Accident
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REPORT ON AVIATION ACCIDENT AT ÅNGARDSVATNET IN OPPDAL MUNICIPALITY 26 FEBRUARY 2017 INVOLVING DYN AERO MCR 4S, LN-DLH

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Photos: AIBN and Trond Isaksen/OSL

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This investigation has been limited in scope. For that reason, AIBN has chosen to use a simplified reporting format. The reporting format in accordance with the guidelines given in ICAO Annex 13 is only used when this is required due to the scope of the investigation.

All time indication in this report is given in local time (UTC + 2 hours) unless otherwise specified.

Aircraft:	
- Type and reg.:	Dyn Aero MCR 4S, LN-DLH (Experimental)
- Production year:	2010
- Engine:	Rotax 912 ULS
Operator:	Private
Date and time:	Sunday 26 February 2017, 3:03 pm
Accident site:	Lake Ångardsvatnet, Oppdal municipality, Trøndelag (62°40`N 09°11`E)
ATS airspace:	Uncontrolled airspace, class G
Type of incidence:	Aviation accident; engine failure with ensuing emergency landing
Type of flight:	Private
Weather conditions:	No wind. No clouds. Temperature: 3 °C. QNH: 994 hPa
Light conditions:	Daylight
Flight conditions:	VMC
Flight plan:	VFR
Persons on board:	3; commander and 2 passengers
Personal injuries:	None
Damage to aircraft:	Damage to nose gear, structure around fire wall, engine and propeller
Other damage:	None
Aircraft commander:	
- Age:	53 years
- License:	PPL(A)
- Flight experience:	240 hours, of which 105 hours on this type. Last 90 days 26 hours, all on this type. Last 24 hours: 2, all on this type.
Sources of information:	NF-2007 «Reporting of accidents and incidents in civil aviation» from aircraft commander, as well as AIBN's own investigations.

FACTUAL INFORMATION

The flight was out of Flesland (ENBR) and was originally planned as a round trip with stops at Sandane (ENSD), Kvernberget (ENKB) and Røros (ENRO) before return to Flesland. Due to the weather conditions at Sandane, the flight continued to Vigra (ENAL) for a ground stop. The weather conditions at Kvernberget were such that the commander decided to go directly to Røros from Vigra. A while after passing Molde en route to Røros at an altitude of approximately 9000 ft., a small bang came from the engine, followed by vibrations and the smell of oil in the aircraft. The engine was stopped and emergency notice was given to ATC. The aircraft commander chose Lake Ångardsvatnet for an emergency landing, since this lake was within gliding distance from the point where the engine stopped (see Figure 1).

Figure 1: The aircraft's position relative to Lake Ångardsvatnet during gliding. Photo: Camera on board LN-DLH

While gliding towards Lake Ångardsvatnet, the engine was started. It vibrated so badly that it was stopped after a short while. The aircraft commander performed two 360 degree turns to arrive at the right altitude for the final approach towards the ice-covered lake (see Figure 2).

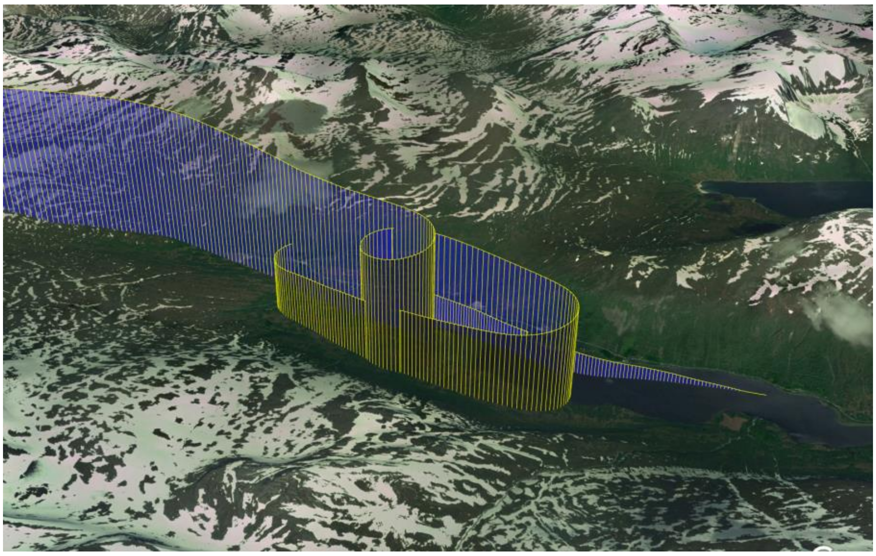


Figure 2: Final stage of the flight. Source: Google Earth and data from the aircraft's instrumentation.

The aircraft was set down at a speed of approximately 55 knots. The snow was 20-30 cm deep, and there was surface water on the ice. During landing, the nose gear mount and a propeller blade were broken. The aircraft ground looped and rotated almost 180 degrees. It came to a halt resting on the main landing gears, nose down in the snow. The aircraft did not catch fire. The aircraft commander and both passengers were unharmed and evacuated eventually the aircraft. ATC was informed about the accident and that assistance not was necessary.

The aircraft's fuel tanks were full (approximately 130 litres) at departure from Flesland and had approximately 90 litres remaining on the tanks when the accident occurred. 98 octane gasoline (Mogas) without ethanol was used.

The aircraft was salvaged to the shore using an improvised sled, which was pulled by a ski tracking machine, and transported on from there by road to a workshop at Eggemoen.

It was 3 °C, and there was surface water on the ice underneath the snow. The aircraft commander and one of the passengers didn't have suitable footwear. They had to borrow suitable footwear from some people who lived nearby and came out to the aircraft.

<u>The aircraft</u>

The single engine aircraft has fixed landing gear, and has a maximum take off mass of 750 kg. The aircraft is delivered as a kit aircraft and was built by in Sweden by a private citizen. It's classed «Experimental» and is thereby subject to provisions of BSL B 2-3 Art. 6 «Maintenance Class III». The owner of LN-DLH purchased the aircraft in used condition, with the original Rotax 912 ULS engine, producing approximately 100 hp. In order to use 95 octane Mogas in places where 98 octane gasoline was not available, he converted the engine himself, using a «Big Bore Kit» which gave the engine a displacement of 1417 cm³ and somewhat lower compression ratio than on the original engine. The kit was delivered by EdgePerformance. The conversion kit was used on an engine that the provider of the conversion kit had installed in his own aircraft. The components had accumulated approximately 12 flight hours in this aircraft. The engine of LN-DLH accumulated approximately 78 flight hours after the modification before it failed on this flight.

The aircraft had an airborne time of 231:45 flight hours at the time of the accident. The engine and the propeller had the same airborne time. The last maintenance, a 100 hrs inspection, was performed at airborne time 204:30 flight hours. The last Certificate of Airworthiness was issued 19.12.2016.

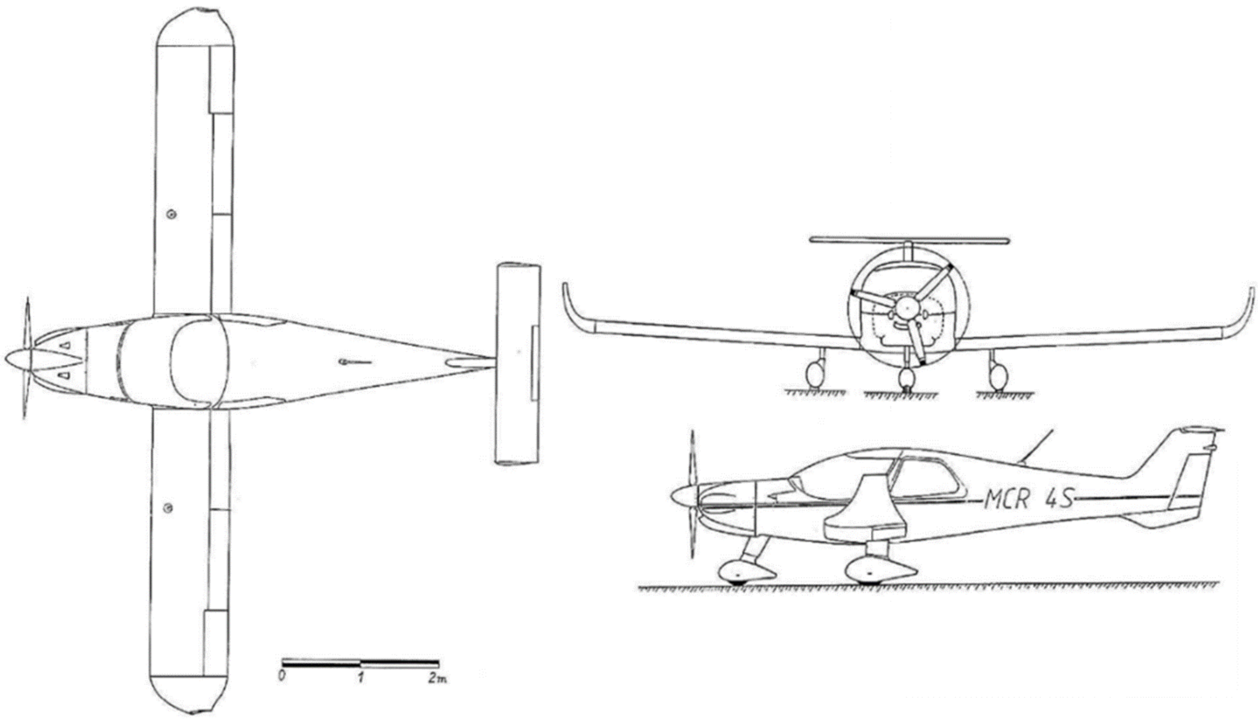


Figure 3: Dyn Aero MCR 4S. Illustration: Dyn Aero

Modification of the engine (Big Bore Kit)

The purpose of this modification was to increase the engine's power output and make it possible to use 95 octane Mogas. This is done by increasing the engine's displacement, which is achieved by increasing the cylinder diameter and installing new pistons with a larger diameter, and with a design different to that of the original Rotax pistons. The engine's displacement was increased from 1352 cm^3 to 1417 cm^3, which, and according to EdgePerformance, gives an increased output of 7 hp together with a lower compression ratio than on the original engine. The pistons that came with the conversion kit didn't have full-circumference piston skirts, which the engine manufacturer's original pistons did (see Figure 4). The modification also meant that the engine manufacturer's original cylinders were bored up to a larger inside diameter. Larger cylinder diameter gives less material thickness in the cylinder walls. This modification was intended for engines equipped with turbo chargers. LN-DLH was not equipped with turbo charger.

EdgePerformance does not have any documentation describing time limitations or maintenance intervals for modified engines or giving any fuel quality requirements. The AIBN has, through the investigation learned that it is generally recommended to use 98 octane car gasoline (Mogas) in engines with a Big Bore modification and not 95 octane which the commander intended to use occasionally pending on availability of 98 octane.

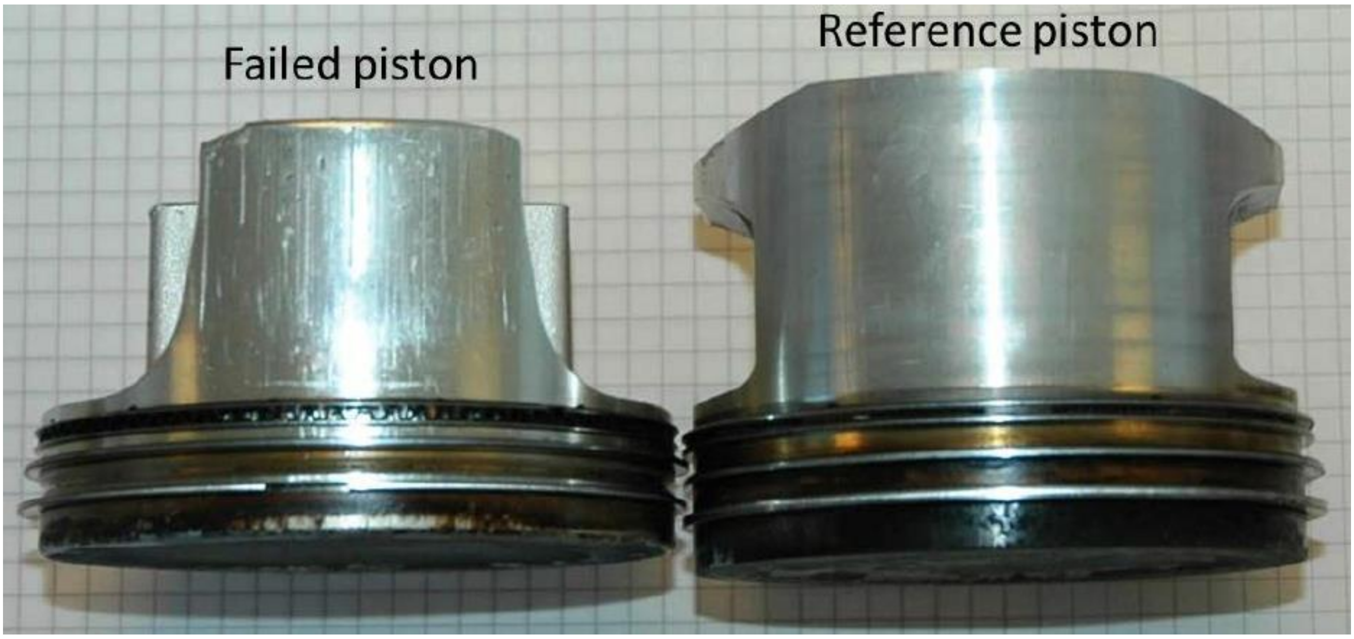


Figure 4: Comparison. Original piston from Rotax to the right. Photo: AIBN/NDLO

Damage to the aircraft

The aircraft sustained extensive structural damage to the nose section.

Examination of the engine

An initial examination of the engine was done at the maintenance facility at Eggemoen. Damage was found and documented. In cylinder no. 2 the connecting rod was bent and broken off, and the piston skirt had broken off on one side of the piston. Due to the missing piston skirt on one side of the piston, it had rotated around the piston pin and was jammed at an angle in the cylinder, with a deformed piston crown and ring zone (see Figure 5 and Figure 6). Further disassembly of the engine was done at EdgePerformance's workshop where necessary special tooling was available. The dismantled engine was transported to AIBN's facilities for further examination.

Figure 5: Piston in cylinder no. 2. Photo: AIBN

The piston rings and the piston ring grooves on piston no. 2 had not been subject to abnormally high temperatures. The circumference of the piston crown was polished due to the contact the tilted piston had with the cylinder walls after the piston skirt had broken off.

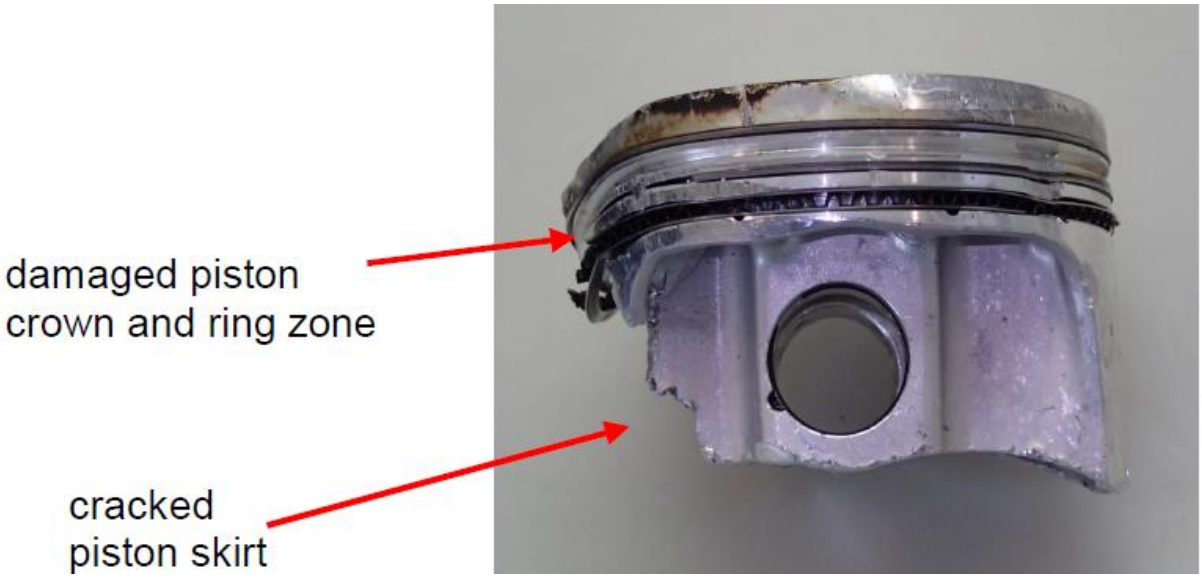


Figure 6: Damages on piston no. 2. Source: Rotax

There were scratches on the piston skirts on all four pistons. The extent of scratches indicates that they were caused by metal debris that was created when the no. 2 connecting rod broke off (see Figure 7).

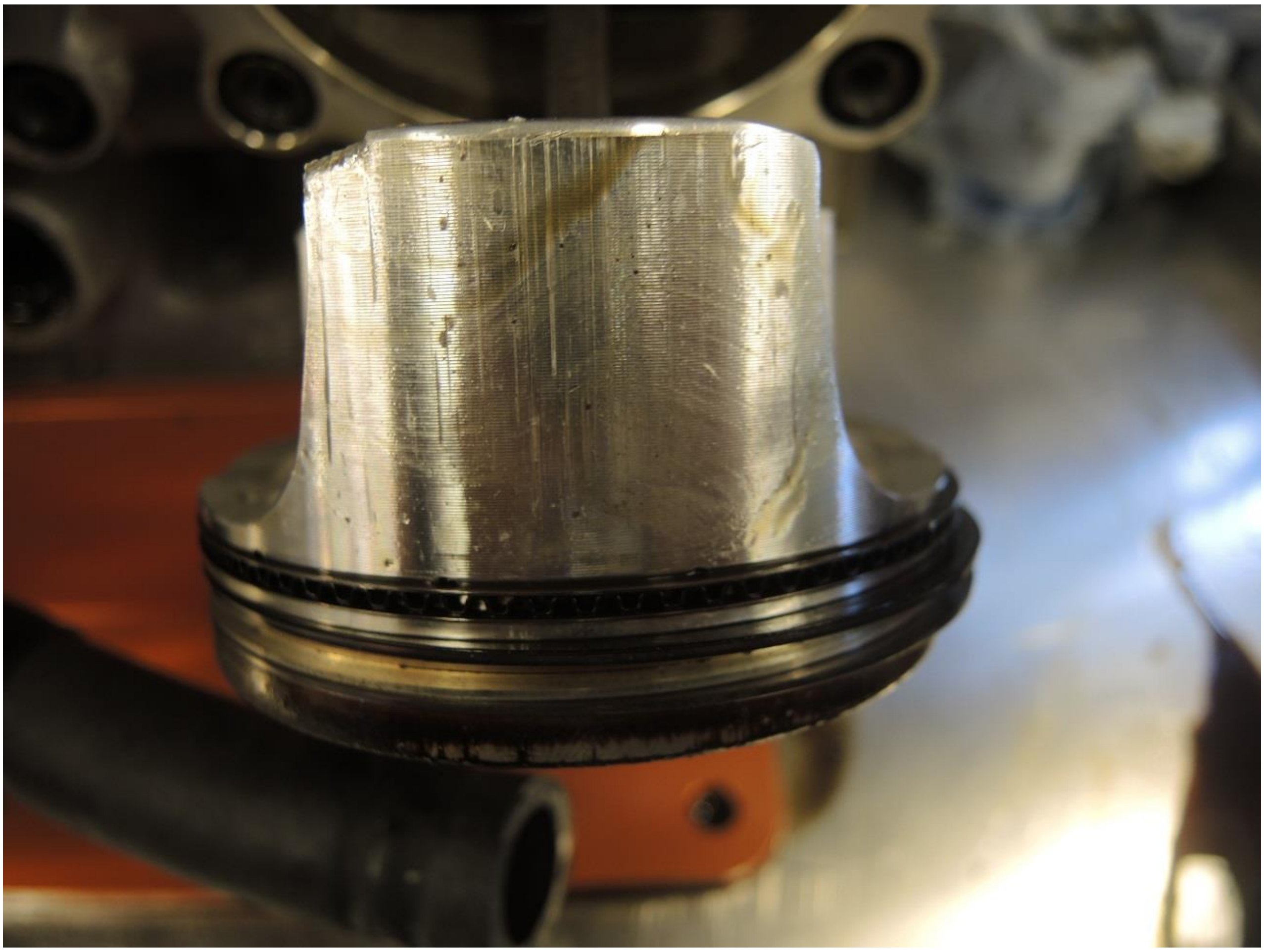


Figure 7: Scratches on the piston skirts on one of the pistons. Photo: AIBN

The pistons were first taken to the Norwegian Defence Laboratories (NDLO) for analysis. The analysis showed that the piston material had a coarse granular structure and that intergranular cracks together with transgranular crushing damage had occurred.

Cylinders, cylinder heads, pistons, crankshaft with connecting rods, and camshaft were later brought to the Rotax engine manufacturer for further examinations. These examinations showed that the fractured connecting rod had impact marks in the fracture zone, indicating that the engine had been running on three cylinders for a while after the piston in cylinder no. 2 had jammed. The lower section of cylinders 1 and 2 had had bits of the bottom part of the cylinder wall chipped off. These were secondary damages that occurred after the connecting rod in cylinder no. 2 broke off (see Figure 8). Metal debris was spread around in the crankcase.

Figure 8: Cylinder no. 2 with piston and upper part of connecting rod. Photo: AIBN

There were marks on piston heads and cylinder heads that could indicate either that there had been detonations in the cylinders, or that foreign objects had entered the cylinders. Closer examination revealed that foreign objects had entered the cylinders while the engine was running. Particularly piston no. 4 had pronounced damages (see Figure 9 and Figure 10).

Figure 9: Damages to the piston crown of piston no. 4. Photo: AIBN

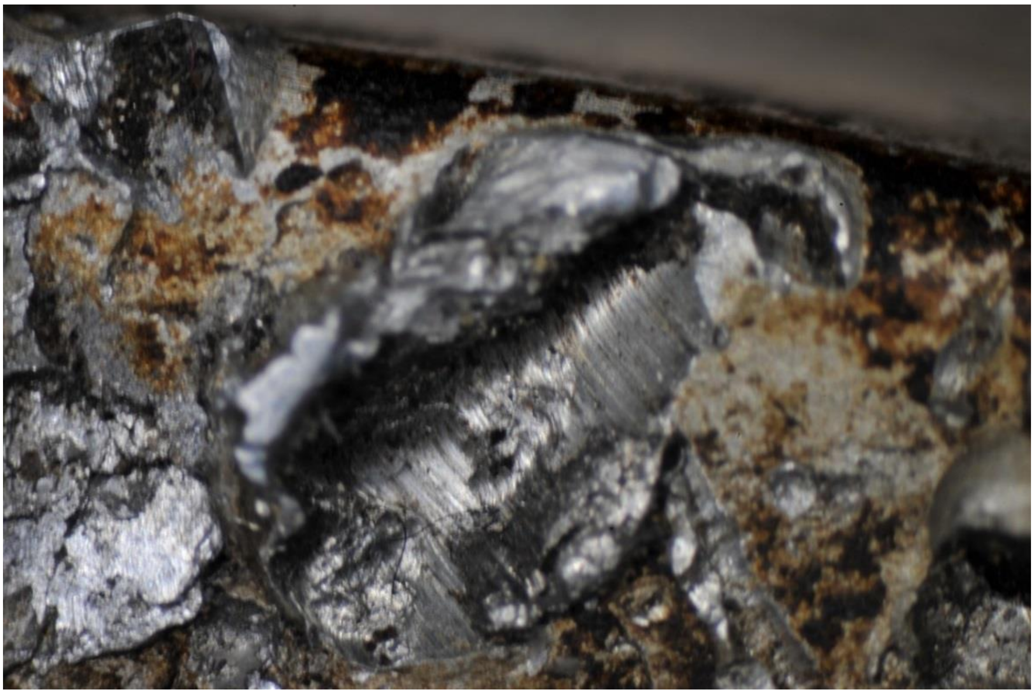


Figure 10: Traces of foreign objects on piston crown on piston no. 4. Photo: AIBN/NDLO

EDS[1] analysis by SEM[2] microscopy showed that the fragments found imprinted in the most damaged piston crown (piston no. 4) mainly consisted of iron (see Figure 12). It has not been possible to establish what caused these fragments to enter the cylinders. Similar damages were found on piston no. 2 (see Figure 11).

Figure 11: Damages on piston crown on piston no. 2. Photo: AIBN

[1] Energy Dispersive X-ray Spectroscopy
[2] Scanning Electron Microscope

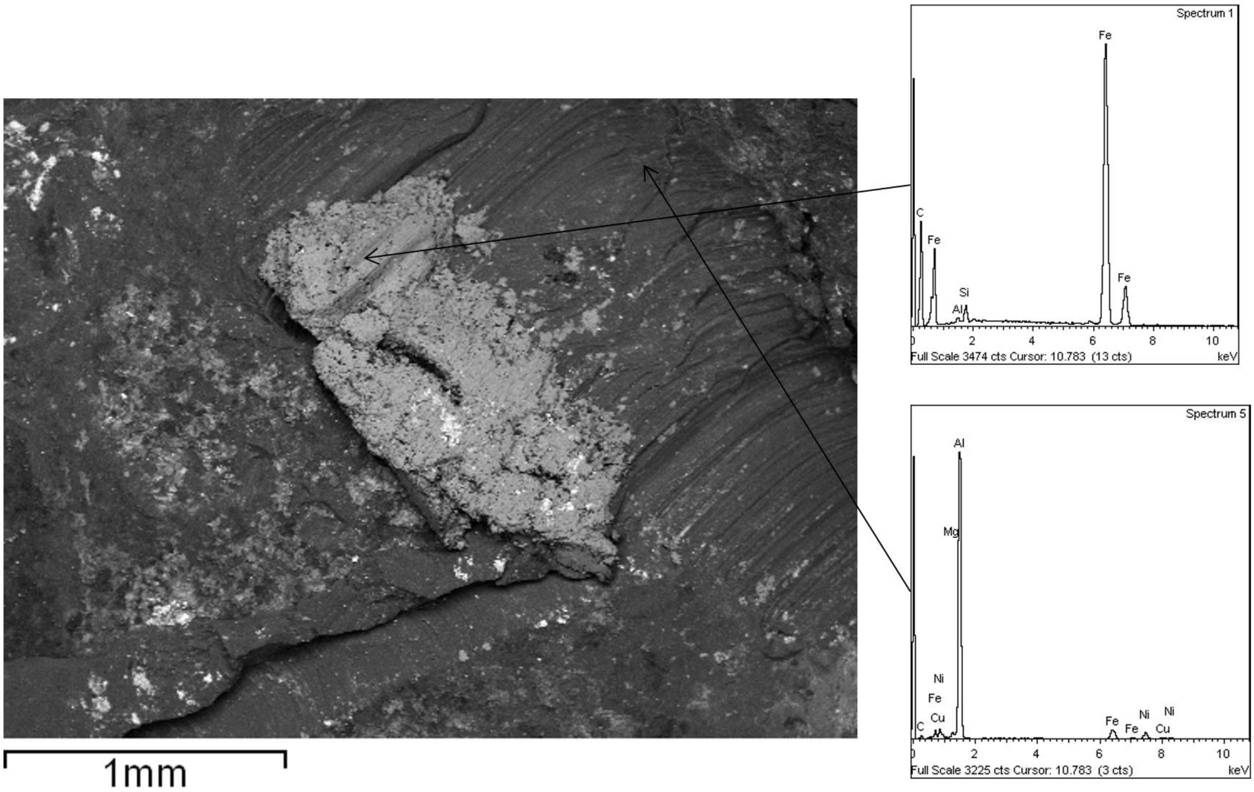


Figure 12: SEM microscopy and EDS spectrum of particles on piston crown on piston no. 4. Photo/illustration: AIBN/NDLO

Cracks were found in the reinforcements that support the piston skirts on all four pistons. The piston pin holes in the pistons were asymmetrically offset with approximately 1 mm. These cracks had appeared on the same side on all four pistons (see Figure 13). It was checked if the pistons had been installed the wrong way compared to similar asymmetry as on the original Rotax pistons. On the original Rotax pistons, an arrow stamped on the piston crown indicates direction of installation. The Big Bore pistons were installed the same way as the original Rotax pistons.

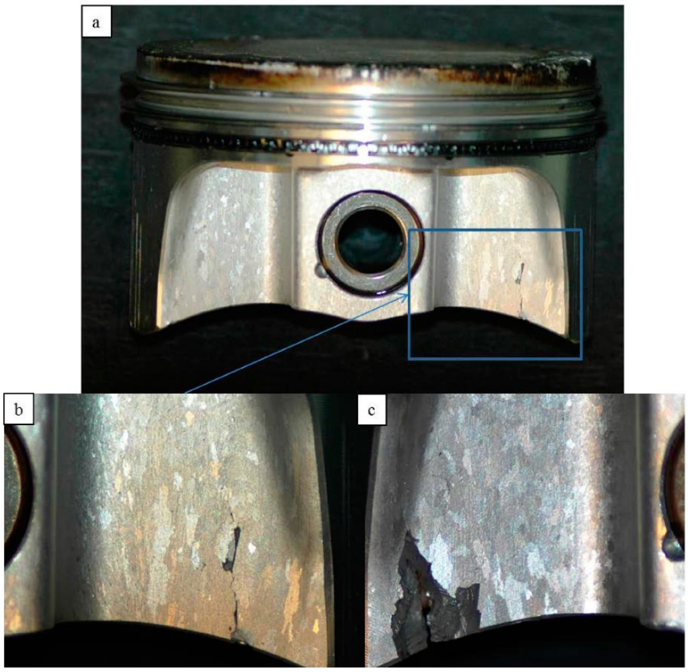


Figure 13: Cracks in piston skirt support structure in one of the pistons. Source: AIBN/NDLO

<u>Design aspects</u>

Piston skirts that don't go all the way around the pistons, which was the case in the LN-DLH engine, requires according to Rotax larger dimensions on the connecting rods linking the pistons to the crankshaft. The connecting rods are a part of the sideways steering of the pistons (in the longitudinal direction of the piston pins). These movements occur due to the clearance necessary between the pistons and the cylinder walls. The Rotax pistons have full-circumference piston skirts, which makes it possible to have connecting rods that are 6 mm thick (detail «h» in Figure 14). Rotax would have used connecting rods with a thickness of approximately 13 mm (detail «h» in the illustration) for the connecting rods to be sufficiently stiff to withstand the forces from the pistons' sideways movements in the cylinders if they had used pistons of the same design as those installed in the engine. These concerns were not taken care of when the «Big Bore» pistons were installed in the LN-DLH engine.

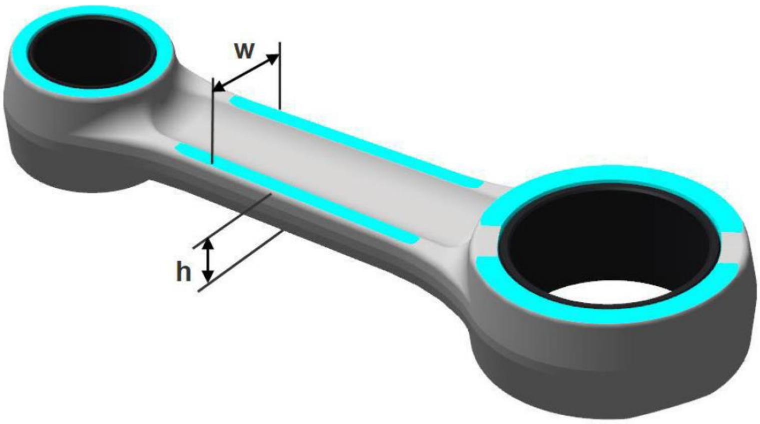


Figure 14: Sketch of connecting rod. Illustration: Rotax

The clearance between piston and cylinder also results in lateral piston movements, which the shaping of the piston skirts should deal with. The piston skirts shall thereby guide the piston in the cylinder. Figure 15 shows how a piston moves around the piston pin axis due to this clearance (exaggerated illustration).

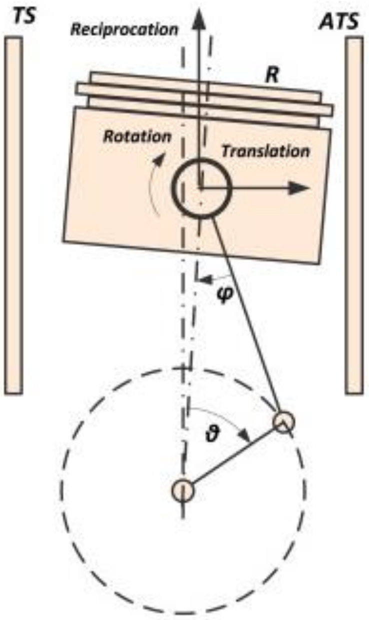
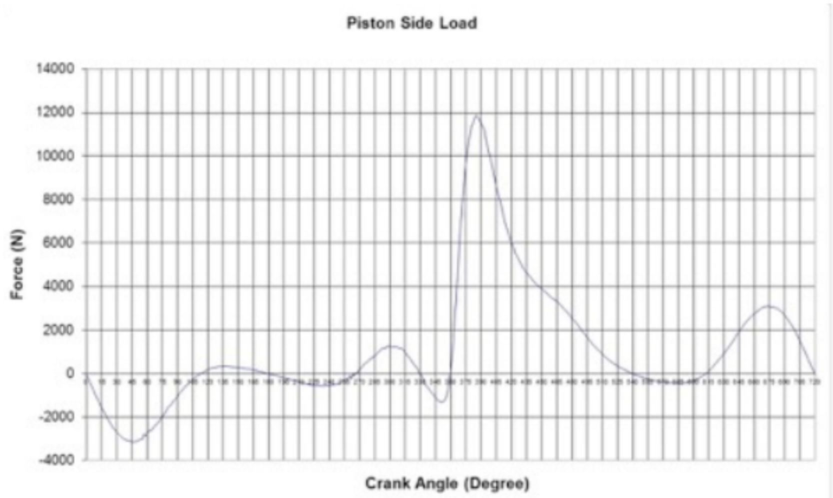


Figure 15: Illustration of lateral movement of piston. Source: Sciencedirect.com

The following diagram gives an illustration of which asymmetrical forces that have an impact on a piston relative to the rotational angle of the crankshaft. The numbers in the diagram do not specifically represent the LN-DLH engine but are an expression of large assymetric variations in the forces a piston is subjected to. These forces have to be absorbed by the structure of the piston skirts (see Figure 16).



This crank angle diagram shows the dramatic difference in loading on the major thrust side of the piston. The profile above the reference line indicates loading on the major thrust side. The profile below the reference line is the minor thrust side.

Figure 16: Asymmetrical forces affecting a piston. Source: JE pistons.com

<u>Metallurgical examination of fracture in piston structure</u>

A metallurgical examination performed by NDLO, revealed a coarse, granular structure in the piston. Such a structure appears in this material at a temperature of more than 300 °C. The pistons were forged and consisted of AA2618 alloy. According to Rotax, the operational temperature in this area of the piston will not exceed 170 °C. According to NDLO, it is likely that the coarse, granular structure occurred in the material during the manufacturing process (see Figure 17). This was also confirmed by the company that produced the pistons for EdgePerformance.

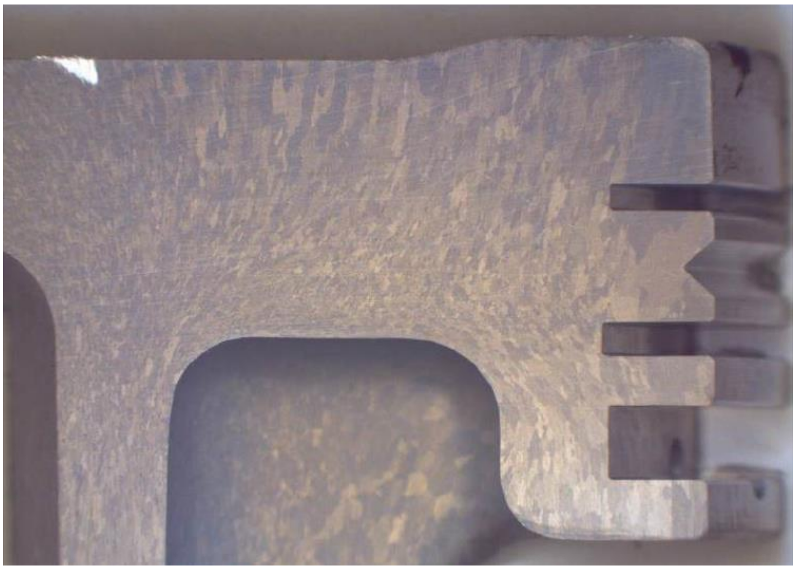


Figure 17: Coarse granular structure in pistons. Photo: Rotax

This structure will weaken the mechanical properties of the material. Intergranular fractures were in the same location on all four pistons. In addition, transgranular crushing damage also occurred in the material, which indicates that the structure near the fracture surfaces has been subjected to compressive forces (see Figure 18).

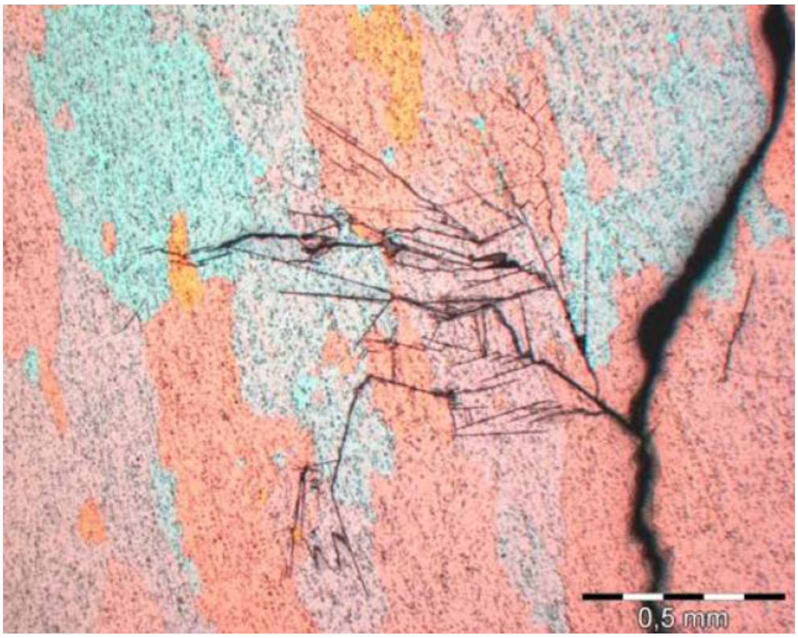


Figure 18: Transgranular crushing in the piston material. Photo: AIBN/NDLO

<u>Examination performed by Rotax</u>

Rotax performed an examination of relevant components from the engine of LN-DLH. The report concludes with the following:

Conclusion and Summary of finding
The reported engine malfunction is caused by the cracked modified piston of cylinder 2. A failure always occurs when a design cannot withstand the loads.

Loads causing the failure
From the fact that all 3 other pistons had cracks in the same area and the Technical Report 80528-09 (provided by the Norwegian Defense Laboratories), it can be deduced that the failure is clearly a fatigue failure. Based on the location of the failure and the cracks on the three other pistons, the loads responsible for the failure are caused by the piston secondary movement. During the up and down movement of the piston, the piston changes the side at which it contacts the cylinder. This is due to the change in force, the changing orientation of the connecting rod and the clearance between piston and cylinder (see Lit. 1[3]). During this event, the piston impacts the cylinder with the top end and the bottom end. An exemplary description can be seen in Lit. 2[4] figure 2. The impact described in {6} in this figure is causing the loads leading to this failure. This type of failure has been observed a few times in the past in other ROTAX pistons for other engine types (no aircraft pistons) during the early development stage but not in production engines.

Altered design of the Big Bore pistons

A new design now exists on the pistons that EdgePerformance delivers. The piston skirt is now larger in area and has thicker walls, and the pistons are covered with Teflon and ceramic coating below the piston rings (see Figure 19) to reduce the friction between the piston skirts and the cylinder walls. This design, as AIBN considers it, is intended to be better to absorb the forces generated by the lateral movements of the pistons in the cylinders.

[3] N. Dolatabadi, S. Theodossiades, S.J. Rothberg 2015 «On the identification of piston slap events in internal combustion engines using tribodynamic analysis»
[4] Momani W. 2017 «Influence of Internal Combustion Engine Parameters on Gas Leakage through the Pistion Rings Area»

Figure 19: New design of «Big Bore» pistons. Photo: EdgePerformance

The manufacturer's reservation concerning third-party conversion kits

Rotax has, through Service Letter SL-912-006 R1 dated 23 July 2014, warned against the use of conversions in the following manner:

- *The use of any third party, after-market replacement pistons for ROTAX® engine type 912 (Series), 912 and 914 (Series) is NOT approved by ROTAX® and is very strongly discouraged.*
- *Use of any third party replacement piston may cause engine damage resulting in catastrophic engine failure.*
- *Use of any third party replacement pistons will void all ROTAX® engine warranties.*

As a principle, Rotax states that an engine modified with a Big Bore kit is no longer to be considered as a Rotax engine.

Regulations

LN-DLH is an amateur built aircraft, as defined in BSL B 3-1 «Home build regulation». The regulations that cover persons who build their aircraft themselves (BSL B 3-1 «Home build regulation» and BSL B 2-3 «Maintenance regulation – private») were not followed on several points. The aircraft belongs to «Maintenance class III» as defined in Art. 5 of BSL B 2-3.

- **Design and production of «Big Bore» kits:**
  BSL B 3-1 states that aircraft engines without type certificate shall be approved by the Civil Aviation Authority Norway (CAA-N). The wording in Art. 8 is as follows (unofficial translation):

Unless otherwise specified by the aircraft type designer, manufacturer or licensee, the engine and propeller must either have a type certificate or be approved by the Civil Aviation Authority.

For engines without ordinary type certificate, the following applies:

a) the engine or identical motor must have been in use for a minimum of 60 operating hours;
b) the engine must have been used with the same electrical system, fuel system and cooling system as in the aircraft,
c) the 60 operating hours can be carried out in a test bench, in an aircraft or in a combination of these.

The Civil Aviation Authority shall approve the modification of the aircraft engine.

When building in accordance with previously stipulated requirements and where the requirements in the first to third paragraphs are not met, the Civil Aviation Authority can grant exemptions from this provision.

The Rotax 912ULS belongs in this class of engines. BSL B 3-1 Art. 21 requires that production of aircraft parts shall be approved by the CAA-N. Aircraft engines are critical components regardless of being type certificated or not. Design and manufacture of parts to be used for modification of aircraft engines shall be subject to approval by the CAA-N. The «Big Bore» modification has not been subject to such an approval process.

- **Conversion of engine:**
  BSL B 3-1 Art. 8 «Engine requirements» were not followed, as the CAA-N hasn't had any knowledge of the conversion of the engine. No permission had been given by the CAA-N to convert the engine using «Big Bore Kit», and the CAA-N wasn't informed that the conversion had taken place. The conversion was done in February 2016. The Accident Investigation Board also knows that the owner in an e-mail dated 8 July 2016 informed the CAA-N that the engine conversion had been «put on hold», even though the engine had already been converted in February the same year.

- **Approval of performing personnel:**
  BSL B 2-3 Art. 6 «Maintenance of aircraft in maintenance classes I, II and III» was not followed, as no special permit from the CAA-N to the owner of the aircraft to be allowed to do the work himself had been issued, as prescribed in subsection (4) b) of this article,.

- **Documentation of work performed:**
  BSL B 2-3 Art. 27 «Technical logbooks» were not followed, as the modification that was performed on the engine was not logged in the aircraft's aircraft logbook.

THE ASSESSMENTS OF THE ACCIDENT INVESTIGATION BOARD

The Accident Investigation Board is of the opinion that this accident was caused by a piston that failed and jammed in the cylinder. The pistons in this engine were provided as parts of a conversion kit from a third-party provider, EdgePerformance. The pistons that came with this kit were of a different design than the original ones and, among other things, had a smaller piston skirt. The piston skirt structure was exposed to a larger load through the compression and combustion cycle than the original Rotax pistons did. Coarse granular structure was found in the material the piston was made of. This granular structure had most likely been incurred when the pistons were manufactured. It was probably the combination of coarse structure and larger mechanical load on the piston skirt structure in this type of pistons that led to cracks in the same place in all four pistons, and to the damage of the piston skirt in cylinder no. 2.

There were marks on the piston crowns and cylinder heads from foreign material that had entered the cylinders. Especially cylinder no. 4 had prominent marks, and fragments containing iron were found on the surface of this piston. The cause of these damages are not found. It is presumed that the fragments at some point have been ingested with the airflow into the engine. The damages are unlikely to have caused the engine breakdown, since these damages were most prominent in a piston on which the piston skirt hadn’t gone to fracture, and not very prominent in the piston that caused the engine breakdown.

There was evidence of foreign object damage of varying extent on all piston crowns and cylinder heads. It is known that increased compression ratio, wrong ignition timing and gasoline with wrong octane number can cause detonation with following engine damage. The aircraft altitude at the time of the engine breakdown was 9 000 ft. This may have influenced the air/fuel mixture negatively. AIBN cannot exclude detonation in LN-DLH’s engine, but the damages observed on the piston crowns and the cylinder heads are atypical for damages that are typical in engines exposed to detonation. This substantiates that the engine breakdown occurred due to structural weakness in the pistons.

To the Accident Investigation Board’s knowledge, EdgePerformance has sold approximately 200 conversion sets worldwide. The converted engines, according to Rotax, have connecting rods that are not dimensioned for this type of pistons. This might be a latent source of engine failure. In Service Letter SL-912-006 R1, Rotax also warns strongly against making such conversions. In the accident with LN-DLH the damage of connecting rod no. 2 was secondary damage caused by the misaligned piston when it hit the cylinder head.

AIBN has called the attention of the Civil Aviation Authority Norway (CAA-N) to the fact that there are several Norwegian aircraft fitted with such converted engines. The Accident Investigation Board expects CAA-N to make the necessary flight safety assessments.

Rotax has defined the maintenance intervals for the engine. The manufacturer of the engines denies liability for converted engines. Definition of component time limitations and maintenance task intervals for converted engines is therefore the responsibility of the vendor of the «BigBore» kit. AIBN considers that this topic should be included in the CAA-N’s safety assessment.

AIBN is of the view that this accident and what has been revealed in the aftermath of it concerning the status of the engine, shows tell-tale signs of non-compliance with the BSL B 3-1 «Home build regulation» and the BSL B 2-3 «Maintenance regulation – private».

AIBN is of the view that the owner/aircraft commander should be consciously aware of the fact that his is an aircraft with a converted engine, which was not approved in accordance with existing regulations. AIBN criticizes that he brought two passengers on the accident flight, thereby exposing them to a risk they were not aware of.

When the engine broke down, the aircraft was near the ice-covered Lake Ångardsvatnet and there was little wind and good visibility in clear weather. In that respect, conditions were the very best for finding an emergency landing option. It is important to make the right choice of flight track when flying single-engine aircraft, to ensure as good a chance of a safe emergency landing as possible.

The pilot handled the situation correctly and chose the ice on Lake Ångardsvatnet as landing area. He made the right assessments when he circled down to the right altitude and minimized the landing speed. It wasn't possible for the pilot to predict that there was surface water on the ice, which led to high rolling resistance with the ensuing nose gear collapse and ground loop.

Due to insufficient equipment for emergency landing in winter conditions, after this accident two of the persons on board had to borrow suitable footwear from people living near the accident site. It was winter conditions in the area where they landed. It is important to be suitably dressed and to have on board the right equipment for the conditions of the flight. Civil Aviation Authority Norway has issued «Winter flight guidelines» which also address issues such as suitable clothing and equipment. AIBN is of the opinion that everybody flying in winter conditions should familiarize themselves with this guide.

Accident Investigation Board Norway

Lillestrøm, 22 March 2019