Safety Investigation Report

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AAIU-2017-11-19-01

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Status:
Final

ACCIDENT
ULTRALIGHT ESQUAL VM 1C
AT LANDEGEM
ON 19 NOVEMBER 2017

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ABOUT THIS REPORT

This safety investigation report is a technical document that reflects the views of the investigation team on the circumstances that led to the accident and is conducted in accordance with Annex 13 to the Convention on International Civil Aviation and Regulation (EU) No 996/2010.

The sole objective of the safety investigation and the Final Report is the determination of the causes, and to define safety recommendations in order to prevent future accidents and incidents.
It is not the purpose of this investigation to apportion blame or liability.

In particular, Article 17-3 of Regulation (EU) 996/2010 stipulates that the safety recommendations made in this report do not constitute any suspicion of guilt or responsibility.

This investigation was conducted by the Air Accident Investigation Unit of Belgium, (AAIU(Be) further in this publication). It is the Belgian permanent national civil aviation safety investigation authority as defined in Article 4 of Regulation (EU) No 996/2010 and established in accordance with the Royal Decree of 8 December 1998.
This unit is part of the Federal Public Service Mobility and Transport and is functionally independent from the Belgian Civil Aviation Authority and other interested parties.

For this investigation, the AAIU(Be) got the support of:

- The Swedish Safety Investigation Authority, Staatens haverikommission, SHK
- The German Safety Investigation Authority, Bundesstelle für Flugunfalluntersuchung, BfU
- The Propeller manufacturer Helix
- The engine manufacturer UL Power

SYMBOLS AND ABBREVIATIONS

’	Minute
‘’	Second
°	Degrees
°C	Degrees centigrade
AAIU(Be)	Air Accident Investigation Unit (Belgium)
AGL	Above Ground Level
AR/KB	Arrêté Royal / Koninklijke Besluit
ARCA	Autorisation Restreinte de Circulation Aérienne
Art.	Article
BCAA	Belgian Civil Aviation Authority
BTL	Beperkte Toelating tot het Luchtverkeer
C	Centigrade
CAS	Calibrated Airspeed
CG	Centre of Gravity
EBAW	Antwerp airport
EBBR	Brussels Airport
EBOS	Ostend airport
EBUL	Ursel airfield
ECU	Electronic Control Unit
EFIS	Electronic Flight Instrument System
ESGE	Boras airfield
EU	European Union
EW	Empty Weight
FH	Flight hour(s)
ft	Foot (Feet)
Gal	US gallon (+/- 3,8 litres)
GPS	Global Positioning System
h	Hour
hp	Horse Power
hPa	Hecto-Pascal
ICAO	International Civil Aviation Organization
kg	Kilogramme
km	Kilometer
km/h	Kilometer per hour
kt	Knot(s)
kW	Kilo watt
LAPL	Light Aircraft Pilot Licence
m	Metre(s)
mm	Millimetre
MAC	Mean Aerodynamic Chord
MAP	Manifold air pressure
mbar	millibar
METAR	METeorological Aerodrome Report
MTOW	Maximum Take-off Weight
Nm	Newton meter

PET	Polyethylene Terephthalate
PIC	Pilot in Command
psi	Pounds per square inch
PVC	Polyvinyle Chloride
QNH	Pressure setting to indicate elevation above mean sea level
RPM	Revolutions per Minute
SCF-PP	Powerplant failure
SEM	Scanning Electron Microscope
SEP	Single Engine Piston
SMS	Short message
TAS	True Airspeed
ULM	Ultralight aircraft
UTC	Universal Time Coordinated
VNE	Never Exceed Velocity

TERMINOLOGY USED IN THIS REPORT

Safety factor: an event or condition that increases safety risk. In other words, it is something that, if it occurred in the future, would increase the likelihood of an occurrence, and/or the severity of the adverse consequences associated with an occurrence.

Causal (safety) factor: any act, omission (individual), behaviour or condition (system) that produces an effect; eliminating a cause will eliminate the effect.

> **Direct causal factor:** the most obvious reason (acts or omissions, so mostly individuals) why an adverse event happens
>
> **Indirect causal factor:** A less obvious reason (acts, omissions, conditions) for an adverse event happening. The hazard has not been adequately considered via a suitable and sufficient risk assessment

Contributing (safety) factor: a condition that influences the effect by increasing its likelihood, accelerating the effect in time, affecting severity of the consequences, etc.; eliminating a contributing factor(s) won't eliminate the effect.

Other (safety) factor: a safety factor identified during an occurrence investigation which did not meet the definition of contributing safety factor but was still considered to be important to communicate in an investigation report in the interests of improved transport safety.

Safety issue: a safety factor that
(a) can reasonably be regarded as having the potential to adversely affect the safety of future operations, and
(b) is a characteristic of an organization or a system, rather than a characteristic of a specific individual, or characteristic of an operational environment at a specific point in time.

Safety action: the steps taken or proposed to be taken by a person, organization or agency on its own initiative in response to a safety issue.

Safety recommendation: A proposal by the accident investigation authority in response to a safety issue and based on information derived from the investigation, made with the intention of preventing accidents or incidents. When AAIU(Be) issues a safety recommendation to a person, organization, agency or Regulatory Authority, the person, organization, agency or Regulatory Authority concerned must provide a written response within 90 days. That response must indicate whether the recommendation is accepted, or must state any reasons for not accepting part or all of the recommendation, and must detail any proposed safety action to bring the recommendation into effect.

Safety message: An awareness which brings to attention the existence of a safety factor and the lessons learned. AAIU(Be) can distribute a safety message to a community (of pilots, instructors, examiners, ATC officers), an organization or an industry sector for it to consider a safety factor and take action where it believes it appropriate. There is no requirement for a formal response to a safety message, although AAIU(Be) will publish any response it receives.

INTRODUCTION

Classification:	Accident	**Occurrence category:**	Powerplant failure (SCF-PP)
Level of investigation:	Full investigation	**Type of operation:**	Non-commercial - Ultralight
Date and time[1]:	19 November 2019 16:12 UTC	**Phase:**	En route
Location:	Landegem (Deinze)	**Operator:**	Private
Aircraft:	Ultralight aeroplane Esqual VM 1C	**Aircraft damage:**	Substantially damaged
Aircraft category:	Fixed Wing - Ultralight	**Injuries:**	None

Abstract

An Esqual VM 1C ultralight aeroplane made a forced landing in a field after one blade of the propeller separated in flight.

AAIU(Be) was notified of the accident by the pilot, immediately after landing on 19 November 2017. A team of 3 investigators inspected the aircraft on 24 November 2017, after it was moved to EBUL airfield.

Summary of factors

Organisational	Development – Design – Design of document/info – Manufacturer (Engine) Development – Design – Design of document/info – Manufacturer (Propeller) Support/oversight/monitoring – Enforcement – Requirements - Regulator
Technical	Propeller system – Propeller section – Fatigue Propeller system – Propeller section – Failure Powerplant – Mounts – Failure
Human	Task performance – Maintenance – Modification/alteration – Owner/builder Action/decision – Action – Incorrect action performance (testing) – Owner/builder Experience/knowledge – Total flight experience – Pilot *(Contributed positively to outcome)*
Environmental	Not determined

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[1] All time data in this report are indicated in UTC, unless otherwise specified

1. FACTUAL INFORMATION

1.1 History of flight

1.1.1 Preamble

The aircraft owner was a student pilot of Aeroclub Brugge, active on the Ursel airfield (EBUL). His flight instructor happened to be the representative of the Swedish ULM manufacturer Arsi AB and importer of ARSI AB aircraft for Belgium. The owner bought the ‘Esqual’ ultralight aircraft while the type was not yet approved in Belgium. The importer provided support for the import and the administration tasks.
The aircraft was manufactured in Sweden and was ferried from the Borås airfield (ESGE) to EBUL on 24 September after all test and acceptance flights were satisfactorily performed.

The ferry flight was performed by the importer; the aircraft was fitted with a 3-blades propeller. The importer reported that during this flight, he had the impression the aircraft performance needed improvement.

To confirm his suspicions, an engine ground test was performed using a 2-blades test propeller, lent by UL Power, the engine manufacturer. The engine maximum RPM was exactly the same as when the engine was tested on the bench (2850 RPM), indicating that the engine was delivering the rated power output.

As a consequence, the importer convinced the owner to look for a better propeller, able to develop the full power of the engine. Several tests (on ground and in flight) with different propellers were performed[2]. Finally a new two-blade ground-adjustable propeller identified as Helix ‘H60V 1,75m R-TM-2’ shortened to 1,65m was found to be the most adequate for the airframe / engine combination.

1.1.2 The accident flight

The importer and the owner agreed to perform flight tests together, in order to determine the optimum blade pitch angle.

The importer would be at the controls and act as pilot in command (PIC) and select different power settings. The owner would sit on the left-hand seat to record the aircraft parameters (speed, engine RPM,..).
The aircraft took off from the EBUL airfield at 15:49.

About 19 minutes later, just after flying above the west side of the city of Gent, the aeroplane was in a descent with a TAS of 215 km/h and an engine power setting of 2800 RPM, passing 2200 ft AGL when suddenly the occupants felt a light vibration. The PIC reduced the power somewhat and the vibration disappeared. But immediately after, the occupants heard a loud bang and the aeroplane experienced heavy vibrations that shook the whole aircraft. The engine stopped abruptly and the vibrations ended.

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[2] See chapter 1.6 for more background information on these tests.

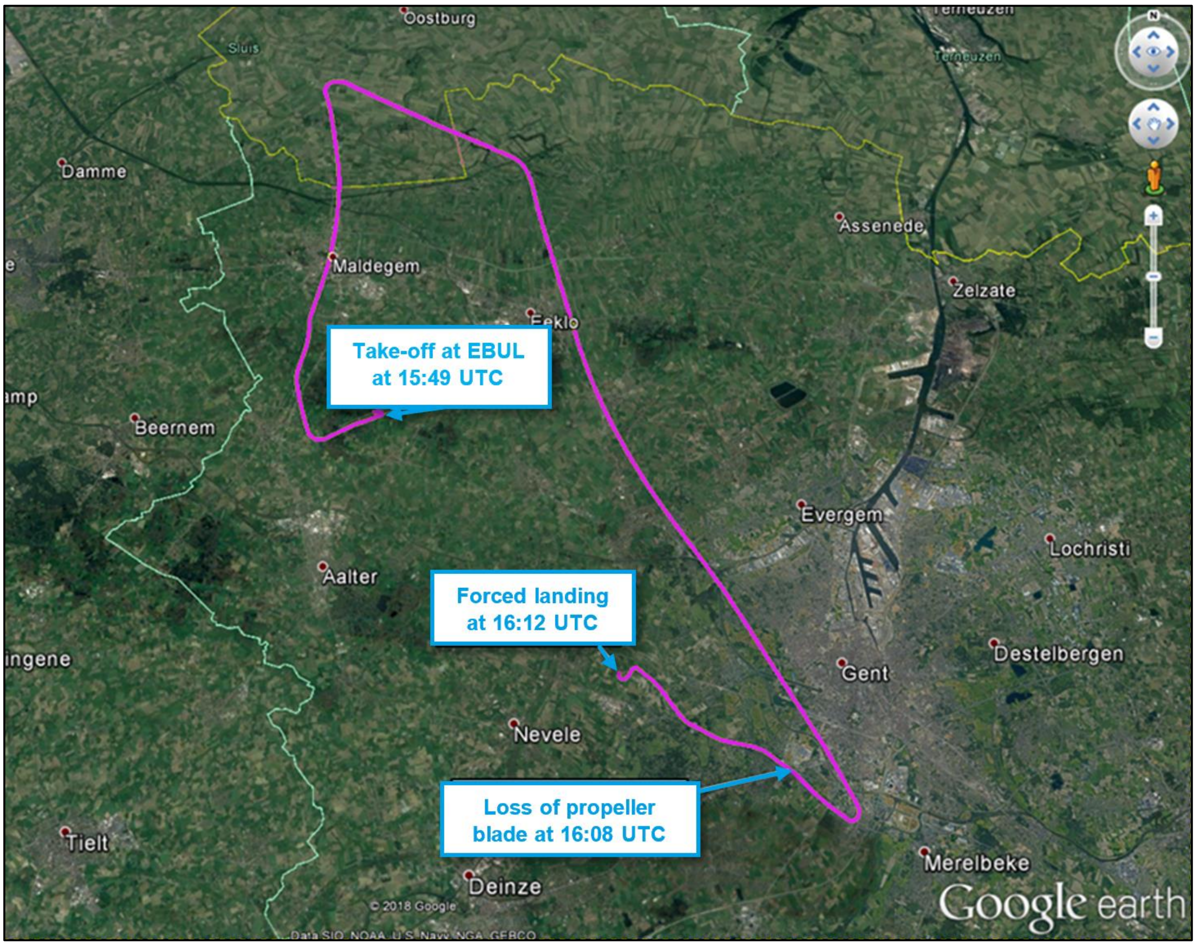


Figure 1 : full flight path

The PIC noticed that the engine cowl seemed loosened and at the same time a sort of mist entered the cockpit. The first impression of the PIC was that the aeroplane had collided with something. The PIC's first action was to check if the aeroplane still responded normally. He noticed that the engine was stopped and did not see any propeller blade. The owner however, still saw one propeller blade on the left side of the engine cowl. The crew then realized the propeller had lost one of the two blades.

The PIC had no choice but to land the aircraft in emergency. He tried to send a mayday, but noticed that the radio was not working. Therefore, the owner sent a SMS text message to the EBUL airfield for warning them about the emergency landing. During the approach, the PIC checked whether the electrical flaps were still operating and shortly before touchdown, selected full flaps. The aeroplane touched down at a ground speed of 65 km/h on a wheat field and rolled over a distance of 45-50 m. The gliding phase lasted about 4 minutes.

The aeroplane did not suffer additional damage further to the emergency landing and both occupants climbed out uninjured. The lost propeller blade was found in a hedge the day after.

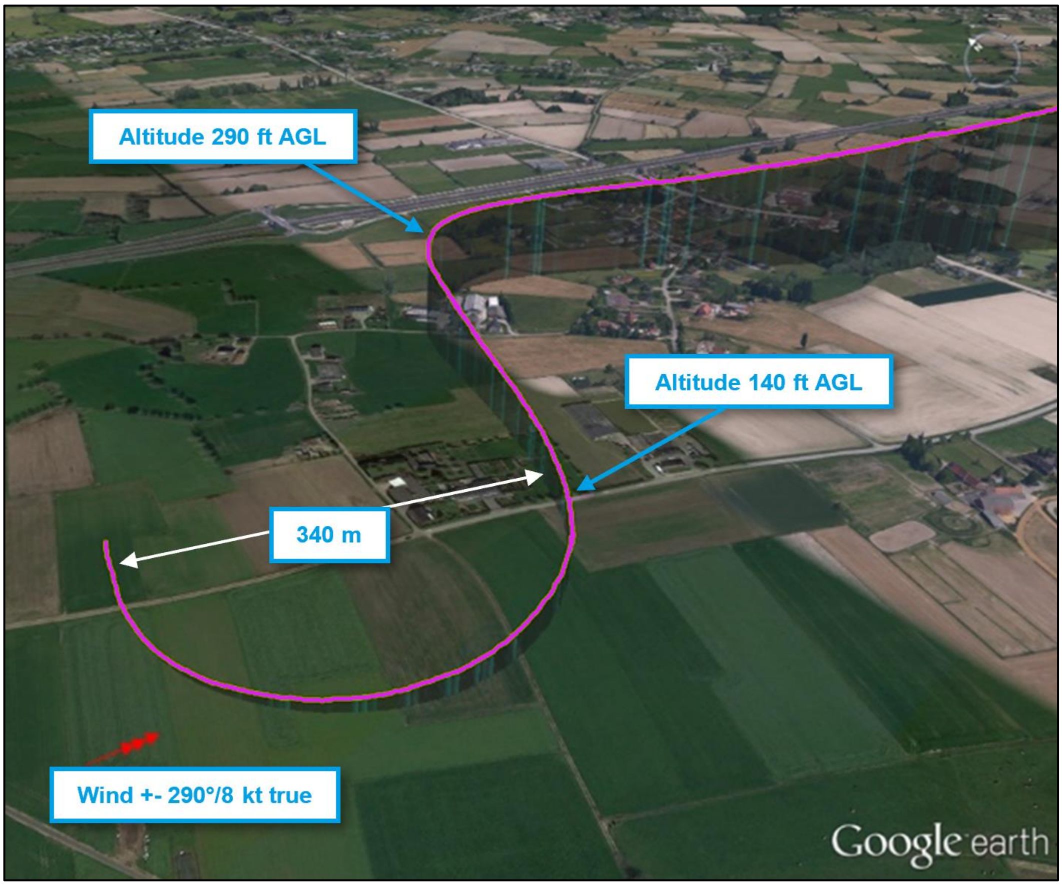


Figure 2 : zoom on the approach phase

Figure 3 : landing site

1.2 Injuries to persons

Table 1: List of injuries

Injuries	Crew	Passenger	Others	Total
Fatal	0	0	0	0
Serious	0	0	0	0
Minor	0	0	0	0
None	1	1	0	2
Total	1	1	0	2

1.3 Damage to aircraft

The aeroplane was substantially damaged by the shocks caused by the propeller unbalance.

1.4 Other damage

Limited damage to the cultivated field.

1.5 Personnel information

Table 2 : General pilot data of the PIC/importer

Nationality	Belgian	Age	66
License	Ultralight aircraft licence First issued by BCAA on 5 April 1998 Valid until 31 August 2018		
Ratings	Monitor rating valid until 31 August 2018. Radiotelephony privilege		
Medical certificate	Class 2 certificate valid until 5 August 2018 (LAPL). Class 4 certificate valid until 8 August 2018		

Table 3 : Flying experience pilot

General	Date of begin of pilots career: 17 May 1971. Large experience as former Belgian Air Force pilot (Siai-Marchetti SF.260, Fouga CM.170, Lockheed T-33, Mirage 5, Lockheed F104, General dynamics F-16, Fairchild Swearingen Merlin IIIA). SEP commercial pilot (aeroplane) licence, no more valid since 2013. Experience flying various single engine aeroplanes as Cessna 150, 152, 172, Piper J3 and Ultralight aeroplanes.
Recent:	232 FH during the last 24 months before the last renewal of the licence dated 10 August 2016 and 788 landings during the last 6 months before 10 August 2016.

1.6 Aircraft information

1.6.1 General

The aeroplane was originally designed in Spain by “Vol Mediterrani” to comply with the “Fédération Aéronautique Internationale” microlight rules, but production was later moved to Sweden.

The aeroplane is a single engine, two-seat, light aircraft constructed in carbon fiber and high density PVC/PET foam with epoxy resins. The fuselage is of a monocoque design. It features a cantilever low-wing, a two-seats-in-side-by-side configuration enclosed cockpit, tricycle landing gear and a single engine in tractor configuration. The wing features electrically-actuated flaps. Manual trim is standard with electric trim optional.

The aeroplane can be delivered with the following engines: Rotax 912 ULS (100 hp), Jabiru 2200 (85 hp), Jabiru 3300 (120 hp) and ULPower UL260i (95 hp), four-stroke powerplants.

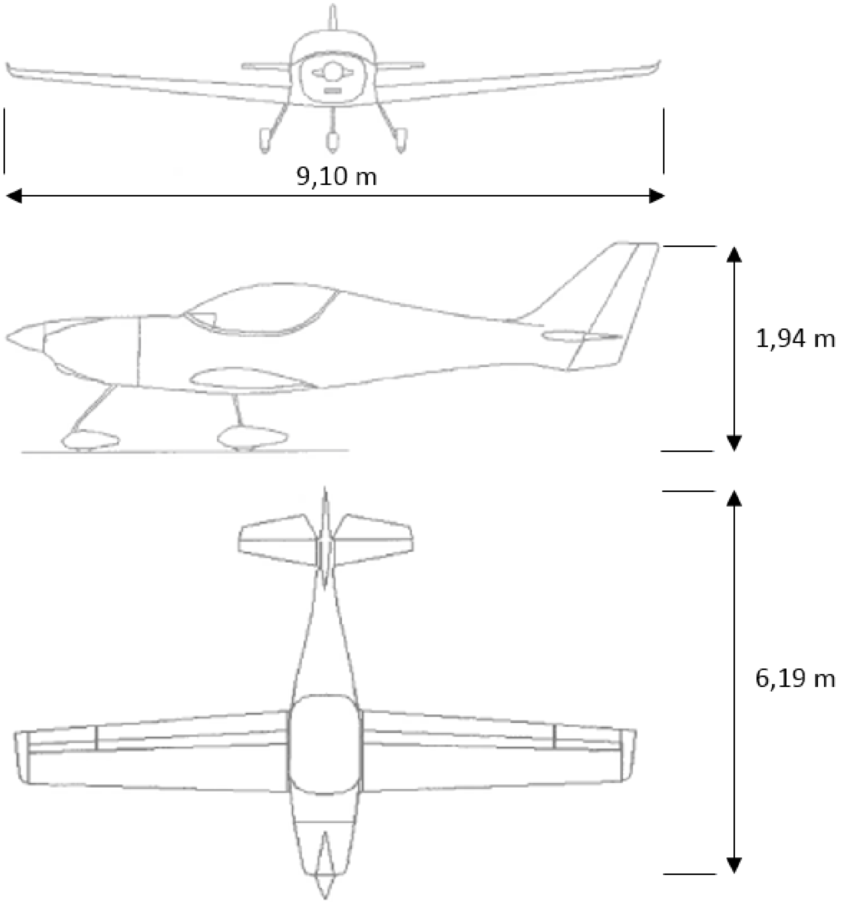


Figure 4 : dimensions

Characteristics

- Crew: one
- Capacity: one passenger
- Serial number: SE 006
- Manufacture date: 2017
- Empty weight: 285,85 kg
  (with the original propeller and spinner installed)
- Max take-off weight: 450 kg
- Fuel capacity: 2 X 55 liters
- Glide ratio: 1:19

Performance (With Helix H60V 1,6m R-TS-3 propeller)

- Stall speed VSO (CAS): 61 km/h
- Best rate of Climb speed: 160 km/h
- Cruise speed (VC): 200 - 265 km/h
- Never exceed speed (VNE): 320 km/h
- Final approach speed: 95 km/h
- Best glide speed: 125 km/h

1.6.2 The accident aeroplane

The accident aeroplane “Esqual VM 1C” bearing the serial number SE006 was built in 2017 by the company “ARSI AB” located in Sweden. It differs somewhat from the standard types mentioned on the airframe manufacturer website as it is equipped with a more powerful high compression ULPower 260is engine (SN: 164101) instead of the ULPower 260i.

The aircraft type was accepted by the BCAA on 23 May 2017, in combination with a three-blade ground adjustable Helix propeller H60V 1,75m R-TS-3 shortened to 1,60m, the original configuration upon delivery from the manufacturer ARSI AB.

The aeroplane was registered in Belgium on 31 July 2017 and an ‘Ultralight Restricted Flight Authorization’ (‘Beperkte Toelating tot het Luchtverkeer’ - BTL in Dutch, ’Autorisation Restreinte de Circulation Aérienne – ARCA in French) was delivered by BCAA on 9 August 2017.

When the accident occurred, the aircraft had only flown 11:27 FH consisting of 5 acceptance flights in Sweden, a ferry flight from Sweden to Belgium and several test flights performed in Belgium after the installation of 2 different propellers (See 1.6.6).

1.6.3 Weight and Balance

Table 4 : Weight and balance calculation (vertical reference: firewall)

	Arm (mm)	Weight (kg)	Moment (kg/mm)
Empty weight	672,09	285,85	192116,93
Pilot	1157	85	98345,00
Occupant	1157	83	96031,00
Luggage	2785	0	0,00
Fuel	1041	15	15615,00
	857,65	**468,85**	**402107,93**
% MAC	**34,1 %**		

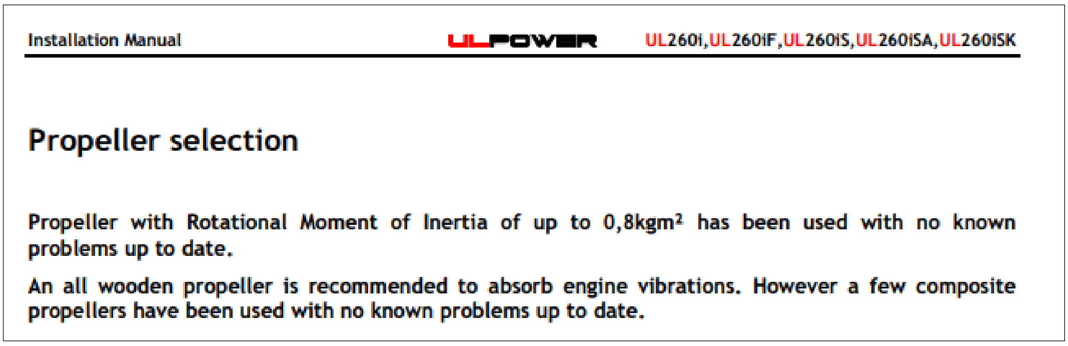
Table 5 : CG limits

	Dist. (mm)	% MAC
Design EW CG	672	16,26
min value	794	27,98
max value	937	41,73

So the CG was within limits but the weight was over the MTOW of 450 kg

1.6.4 The ULPower 260is engine

The ULPower 260is is an (non-EASA certified) aircraft engine manufactured by the company "ULPower" in Belgium. It is a direct clockwise propeller drive, flat four boxer layout with ram air cooled cylinders and cylinder heads. It features a multipoint fuel injection, dual ignition and engine management ECU. This engine type, compared with the ULPower 260i, has a higher compression ratio (9,10:1 instead of 8,16:1) and develops a higher power output of 107 hp instead of 95 hp developed by the ULPower 260i at the same 3300 RPM.
As seen in the figure below, although several composite propellers are used without known problem, ULPower recommends to use wooden propeller deemed to better absorb engine vibrations.



Installation Manual ULPOWER UL260i,UL260iF,UL260iS,UL260iSA,UL260iSK

Propeller selection

Propeller with Rotational Moment of Inertia of up to $0,8kgm^2$ has been used with no known problems up to date.

An all wooden propeller is recommended to absorb engine vibrations. However a few composite propellers have been used with no known problems up to date.

Figure 5 : Recommendation of ULPower on propeller selection

1.6.5 The Helix H60 propellers

The Helix propeller H60 type is a ultralight aircraft propeller manufactured by Helix-Carbon in Germany. It is designed for a range of engine output power from 40 kW to maximum 85 kW and a maximum rotational speed of 3400 RPM. H60 propellers are available in various versions: fixed pitch, ground adjustable or in-flight adjustable propellers. Additionally, different blade profiles and propeller diameters can be selected to fulfill specific requirements such as fast flight, cruising, maximum climbing, short take-off and low noise. The propellers blades are made out of reinforced glass and carbon fibre. For ground adjustable propellers, an aluminium shoe is inserted in the blade root and thoroughly glued and bolted onto the blade.

Figure 6 : View of H60V 1,75m R-TS-3 shortened 1,60m

Figure 7: Aluminium root of the blade

The blade geometry of ground adjustable propeller is the same as the fixed pitch one. A ground adjustable propeller can be used as a definitive choice or as a test propeller to find the best combination of blade profile and pitch before the installation of a definitive fixed pitch propeller.

Shortly after the accident, the propeller manufacturer stated the following[3]:

> Numerous H60V 1.60m R-TS-3 propellers are already installed on ROTAX 912ULS engine and this configuration is well approved since 2014, and no failure like this was reported to us. The accident aircraft was equipped with a direct driven 4-cylinder boxer engine. On these engines we always recommend our fix-pitched propeller because the direct driven engines use the propeller as a flywheel and transfer high frequency vibrations into the propeller. Therefore the fixed pitched propeller is always the homologated version.
> However, to ensure that the ground adjustable propeller H60V is adequate safe on direct driven applications we made run tests on vibrationally representative direct driven 4-cylinder engines. The 50 hours endurance testing on 160hp engine was passed without any defects for engine and propeller. This test cannot replace the individual testing of each new engine-propeller configuration.
> For UL-Power engines, up to now, we delivered only H50F fixed-pitched propellers.

As seen below, 3 different H60V ground adjustable propellers types were flight tested on the accident aeroplane. These propellers featured two different blade profiles, the “TS” and the “TM” profile. As stated by the manufacturer, the production specifications are identical, but the chord of the “TM” profile is 76 mm instead of 56mm for the “TS” (at 656 mm radius). The physical characteristic of both blade types were quite close concerning weight, inertia and vibration.

1.6.6 Identification of the different propellers fitted on the airplane

The test and acceptance flights performed in Sweden at ESGE airfield between 20 and 23 September 2017 and the ferry flight to EBUL on 24 September 2017 were performed by the importer. At that time, the aeroplane was equipped with the original Helix propeller H60V 1,75m R-TS-3 shortened 1,60m, bearing the serial number 0062-0042-0059[4].

The importer contacted the propeller manufacturer to determine another propeller type susceptible to be more efficient. A used ground-adjustable propeller with another blade profile, identified Helix H60V 1,75m R-TM-3 shortened 1,65m was made available for further tests. The intent was to verify whether this blade profile was better suited and to determine the optimum blade angle balance for each flight situation before replacing it by a fixed pitch propeller having the same characteristics. This propeller, with respect to the original one, featured a blade profile “TM” instead of “TS” and longer blades (1,65 m diameter instead of 1,60 m). On 15 October 2017, after having performed two local flights lasting 42 and 29 minutes the importer stated that the results were unsatisfactory and also that vibrations were felt when the engine was running at high RPM.

The propeller manufacturer concluded that the best solution was to switch to a two-blade propeller using the same blade profile “TM” but with a larger blade angle. A new two-blade propeller identified Helix H60V 1,75m R-TM-2 shortened 1,65m was delivered and, after several ground tests to adjust the blades angle, a new test flight was performed on 21 October 2017.

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[3] The original text, coming from an email message dated 28 November 2017, has been slightly reformulated.
[4] The sticker identifying this propeller as H50V 1,75m R-TS-3 shortened 1,60m and SN: 0062-0040-0059 was wrong.

This propeller was installed using the same back plate as the three-blade propeller but without the original spinner

On 26 October 2017, Helix informed the importer that the inspection of the returned three-blade propeller revealed damage at the root bushing of one blade, looking as if the blade had moved slightly forward and backwards in the hub[5]. At that time, Helix stated that they thought that the damage were resulting from insufficiently torqued hub bolts or too often readjusted pitch settings. However, likely alarmed by the damage found, Helix recommended to re-open the hub of the new two-blade for inspection after the first runs. Helix also insisted to exchange the propeller with an equivalent two-blade fixed pitch propeller, as soon as the flight tests with this propeller were satisfactory.

As a response, the importer stated that he was trying to solve an additional problem before continuing the test flights with the two-blade propeller; this problem being a suspected loss of airflow in the induction system once the aeroplane had some forward velocity. However, on 19 November 2017, despite the fact that the induction system remained unchanged, the importer and the owner made a new test flight during which the two-blade propeller failed after 19 minutes of flight.

Table 6 : Summary of the different flights performed with the corresponding propeller types

Date and type of flight	Flight hours	Make and Model	Nr of blades	Spinner Yes/No
20 => 24 Sept. 2017 (5 acceptance flights at ESGE + Ferry flight to EBUL).	8h50	Helix H60V 1,75m R-TS-3 shortened 1,60m	3 “TS”	Y
Date unknown (Engine power test on the ground)	/	Sensenich W68CJ530 (From the ULPower stock of test bench propellers)	2	N
15 September 2017 (Test flight)	1h11	Helix H60V 1,75m R-TM-3 shortened 1,65m	3 “TM”	Y
21 Oct. and 19 Nov. 2017 (Test flight)	1h26	Helix H60V 1,75m R-TM-2 shortened 1,65m	2 “TM”	N

1.7 Meteorological conditions

As a deduction from the METARs of EBAW, EBBR and EBOS, the wind speed at the time of the accident was about 08 kt predominately from 290 degrees. Visibility was more than 10 km and few clouds (1-2 octas) with ceiling at 2600 AGL. Temperature was 07°C and dew point was 03°C. QNH was 1022 hPa.

1.8 Aids to navigation

Not applicable.

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[5] This propeller, coming from the manufacturer test propeller pool, was thereafter scrapped because it needed intensive repair.

1.9 Communication

After the propeller failure, the PIC tried to send a mayday but the radio was not working anymore. Inspection of the aircraft revealed that several electrical wirings had been ripped off, obviously by the heavy vibrations that shook the whole aircraft.
The passenger (owner) had the time to send a SMS text message to the EBUL airfield for warning them about the emergency landing. After the forced landing both occupants could use their mobile phone.

1.10 Aerodrome information

Not applicable.

1.11 Flight recorders

The aeroplane was equipped with an Electronic Flight Instrument System (EFIS) manufactured by Dynon, model SkyView HDX that records specific parameters every 5 seconds.

Amongst others, the following data were downloaded:

- Time (hour, minute, second with 1 recording every 5 seconds),
- Pressure Altitude (feet),
- GPS Altitude (feet)
- Engine RPM
- Fuel Flow (Gal/h)
- 4 cylinder head temperature (degrees C)
- 4 exhaust gas Temperature (degrees C)
- Oil pressure (psi)
- Oil temperature (degrees C)
- Fuel pressure (psi)

The Electronic Control Unit (ECU) of the ULPower engine also features an electronic memory that records specific engine parameters 12 times per second. The ECU was downloaded after the accident with the support of the engine manufacturer.

The following data were available for the last 21 minutes and 45 seconds of flight:

- Engine time since manufacture (sec)
- RPM
- Throttle position (volt),
- Barometric pressure (hPa),
- Air induction temperature (degrees C)
- Oil temperature
- ECU temperature (degrees C)
- Battery electrical tension (volt)

There is no recording of manifold air pressure (MAP), neither in the SkyView HDX, nor in the ECU.
The data from both the ECU and the SkyView HDX were synchronized and combined on a single spreadsheet. This shows that the aircraft took off after about 13 minutes of engine running and the propeller failure occurred after about 19 minutes of flight when the aeroplane was flying at about 2600 ft AGL.

1.12 Wreckage and impact information

The aircraft made a forced landing in a wheat field on a 32° magnetic heading. Elevation of the landing field was 26 ft.

As mentioned in § 1.1., the aeroplane did not suffer additional damage further to the emergency landing. The lost propeller blade was found in a hedge the day after.

In addition to the propeller failure, the engine rear plate and the engine mount suffered significant damage causing the engine remaining attached to the airframe structure at only one location instead of four. The oil cooler and its flexible lines were ruptured causing an oil leak. The engine cowlings were damaged by the movement of the engine inside the engine compartment.

The dashboard attachments were also found broken. It is expected that the structure of the aeroplane, the accessories and the instruments also could have suffered from the heavy shocks caused by the unbalance of the separated blade of the propeller.

The nose landing gear fairings were damaged by the severe shocks sustained when the propeller separated or during the forced landing roll on a soft ground field during.

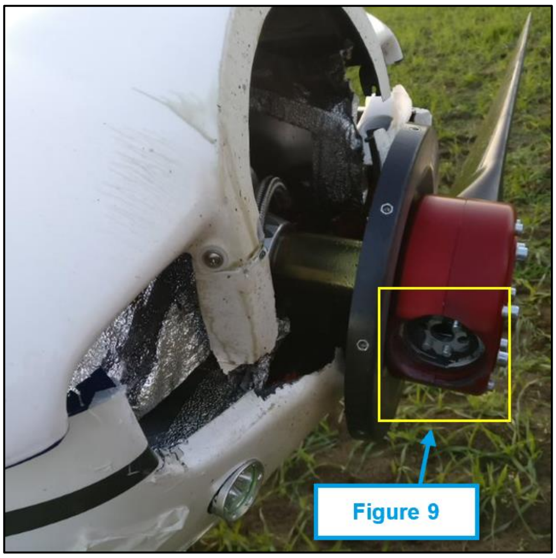

Figure 8 : overview of the damage at the nose of the A/C

Figure 9 : zoom on the damage of the hub

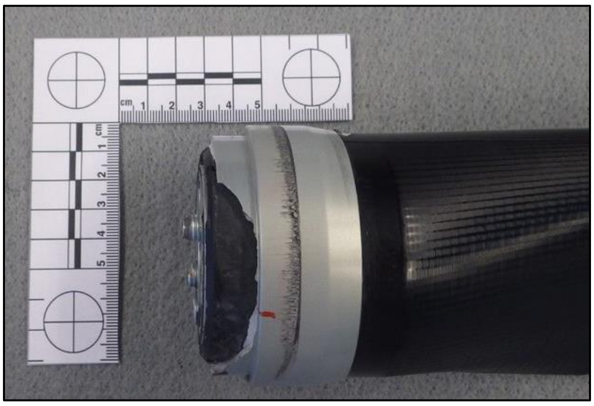

Figure 10 : root of the lost propeller blade

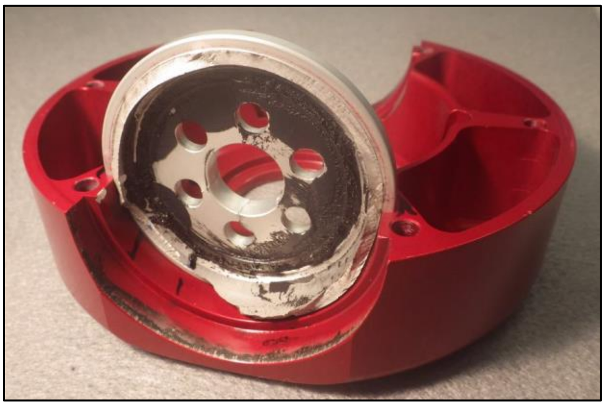

Figure 11 : broken part of the blade root left in the hub

1.13 Medical and pathological information

Both occupants did not suffer any injuries.

1.14 Fire

Although the engine was severely shocked, no fuel line ruptured and there was no fuel leak and no fire. It has to be noted that the ECU of the ULPower engine automatically switches off the electrical fuel pump(s) when, for any reason, the engine stops.

1.15 Survival aspects

Both occupants wore their lap belt + dual shoulder belts.
The aircraft was not equipped with an emergency recovery parachute nor is it required.

1.16 Tests and research

Before the disassembly of the hub, the torque applied to the six M6 bolts assembling the two halves of the hub was evaluated with a calibrated torque wrench used in the tightening direction, beginning from a torque value of 5 Nm and gradually increasing it by step of 1 Nm (NB: Helix recommends a tightening torque of 8 Nm to 10 Nm).

The measured torque of the 2 bolts located along the separated root blade was determined to be about 6 Nm.

The measured torque of the 2 bolts located along the intact blade was around 9 Nm and the intermediate bolts, located between both blades roots were tightened at about 7 Nm.

The propeller was examined by a laboratory of the “Royal Military Academy”[6] to determine the type of fracture, in an attempt to find the root cause of the rupture. The laboratory was also requested to examine a damage at the trailing edge of the separated blade to determine whether this damage could have been present before the blade separation.

The examination concluded that the propeller blade failed due to fatigue, causing the fracture of the aluminium root fitting. The fatigue crack started in the shouldering of the ring, where a stress concentration is present. The bolt fractures and the grooves on the hub halves are consequential damage. The full report of the laboratory is in appendix.

The broken propeller root part that was found in the hub on has been examined in the scanning electron microscope (SEM).

Figure 12 shows the part at higher magnification. 4 zones have been identified:

- zone 1a (indicated by the larger double arrow): exhibits a very smooth aspect with very clear beach marks; these beach marks indicate presence of a fatigue phenomenon;
- zone 1b (indicated by the smaller double arrow): has an aspect similar to that of zone 1a but is smaller; this zone also shows beach marks indicating presence of fatigue;
- zone 2a and 2b: these zones make up the rest of the fracture surface between the zones 1a and 1b. They correspond to the overload fracture.

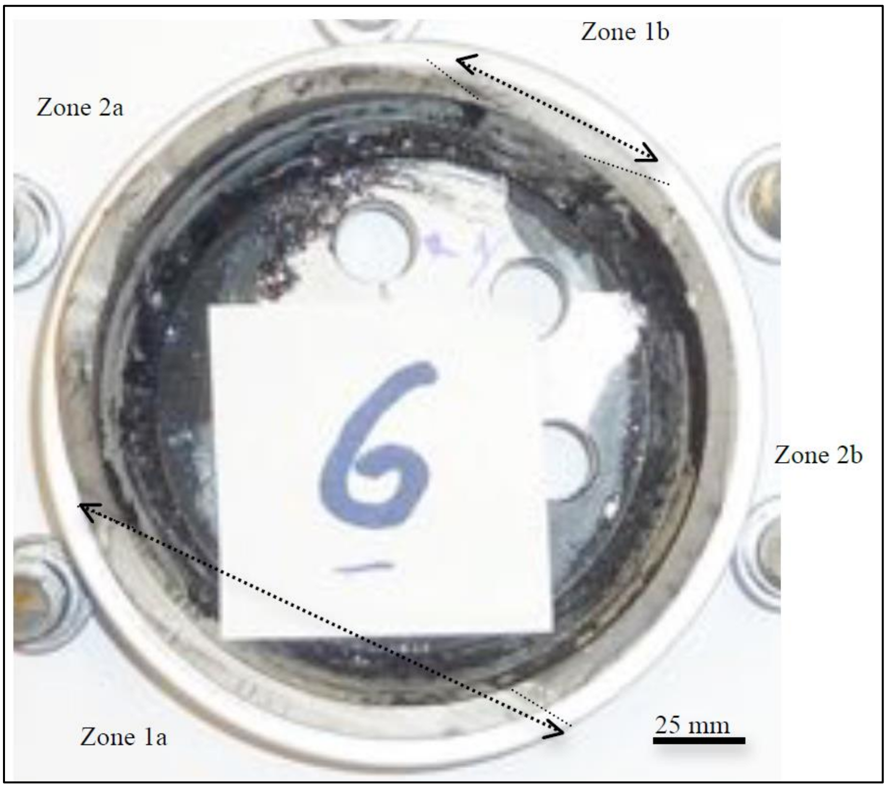

Figure 12 : fracture surface of the fixation ring of propeller blade 2;
indication of particular zones (the number 6 is an identification tag used by the lab)

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[6] Royal Military Academy - Department of Civil & Materials Engineering Materials Lab - Belgian Defence.

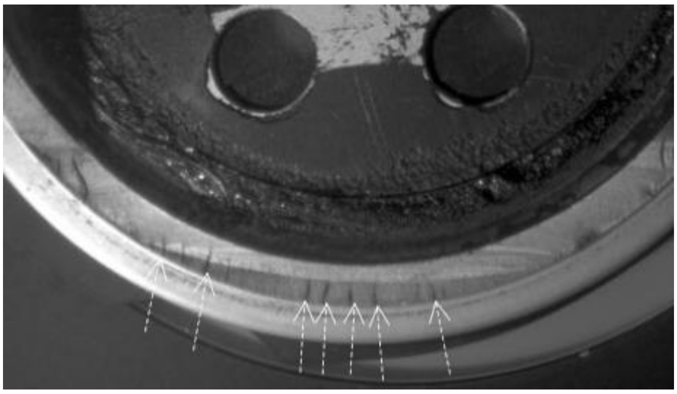

Figure 13 : detail of zone 1a with presence of beach marks; white arrows indicate multiple initiation points of the fatigue crack

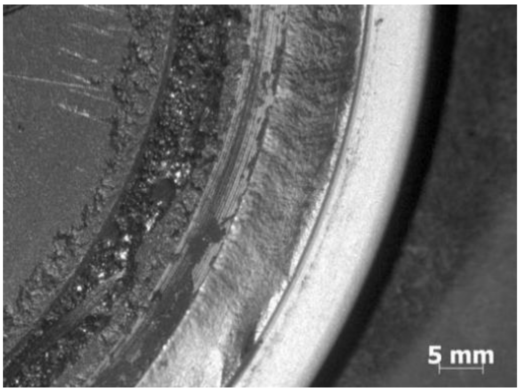

Figure 14 : detail of overload zone 2b

1.17 Organizational and management information

This section will focus on the regulation.

Ultralight operations in Belgium fall under national regulations. Currently the Royal Decree (AR/KB) dated 25 May 1999 is the legal basis. Article 26 states that an ultralight aircraft may only be used if it is properly maintained in such a way that its basic characteristics are preserved and a safe operation is guaranteed.

Art. 26. L'aéronef ultra-léger motorisé ne peut être utilisé que s'il se trouve dans un état d'entretien tel que ses caractéristiques de base sont maintenues et s'il présente toutes les garanties d'un fonctionnement sûr.
Art. 26. Het ultralicht motorluchtvaartuig mag enkel gebruikt worden als het zich in zulke staat van onderhoud bevindt dat zijn basiskarakteristieken behouden blijven en het alle waarborgen vertoont voor een veilig gebruik.

The conditions to obtain a ‘Ultralight Limited Flight Authorization’[7] is further elaborated in the Royal Decree (AR/KB) of 11 July 2003 and BCAA Circular CIR-AIRW-12.

Chapter 1.3 of that circular states that major modifications require the production of a technical file to BCAA.

Major modifications are further defined as “every modification concerning one of the descriptive elements of the type authorization; or a modification which has a substantial effect on performance, mass, balance, structural resistance, reliability or characteristics of use of the ultralight.”

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[7] ‘Ultralight Limited Flight Authorization = ‘Beperkte toelating tot het luchtverkeer voor ultralight luchtvaartuig’ in Dutch language and ‘Autorisation restreinte de circulation aérienne pour aéronef ultra-leger’ in French language

1.3 Modification	1.3 Wijziging
Toute modification majeure d'un aéronef ultra-léger motorisé ayant reçu antérieurement une autorisation de type doit faire l'objet d'un dossier de modification établi suivant les mêmes règles que pour l'établissement du dossier technique de base. On entend par "modification majeure" toute modification qui concerne un des éléments descriptifs de l’autorisation de type; ou une modification qui a un effet appréciable sur les performances, la masse, le centrage, la résistance structurale, la fiabilité ou les caractéristiques d'utilisation de l'aéronef ultra-léger motorisé.	Elke belangrijke wijziging aan een ultralicht motorluchtvaartuig waarvoor eerder een typetoelating werd afgeleverd, dient verantwoord te worden in een wijzigingsdossier, opgesteld volgens dezelfde regels als voor het technisch basisdossier. Onder “belangrijke wijziging” verstaat men elke wijziging betreffende de beschrijvende elementen van de typetoelating; of een wijziging die een aanzienlijk effect heeft op de prestaties, de massa, de zwaartepuntsgrenzen, de structurele weerstand, de betrouwbaarheid, de gebruikerskarakteristieken van het ultralicht motorluchtvaartuig.

AR/KB 25 May 1999

Art. 20.

§ 1er. L'admission à la circulation aérienne d'un aéronef ultra-léger motorisé est constatée par une autorisation restreinte de circulation aérienne.

§ 2. Une autorisation provisoire de vol dite laissez-passer de navigation peut être accordée à tout aéronef ultra-léger motorisé. Celle-ci mentionne les conditions spéciales d'utilisation de l'aéronef.

Art. 20.

§ 1. De toelating tot het luchtverkeer van een ultralicht motorluchtvaartuig wordt vastgesteld door een beperkte toelating tot het luchtverkeer.

§ 2. Een voorlopige toelating tot het luchtverkeer, luchtvaartpas genoemd, kan toegekend worden aan elk ultralicht motorluchtvaartuig. Deze luchtvaartpas vermeldt de bijzondere voorwaarden van het gebruik van het luchtvaartuig.

AR/KB 11 July 2003

Art. 4.

De luchtvaartpas wordt alleen uitgereikt in de volgende gevallen :

1° hetzij in de plaats van een individueel bewijs van luchtwaardigheid of een beperkte toelating tot het luchtverkeer, waarvan de uitreiking om een of andere reden is uitgesteld, indien het luchtvaartuig voldoet aan alle technische eisen voor het uitreiken van één van deze documenten;

2° (…)

3° hetzij wanneer met het luchtvaartuig proefnemingen gedaan worden;

Art. 4.

Le laissez-passer de navigation est uniquement délivré dans les cas suivants :

1° soit en lieu et place :

- d'un certificat de navigabilité individuel ou

- d'une autorisation restreinte de circulation aérienne, dont la délivrance est retardée pour une raison quelconque, lorsque l'aéronef satisfait à toutes les conditions techniques de délivrance d'un de ces documents;

2° (…)

3° soit lorsque l'aéronef est en cours d'expérimentation;

1.18 Additional information

Not applicable.

1.19 Useful or effective investigation techniques

Not applicable.

2. ANALYSIS

2.1 Flight parameters

The flight data, recorded by both the Dynon SkyView HDX and the engine ECU, show 36 minutes of engine operation for the flight:

- the engine ran for about 13 minutes on the ground before the take-off.
- The engine operated for 19 minutes from the take-off to the failure,
- The airplane flew 4 minutes after the failure.

The propeller failure causes the immediate shut-down of the engine, identified on the graph on Figure 16.

During the take-off the engine speed stabilized at about 2500 RPM and after that, the engine mostly ran between 2500 RPM and 3000 RPM with 2 short excursions at about 3100 and 3250 RPM.

After the take-off the aeroplane climbed at 1900 ft AGL before descending at 700 ft. Thereafter, it climbed again up to an altitude of 2100 ft before descending down to 1600 ft. After that, it flew horizontally for several minutes. During this horizontal flight, the pilot progressively reduced the throttle position and the engine RPM decreased from 2900 RPM to 1800 RPM. At the end of this horizontal flight, the airspeed was low and the aeroplane lost about 200 ft altitude. After that, the throttle was fully opened increasing the engine speed to 2500 RPM and the aeroplane climbed up to about 2600 ft.

Few seconds later, just after flying above the east side of the city of Gent, when the aeroplane was descending, the pilot reported a light vibration, that disappeared when he reduced RPM. This vibration is not visible in the parameter records. At 16:08:54 UTC, the record shows a peak in vertical and horizontal acceleration – corresponding to the loud bang and heavy vibration felt by the pilot – and the engine RPM drops to zero. This moment corresponds to the propeller blade failure and departure from the aircraft.

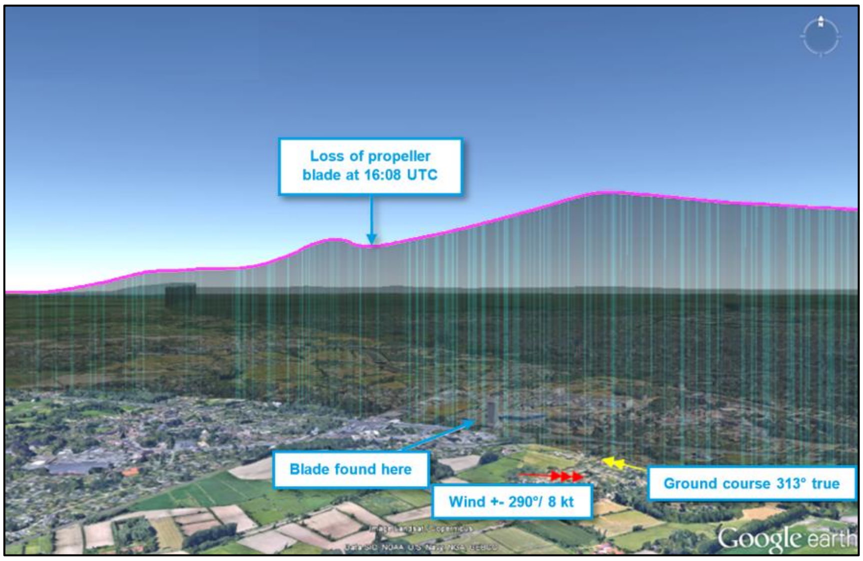

Figure 15 : zoom on the phase in flight were the propeller was broke off

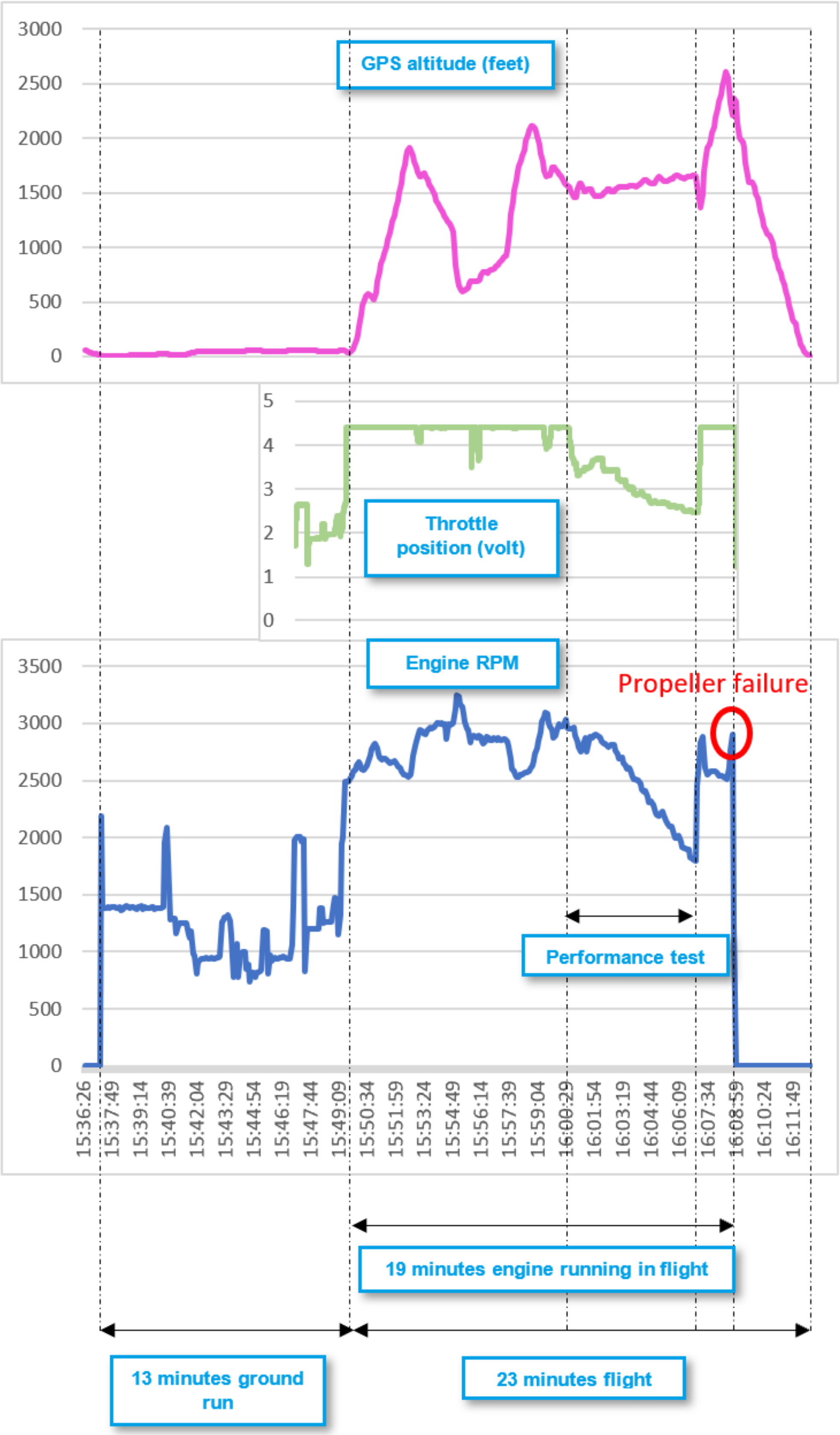

Figure 16 : overview of the parameters during the different phases of flight

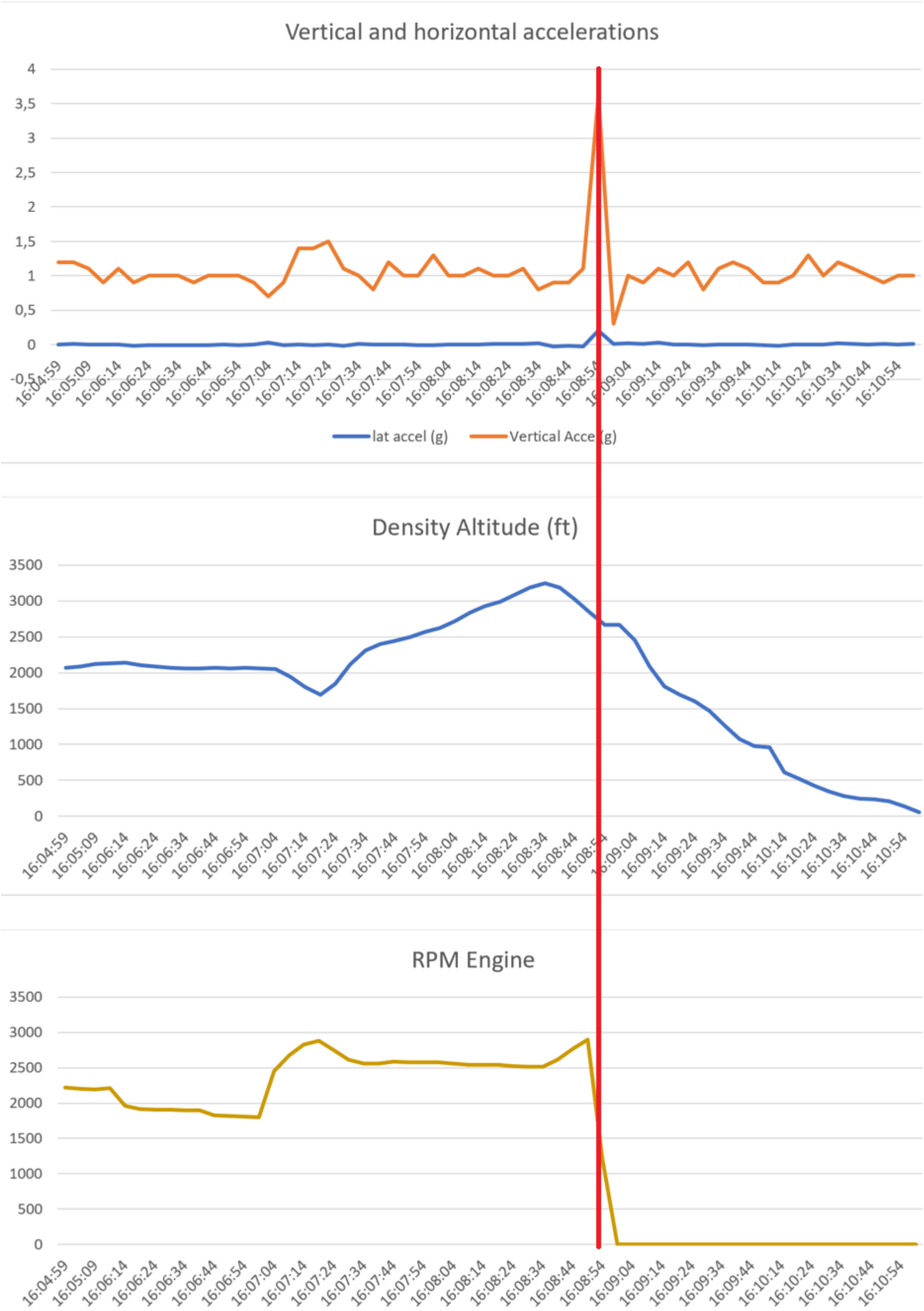

Figure 17 : zoom on the parameters during the propeller loss

At no time during the flight an exceedance of VNE (320 km/h) or engine speed limit (3400 RPM) was observed.

2.2 Air pressure fluctuations inside the air filter box

Because of the aeroplane performances were deemed disappointing, the importer went to Helix, the propeller manufacturer to discuss the matter. Among others, a restriction of airflow in the induction system once the aeroplane had some forward velocity was suspected.

The recorded ECU data were examined to establish the facts and verify whether it could have had an impact on the working of the engine, particularly the generation of specific vibrations. The analysis determined that the air pressure inside the engine air filter box became unstable as soon as the engine speed was above about 2400 RPM regardless the aeroplane was stationary on the ground or in flight. This finding was made at different engine settings (above 2400 RPM) including when the throttle was in a fixed position and the engine was running at a constant engine speed. Sinusoidal air pressure fluctuations were observed inside the air filter box[8] with a period between 3 and 6 seconds and a peak-to-peak amplitude comprised between 30 and 50 mbar. The observation of the engine data also revealed that the airspeed of the aeroplane was not a factor influencing this phenomenon.

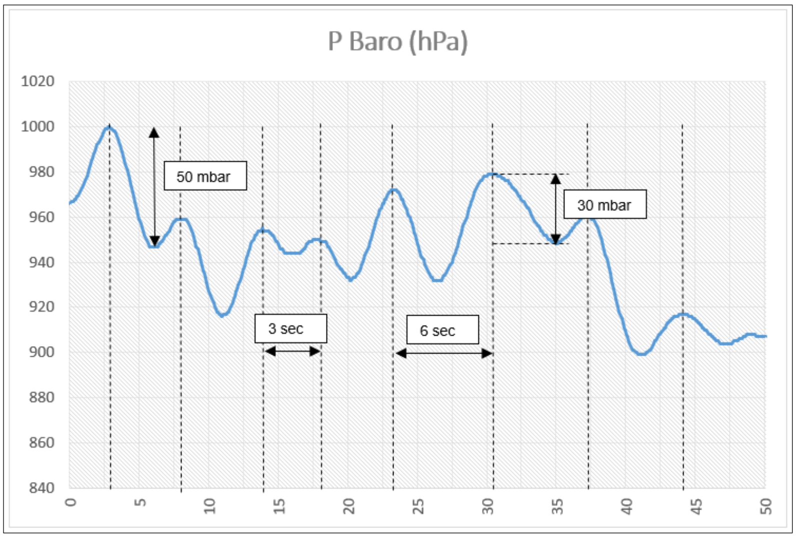

Figure 18 : intervals of the pressure fluctuations

The investigation could not determine the origin of this phenomenon, besides it having an effect similar to a “side window buffeting”.

The RPM data recorded by the ECU don’t indicate the presence of engine speed fluctuations caused by the induction pressure fluctuations and it was also not reported by the importer. However, it is not excluded that limited engine speed fluctuations and/or vibrations caused by the induction pressure fluctuations were present but not detectable.

When asked about possible negative effects of air pressure fluctuations, the engine manufacturer stated that such pressure fluctuations do have an influence on the mixture but, as the pressure data are smoothed by the ECU, real influence is negligible. During the course of this investigation, AAIU(Be) suggested ULPower to verify the presence of air pressure

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[8] The air pressure tap was installed on the air filter box, upstream of the air filter and the pressure signal was transmitted to the ECU through a small plastic flexible line. The pressure sensor is installed inside the ECU box.

fluctuations upstream of the butterfly of the injection system during the test of similar engines on the test bench. No feedback was received as of the date of the publication of this report.

In summary, it is likely that the air pressure fluctuations didn't have a significant impact on the working of the engine and on possible engine vibration generation, possibly leading to fatigue of the propeller, however the investigation could not positively establish it.

2.3 Thorough examination of the failed propeller

The measured torque of the 2 bolts located along the separated root blade was determined to be about 6 Nm. This insufficient torque can be explained by the partially missing blade root that released partially the originally applied torque.

The measured torque of the 2 bolts located along the intact blade was around 9 Nm and the intermediate bolts, located between both blades roots were tightened at about 7 Nm. These findings show that the hub halves likely were properly tightened before the blade separation.

Like already mentioned in 1.16, the report of the metallurgic lab concludes that the propeller blade has failed by fracture of its aluminium root fitting because it was affected by fatigue. The fatigue crack started in the shouldering of the ring, where a stress concentration is present. The bolt fractures and the grooves on the hub halves are consequential damage.

As indicated on Figure 13, zone 1a shows small terraces, which indicate multiple initiation points of the fatigue phenomenon; therefore it is very likely that the stress loading to the crack was rather high. This is also in agreement with the location of the crack in the shouldering of the ring. At this location there is presence of a large stress concentration, which is very probably the cause of the crack initiation. Because of the high stress level, the fatigue phenomenon can be classified as low cycle fatigue, leading to the inevitable overload failure.

Two organic particles have been found on the damaged trailing edge of propeller blade. These particles are very probably small chunks of wood with contaminants. There are no indications that these particles and the damage of the blade are at the origin of an accidental load having caused initiation of the fatigue crack.

It is likely that the wood particles and the damage found at the trailing edge of the blade are subsequent events to the in-flight blade separation. The separated blade fell to the ground and was retrieved in a hedge near the fire brigade facility. The investigation cannot exclude that the contamination occurred at that time.

2.4 Possible causes of the propeller failure

As said in Chapter 1.6., the first propeller installed in the aeroplane (Helix H60V 1,75m R-TS-3 shortened 1,60m) ran for 8 hours and 50 minutes without problem. It was removed from the aeroplane, dismantled and stored. After the accident all the components of this propeller were visually inspected and were found undamaged.

Despite the fact that the second Helix propeller installed (Helix H60V 1,75m R-TM-3 shortened 1,65m) was only fitted on this aeroplane for 1 hour and 11 minutes, damage at the root of one blade was detected during the in-coming inspection performed after it came back to Helix.
The accident propeller was new at installation but failed after only 1 hour and 26 minutes of run.

The owner and the importer also confirmed that in the short time the propeller was installed, it was not involved in a propeller strike on the ground or in flight or any other event that would have caused accidental damage to the blade.

There are 2 commonalities between the propeller that suffered damage and the accident propeller:

- the type of blade "TM"
- the fact that the propeller was assembled and installed by the same person.

On the other side there is a difference of diameter between both the damaged and the failed propellers (1,60 m diameter) and the one originally installed propeller (1,65 m diameter) that properly resisted during 8 hours and 50 minutes without problem.

2.4.1 Possible resonance between the engine and the "TM" blades

Although Helix stated that the physical characteristic of "TS" and "TM" blade types are quite close concerning weight, inertia and expected vibrations, it is not demonstrated that their interaction with the vibrations and the cyclic accelerations produced by the engine are similar.
It has to be noted that Helix stated that they performed a 50 hours endurance test of a H60V propeller installed on a 160-hp direct drive engine without any defects for engine and propeller. But no detail about this test was provided meaning that the type of engine, the number of blades and the blade profile is unknown. Therefore, unless more information are provided, this test cannot be considered as a demonstration of endurance for the propeller type that suffered the blade separation in flight.

In all aero engines it is important to ensure that the propeller is matched to the engine to prevent resonant vibration frequencies from damaging both the engine and/or the propeller.
For information, engine manufacturer Jabiru has released a Service Bulletin "JSB 014-2" regarding "Propeller Installation and Maintenance". This Service Bulletin states amongst others:

> *Before Jabiru Aircraft Australia will approve or recommend any propeller for use on Jabiru Engines the following minimum testing must be carried out:*
>
> *a)* ***Propeller weight.*** *The weight of the propeller is assessed. Heavy propellers are generally rejected unless there is good data available demonstrating the propeller is safe for use.*
>
> *b)* ***A vibration survey.*** *This type of test generally involves fitting gauges to the crankshaft to measure stress, then running the engine with the propeller fitted and monitoring the stress levels. In some cases the propeller itself may be monitored instead of the engine.*
>
> *c)* ***An over-rev test.*** *Typically this test involves running the propeller to around 10% beyond the propeller's redline – around 3700rpm for Jabiru Engines.*
>
> *d)* ***Strength testing.*** *Before the propeller is flown the blade retention system and the blade itself will be tested to ensure adequate strength.*

As said in Chapter 1.6. of this investigation report, numerous H60V 1.60m R-TS-3 propellers run on ROTAX 912ULS without problem, which suggests that the combination engine/propeller doesn't generate destructive vibrations. As this engine has a smaller displacement, runs faster and incorporates a gearbox reducing the propeller speed and also incorporates a clutch, it is not surprising that the vibrations and the stress applied to the propeller are reduced compared to those produced by a bigger displacement direct drive engine.

2.4.2 Installation

The most common installation errors during the installation of such an adjustable propeller are linked:

- to a tightening problem of both the mounting bolts or the hub assembly bolts.
- to an adequate and similar angle setting of all blades.

As both the tightening torque of the propeller mounting bolts and the torque applied to the six M6 bolts assembling the two halves of the hub were found within the prescribed values or, if out of limit there was a logical explanation for it, it is demonstrated that possible vibrations generated by the propeller could not have been caused by a tightening mistake.

The setting of the blade angle is a delicate operation requiring great care and precision as well as to dispose a precision angle indicator. It is imperative that all blade angles are strictly identically adjusted, otherwise the efficiency of the propeller will be affected and vibration will be generated by the propeller. The importer used a “Mini Digital Protractor” having a resolution of 0,1° which is deemed to be adequate to properly set the blades angles. When asked about the procedure the pilot used to set the blades angle, no indication was found showing he made something wrong.

However, a backplate was installed between the crankshaft flange and the propeller but without spinner installed on it, which is not ideal as it is conducive to produce turbulences around the propeller hub.

In summary, with the exception of the missing spinner, it is likely, but not demonstrated that the propeller was adequately installed.

2.5 Regulation regarding major modification of ultralight aircraft

The installation of another type of propeller must be primarily regarded as a major modification which is governed by BCAA Circular CIR-AIRW-12. Amongst others, this document specifies in §1.3 that significant changes of one of the descriptive elements, such as in this case, the installation of another propeller type, would require the production of a technical file to BCAA.

This would be followed by the delivery of a new type authorization and possibly a Permit to Fly if test flights are necessary. However this is not clearly stated in the Circular.
The regulation allows for flight testing during the period the modification is being applied and the technical file pertaining to the modification is not yet approved by BCAA. A specific flight

permit (Laisser-passer de navigation / Luchtvaartpas) is required in this case. The BCAA determines the specific conditions under which these flights occur on case-by-case basis.

BCAA had received no file or any letter from the aircraft owner or other persons pertaining to the installation of non-approved propeller types, nor any application for a specific flight testing permit.

2.6 Safety considerations

Throughout the investigation, it became clear that the safety aspects of the flight were underestimated by the various stakeholders. The installation of a new propeller was considered merely as a minor adjustment to improve the performance of the aircraft and the test flight was considered to be a normal flight to note down some engine parameters.

The aircraft manufacturer entrusted the Belgian importer to perform the modification and flight tests with little guidance, based on his experience as a military pilot.

With respect to the flight, as seen previously, it is far from the precautions taken – in "certified" aviation – for the same operation;

- The flight was conducted with a passenger, whose function was to record a few parameters;
- The MTOW was exceeded,
- The flight was performed partly above urban area,
- The modification was not completed, no spinner cone was installed.

For such a modification, as part of the file requested by the BCAA for the issue of a flight permit, it would be customary to:

- Perform endurance ground tests
- Perform a risk assessment before the flight

The result would be a technical validation of the combination engine/propeller and mitigating measures to cope with possible problems during the flight.
In hindsight, the equipment of the airplane, or the occupants with a parachute would have been an adequate mitigating measure, considering that the engine, having lost 3 out of the 4 connecting point to the aircraft structure, could have fallen from the aircraft, with irreversible catastrophic consequences.

Although the regulation provides a safety mechanism through the application for a flight permit, for which specific conditions can be defined, there is no clear guidance from the Authority on when, how and by whom flight tests are to be conducted. The BCAA states that it is impossible to prescribe for every single modification what the tests should look like and what the qualification of the pilot would need to be.

3. CONCLUSIONS

3.1 Findings as to causes and contributing factors

- The investigation determined that the in-flight separation of one blade of the propeller was due to low cycle/high stress fatigue at the blade root.
  [direct cause]

  [Propeller system – Propeller section – Fatigue]

  [Propeller system – Propeller section – Failure]
- The investigation could not determine the exact origin of the fatigue. The ruptured blade did not show sign of accidental damage that occurred prior to the event, nor did the owner indicate that any incident occurred that was likely to weaken the concerned blade. It is therefore likely, given the fact the failed during a test flight after having run only 1h26 (ground checks included) that the origin of the fatigue at the blade root was caused by vibrations originating from the engine/propeller combination.
- The two blades are installed on the propeller hub and the blade angle is set manually. Any unbalance between the angle of both propeller blade and tightness of fixation is susceptible to generate vibrations. The investigation could not identify whether such condition existed prior to the event.
- The analysis of recorded engine parameters showed air pressure fluctuations inside the air filter box at high RPM. The investigation could not determine the cause of this phenomenon and whether the engine could have generated some abnormal vibrations susceptible to damage the propeller
  [direct cause]
- Test-flight with a new engine/propeller combination was performed without having first reasonably verified that they are compatible, amongst others through the performance of endurance tests on a test bench
  [indirect cause]

  [Action/decision – Action – Incorrect action performance (testing) – Owner/builder]
- The airframe manufacturer entrusted the importer to develop a major modification without insuring that he had sufficient technical background and knowledge to cope with all the aspects of such a modification.
  [contributing factor]
- Neither caution statement nor guidance material exists from both the engine and the propeller manufacturers to assess the compatibility of the engine with the propeller.
  [contributing factor]
  [see safety issue 4.1]

  [Development – Design – Design of document/info – Manufacturer (Engine)]

  [Development – Design – Design of document/info – Manufacturer (Propeller)]

3.2 Findings as to factors that increase(d) risk

- Upon the arrival of the ultralight aeroplane in Belgium, two different propellers were installed and flight-tested without requesting any authorization from the BCAA. The importer did not inform BCAA of his intentions. No application for a specific flight testing permit was made.

[Task performance – Maintenance – Modification/alteration – Owner/builder]

- After the first installed propeller was returned to its manufacturer, an inspection revealed the presence of damage at the root of one blade. The importer was informed of this finding and was encouraged to inspect the two-blade propeller after the first runs for possible similar damage. There is no indication that the importer inspected this propeller before the accident flight.
- The owner did not inform the authorities of the modification and the flight. Although a ‘technical file’ is requested in case of a modification.
- Although that technical file is requested, it is not clear in Circular CIR-AIRW-12 that the previously delivered restricted flight authorization or ARCA is no longer valid.
  [see safety issue 4.2]
- The owner provided the investigators no indication that a thorough risk assessment (anticipating amongst others a blade failure) was made prior to the test flight.
- Neither such a risk assessment nor a minimum of ground tests is currently required by the authorities.
  [see safety issue 4.2]

[Support/oversight/monitoring – Enforcement – Requirements – Regulator]

- For the flight, the aeroplane weight exceeded the MTOW.
- The engine rear plate and the engine mount suffered significant damage causing the engine remaining attached to the airframe structure at only one location instead of four.

[Powerplant – Mounts – Failure]

3.3 Other findings

- The importer succeeded to perform a forced landing without causing additional damage
- The latter is highly likely thanks to the large experience as former Belgian Air Force pilot and former SEP commercial pilot (aeroplane).

[positive factor – Experience/knowledge – Total flight experience – Pilot]

- At the time of the accident, he held a valid ultralight licence and a valid monitor rating.
- The originally installed (and approved) propeller Helix H60V 1,75m R-TS-3 shortened 1,60m ran for more than 8 hours without any indication of anomaly. This propeller was equipped with “TS” profile blades while the damaged/failed propellers were equipped with “TM” profiles blades.
- The ECU of the engine automatically switched off the electrical fuel pump(s) when the engine stopped.

[positive factor - hardware safety net]

4. SAFETY ACTIONS AND RECOMMENDATIONS

4.1 Safety issue: lack of guidance and warning from the manufacturers

Safety recommendation BE-2020-0008:

It is recommended that UL Power develops a guidance to ULM operators (owners, pilot, importers,..) when performing modification to the propulsion system of ULM (such as, but not limited to the installation of a new propeller, modifying the airstream around the engine, etc..).

Safety recommendation BE-2020-0009:

It is recommended that Helix develops a guidance to ULM operators (owners, pilot, importers,..) when selecting a new propeller for the ULM aircraft, highlighting the critical tasks and defining what tests and recordings have to be performed.

4.2 Safety issue: no clear info and requirements by the authorities

CIR AIRW 12 is primarily dealing with the initial issue of Type and Operations authorization for ULM. Only chapter 1.3 deals with modifications, with a definition of a “major modification”, stating that a major modification file, similar to the original technical file must be submitted for approval.

The chapter does not emphasize that a modified aircraft does not comply to the original technical file anymore and that therefore the ARCA is no longer valid. A flight permit is therefore required for any further flights before the issue of the new authorization.
Annex 5 of CIR AIRW 12 defines the requirements for ground tests. However, the text indicates its only purpose is to determine the structural strength. A propeller change requires ground testing, which is not captured by the text of Annex 5.
As commented by BCAA, “In ULM, there are no test pilot or other qualifications”, leading the reader of CIR AIRW 12 to conclude that any ULM pilot can perform the flight tests if he feels confident in his abilities. The nature of the test flights, for example “The stall should be repeated enough times to ensure a consistent speed” is clearly outside the abilities of the average ULM pilot. While a manufacturer can determine the qualifications needed for a test pilot, a modification is generally performed by the aircraft owner itself, not having the resources of a manufacturer.

For the above reasons;

Safety recommendation BE-2020-0010:

It is recommended that the BCAA further develops the guidance – CIR AIRW 12, or another – for ULM operators (owners, pilots, importers) emphasizing that a change in one of the descriptive elements (engine, propeller, wing (for DPMs)) makes the ARCA no longer valid and that a flight permit must be obtained prior to any test flight.

Safety recommendation BE-2020-0011:

It is recommended that, when an ultralight aircraft owner applies for a permit to fly in the scope of a change of propeller type or model, the BCAA requires, in consultation with the manufacturer, a ground endurance test specifying a minimum amount of cycles/time for the usable engine speed and pitch range.

5. APPENDIX

DEFENCE

Royal Military Academy
Department of Civil &
Materials Engineering
Materials Lab

Brussels, June 03th, 2018
Pages: 10
Annexes : /

To Federal Public Service
Mobility and Transport
Air Accident Investigation Unit
CCN-2nd Floor – Rue du Progrès 80 – Boîte 5
1030 Brussels - Belgium

CONCERNS: Failure analysis of a carbon fibre propeller

Ref:
1. Your request by mail d.d. 15/01/2018
2. RMA Materials Lab Activity 18-007-EXP-C

1. Mission

To make a failure analysis of following components from a propeller assembly. More in particular it was asked to:

- determine the composition of the propeller blade and propeller fixation ring;
- analyze the failure of the propeller blade, both hub halves and 6 fixation bolts;
- analyze the propeller blade trailing edge and look for eventual foreign particles.

This report is archived as Ref 2.

2. Received parts/fragments

All received parts are numbered from 1 to 7 as shown on figure 1.

Figure 1: the received fragments are numbered from 1 to 7

In this report, components are referred to as indicated on figure 1:

- 1: an undamaged propeller blade with an undamaged hub fixation ring;
- 2: a damaged propeller blade with fractured fixation ring and bolts;
- 3 and 4: two hub halves;
- 5: bushing to be centred between the two hub halves;
- 6: fractured part of the fixation ring from propeller 2;
- 7: six bolts from the fixation ring propeller 2.

3. Methodology

The propeller blades were inspected using light optical stereomicroscopy (LOM) without cleaning, in order not to remove eventual particles stuck in the blade material.

All other parts were examined using light optical stereomicroscopy (LOM) and scanning electron microscopy (SEM) after thoroughly cleaning them using an ultrasonic bath.

The chemical composition of the fixation ring alloy was determined using an energy-dispersive X-ray spectrometer (EDX) coupled to a FEI Quanta 400 SEM. This technique allows the standardless quantitative chemical analysis for elements with atomic number larger then Z=11 and with a precision not better then 0,1 weight percent.

4. Composition of the propeller blade and propeller fixation ring

The propeller blades are made of carbon fibre /resin composite material. The resin composition has not been determined.

The propeller fixation ring is made from an 7000 aluminium alloy with composition given in table 1 (see figure 2 for the EDX spectrum).

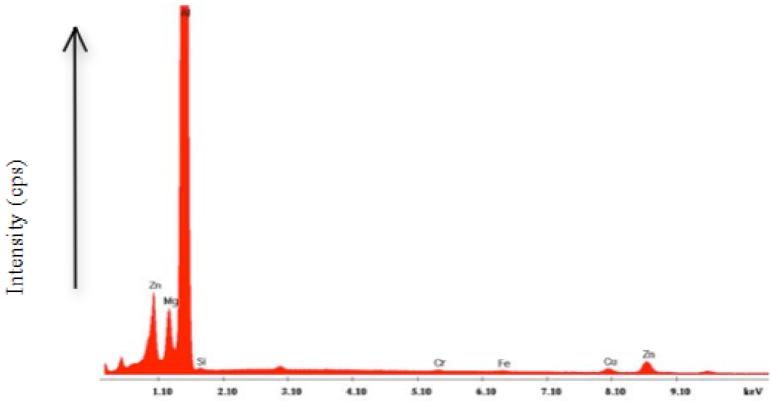


Figure 2: EDX energy spectrum of the propeller fixation ring

Element	Al	Zn	Mg	Cu	Si	Cr	Fe
Weigth%	86,9	7,1	3,2	2,1	0,2	0,2	0,3

Table 1: chemical composition of the propeller fixation ring
Values in weight percent

5. Fractographic analysis of the propeller blade No 2

Propeller blade 1 being intact, only propeller blade 2 and its fixation ring were investigated.

5.1 Global view

Figure 3 (a) and (b) give a global view on the two complementary fractured parts of the failed propeller fixation ring. On both pictures one clearly sees surface grooves parallel to the propeller axis. As will become clear from the rest of current analysis, these grooves were created after the primary fracture of the fixation ring by centrifugal projection of the propeller blade from its position between the hub halves. The observed grooves indeed correspond to those observed on the interior surface of both hub halves (see figures 15 and 16).

(a) (b)

Figure 3: both complementary parts of the fractured fixation ring have been put together; they exhibit perfectly axial surface grooves caused by centrifugal projection of the blade after primary failure of the fixation ring

Figure 4 shows the fragment of the fixation ring that remained fixed to the propeller blade (lower part on figure 3), while figure 5 shows the complementary part with the bore holes for the bolts (upper part on figure 3).

The black material between the outer remnants of the fixation ring and the inner metallic insert has been identified as the carbon fibre/resin composite material. The metallic insert is still properly fixed within the propeller body.

Figure 4: fragment of the fixation ring that remained fixed to the propeller blade (lower part on figure 3); fragments from the broken bolts are still present in the bore holes. Bolt 1 is identified with blue marker. The black material between the outer remnants of the fixation ring and the inner metallic insert are the carbon fibre/resin composite material.

Figure 5: complementary part of the fixation ring (upper part on figure 3), together with the fragments of the broken bolts (see also figure 4). Bolt fragments have been numbered for detailed analysis

5.2 Fracture surface of the broken fixation ring

Both fracture surfaces (see figure 4 and 5) essentially shown the same fractographic details. Although the fragments have been examined using LOM, only the part visible on figure 5 has been examined in SEM. Indeed, only this smaller fragment could be entered in the SEM chamber without the need to cut it.

Figure 6 shows the latter part at higher magnification. Four zones have been identified:

- zone 1a (indicated by the larger double arrow): exhibits a very smooth aspect with very clear beach marks; these beach marks indicate presence of a fatigue phenomenon;
- zone 1b (indicated by the smaller double arrow): has an aspect similar to that of zone 1a but is smaller; this zone also shows beach marks indicating presence of fatigue;
- zone 2a and 2b: these zones make up the rest of the fracture surface between the zones 1a and 1b. They correspond to the overload fracture

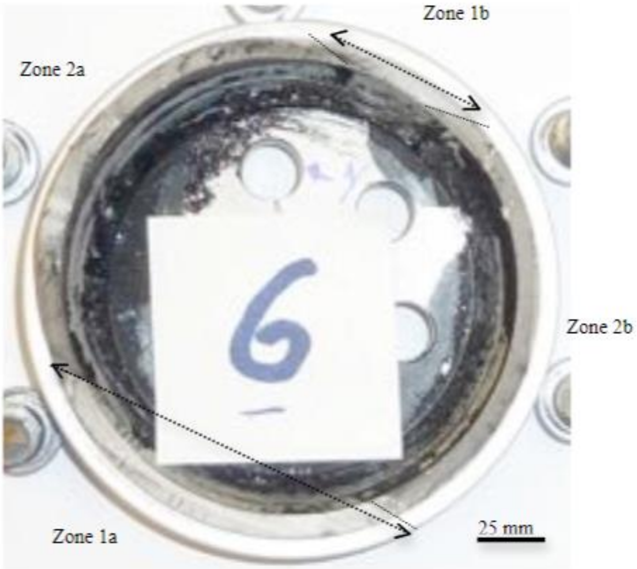


Figure 6: fracture surface of the fixation ring of propeller blade 2; indication of particular zones. Zones 1a and 1b correspond to the propagation of a fatigue crack; zones 2a and 2b correspond to the overload fracture of the ring. For further explanation, see text.

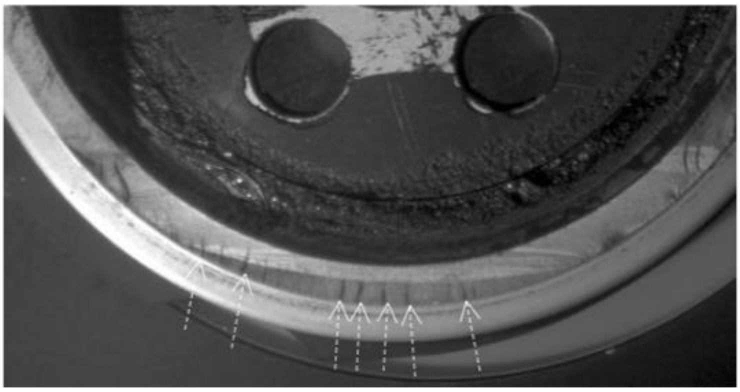


Figure 7: detail of zone 1a with presence of beach marks; white arrows indicate multiple initiation points of the fatigue crack

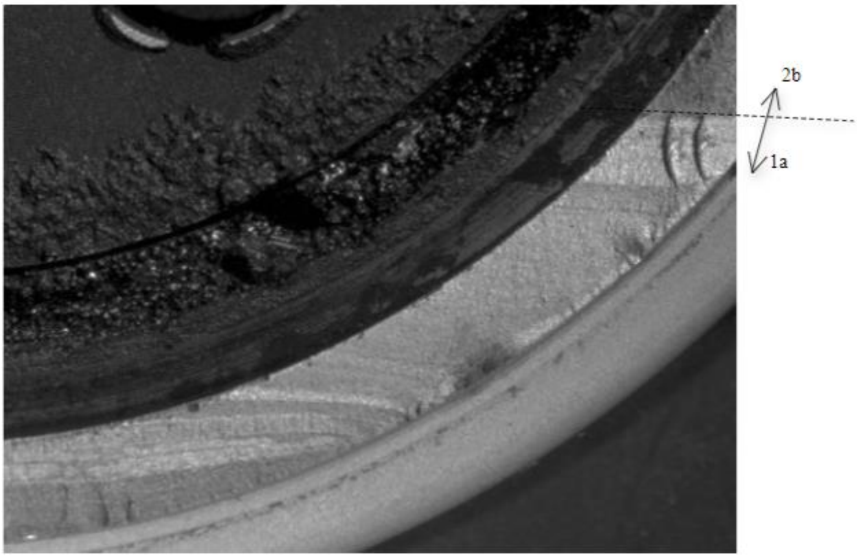


Figure 8: detail of zone 1a with indication of the transition of the fatigue zone towards the overload zone 2b

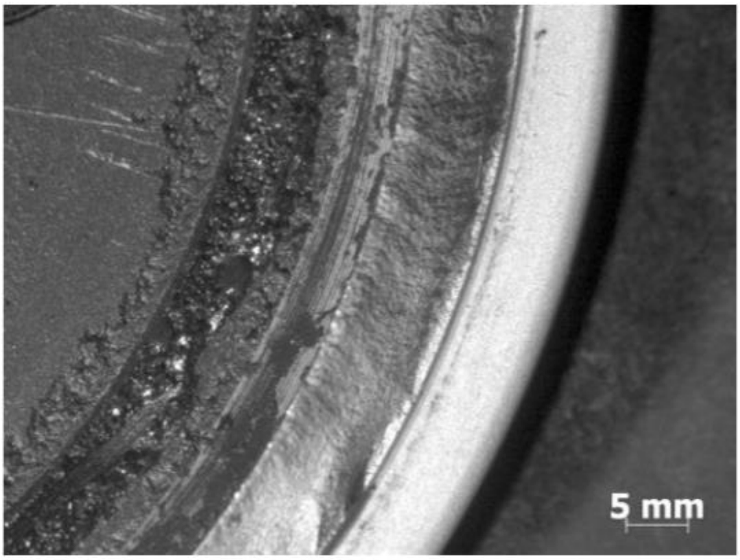


Figure 9: detail of overload zone 2b

As indicated on figure 7, zone 1a shows small terraces, which indicate multiple initiation points of the fatigue phenomenon; therefore it is very likely that the stress loading to the crack was rather high. This is also in agreement with the location of the crack in the shouldering of the ring, as can be clearly seen on figure 3a. At this location there is presence of a large stress concentration, which is very probably the cause of the crack initiation. Because of the high stress level, the fatigue phenomenon can be classified as low cycle fatigue, leading to the inevitable overload failure. It is noted that the overload failure doesn't follow the shouldering. Finally, the presence of a second fatigue zone, zone 1b, indicates the presence of a reversed bending component on the propeller blade.

To conclude the fractographic analysis, secondary cracks have been observed in the fixation ring (see figure 10). They are located near the boreholes at the weakest section; all 6 holes exhibit a crack. They are the result of compressive stresses applied by the bolt heads on the fixation ring. Figure 11 shows a detail of hole No. 1 indicated on figure 10.

Figure 10: view on the fixation ring and the cracks in the weakest section near each hole;

Figure 11: detail of the crack near hole No. 1, as indicated on figure 10

5.3 Fracture surface of the broken bolts

The fixation ring is fixed to the metallic propeller insert by means of 6 bolts. One of these bolts failed first; this bolt is indicated as No. 1 on figures 4 and 5.

Bolt No.1 has failed in its head by shearing off; this is a typical failure mode for this type of bolts with hexagonal Allen key socket. Figure 12 and 13 show the overload fracture surface of bolt No. 1.

Figure 12: overload of bolt No. 1; ductile shearing off of the head

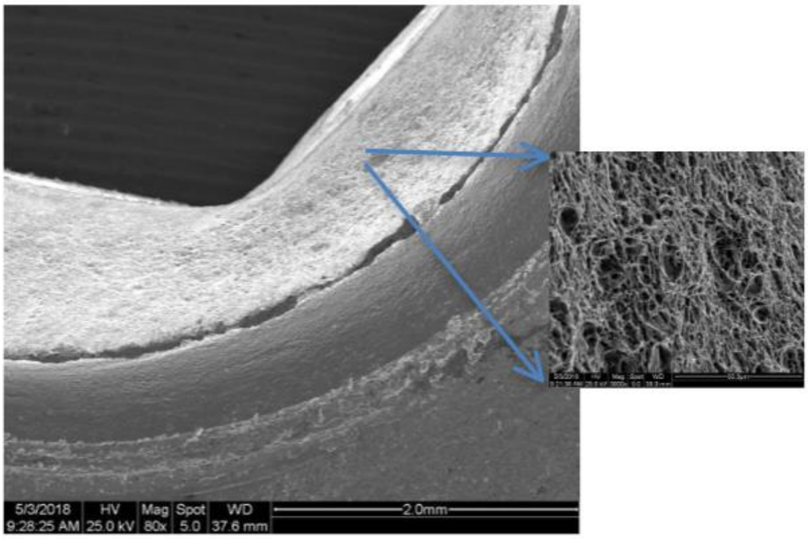


Figure 13: SEM picture of fracture surface of bolt No. 1; insert showing dimples indicating a ductile overload

The 5 remaining bolts have all failed in the shank in a ductile way typical for overload. As an illustration, figure 14 shows the fracture surface of bolt No. 3

Figure 14: ductile fracture surface of bolt No.3

5.4 Hub halves

Both hub halves are intact, except for axial grooves (in the direction of the propeller blade) as can be noticed on figure 15 and 16. This indicates that the grooves were created during the axial movement during and immediately after breaking of the fixation ring of the propeller blade 2.

Figure 15: overview on a hub halve with the undamaged propeller blade in place

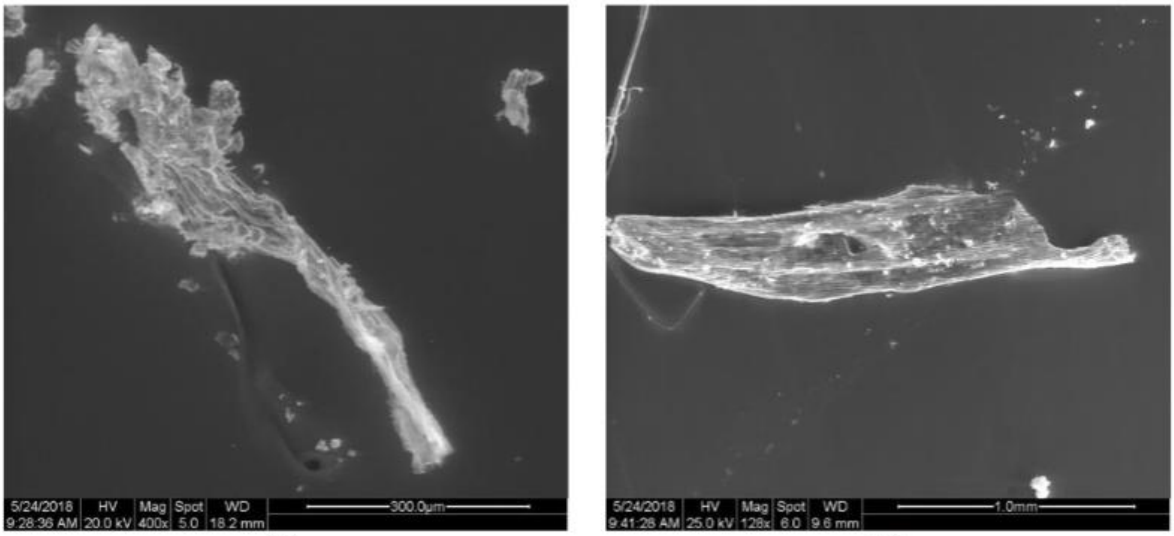
Figure 16: view on both hub halves, showing sliding grooves created by failure of propeller blade 2; no significant traces have been observed on the location for undamaged propeller blade 1

6. Analysis of impact traces on propeller blade 2

This paragraph reports the results of the observations on propeller blade 2, propeller blade 1 being intact.

Figure 17 shows the trailing edge of the extremity of blade 2; two particles have been found (see figure 18(a) and (b)). Both particles have a brownish colour and a fibrous texture. The EDX spectrum of particle 1 (see figure 19) reveals carbon and oxygen (hydrogen is not visible using EDX) and a variety of elements between Na and Cu. Particle 2 has a similar spectrum. Both particles are organic, probably wood, with small contaminations of other elements.

Figure 17: extremity of blade with damage on the trailing edge



(a) (a)

Figure 18: two particles with fibrous texture found in the damaged zone of the blade extremity

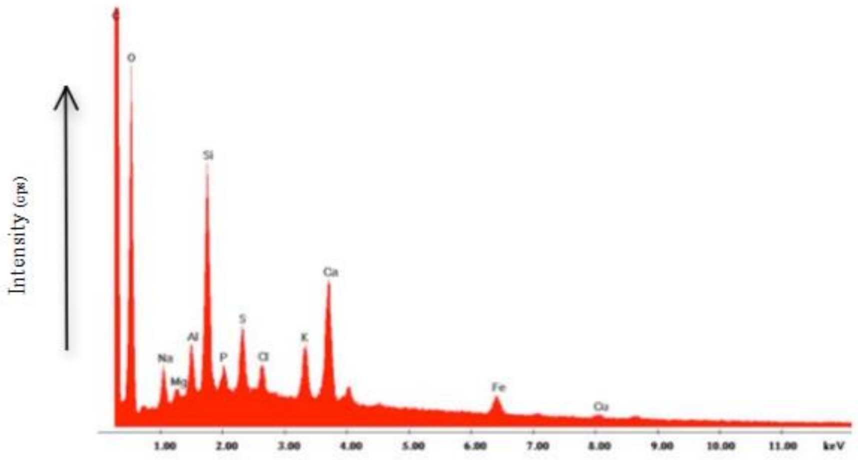


Figure 19: EDX spectrum of particle 1 found on the extremity of propeller blade 2

7. Conclusions

Propeller blade 2 has failed by fracture of its fixation ring. The fixation ring is affected by fatigue. The fatigue crack started in the shouldering of the ring, where a stress concentration is present. The bolt fractures and the grooves on the hub halves are consequential damage.

Two particles have been found on the damaged trailing edge of propeller blade 2. These particles are very probably small chunks of wood with contaminants. There are no indications that these particles and the damage of the blade are at the origin of an accidental load having caused initiation of the fatigue crack.

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