Final Report AO-2016-008: Robinson R66 helicopter, Partial power loss– forced landing, Hokonui Hills, Southland, 14 November 2016

Final Report

Aviation inquiry AO-2016-008

Robinson R66 helicopter
Partial power loss– forced landing
Hokonui Hills, Southland
14 November 2016

Approved for publication: October 2018

Transport Accident Investigation Commission

About the Transport Accident Investigation Commission

The Transport Accident Investigation Commission (Commission) is a standing commission of inquiry and an independent Crown entity responsible for inquiring into maritime, aviation and rail accidents and incidents for New Zealand, and co-ordinating and co-operating with other accident investigation organisations overseas. The principal purpose of its inquiries is to determine the circumstances and causes of occurrences with a view to avoiding similar occurrences in the future. Its purpose is not to ascribe blame to any person or agency or to pursue (or to assist an agency to pursue) criminal, civil or regulatory action against a person or agency. The Commission carries out its purpose by informing members of the transport sector and the public, both domestically and internationally, of the lessons that can be learnt from transport accidents and incidents.

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Nature of the final report

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Citations and referencing

Information derived from interviews during the Commission's inquiry into the occurrence is not cited in this final report. Documents that would normally be accessible to industry participants only and not discoverable under the Official Information Act 1982 have been referenced as footnotes only. Other documents referred to during the Commission's inquiry that are publicly available are cited.

Photographs, diagrams, pictures

Unless otherwise specified, photographs, diagrams and pictures included in this final report are provided by, and owned by, the Commission.

Verbal probability expressions

The expressions listed in the following table are used in this report to describe the degree of probability (or likelihood) that an event happened or a condition existed in support of a hypothesis.

Terminology (Adopted from the Intergovernmental Panel on Climate Change)	Likelihood of the occurrence/outcome	Equivalent terms
Virtually certain	> 99% probability of occurrence	Almost certain
Very likely	> 90% probability	Highly likely, very probable
Likely	> 66% probability	Probable
About as likely as not	33% to 66% probability	More or less likely
Unlikely	< 33% probability	Improbable
Very unlikely	< 10% probability	Highly unlikely
Exceptionally unlikely	< 1% probability	

Robinson Helicopter Company R66, ZK-HAG
Photo courtesy of the maintenance provider

Source: mapsof.net

Location of accident

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Abbreviations

Commission	Transport Accident Investigation Commission
ELT	emergency locator transmitter
EMU	engine monitoring unit
GPS	global positioning system
kg	kilogram(s)
mm	millimetres
Robinson Helicopters	Robinson Helicopter Company
RPM	revolution(s) per minute

Glossary

absolute rating (of a filter)	diameter of the largest spherical particle which will pass through a fluid filter under laboratory conditions
autorotation	a process of producing lift in an unpowered rotor system by inducing an airflow up through the main rotor blades as the helicopter descends
collective lever	one of the flight controls, used by a helicopter pilot to 'collectively' adjust the pitch angle of all main rotor blades at the same time to alter the amount of thrust/lift being produced
gas temperature	the average measured temperature of the gas path in an engine
gas generator RPM	engine gas generator (compressor) speed, expressed as a percentage of revolutions per minute
knot	a measurement of speed, in nautical miles per hour, equivalent to 1.85 kilometres per hour
micron	a metric unit of measurement equal to one-millionth of a metre
nominal rating (of a filter)	diameter of the largest spherical particle which will pass through a fluid filter a defined percentage of the time
output shaft RPM	engine output shaft speed, expressed as a percentage of revolutions per minute
Pilot Operating Handbook	a controlled document accessible to the pilot from within the cockpit to provide information including system descriptions, limitations, normal and emergency procedures
run-on landing	a manoeuvre used to transition from forward flight to a landing on a surface when there is insufficient power available to sustain a hover
TracMap	the proprietary name for a specific GPS guidance and job-management tool utilised in various air- and ground-based agricultural operations

Data summary

Aircraft particulars

Aircraft registration:	ZK-HAG
Type and serial number:	Robinson Helicopter Company R66, 0015
Number and type of engines:	one, Rolls-Royce RR300, S/N: RRE 200019
Year of manufacture:	2011
Operator:	HeliOps Southland Limited
Type of flight:	agricultural
Persons on board:	one

Crew particulars

Pilot's licence:	commercial pilot licence helicopter
Pilot's age:	37
Pilot's total flying experience:	4,400 flight hours (660 hours on type)

Date and time	14 November 2016, 1538[1]
Location	Hokonui: 47 kilometres northeast of Invercargill, at an elevation of 1,200 feet (365 metres) above sea level latitude: 46° 1.36´S longitude: 168° 35.18´E
Injuries	minor
Damage	substantial

[1] Times are New Zealand Daylight Time (co-ordinated universal time + 13 hours) and are in 24-hour format.

1. Executive summary

1.1. On 14 November 2016, a Robinson Helicopter Company R66 helicopter was conducting an agricultural spraying operation around the Hokonui Hills in Southland, with one pilot on board. On the last spray run for the day the pilot received an indication of low rotor revolutions-per-minute, which was a critical condition that required immediate action. However, at that time the helicopter was too low to recover from the situation, so the pilot turned the helicopter and attempted a 'run-on landing' – a manoeuvre used to transition from forward flight to a landing on the surface when there is insufficient power available to sustain a hover.

1.2. The helicopter landed heavily and pitched forward, causing the main rotor blades to contact the ground. The helicopter was substantially damaged, but the pilot escaped with minor injuries only.

1.3. The Transport Accident Investigation Commission (Commission) found that the condition of low rotor revolutions-per-minute very likely resulted from a momentary reduction in available engine power caused by contaminated fuel.

1.4. The Commission also found that the operator's refuelling procedures for remote sites left several opportunities for fuel contamination to occur.

1.5. The Commission identified the safety issue that more educational material is needed to alert operators to the risk of contaminated fuel when operating and refuelling in remote, dusty environments.

1.6. The Commission made two recommendations, one to the Director of Civil Aviation to provide the industry with more educational material and guidance on mitigating the risk of contaminated fuel when operating at remote sites, and one to the President of Aviation New Zealand to promulgate the lessons learned from this accident to its members with a view to increasing awareness of the risk of fuel contamination during remote refuelling procedures.

1.7. The key lessons arising from this inquiry are:

- refuelling aircraft at remote locations increases the risk of fuel contamination. Operators should take all precautions to prevent any debris entering the fuel supply chain, from the initial fuel supplier to the aircraft fuel tank

- aircraft fuel-filtering systems are an important defence against contaminated fuel causing an accident. Where available, operators should consider fitting additional airframe filters to aircraft being operated and refuelled at remote locations.

2. Conduct of the inquiry

2.1. At 1600 on 14 November 2016, the Civil Aviation Authority notified the Transport Accident Investigation Commission (Commission) of the accident involving a Robinson Helicopter Company (Robinson Helicopters) R66 helicopter. The Commission opened an inquiry under section 13(1) of the Transport Accident Investigation Commission Act 1990 and appointed an investigator in charge.

2.2. On 15 November 2016 two Commission investigators travelled to Invercargill and conducted the initial scene examination and interviews with three witnesses.

2.3. On 16 November 2016 the helicopter wreckage was moved to a secure location at Invercargill Airport.

2.4. On 17 November 2016 the Commission investigators conducted a preliminary engine inspection with the assistance of an independent licensed aircraft engineer. The helicopter global positioning system (GPS) navigation equipment was removed for data extraction and analysis.

2.5. On 28 November 2016 the Commission investigators returned to Invercargill accompanied by a Rolls-Royce representative to conduct a detailed engine investigation and to download recorded data from the engine monitoring unit (EMU).

2.6. The helicopter wreckage was then relocated to the Commission's storage facility in Wellington.

2.7. Fuel samples were forwarded to the Defence Technology Agency[2] for analysis. The fuel control unit and power turbine governor were removed from the engine and sent to the manufacturer, Honeywell Aerospace in the United States, for further testing. Testing was conducted under the supervision of a United States Accredited Representative from the National Transportation Safety Board.

2.8. The Commission appointed an independent overhaul facility to inspect and test the sprag clutch[3]. The Commission also appointed an independent overhaul facility to inspect and test the fuel nozzle.

2.9. On 6 September 2018 the draft report was sent to interested persons for comment. Written submissions were received from five interested persons. The Commission considered the submissions and any changes as a result of those submissions have been included in the final report.

2.10. On 24 October 2018 the Commission approved the final report for publication.

[2] The Defence Technology Agency, located in Auckland, New Zealand, is the main provider of research, science and technology support to the New Zealand Defence Force and the Ministry of Defence.
[3] A detailed description of the sprag clutch is provided in section 3.10.

3. Factual information

3.1. Narrative

3.1.1. On the morning of Monday 14 November 2016, a Robinson Helicopters R66 helicopter registered ZK-HAG (the helicopter), the pilot, a ground support vehicle and a ground crew member were tasked with four agricultural spraying jobs.

3.1.2. The pilot's day commenced at the operator's base near Otautau, Southland by sterilising the helicopter spray system[4] and preparing ground loading equipment. The pilot flew the helicopter to the first job of the day and commenced spraying by approximately 0730.

3.1.3. The pilot kept the helicopter engine running continuously throughout the working day, including during all refuels and rest breaks.

3.1.4. At approximately 1530 the helicopter was loaded for the last run of the day with 150 litres of water. This 'flushing' run was to rinse residual chemicals from the helicopter spray system.

3.1.5. The helicopter returned to the targeted spray area for what was expected to be a two-minute flight. From a straight and level flight at approximately 80 knots[5], the pilot initiated a descending right-hand turn to line up with the spray run (Figure 1). While in descent, the low rotor RPM (revolutions per minute) warning light and horn activated. The pilot responded by lowering the collective lever[6], and the rotor RPM recovered to within the operating range. The pilot then decided to continue the descent and lined up for the spray run.

3.1.6. As the helicopter levelled out, the low rotor RPM warnings activated again. At that point the helicopter had insufficient height or airspeed to recover the rotor RPM, so the pilot turned towards a more suitable area and attempted a run-on landing[7].

3.1.7. At 1538 the helicopter struck the ground heavily at a shallow angle, before bouncing and pitching forward, causing the main rotor to contact the ground. The helicopter rolled on to its left side then rotated through 360° while the rotor blades continued to strike the ground.

3.1.8. The engine continued to operate with sufficient power to damage the helicopter further as the rotating blades dug into the ground. The tail section was separated at the tail boom and the main rotor blades broke off at approximately 600 millimetres (mm) from the centre of the main rotor head (Figure 2). At this point the engine RPM increased due to the lack of load.

3.1.9. The pilot shut down the engine by closing the fuel cut-off valve, then turned off the master electrics and emergency locator transmitter (ELT). The pilot climbed out of the helicopter and turned off the externally mounted spray pump, then phoned the Rescue Coordination Centre New Zealand to advise it of the accident and to cancel the ELT alert.

3.1.10. The pilot received minor bruising. There was no post-accident fire.

[4] A process to neutralise/deactivate any residual chemicals from previous jobs.
[5] A measurement of speed, in nautical miles per hour, equivalent to 1.85 kilometres per hour.
[6] One of the flight controls, used by a helicopter pilot to 'collectively' adjust the pitch angle of all main rotor blades at the same time to alter the amount of thrust/lift being produced.
[7] A manoeuvre used to transition from forward flight to a landing on a surface when there is insufficient power available to sustain a hover.

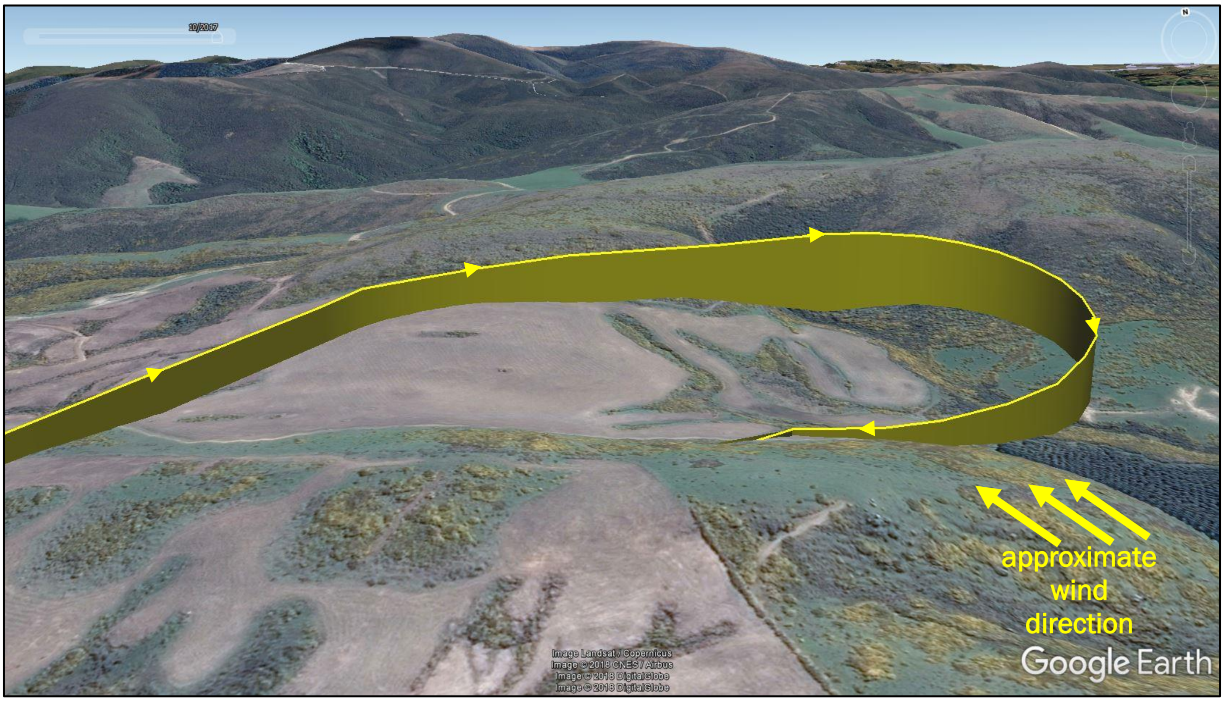

Figure 1
Accident flightpath

Figure 2
Wreckage

3.2. Location and weather

3.2.1. The accident site was a recently ploughed paddock 47 kilometres northeast of Invercargill in the Hokonui Hills. The surrounding terrain consisted of rolling hill country with a mixture of farm land, scrubby gorse and some forest.

3.2.2. The weather conditions in the vicinity at the time were clear, with the wind estimated by the pilot to have been seven to 10 knots from the southeast.

3.2.3. A weather station located approximately 13 kilometres southwest of the accident site recorded the following data at the approximate time of the accident:

- air temperature: 15° Celsius
- humidity: 70%
- precipitation: Nil
- wind: Seven knots, gusting nine knots from the southeast.

3.3. The operation

3.3.1. A normal spraying operation involved numerous short flights lasting between two and 10 minutes, depending on the application rate and nature of the block being sprayed.

3.3.2. The ground crew member would position the support vehicle on an open, flat site as close as practicable to the targeted spray area and with access to a water supply. The ground crew member would prepare a product load while the helicopter was away, then when it returned add the product and water to the helicopter spray tank to make up the next load.

3.3.3. This pilot normally refuelled the helicopter and left the engine running while the ground crew member loaded the spray tank. A standard fuel load provided for 20 minutes of flying. Where possible, refuelling was conducted from the supply tank on the back of the support vehicle using an electric pump. Otherwise the pilot would transfer fuel from the support vehicle to the helicopter in 20-litre plastic fuel containers. Both methods of refuelling were used that day.

3.4. Organisational information

3.4.1. The operator held a Civil Aviation Rules Part 137 operating certificate for commercial agricultural operations. At the time of the accident the operator had four helicopters, including the accident aircraft.

3.4.2. The operator had a drug and alcohol policy that required all pilots to be tested as a pre-employment condition, with random testing conducted annually. The test results for this pilot had been negative. The Commission considers that it is good practice to conduct post-accident and incident drug and alcohol testing. However, the operator's policy did not require this and no post-accident testing was carried out in this instance.

3.5. Personnel information

3.5.1. The pilot had obtained a commercial pilot licence (helicopter) in October 2004 and commenced work with the operator in 2010. All licensing requirements were current at the time of the accident.

3.5.2. At the time of the accident the pilot had accrued a total of 4,400 helicopter flight hours, almost entirely on Robinson helicopters, with 660 hours on the R66 and 3,020 hours flying on agricultural operations. The pilot was the operator's chief pilot and provided a supervisory role for Grade 2 agricultural pilots within the company.

3.5.3. The pilot held a current Class 1 aviation medical certificate that was valid until 6 April 2017.

3.6. Aircraft information

3.6.1. The Robinson R66 is a light helicopter with seating for a pilot and four passengers. It is powered by a single Rolls-Royce RR300 turbine engine.

3.6.2. The helicopter had been imported into New Zealand in February 2011 and purchased by the operator in September 2014. The helicopter airframe and engine both had a total recorded flight time of 1,683.9 hours.

3.6.3. The helicopter was equipped with an agricultural spray system that had been installed in accordance with the equipment manufacturer's supplemental type certificate. The spray system had been approved for agricultural operations under Civil Aviation Rules Part 137. The system comprised: an underbelly-mounted, fibreglass spray tank; two non-metallic spray booms; and a petrol-powered spray pump mounted on one of the skids. A GPS-guided TracMap[8] system had been installed to track and record the areas sprayed.

3.6.4. The helicopter had been maintained in accordance with the manufacturer's instructions. The most recent technical log had been issued on 13 August 2016. The next scheduled maintenance was due in 1.3 hours at an airframe total time of 1,685.2 hours. The helicopter had been booked to have that maintenance at the completion of the accident job. The next annual review of airworthiness was due on 29 July 2017.

3.6.5. At the time of the accident there were no recorded defects and the pilot reported that the helicopter had been performing normally.

3.7. Emergency locator transmitter

3.7.1. The ELT installed on the helicopter was a Kannad 406AF-Compact. This automatically activated during the accident sequence and remained connected to its externally mounted aerial. An alert message generated at 1538 was received by the Rescue Coordination Centre in Wellington at 1543. The message had been detected by the medium-altitude earth orbit search and rescue satellite network. This satellite network was operational but still under development and had not yet reached its full operational capability.

3.7.2. The pilot turned off the ELT soon after the accident. At 1543 the pilot called the Rescue Coordination Centre to advise it of the accident, that there were no injuries and that there was no need for a rescue operation. This action prevented any unnecessary deployment of search and rescue resources.

3.8. Weight and balance

3.8.1. On the accident flight the helicopter spray tank was loaded with 150 litres of water for a flushing run. The fuel tank was reported by the pilot to be between one-eighth and one-quarter full. This gave a total weight of no more than 1,032 kilograms (kg), 193 kg below the maximum allowable all-up weight of 1,225 kg.

3.8.2. The longitudinal centre of gravity position with a quarter of a tank of fuel was calculated to be 2,433mm aft of the datum[9] at a total weight of 1,032 kg, and the zero-fuel longitudinal position was calculated to be 2,423mm at a total weight of 978 kg. Both of these positions were within the allowable longitudinal centre of gravity range of 2,311 to 2,603mm for that weight range.

3.8.3. The operator made use of quick-reference charts specifying the spray loads that could be carried for specific aircraft, pilots and fuel loadings. With a standard fuel load of 20 minutes, the maximum spray load that the pilot was able to carry with the helicopter was 374 kg.

[8] The proprietary name for a specific GPS guidance and job-management tool utilised in various air- and ground-based agricultural operations.
[9] A reference point on an aircraft used to calculate centres of gravity. The point may vary between different aircraft types.

3.9. Engine

3.9.1. The RR300 engine had achieved Federal Aviation Administration type certification in February 2008. The engine was rated at 300 shaft horsepower, but when installed in the R66 helicopter it was de-rated to 224 shaft horsepower maximum continuous power and 270 shaft horsepower for a five-minute peak. See Appendices 1 and 2 for more details on the engine and its arrangement within the helicopter.

3.9.2. The installed engine had been fitted when the helicopter was manufactured.

Fuel system

3.9.3. The R66 fuel system was gravity fed from the fuel tank to the engine following the path shown in Figure 3.

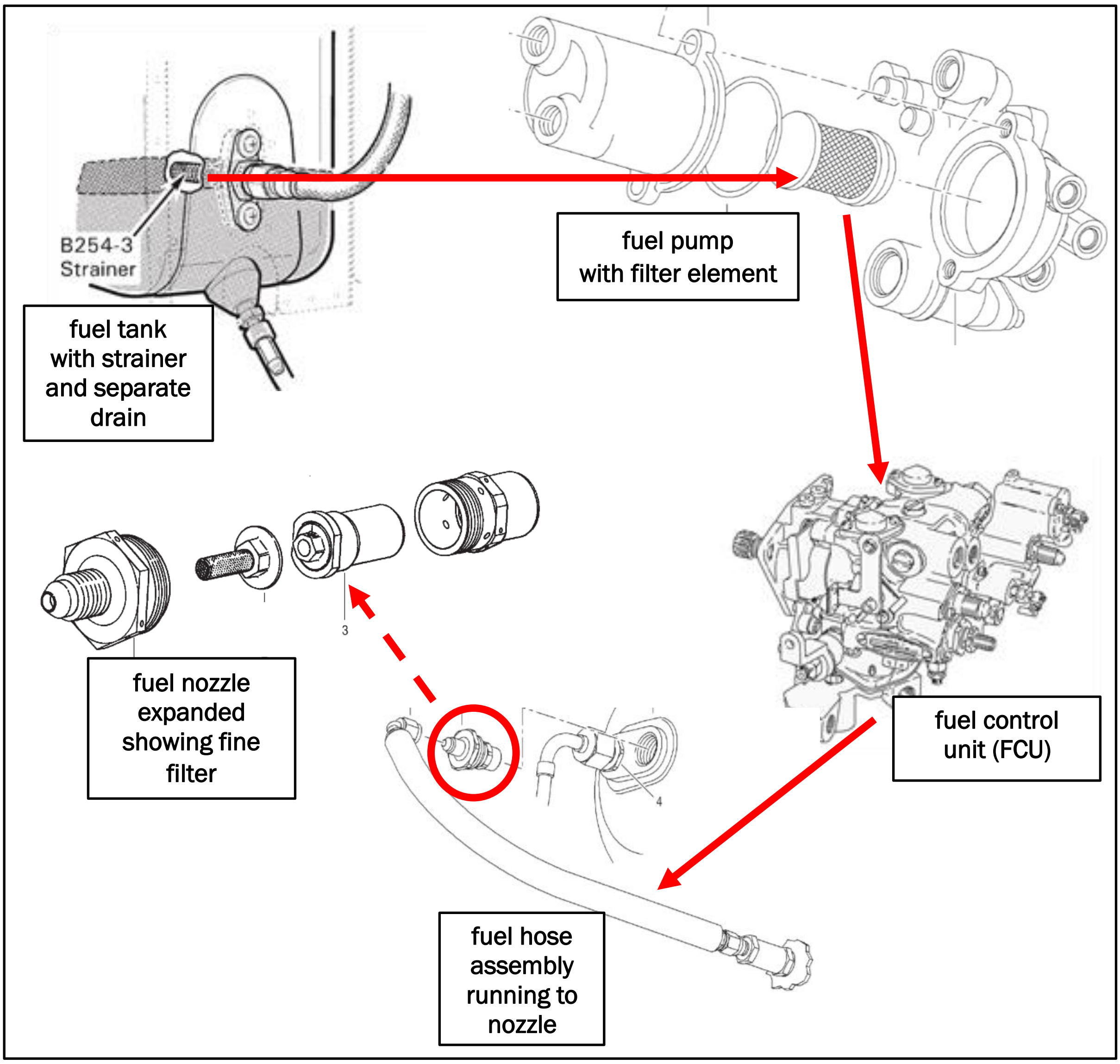

Figure 3
R66 fuel filtering system arrangement

(Modified images from: Robinson Helicopters' R66 Maintenance Manual, Honeywell Component Maintenance Manual, Rolls-Royce RR300 Maintenance Manual)

3.9.4. The fuel tank was a single, crash-resistant bladder secured inside an aluminium structure. The supply take-off point for the engine was above the lowest level of the tank and through a strainer. Any sediment or water would collect below the outlet and could be drained manually from the tank through a fuel drain tube. The drain tube was accessible via a left-side cowl door (see Appendix 6: R66 fuel system layout).

3.9.5. A fuel shut-off valve was fitted between the tank and the engine. The pilot operated the valve with a push-pull knob located near the base of the pilot's collective lever. A separate fuel cut-off push-pull knob mounted near the centre of the upright control console turned off the fuel flow at the fuel control unit.

3.9.6. The fuel level was displayed on a fuel gauge in quarter-tank increments. A separate LOW FUEL sensor and caution light was calibrated to illuminate with 19 litres remaining in the tank. This equated to approximately 10 minutes' flying time.

3.9.7. The engine pump drew fuel from the tank, filtered it and fed it to the fuel control unit. The fuel control unit controlled the fuel flow rate to the fuel nozzle. The fuel nozzle converted the pressurised fuel into a spray pattern and injected it into the combustion chamber.

Engine controls

3.9.8. The engine controls were designed to maintain a constant engine output shaft RPM[10] to keep the rotor RPM at 100% under varying loads.

3.9.9. The throttle was controlled by the pilot with a twist-grip on the collective lever. It was set to either the ground idle or full (flight idle) throttle position. The power turbine governor and the fuel control unit worked together to maintain the engine output shaft RPM at 100% and anticipate the load indicated by the collective lever position.

3.9.10. The fuel control unit monitored the air pressure at the compressor and controlled the fuel flow to the fuel nozzle to maintain a constant pressure.

3.9.11. The power turbine governor monitored the output shaft RPM, which connected to the main rotor through the engine reduction gearing, sprag clutch and main transmission. The power turbine governor generated a pneumatic control signal to the fuel control unit to maintain the output shaft RPM at 100%.

3.9.12. If the automatic controls stabilised at a point where output shaft RPM was different from that desired, the pilot could make small, incremental adjustments to correct it with a momentary-action toggle switch (called the beep switch) on the collective lever.

Engine monitoring unit

3.9.13. The R66 engine was equipped with a digital engine monitoring unit (EMU). This continuously monitored four engine parameters and saved a digital record for the entire life of the engine. The parameters were: the gas generator RPM[11], the output shaft RPM; the percentage of output torque (torque); and the average measured gas temperature (gas temperature)[12]. An exceedance beyond the manufacturer's specified limitations for any of the four parameters was indicated to the pilot by a flashing cockpit caution light.

3.9.14. Digital data archived within the EMU could be extracted in two formats: local maintenance personnel were able to download simplified reports with details of any exceedances, while downloading the full spectrum of recorded data required the Rolls-Royce proprietary software. The Commission obtained a copy of both data sets (Appendices 3 and 4 contain graphs produced from the downloaded EMU data).

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[10] The engine output shaft speed, expressed as a percentage of RPM (commonly referred to as N2).
[11] The engine gas generator (compressor) speed, expressed as a percentage of RPM (commonly referred to as N1).
[12] The average measured temperature of the gas path within the engine (commonly referred to as MGT).

3.10. Tests and research

Engine

3.10.1. The engine was initially inspected by a local licensed aircraft engineer, then later by a Rolls-Royce accident investigator. The engine was not disassembled, but a borescope was used to check for internal damage. Some of the compressor blades had been damaged when debris was ingested during the ground impact, but no further damage was found.

Fuel contamination

3.10.2. Jet fuel as used in this engine type was normally clear in appearance. Residual fuel recovered from the engine fuel pump filter housing, the fuel hose assembly and the fuel nozzle showed signs of contamination (Figure 5). This was in the form of a fine sediment that partially remained in solution, giving the fuel a muddy brown colour, and partially settled as sludge as shown in Figure 4. The remaining fuel in the main tank was drained, measured and checked for water and other contamination. None was found.

3.10.3. Fuel samples taken from the engine, the helicopter fuel tank and the supply tank on the support vehicle were sent to the Defence Technology Agency for analysis. The results are discussed in section 4 of this report.

Figure 4
Fuel filter housing showing sludge residue

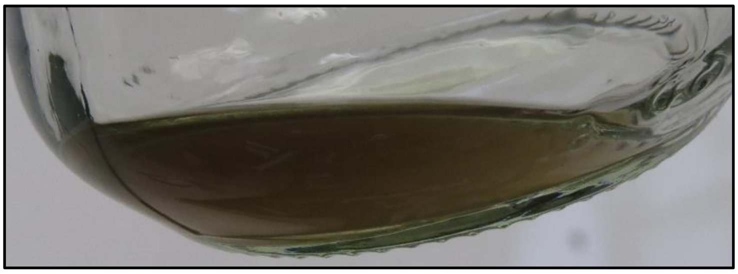

Figure 5
Discoloured sample from fuel hose assemnbly

Power turbine governor and fuel control unit

3.10.4. The power turbine governor and fuel control unit were removed from the engine and sent to the manufacturer (Honeywell Aerospace in the United States) to be disassembled and inspected under the supervision of the National Transportation Safety Board on behalf of the Commission. The inspections were witnessed by Rolls-Royce representatives.

3.10.5. Functional testing of the power turbine governor and fuel control unit included a complete 'run as received' test[13]. Output signals and fuel flow at selected control setting positions were also checked. Both units operated as expected on the test bench, with no 'out of limit' or abnormal component conditions found. No evidence of fuel contamination was found within the units.

Fuel nozzle

3.10.6. The fuel nozzle was tested in New Zealand by a maintenance facility equipped for and experienced in repairs of this component. The results are discussed in section 4.

Sprag clutch

3.10.7. The function of the sprag clutch was to isolate the engine from the rotor system during autorotative[14] flight. During the initial post-accident inspection of the aircraft, the sprag clutch was checked by manually rotating the output shaft. It operated correctly and was free to rotate.

3.10.8. The sprag clutch was removed from the aircraft and sent to an independent component overhaul facility[15] to be stripped and inspected. During that inspection one of the oil seals was found to be deformed (Figure 6), the oil had drained out and internal fretting damage was observed (Figure 7). The mode of failure was notified to Robinson Helicopters and it carried out flight tests on another helicopter to determine if it was relevant to this accident. Further details of the sprag clutch fault and flight tests are provided in section 4.

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[13] A test of the component's functionality in the condition it was at that time and before any disassembly or further inspections.
[14] A process of producing lift in an unpowered rotor system by inducing an airflow up through the main rotor blades as the helicopter descends.
[15] The independent investigation of the sprag clutch was carried out by Rotor and Wing Maintenance Limited.

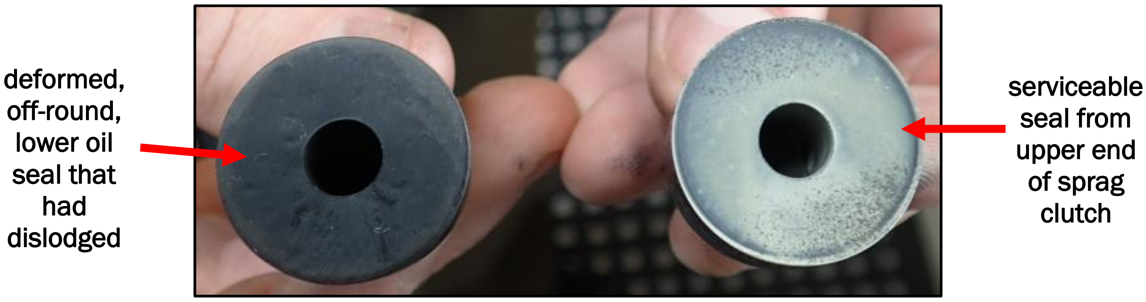

Figure 6
Sprag clutch oil seals

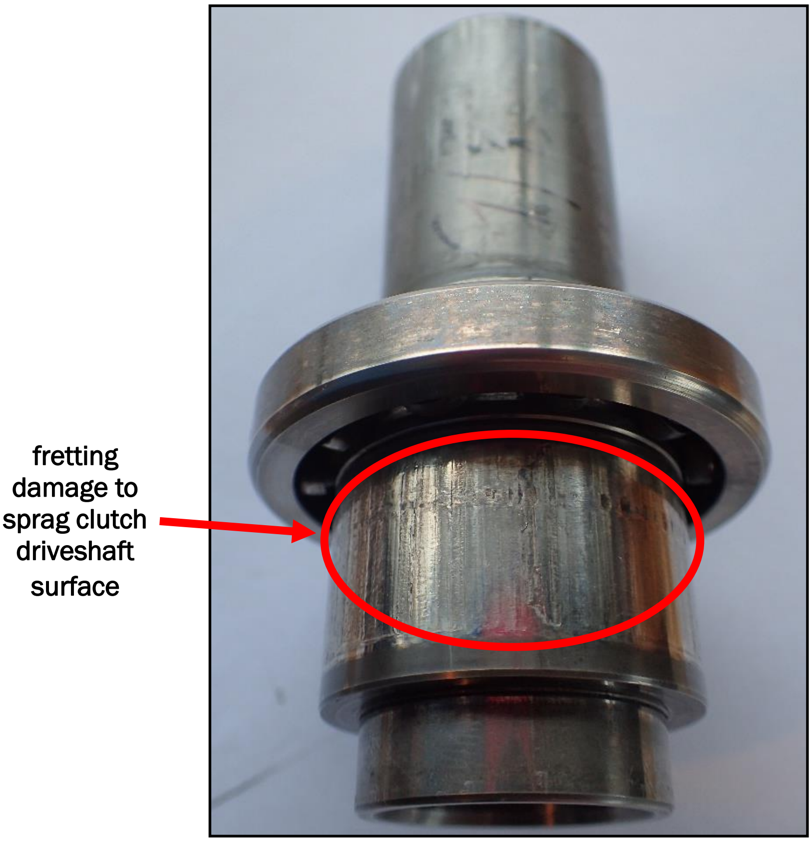

Figure 7
Sprag clutch internal damage

4. Analysis

4.1. Introduction

4.1.1. The pilot was forced to attempt a run-on landing when the helicopter had insufficient height and forward speed to recover from a low rotor RPM situation. It was the second low rotor RPM in quick succession.

4.1.2. The pilot said that the first RPM decrease had been dismissed as being a result of control inputs demanding power more quickly than the engine was able to provide. So when the rotor RPM recovered, the flight was continued to descend and line up for the spray run.

4.1.3. The engine was still operating during the initial impact with the ground and continued to produce power until the pilot shut it down.

4.1.4. This analysis discusses what could have caused the two low rotor RPM events. Data from the EMU indicated that a momentary reduction in available power occurred. This is discussed in more detail below. Consideration is also given to whether the faulty sprag clutch was a factor in the accident.

4.1.5. The analysis also discusses a safety issue whereby more educational material is needed to alert operators to the risk of contaminated fuel when operating and refuelling in remote, dusty environments.

4.2. Momentary reduction in engine power

4.2.1. The downloaded EMU data record was combined with position data obtained from the TracMap spray guidance system to analyse the sequence of events leading up to and during the accident. A graphic representation of the final minute of EMU data is shown in Appendix 3.

4.2.2. The two spray runs immediately before the accident flight were normal. As shown in the graph in Appendix 4, the output shaft RPM increased to about 100% and was controlled to remain near that value until the pilot closed the throttle. The graph also shows the torque increasing and decreasing as the aerodynamic load changed throughout the flight. The gas temperature followed the torque loading. This demonstrates how the power turbine governor and fuel control unit worked together to maintain output shaft RPM at 100%.

4.2.3. The accident sequence started first with a decrease in the gas temperature, followed by a decrease in the gas generator RPM. The output shaft RPM then decreased to 94.4%. During normal engine operation a decreasing output shaft RPM would be detected by the power turbine governor, which would then signal the fuel control unit to schedule more fuel to increase the output shaft RPM. The addition of more fuel to the engine would result in an increase in the gas temperature.

4.2.4. However, in this case both the gas producer RPM and the output shaft RPM were initially decreasing, but the expected corresponding increase in the gas temperature did not immediately occur. This indicates that the fuel flow had not been increased to correct the decrease in output shaft RPM. The output shaft RPM was below the normal operating parameters for approximately three seconds before the gas temperature started to increase.

4.2.5. The gas temperature peaked from this initial recovery then immediately began to decrease again. The gas producer RPM and output shaft RPM followed the decrease in gas temperature. At this point the pilot received the second low rotor RPM warning and had no option but to attempt a run-on landing.

4.2.6. The graph shows the point at which the main rotor blades struck the ground as a spike in the torque value. At the same time the gas temperature increased, and after approximately three seconds the output shaft RPM rapidly increased and remained within the normal operating parameters for another five seconds until the engine was shut down by the pilot. This rapid increase in shaft RPM coincided with the partial loss of the main rotor blades after striking the ground.

4.2.7. No mechanical defects were found in the engine, the power turbine governor or the fuel control unit that could have prevented normal operation. In the absence of any mechanical defects, the lack of an increasing gas temperature to correct the decrease in RPM suggests that there was either insufficient fuel flow available or poor fuel quality.

4.2.8. There were four possible reasons for the low gas temperature:

- the throttle was closed
- fuel exhaustion
- fuel control system fault
- contaminated fuel or restricted fuel flow.

4.2.9. In relation to the first point, closing the twist-grip throttle would have resulted in a decrease in engine RPM and temperature similar to that seen in the EMU data.

4.2.10. The majority of the pilot's flight experience was flying variants of Robinson helicopters, all of which employed similar twist-grip throttles. The same spray routine had been conducted for most of the day. Therefore, it is very unlikely that the pilot inadvertently closed the throttle at a time when more power was being demanded to overcome a low rotor RPM warning.

4.2.11. In relation to the second point, it is virtually certain that fuel exhaustion was not a factor. There were at least 36 litres remaining in the fuel tank after the accident, which equated to approximately 24 minutes of run time[16]. Also, the engine continued to run until the pilot shut it down manually, and when the engine was later inspected the fuel hose leading to the fuel nozzle was still full of fuel.

4.2.12. In relation to the third point, it is very unlikely that a fault with the fuel control system was a factor in the accident. The power turbine governor and fuel control unit were removed from the engine and sent to Honeywell Aerospace for testing. They were visually inspected then set up on test rigs and operated in the condition in which they had been received. After checking key control test point results, they were stripped and inspected for internal damage or faults. No faults were found and the control settings were within normal tolerances. No evidence of fuel contamination was found in these two components.

4.2.13. Additionally, the fuel control unit operated correctly by maintaining the output shaft RPM at 100% immediately before the pilot shut down the engine.

Contaminated fuel or restricted fuel flow

4.2.14. During the engine investigation, contaminants were found in: the fuel filter housing (Figure 4); the fuel hose assembly running to the fuel nozzle (Figure 5); and the fuel nozzle itself. With respect to these contaminants the Defence Technology Agency concluded:

> … the majority of particles were comprised mainly of silicon and aluminium with varying quantities of other metal elements such as sodium, magnesium, calcium, iron and zinc. The appearance and composition of the particles strongly suggest that they are an aluminosilicate clay material. Clays are common components of most soils.

4.2.15. The fuel nozzle was removed from the engine after the accident and tested by an independent maintenance provider using the standard test procedure for a Rolls-Royce fuel nozzle. More dried contaminants were found within the fuel hose assembly and the outer air shroud of the fuel nozzle. The nozzle was installed on a test rig to assess the spray pattern and flow rates at various fuel pressures, using clean fuel.

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[16] Civil Aviation Rules 137.65 requires a helicopter conducting agricultural operations to maintain minimum fuel reserves of "3 times the anticipated flight time or 30 minutes' flight time, whichever is the lesser".

4.2.16. Some anomalies were apparent in the spray pattern, which became more defined as the fuel pressure was increased.

4.2.17. It is likely that the anomalies were the result of fine contaminates restricting the movement of the needle valve and slider within the fuel nozzle's inner spray tip assembly. The anomalies as observed may have caused some hot spots within the combustion chamber, but were unlikely to have been sufficient to cause the reduction in power that led to the low rotor RPM.

4.2.18. The fuel sample recovered from the hose between the fuel control unit and the fuel nozzle was a muddy brown colour. This contamination could have had two effects: either a slug of contaminated fuel passed into the combustion chamber that did not have the same heat output as clean fuel, or the sludge temporarily restricted the fuel flow through the spray tip assembly within the fuel nozzle. Either scenario could have caused a short-term reduction in available power.

4.3. Source of fuel contamination

Fuel filtering

4.3.1. The fuel samples taken from the helicopter main tank and from the supply tank on the support vehicle did not contain any of the contaminants found in the downstream components, or any other impurities that would have been detrimental to the normal functioning of the engine.

4.3.2. Fuel-filtering elements are designed to prevent contaminants reaching engine components that could affect the normal running of an engine. The engine fuel filter element was found to be clear of residue. This is partially explained by the fact that the engine fuel filter element had a nominal rating[17] of five microns[18] and an absolute rating[19] of 15 microns, whereas a high percentage of the contaminate particles found within the fuel hose assembly were three to five microns, smaller than the filter rating. A lesser number of larger particles measured 20-30 microns.

4.3.3. Installing an additional airframe fuel filter to provide secondary protection is an option available on other light turbine helicopters when operating from unpaved surfaces. Rolls-Royce, on 7 February 2011, had issued Notice to Operators – No: RR300-015, recommending the fitting of such additional fuel filters when:

> … operating aircraft from isolated locations where the fuel is stored in drums or similar extended fuel storage containers.

4.3.4. In relation to the R66 helicopter, the fuel system is gravity fed. Therefore, installing an additional airframe fuel filter would restrict the fuel flow, potentially requiring an additional fuel pump to maintain the required fuel pressure. In view of this technical limitation, Robinson Helicopters has not developed an optional airframe fuel filter for the R66.

4.3.5. Operators of helicopters need to be alert to the risk of fuel contamination when operating in remote areas and mitigate the risk with good fuel-handling procedures.

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[17] The diameter of the largest spherical particle that will pass through the filter a defined percentage of the time.
[18] A metric unit of measurement equal to one-millionth of a metre.
[19] The diameter of the largest spherical particle that will pass through the filter under laboratory conditions.

Refuelling procedures

Safety issue: more educational material is needed to alert operators to the risk of contaminated fuel when operating and refuelling in remote, dusty environments.

4.3.6. The operator's procedures left several opportunities for fuel contamination.

4.3.7. The operator's fleet consisted of both turbine and piston-engine helicopters that used different fuel types. Procedures were in place to avoid cross-contamination of fuel types. The fuel found in the accident helicopter was of the right type for the engine.

4.3.8. The operator's procedures for supplying jet fuel to the helicopter involved multiple transfers:

- the jet fuel was purchased from a commercial supplier at the local airport and pumped into a 4,000-litre, truck-mounted fuel tank
- from this tank, the fuel was pumped into a smaller supply tank mounted on the back of the support vehicle to enable refuelling at remote sites
- depending on the loading site, the helicopter would be refuelled directly from the smaller supply tank or from 20-litre fuel containers
- the 20-litre fuel containers were refilled from the smaller supply tank.

4.3.9. No contaminants were identified in the fuel supply path from the bulk supply tanker at the operator's base to the helicopter fuel tank on the day.

4.3.10. The R66 fuel filler port differed from that used on R22 and R44 helicopters. The filler port was larger and sat flush within a flat area under a hinged cowling (Figure 8). The R22 and R44 fuel ports, by comparison (Figure 9), were mounted on the top surface and had raised edges around them.

4.3.11. A foot step for accessing and inspecting the rotor head was located adjacent to the refuelling port on the R66. This foot step was a point where dirt could potentially accumulate. The pilot also made use of this foot step area to stow a fuel pourer spout. The pilot said that the spout was always inspected before use. It was nevertheless a possible source of contamination.

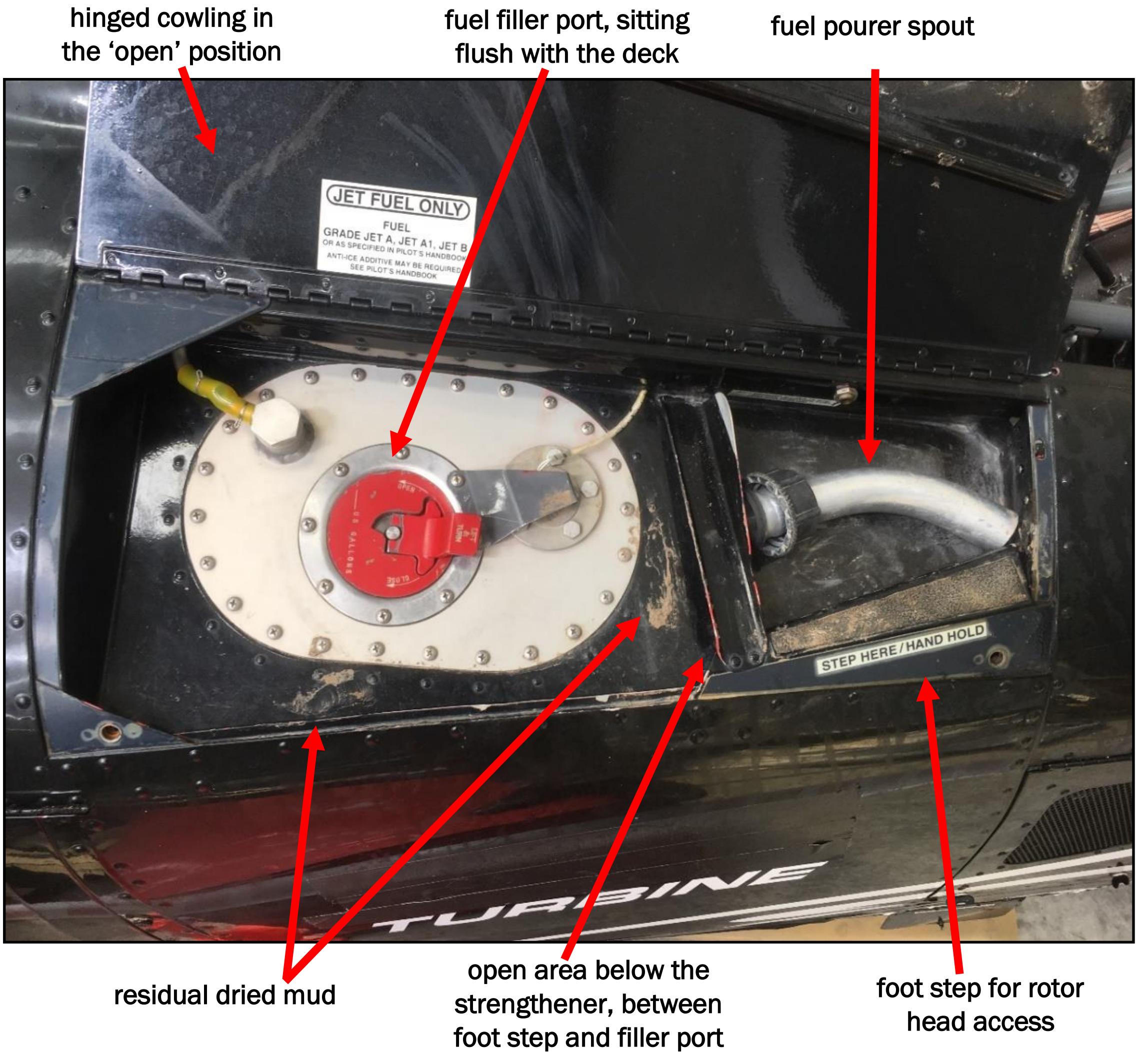


Figure 8
Fuel filler port on R66 ZK-HAG

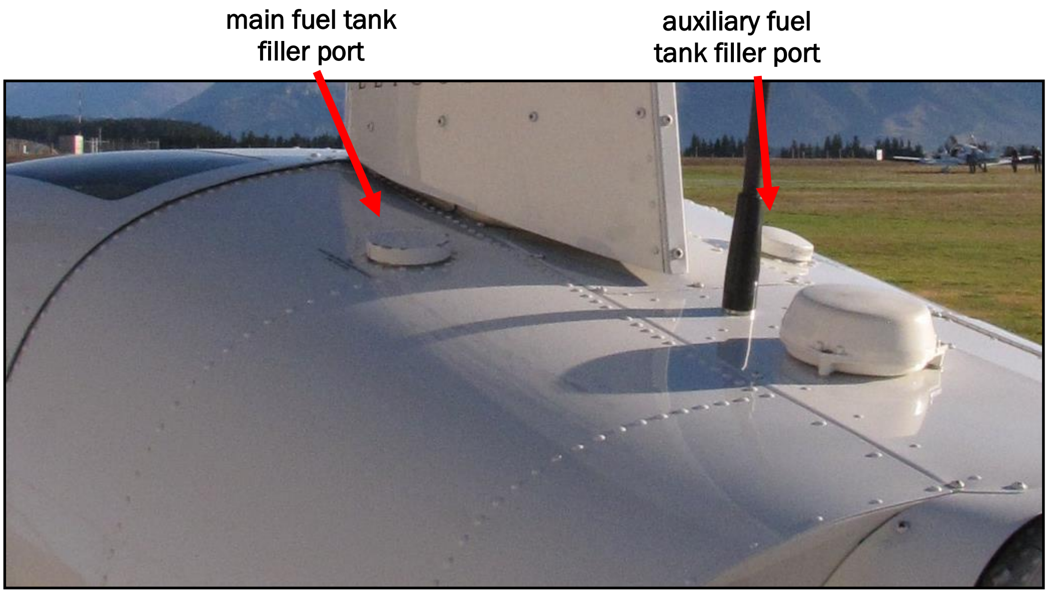


Figure 9
Comparison Robinson Helicopters R22 refuelling ports

4.3.12. Another potential point of contaminate entry was the fuel nozzle for the supply tank mounted on the support vehicle. The vehicle routinely operated from gravel roads, paddocks and generally unpaved surfaces, but the nozzle was not covered or protected from contamination (Figure 10).

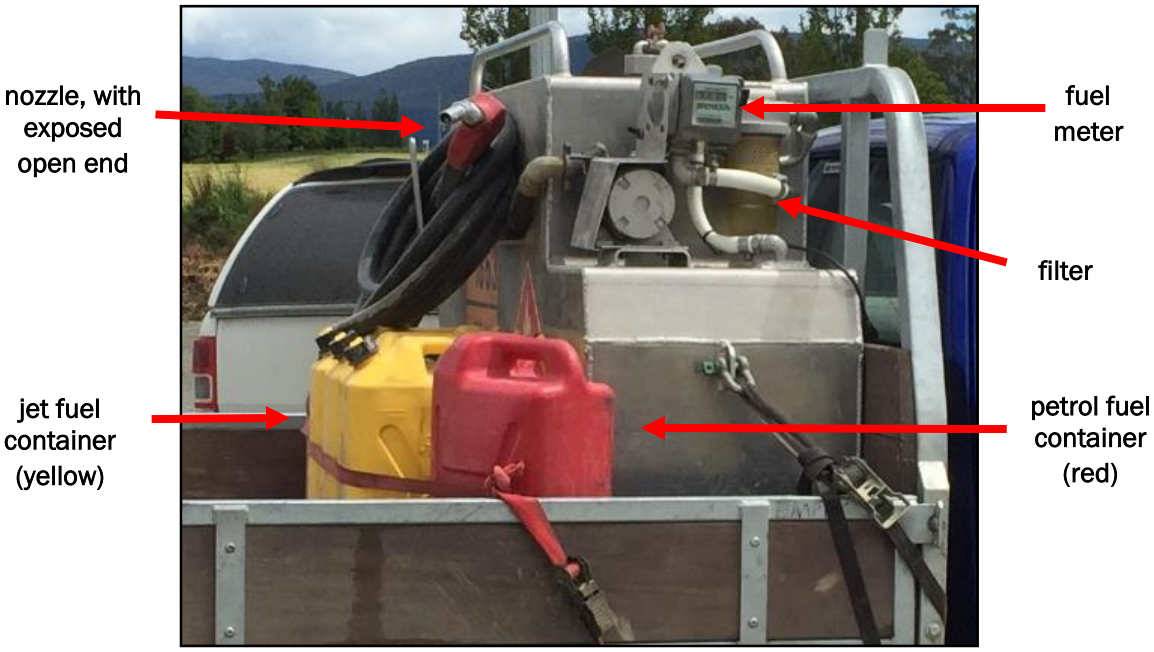


Figure 10
Supply tank mounted on support vehicle

4.3.13. The frequent refuelling cycles for this helicopter, with the engine running and rotor blades turning in a dusty environment, increased the risk of the fuel becoming contaminated. This operating environment created the potential for a one-off fuel contamination event or for cumulative contamination to build up over time.

4.3.14. The operator had experienced two previous instances of fuel contamination with the accident helicopter, both of which were corrected by the maintenance provider. The first instance had been on 10 August 2015 at 1,080 flight hours and the second on 15 January 2016 at 1,385 flight hours. The maintenance provider had not analysed the composition of the earlier contaminants, but described them as being different from the clay found after the accident flight.

4.3.15. The pilot subsequently explained that the earlier two incidents had been due to water in a truck-mounted fuel tank that initiated the growth of a fuel bug[20]. Corrective action was reported to have included: treating the fuel bug with a biocide[21]; draining and cleaning the fuel tank; and raising awareness of the water contamination issue at an internal safety meeting.

4.3.16. Three fuel contamination occurrences in a 15-month period suggest that opportunities existed to improve the operator's fuel handling practices. It is good practice for operators to have documented procedures, guidance material and recorded training for the handling of aviation fuels. The operator did not have any such documentation.

[20] A commonly accepted term for a number of contaminants that include microbial bacteria, fungi and algae.
[21] A chemical substance or microorganism intended to destroy, deter, render harmless or exert a controlling effect on any harmful organism by chemical or biological means.

4.4. Sprag clutch

4.4.1. The investigation examined whether the damage observed in the sprag clutch was a result of the accident or was a pre-existing condition that contributed to the decrease in rotor RPM.

4.4.2. The Commission obtained the EMU data from the accident helicopter. This data was then forwarded to Robinson Helicopters to compare with data from a test helicopter. The engine RPM for both helicopters decreased at about the same rate, which indicates that the accident helicopter sprag clutch was operating normally. For the accident helicopter the engine RPM was noted to decrease faster than the main rotor RPM, which is considered normal. The two RPM indications were displayed on one gauge in the cockpit, which made a difference (or 'RPM split') immediately obvious to a pilot.

4.4.3. If the sprag clutch had failed and been unable to disengage the driveline, the engine RPM would have decreased at a slower rate on shut-down because it would still have been driven by the rotor system. Robinson Helicopters therefore concluded that the sprag clutch on the helicopter was functioning correctly the last time the helicopter was shut down.

4.4.4. For these reasons it is very unlikely that the damage found in the sprag clutch assembly contributed to the low rotor RPM event.

4.4.5. Turning to the issue of the damage found to the sprag clutch, the shutdown procedure in the pilot's operating handbook[22] included a requirement for the pilot to confirm that the sprag clutch had disengaged by checking for the needle split indication on the combined engine/main rotor RPM gauge. This was a daily check on sprag clutch performance.

4.4.6. No scheduled inspections of the sprag clutch were prescribed in the maintenance manual. The sprag clutch was a life-limited component and a replacement was included in the 2,000-hour maintenance and inspection kit.

4.4.7. Robinson Helicopters advised that it was aware of previous cases where the R66 sprag clutch oil seal had failed. The R66 sprag clutch had been redesigned in November 2015 and the manufacturing process improved to prevent oil seal failure. The earlier-design sprag clutches were still performing their intended function and Robinson Helicopters was not aware of any functional problems caused by oil loss. Consequently, it did not see the need to issue a service bulletin requiring the immediate replacement of sprag clutches. All new and replacement units would be of the improved design.

4.4.8. A defect report detailing the condition of the sprag clutch was submitted to the Civil Aviation Authority by the component overhaul facility conducting the inspection.

4.4.9. In view of the above, the Commission saw no need to recommend any further action.

[22] A controlled document accessible to the pilot from within the cockpit to provide information, including system descriptions, limitations, and normal and emergency procedures.

5. Findings

5.1. The accident occurred when the helicopter developed a condition of low rotor revolutions per minute when it did not have sufficient height and forward speed for the pilot to recover the situation.

5.2. There was no mechanical fault found within the helicopter power plant that could have affected the engine performance.

5.3. The condition of low rotor revolutions per minute very likely resulted from a momentary reduction in available engine power caused by contaminated fuel.

5.4. The operator's refuelling procedures for remote sites left several opportunities for fuel contamination to occur.

6. Safety issue

6.1. More educational material is needed to alert operators to the risk of contaminated fuel when operating and refuelling in remote, dusty environments.

7. Safety actions

General

7.1. The Commission classifies safety actions by two types:

(a) safety actions taken by the regulator or an operator to address safety issues identified by the Commission during an inquiry that would otherwise result in the Commission issuing a recommendation

(b) safety actions taken by the regulator or an operator to address other safety issues that would not normally result in the Commission issuing a recommendation.

Safety actions addressing safety issues identified during an inquiry

7.2. None identified

Safety actions addressing other safety issues

7.3. A defect report detailing the condition of the sprag clutch was submitted to the Civil Aviation Authority by the component overhaul facility conducting the inspection.

7.4. Prior to this accident the R66 sprag clutch had been redesigned and the manufacturing process improved to prevent oil seal failure.

8. Recommendations

General

8.1. The Commission may issue, or give notice of, recommendations to any person or organisation that it considers the most appropriate to address the identified safety issues, depending on whether these safety issues are applicable to a single operator only or to the wider transport sector. In this case, recommendations have been issued to the operator.

8.2. In the interests of transport safety, it is important that these recommendations are implemented without delay to help prevent similar accidents or incidents occurring in the future.

Recommendation to the Director of Civil Aviation

8.3. This accident was the result of fine clay particles within the engine fuel system causing a momentary reduction in engine power. Fuel contamination is a greater risk for operators that conduct refuelling in the field or at remote locations.

8.4. Clear guidance material for remote refuelling procedures is not readily accessible to general aviation operators. Advisory Circular AC91-22 and the Fuel Management – Good Aviation Practice booklet both contain some information under the heading 'Fuelling Procedures'. However, this content is limited with regard to remote operations, mobile tanks, in-field fuel handling, crew training and equipment recommendations.

8.5. On 24 October 2018 the Commission recommended that the Director of Civil Aviation review and enhance all CAA-published guidance information to better inform the industry on hazards associated with remote refuelling. (027/18)

On 8 November 2018, Civil Aviation Authority replied:

> The CAA can confirm that recommendation 027/18 will be implemented as follows:
>
> All relevant information regarding remote refuelling will be placed on the CAA website by the end of November 2018.
>
> Advisory Circulars will be reviewed by the end of January 2019, and the updating of all documentation will be completed by end of February 2019.

Recommendation to the President of Aviation New Zealand

8.6. This accident was the result of fine clay particles within the engine fuel system causing a momentary reduction in engine power. Fuel contamination is a greater risk for operators that conduct refuelling in the field or at remote locations.

8.7. Clear guidance material for remote refuelling procedures is not readily accessible to general aviation operators. AC91-22 and the Fuel Management – Good Aviation Practice booklet both contain some information under the heading 'Fuelling Procedures'. However, this content is limited with regard to remote operations, mobile tanks, in-field fuel handling, crew training and equipment recommendations.

8.8. Aviation New Zealand represents the interests of the commercial aviation community, and the New Zealand Helicopter Association is a division of Aviation New Zealand.

8.9. On 24 October 2018 the Commission recommended that the President of Aviation New Zealand promulgate the lessons learned from this accident to its members with a view to increasing awareness of the risk of fuel contamination during remote refuelling procedures. (028/18)

On 27 November 2018, Aviation New Zealand replied:

> We accept the Aviation NZ recommendation in the referenced TAIC report; will be advising our members through the weekly newsletter, in the divisional newsletters to

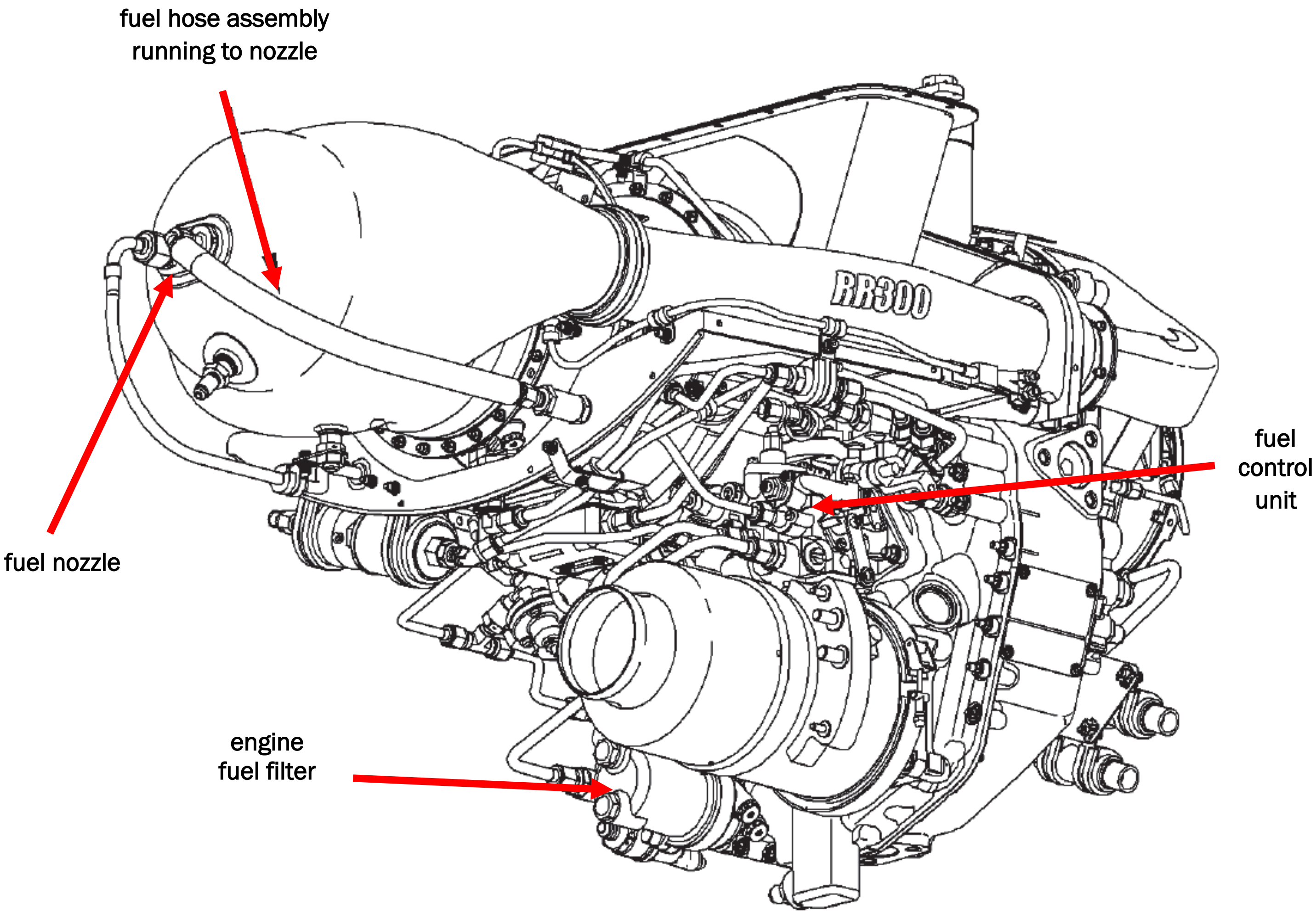
the NZAAA and NZHA divisions as well as communicating it in divisional meetings; reaffirming it in the upcoming Council meeting; that we expect to finish these actions by the end of January; and that we will ensure the importance of this issue is communicated through the safety seminars we will be running with members next year.

9. Key lessons

9.1. Refuelling aircraft at remote locations increases the risk of fuel contamination. Operators should take all precautions to prevent any debris entering the fuel supply chain, from the initial fuel supplier to the aircraft fuel tank.

9.2. Aircraft fuel-filtering systems are an important defence against contaminated fuel causing an accident. Where available, operators should consider fitting additional airframe filters to aircraft being operated and refuelled at remote locations.

Appendix 1: RR300 engine schematics



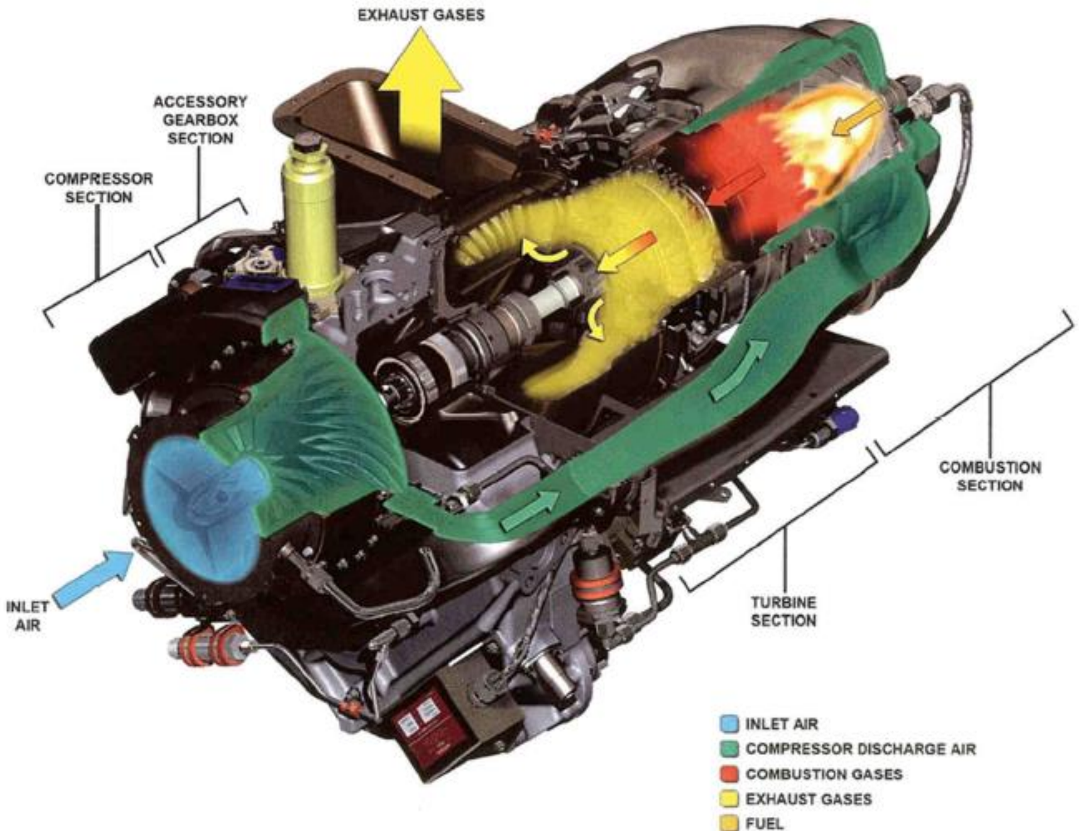
Copied from Rolls-Royce RR300 Operation and Maintenance Manual

Engine Airflow & Combustion

Air drawn into the inlet is compressed and delivered to the combustion chamber via the diffuser and air discharge tubes.

Fuel is added resulting in thermal expansion.

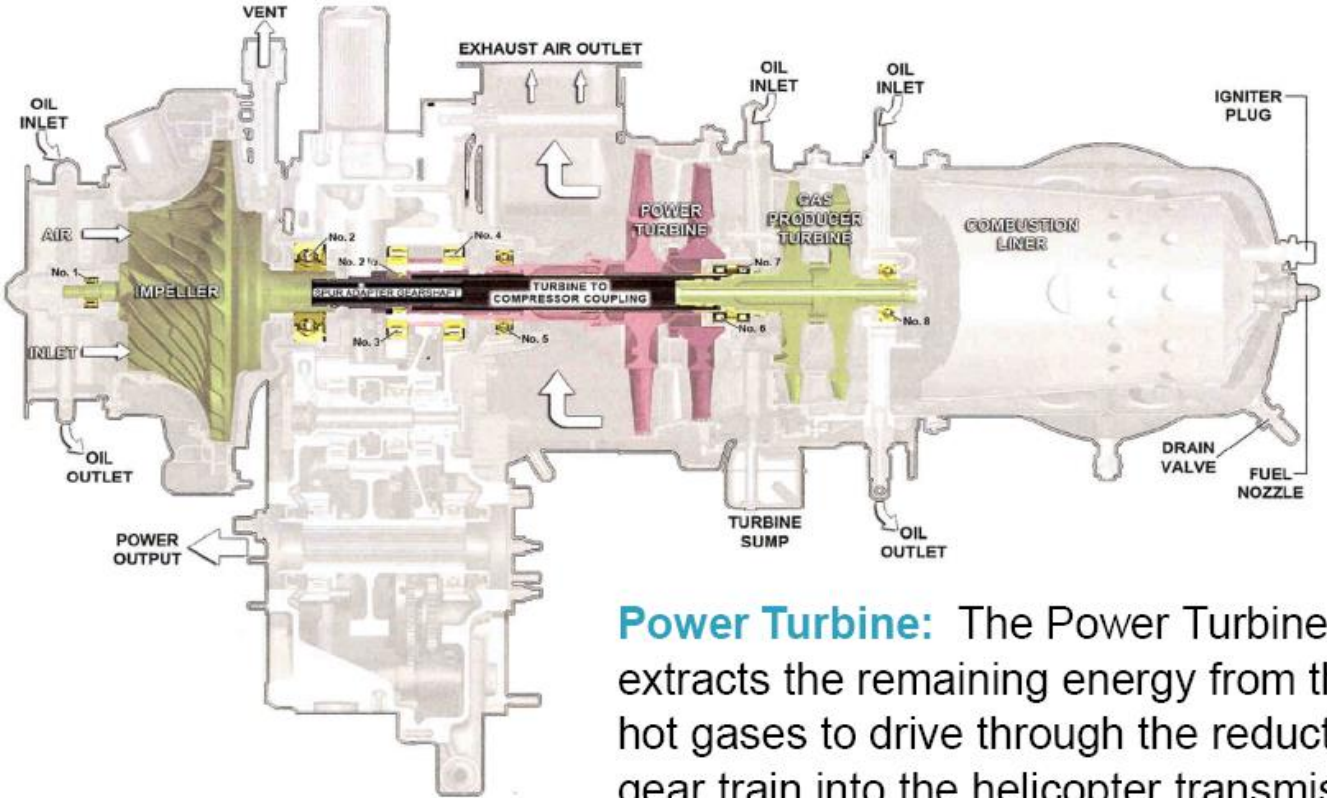
The hot gas is directed through the turbine sections where the energy is extracted by the turbine wheels to drive the compressor and helicopter transmission.



Copied from Robinson Helicopters R66 Familiarization and Pilot Check-out Course

Turbines

Gas Producer Turbine: The main function of the GP turbine is to drive the compressor, oil pump and fuel system accessories.



Power Turbine: The Power Turbine extracts the remaining energy from the hot gases to drive through the reduction gear train into the helicopter transmission.

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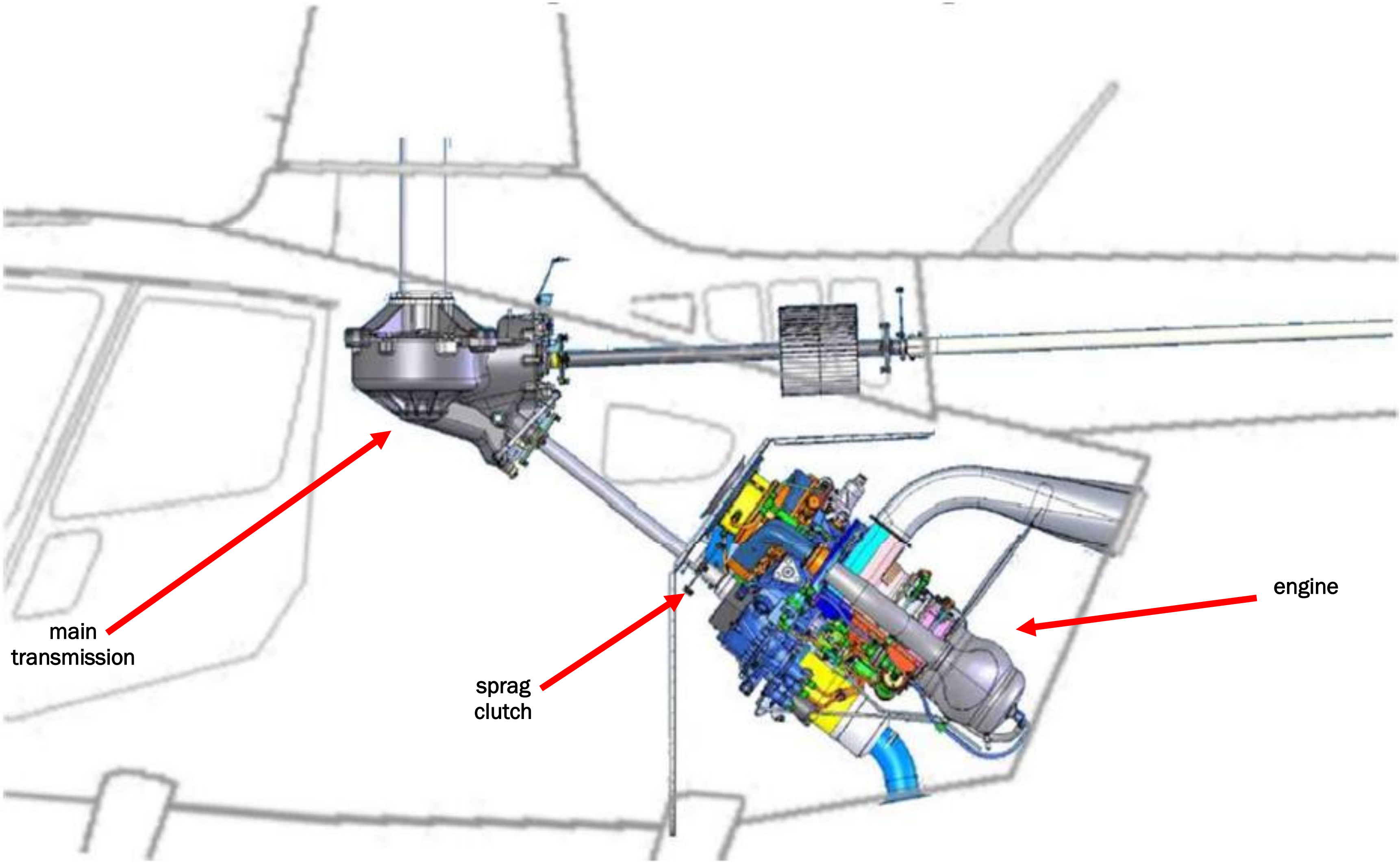
Appendix 2: R66 drive system schematic



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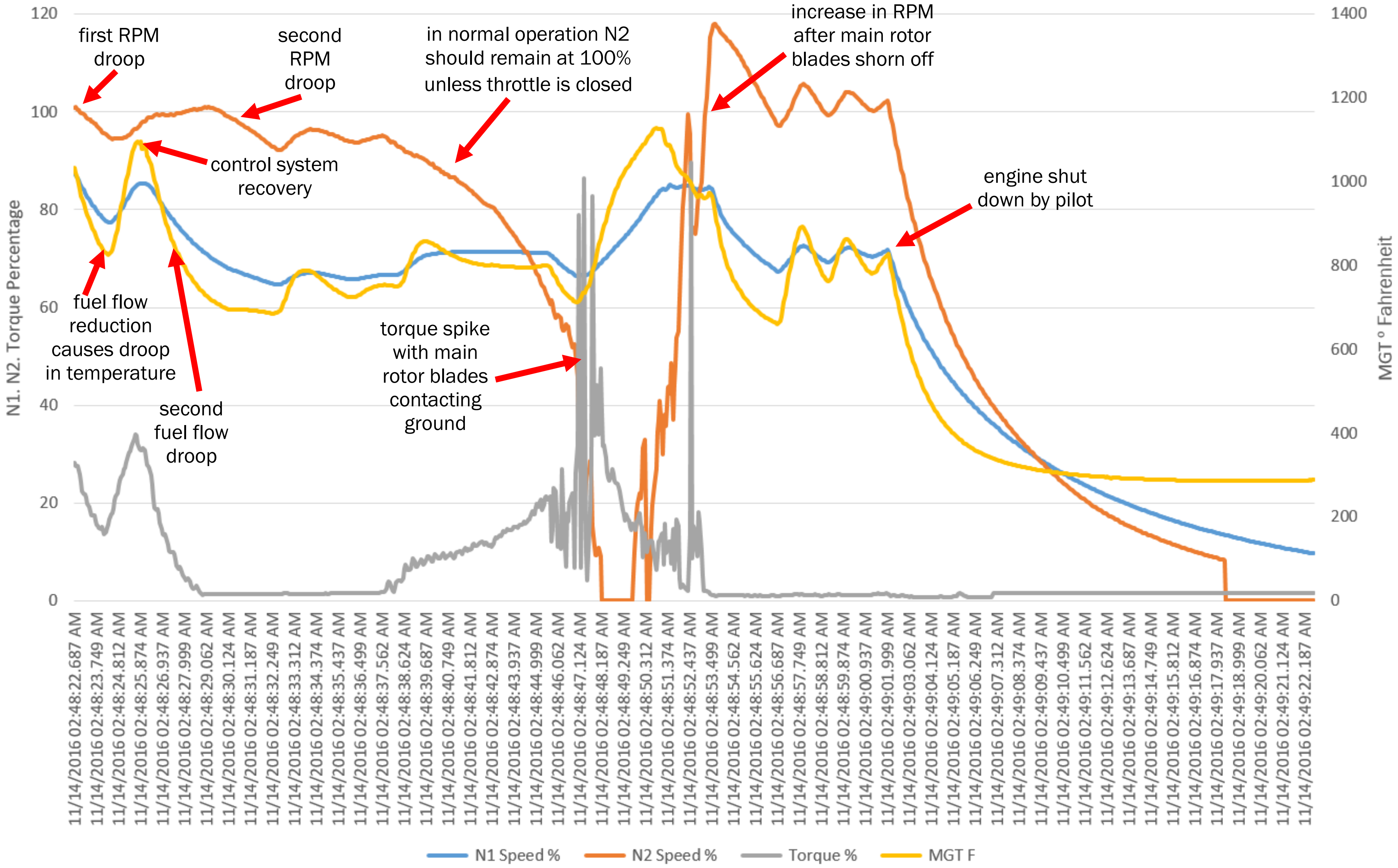
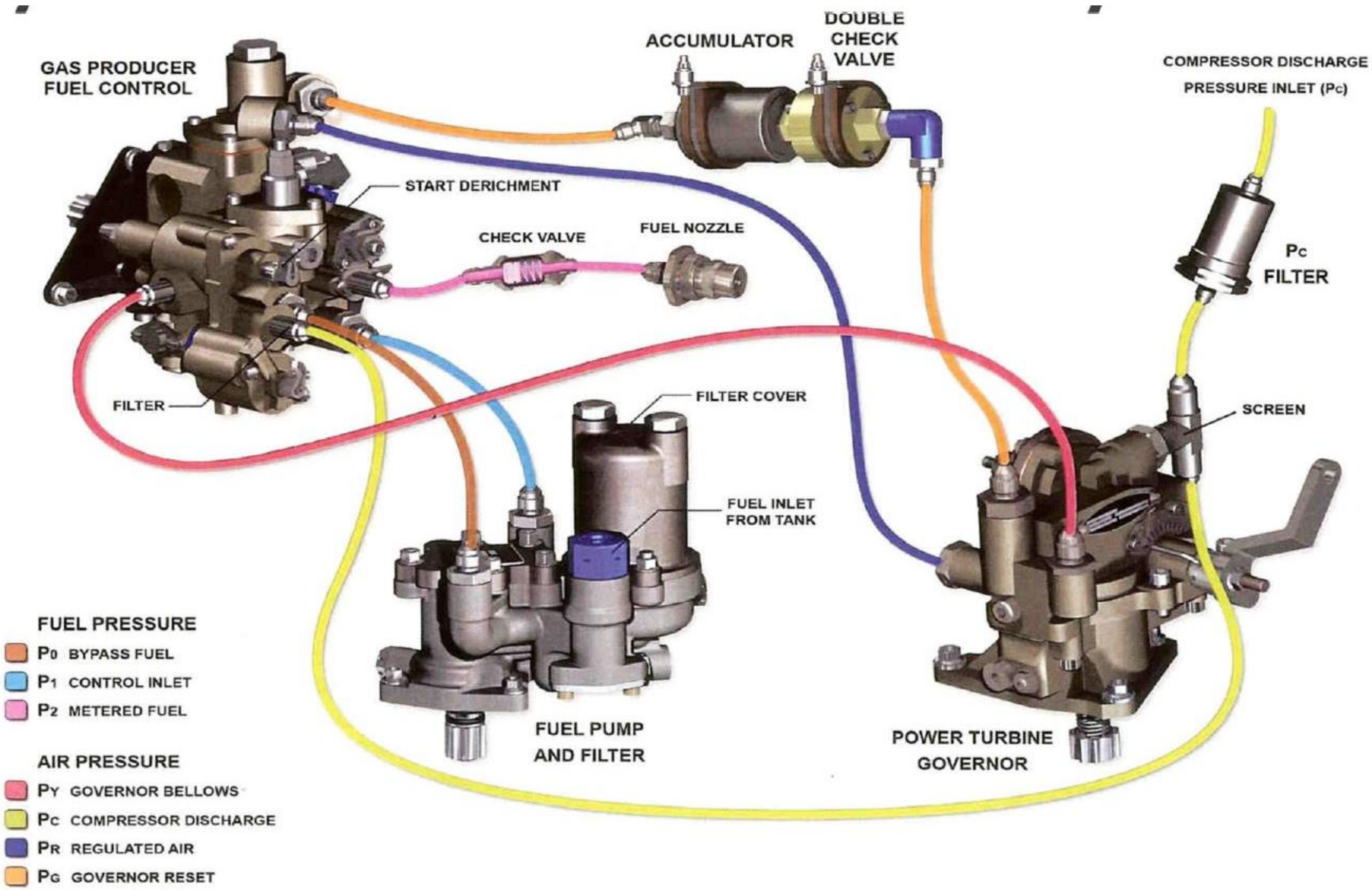
Appendix 3: Final minute of EMU data



Appendix 4: EMU data from preceding two flights

Appendix 5: Hydromechanical fuel system



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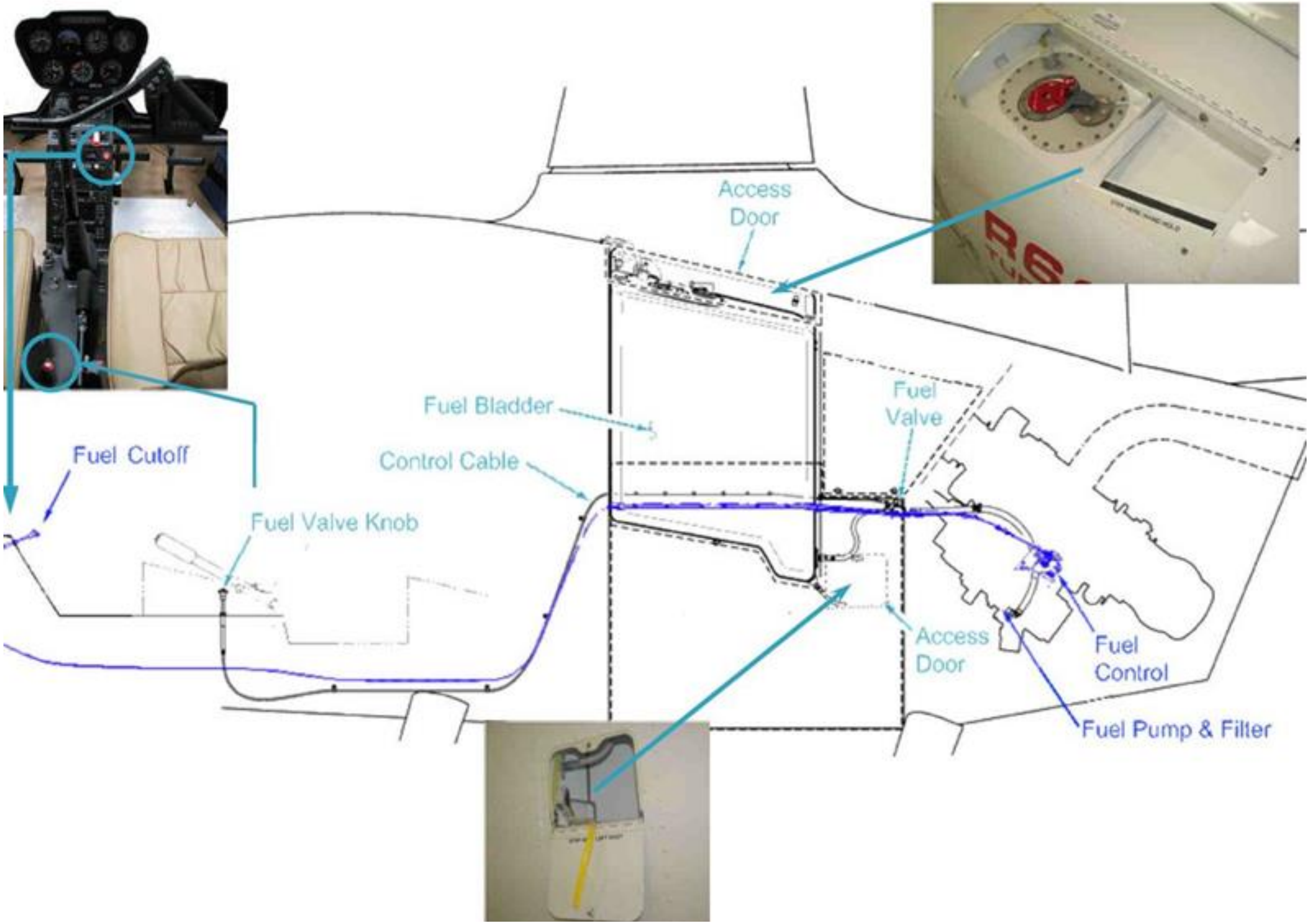
Appendix 6: R66 fuel system layout



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AO-2013-010	Aérospatiale AS350B2 'Squirrel', ZK-IMJ, collision with parked helicopter, near Mount Tyndall, Otago, 28 October 2013
Addendum to final report AO-2015-002	Mast bump and in-flight break-up, Robinson R44, ZK-IPY, Lochy River, near Queenstown, 19 February 2015
Interim Report AO-2017-001	Collision with terrain, Eurocopter AS350-BA, ZK-HKW, Port Hills, Christchurch, 14 February 2017
AO-2013-011	Runway excursion, British Aerospace Jetstream 32, ZK-VAH, Auckland Airport, 2 November 2013
AO-2014-006	Robinson R44 II, ZK-HBQ, mast-bump and in-flight break-up, Kahurangi National Park, 7 October 2014

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