Issued June 2022

REPORT AVIATION 2022/05

Serious aviation incident near Råde Church in Østfold, Norway, on Wednesday 21 June 2017 involving Diamond DA 40 NG, LN-FTR, operated by Pilot Flight Academy

Photo: NSIA

This report has been translated into English and published by the NSIA to facilitate access by international readers. As accurate as the translation might be, the original Norwegian text takes precedence as the report of reference.

Table of contents

Report on serious aviation incident

Table 1: Data relating to the incident

Type of aircraft:	Diamond Aircraft Industries GmbH DA 40 NG
Nationality and registration:	Norwegian, LN-FTR
Owner:	Sky Management AS, Norway
Operator:	Pilot Flight Academy, Norway
Crew/pilot in command:	2, instructor/pilot in command and student pilot
Passengers:	None
Incident site:	Forced landing in a field near Råde Church in Viken County (N 059.34321 E 010.88803)
Time of incident:	Wednesday 21 June 2017 at 1910 hours

All times given in this report are local times (UTC + 2 hours), unless otherwise stated.

Notification of the incident

The accident investigator on duty was initially notified by one of the investigating authority's own investigators who was in the air on board another aircraft when the incident occurred. He had heard over the radio that LN-FTR experienced engine trouble and had to perform a forced landing. The NSIA subsequently received notifications from Østfold Police, Oslo Air Traffic Control Centre, the Joint Rescue Coordination Centre for Southern Norway (JRCC-S), the pilot in command, Pilot Flight Academy and a witness who had observed the aircraft as it was about to perform the forced landing. The NSIA deployed two accident investigators to the landing site that same evening.

In accordance with ICAO Annex 13 'Aircraft Accident and Incident Investigation', the NSIA notified the Civil Aviation Safety Investigation Authority in Austria, the country of manufacture. The Civil Aviation Authority Norway (CAA-N) and the European Aviation Safety Agency (EASA) were also notified.

The Austrian Civil Aviation Safety Investigation Authority has contributed with an accredited representative, while Austro Engine, the engine manufacturer, has contributed with technical advisors.

Summary

On 21 June 2017, a student pilot and an instructor took off in LN-FTR from Torp Airport Sandefjord (ENTO) to perform an IFR flight to Karlstad in Sweden. Being established at a cruising altitude of 6,000 ft over Fredrikstad area, the crew heard a bang from the engine. This was followed by uncontrolled variations in rpm. After a while, it was no longer possible to maintain the aircraft's altitude, and the engine eventually came to a complete stop.

The crew transmitted a distress message and headed towards the nearest airport; Moss Airport Rygge (ENRY). When it became clear that the aircraft would not make it to Rygge, the instructor performed a forced landing in a field near Råde Church. The crew sustained no injuries and the aircraft was not damaged during the landing.

The NSIA's investigation has shown that LN-FTR suffered engine failure as a result of significant internal engine damage. It is probable that cylinder 1 was damaged first and that the damage then spread to the remaining cylinders. The investigation indicates two possible failure scenarios. The origin of the damage may either have been incorrect installation of the timing chain, or it was local damage caused by other factors. The investigation has not given sufficient basis for concluding which of these two is most likely.

On the day before the incident, the aircraft had left the repair shop after replacement of the engine's cylinder head. It had subsequently flown 5:30 flight hours before the incident flight.

The crew received no prior warning of the engine failure. The investigation has shown that the crew could neither have prevented the engine failure nor restarted the engine after it stopped. In the NSIA's opinion, the emergency situation was well handled.

About the investigation

Purpose and method

The NSIA has classified the incident as a serious aviation incident. The purpose of this investigation has been to determine the cause of LN-FTR's engine failure. The NSIA has also assessed the crew's handling of the emergency situation that arose after the engine failure.

The incident and the circumstances surrounding it have been investigated and analysed in line with the NSIA's framework and analysis process for systematic safety investigations (the NSIA method[1]).

Focus and delimitation of the investigation

The investigation has primarily been of a technical nature, focusing on finding possible causes of the engine failure. In order to delimit the investigation, the NSIA has chosen not to conduct any detailed review of the design, manufacture or type certification, or of any organisational factors relating to maintenance or regulatory/surveillance aspects.

Organisational factors at the flight school have also not been a subject of investigation.

Sources of information

- NF2007 Rapportering av ulykker og hendelser i sivil luftfart, from the pilot in command and Pilot Flight Academy
- NF2007 Rapportering av ulykker og hendelser i sivil luftfart, from Oslo Air Traffic Control Centre, Farris
- NF2007 Rapportering av ulykker og hendelser i sivil luftfart, from the control tower at Rygge

Examinations carried out by Flyteknisk Notodden AS, Austro Engine, the Norwegian Defence Laboratories, and the NSIA's own investigations

The investigation report

The first part of the report, 'Factual information', contains a description of the sequence of events, data and information gathered in connection with the incident, and describes the NSIA's investigations and related findings.

The second part, the 'Analysis' part, contains the NSIA's assessment of the sequence of events and contributing causes based on factual information and completed investigations/examinations. Investigations and factors found to be of little relevance to explaining and understanding the incident are not discussed in any depth.

The NSIA's conclusions are described at the end of the report.

[1] https://www.nsia.no/About-us/Methodology

1. Factual information

1. Factual information

1.1 History of flight

The description of the sequence of events is chiefly based on interviews with each crew member, data from the flight and engine instruments, and reports from the air traffic services.

The instructor and student pilot had planned to fly from Sandefjord Airport Torp (ENTO) to Karlstad Airport (ESOK) in Sweden, where the student pilot was to receive instrument approach training.

The crew took over LN-FTR, which had just landed after a two-hour flight, approximately 20 minutes before take-off. According to the aircraft's logbook, the previous flight had been completed without comment. On taking over the aircraft, the crew conducted a pre-flight inspection and completed checklists and start-up procedures. According to the crew, they found nothing out of the ordinary.

At 18:50, LN-FTR took off to the south from runway 18. The flight was conducted in accordance with the submitted IFR[2] flight plan. After take-off, the crew were given clearance by the air traffic services to set course towards the border crossing point VATEX, and to climb to 6,000 ft. The aircraft was flown by the student pilot.

When the aircraft was established at 6,000 ft, the student pilot completed the cruise checklist. Approximately 13 minutes after take-off, the aircraft was over Fredrikstad when the crew heard a bang from the engine. Immediately thereafter, the engine's propulsive power and rpm began to vary. At first, there was no indication or warning on the instrument panel other than the varying readings on the rpm indicator.

At this point, the instructor took control of the aircraft, set course for Moss Airport Rygge (ENRY) and, at the same time, informed the air traffic services that they were experiencing engine trouble. LN-FTR received clearance to head directly to Rygge.

The instructor tried to maintain engine power by adjusting the power lever, but found that the engine power continued to decrease until the engine finally stopped responding. He also attempted to switch manually between the two channels (ECU A and ECU B) in the electronic engine control system, but it was to no avail.

After a while, they were unable to maintain altitude and the instructor established best glide speed. Two minutes after the situation had arisen, both engine control system channels warned of faults. The engine then stopped completely so that the propeller stopped turning, and the low oil pressure warning light illuminated. The instructor made a total of four attempts to restart the engine, which proved impossible.

When the engine failed to start, the crew issued a mayday call. The air traffic services acknowledged receipt and informed them that the control tower at Rygge would try to establish visual contact with LN-FTR.

When the propeller had stopped, the crew considered that there was little chance of reaching Rygge, and that they would therefore have to land in one of the fields below.

Just after registering the engine trouble, the instructor had spotted a field that he considered suitable for a forced landing. When they got closer, they observed high-voltage cables spanning

[2] IFR flying – flying in accordance with instrument flight rules.

over the first part of the field (see Figure 1). With a view to getting rid of surplus altitude, and also to check for better landing options in the close vicinity, the instructor performed a 360° turn. He assessed the originally spotted field as the best option and continued the approach in that direction.

He performed the approach in such a way that there was good clearance to the high-voltage cables. He postponed setting full flaps until they had passed the cables. To further reduce the altitude after passing the power cables, he performed a series of sideslips and S-turns before landing in a north-easterly direction.[3]

Figure 1: The wheel tracks seen from the opposite direction to the landing direction. The red circles mark the high-voltage pylons that were passed before landing. Photo: NSIA

The initial ground tracks indicate a soft landing. The landing roll was approximately 150 metres before the aircraft stopped in the field, not far from Råde Church, at a distance of 80 metres from a road that divided the field (see Figure 2).

Once the aircraft had stopped, the crew made contact with the air traffic services by radio. They stated that they had performed a forced landing and that both crew members were safe and sound. They then completed the shutdown checklist and evacuated the aircraft.

Police and ambulance vehicles arrived soon after the aircraft had landed.

[3] Data from the flight instruments indicate varying wind directions during the approach to the field. Immediately before landing, a registered downwind component of approximately 5 kt was registered.

Figure 2: LN-FTR after the forced landing. Råde Church in the background, to the right of the aircraft. Photo: NSIA

1.2 Injuries to persons

Table 2: Injuries to persons

Injuries	Crew	Passengers	Others
Dead			
Serious			
Minor/none	2		

1.3 Damage to aircraft

The aircraft did not sustain any damage in the forced landing. The damage to the engine is described in more detail in section 1.16.

1.4 Other damage

Landing gear impressions in the field.

1.5 Personnel information

The pilot in command was 26 years old, held a CPL (A) commercial pilot's licence, with valid instructor and instrument ratings. At the time of the incident, he had been employed as an instructor by Pilot Flight Academy for 1½ years.

The pilot in command had had a rest period of 15 hours before reporting for duty.

Table 3: Flying hours, commander

Flying hours	All types	Relevant type
Last 24 hours	3	3
Last 90 days	112	112
Total	794	582

The student pilot was 22 years old and was undergoing an integrated CPL (A) course. He had a total of 138 hours of flight time, including 113 hours on the relevant aircraft type.

The student pilot had had a rest period of 14 hours before reporting for duty.

1.6 Aircraft information

1.6.1 GENERAL FACTS ABOUT DIAMOND DA 40

Diamond DA 40 is a single-engine four seater aeroplane with fixed landing gear. The type is low-winged with a T-tail. The structure is mainly made up of glass and carbon fibre-based composite materials. The are several different type variants. They are equipped with either petrol or diesel-fuelled piston engines. According to Diamond Aircraft Industries, as of 2019, they had manufactured more than 2,240 aircraft of all variants at their factories in Canada, China and Austria.

1.6.2 THE DIAMOND DA 40 NG TYPE VARIANT

The DA 40 NG type variant (see Figure 3) has a maximum take-off weight (MTOW) of up to 1,310 kg.

The DA 40 NG was initially issued with an EASA type certificate; see TCDS EASA.A.022 Issue 9, dated 8 April 2010. The variant was granted a type certificate in accordance with the design provisions in JAR 23, including Amendment 1, and additional specifications in the form of eight Certification Review Items (CRI), of which four concerned the engine. The DA 40 NG is equipped with an Austro Engine E4-A diesel engine and an MTV 6 R/190 69 propeller manufactured by MT-propeller Entwicklung GmbH.

From 15 November 2017, design responsibility for the aircraft type was transferred from Diamond Aircraft Industries GmbH (Austria) and EASA, to Diamond Aircraft Industries Inc. (Canada) and Transport Canada. Hence the type certificate is now held by Diamond Aircraft Industries Inc. (Canada), and Transport Canada is the authority responsible for type certification and follow-up of continued airworthiness.

Figure 3: The Diamond DA 40 NG. Photo: Diamond Aircraft Industries

1.6.3 AUSTRO ENGINE E4

The DA 40 NG is fitted out with a liquid-cooled, four-cylinder, four-stroke diesel engine of the type Austro Engine E4-A.[4] The maximum power output is 123.5 kW (168 hp). The flight manual specifies use of the same type of fuel as for turbine engines (jet fuel), but automotive diesel fuel can also be used.

The engine has direct fuel injection and is turbocharged. An electronic engine control unit (EECU), neccesitates only one engine control lever in the cockpit. Both engine power and propeller pitch are adjusted using the same lever. The engine control system consists of two identical control units or channels: ECU A and ECU B. The EECU alternates between these units for engine control each time the engine is started. The redundant unit monitors sensor values and provides back-up should the active unit fail. The switch takes place automatically, but the system can also be overridden by the pilot, who can select control unit manually.

The engine has double overhead camshafts driven by the crankshaft via several gear wheels and a timing chain. Each cylinder has two intake valves and two exhaust valves. Synchronisation of the valves' opening and closing sequences with the pistons' work cycles depends on the positions of a crankshaft chain wheel relative to a camshaft drive wheel, and to an intake camshaft gear and an exhaust gear in relation to each other. This timing is purely mechanical and cannot be adjusted without taking the engine apart.

The Austro Engine E4-A is a modified version of the Mercedes-Benz car engine produced in Austria. It has been granted an EASA type certificate. See TCDS EASA.E.200 for further specifications and limitations.

1.6.4 PROPELLER

The DA 40 NG is fitted out with a three bladed MTV 6 R/190 69 propeller manufactured by MT-Propeller Entwicklung GmbH. The propeller is connected to the engine via a gearbox that reduces

[4] *The engine is marketed as Austro Engine AE 300.*

rpm for the propeller with a ratio of 1:1.69. The propeller has a hydraulically operated variable pitch, which is automatically adjusted to the rpm (constant speed). See TCDS EASA.P.094 for further specifications and limitations.

1.6.5 LN-FTR

1.6.5.1 The aircraft

LN-FTR is a model DA 40 NG. The aircraft was new when it was entered in the Norwegian Civil Aircraft Register on 8 February 2016. It was put into operation by Pilot Flight Academy the same year. LN-FTR had a Garmin 1000 EFIS "glass cockpit".

Table 4: Specifications for LN-FTR

Year of manufacture:	2016
Serial number:	NG 40.N305
Maximum take-off weight:	1,310 kg.
Estimated weight when the incident occurred:	1,200 kg.
Engine type:	Austro Engine E4-A
Fuel:	Jet A1
Fuel capacity:	155.2 litres
Reported fuel volume before take-off:	115 litres
Best glide ratio on loss of engine power:	1:9.7

At the time of the incident, the aircraft had a valid Certificate of Airworthiness and an Airworthiness Review Certificate (ARC) valid until 10 February 2018. According to the aircraft log, the aircraft had a total flight time of 1,073:25 hours. The next scheduled maintenance inspection was due at 1,100 hours.

1.6.5.2 Engine

The engine, serial number E4-A-00380, was manufactured in 2015. It was new when it was installed in LN-FTR. According to the logbook, engine run time was the same as the aircraft's flight hours, i.e. 1073:25 hours. NSIA's review of the documents has indicated that all prescribed maintenance and service bulletins had been completed with, and within applicable deadlines.

There were no remarks in the engine's technical logbook concerning problems requiring troubleshooting before spring 2017. On 24 May 2017, the cooling system's expansion tank was replaced in response to a remark on coolant leakage.

1.6.5.3 Replacement of the engine's cylinder head

Since the coolant leakage problem continued after the replacement of the expansion tank, the repair shop[5] suspected the presence of cracks in the cooling liquid channels in the cylinder head. It therefore replaced the cylinder head and pertaining gaskets. The descriptions in Austro Engine Maintenance Manual E4, Revision no. 27 dated 23 February 2017, was used as the basis for this work.

To replace the cylinder head, it is necessary to dismantle the camshafts and remove the timing chain. When these are reinstalled, it is important to ensure that both the camshafts and the

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[5] The repair shop Flyteknisk Notodden was the appointed maintenance organisation for aircraft operated by Pilot Flight Academy (see section 1.17).

crankshaft are correctly mounted in relation to each other. Before the timing chain is put into place, the crankshaft must be in the top dead centre position for piston 1, while the camshaft gear wheels must be correctly positioned in relation to each other as well as in relation to the crankshaft. Among other things, a special tool must be used to lock the camshaft drives in the correct position (see Figure 4). Misalignment of the wheels and timing chain will cause the opening and closing of the valves to be incorrectly synchronised with the piston movements.

It was the first time the aircraft technician replaced cylinder head on this engine type.[6] He told the NSIA that he had been careful to ensure that the wheels and timing chain were correctly aligned and that he had verified that this was the case. He had also ensured double verification by two of his colleagues.

Test runs of the engine were conducted both before and after replacement of the cylinder head. The EECU data from both test runs were sent to Austro Engine, and did not lead to any comment. The aircraft was then put into operation on 20 June 2017, the day before the incident. From that time until the final take-off before the incident occurred, four flights had been logged with an aggregate duration of 5:30 flight hours, exclusive of block time and other engine operation on the ground. According to information from Flyteknisk Notodden, the data log showed a total engine run time of 7.75 hours from the time the cylinder head was replaced up until the forced landing.

The aircraft log was without any remarks after a total of four flights conducted after replacement of the cylinder head.

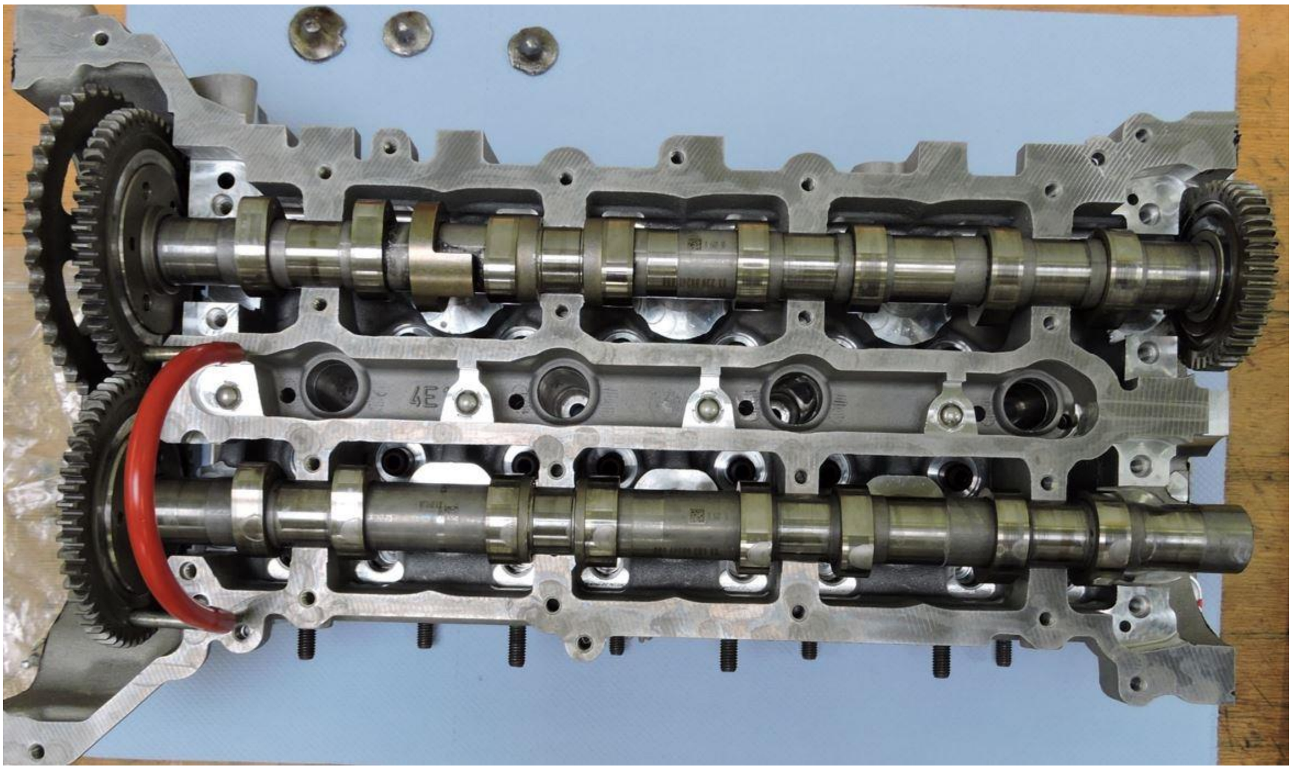

Figure 4: The camshaft gear locked in the correct position using a special tool (with a red plastic handle). The timing chain is to be connected to the camshaft drive wheel on the outside of the intake camshaft gear. Photo: Austrian Civil Aviation Safety Investigation Authority

[6] The aircraft technician held a valid aircraft technician certificate and had experience of the aircraft type. He had completed type courses on the DA20, DA40, DA42 and DA62 series in 2014.

1.7 Weather

A moderate south-westerly breeze and no clouds were reported for the area at the time of the incident. There was daylight and good visibility. The temperature was 16 °C and the barometric pressure was 1,012 hPa.

Weather observations from Sandefjord Airport Torp at 19:20:

METAR ENTO 211720Z 20010KT CAVOK 16/08 Q1011=

Weather observations from Moss Airport Rygge at 19:20:

METAR ENRY 211720Z 19011KT 160V230 CAVOK 16/08 Q1012=

1.8 Aids to navigation

Not relevant.

1.9 Communications

The crew on board LN-FTR followed an IFR flight plan and had established communication with Oslo Air Traffic Control Centre (Farris Approach) before the engine trouble occurred. This contact was maintained until the aircraft had landed. The air traffic control centre coordinated with the control tower at Rygge (ENRY), which ensured that the airport's fire and rescue service was ready to respond, and observed the aircraft on the radar. When it became clear that LN-FTR would not make it to Rygge, Farris notified the emergency response services.

In connection with the forced landing, the crew activated the emergency locator transmitter manually, and set the code for emergency on the aircraft's transponder. This was observed on the radar.

After landing, the crew notified by radio that the plane had landed and that the two crew members were unharmed. The message was received by Farris, but Rygge did not hear it. Farris acknowledged receipt of the message, but the LN-FTR crew had difficulties understanding what was being said because of poor radio coverage. Other aircraft also heard the message from LN-FTR and relayed it to Farris. The problems encountered when trying to maintain communication after landing have been ascribed to poor radio coverage at the landing site.

When radio communication did not work as intended after landing, the pilot in command called Oslo Air Traffic Control Centre to re-report on the status of the aircraft and crew.

1.10 Aerodrome information

Not relevant.

1.11 Flight recorders

There was no ordinary cockpit voice recorder (CVR) or flight data recorder (FDR) in LN-FTR. Nor are there any requirements for this aircraft category to carry such equipment.

However, the NSIA has been given access to other data from the flight that have been useful during the investigation:

- The entire flight had been stored in the flight academy's CloudAhoy, a system for analysing flights on the basis of stored data from the flight instruments (Garmin 1000 EFIS).
- Data from a number of different engine parameters stored in the EECU showed values whereby it was possible to map engine performance. The graphs in Figure 5 show four engine parameters from the incident. The four parameters are: propeller rpm, power lever position (in % of full throttle), atmospheric pressure (hPa) and manifold pressure (hPa). The engine trouble started with a marked drop in manifold pressure at the same time as propeller rpm started to fluctuate, before the engine stopped completely.

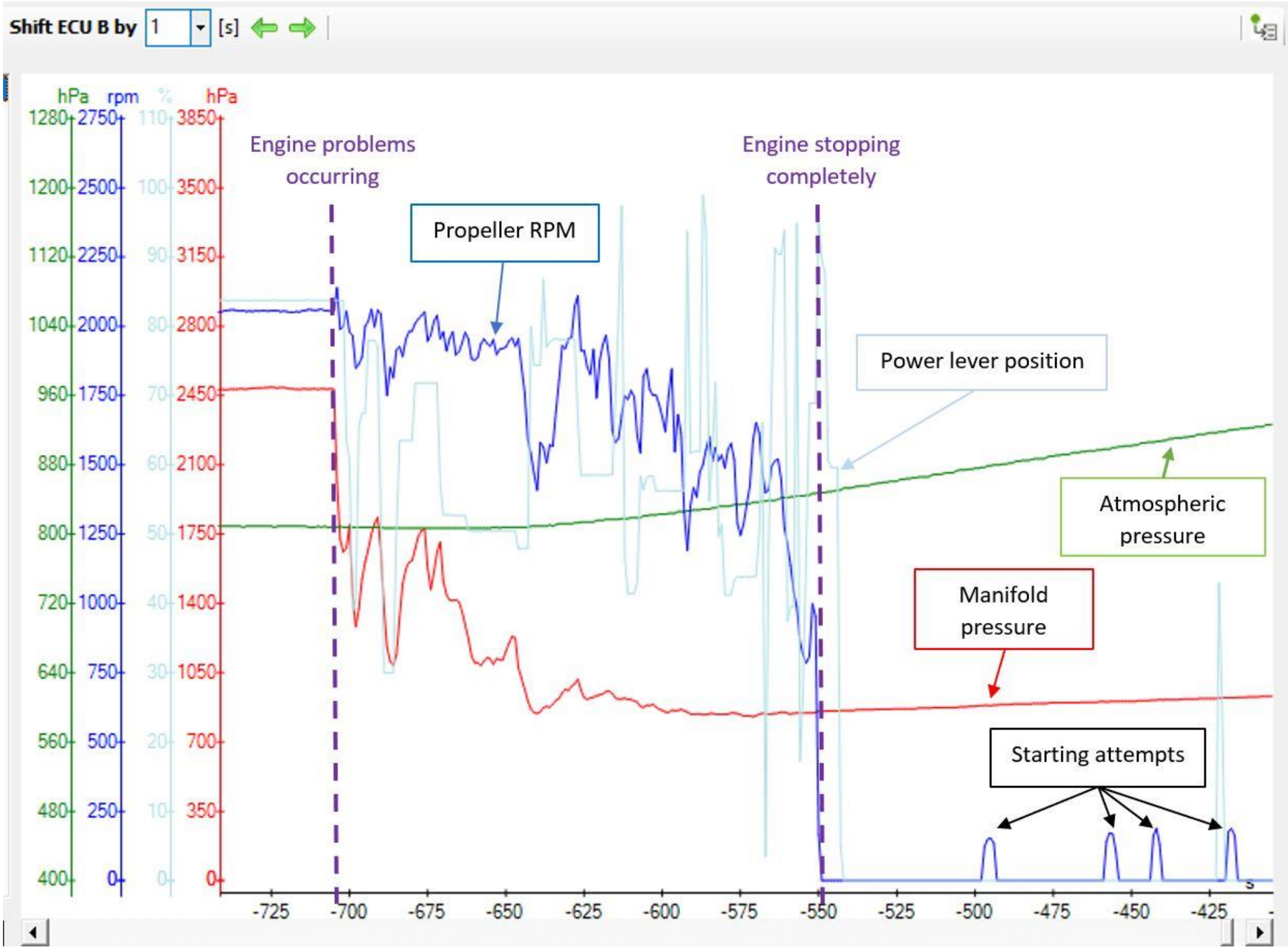

Figure 5: Engine data from the incident involving LN-FTR. The graphs were produced using Austro Engine AE300 Wizard. Illustration: NSIA

It has not been possible, on the basis of the engine parameters in the data log, to determine whether or not the crankshaft/camshaft timing was correct. After the LN-FTR incident, Austro Engine has made changes to AE300 Wizard, the software for analysing EECU data, whereby it should be possible to diagnose faulty timing. In connection with the work on the NSIA's investigation report, the manufacturer stated that work was in progress to further develop this tool to ensure that timing faults could be even more easily detected.

1.12 Landing site and aircraft

Figure 6 shows a map section with indication of the approach direction, touch-down point and stop point for the aircraft after it landed. The landing roll was slightly uphill. The field's surface was relatively soft, and the final part of the rollout left deep wheel tracks (see Figure 7).

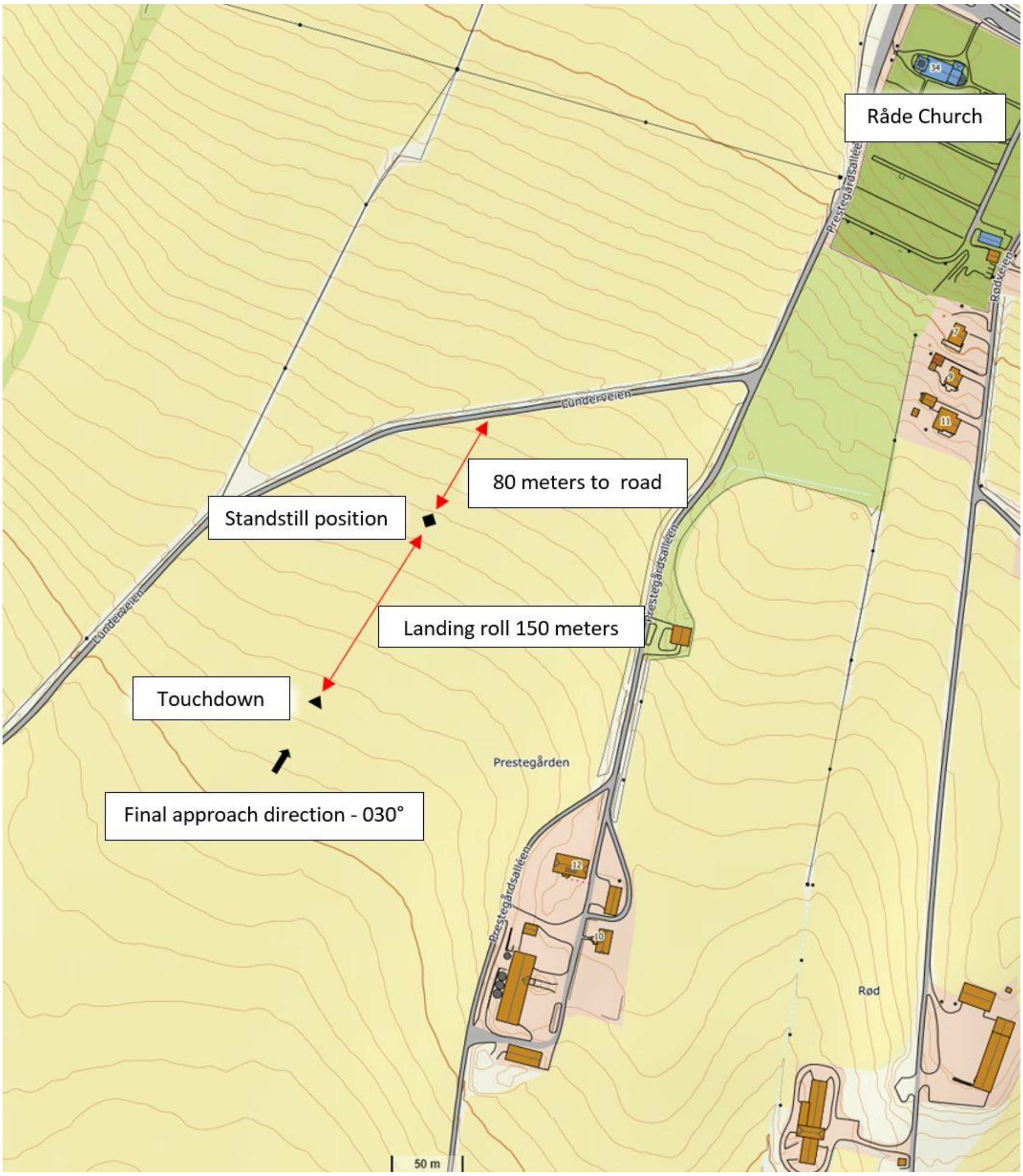

Figure 6: Map section showing the landing site, marked in accordance with the NSIA's measurements. Map: © Norwegian Mapping Authority. Markings: NSIA

Figure 7: Deep tracks in the surface from the left main wheel. Photo: NSIA

In addition to surveying and measuring the landing site, the NSIA conducted an initial examination of the aircraft.

There were no signs of external damage to the aircraft. The engine compartment was clean and dry, but leaked oil was observed on the nosewheel leg and around the vent pipe from the oil drain collector. The engine oil gauge indicated that the level was approximately half-way between the MIN and MAX marks.

The NSIA also took oil and fuel samples that were sent to the Norwegian Defence Laboratories for further analysis. The analysis results are described in more detail in section 1.16.

The aircraft was then disassembled and sealed by the NSIA before it was transported to Flyteknisk Notodden. Before the wings were removed, 110 litres of fuel was removed from the aircraft's tanks.

Section 1.16 contains a description of the NSIA's technical examinations of the aircraft.

1.13 Medical and pathological information

Not relevant.

1.14 Fire

No fire occurred in connection with the forced landing. Nor were there any signs of fire or incipient fire in the engine compartment. One eyewitness reported seeing white smoke emanating from the aircraft before the forced landing, however.

1.15 Survival aspects

The incident occurred in an area with several suitable forced landing options. The landing took place in a relatively open and level field. It was almost like a normal landing. The aircraft was undamaged and positioned as normal on the landing gear when it stopped. Since there was no fire, the crew had ample time to leave the aircraft in the normal manner.

1.16 Tests and research

1.16.1 EXAMINATIONS BY FLYTEKNISK NOTODDEN AS

The first examinations of the engine were carried out at Flyteknisk Notodden AS, the aircraft's maintenance organisation, under the leadership of two investigators from the NSIA. A representative of Austro Engine, the engine manufacturer, was also present. Before the work started, it was verified that the NSIA seal around the aircraft was intact (see section 1.12).

- The engine contained six litres of engine oil. The MIN mark on the engine oil gauge stick corresponds to 5 litres, while the MAX mark corresponds to 7 litres. It was found that there was some leakage from the drain collector. Traces of oil were also found from the intake part of the engine's cylinder head (see Figure 10). Furthermore, a significant quantity of metal chips was found in the oil filter.
- The turbocharger exhaust section contained remnants of burnt cooling liquid.
- The fuel injection nozzle for cylinder 1 was broken. The other three nozzles appeared to be intact.
- The glow plug for cylinder 1 was broken. The other three glow plugs were intact.
- The alignment marks on the camshaft gear wheels showed that they were correctly positioned in relation to each other (see Figure 8). By mistake, the crankshaft position was not measured before the chain was removed.
- The rocker arm for the forward exhaust valve in cylinder 1 was broken.
- The chain tensioner was tensioned and appeared to be intact.
- After removal of the cylinder head, the piston crown in cylinder 1 was found to have been completely destroyed. Parts of a broken valve protruded from the piston crown. Part of the piston rod was visible through a hole in the piston (see Figure 9). Three of four valve stems were broken.
- The other pistons were also damaged with scars, notches and pits after impact with jagged foreign objects. Metal fragments were found on the crowns of these pistons, mostly in cylinder 2, but with decreasing amounts in cylinders 3 and 4, respectively (see Figure 9).
- Imprints from the exhaust valves could be observed in the three pistons crowns that had not been completely destroyed.
- The cylinder head had sustained damage corresponding to that on the piston crowns. The most extensive damage was found in cylinder 1 (see Figure 10).
- All bolts were in place and tightened. The torque with which they had been tightened was not measured, however.

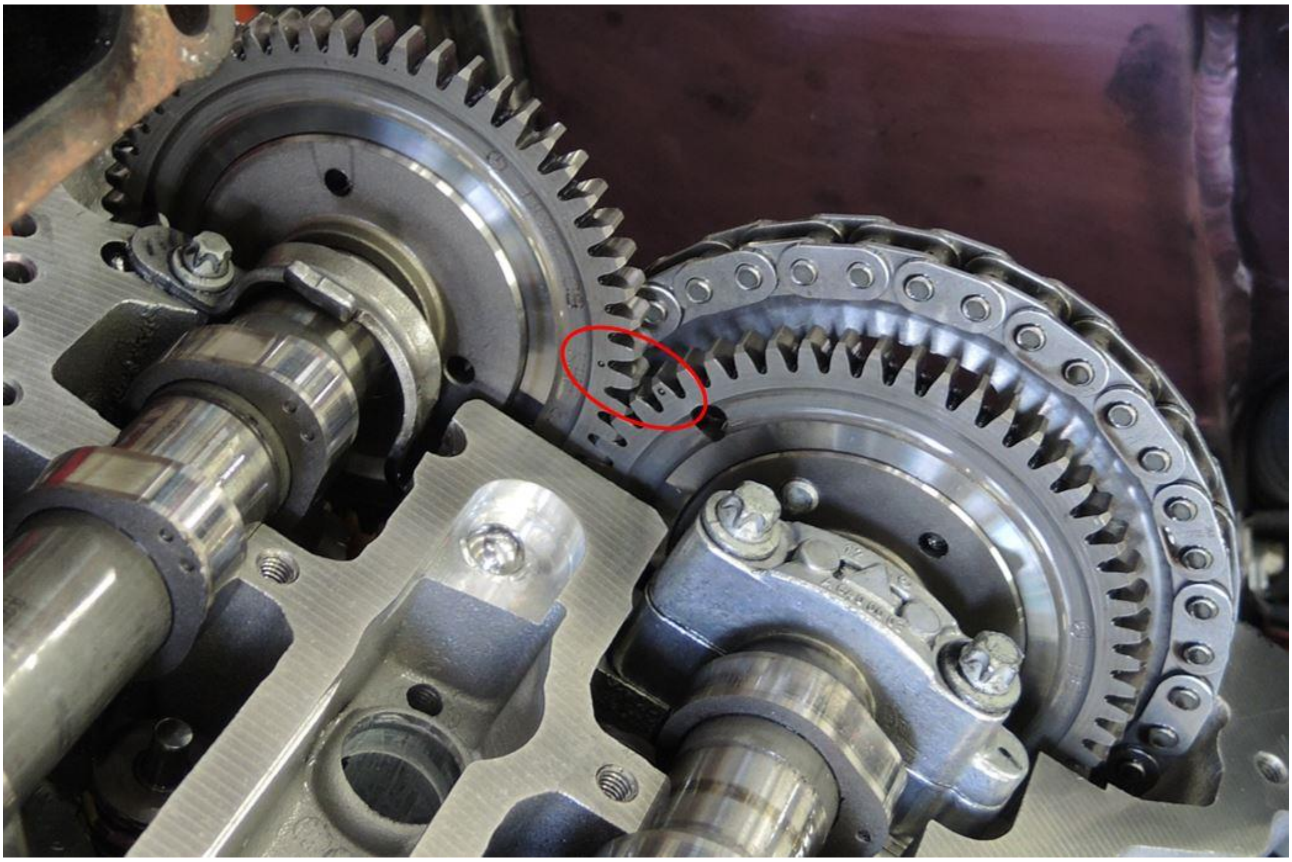

Figure 8: The photo shows that the camshaft gear wheels were correctly positioned in relation to each other. The red circle marks the alignment marks on the wheels. Photo: NSIA

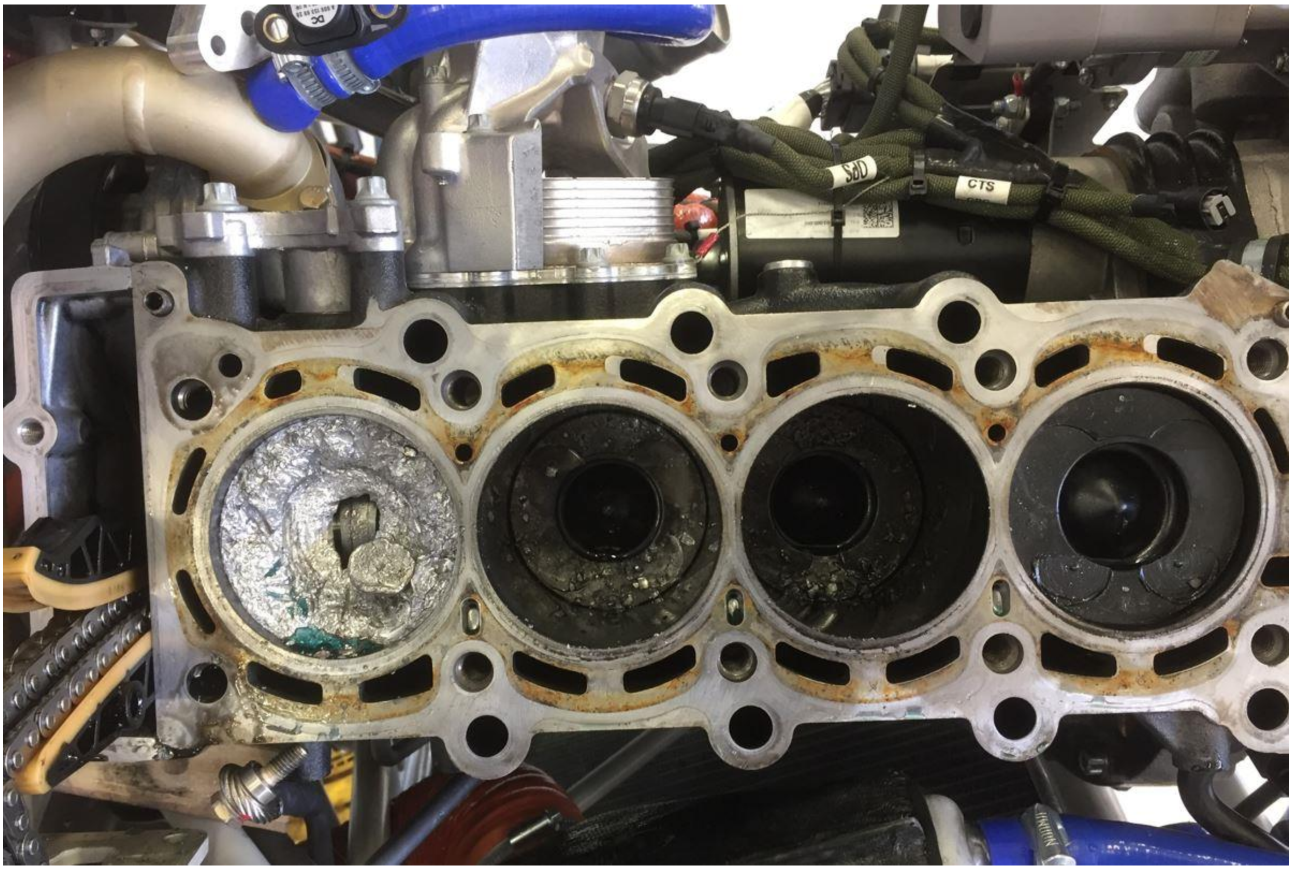

Figure 9: The engine's piston crowns. Cylinder 1 can be seen on the far left. The top of the piston rod (grey in colour) can be seen in the hole near the centre of piston 1. A broken exhaust valve is lodged in the piston. Coolant residue (turquoise in colour) can be seen on the piston crown. Photo: NSIA

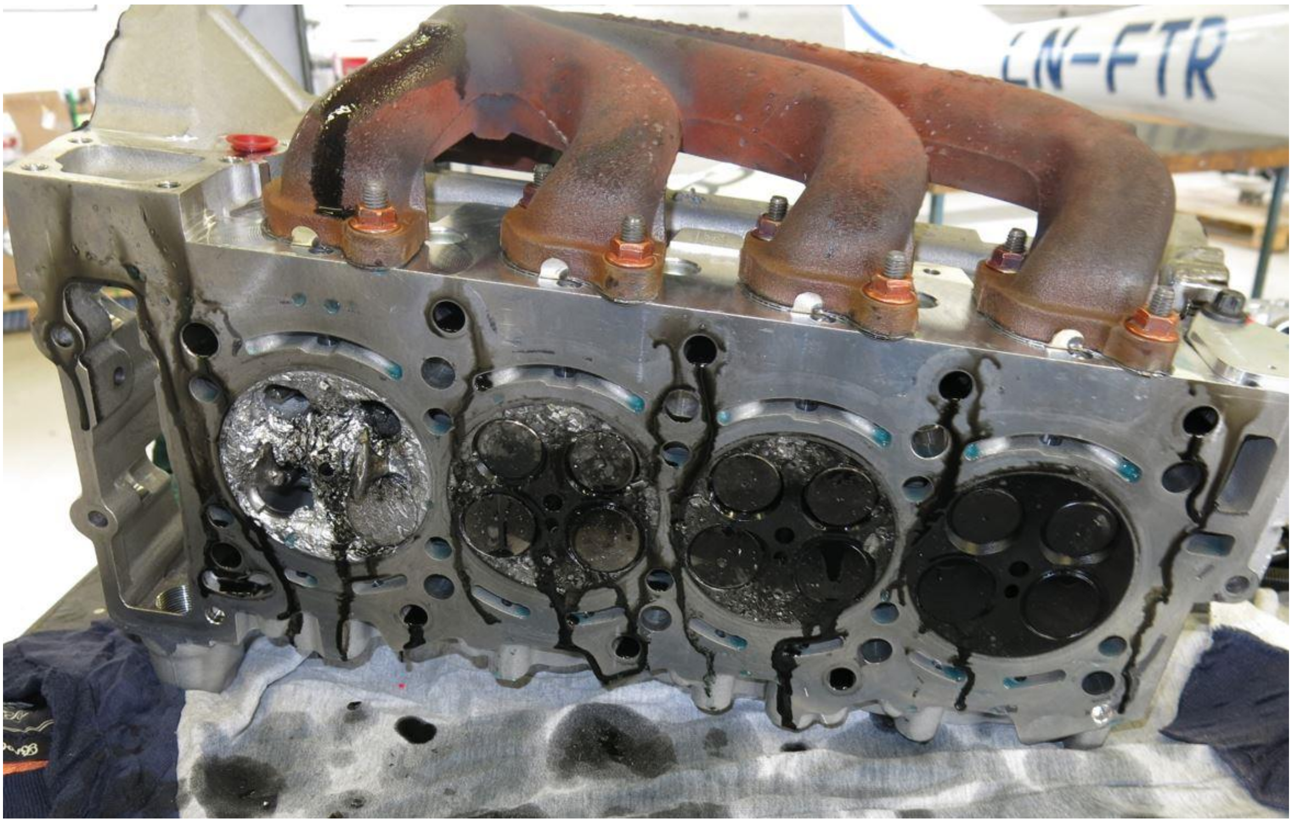

Figure 10: The engine's cylinder head. Cylinder 1 can be seen on the far left. Two valves had been knocked into the metalwork and one intake valve was found to be in the closed position. The photo shows that cylinder 4, on the far right, was the least damaged. Photo: NSIA

1.16.2 EXAMINATIONS AT AUSTRO ENGINE'S FACTORY IN AUSTRIA

After the examinations at Flyteknisk Notodden, the engine was removed the aircraft. It was packed in a transport box, which was sealed and sent to the engine factory in Austria for further examination. The seal was intact when the NSIA's investigator arrived at the factory.

The examinations at the factory were led by an NSIA investigator, assisted by an accredited representative from the Austrian investigating authority. In addition to an investigation team from Austro Engine, a representative of MBtech in Germany also took part.

Extensive examinations of the engine were carried out. These examinations resulted in a 136-page report from Austro Engine. In the report, Austro Engine concluded that the engine failure was a consequence of serious damage to cylinder 1, and to the other cylinders' exhaust valves. Metal fragments from cylinder 1 had probably spread to the other cylinders via the intake manifold. As the valves were being damaged, compression was reduced and combustion stopped. According to the report, increased friction in connection with the destruction of cylinder 1 probably contributed to the engine eventually stopping.

The underside (inside) of each piston was also examined. The Austro Engine report contained the following statement about the condition of piston 1: *"Slight engine oil varnish in the residues of the cavity as an indication for low thermal load on the piston".*

Austro Engine concluded that the engine damage was a consequence of incorrect timing, whereby the exhaust valves were not closed when the pistons reached the top dead centre position. Austro Engine pointed out that there is very little clearance between the valves and piston crown to start with. This means that a minor fault in the timing is enough to create physical contact; the piston crowns knock into the valves and thereby damage both pistons and valves.

According to the manufacturer, the incorrect timing theory was supported by findings in the form of three broken and one bent valve stem in cylinder 1, and bent exhaust valve stems in cylinders 2, 3 and 4. Reference was also made to the valve imprints on the piston crowns in cylinders 2, 3 and 4. Figure 11 shows bent valve stems, while Figure 12 shows exhaust valve imprints on piston crown 4.

The manufacturer also believed that the camshaft may have been twisted while the engine was running. That would have increased the timing error closest to the camshaft gear, which could in turn explain why cylinder 1 sustained the greatest damage.

Since the camshaft and timing chain had not been removed previously, the timing fault was seen as having to do with the replacement of the cylinder head shortly before the incident occurred. Signs were found that, according to Austro Engine, could indicate that relatively strong force was applied to reinstall the timing chain after replacement of the cylinder head. Among other things, the locking tool had left marks on the metalwork (see Figure 13).

Marks were also found on the dowel pin for alignment of the camshaft drive wheel, suggesting that it may have been necessary to apply force to get it into place. The timing chain was otherwise found to be of normal length and wear.

According to Austro Engine, the engine could have continued running even if incorrectly timed. The EECU would probably have partially compensated for the valves being opened and closed at the wrong times, which may have made it difficult to discover the faulty timing. Austro Engine assumed in its report, however, that the engine had only run for one hour after the replacement of the cylinder head when it failed. This does not tally with the NSIA's information about engine run time (see section 1.6.5.3).

Figure 11: Exhaust valves from cylinders 2 and 3 with bent stems. Photo: NSIA

Figure 12: Imprints in piston crown 4 after impact with both exhaust valves (lower part of photo). Photo: Austrian Civil Aviation Safety Investigation Authority

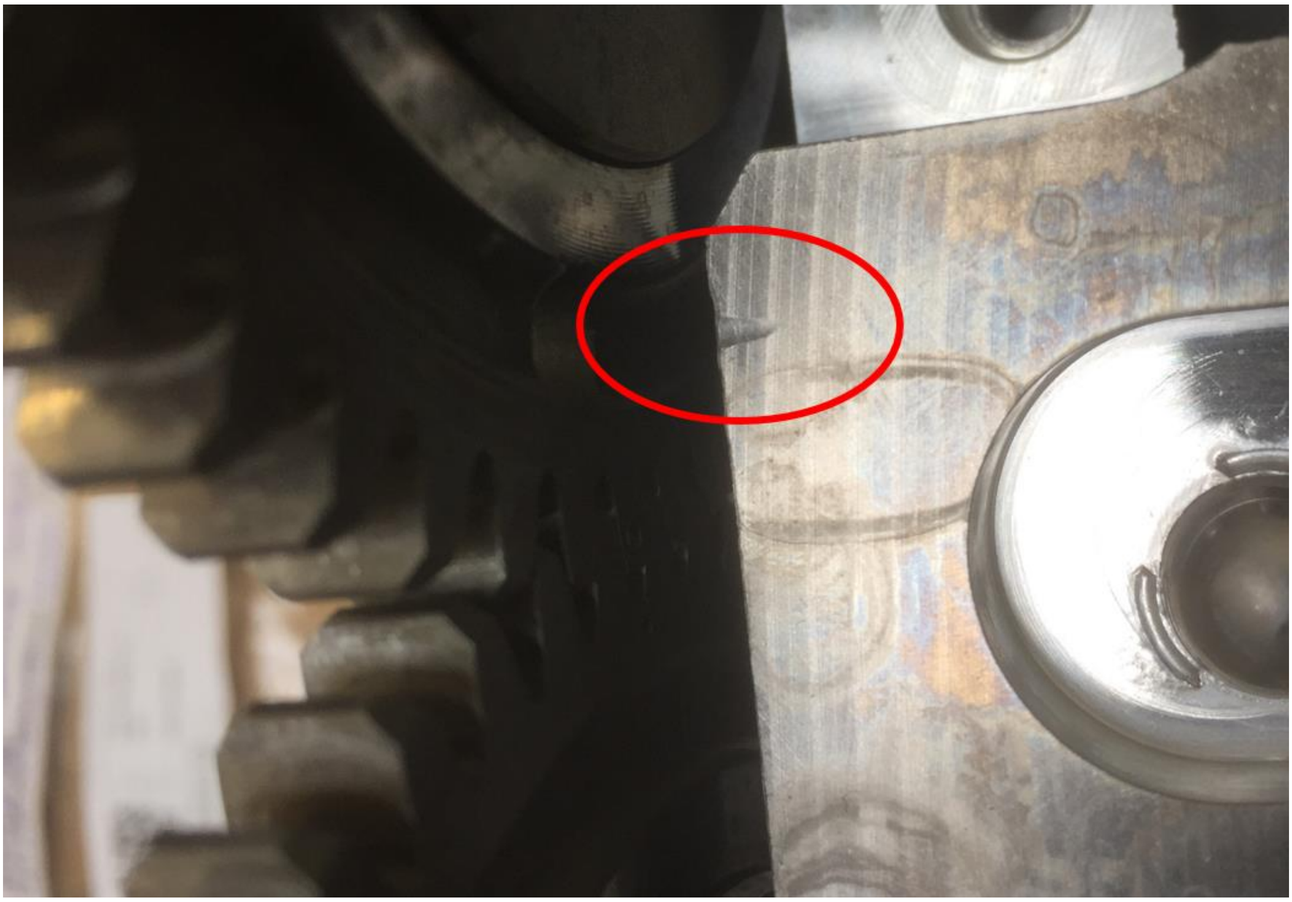

Figure 13: Marks left by the camshaft locking tool. Photo: NSIA

1.16.3 CHEMICAL ANALYSES OF ENGINE OIL, GEAR OIL AND FUEL

The Norwegian Defence Laboratories analysed the oil and fuel samples from LN-FTR.

The analysis of the engine oil (Aeroshell Diesel Ultra 5W40) showed that it contained large quantities of iron, aluminium and zinc. The results of the oil analysis were as expected, given the damage to the engine.

The oil from the propeller reduction gear (Shell Spirax S6 GXME 75W-80) had no significant contamination.

The fuel analysis showed that it was Jet A-1 fuel which met the applicable quality specifications.

1.16.4 ADDITIONAL INVESTIGATIONS AT PILOT FLIGHT ACADEMY AT TORP

At one stage during the investigation, there was a need to check whether it was possible to install the timing chain with one tooth displacement even if the camwheels and crankshaft were locked in the correct position. Pilot Flight Academy made an E4 aircraft engine available to the NSIA. Based on the tests that were carried out, it appeared to be impossible to install the timing chain incorrectly without visibly moving the crankshaft or camshaft out of position.

1.17 Organisational and management information

Flyteknisk Notodden was the appointed maintenance organisation for aircraft operated by Pilot Flight Academy. The repair shop held EASA Part 145 approval covering the relevant aircraft type.

In this investigation, the NSIA has chosen to not review organisational factors relating to the operator or maintenance organisation in any detail.

1.18 Additional information

1.18.1 THE THEORY THAT THE DAMAGE TO CYLINDER 1 OCCURRED FOR OTHER REASONS

Following the examinations at Austro Engine, Flyteknisk Notodden was presented with the results and the theory that the timing chain had been incorrectly installed after the replacement of the cylinder head. The repair shop found the theory somewhat doubtful and pointed out the following:

- The timing chain was reinstalled by qualified personnel who were aware of the importance of doing this correctly.
- Several technicians had verified that the timing chain was correctly installed.
- Data from test runs of the engine both before and after the cylinder head replacement had been sent to Austro Engine, which had not had any objections to putting the engine back into operation.
- How could any faulty timing possibly go unnoticed during trial runs of the engine after the cylinder head replacement? Displacement of the chain by only one tooth would have caused rotational deviations between the crankshaft and camshaft of almost 20°. Given such a wide deviation, vibrations and uneven operation would be expected, in addition to poorer performance.
- The engine operated for a relatively high number of hours after the cylinder head replacement, without anyone noticing anything out of the ordinary in the form of vibrations or reduced performance.

It may therefore be pertinent to ask whether the damage to cylinder 1 was caused by factors other than incorrect installation of the timing chain.

1.19 Useful and efficient investigation methods

No methods warranting special mention have been used in this investigation.

2. Analysis

2. Analysis

2.1 Introduction

The NSIA's analysis of the incident is in four parts. The first part considers how the engine failure was dealt with from a flight operations viewpoint, including how the forced landing was performed. This is followed by discussions of two different theories relating to the origin of the damage to cylinder 1: incorrect installation of the timing chain, or local damage caused by other factors. These theories are then assessed in the fourth part.

2.2 The forced landing

The crew received no prior warning before they heard the bang from the engine at an altitude of 6,000 ft over Fredrikstad and started to experience uncontrolled variations in engine power and rpm. Initially, there were no other indications or fault warnings that could help identify the problem.

The pilot in command's account of the engine trouble tallies well with the data from the electronic engine log (see section 1.11). Though he tried his best to keep the engine running, the investigation has shown that there was in fact nothing he could have done to prevent the engine from stopping.[7]

The NSIA has estimated that a direct glide from an altitude of 6,000 ft at Fredrikstad to the threshold of runway 30 at Rygge would have required a glide ratio better than 1:11 and no headwind. Factors such as partial engine power to start with and varying wind directions and wind speeds make it impossible for the NSIA to ascertain whether LN-FTR could theoretically have made it all the way to Rygge.

Had the crew attempted to reach the airport and not succeeded, they would have run the risk of ending up at low altitude over an area with much fewer suitable landing sites. Such an attempt could easily have resulted in an accident. The NSIA is therefore of the opinion that it was a good decision by the pilot in command to resist the temptation to aim for Rygge, and instead choose a suitable field for a forced landing that more closely resembled a normal approach and landing.

The air traffic services made a positive contribution by following up LN-FTR, and by notifying the emergency services.

2.3 The theory that the timing chain was incorrectly installed

If, in connection with changing the cylinder head, the timing chain was mistakenly reinstalled with 'one tooth slack', the closing of the exhaust valves would have been delayed by 20°. The relatively uniform exhaust valve imprints on the three piston crowns that remained intact support this theory.

It is conceivable that the impact forces on the piston crowns, valves and valve stems was reduced, though most likely not eliminated, as the engine was 'wearing in'. That can explain why the valves and piston crown in cylinder 1 eventually failed.

In the NSIA's opinion, the pattern of the engine damage is compatible with faulty timing. It must also be taken into account that, according to Austro Engine, it is possible to start and operate an incorrectly timed engine.

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[7] The smoke observed by the witness on the ground (see section 1.14) was probably burnt cooling liquid and/or oil emanating from the exhaust pipe via the engine's turbocharger (see section 1.16.1 second bullet point).

One conceivable reason why poor engine performance was not registered is compensation on the part of the EECU in the form of adjusted fuel metering and adjustment of the propeller pitch, which would have camouflaged the timing fault. The NSIA finds it remarkable nonetheless that the engine continued to run for so long without anything out of the ordinary being registered.

The investigation has shown that it was probably not possible to install the timing chain incorrectly without misaligning the camshaft drives and crankshaft, something that the alignment marks would have shown to be the case. This would probably not have been overlooked by the technicians had they checked and double-checked as they have explained.

2.4 The theory that damage occurred locally in cylinder 1

It is also conceivable that the damage to cylinder 1 occurred locally for other reasons. For example, the failure of a valve, glow plug or injection nozzle may have given rise to a cascading failure leading to the destruction of the piston and valves and finally to engine failure.

Just as in the case of faulty timing, metal fragments from cylinder 1 may have spread to the other cylinders via the intake manifold. If the origin of the fault was failure of an injection nozzle, it is also conceivable that the piston crown was damaged as a consequence of a changed combustion pattern and/or detonation. If so, the indication of low thermal load on the piston (see chapter 1.16.2) imply that this did probably not lead to any extensive or prolonged overheating of the piston.

This theory is perhaps a more likely explanation of why no strong vibrations were registered when the engine was first started after the cylinder head replacement and, not least, of how the engine was able to run for so long without anything out of the ordinary being registered.

It goes against this theory that the exhaust valve imprints in cylinders 2, 3 and 4 were relatively similar.[8] That seems more likely in a case of faulty timing. However, it cannot be completely excluded that the camshaft was twisted as a result of resistance in the valve mechanisms, if the valve stems were bent and jammed as a result of metal fragments from cylinder 1.

2.5 Assessment of the theories

Like Austro Engine, the NSIA believes that the engine failure was a consequence of serious damage to cylinder 1, and to the exhaust valves in the other cylinders. As the valves were being damaged, compression was reduced and combustion stopped. In addition, increased friction in connection with the destruction of cylinder 1 probably contributed to the engine eventually stopping.

The origin of the damage to cylinder 1 can likely be ascribed to one of the two theories described in sections 2.3 and 2.4. However, the investigation has not provided the NSIA with enough evidence to determine which of the two theories is most probable.

The investigation has not supported other explanations of how the damage to cylinder 1 arose.

[8] *It appears, however, that the imprints were deepest on piston crown 4.*

3. Conclusion

3. Conclusion

3.1 Main conclusion

LN-FTR experienced engine failure in flight as a consequence of significant internal engine damage. It is probable that cylinder 1 was damaged first and that the damage then spread to the remaining cylinders. The investigation indicates that the origin of the damage to cylinder 1 may have been either incorrect installation of the timing chain, or local damage caused by other factors.

The crew on board LN-FTR received no prior warning of the engine failure. In the opinion of the NSIA, the aircrew handled the emergency situation well.

3.2 Investigation results

A. LN-FTR experienced engine trouble at 6,000 ft above Fredrikstad.

B. First, the crew heard a bang. This was followed by uncontrolled variations in engine rpm together with gradual loss of engine power.

C. The crew were unable to adjust the rpm and the engine finally stopped completely.

D. The pilot in command made four unsuccessful attempts to start the engine.

E. He performed a successful forced landing.

F. The investigation has shown that the crew could neither have prevented the engine failure nor restarted the engine after it stopped.

G. The internal engine damage was extensive, particularly in cylinder 1.

H. On the day before the incident, the aircraft had left the repair shop after replacement of the engine’s cylinder head.

I. From replacement of the cylinder head up until the final take-off before the incident occurred, four flights had been logged with an aggregate duration of 5:30 flight hours, without any remarks. This flight time was exclusive of block time and other engine operation on the ground.

J. The data log from test runs before and after replacement of the cylinder head was sent to Austro Engine, and did not lead to any comment.

K. After the incident, Austro Engine has made changes to AE300 Wizard, the software for analysing EECU data, whereby it should be possible to diagnose faulty timing.

4. Safety recommendations

4. Safety recommendations

The Norwegian Safety Investigation Authority submits no safety recommendations in connection with the investigation.

Norwegian Safety Investigation Authority
Lillestrøm, 13 June 2022

Abbreviations and references

Abbreviations

ARC	Airworthiness Review Certificate
CAA-N	Civil Aviation Authority Norway
CPL (A)	Commercial Pilot's Licence (Aeroplane)
CRI	Certification Review Item – element identified for further clarification in connection with type certification
CVR	Cockpit voice recorder
EASA	European Union Aviation Safety Agency
EFIS	Electronic Flight Instrument System
EECU	Electronic Engine Control Unit
ECU	Engine Control Unit
FDR	Flight data recorder
FOLAT	Norwegian Defence Laboratories
IFR	Instrument Flying Rules
JRCC-S	Joint Rescue Coordination Centre for Southern Norway
MAX	Maximum
METAR	Weather observations for aviation
MIN	Minimum
MTOW	Max Take-Off Weight
NSIA	Norwegian Safety Investigation Authority

References

Austro Engine E4-00380_Inspection Report_r0, dated 5 October 2017

Norwegian Defence Laboratories FOLAT Report No 170927-03, dated 8 September 2017

Norwegian Defence Laboratories FOLAT Report No 170927-01, dated 12 September 2017