of the tail rotor because of collision with the ground, the 'tongue' breaks, but the fork does not make a complete revolution around the conical shaft. What was seen in the PT-YRE was different: the fork rotated freely in relation to the conical shaft.

Fork

It is possible to affirm that the blade support-fork rotated relatively to the conical shaft. On account of the speed to which the system was submitted and on account of the design concept, an instantaneous re-connection between the fork and the conical shaft took place at a given moment. The speed differential between the tail rotor and its transmission shaft was such that it created a torque which led to the breakage of the tail rotor transmission shaft at the connection between the long and short shafts.

The marks observed on the conical shaft and on the fork suggest that there was no torque on the fastening bolt, and that the fork progressed only 33 mm upon entering the conical shaft.

Two incorrect-assembly ('tongue' outside the groove) simulations were carried out, and the results obtained were rather similar. It was observed that the fork progressed 31 mm when the torque was applied and, after a complete turn of the fork and entry of the 'tongue' in the groove, the fork moved 1 more millimeter forward.

Bolt

The distance traveled by the fork fastening-bolt inside the conical shaft will vary depending on a correct or incorrect installation of the fork.

At the exam of the Loctite marks on the bolt, it was verified that the bolt had traveled 12 mm inside its receptacle, instead of the expected 19.65 mm + 1,8 mm when the system is correctly assembled.

The values found are compatible with an incorrect coupling between the conical shaft and the fork.

Tests and research

Research was done with the purpose of understanding what really happened with the aircraft. Also, special attention was paid to the time line of the events in order to clarify the participation of every aspect in this accident.

Engine and free wheel

The analyses conducted at Turbomeca led to the conclusion that there was neither engine nor free-wheel failure (nor evidence thereof). The internal state of the engine suggested that it had been shut down by the pilot, and was decelerating at the time of impact with the ground. The right-angle gearbox was opened and showed preserved characteristics, an indication that this system did not contribute to the accident.

Shutoff valve

The shutoff valve was activated by the pilot. Such affirmation is possible because:

a) it was in its activated position (closed) in the middle the wreckage;

b) it was not possible to move it, on account of deformation of the helicopter structure;

c) the engine had been shut down prior to the impact with the ground; and

d) In the images of the helicopter crash, a white smoke is seen between the third and fourth turns around the vertical axis, followed by a reduction of the aircraft yaw speed. The smoke may be associated with the engine shutdown, and the reduction of the turn rate may be associated with the diminishing torque generated by it.

Simulations at Helibras

Simulations were carried out in order to verify whether it was possible to install the fork without considering the correct position of the ‘tongue’ inside the groove. Three types of installation were simulated:

a) ‘tongue’ in the correct position;

b) ‘tongue’ in an incorrect position (“superimposed”) without application of torque on the bolt; and

c) ‘tongue’ in an incorrect position (“superimposed”) with application of torque on the bolt.

The hypothesis that the system could have been assembled in the way represented by the simulation nº 2 (with the ‘tongue’ superimposed and without application of torque) was ruled out. In such condition, the fork stays completely out of its position, and does not connect to the conical shaft, making the system unstable. The left pedal of the helicopter has to be moved 3 to 4 cm ahead of its central position for the tail rotor blades to assume a neutral pitch position.

It was possible to observe that, despite the gross appearance, the system could be assembled as in the simulation nº 3, with the ‘tongue’ outside the groove, and with application of torque on the fastening bolt. In such condition, it is possible to follow all the steps required for assembling the system, including application of the required torque on the fastening bolt.

It was also observed that the fork moves in relation to the conical shaft, if one applies a torque of about 60 kgf.m in the direction of the tail rotor drag, simulating the condition of the rotor in flight. When the ‘tongue’ enters the groove as a result of the relative motion between the parts, the torque applied to the bolt at the assembling of the system is lost. Both in the tail rotor of the accident aircraft and in the two simulations performed a force of only 2 kgf.m was needed for removing the fastening bolt.

To brake the ‘tongue’, approximately 60 kgf.m are necessary. After the ‘tongue’ is broken, just 10 kgf.m are needed to move the fork in relation to the conical shaft.

It was seen that when the ‘tongue’ enters the groove in the fork, this latter tends to move forward, causing the polymer applied to its back to be removed. The fork was also deprived of the polymer in that position. One also observed that it is possible for the polymer to enter the space between the fork and the conical shaft resulting from an incorrect assembly (‘tongue’ outside the groove)

Finally, in order to fully accept the hypothesis of an incorrect installation of the fork, it would be necessary to admit that the system would allow the tail rotor to be balanced.

Tail rotor balancing

For one to think of the possibility of an incorrect assembling (with the ‘tongue’ outside the grove), one has to consider that the system ‘accepted’ the balance, according to the data obtained from the company responsible for the service provision.

According to information provided by the helicopter manufacturer, considering the change of the angle and position of the tail rotor disk, and also considering that the system rotates at 2,048 RPM, it is mathematically impossible to balance the tail rotor in such situation.

In the analysis of the documents, it was observed that the last balance records refer to the same inspection in which the assembly of the tail rotor was required. The records confirm that the balance was made and that the values were within the limits prescribed by the manufacturer, but no mention is made about the weights that were put in order to achieve the tail rotor balance.

After that, there are records of a balance of the tail rotor transmission shaft at the last 100-hour inspection, but it seems that no service to the tail rotor was provided.

It is worth stressing that no complaints were made by the operator about any abnormalities associated with the pedals of the PT-YRE, in terms of either amplitude and functioning or vibration.

Functioning of the tail rotor

The maximum torque available to the tail rotor for normal functioning is 90 kW.

Without considering the ‘tongue’, a torque of 26 kgf.m correctly applied to the fastening bolt allows the system to transmit a torque of 190 + 7 kW. The 7 kW correspond to the aerodynamic forces generated by the tail rotor in operation.

For a torque on the bolt in the order of 12 to 13 kgf.m without applying the pre-torque of 26 kgf.m and without the ‘tongue’, it is possible to transmit 95 + 7 kW in the tail rotor shaft. If one considers the ‘tongue’ installed, it is possible to transmit 178 + 7 kW in the conical shaft. The 7 kW correspond to the aerodynamic forces generated by the tail rotor in operation.

Without application of any torque, the ‘tongue’ alone is capable of transmitting 83 + 7 kW. The 7 kW correspond to the aerodynamic forces generated by the tail rotor in operation.

The ‘tongue’ is made of metal, and will break due to fatigue upon receiving a torque of approximately 90 kW. But the tail rotor operates with 22 kW on average. This force is stood by the ‘tongue’ (without the need of torque) by approximately 180 flight hours, when the fatigue curve shows that breakage may occur with normal operation of the tail rotor, i.e., with 22 kW or less.

Helibras questioned whether the type of operation to which the aircraft was subjected would not change the calculations presented. In reply, Eurocopter made new calculations, taking into consideration that prolonged hovering and short movements sideways are part of the reality that increase the need for average power in the tail rotor system.

For this type of flight, the manufacturer stated that the average torque of the tail rotor was approximately 31 kW, and could even reach 65 kW on flights with lateral movement. With such values, the failure of the ‘tongue’ on account of fatigue would occur at about 100 flight-hours.

The DCTA (responsible for the material factor related to this accident) accepted the numerical data provided by the manufacturer. However, the hypothesis of ‘tongue’ fatigue was questioned due to the fractured part which, in this case, should have been found in the groove, but it had instead been worn out on account of the friction with the fork.

Hypotheses

It is a fact that the problems in this accident began in the connection between the fork and the conical shaft. Following the tests and research conducted, two hypotheses for the occurrence were raised:

1) incorrect installation of the fork in the conical shaft, with application of torque as prescribed in the maintenance manual; and

2) Correct installation of the fork, without application of the torques prescribed in the manual.

Analysis of the hypothesis “1”:

In favor of this hypothesis, one has that:

- the bolt for fastening the fork to the conical shaft would not enter to the maximum extent prescribed in the design. Both for the bolt installed in the aircraft, and the bolt utilized for the tests and research, it was observed that it penetrated approximately 13mm, a value well below the expected 19mm when the assembly is done correctly.
- the bolts limiting the flapping of the blades do not hit the head of the fork fastening-bolt, even after the ‘tongue’ re-enters the groove. This information was obtained in a static manner. In dynamic terms, more study would be necessary to explain the rubbing by the bolts which limit the flapping;
- when the ‘tongue’ enters the groove, the system loses the torque previously applied on the bolt;
- for loosening the fastening bolt of the accident fork, 2 kgf.m were required, a value identical to the one used during the tests at Helibras;
- the polymer marks observed on the conical shaft suggest that the material entered the space between the shaft and the fork, something impossible if one considers a correct assembly;
- the wear of the ‘tongue’ and the rubbing observed on the conical shaft of the accident aircraft are similar to the one observed on the conical shaft utilized for the tests;
- there was no variation in the pilots’ pedals;
- it is possible to assemble and apply torque to the system but, in order to move the fork in relation to the conical shaft, approximately 60 kgf.m are required; and
- the rear section of the fork lost the sealant both in the accident aircraft and in the fork used for the tests.

Against the hypothesis, one has that:

- per se, the uneven look of an incorrect assembly represents a barrier against such big error;
- in order to obtain the final torque of the bolt fastening the fork to the conical shaft, more turns than normally expected are required with the torquemeter; and
- mathematically, according to Eurocopter, the incorrect assembly would be noticed during the Vibrex of the tail rotor, since it would not be possible to balance the system under such conditions.

Analysis of hypothesis “2”:

In favor of this hypothesis, one has that:

- the assembly of the system is rather similar to the normal one. The fork enters the conical shaft for about 36 mm, and the ‘tongue’ remains in its normal position;
- there was no variation in the pilots’ pedals;
- it is easier to consider the possibility of tail rotor balance, if compared with hypothesis “1”; and
- for loosening the fastening bolt of the accident fork, 2 kgf.m were required, a value identical to the one used for loosening it during the tests at Helibras.

Against this hypothesis, one has that:

- the fork fastening-bolt would enter more than the 13 mm observed in the tests and in the bolt of the aircraft;
- the marks of the polymer observed on the conical shaft would not (in theory) get into the space between the conical shaft and the fork, on account of the perfect coupling of the two parts; and
- the use of Loctite practically requires the application of torque on the bolt after installing it, and there was presence of Loctite on the bolt.

Considering that it is not possible to balance a tail rotor installed incorrectly (hypothesis “1”), it is unlikely that the helicopter would have flown more than 185 hours without any report of the problem by the operator.

During the analyses, a 3rd hypothesis was considered, combining hypotheses “1” and “2”. It is possible that the system was assembled as described in the hypothesis “1” (‘tongue’ out of the groove, with application of torque on the bolt) and that, at the first turn by maintenance for verification of the Vibrex, the ‘tongue’ entered the groove. In this manner, the fork would match the conical shaft, making it possible to balance the tail rotor. The fastening-bolt would lose its torque, and the system would assume the condition described in the hypothesis “2” (‘tongue’ inside the groove, with not torque on the bolt).

Under such conditions, all the tail rotor torque would have to be stood by the ‘tongue’ which would be worn until getting out of the groove, allowing the fork to rotate in relation to the conical shaft. However, according to the manufacturer, the ‘tongue’ would not withstand the tail rotor efforts and would break due to fatigue before the 185 flight-hours. Even so, this hypothesis cannot be totally ruled out because there is no way to prove that the manufacturer’s calculations correspond to reality.

In order to fully prove that a tail rotor could be assembled with the ‘tongue’ outside of the groove, and make sure that the system would accept balance, it would be necessary to make the incorrectly assembled tail rotor function at operating speeds. In light of the risks that such test would bring, coupled with the fact that hypotheses and facts have the same weight for the investigation of aeronautical accidents, such procedure was not considered justifiable.

3. CONCLUSIONS.

3.1 Facts.

a) the pilot had a valid aeronautical medical certificate (CCF);

b) the pilot had a valid technical qualification certificate (CHT);

c) the pilot was qualified and had enough experience for the flight in question;

d) There are no records of pilot training in the year preceding the accident;

e) The pilot was experienced in the type of helicopter and type of flight;

f) The aircraft had a valid airworthiness certificate (CA);

g) The aircraft was within the weight and balance limits:

h) All the maintenance records refer to the same certified company;

i) The last records relative to the assembly of the tail rotor and execution of Vibrex dated from December 2009;

j) The mechanic and the inspector who were responsible for the last assembly of the tail rotor possessed the training required for the task;

k) The last maintenance intervention in the aircraft was of the 100-hour type, and was completed on 21 January 2010, with the aircraft flying 73 hours and 25 minutes before the crash;

l) on the occasion of the last inspection, the aircraft was with expired dates concerning the 100-hour and intermediate inspections (7 days, 10 hours, 25 hours, 30 hours and 50 hours), and there were no records concerning any preflight and/or post-flight inspections;

m) on the date of the accident, the aircraft was with expired dates concerning the intermediate inspections (7 days, 10 hours, 25 hours, 30 hours and 50 hours), and there were no records concerning any preflight and/or post-flight inspections;

n) the helicopter was registered in the Private Public Transport category (TPP), and the aircraft operating company flew under the RBHA 91;

o) there was rupture of the tail rotor transmission tree due to system overload;

p) the pilot lost control of the helicopter;

q) the helicopter crashed into the ground;

r) the pilot perished in the crash site;

s) the cameraman was taken to hospital seriously injured but managed to survive; and

t) the aircraft sustained substantial damage.

3.2 Contributing factors.

- **Control skills – undetermined.**

Speed reductions to values below 50kt are dangerous when there is failure of the tail rotor and, as a consequence, a loss of control of the helicopter may occur. In the case of the AS-350, such loss of control is characterized by a yaw to the left.

The commission verified that there had been problems related to tail rotor control. This type of failure is contemplated in the aircraft flight manual, and among the prescribed actions, it instructs the pilot to maintain forward speed values so that the drift may keep enough aerodynamic efficiency to counteract the main rotor torque, maintaining directional control of the aircraft.

In this accident, there is the possibility of inadequate use of the controls, either due to increase of the engine torque, or due to excessive reduction of the forward speed, or both.

- **Work-group culture – a contributor.**

The pilots shared the idea that flying a helicopter without the pre-flight, post-flight and intermediate inspections prescribed in the aircraft manual would not cause relevant problems. Such group culture influenced the execution of the flight without the intermediate inspections, and without verification of the problem reported by the pilot on the day before the accident.

- **Organizational culture – a contributor.**

The presence of informality in the organizational culture interfered in the flow of information, in determining functions and responsibilities, as well as in the standardization of operational procedures, making it difficult to detect and mitigate latent hazards to the air activity.

- **Stress – undetermined.**

The type of flight performed by the pilot was stressing per se. The insertion of an emergency considered critical may have raised the pilot’s level of stress to a great extent, affecting his cognitive and emotional systems.

- **Fatigue – undetermined.**

Due to the possibility that the estimated time available for rest was less than the one prescribed by legislation, the pilot is suspected to have been fatigued on the day of the accident.

- **Training – undetermined.**

The company did not have control over the periodicity of crew emergency training. The pilot involved in the accident had done his last training two years before, something that may have affected his performance during the emergency situation.

- **Instruction – undetermined.**

It was observed that the last training of the pilot was done in 2006. In 2008, a check-ride was utilized for practicing emergency procedures. The investigation commission considered that the period of one year and ten months between this refresher activity and the accident may have contributed to the poor performance on the part of the pilot in establishing the type of problem and applying the prescribed procedures for a safe landing of the helicopter.

- **Aircraft maintenance – a contributor.**

The last entry of records concerning maintenance actions date from December 2009. After that, the helicopter flew approximately 180 hours, mostly in aerial footage operations at low speed, or even hover flight.

During the tests, it was seen that, however improbable, it is possible to mount the fork in an incorrect manner so that it fits the housing in the conical shaft with the tongue outside the groove, including application of torque as prescribed in the manual.

Thus, although it is not possible to determine with accuracy the moment at which there was an error in the assembly of the system, one may suppose that the fork was not correctly installed in the conical shaft, either due to being assembled with the tongue outside of the groove (hypothesis 1), or due to lack of application of torque on the fastening bolt (hypothesis 2).

The investigation commission concluded that, if the fork had been correctly assembled, the bolt would not have come loose and, consequently, the fork would not have rotated in relation to the conical shaft.

As for the inspections, it was observed that the records were always entered by the same maintenance company, which assembled the tail rotor and did the Vibrex. However, on the day of the accident, the intermediate inspections were not up-to-date. It was also observed that the helicopter operator used to ground the helicopter only for the 100-hour inspections, and on these occasions the remainder of the overdue inspections would be carried out.

It was observed that the daily inspections were not performed or, at least, were not put in the records in accordance with the Maintenance Manual prescriptions. In this sense, the washings of the engine compressor recommended by the manufacturer were not either done or annotated with a desirable frequency.

Intermediate inspections are indispensable. At these inspections, it is possible to observe errors, tendencies, wear, material fatigue, etc. They help prevent accidents. In the occurrence in question, mechanics could have noticed an erroneous assembly with an intermediate inspection, thus preventing the occurrence of the accident.

- **Work organization – a contributor.**

The work organization in the company was not systematized, allowing informal procedures, pervasive leaderships, and errors in planning. Such situation, as a reflection of the organization culture in force, contributed to the occurrence of failures in the control and provision of aircraft maintenance.

- **Support personnel – undetermined.**

The day before the accident, the pilot mentioned a difficulty upon landing the helicopter. However, nothing was written, nor was a preventive verification made in order to determine the cause of the problem.

It is possible to suppose that the presence of a mechanic at the moment of receiving the helicopter would have discontinued the sequence of events that led to this accident, simply by conducting an inspection of the tail rotor.

Without a direct contribution to the accident, the lack of qualified support personnel hindered the execution of daily inspections (preflight/post flight), and the washing of the engine compressor, affecting the operation of the aircraft.

- **Management planning – undetermined.**

Despite the fact that the operations were conducted in accordance with the RBHA 91, the specifics of the operation, the number of pilots, the lack of a flight schedule, the amount of daily sorties and flight hours, among other aspects, required more attention from the management staff.

In this sense, it was observed that the informality of the processes and procedures for the operation of the aircraft, the lack of technical knowledge in the decision-making hierarchical line, the lack of technical personnel, especially a qualified mechanic to support the aircraft operation may have contributed to the accident.

- **Managerial oversight – a contributor.**

Operator of the helicopter:

The investigation commission verified that the supervisors of the air activity did not possess the technical knowledge necessary for the exercise of their functions. In consequence, they accepted the suggestions and requests made by the pilots, considering that, by doing so, they would maintain a good flight safety standard.

The informality of the processes and procedures, the friendship between those involved with the air activity created a very agreeable work environment, which some considered to be an extension of their families.

If there was a bright side in this type of environment, there was also a lack of definition regarding the functions and responsibilities of every one involved with the air activity, in addition to the admission of flexibilities, which sometimes interfered with the decision-making process.

In this sense, it is worth highlighting the informal conduct adopted by the pilot in view of his difficulty landing the aircraft on the day prior to the accident; the lack of procedures and records of the various activities performed by the company; and the lack of support personnel qualified in the maintenance of the helicopter.

Maintenance workshop:

With respect to the last inspection of the PT-YRE tail rotor in December 2009, it was observed that at the moment of application of torque on the fork fastening-bolt, the inspector in charge was servicing another aircraft and was not present at the location.

- **Medicine intake – undetermined.**

It was observed that the pilot was making use of Omeprazol. This medicine has dizziness and drowsiness as possible adverse reactions. Such condition, together with inadequate rest, may have generated consequences conducive to a condition of fatigue on the part of the pilot.

4. SAFETY RECOMMENDATION.

A measure of preventative/corrective nature issued by a SIPAER Investigation Authority or by a SIPAER-Link within respective area of jurisdiction, aimed at eliminating or mitigating the risk brought about by either a latent condition or an active failure. It results from the investigation of an aeronautical occurrence or from a preventative action, and shall never be used for purposes of blame presumption or apportion of civil, criminal, or administrative liability.

In consonance with the Law n°7565/1986, recommendations are made solely for the benefit of the air activity operational safety, and shall be treated as established in the NSCA 3-13 "Protocols for the Investigation of Civil Aviation Aeronautical Occurrences conducted by the Brazilian State".

Recommendations issued at the publication of this report:

To the National Civil Aviation Agency (ANAC):

A-009/CENIPA/2014 – 01 **issued on 22/04/2016**

Study the need for a specific regulation establishing criteria for obtaining an Air Operator Certificate for companies that commercially explore the aerial services, and other provided in RBHA 91, in a manner similar to what already occurs with the agricultural Air Service.

A-009/CENIPA/2014 – 02 issued on 22/04/2016

Acting together to the maintenance workshops that carry out the assembly of the fork in AS 350 aircraft, in order to make sure that their mechanics are recycled in relation to this type of service as well, be aware of the importance of observing all the steps provided for in manufacturer's maintenance manual.

A-009/CENIPA/2014 – 03 issued on 22/04/2016

Acting together to the maintenance workshops that carry out the assembly of the fork in AS 350 aircraft, in order to ensure that their inspectors are aware of the importance of monitoring services, especially in the most critical phases and those that directly affect the airworthiness of aircraft.

5. CORRECTIVE OR PREVENTATIVE ACTION ALREADY TAKEN.

Helibras changed its procedures concerning the receipt of aircraft for maintenance, and register of helicopters which come with expired inspection dates.

On April 22th 2016.