



ROTECH FLIGHT SAFETY INC.

Rotech Flight Safety INC.
6235 Okanagan Landing Road
Vernon, BC V1H 1M5 Canada
Phone: 250-260-6072

INVESTIGATION REPORT

ACCIDENT INFORMATION

Date of accident:	September 25 th 2023	NTSB file number:	WPR23LA352
Location of accident:	Torrance, California	FAA Inspector:	Unknown
Location of Investigation:	Air Transport, Phoenix, AZ & Rotech Flight Safety, Vernon B.C, Canada	Law Enforcement:	Unknown
Investigator In charge:	Stephen Stein	Coroner/Medical Examiner	Unknown

AIRCRAFT INFORMATION

Aircraft Make:	Sling	Aircraft registration:	N135WT
Aircraft Model:	4 TSI	Aircraft S/N	131S
Propeller make, model & S/N	Airmaster AP430 CTF S/N 1971 Electronic Constant Speed		

ENGINE INFORMATION

Engine Type:	Rotax 915iS 3 A	Engine TTSN	688.50
Engine Serial Number:	9133652	Engine TTSOH	0
Engine Manufacture date:	August 23 rd 2021	Engine position:	Tractor

ADDITIONAL INFORMATION

Persons in attendance:	Stephen Stein – Senior Aviation Accident Investigator – NTSB		
	Jordan Paskevich – Rotech Flight Safety – Rotax Aircraft Engines		
	Matt Liknaitzky – Sling Pilot Academy		
	Jean d'Assonville – Sling Pilot Academy		
	Evan Brunye – EBM Aviation		
Date of Report:	11/5/2024		
RFS File number:	2023-052		

DATE	ENGINE MODEL	ENGINE SERIAL NO	REGISTRATION	File number
Sep /25/ 2023	Rotax 915iS 3 A	9133652	N135WT	2023-052

NTSB Preliminary

On September 25, 2023, about 1250 Pacific daylight time, an experimental amateur-built Sling 4 TSI, N135WT, was substantially damaged when it was involved in an accident near San Pedro, California. The pilot and passenger were seriously injured. The airplane was operated as a Title 14 Code of Federal Regulations Part 91 instructional flight.

According to preliminary Automatic Dependent Surveillance Broadcast data, the airplane departed about 1223. After a flight near the coastline, the instructor turned to a northerly heading to return to the airport. At 1245 the airplane turned to a northerly heading and about one minute later it began a descent from an altitude of about 2,400 ft mean sea level. At 1246:46, the pilot reported to air traffic control that he had “an engine failure” and requested approval to land. The controller immediately cleared the airplane to land and the pilot acknowledged the clearance. He then asked the pilot for his desired runway and the pilot responded with the “south runways”, referring to runways 29R and 29L. There were no further transmissions from the pilot.

A witness video that recorded the accident flight from about 1249 showed a trail of white smoke behind the airplane as it maintained a northerly heading. Approximately 12 seconds later the smoke ceased and the airplane subsequently began a right descending turn. The airplane then entered a steep right turn in a nose down attitude and rapidly descended towards the ground as it disappeared from view.

The airplane impacted a field about 3 nm southeast from the pilot’s destination airport, Zamperini Field Airport (TOA), Torrance, California.

The wreckage was retained for further examination.



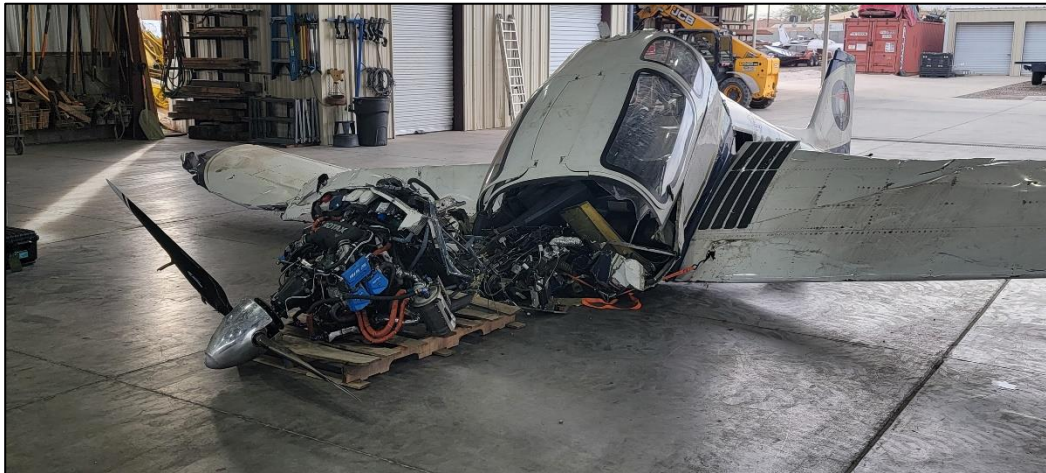
Photograph 1: Accident airplane seconds before impact

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Initial Inspection

On January 17, 2024, an on-site investigation was conducted at Air Transport in Phoenix, Arizona, under the supervision of NTSB Aviation Accident Investigator Stephen Stein. The inspection revealed extensive impact damage to the aircraft. While the engine was in generally good physical condition and remained attached to its mount, both the engine mount and firewall had separated from the main wreckage.

The aircraft was equipped with a three-bladed electric constant-speed propeller. One blade was completely sheared off at the root, while the remaining blades showed no signs of rotational scoring.



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Detailed Engine Inspection

Spark Plugs: The spark plugs were removed and placed in a holding tray for orientation. They were visually inspected for condition and any signs of abnormal operation. Each plug was marked "ROTAX" on the insulator with part number 297 656. For additional specifications, please refer to the BOSCH report.



#1 Cylinder - Top Spark Plug: The #1 top spark plug appeared in normal condition, with electrode coloration indicating a proper fuel-to-air ratio. This suggests that combustion was occurring within expected parameters.



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Detailed Engine Inspection

#1 Cylinder - Bottom Spark Plug: The bottom spark plug for the #1 cylinder displayed a substantial buildup of a liquid substance consistent with engine oil, likely due to the engine's storage position, which may have allowed oil to migrate into the combustion chamber. Electrode coloration indicated a proper fuel-to-air ratio, with no evidence of oil consumption.



#2 Cylinder - Top Spark Plug: The top spark plug for the #2 cylinder exhibited impact damage on the electrodes, and metallic flakes were observed on the insulator. It was also wet with a liquid substance consistent with engine oil, likely due to the engine's storage position. Electrode coloration indicated a proper fuel-to-air ratio, with no evidence of oil consumption.



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Detailed Engine Inspection

#2 Cylinder - Bottom Spark Plug: The bottom spark plug for the #2 cylinder showed substantial impact damage on both the electrodes and insulator, with metallic flakes present on the insulator. It was also wet with a substance consistent with engine oil, likely due to the engine's storage position.



#3 Cylinder - Top Spark Plug: The top spark plug for the #3 cylinder was in normal condition, with electrode coloration indicating a proper fuel-to-air ratio, suggesting that combustion was within expected parameters. However, thermal paste was observed on the ground electrodes, indicating possible over-application.



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#3 Cylinder - Bottom Spark Plug: The bottom spark plug for the #3 cylinder displayed darker electrodes and insulator compared to the other plugs, with coloration indicating a richer fuel-to-air ratio. The plug was also slightly wet with a substance consistent with engine oil.



#4 Cylinder - Top Spark Plug: The top spark plug for the #4 cylinder exhibited substantial impact damage, with broken and crushed electrodes and insulator.



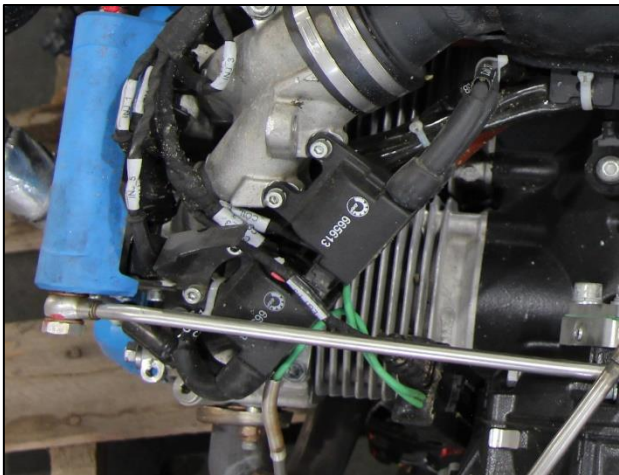
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Detailed Engine Inspection

#4 Cylinder - Bottom Spark Plug: The bottom spark plug for the #4 cylinder also exhibited substantial impact damage, with broken and crushed electrodes and insulator.



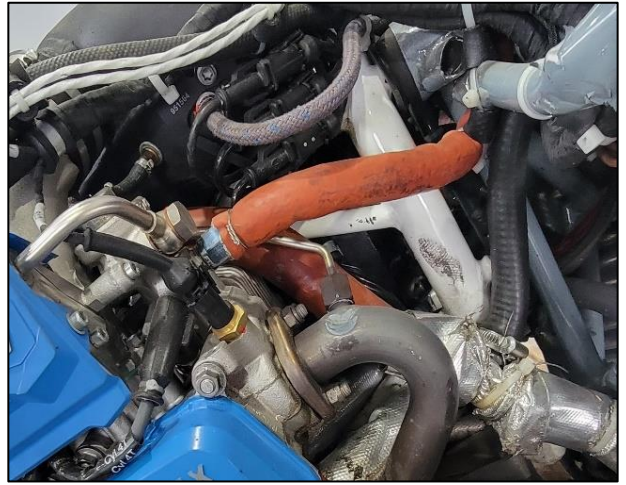
Ignition System: The ignition system components, including the ignition coils and plug leads, were inspected for physical condition but were not functionally tested. The system appeared to be in good physical condition, with no visible impact damage.



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Fuel System: The fuel lines were found breached at the firewall, with a small quantity of fuel recovered from the lines on the airframe side. The inlet and return fuel lines remained securely attached to their respective ports on the fuel rail (inlet side) and the fuel pressure regulator (return side). The crossover feed line between the inlet and return sides was also intact. All fuel lines were protected with a fire sleeve and appeared to be in good overall condition. The injectors and fuel pumps were not removed, inspected, or tested.



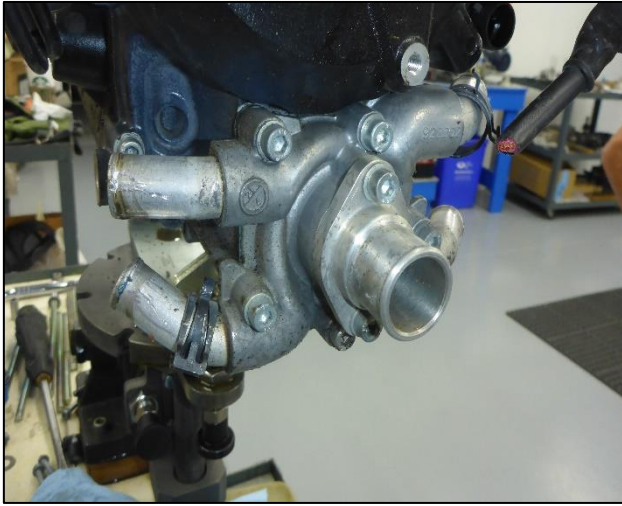
Cooling system: The coolant expansion chamber and expansion tank were both opened and found empty, with no coolant present. The cooling system had been breached due to impact damage sustained by the coolant radiator and coolant lines.



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Cooling system (Continued): The water pump housing was removed, and the impeller was inspected. No anomalies were observed.



Lubrication system: Approximately 250 mL of oil was drained from the oil tank into a clean glass container. The oil had a sludge-like consistency and a dark grey color. Additionally, a liquid resembling coolant antifreeze was found within the tank.



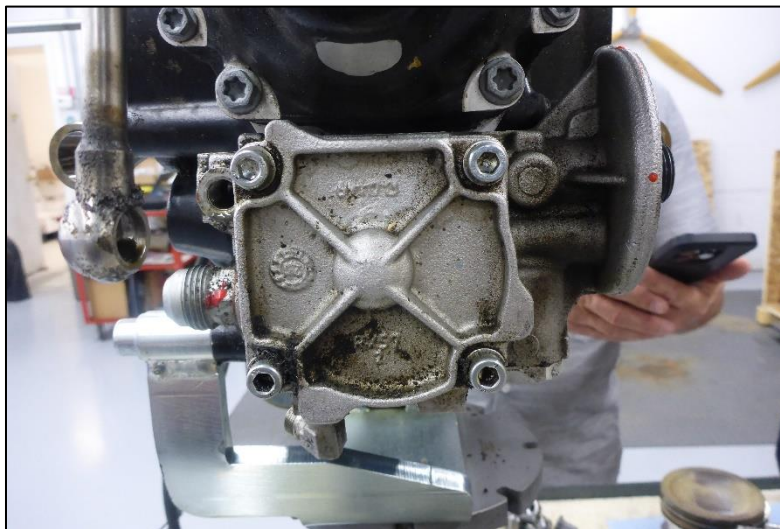
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Lubrication system (Continued): Upon internal inspection, a significant amount of foreign object debris (FOD) was observed at the bottom of the oil tank.



The oil pump was removed and inspected. No anomalies were discovered.



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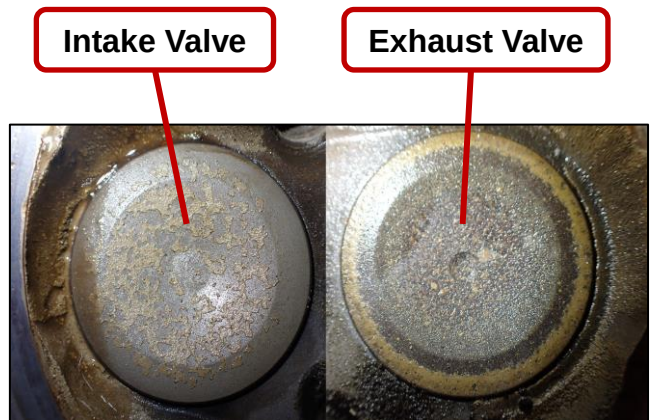
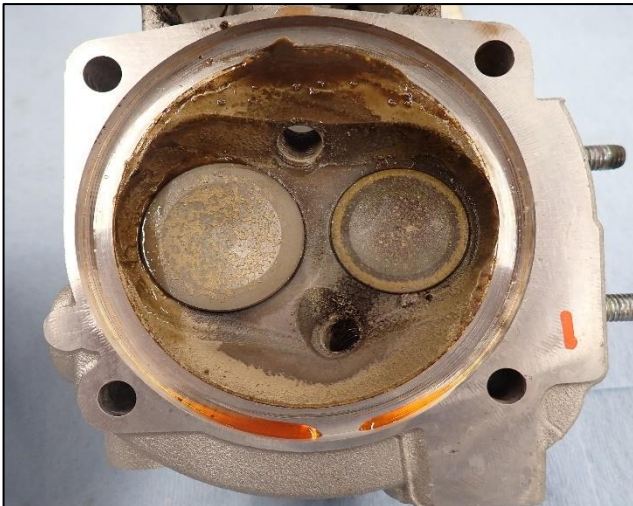
Detailed Engine Inspection

Cylinder Heads: The cylinder heads were removed from the cylinders to allow for examination of the heads, intake and exhaust valves, and the valve train.

#1 Cylinder head: The rocker cover was removed to expose the rocker arms, rocker arm shafts, valve spring retainer washers, valve spring keepers, valve springs, and pushrods. Evidence of lubrication oil was observed within the valve cover. All components appeared intact and in good physical condition.



Upon removing the intake and exhaust manifolds, the cylinder head was taken off the cylinder, exposing the #1 combustion chamber and valves.



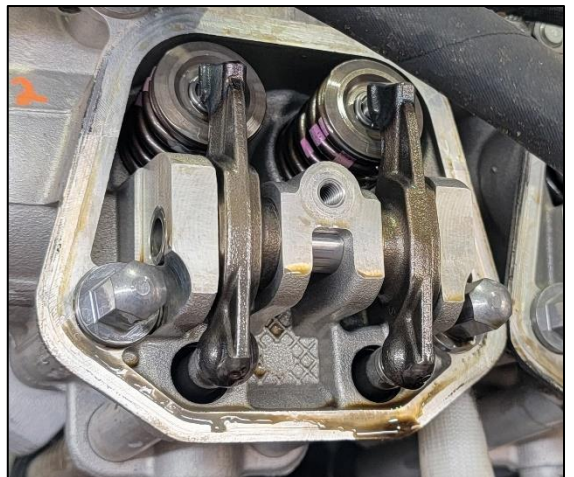
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Detailed Engine Inspection

#1 Cylinder head (Continued): A buildup of engine oil, coolant, and a small amount of metallic material was observed on the face and combustion section of the cylinder head. Additionally, a small buildup of what appeared to be lead was found on the face of the cylinder head and on the intake and exhaust valves, indicating the engine was operating with 100LL Av-Gas fuel. Unusual burn patterns and material buildup were observed near the top spark plug and the exhaust valve.



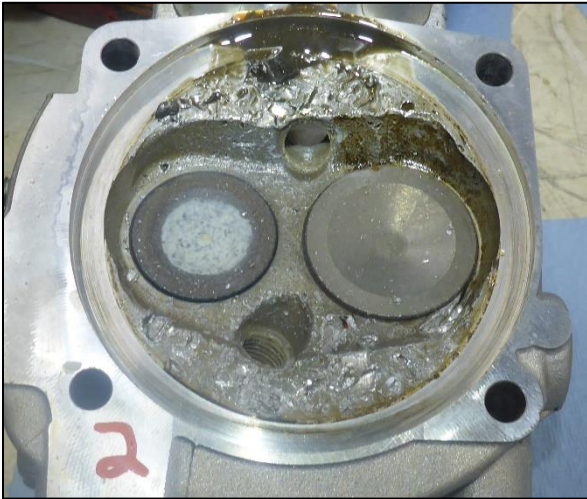
#2 Cylinder head: The rocker cover was removed to expose the rocker arms, rocker arm shafts, valve spring retainer washers, valve spring keepers, valve springs, and pushrods. Evidence of lubrication oil was observed within the valve cover. All components appeared intact and in good physical condition.



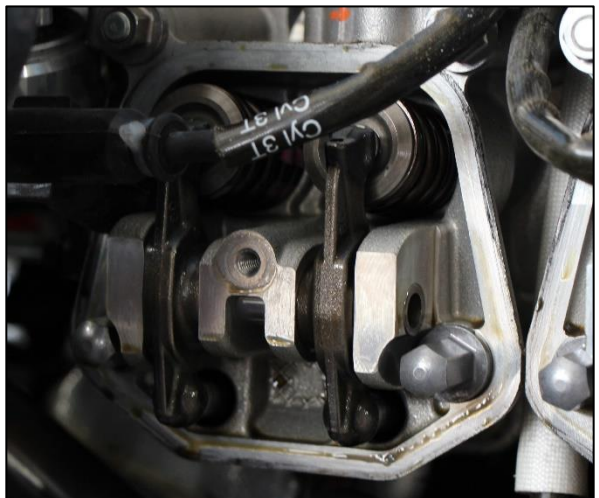
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Detailed Engine Inspection

#2 Cylinder head (Continued): Impact damage was observed on the face and combustion section of the cylinder head, including the exhaust and intake valve faces. A metallic object was embedded in the cylinder head beneath the bottom spark plug hole on the combustion side. Additionally, a buildup of engine oil and metallic material was present on the face of the cylinder head.



#3 Cylinder head: The rocker cover was removed to expose the rocker arms, rocker arm shafts, valve spring retainer washers, valve spring keepers, valve springs, and pushrods. Evidence of lubrication oil was observed within the valve cover. All components appeared intact and in good physical condition.



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Detailed Engine Inspection

#3 Cylinder head (Continued): A small buildup of what appeared to be lead was observed on the face of the cylinder head and on the intake and exhaust valves, indicating that the engine was operating with 100LL Av-Gas fuel. No impact marks, metallic material, or unusual burn patterns were observed on the face of the #3 cylinder head. However, upon removal of the intake valve, small metallic particles were found in the intake bore of the cylinder head, behind the intake valve.



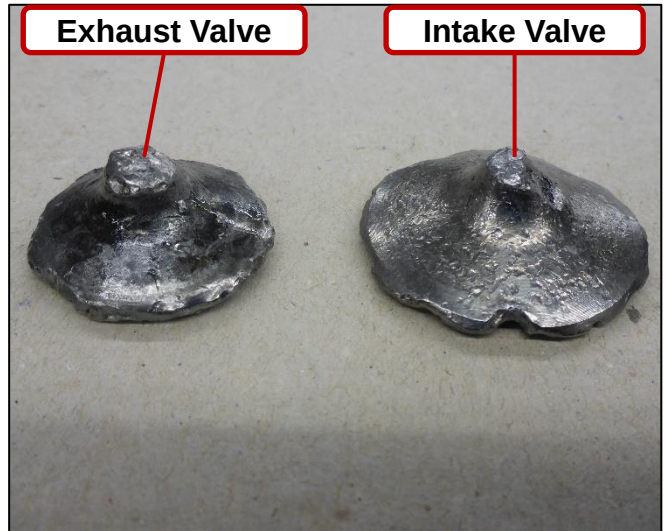
#4 Cylinder head: The rocker cover was removed to expose the rocker arms, rocker arm shafts, valve spring retainer washers, valve spring keepers, valve springs, and pushrods. Evidence of lubrication oil was observed within the valve cover. All components appeared intact and in good physical condition.



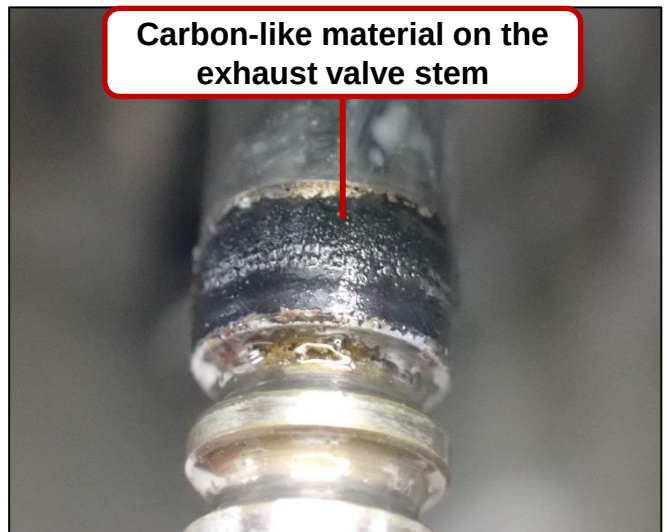
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Detailed Engine Inspection

#4 Cylinder head (Continued): The #4-cylinder head was heavily damaged, with both intake and exhaust valve heads broken off. The intake valve head remained in the combustion chamber, while the exhaust valve head was found deep within the intake manifold. A breach in the coolant water jacket likely caused the coolant found in the oil tank. Additionally, the intake valve and pushrod were bent, suggesting impact by a solid object.



An unusual accumulation of carbon-like material was observed on the exhaust valve stem near the valve spring retainer, just below the cotter keeper grooves. This buildup was unique to this valve, as no similar deposits were found on any other valves.



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Detailed Engine Inspection

Pistons: With the cylinder heads removed, the pistons were accessible for thorough examination.

#1 Piston: A buildup of engine oil was observed on the combustion side of the piston. Additionally, a small accumulation of what appeared to be lead was found on the piston face, indicating the engine was operating with 100LL Av-Gas fuel. Unusual burn patterns and material buildup were noted near the top 12 o'clock position of the piston face.



#2 Piston: Impact damage was observed on the piston face. Additionally, a buildup of engine oil was present on the combustion side of the piston.



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#3 Piston: A buildup of engine oil was observed on the combustion side of the piston. Additionally, a small accumulation of what appeared to be lead was found on the piston face, indicating the engine was operating with 100LL Av-Gas fuel.



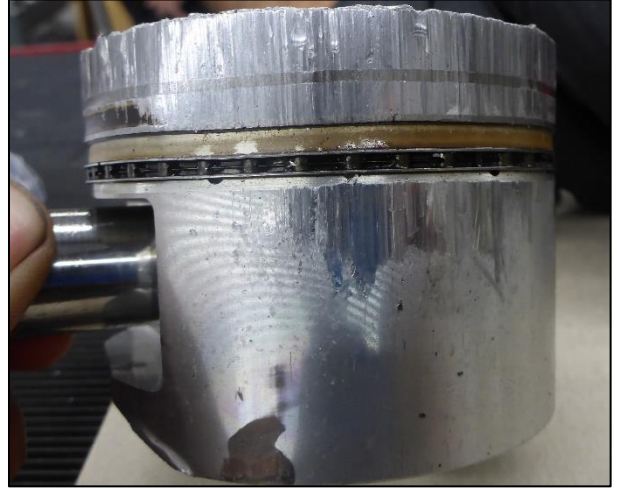
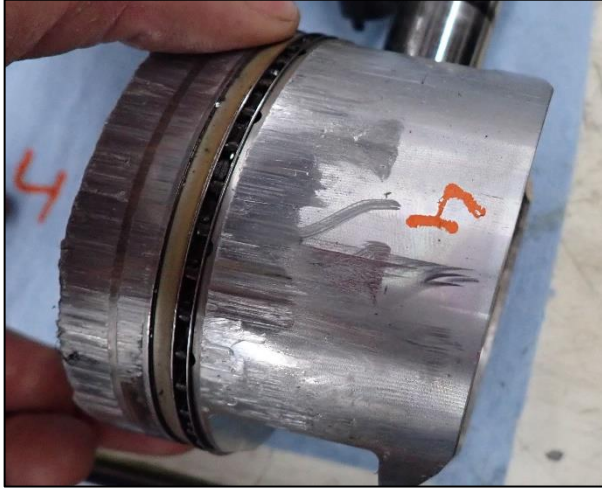
#4 Piston: The #4 piston sustained severe impact damage, resulting in a large hole in the center that exposed the connecting rod. The intake valve head was found resting at the bottom of the cylinder bore, on the combustion side of the piston.



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#4 Piston (continued): The #4 piston skirts and rings displayed vertical scoring marks, with both compression rings stuck within their land grooves.



Cylinders: With the cylinder heads removed, the cylinders were accessible for thorough examination.

#1 Cylinder: The #1 cylinder was removed and examined. No damage was observed on the cylinder bore, including any signs of excessive heat or metal transfer. Evidence of oil lubrication was present, and the cross-hatching remained visible



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Detailed Engine Inspection

#2 Cylinder: The #2 cylinder was removed and examined. No damage was observed on the cylinder bore, including any signs of excessive heat or metal transfer. Evidence of oil lubrication was present, and the cross-hatching remained visible. A small buildup of metallic material was observed on the piston bore.



#3 Cylinder: The #3 cylinder was removed and examined. No damage was observed on the cylinder bore, including any signs of excessive heat or metal transfer. Evidence of oil lubrication was present, and the cross-hatching remained visible



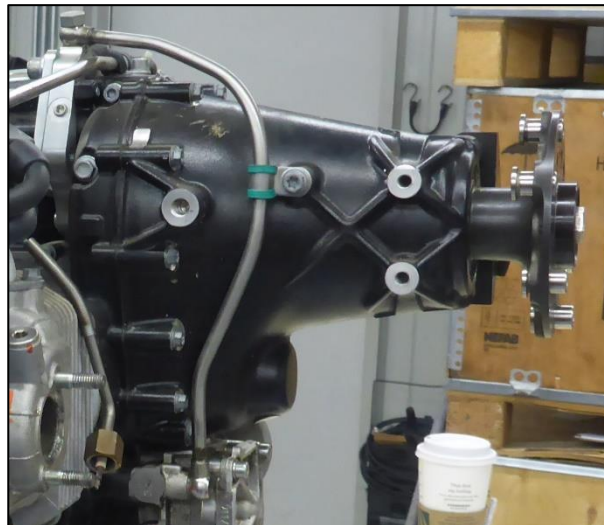
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#4 Cylinder: The #4 cylinder was removed and examined. Deep gouges, scoring, and signs of impact damage were observed on the cylinder walls.



Reduction Gearbox: The reduction gearbox was removed and inspected. The prop shaft was rotated, and no unusual noises or roughness were detected in the propeller shaft bearing. The small drive gear and large gear within the gearbox were inspected in situ, as the gearbox was not disassembled. No anomalies were observed with the reduction gearbox.



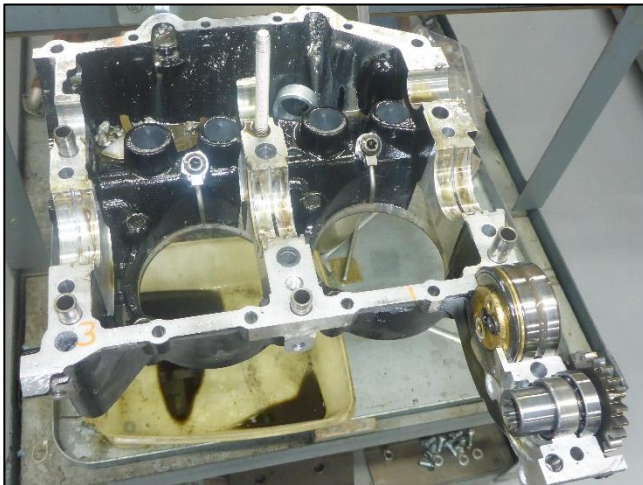
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Ignition housing: The ignition housing, containing the stator assembly and water pump drive gear, was visually examined but not function tested. The stator windings and wiring showed no signs of overheating, and no anomalies were observed with the stator assembly. The water pump drive gear was in good condition, and no anomalies were found within the stator housing or its internal components.



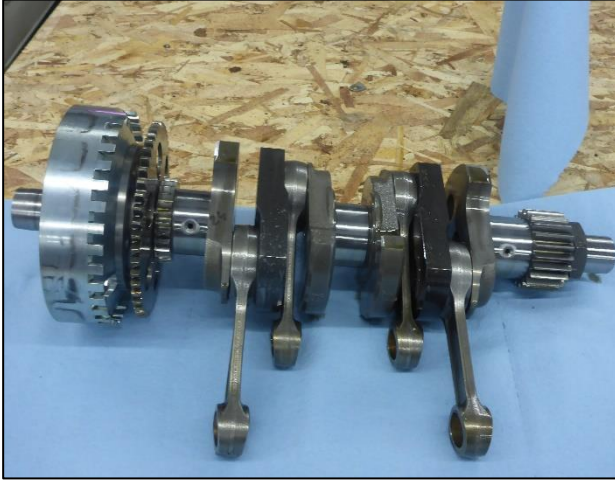
Crankcase: The crankcase halves were separated and inspected both externally and internally. Large pieces of metallic contamination were found at the bottom of the crankcase, with some fragments partially obstructing the oil return and transfer ports. The piston oil squirters were intact and undamaged. The camshaft bearings appeared to be in good condition, with minimal impact from the metallic contamination, while the crankshaft bearings showed some scoring. Beyond the metallic contamination and bearing surface scoring, no other anomalies were observed.



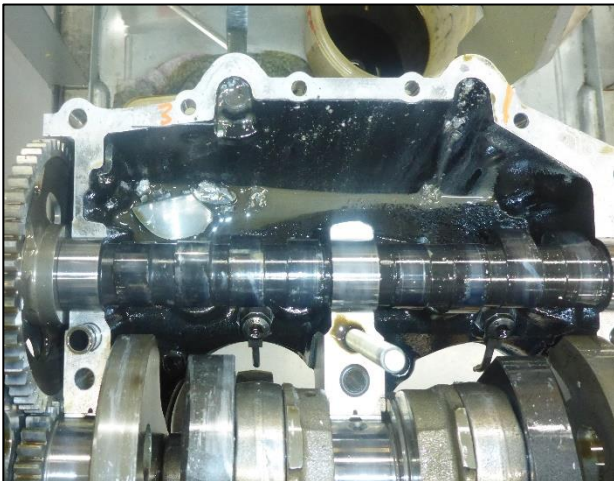
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Detailed Engine Inspection

Crankshaft: The crankshaft was removed from the crankcase for inspection. It was found to be in good physical condition, except for impact damage observed on the wrist pin journal of the #4 connecting rod.



Camshaft: The camshaft was removed from the crankcase for inspection. Several cam lobes had metallic material embedded in their surfaces. No other anomalies were observed with the camshaft.



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Summary of Engine Examination

The engine sustained substantial internal damage, particularly within the #4 cylinder, which suffered a critical structural failure. Both intake and exhaust valve heads detached, with the exhaust valve head becoming lodged in the airbox. Additionally, a breach in the coolant water jacket allowed coolant to mix with the oil in the tank. The #4 piston was also severely compromised, exhibiting a large hole that exposed the connecting rod, while scoring on the cylinder walls suggested additional internal impact.

Both the #2 spark plug—and especially the #4—showed extensive damage, likely due to intense internal forces caused by valve fragments colliding within the combustion chamber.

NTSB Lab

The following components were sent to the NTSB Laboratory for further analysis, where a comprehensive engine examination was conducted. The findings from this in-depth analysis take precedence over the visual inspection results presented in this report. Please refer to the NTSB lab report for a detailed analysis.

- **4 x Cylinder heads and related valvetrain**
- **4 x Pistons**
- **8 x Spark plugs**
- **8 x Hydraulic lifters**
- **8 x Pushrods**

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Airframe and Engine Maintenance Logs Review

A copy of the airframe and engine maintenance logbooks was provided for review.

Airframe Maintenance Log

N135WT Sling 4 TSI Engine: Rotax 915iS A Propeller: Airmaster AP430 CTF HOBS: 2416.1 TACH: 1194.6 02/20/2023		S/N: 1316 S/N: 9132537 Hub S/N: 1971 02/20/2023		Description of Inspections, Tests, Repairs and Alterations Entries must be endorsed with Name, Rating and Certificate Number of Technician or Repair Facility. (See back pages for other specific entries.)
Left/Right Main Tire Change Pilot reported right main tire showing chord. Performed left and right main tire change with QTY 2 new tires Air Trac 15X6.00-6 P/N AA1F4. Operational check complete, this aircraft is safe for flight and returned to service.		Engine Removal Removed propeller assembly S/N 1971, propeller cone/s/n 2344, engine assembly S/N 9132537, fuel pump assembly S/N 204327 with fuel pump S/Ns 21.3749 and 21.3754, fuse box S/N 19.1367, ECU S/N 19.5095, oil tank P/N 656852 and start relay P/N 992818, due to engine reaching TBO. Final engine run was reported with strong vibration. All work performed in accordance with Rotax 915 i A/C24 Series MMH Ed. 0 Rev. 2, Rotax 915 i A/C24 Series MMH Ed. 0 Rev. 2, Rotax 915 i A/C24 Series TM Ed. 0 Rev. 4, Sling 4 TSI AMH Rev. 1.1, and acceptable methods per AC43.13.		
All work performed in accordance with Matco M1626 & M1626-SC External Caliper Wheel and Brake Instructions, Sling 4 TSI maintenance manual Rev. 1.1, and acceptable methods per AC43.13. Roberto Lopez A&P 3570191				

According to the airframe maintenance logs, the previous Rotax 915iS engine (S/N 9132537), along with the fuel pumps, ECU, fuse box, starter relay, and oil tank, was removed from the aircraft after reaching its TBO at 1202.5 tach hours. The final engine run reportedly exhibited strong vibrations, though the cause of these vibrations is unknown. It is also unclear where the 915iS engine with S/N 9132537 is currently located or if it is available for inspection and ECU data review.

Airframe Maintenance Log

YEAR 20 DATE	RECORDING TACH TIME	TODAY'S FLIGHT	TOTAL TIME IN SERVICE	Description of Inspections, Tests, Repairs and Alterations Entries must be endorsed with Name, Rating and Certificate Number of Technician or Repair Facility. (See back pages for other specific entries.)
				N135WT Sling TSI Engine: Rotax 915iS A Propeller: Airmaster AP430 CTF HOBS: 2424.2 TACH: 0.0 03/23/2023 Sling 4 Installation Installed the following components onto Sling TSI N135WT S/N 1316: new engine Rotax 915i A S/N 9133652 using new mounting hardware, new fuel box P/N 656848 S/N 21.3555, new fuel pump assembly P/N 889667 S/N 21.2201 with fuel pump S/Ns 21.2334 and 21.2116, new ECU P/N 864357 S/N 21.5225, new fuel filter Bosch P/N F5023, new start relay P/N 992818 and new oil tank P/N 656852. Installed new propeller: Airmaster AP430 CTF S/N 2364 with blade S/Ns 83366, 83367, and 83566. Installed new propeller cone/s/n, Airmaster A2300P S/N 2516. Filed engine with Precision Dex-Cool Pre-diluted 50/50 and 4L of Arcticville Sport Hu-4. Performed oil purge, performed ground run and leak check, no discrepancies noted at this time. All work performed in accordance with: (A) Sling TSI AMH Rev. 1.1, Rotax 915i A/C24 Series MMH Ed. 0 Rev. 4, and Airmaster AP4 Series MMH Ed. 0 Rev. 2. Roberto Lopez A&P 3570191
				N135WT Sling TSI Engine: Rotax 915iS A Propeller: Airmaster AP 430 CTF HOBS: 2263.0 TACH: 1042.8 03/23/2023 800 Hour Anniversary I certify that this aircraft has been inspected on 23rd of March 2023 in accordance with CofS Sling TSI AMH, Rotax 915iS MMH, Airmaster AP4 Series Operators Manual, 100 hour checklists and acceptable methods per AC43.13. (A) Removed LH and RH wing assemblies for corrosion and wing root inspection, no issues noted, air installed LH and RH wing assemblies with new mounting hardware. Installed new industry wing base liners. (B) P/N 19.1367 ECU replaced. Replaced LH brake line from center line fitting to LH brake caliper with new part. Performed brake bleed with AC7. Installed new fusible cable housing and throttle cable master wire. Installed 3 of 2

On March 23, 2023, a new Rotax 915iS engine (S/N 9133652), along with new fuel pumps, ECU, fuse box, starter relay, and oil tank, was installed in the aircraft.

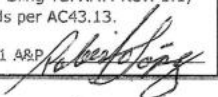
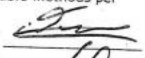
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Airframe and Engine Maintenance Logs Review

Most of the engine maintenance log entries pertain to general maintenance conducted during annual and 100/200-hour inspections. On August 3, 2023, with a Hobbs time of 2983.2 and tach time of 555.2, a maintenance entry notes that the pilot reported flashing lane lights, and a main voltage drop to 12.3 volts during descent. To address this issue, the mechanic downloaded the ECU log data, inspected the engine wiring harness connections for security, tightened all breaker connections, cleaned and re-secured battery connections, and performed a ground run. No defects were noted, and the aircraft was returned to service.

Following this entry, another maintenance entry was made on August 15, 2023, with a Hobbs time of 2994.0 and tach time of 565.9. This entry reports that the pilot observed a main voltage drop to 11 volts during cruise. The mechanic noted irregular resistance values in Stator A. To address this, the mechanic removed and replaced the stator assembly and installed new Regulators A and B. Additional maintenance items, including an oil change and coolant flush, were also performed. An engine run was completed before the aircraft was returned to service.

Engine Maintenance Log

Maintenance record:				
Date:	Engine hours:		Work performed:	Signature & Licence no.:
	TSN:	TSO:		
N135WT Sling TSi S/N: 131S Engine: Rotax 915iS A S/N: 9133652 Propeller: Airmaster AP 430 CTF S/N: 2364 HOBBS: 2983.2 Tach: 555.2 08/03/2023 Lane Lights Flashing Pilot reported Lane lights flashing and main voltage dropped to 12.3v on decent. Downloaded ECU logs using B.J.D.S. software V4.0.0. Inspected engine wiring harness connections for security. Tightened all breaker connections. Cleaned and re-secured battery terminals and connections. Performed ground run and run-up, no defects noted at this time. All work performed in accordance with TAF Sling TSi AMM Rev. 1.1, and acceptable methods per AC43.13. Roberto Lopez 3570191 A&P  N135WT Sling TSi S/N: 131S Engine: Rotax 915iS A S/N: 9133652 Propeller: Airmaster AP 430 CTF S/N: 2364 HOBBS: 2994.0 Tach: 565.9 08/16/2023 Low Voltage Pilot reported main voltage dropped to 11v in cruise. [No Title] Noted stator side A resistance values irregular. Removed stator assembly P/N 685067 S/N 21.0451. Installed new stator P/N 685067 S/N 22.1304, new Regulator A P/N 864392, and new Regulator B P/N 864397. Replaced oil seal P/N 230428, o-ring P/N 831929, o-ring P/N 250140, o-ring P/N 430225, QTY 2 o-rings P/N 431580, gasket P/N 850981, gasket ring P/N 230415, and QTY 2 gasket rings P/N 230150. Flushed coolant system with Prestone Dex-Cool Prediluted 50/50. Performed oil purge with Aeroshell Sport Plus 4. Performed ground run and leak check, no defects noted at this time. All work performed in accordance with TAF Sling TS AMM Rev. 1.1, Rotax 915 A/C24 Series MML ED.0 Rev.2, Rotax 915 A/C24 Series MMH ED.0 Rev.2, and acceptable methods per AC43.13. Dylan Cerven 3881 Rotax IRMT  Roberto Lopez 3570191 A&P 				

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Summary of Airframe and Engine Maintenance Logs

No additional snags were recorded in the engine or airframe logbooks. One notable observation during the engine maintenance log review was the consistently lower compression readings for the #4 cylinder, averaging around 8 PSI lower than the other cylinders. This discrepancy was evident from the first compression test at the 100-hour inspection and persisted throughout the engine's service life, particularly affecting the #4 cylinder with the failed exhaust valve.

Page 7 (Tach 106.0) • #1: 79/80 • #2: 80/80 • #3: 79/80 • #4: 73/80	Page 8 (Tach 209.3) • #1: 79/80 • #2: 80/80 • #3: 80/80 • #4: 80/80	Page 8 (Tach 305.7) • #1: 70/80 • #2: 80/80 • #3: 80/80 • #4: 70/80
Page 9 (Tach 405.6) • #1: 72/80 • #2: 80/80 • #3: 80/80 • #4: 72/80	Page 9 (Tach 501.3) • #1: 80/80 • #2: 80/80 • #3: 80/80 • #4: 72/80	Page 11 (Tach 603.1) • #1: 79/80 • #2: 80/80 • #3: 78/80 • #4: 72/80

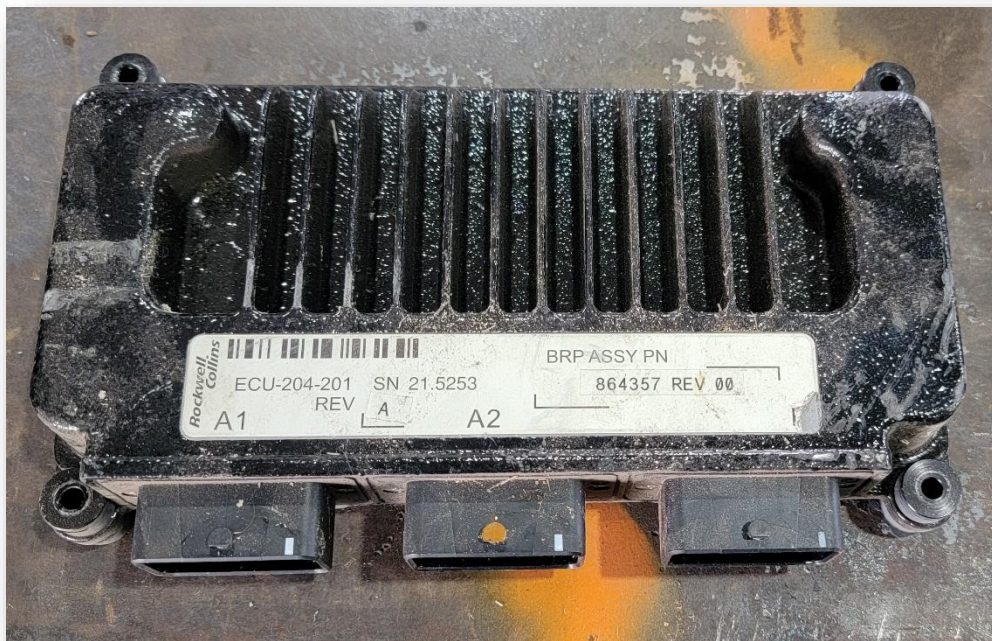
While these readings alone do not raise immediate suspicion, as Rotax allows for a high tolerance in compression checks (with a maximum permissible pressure drop of 45%, or 44 PSI), they could indicate a valve was not seating correctly. The inconsistency—particularly with the #4-cylinder reading returning to 80/80 at a tach time of 209.3 (page 8) and then dropping again afterward—might suggest an intermittent valve seating issue.

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Rotax Engine Control Unit (ECU)

The Rotax Engine Control Unit (ECU) is the central component of the engine management system. It receives continuous data from sensors that monitor pressure, RPM, temperature, load, and knock signals. Using this data, the digital ECU calculates the ideal air-fuel mixture and determines precise ignition timings for each cylinder.

The ECU consists of two modules, referred to as Lane A and Lane B. Both modules are active during normal operation. If Lane A encounters an issue, Lane B seamlessly takes over control to ensure the engine continues running smoothly. Many sensors and actuators in the engine are redundant, meaning each Lane receives identical sensor data and sends identical output signals. Non-redundant sensors are connected to one Lane for expanded engine monitoring. Communication between the two Lanes ensures data exchange, assuming both Lanes are operational and error-free.



The ECU was removed from the aircraft and connected to a laptop via a BUDS dongle to extract engine data for analysis. After extraction, the ECU data was analyzed using the Rotax BUDS Log Viewer program, version 1.1.0.

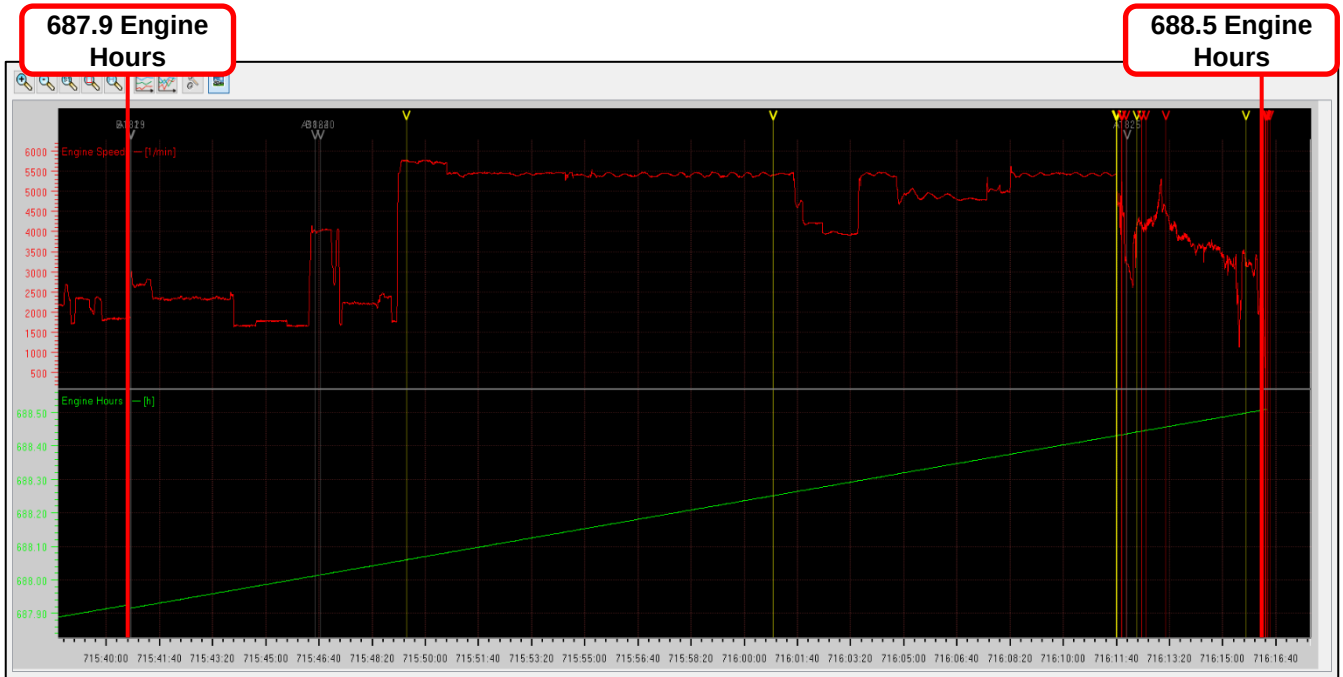
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ECU Data Analysis

Engine Hours:

According to the ECU data, the engine had accumulated a total of 687.90 engine hours and 715:40:47.200 ECU hours at the start of the accident flight. At the time of the incident, the ECU recorded 688.50 engine hours and 716:16:19.500 ECU hours, indicating that the engine was running for approximately 0.6 hours, or 36 minutes, during the accident flight.

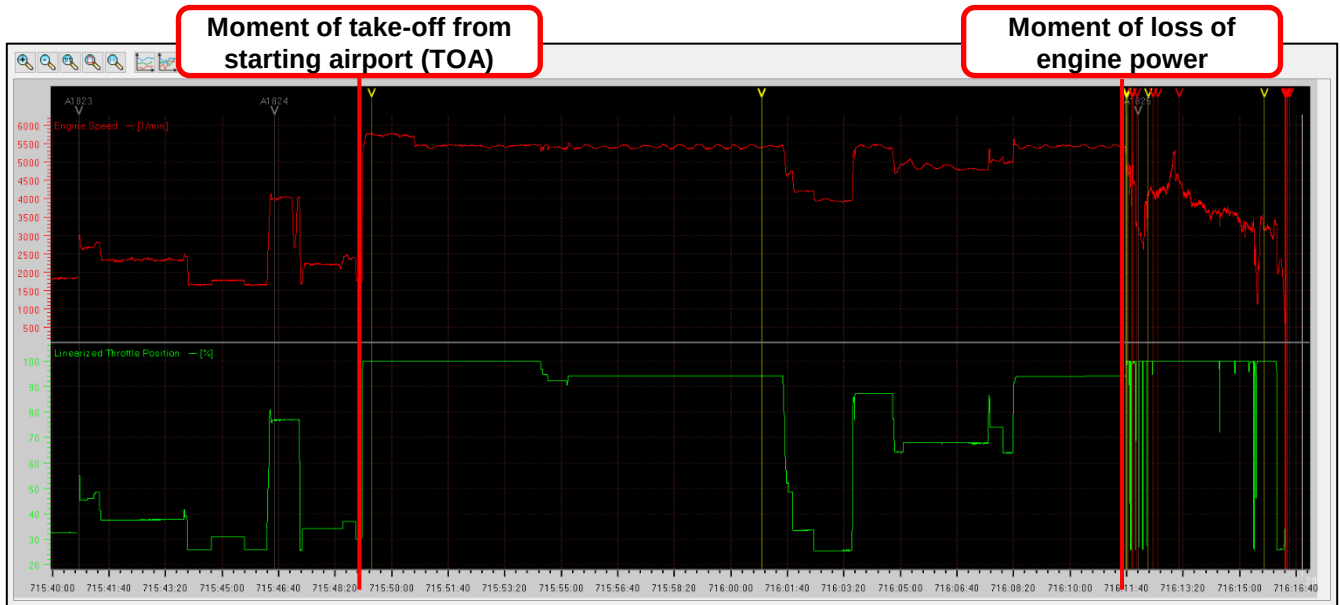
This analysis provides insight into the engine's operational status leading up to the incident and supports further investigation into the factors contributing to the engine's performance at the time of the accident.



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ECU Data Analysis

Analysis of Throttle Position and RPM: The throttle position and RPM were analyzed to assess if the engine responded correctly to the pilot's inputs throughout the flight. This analysis is essential for verifying the engine's performance under pilot command and for understanding the aircraft's behavior before the incident.



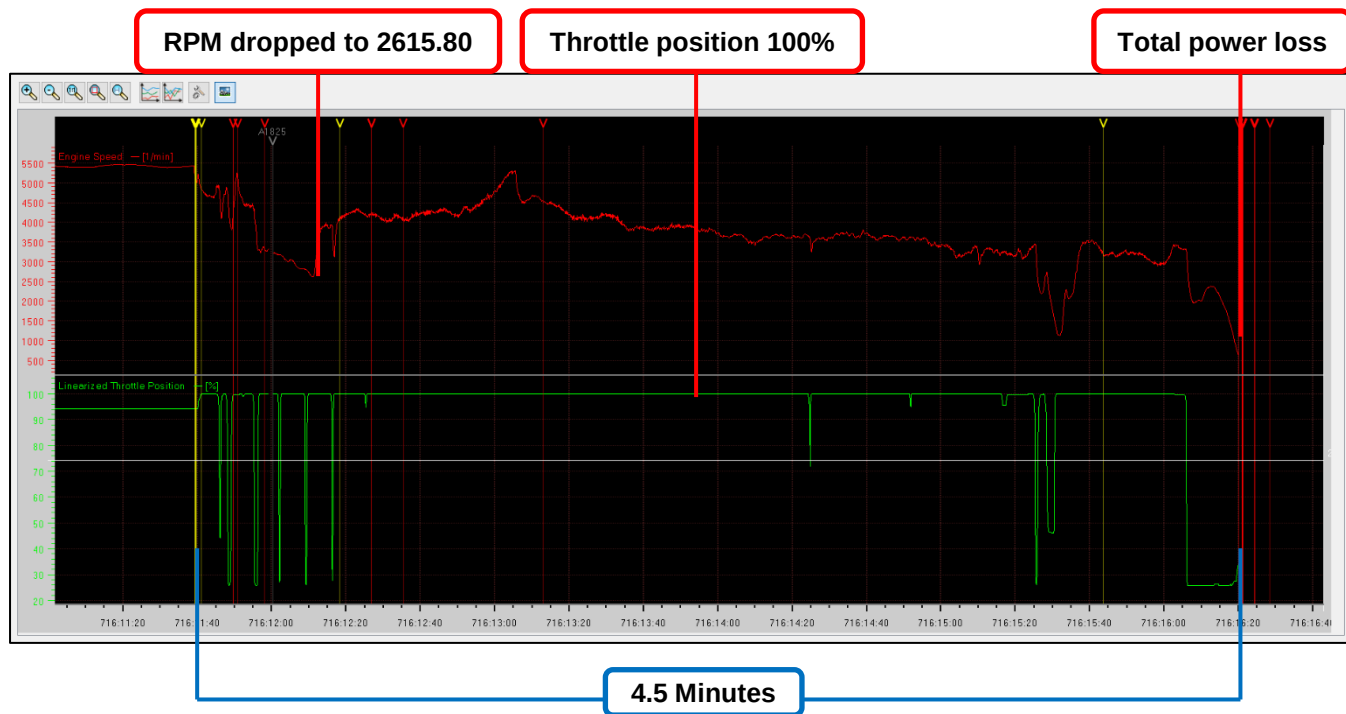
According to ECU data, the linearized throttle position remained synchronized with engine RPM for most of the accident flight, indicating that the engine was responding appropriately to the pilot's inputs. During the critical moments leading up to the accident, the throttle was set at 94%, with the engine running at 5427.93 RPM. Shortly afterward, the engine RPM began to decrease and fluctuate, indicating a rough running condition and a loss of engine power. In response, the pilot increased the throttle to 100%, but the engine did not respond.

The pilot then cycled the throttle between 25% and 100% several times in an apparent attempt to stabilize the RPM. Despite these efforts, the RPM dropped to 2615.80 with the throttle near 100%, briefly recovering to 5303.30 RPM before continuing to degrade and ultimately ceasing to respond to throttle inputs.

This sequence began at 688.43 engine hours and ECU timestamp 716:11:39.500, continuing until 688.50 engine hours and timestamp 716:16:19.500, when the engine stopped running. This rough running and loss of power event lasted approximately 4.5 minutes.

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ECU Data Analysis



Analysis of Key Engine Parameters: An in-depth analysis of key engine parameters was conducted between engine hours 688.30 (ECU timestamp 716:08:20.500) and 688.43 (ECU timestamp 716:11:57.000), with ECU timestamp 716:11:39.000 marking the moment of power loss. This analysis aimed to identify trends or anomalies both preceding and following the initial RPM drop and onset of engine roughness.

The following ECU data and engine parameters were analysed:

Engine Hours:

Ambient Temperature:

Coolant Temperature (Deg C):

Fuel injection mass Cylinder 1 (mg/inj):

Fuel injection mass Cylinder 2 (mg/inj):

Fuel injection mass Cylinder 3 (mg/inj):

Fuel injection mass Cylinder 4 (mg/inj):

EGT Cylinder 1 (Deg C):

EGT Cylinder 2 (Deg C):

EGT Cylinder 3 (Deg C):

EGT Cylinder 4 (Deg C):

Engine Speed:

Calculated Mass Air Flow (g/min):

Manifold Air Pressure (KPA):

Boost Pressure (KPA):

Calculated fuel flow (G/min):

Metered Air/fuel Ratio Target:

Linearized Throttle position (%):

Calculated Ignition Dwell Time (ms):

Ignition timing Cylinder 1 & 2 (Deg ATDC):

Ignition timing Cylinder 2 & 1 (Deg ATDC):

Ignition timing Cylinder 3 & 4 (Deg ATDC):

Ignition timing Cylinder 4 & 3 (Deg ATDC):

Transient Enrichment:

EGT Lambda Target:

SSW: Kock State:

Knock Ignition Retard Cylinder 1 & 2 (Deg ATDC):

Knock Ignition Retard Cylinder 2 & 1 (Deg ATDC):

Knock Ignition Retard Cylinder 3 & 4 (Deg ATDC):

Knock Ignition Retard Cylinder 4 & 3 (Deg ATDC):

Knock events Cylinder 1:

Knock events Cylinder 2:

Knock events Cylinder 3:

Knock events Cylinder 4:

Oil Pressure:

Oil Temperature:

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ECU Data Analysis

1. Exhaust Gas Temperature (EGT):

Pre-Failure (Up to ECU Time 716:11:39):

- EGT for Cylinder #4 shows a gradual rise from around 785°C to a peak of 898°C by 716:11:39, which is noticeably higher than the other cylinders.

Post-Failure (ECU Time 716:11:39 Onwards):

- EGT in Cylinder #4 plummets dramatically after 716:11:39, dropping to 557°C by 716:11:42 and continuing to decrease to 331°C by 716:11:57.

2. Fuel Injection Mass and Air/Fuel Ratio:

Pre-Failure(Up to ECU Time 716:11:39):

- Injection mass is consistent across all cylinders initially, with values around 8.96 mg/inj per cylinder. Metered air/fuel ratio targets hover around 15.41, indicating the ECU aimed for a relatively lean mixture.

Post-Failure (ECU Time 716:11:39 Onwards):

- Post-failure, fuel injection mass for Cylinder #4 starts to vary, with some data points showing a zero-injection mass for Cylinder #4 by 716:11:57.
- The shift in metered air/fuel ratio target to values below 13.80 by 716:11:41 suggests that the ECU may have enriched the mixture to stabilize combustion.

3. RPM and Throttle Position:

Pre-Failure (Up to ECU Time 716:11:39):

- RPM remains stable around 5383 with a throttle position of approximately 94%, indicating consistent power output.

Post-Failure (ECU Time 716:11:39 Onwards):

- RPM becomes erratic, fluctuates and drops significantly reaching as low as 3221.85 RPM despite the throttle position being at 100%, reflecting unbalanced operation and a lack of engine response to the pilot's inputs

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ECU Data Analysis

4. Manifold Air Pressure (MAP) and Boost Pressure:

Pre-Failure (Up to ECU Time 716:11:39):

- MAP and boost pressures rise steadily with throttle increases. MAP goes from 52.54 KPA at the start to 109.8 KPA by 716:11:39, with boost pressures following suit. The stable rise indicates that the turbocharging system was responsive and consistent, delivering increased airflow to meet throttle demands.

Post-Failure (ECU Time 716:11:39 Onwards):

- Following the drop in RPM, MAP and boost pressures decrease erratically. MAP falls to 95.68 KPA by 716:11:57, a clear indication of reduced engine demand and unbalanced airflow.

5. Oil Temperature and Pressure:

Pre-Failure (Up to ECU Time 716:11:39):

- Oil temperature starts at 68.21°C and gradually rises to 85.07°C, while oil pressure decreases from 425.75 KPA to 384.2 KPA. These values are within normal operating ranges.

Post-Failure (ECU Time 716:11:39 Onwards):

- After 716:11:39, oil temperature continues to increase slightly, reaching 85.92°C, while oil pressure drops further to around 346.25 KPA. The drop in oil pressure combined with the steady rise in temperature reflects an increased thermal load

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ECU Data Analysis

6. Knock Events and Ignition Timing:

Pre-Failure (Up to ECU Time 716:11:39):

- Knock ignition retard values remain at zero across all cylinders, except for a few instances at ECU timestamps 716:09:59.00 and 716:10:00.00, where Cylinder 4 shows a timing retard of -0.5019 degrees ATDC. This timing adjustment suggests a transient knock detection on Cylinder 4.

Post-Failure (ECU Time 716:11:39 Onwards):

- After the RPM drop , knock events become more frequent, especially in Cylinder #4, where ignition timing begins to retard up to -6.27° ATDC in an attempt to prevent detonation. Knock State transitions to “Timing Retarded,” reflecting the ECU’s effort to protect against potential damage due to the uneven combustion.

Summary of ECU Data Analysis

The ECU data indicates that Cylinder #4 experienced significant stress leading up to the failure, marked by elevated exhaust gas temperatures (EGTs), fueling irregularities, and chronic knock events. After the failure, the engine displayed unbalanced operation, with RPM instability, manifold air pressure (MAP) fluctuations, and increased knock mitigation efforts.

From ECU timestamp 716:08:20.500 to the power loss at 716:11:39.000, rising thermal stress, injector and timing adjustments reflected attempts to stabilize combustion. Although initial load responses appeared balanced, a gradual divergence in EGTs and manifold air temperature, along with increasing knock activity, revealed a systemic imbalance under load.

This instability impacted both RPM and combustion stability, contributing to the engine's performance issues and ultimate failure.

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ECU Errors/Events Analysis

Analysing ECU Warnings, Faults and Failures: The maintenance team for the accident aircraft provided the ECU history log files for review, enabling a comprehensive evaluation of recorded Warnings, Faults, and Failures throughout the engine's operational history. Over the course of 688.50 hours of operation, the logs documented the following events:

- **873 Warnings**
- **144 Faults**
- **100 Failures**

873 Warnings Recorded

Errors/Events						
Filter Settings						
Clear Filter	Clear All	Select All	Deselect All			
Error/Event Category	Warnings	Occurrences	Category	Class	Type	Test
Lane	Both AB	17	Warning	5: CBIT/ABIT Logs	1: ABIT	29: PCV Test 1
Class	All	4	Warning	5: CBIT/ABIT Logs	1: ABIT	30: PCV Test 2
Type	All	72	Warning	5: CBIT/ABIT Logs	1: ABIT	29: PCV Test 1
Test	All	13	Warning	1: Sensor	26: Compensated Oil Pressure	3: Operating Range Test
Error	All	94	Warning	5: CBIT/ABIT Logs	1: ABIT	29: PCV Test 1
		8	Warning	5: CBIT/ABIT Logs	1: ABIT	30: PCV Test 2
		1	Warning	3: Component	8: CAN Bus (Pilot Display)	1: CAN Status Test
		67	Warning	5: CBIT/ABIT Logs	1: ABIT	29: PCV Test 1
		7	Warning	5: CBIT/ABIT Logs	1: ABIT	30: PCV Test 2
		1	Warning	1: Sensor	26: Compensated Oil Pressure	3: Operating Range Test
		55	Warning	5: CBIT/ABIT Logs	1: ABIT	29: PCV Test 1
		5	Warning	5: CBIT/ABIT Logs	1: ABIT	30: PCV Test 2
		1	Warning	1: Sensor	26: Compensated Oil Pressure	3: Operating Range Test
		1	Warning	1: Sensor	26: Knock Sensor	6: Knock Event on Cylinder 1
		79	Warning	5: CBIT/ABIT Logs	1: ABIT	29: PCV Test 1
		3	Warning	5: CBIT/ABIT Logs	1: ABIT	30: PCV Test 2
		3	Warning	1: Sensor	26: Compensated Oil Pressure	3: Operating Range Test
		87	Warning	1: Sensor	26: Knock Sensor	8: Knock Event on Cylinder 3
		350	Warning	1: Sensor	26: Knock Sensor	4: Knock State - Maximum
		1	Warning	4: EGT	2: Cylinder 2	1: EGT Mode Transition Event
		1	Warning	4: EGT	4: Cylinder 4	1: EGT Mode Transition Event
		3	Warning	5: CBIT/ABIT Logs	1: ABIT	29: PCV Test 1
						0: CBIT Reset

WARNINGS

CBIT/ABIT PCV TEST 1 & 2:

ECU Time: 27:20:21 – 715:49:24

414 Occurrences:

CBIT/ABIT PCV Test 1 & 2 refers to diagnostic checks performed by the engine's Continuous Built-In Test (CBIT) and Advanced Built-In Test (ABIT) systems on the Pressure Control Valve (PCV).

414 warnings for PCV Test 1 & 2 means the ECU is repeatedly detecting minor issues with the Pressure Control Valve. Likely causes include:

- The valve may be sticking or responding slowly, possibly due to dirt or wear.
- Loose or corroded wiring to the PCV or related sensors

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WARNINGS

Compensated Oil Pressure

ECU Time: 133:26:32 – 716:15:43

18 Occurrence:

Compensated Oil Pressure Sensor recorded 18 instances of below-range readings. These warnings were isolated and infrequent, showing no significant pattern or increase in frequency over time. the most likely cause:

- **Sensor Calibration or Fault**
- **Ambient Air Pressure Anomaly**
- **Electrical or Grounding Issues**
- **Software or Configuration Error**

CAN bus (Pilot Display)

ECU Time: 236:46:11

1 Occurrences

This fault may occur when the pilot display's supply voltage drops below a critical level, causing it to turn off due to insufficient power (e.g., during engine start). If a CAN Bus transmit error from the pilot display is detected, this fault is triggered.

Cylinder 2 and 4 EGT

ECU Time: 716:12:18, 716:11:41

1 Occurrence on Cylinder #2

1 Occurrence on Cylinder #4

The EGT transition event was triggered by rapid changes in exhaust temperature when the engine power dropped. When an engine loses power, exhaust system temperatures can fluctuate, prompting the ECU to monitor for unexpected or extreme values.

Knock Sensor

ECU Time: 469:45:04, 712:01:51-716:11:39

1 Occurrence Cylinder #1

87 Occurrence Cylinder #3

350 Occurrence Cylinder #4

- The one-time knock event on Cylinder #1 at ECU timestamp 469:45:04 is likely an isolated incident, potentially caused by a transient condition, such as a fuel quality variation or minor operational anomaly.
- The 87 knock events on Cylinder #3, spanning from ECU timestamp 712:01:51 to 716:11:39, suggest a developing and severe issue, though less intense than that observed on Cylinder #4.
- With knock starting at ECU timestamp 712:30:40 and persisting through 716:11:39, Cylinder #4 displays substantial and persistent knock activity. The high frequency of these events indicates an ongoing or worsening condition.

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144 Faults Recorded

Errors/Events Data Graph						
Filter Settings						
Clear Filter	Clear All		Select All	Deselect All		
Error/Event Category	Faults	Occurrences	Category	Class	Type	Error
Lane	Both AB	☐ 2	Fault	1: Sensor	15: Coolant Temperature	2: Failure Test
Class	All	☐ 2	Fault	1: Sensor	23: Throttle Position	2: Failure Test
Type	All	☐ 6	Fault	2: Actuator	7: Generator Select	2: Test While Gen B Commanded
Test	All	☐ 2	Fault	3: Component	6: Lane Communication	8: Interlane CAM Pulse
Error	All	☐ 14	Fault	2: Actuator	7: Generator Select	2: Test While Gen B Commanded
		☐ 2	Fault	3: Component	6: Lane Communication	6: Communication Validity Test
		☐ 19	Fault	2: Actuator	7: Generator Select	2: Test While Gen B Commanded
		☐ 7	Fault	2: Actuator	7: Generator Select	3: Test While Not Commanding Gen
		☐ 15	Fault	2: Actuator	7: Generator Select	2: Test While Gen B Commanded
		☐ 2	Fault	2: Actuator	7: Generator Select	3: Test While Not Commanding Gen
		☐ 17	Fault	2: Actuator	7: Generator Select	2: Test While Gen B Commanded
		☐ 2	Fault	2: Actuator	7: Generator Select	3: Test While Not Commanding Gen
		☐ 19	Fault	2: Actuator	7: Generator Select	2: Test While Gen B Commanded
		☐ 9	Fault	2: Actuator	7: Generator Select	2: Test While Gen B Commanded
		☐ 8	Fault	2: Actuator	7: Generator Select	3: Test While Not Commanding Gen

FAULTS

Coolant Temperature Sensor

ECU Time: 469:45:04, 712:01:51, 716:16:21

3 Occurrence

The Coolant Temperature sensor's "Below Range" error points to low bus voltage impacting sensor performance. This low voltage condition, as indicated by the ECU, suggests an intermittent power supply stability issue that is disrupting consistent sensor readings.

Throttle Position Sensor

ECU Time: 469:45:04, 712:01:51, 716:16:21

3 Occurrence

The throttle position sensor's "Below Range" error points to low bus voltage impacting sensor performance. This low voltage condition, as indicated by the ECU, suggests an intermittent power supply stability issue that is disrupting consistent sensor readings.

CBIT/ABIT PCV Test

ECU Time: 27:11:33 – 695:16:25

1 Occurrence

A CBIT/ABIT fault was logged for an error detected during PCV Test 1, resulting in a CBIT reset. While several sensor readings indicated no significant issues, EGT (Exhaust Gas Temperature) errors were noted on cylinders 2 and 4 in Lane A.

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FAULTS	
Generator Select in Failsafe	ECU Time: 27:11:33 – 695:16:25
126 Occurrence	The Generator Select system entered failsafe mode multiple times over an extended period, indicating issues with maintaining the correct generator state. This mode was activated to stabilize power generation and distribution, as the GSM consistently encountered issues with generator selection. Possible causes included electrical/voltage instability, faults in the generator select actuator, or intermittent connectivity issues. This fault was documented in the engine maintenance logs, and it appears to have been addressed through the replacement of the stator
Lane Communication CAM Pulse	ECU Time: 66:36:04
2 Occurrence	This fault is logged if the Internal Cam Pulse is not received by the lane not currently in control, preventing it from achieving Full Synchronization within the defined persistence time. Since this error only occurred twice early on and then resolved, it likely indicates a temporary electrical glitch rather
Lane Communication CAM Pulse test	ECU Time: 91:32:22, 91:33:58
2 Occurrences	Communication failure was detected between the lanes of the ECU. This fault indicates that one lane did not receive the expected communication from the other lane. Since this error only occurred twice early on and then resolved, it likely indicates a temporary electrical glitch rather than a persistent issue.
Knock Sensor Fault Cylinder 3	ECU Time: 716:11:50
1 Occurrences	A knock event on Cylinder 3 reached the maximum allowable knock state. The ECU detected a severe knock condition that could not be mitigated, even with maximum timing retard applied.

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FAULTS

EGT Transition event and sensor fault

ECU Time: 716:11:49 – 716:12:35

6 Occurrences

Substate Test A Initiated – The ECU has entered a specific diagnostic substate (Test A) due to an observed issue or anomaly in the EGT Mode Transition event for cylinder 2 and 4. Recalibration attempt due to inconsistent temperature readings or a mode switch in engine operation.

Sensor Failed Low - This error indicates that the EGT sensor on cylinder 2 and 4 registered a “failed low” status, meaning the sensors reading were below expected operational levels, signaling a fault or misread in the sensor for cylinder 2 and 4.

This fault occurred following the loss in engine power and is a result of that not a cause

100 Failures Recorded

Errors/Events							
Filter Settings							
Clear Filter		Clear All		Select All		Deselect All	
Error/Event Category	Failures	Occurrences		Category	Class	Type	Test
Lane	Both AB						Error
Class	All						
Type	All						
Test	All						
Error	All						
		4	Failure	1: Sensor	0: Manifold Air ...	2: Failure Test	1: Below Range
		4	Failure	1: Sensor	1: Manifold Air ...	2: Failure Test	1: Below Range
		3	Failure	1: Sensor	6: Crank Bias Po...	2: Failure Test	2: Above Range
		4	Failure	1: Sensor	10: Boost Press...	2: Failure Test	1: Below Range
		4	Failure	1: Sensor	11: Crank Bias ...	2: Failure Test	1: Below Range
		2	Failure	1: Sensor	14: Engine Amb...	2: Failure Test	1: Below Range
		2	Failure	1: Sensor	14: Oil Pressure	4: Railed Test	2: Above Range
		2	Failure	1: Sensor	15: Oil Tempera...	2: Failure Test	1: Below Range
		2	Failure	1: Sensor	16: EGT 1	2: Failure Test	2: Above Range
		2	Failure	1: Sensor	17: Engine Amb...	2: Failure Test	1: Below Range
		2	Failure	1: Sensor	17: EGT 2	2: Failure Test	2: Above Range
		1	Failure	1: Sensor	17: EGT 2	3: Operating Ra...	2: Above Range
		2	Failure	1: Sensor	18: EGT 3	2: Failure Test	2: Above Range
		1	Failure	1: Sensor	18: EGT 3	3: Operating Ra...	2: Above Range
		2	Failure	1: Sensor	19: EGT 4	2: Failure Test	2: Above Range
		2	Failure	1: Sensor	25: Engine Amb...	2: Failure Test	1: Below Range
		4	Failure	2: Actuator	1: Injector Cyl 1	1: Injection Driv...	1: Injector Open Error
		4	Failure	2: Actuator	2: Injector Cyl 2	1: Injection Driv...	1: Injector Open Error
		4	Failure	2: Actuator	3: Injector Cyl 3	1: Injection Driv...	1: Injector Open Error
		4	Failure	2: Actuator	4: Injector Cyl 4	1: Injection Driv...	1: Injector Open Error
		4	Failure	2: Actuator	12: PCV PWM O...	3: Driver Test	4: Open Circuit Error
		2	Failure	2: Actuator	13: Overboost V...	1: Driver Test	1: Open/STG Error
		2	Failure	3: Component	5: ETPU	0: ETPU Test	1: Synchronization Lost
		2	Failure	1: Sensor	0: Manifold Air ...	2: Failure Test	1: Below Range
		2	Failure	1: Sensor	1: Manifold Air ...	2: Failure Test	1: Below Range
		1	Failure	1: Sensor	6: Crank Bias Po...	2: Failure Test	2: Above Range
		2	Failure	1: Sensor	10: Boost Press...	2: Failure Test	1: Below Range
		2	Failure	1: Sensor	11: Crank Bias ...	2: Failure Test	1: Below Range
		1	Failure	1: Sensor	14: Engine Amb...	2: Failure Test	1: Below Range
		1	Failure	1: Sensor	14: Oil Pressure	4: Railed Test	2: Above Range
		1	Failure	1: Sensor	15: Oil Tempera...	2: Failure Test	1: Below Range
		1	Failure	1: Sensor	16: EGT 1	2: Failure Test	2: Above Range
		1	Failure	1: Sensor	16: EGT 1	3: Operating Ra...	2: Above Range
		1	Failure	1: Sensor	17: Engine Amb...	2: Failure Test	1: Below Range
		1	Failure	1: Sensor	17: EGT 2	2: Failure Test	2: Above Range
		1	Failure	1: Sensor	18: EGT 3	2: Failure Test	2: Above Range
		1	Failure	1: Sensor	19: EGT 4	2: Failure Test	2: Above Range
		1	Failure	1: Sensor	19: EGT 4	3: Operating Ra...	2: Above Range
		1	Failure	1: Sensor	21: Sensor Drive...	1: Reference Vol...	1: Below Range
		1	Failure	1: Sensor	25: Engine Amb...	2: Failure Test	1: Below Range
		2	Failure	2: Actuator	1: Injector Cyl 1	1: Injection Driv...	1: Injector Open Error
		2	Failure	2: Actuator	2: Injector Cyl 2	1: Injection Driv...	1: Injector Open Error
		2	Failure	2: Actuator	3: Injector Cyl 3	1: Injection Driv...	1: Injector Open Error
		2	Failure	2: Actuator	4: Injector Cyl 4	1: Injection Driv...	1: Injector Open Error
		1	Failure	2: Actuator	7: Generator Sel...	2: Test While Ge...	5: Generator Select In Failsafe
		2	Failure	2: Actuator	7: Generator Sel...	3: Test While No...	5: Generator Select In Failsafe
		1	Failure	2: Actuator	12: PCV PWM O...	3: Driver Test	4: Open Circuit Error
		1	Failure	2: Actuator	13: Overboost V...	1: Driver Test	1: Open/STG Error
		3	Failure	3: Component	5: ETPU	0: ETPU Test	1: Synchronization Lost

DATE	ENGINE MODEL	ENGINE SERIAL NO	REGISTRATION	File number
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FAILURES	
Manifold Air Pressure Error ECU Time: 0:00:00 - 76:29:24	
6 Occurrences	The MAP sensor is not functioning correctly, as it is reporting readings below the expected range. This has been confirmed by a failure test, and the fault has triggered the warning lamp to alert the operator of the issue.
Manifold Air Temperature Error ECU Time: 0:00:00 - 716:29:24	
6 Occurrences	The manifold air temperature sensor is providing readings that are below the expected range, suggesting a possible sensor malfunction.
Crank Bias Positive Voltage Error ECU Time: 27:09:10, 716:29:24	
4 Occurrences	The Crank Bias Positive Voltage sensor detected voltage levels exceeding the expected range. At the time of the logged event, the engine speed was zero. This could be caused by a malfunctioning sensor or an intermittent wiring issue, potentially leading to voltage spikes if the connection is faulty or grounding is compromised.
Boost Pressure Error ECU Time: 0:00:00, 27:09:10, 716:16:21	
6 Occurrences	The Boost Pressure Sensor failed a diagnostic test by consistently reporting pressure readings below the expected range. At the time of the logged event, the engine speed was zero. Possible causes include low battery charge, a defective boost pressure sensor, or issues with the power supply wiring or grounding.
Crank Bias Negative Voltage Error ECU Time: 0:00:00, 27:09:10, 716:16:24	
6 Occurrences	The Crank Bias Negative Voltage sensor detected low voltage levels with the engine speed at zero. This fault may occur if the start button is pressed immediately after toggling the start power switch, or due to an unintended connection between the engine and aircraft ground.
Sensor Drive Voltage Error ECU Time: 716:16:24	
1 Occurrence	The Sensor Drive Voltage has dropped below the acceptable range, potentially due to electrical fluctuations or low battery voltage.

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FAILURES	
Engine Ambient Pressure Error ECU Time: 0:00:00, 27:09:12, 716:29:24	
6 Occurrence	The Ambient Pressure Sensor is providing readings below the expected range. At the time of the logged event, the engine speed was zero. This issue may be due to a connection problem or a disconnection of the sensor.
Oil Pressure Error ECU Time: 27:09:10, 716:29:24	
3 Occurrences	The Oil Pressure Sensor is providing readings above the expected range. At the time of the logged event, the engine speed was zero. Possible causes include a sensor malfunction, an electrical issue, or a connection problem, as a loose or intermittent connection could produce false high readings.
Oil Temperature Error ECU Time: 27:09:10, 716:29:24	
3 Occurrences	The oil Temperature sensor is providing readings below the expected range. At the time of the logged event, the engine speed was zero. Possible causes include a sensor malfunction, an electrical issue, or a grounding issue, as poor grounding could result in abnormally low readings.
EGT Test Error ECU Time: 0:00:00, 27:09:12, 716:16:21	
16 Occurrence	Exhaust Gas Temperature (EGT) sensors on cylinders 1, 2, 3, and 4 reported failures, with readings above the expected range. At the time of the logged event, the engine speed was zero. Possible causes include faulty EGT sensors, the need for software or firmware updates, or low bus voltage.
Engine Ambient Temperature Error ECU Time: 0:00:00, 27:09:12, 716:16:21	
3 Occurrence	The Ambient Temperature Sensor is providing readings below the expected range, and at the time of the logged event, the engine speed was zero. Possible causes for this issue include a disconnected or loose sensor, an outdated ECU software version, or a low battery charge.

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FAILURES	
Injector Error	ECU Time: 0:00:00, 27:09:10, 716:29:24
24 Occurrences	The injectors for cylinders 1, 2, 3, and 4 registered an "Injector Open Error," indicating an open load or disconnect. At the time of the logged event, the engine speed was zero. Possible causes for this issue include low ECU bus voltage, disconnected injectors, or a harness failure.
PCV PWM Output Error	ECU Time: 0:00:00, 27:09:10, 716:29:24
6 Occurrences	An open circuit error was detected in the Pressure Control Valve (PCV) PWM output. At the time of the logged event, the engine speed was zero. Possible causes for this issue include wiring harness issues, a malfunctioning PCV valve, or an output pin voltage problem.
Overboost Valve Error	ECU Time: 0:00:00, 27:09:12, 716:29:24
3 Occurrences	An open circuit error was detected in the Overboost Valve Output, with the engine speed recorded as zero at the time of the logged event. Possible causes for this issue include wiring harness problems, a malfunctioning Overboost Valve, or an output pin voltage anomaly.
ETPU Test Error	ECU Time: 276:09:38, 695:54:48, 716:16:20
5 Occurrences	An ETPU Synchronization Lost error has been logged multiple times, with the ECU recording a stall state. This issue could result from an engine turn-off via fuel pumps, an engine stall event, or a momentary loss of synchronization likely linked to fluctuations in crankshaft position or RPM.
Generator Select Error	ECU Time: 716:16:24, 716:16:28
2 Occurrences	The Generator Select Manager (GSM) has entered a failsafe mode, switching to a safer default power configuration due to a detected issue. This likely occurred while the engine was not running or in the process of shutting down. The GSM can enter failsafe mode if the engine is shut down via fuel pumps or if there are rapid or unexpected transitions between lanes or generators.

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Summary of ECU Errors/Events

Below is a breakdown of the most notable warnings, faults, and failures before the engine lost power at ECU timestamp 716:11:39.

Warnings:

CBIT/ABIT PCV Test 1 & 2

- Occurrences: 414

Description: Persistent issues with the Pressure Control Valve (PCV) tests, indicating intermittent performance issues or calibration problems within the PCV system. This may impact pressure control during the flight. The valve may be sticking or responding slowly, possibly due to dirt or wear.

Knock Sensor Warnings on Cylinder 4

- Occurrences: 350

Description: The knock sensor registered a high number of events on Cylinder 4, indicating persistent knock activity. This could suggest fuel or ignition issues, potential hot spots, or other factors causing abnormal combustion in Cylinder 4.

Knock Sensor Warnings on Cylinder 3

- Occurrences: 87

Description: Cylinder 3 also experienced multiple knock events, although less severe than those on Cylinder 4, indicating it may have been subject to similar conditions leading to pre-ignition or detonation.

Faults:

Generator Select in Failsafe

- Occurrences: 126

Description: The Generator Select Manager repeatedly entered failsafe mode, likely due to generator instability or electrical fluctuations.

NOTE: This fault was documented in the engine maintenance logs, and it appears to have been addressed through the replacement of the stator assembly and Regulators A & B.

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Summary of ECU Errors/Events

Failures:

ETPU Test Error:

- Occurrences: 5

Description: An ETPU Synchronization Lost error has been logged multiple times, with the ECU recording a stall state. This issue could result from an engine turn-off via fuel pumps, an engine stall event, or a momentary loss of synchronization likely linked to fluctuations in crankshaft position or RPM.

Summary of All Findings

The investigation revealed significant damage to Cylinder #4, including detached intake and exhaust valves, a large hole in the piston, and severe scoring on the cylinder walls caused by internal debris impact. A breach in the coolant jacket allowed oil and coolant to mix, and the #4 spark plug showed considerable impact damage from debris within the combustion chamber.

Maintenance records indicated consistently lower compression readings for Cylinder #4, suggesting a possible valve seating issue dating back to early inspections. While within allowable limits, this pattern possibly aligns with the eventual valve failure.

ECU data analysis showed escalating stress on Cylinder #4, with high knock activity, fueling irregularities, and rising exhaust gas temperatures leading up to power loss. From timestamp 716:08:20.500 to the failure at 716:11:39.000, rising thermal stress, injector and timing adjustments were noted as attempts to stabilize combustion.

The ECU Errors/Events data indicated significant knock activity, especially in Cylinder #4, which logged 350 knock warnings, suggesting chronic abnormal combustion. Cylinder #3 also recorded 87 knock events, pointing to similar stress conditions and highlighting an overall imbalance within the engine