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Partial loss of engine power during cruise flight Robinson R44 helicopter

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The Hague, June 2014

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Source photo cover: Erwin van Hassel

Dutch Safety Board

The aim in the Netherlands is to limit the risk of accidents and incidents as much as possible. If accidents or near accidents nevertheless occur, a thorough investigation into the causes, irrespective of who are to blame, may help to prevent similar problems from occurring in the future. It is important to ensure that the investigation is carried out independently from the parties involved. This is why the Dutch Safety Board itself selects the issues it wishes to investigate, mindful of citizens' position of independence with respect to authorities and businesses. In some cases the Dutch Safety Board is required by law to conduct an investigation.

Visiting address:	Anna van Saksenlaan 50 2593 HT The Hague The Netherlands	Postal address:	PO Box 95404 2509 CK The Hague The Netherlands
Telephone:	+31 (0)70 333 7000	Fax:	+31 (0)70 333 7077
Website:	www.safetyboard.nl		

NB: This report is published in the Dutch and English languages. If there is a difference in interpretation between the Dutch and English versions, the Dutch text will prevail.

CONTENT

GENERAL

Identification number:	2012013
Classification:	Serious Incident
Date, time[1] of occurrence:	21 January 2012, 14.32 hours
Location of occurrence:	Oosterschelde, vicinity of Yerseke
Aircraft registration:	PH-WMW
Aircraft model:	Robinson R44
Type of aircraft:	Helicopter
Type of flight:	Passenger flight
Phase of operation:	Cruise
Damage to aircraft:	None
Cockpit crew:	One
Passengers:	Two
Injuries:	None
Other damage:	None
Lighting conditions:	Daylight

Figure 1: The PH-WMW, Lelystad 7 November 2010. (Source: Erwin van Hassel)

1 All times in this report are local times, unless otherwise specified.

SUMMARY

During a sightseeing flight with a Robinson R44 helicopter, the cylinder head temperature (CHT) indication failed and shortly thereafter the low rotor revolutions per minute (RPM) warning sounded. The pilot continued the flight to the destination. A precautionary landing was considered but was rejected.

The partial power loss was the result of an overheated engine, which caused the CHT indicator to fail. The probable cause of the overheating was a leaking inlet manifold rubber hose, causing an excessively lean air/fuel mixture. It was concluded that the long term use of automotive gasoline, which was permitted according to a supplemental type certificate, caused the leaking of the hose.

After landing, the rotor was inspected visually and turned manually. No abnormalities were detected. After consulting the helicopter company headquarters the decision was made by the pilot to fly the helicopter back to the company's operating base in Bergen op Zoom, a 10 minute flight over land. The return flight was uneventful. The helicopter was operating on automotive gasoline.

FACTUAL INFORMATION

General information

The pilot executed a sightseeing flight on 21 January 2012. Detailed flight instructions were delivered to the pilot by the company on 17 January 2012, four days before the actual flight. The flight consisted of three separate phases or 'legs':

- a positioning flight from the operating base in Bergen op Zoom to Kruiningen,
- a sightseeing tour with two passengers starting and ending in Kruiningen and
- a return flight to the base in Bergen op Zoom.

Flight preparation

The pilot arrived at Heliport Bergen op Zoom at 12:30 hours where the ground operations manager was present to assist him with the flight preparation. Pre-flight checks included checking the KNMI[2]-weather forecast and relevant Notices to Airmen (NOTAMs). The helicopter pre flight check (to check the critical elements of the helicopter before start-up) was done inside the hangar, the ground operations manager assisted in filling the fuel tanks with automotive gasoline and adding engine oil.

At approximately 13:00 hours the pilot started the engine of the helicopter. It took three start sequences to achieve this.

Flight execution

Positioning flight from Bergen op Zoom to Kruiningen.
Before the flight started, the pilot checked the maximum available manifold air pressure (MAP) to be 23,5 inches Hg.[3] After conducting a short hover flight to verify power available and instruments functioning, the pilot took off in the direction of Kruiningen at around 13:03 hours. At the cruising altitude of 500 feet above mean sea level (MSL), radio contact was established with Dutch Military Info (Dutch Mil). The landing in Kruiningen was uneventful and the engine was shut down after landing.

2 KNMI = Royal Netherlands Meteorological Institute.
3 The manifold pressure of reciprocating engines is given in inches of mercury (in Hg); this is an indirect indication of the power setting of the engine.

Sightseeing tour
At the starting point of the sightseeing tour the envisaged flight plan was presented to the passengers. Both passengers were then seated on the left hand side of the helicopter, one in the front seat, one in the back seat. When the engine was restarted (which took two attempts), the pilot once again checked maximum available MAP. At 13:30 hours the pilot took off in a south-westerly direction after conducting a short hover to verify available power.

When approaching the harbour of *Stellendam (location 1 in figure 1)*, at approximately 14:05 hours, the pilot reduced power to reduce the forward speed thus enabling the passengers to take pictures. The pilot stated that, after increasing forward speed to continue the flight at normal cruising speed, he noticed a warning light and horn indicating 'low RPM'. The pilot's initial reaction was to push down the collective to increase RPM at which point he felt the throttle twisting in his hands, but this effectively resulted in the disappearance of the 'low RPM' warning. The pilot assumed the warning was caused by himself squeezing the throttle control too tight. Because everything seemed to be working normally again, the pilot continued his flight.

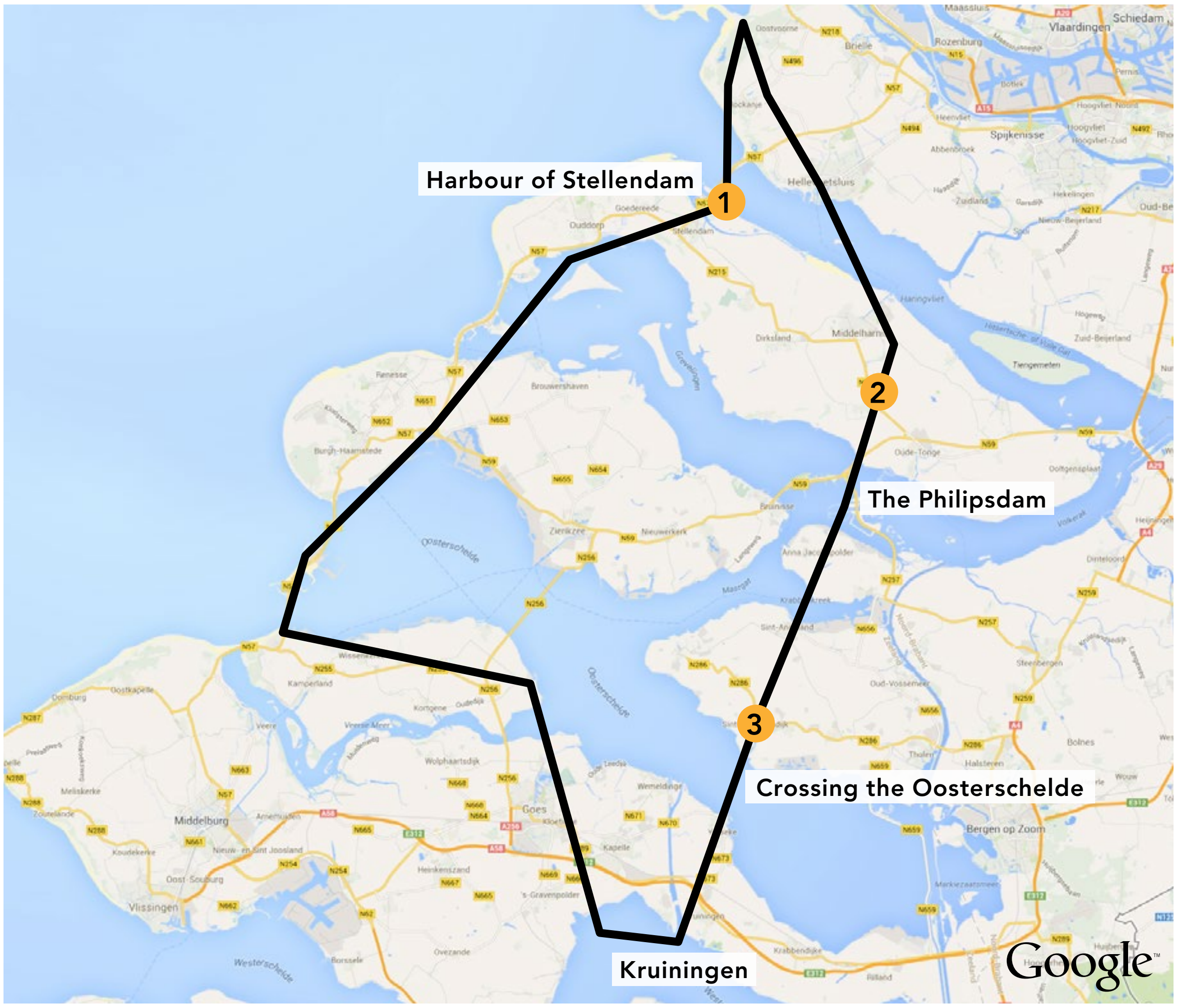

Figure 2: Flight route with locations of incidents. (Source: Google)

Shortly before arriving at the *Philipsdam, (location 2 in figure 1)*, the pilot noticed that the cylinder head temperature indicator was below zero. Because this value cannot be correct during flight, the pilot checked all circuit breakers. None had popped out so the pilot assumed it had to be a malfunction in the CHT measuring system. According to the pilot, the remaining instruments, including the Carburettor Air Temperature, showed normal values.

The pilot continued the flight and crossed the Oosterschelde flying from Sint Maartensdijk to Yerseke. At approximately 14:32 hours, the 'low RPM' light and audio warnings came on again (*location 3 in figure 1*). Again, the collective was pushed down and the throttle was checked fully open. The pilot also reduced the speed to 80 knots. In spite of these measures the warnings persisted. The pilot then turned off the auto governor to allow maximum manual throttle. This however did not change the situation. The cross winds caused the helicopter to shake moderately. In addition, the pilot noticed that the helicopter yawed several times. In his opinion this was not as a result of the strong winds. The RPM was stabilized at 95%-97%, the oil pressure and oil temperature were within limits and the throttle was fully open. Apart from the constant 'low RPM' audio warning, no other alarming or unusual noises were heard.

The pilot decided to continue towards the intended landing location. The tail wind would bring him over the coastline faster and the remaining flight time would be another few minutes. Because of the tailwind, the pilot decided that the prescribed 'landing as soon as practical' would take place at the intended landing location in Kruiningen. The pilot informed the passengers about the situation and the landing at the destination was at 14:45 hours. The elapsed time between the second 'low RPM' warning and the landing was approximately 13 minutes. On shutdown of the engine the pilot did not notice any abnormalities.

After landing the pilot contacted the company headquarters to inform them about the indications during the flight. From this communication he concluded that the helicopter could be flown without CHT indication. It was decided that the pilot would perform a prolonged hover flight. If no problems occurred during this hover, the helicopter would be flown back to the company's operating base in Bergen op Zoom to be inspected, with only the pilot on board.

Return flight from Kruiningen to Bergen op Zoom

During the pre flight check just before taking off to Bergen op Zoom, the rotor was turned manually for inspection. No unusual noises or resistance were noticed. The oil level was adequate. The engine fired during the first attempt without any unusual noises and the start-up procedure showed no abnormalities. Subsequently, no abnormalities were experienced during the prolonged hover to verify performance (except for the malfunctioning CHT indicator) and the decision was made to return to Bergen op Zoom avoiding flying over water. During this flight no problems occurred.

The aircraft

The Robinson R44 Raven 1[4] with registration PH-WMW is a two bladed four seat helicopter powered by a piston engine. The undercarriage consists of two metal rods, also known as skids. The R44 was registered in the Netherlands in April 2010 together with two other R44 helicopters the company purchased.

The engine

The helicopter is powered by a Lycoming six cylinder O-540-F1B5 engine. The helicopter is equipped with carburettor heat assist which adjusts carburettor heat in response to power changes by the pilot. The pilot must select carburettor heat 'on' before the system begins to provide heated air. The carburettor air temperature must be monitored by the pilot, small adjustments may be necessary.

Supplemental type certificate

According to the type certificate, the Robinson R44 Raven 1 is approved to operate on Avgas. For the R44 Raven 1, a supplemental type certificate (STC) is available that approves the helicopter operating on automotive gasoline, also known as motor gasoline (Mogas).

The reason to operate a helicopter on Mogas rather than on Avgas is the lower price of the fuel. The issuer of the STC must demonstrate to the authorities during a certification process that the engine and airframe combination are suitable to operate on Mogas. If the combination is certified, a STC can be issued for every similar aircraft / engine combination and will then become part of the airworthiness documentation of the aircraft.

PH-WMW operated on Mogas. The STC was issued in April 2010, the same month the aircraft was registered in the Netherlands.

The pilot

In June 2011, the pilot was issued a CPL(H)[5] based on his military pilot's license for helicopters. The type rating for the R44 was issued in August 2011 with a subsequent OPC/LPC[6] check in September 2011. This flight was the pilot's second revenue flight.

total flight hours (mainly on turbine engine aircraft)	4545
flight hours on type (piston engine helicopter)	12
flight hours on type during the last three months	2

Table 1: Flying experience pilot PH-WMW.

4 http://www.robinsonheli.com/rhc_r44_raven_series.html
5 CPL(H)= commercial pilot license helicopters.
6 LPC = License Proficiency Check and OPC = Operators Proficiency Check.

Mass and balance

Maximum take-off weight Robinson R44	1089 kg
Empty weight Robinson R44	654 kg
Available for fuel, crew and cargo	435 kg
Actual payload[7]	Pilot and two passengers (one in front seat one in rear seat) 235 kg plus 176 kg fuel = 411 kg
Take-off weight	1065 kg (= 98% of max TOW)

Table 2: Mass and balance.

Mass and balance were within limits during the flight.

The weather

According to data received from the KNMI, the wind during the incident came from a westerly direction (270-290 degrees) at 20-28 knots gusting to 40 knots. It was a rainy day with alternating showers and drizzle. The temperature was approximately 10 degrees Celsius, with dew point of 8 degrees Celsius. The visibility was more than 10 kilometres, reduced to 3-6 kilometres in showers.

7 Data from pilot report.

Weather

It was a rainy day with alternating showers and drizzle. The outside air temperature (OAT) was approximately 10 ˚Celsius and the dew point 8 ˚Celsius. Under those conditions, with a small difference between OAT and dew point, there is a risk of carburettor icing. During the inspection after the occurrence no indications were found that the carburettor anti-icing system had malfunctioned. The pilot stated that the carburettor temperature was within the prescribed limits during the flight.

Technical investigation of the helicopter

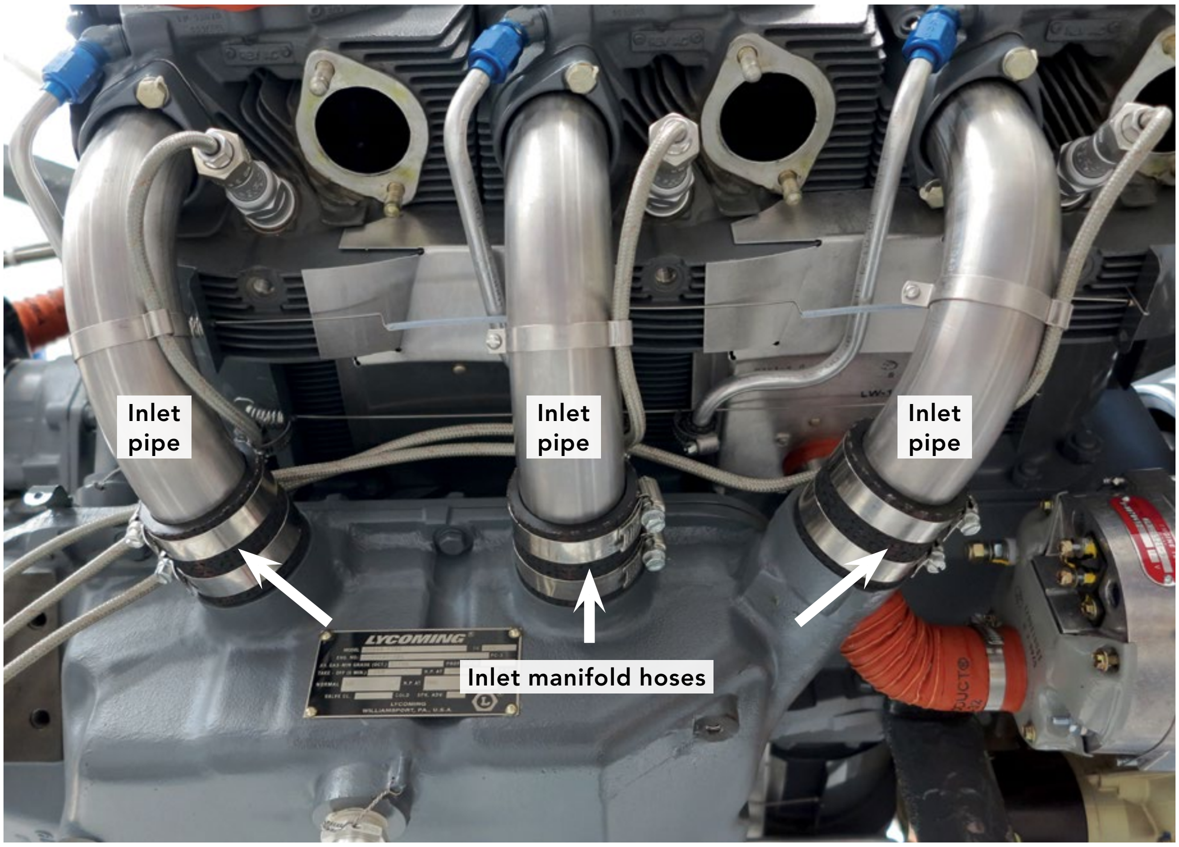

Figure 3: Lycoming O-540 engine, bottom, right side. (Source: Robinson helicopters)

The helicopter engine was inspected at the maintenance facility in Belgium. The inspection showed that the CHT sensor located on cylinder #2, had melted away. Also, the hoses connecting the manifold to the cylinder intake pipes (inlet manifold hoses) showed extensive wear of the rubber, which resulted in at least one porous hose. A leaking hose can cause a lean fuel/oxygen mixture, resulting in high temperatures during combustion, and possible overheating of pistons and cylinders.

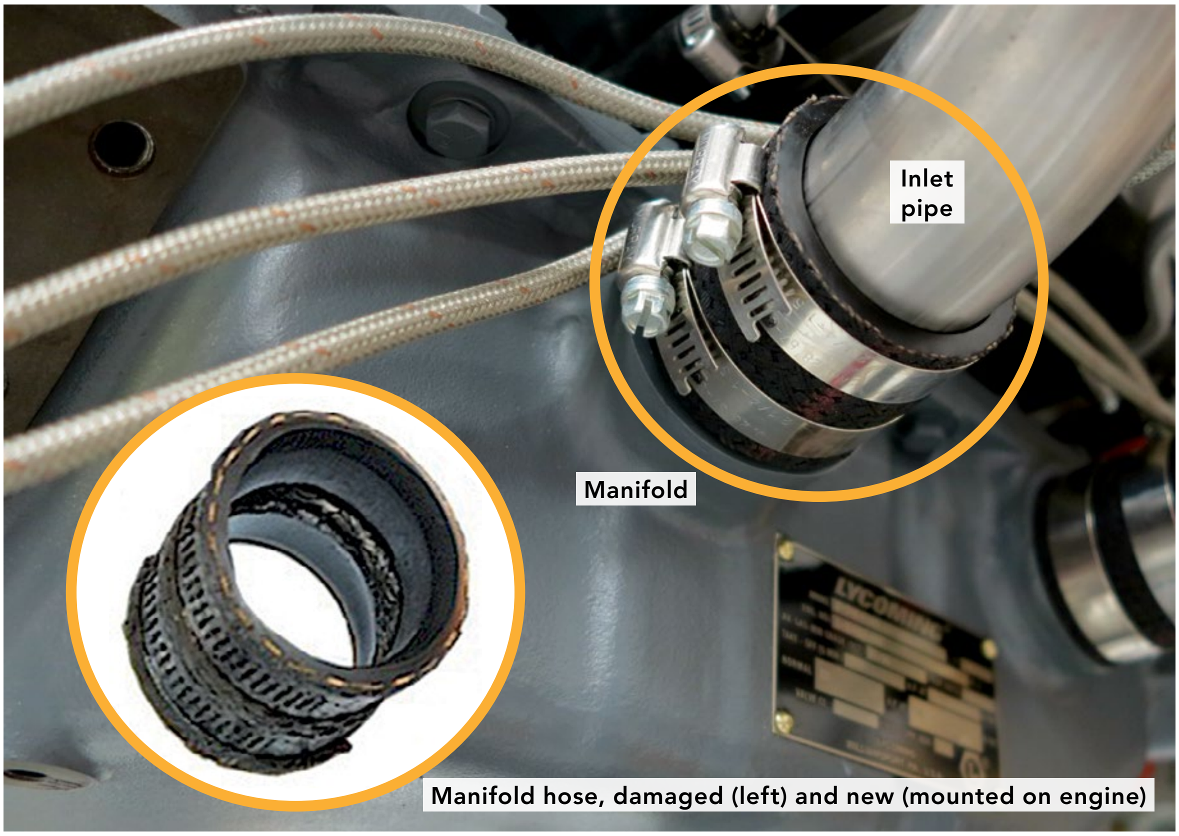

Figure 4: Damaged (left) and mounted inlet manifold hose. (Source: Robinson helicopters)

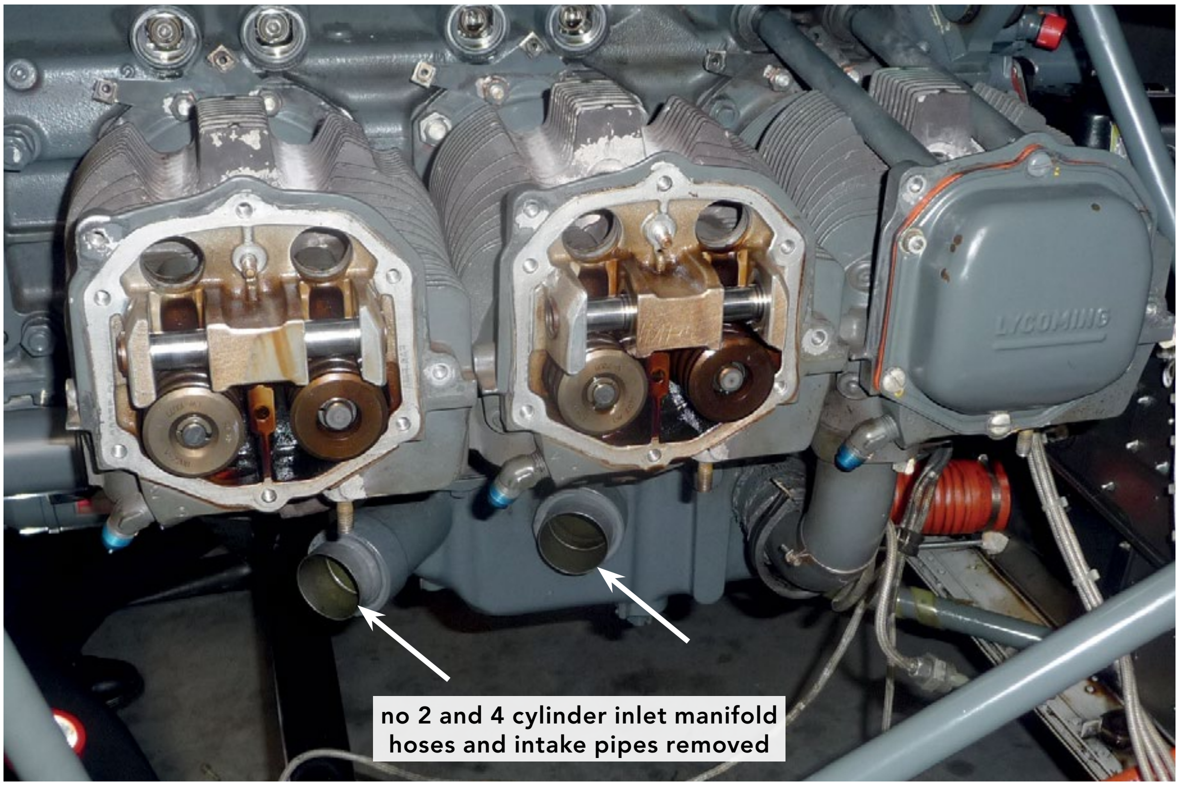

Figure 5: PH-WMW engine. Hoses and intake pipes of cylinder 2 and 4 removed. (Source: Dutch Safety Board)

The engine was removed from the helicopter and investigated. Two cylinders were found to have overheated (numbers 2 and 4) which probably caused the failure of the CHT-sensor and the partial power loss.

The inspection regime

The aforementioned rubber hose is part of the inlet manifold and thus part of the fuel line and induction system. The Lycoming O-540 Operating Manual states that this system should be inspected during every 50 hours inspection:

'Fuel Line and Induction System – Check the primer lines for leaks and security of the clamps. Remove and clean the fuel inlet strainers. Check the mixture control and throttle linkage for travel, freedom of movement, security of the clamps and lubricate if necessary. ***Check the air intake ducts for leaks****, security, filter damage; evidence of dust or other solid material in the ducts is indicative of inadequate filter care or damaged filter. Check vent lines for evidence of fuel or oil seepage; if present, fuel pump may require replacement.'*

The part numbers of the rubber hoses were found to be the correct numbers as prescribed by Lycoming and Robinson. The engine manufacturer stated that examination of the hoses indicated that they were 'genuine Lycoming'.

It is unknown when the wear of the rubber hose had started. The outside of the hose was relatively undamaged. The air intake ducts were visually checked for leakage every 50 flight hours. This inspection is unlikely to reveal excessive wear of the inside of the hose. Maintenance company records make no mention of exchanges of rubber hoses.

The wear of similar rubber hoses in other R44s was checked to determine if the damage was related to this type of helicopter, or only to the helicopter under investigation. The company's two other R44 helicopters, that were also operated on Mogas were inspected shortly after the occurrence with PH-WMW and these helicopters had suffered damage to the same hoses but less severe than PH-WMW. Maintenance of the R44 was performed by a company that regularly services this type of helicopter, albeit the vast majority of the engines run on Avgas. Only the R44s owned by this operator operated on Mogas. The maintenance organisation had never encountered rubber hoses with similar excessive wear on Avgas operated helicopters.

The influence of Mogas

To determine whether the excessive wear on the hose of the investigated helicopter was an isolated case, the Dutch Safety Board contacted manufacturer Robinson. When asked about the damaged rubber hoses, the helicopter manufacturer stated it was unaware of similar problems on any of their helicopters. In the Netherlands, no other Robinson R44 operator was found that operated on Mogas.

The Lycoming engine is designed to operate on Avgas, but PH-WMW had a STC allowing operation on Mogas. PH-WMW left the factory 14 April 2010 and had been operating on (mainly) Mogas since it was delivered to the company. In line with the requirements of the STC, approximately every 75 hours one full tank of Avgas was used. On the day of the incident the helicopter had approximately 1050 flying hours.

After the incident fuel samples were taken from the helicopter's tank and analysed. The composition of the fuel samples was found to be according to the specifications for Automotive Fuel (EN228[8]). The samples contained 0,42 % volume Ethanol. According to the STC, no Ethanol is allowed. The operator stated that the fuel was checked regularly for ethanol. Other than that the engine was operated on Mogas, no detailed information is available about the composition of the fuel used during the life span of the helicopter.

A test was performed to determine the possible influence of Avgas and Mogas on the rubber hoses. Two new hoses were used. Laboratory tests revealed that the volume change properties of the new hose met the requirements according to MIL-STD-6000.[9] The hoses were exposed to respectively Avgas and Mogas for 24 hours to examine the effects on the hoses. The hoses have reinforcement webbing at the outside, which has limited expandability. The picture below shows that Mogas 'inflates' the rubber hose where Avgas causes only a slight increase in volume. The outer webbing effectively limits the possibilities for length increase of the rubber as a whole. The volume increase is limited outwards, and so the volume increase is vectored towards the ends of the hose where it causes the characteristic concave shape as seen below.

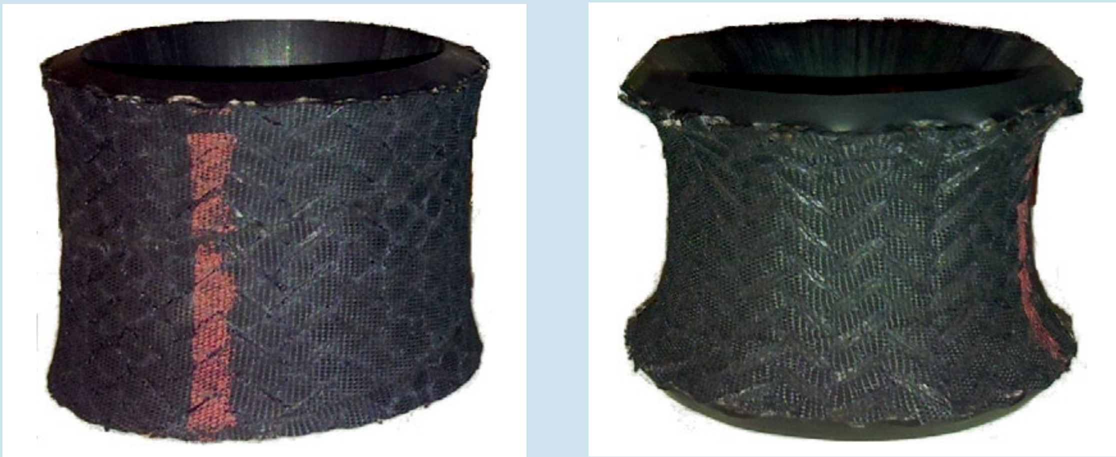

Figure 6: Inlet manifold hose after 24 hours in Avgas (left) and after 24 hours in Mogas (right). (Source: Dutch Safety Board)

8 EN228 = European standard for unleaded petrol as automotive fuel (http://www.en-standard.eu/csn-en-228-automotive-fuels-unleaded-petrol-requirements-and-test-methods/?gclid=CJjY6dnfhLsCFQrJtAodcX8Asw).

9 Average of three samples in Mogas for 24 hours: 70,6 % volume change. In Mogas + 5 % Ethanol: 80,7 % change. Requirement MIL-STD-6000: max 85 % change.

On the aircraft, the rubber is generally encased by webbing, pipes and clamps. Therefore it can only expand (bulge) in one direction, which is inwards in between the two pipes.

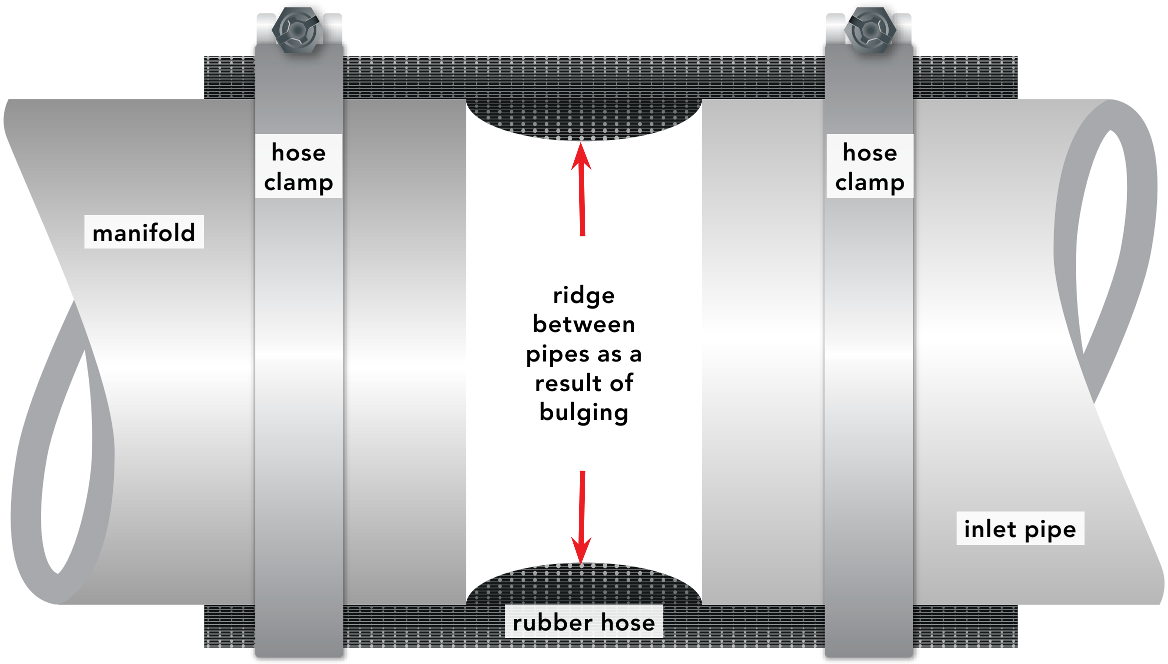

Figure 7: Drawing of ridge in inlet manifold hose between two pipes. (Source: Dutch Safety Board)

As a result, a ridge is formed in the hose, between the two pipes. It is concluded that the ridge as found in the hose of PH-WMW was caused by the (long term) use of Mogas.

During the investigation a maintenance organisation provided the Safety Board with a hose that was removed from a fixed wing aircraft that was operated on Mogas for a considerable time. This hose showed the result of bulging between the two pipes, a ridge was clearly visible. Approximately 75 % of the ridge was undamaged, in the remaining part, pieces had broken away. It was concluded that this hose showed a stage of the degradation process prior the stage as found on PH-WMW.

Figure 8: Hose with ridge, partly undamaged (left) and damaged (right). (Source: Dutch Safety Board)

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Investigation of the inlet manifold hose

The rubber hoses from PH-WMW were investigated by a laboratory to determine the failure mechanism and failure cause of the rubber hoses.

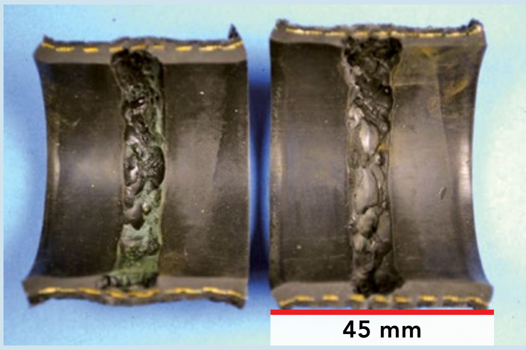


Figure 9: Inside of the hose with broken out material. (Source: Element)

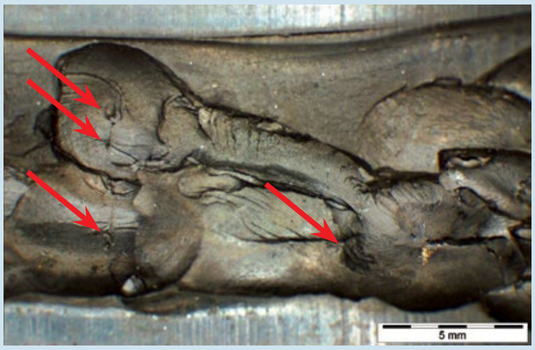


Figure 10: Detail of broken out material. (Source: Element)

The laboratory concluded that the main cause of the failure was a fatigue mechanism.

The use of Mogas generated bulging, causing increased stress levels at the rubber surface between the pipes, resulting in fatigue. This fatigue mechanism was evidenced by initiation points and broken out rubber. The arrows in figure 10 show the initiation points. The alternating stresses caused by vibration and (internal) material stress due to bulging, in combination with the temperature, were contributing factors to the fatigue mechanism. As bulging hardly occurs when the engine is operated on Avgas, this phenomenon is only present when Mogas is used for a relatively long time. For details see appendix.

The return flight to Bergen op Zoom

After the incident over the Oosterschelde the helicopter landed at the intended landing location where the passengers disembarked. The pilot consulted the company about what had happened and the decision was made to fly the helicopter back, avoiding flying over water. The decision was based on the assumption that there was no structural damage to the engine despite the fact that the 'low RPM'-warning had sounded during the previous flight.

A prolonged hover was performed prior to the return flight, to reassure the pilot that indeed no structural damage existed. The pilot stated that he would not have commenced the return flight if he had noticed anything out of the ordinary in the behaviour of the helicopter during the hover flight. As the helicopter functioned properly at that stage (except for the failed CHT indicator) the pilot decided to fly back following a safe route over land.

According to the Flight Manual, the CHT system is 'essential equipment', and the helicopter shall not be operated without it. The return flight without CHT indication was therefore not permitted.

In retrospect, the engine had already suffered structural damage during the sightseeing flight, the damage had simply not resulted in a total failure of the engine. Taking into account the limited experience with piston engine driven helicopters, the decision to continue the flight to the home base in Bergen op Zoom, over land, was understandable as there were no clear indications that the engine had suffered structural damage and the helicopter responded correctly to the controls.

The pilot stated that, in hindsight, he had found limited guidance in the Operations Manual and received limited operational guidance from the company in relation to the event.

CONCLUSIONS

The aircraft operated on automotive gasoline, also known as motor gasoline (Mogas), which was permitted according to the supplemental type certificate.

The partial power loss was the result of an overheated engine, which caused the CHT indicator to fail. The probable cause of the overheating was a leaking inlet manifold rubber hose, causing an excessively lean air/fuel mixture.

The long term use of Mogas most probably caused the bulging of the inlet manifold rubber hose between the two metal connecting pipes of the manifold and the cylinder intake pipes.

The main cause of the failure of the inlet manifold hose was a fatigue mechanism. The broken out rubber particles are a result of fatigue initiated on small particles in the rubber.

The fuel used was a factor in the damage to the rubber hose, but details of the composition of the fuel used during the lifetime of the helicopter are not available. The fuel taken from the aircraft after the occurrence was compliant with the European standard for automotive fuel. The fuel contained less than 0.5 % Ethanol. The STC does not allow the use of fuel that contains Ethanol.

The damage to the rubber hose was not discovered during the prescribed 50 hours inspections. The wear is difficult to notice through visual inspections only, since the outside of the hose was relatively undamaged, and no visual inspection of the inside of the hose is required.

The return flight without CHT indication was not permitted according to the Flight Manual.

APPENDIX A

FUEL ANALYSIS

After the incident, samples of fuel were taken from helicopter's tank and tested in a laboratory. The fuel was identified as Mogas. The samples contained approximately 10% Ethyl-tert-butyl ether (ETBE) and 0,42% ethanol.

Research tests from the FAA of auto gas blended with ETBE have not shown any safety related problems, thus the use of MOGAS with ETBE (which is used as a lead substitute) is approved by the FAA. EN228[10] states that up to 15 vol. % is approved for automotive gasoline. The STC does not allow the use fuel that contains Ethanol. Experience shows that Ethanol content of 1% or less, did not cause any perceivable additional numbers of accidents or casualties.[11]

Laboratory investigation of the inlet manifold rubber hoses
The rubber hoses from PH-WMW were investigated by a laboratory to determine the failure mechanism and failure cause of the rubber hoses.

When mounted on the aircraft, pipes are fitted into the hose to a depth of about 18 mm. This corresponds with the unaffected surface. The distance between the two metal pipes was about 10 mm. The inner surface of the rubber hose between the metal pipes shows broken out rubber. The rubber is broken out in shell shaped parts. Radial orientated fracture lines in these shell shaped parts, pointed to a central position. At these central positions, a small pinhole was present. Some pinholes were filled with a particle. At some positions, perpendicular to the radial fracture lines, 'beach marks'[12] are visible. At the area were the rubber is not broken out, the surface has an eroded appearance.

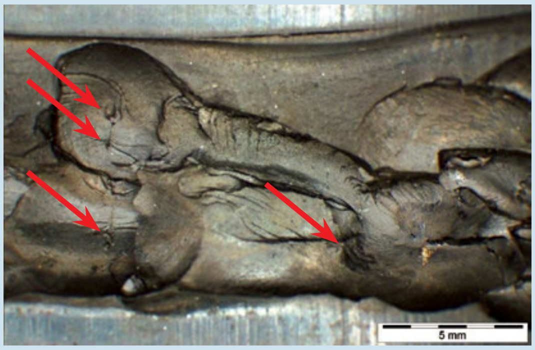
It was observed that the damage was only present in the area that was not covered by the inserted metal pipes. When the degradation is a direct result of chemical attack by the fuel, it is to be expected that the rubber around the metal pipes would also be affected by the ongoing chemical process.

Most likely the main cause of the broken out rubber particles is not directly related to chemical attack and flow of fuel. The investigation of the area with broken out rubber shows that rubber particles are broken out by a mechanical mechanism. Small fatigue cracks were initiated on the small particles present in the rubber.

10 EN228 = European standard for unleaded petrol as automotive fuel . http://www.en-standard.eu/csn-en-228-automotive-fuels-unleaded-petrol-requirements-and-test-methods/?gclid=CJjY6dnfhLsCFQrJtAodcX8Asw
11 http://www.easa.europa.eu/safety-and-research/research-projects/docs/miscellaneous/Final_Report_EASA.2008-6-light.pdf, page 19 Paragraph 3.1
12 'beach marks' on the fatigue fracture surface can be seen as a result of successive arrests or decrease in the rate of fatigue crack growth.

It can be concluded that the rubber is degraded slightly due to another cause, e.g. heat. As the hoses are installed between the manifolds of carburettors and the cylinders of a the engine, the hoses are exposed to vibration. It is to be expected that these vibrations generated additional heat in the rubber. The distance between the two metal pipes (10 mm) is relative short in comparison with the hose diameter (50 mm). Due to this relatively short distance, the vibrations between the manifold of the carburettor and the fuel inlet of the cylinder, will introduce alternating stresses in the rubber.

Figuur 11: Track with broken out material. (Source: Element)



Figuur 12: Detail of broken out material. (Source: Element)

The arrows in figure 12 point to the initiation points.

The alternating stresses in combination with the heat generated in the rubber caused the fatigue cracks in the bulged part. The small particles in the rubber acted as stress initiators. As a result the fatigue cracks initiated at the particles. As bulging hardly occurs when the engine is operated on Avgas, this phenomenon is only present when Mogas is used for a relatively long time.

It was concluded that the main cause of the failure was a fatigue mechanism. However, the use of Mogas caused the bulging between the pipes, which resulted in increased stress levels of the surface. The broken out rubber particles were a result of fatigue initiated on small particles in the stressed surface of the rubber. The alternating stresses caused by the (internal) material stress due to the bulging in combination with the temperature were a contributing factor to the fatigue mechanism.

DUTCH
SAFETY BOARD

Visiting Address
Anna van Saksenlaan 50
2593 HT The Hague
T +31(0)70 333 70 00
F +31(0)70 333 70 77

Postal Address
PO Box 95404
2509 CK The Hague

www.safetyboard.nl