

National Transportation Safety Board

Office of Aviation Safety

Washington, DC 20594



WPR24LA130

FUEL SUPPLEMENT

ACCIDENT

Location: Benson, AZ
Date: April 22, 2024
Time: 0945 mountain standard time
Airplane: Rans S-7S

IIC Zoë Keliher
National Transportation Safety Board
Portland, Oregon

Investigator Greg Hughes
National Transportation Safety Board
Portland, Oregon

Investigator Dan Baker
National Transportation Safety Board
Tucson, Arizona

FUEL SYSTEM DESIGN

The fuel system consisted of a header tank connected to electric fuel pumps via a 10-foot lateral fuel line with approximately one foot of vertical lift when in a level-flight attitude.

A representative of engine manufacturer ULPower Aero Engines stated that the fuel supply line was undersized (3/8 inch inside diameter vs. 1/2 inch inside diameter needed for the specific installation, due to the 10+ foot length of the supply line). In addition, the fuel return line was undersized (1/4 inch inside diameter vs. ULPower specified 5/16 inch minimum diameter; and in the case of this installation he would recommend a 3/8 inch inside diameter line, due to the length of the tube). He pointed out that the 1/4 inch fuel return line provides less than half the flow volume of the 5/16 inch line.

The fuel pumps were located on the firewall, approximately 10.1 feet from the header tank, and operated a suction-feed system. The approximate one-foot vertical lift in the fuel line in level/cruise condition resulted in a static pressure loss, calculated as .043 psi. In a climb attitude (nose of the airplane raised above the horizon) the vertical lift would be greater, hence the pressure loss would be more, as well.

The airplane's fuel system was a combination gravity- and suction-fed design: which gravity-fed fuel flowed from the composite fuel tanks in the inboard section of each wing to a 1.75 gallon "header" tank, located in the lower fuselage behind the back seat. Two electric fuel pumps were mounted to the engine side of the firewall and pulled fuel from the header tank through approximately 10.1 feet of fuel tubing, routing through a shut-off valve near the pilot seat and then through the firewall, where fuel entered an aluminum gascolator attached to the lower left firewall. The engine exhaust pipe was also located along and under the lower firewall near the gascolator.

Fuel exited the gascolator through an insulated, flexible fuel hose made 180-degree 90-degree bends, with restrictive bend radii smaller than specified in accepted aircraft maintenance practices (refer to AC 43.13-1B Chapter 9, Section 2, Table 9-2). The flexible hose was connected via non-insulated metal fittings containing a 90-degree bend to a non-insulated metal tube manifold/divider, located above the gascolator on the firewall. The manifold divided the fuel path into two non-metallic lines, each of which routed fuel in parallel paths to fuel filters contained in metal canisters and then into corresponding metal fuel pumps, which were mounted to the firewall. After exiting the fuel pumps, pressurized fuel from both pumps entered a banjo fitting and from there a single common fuel line routed fuel through a fine fuel filter and a flow transducer mounted atop the engine, and to the engine's electronic fuel ignition and injection system. Unused fuel was routed through a second fuel flow transducer before entering the return line, which passed through the firewall and aft approximately 10 feet, returning unused fuel back to the header tank located behind the back seat.

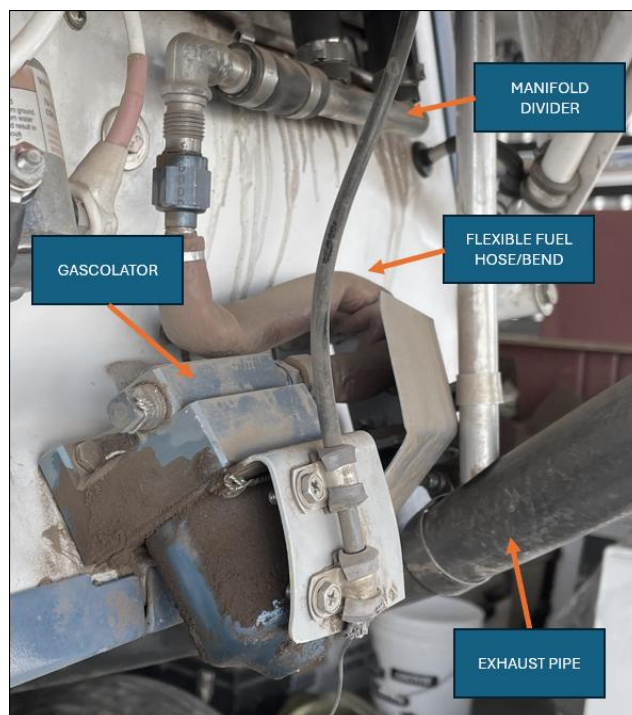


Figure 1: Firewall-mounted components

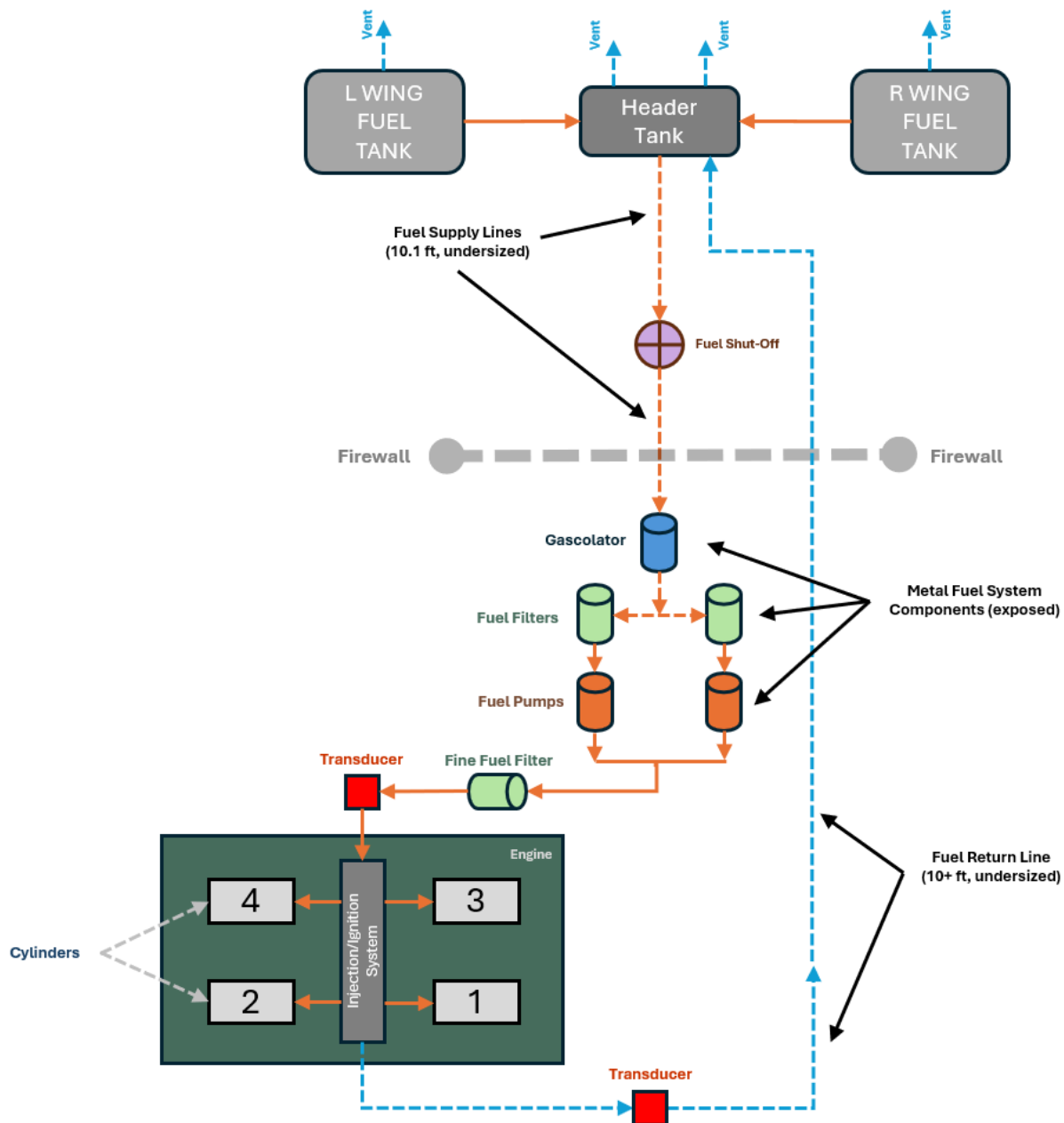


Figure 2: Fuel System Diagram

FUEL

The pilot stated that before the accident flight, he fueled the airplane with a mixture of approximately 85% automotive gasoline (91 octane) and 15% 100LL aviation fuel; this resulted in a calculated blended octane rating of approximately 92.3¹. The pilot reported that the automotive fuel was purchased in the Tucson area a week or two before the April 22 accident flight. State of Arizona and Federal standards^{2,3} mandate that auto fuel is manufactured as a “winter blend” from October 1 through March 31, allowing a Reid Vapor Pressure (RVP) of up to 15.0 psi, compared to an RVP of 9.0 psi for “summer blend gasoline.”²³ The purpose of the winter blend fuel is to ensure it will combust reliably in cold winter

¹ The fuel blend calculation used was: 85% 91-octane automotive fuel + 15% 100LL $\approx$ 92.3 octane. This was derived from Blended Octane = $(0.85 \times 91) + (0.15 \times 100) = 77.35 + 15.0 = 92.35$ (Sources: Sunoco Race Fuels - "Mixing Fuels and Calculating Octane" General Aviation News - "The trick to blending fuels" (2018))

² Arizona Revised Statutes § 3-3495 (Area B gasoline requirements), Arizona Administrative Code § R3-7-708 (Gasoline Oxygenate Blends), EPA Gasoline Reid Vapor Pressure standards (40 CFR 1090.215)

³ "Area B (Tucson metropolitan area) requires oxygenated gasoline containing at least 1.8% oxygen by weight from October 1 through March 31"

temperatures. For comparison, aviation fuels such as 100LL avgas are manufactured to ASTM standards with an RVP rating generally between 5 and 7.1 psi.

FUEL VAPORIZATION

RVP is an industry measurement standard that describes fuel volatility at a standard temperature of 100 degrees Fahrenheit. An RVP rating of 15 implies that at that standard temperature, the fuel's vapor pressure is 15 psi, meaning it will vaporize if the surrounding atmosphere or container exerts *less than* 15 psi of pressure on the fuel. As a fuel's temperature decreases, so does its vapor pressure (and, therefore, less atmospheric pressure is required to prevent the fuel from vaporizing). Conversely, when the fuel's temperature increases, its vapor pressure also increases, and the amount of external pressure required to prevent vaporization is greater.

When the surrounding pressure falls below the fuel's vapor pressure, the fuel will vaporize (i.e., form gas bubbles, or boil). By using the ambient pressure and the RVP value of a fuel sample, one can calculate an approximate fuel temperature at which the fuel sample will vaporize.

In the Tucson area, manufacturers are required to deliver winter-blend auto fuel to retail service stations through the end of March and may continue to deliver winter-blend fuels through the last day of April. After that date, manufacturers are required to deliver summer-blend fuels. However, winter blend fuel often remains in service station tanks and retailers may continue to sell winter-blend fuel at the pump through May 31st. After that date, retailers are required to sell summer-blend fuel. During the "transition" period it is difficult to determine whether the fuel being purchased is winter or summer blend without asking, and service station personnel may not have that information. In addition, retail station tanks are rarely completely emptied of one fuel before refilling. There is no consumer test available to evaluate fuel to determine whether it is winter- or summer-blend or the RVP value of the fuel.

ENVIRONMENTAL CONDITIONS

The Benson Municipal Airport (E95) field elevation is 3,831 msl. At the time of the accident, nearby Davis Monthan Air Force Base (KDMA, field elevation 2,704 ft) reported a barometric pressure of 29.91 inHg, which equates to an atmospheric pressure of 14.69 psi⁴. Accounting for the difference in elevation between the two airports, the estimated atmospheric pressure at Benson Municipal Airport was approximately 14.14 psi.

At the time of the accident, the outside air temperature at KDMA was 29°C (84.2°F). The airplane's wing-mounted fuel tanks were exposed directly to warm air and sun during ground and flight operations. Solar heating in desert conditions increases in-tank fuel temperature. While it is not possible to quantify the specific amount of solar heating that occurred on the day of the accident flight, the conditions (clear, warm, and sunny) were right for some amount of solar heating.

In post-accident testing, the engine was operated with the cowling removed. The exhaust system transferred significant radiated heat to metallic fuel-system components located on the firewall, close to the exhaust pipe. These fuel system components included (in order of proximity to the exhaust pipe) the gascolator, fuel lines, two fuel filter housings, and two fuel pumps. They were heated by the exhaust pipe during engine tests and retained heat for an extended period: fuel vaporization was observed by investigators when they tested the heat-soaked components 20+ minutes after the engine was stopped. Heating of the fuel by the heat-soaked fuel system components increased fuel vapor pressure locally, raising the likelihood of vaporization within the fuel system.

On the day of the accident flight, extended ground operations were conducted for at least 9.2 minutes before take-off (the engine monitor data shows the engine was already running when data logging was initiated), which would have facilitated heating of the exposed metal fuel system components by the exhaust, with little compensating airflow through the engine cowl.

During the airplane's 6.5-minute climb from 3,831 feet to approximately 6,000 feet MSL (2,169 feet altitude gain), the surrounding atmospheric pressure decreased from approximately 14.14 psi to approximately 12.52 psi. In a 12.52 psi environment, RVP 15 fuel will vaporize at any fuel temperature above about 93 degrees Fahrenheit. This reduction of surrounding static air pressure as the airplane climbed created an environment highly conducive to vaporization. When the

⁴ The atmospheric pressure conversion was obtained by $\text{Pressure (psi)} = \text{Barometric Pressure (inHg)} \times 0.491154$; thus $\text{Pressure (psi)} = 29.91 \times 0.491154 = 14.69 \text{ psi}$; and $29.91 \text{ inHg} = 14.69 \text{ psi}$ (Standard atmospheric pressure conversion factor (NIST))

fuel vaporized, it formed bubbles in the system, preventing the reliable flow of liquid fuel through the system. This condition is commonly referred to as “vapor lock.”

ENGINE MONITOR DATA

A review of the parameters in the downloaded Dynon Skyview tabular data revealed that the engine was running when data recording initiated at 08:23:14 local time (represented by 550 elapsed seconds in Figures 3-7), and operated for approximately 9 minutes during ground operations with normal fuel flow (~40 GPH) and pressure (~40 psi), demonstrating functional operation despite marginal fuel vaporization conditions. Take-off occurred at 08:32:30, followed by just under seven minutes of powered flight, during which fuel flow and pressure progressively degraded. Complete fuel system failure occurred abruptly at 08:39:20, with fuel flow and pressure dropping suddenly and simultaneously to near zero psi. Exhaust gas temperatures spiked to 775-780°C just prior to the sudden fuel pressure/flow drops, indicating engine operation under lean, fuel-starved conditions. The forced landing occurred at 08:42:30.

Based on the recorded data; component heating observed during post-accident engine tests; and fuel flow limitations associated with the restricted fuel lines, which extended the amount of time fuel was in contact with hot fuel system components; it is likely that heating of the fuel as it passed through the airplane’s fuel system was a significant factor contributing to fuel vaporization during the accident flight.

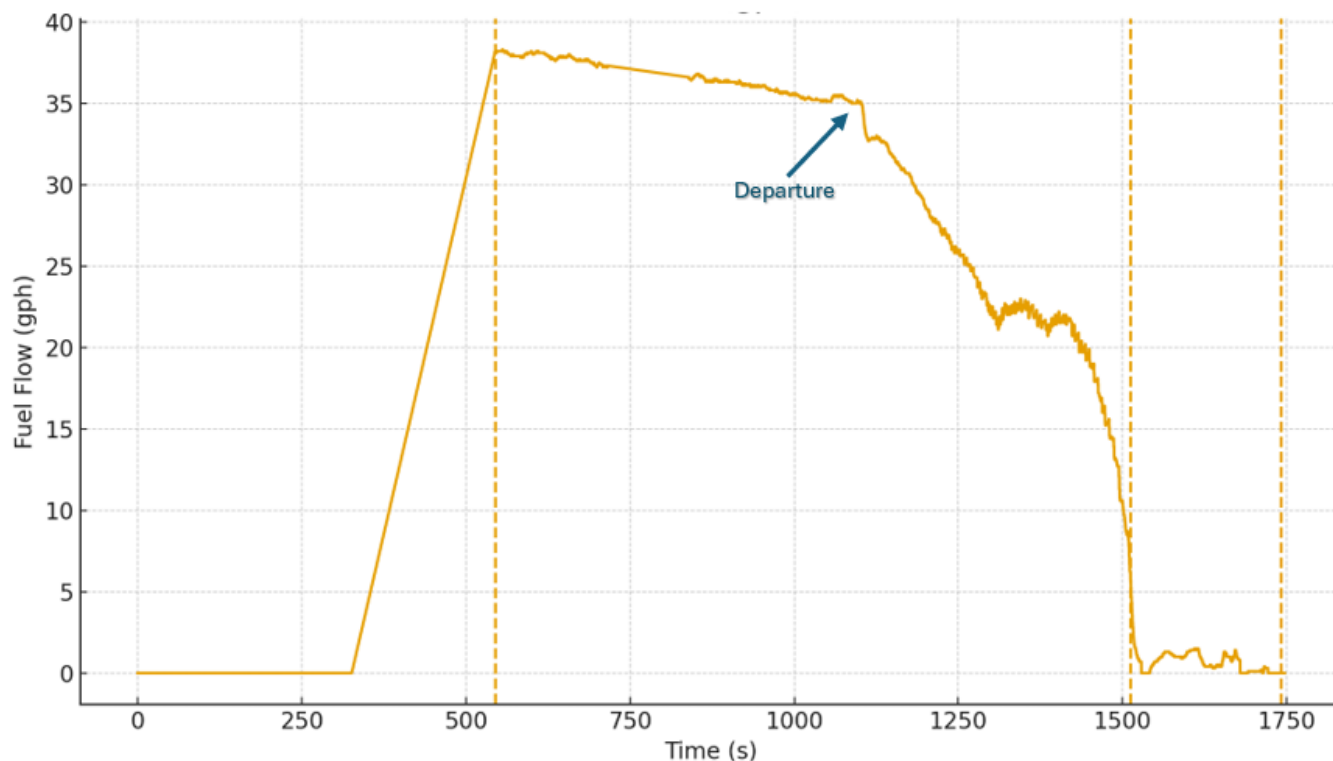


Figure 3: Recorded Fuel Flow Data – Accident Flight

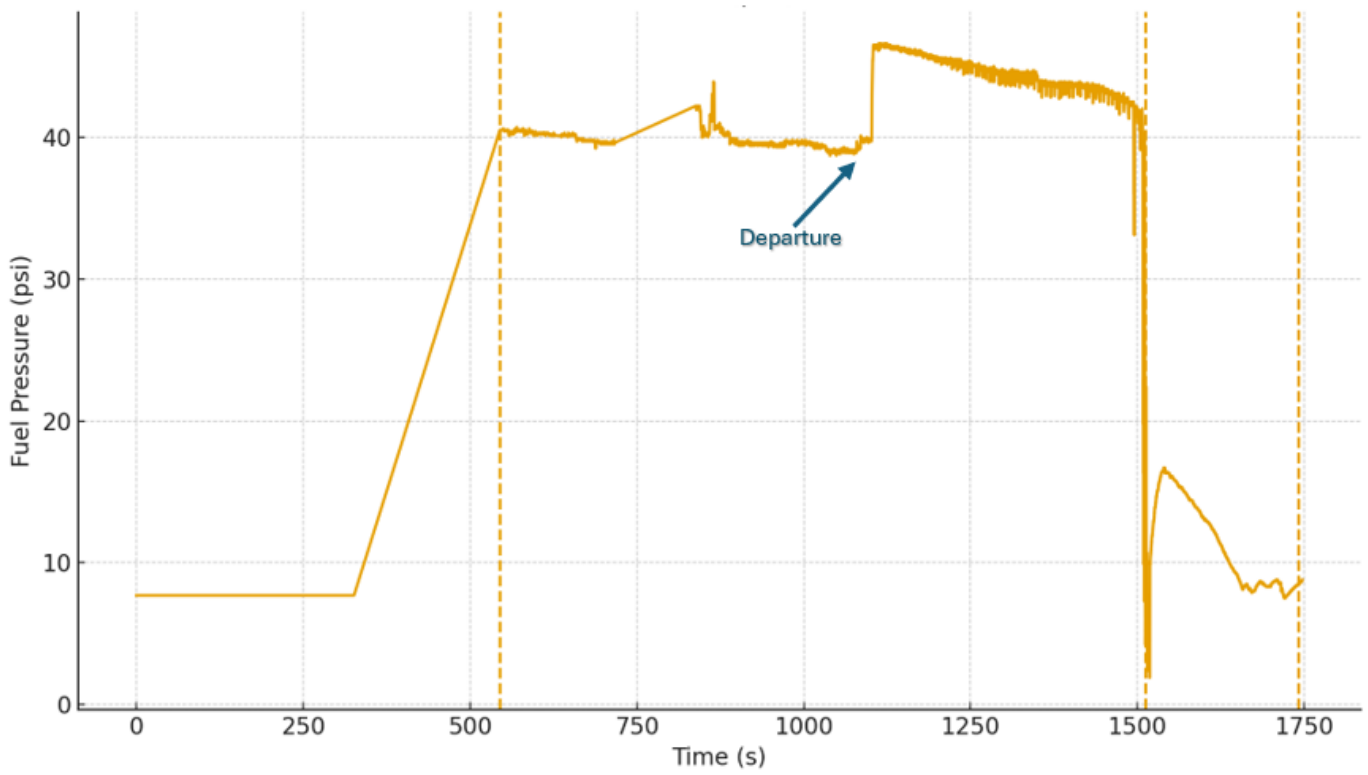


Figure 4: Recorded Fuel Pressure Data – Accident Flight

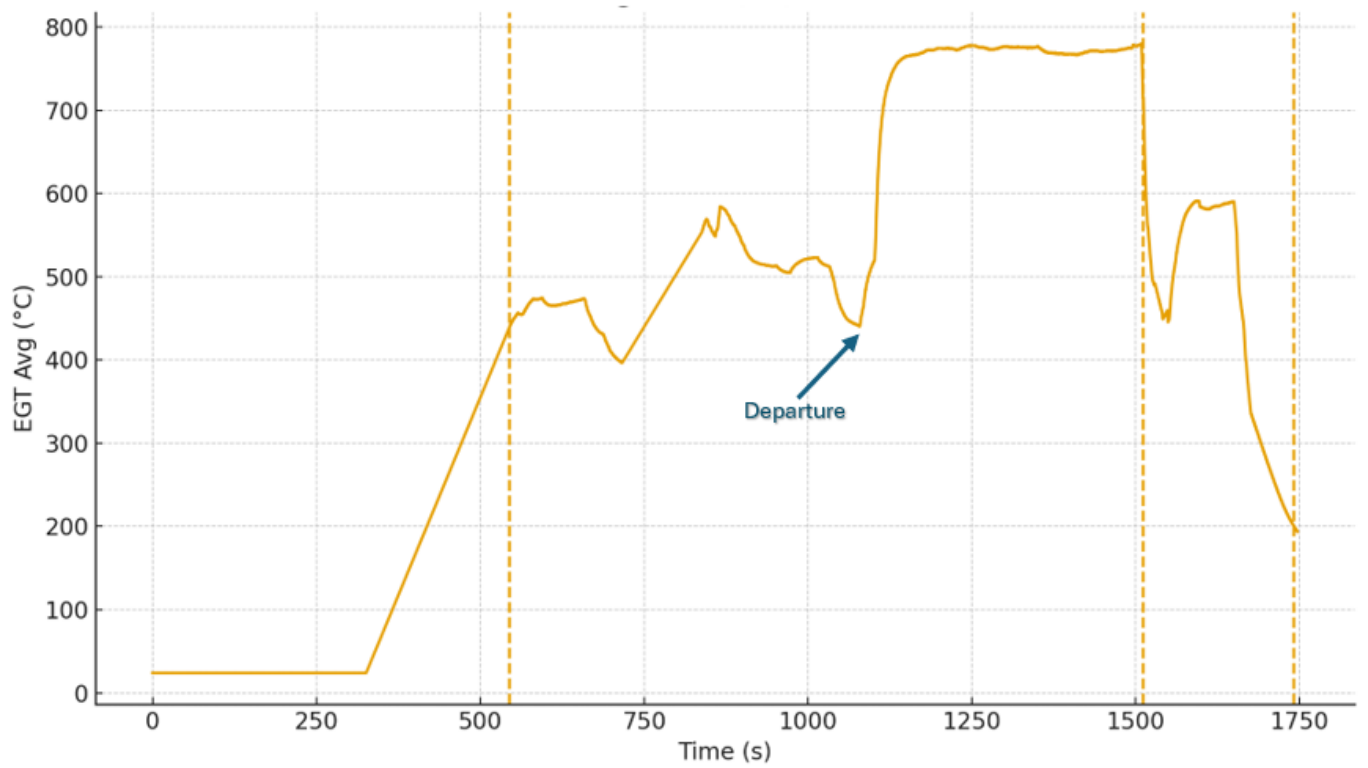


Figure 5: Recorded Exhaust Gas Temperature (EGT) Data – Accident Flight

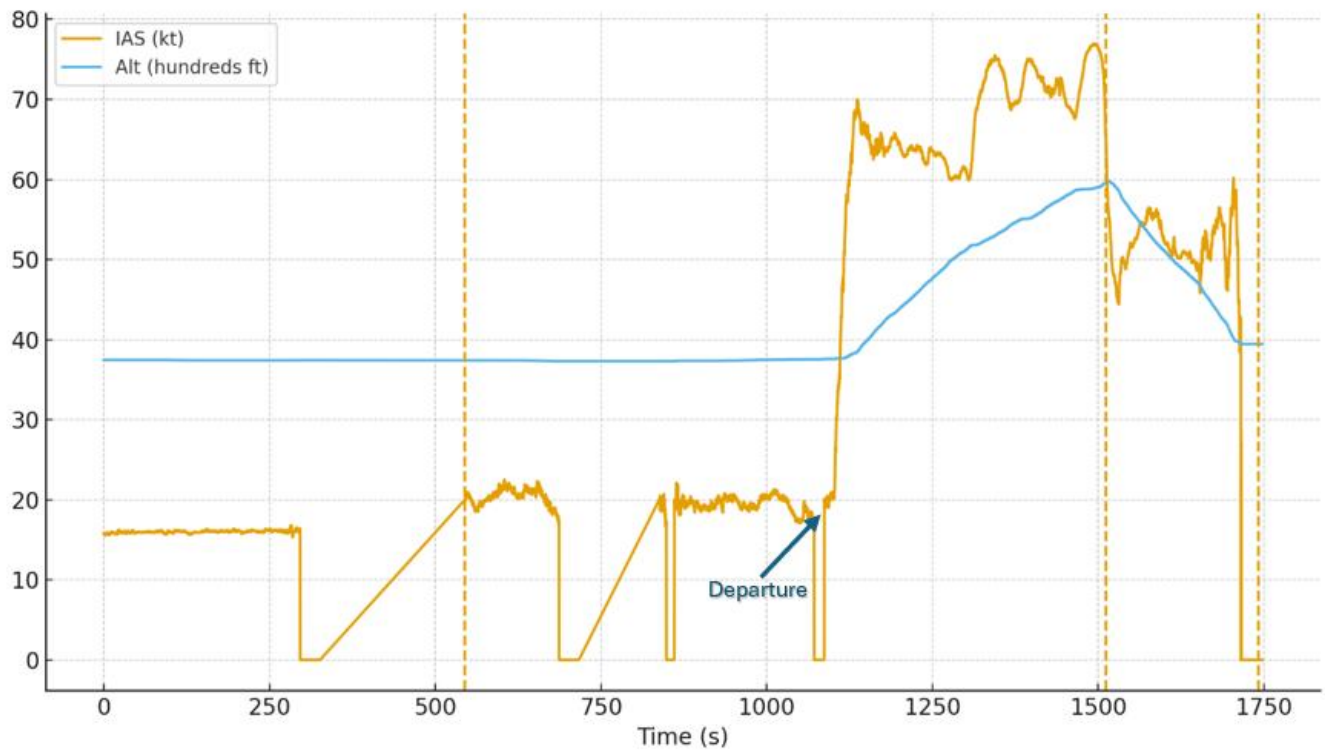


Figure 6: Recorded Airspeed/Altitude Data – Accident Flight

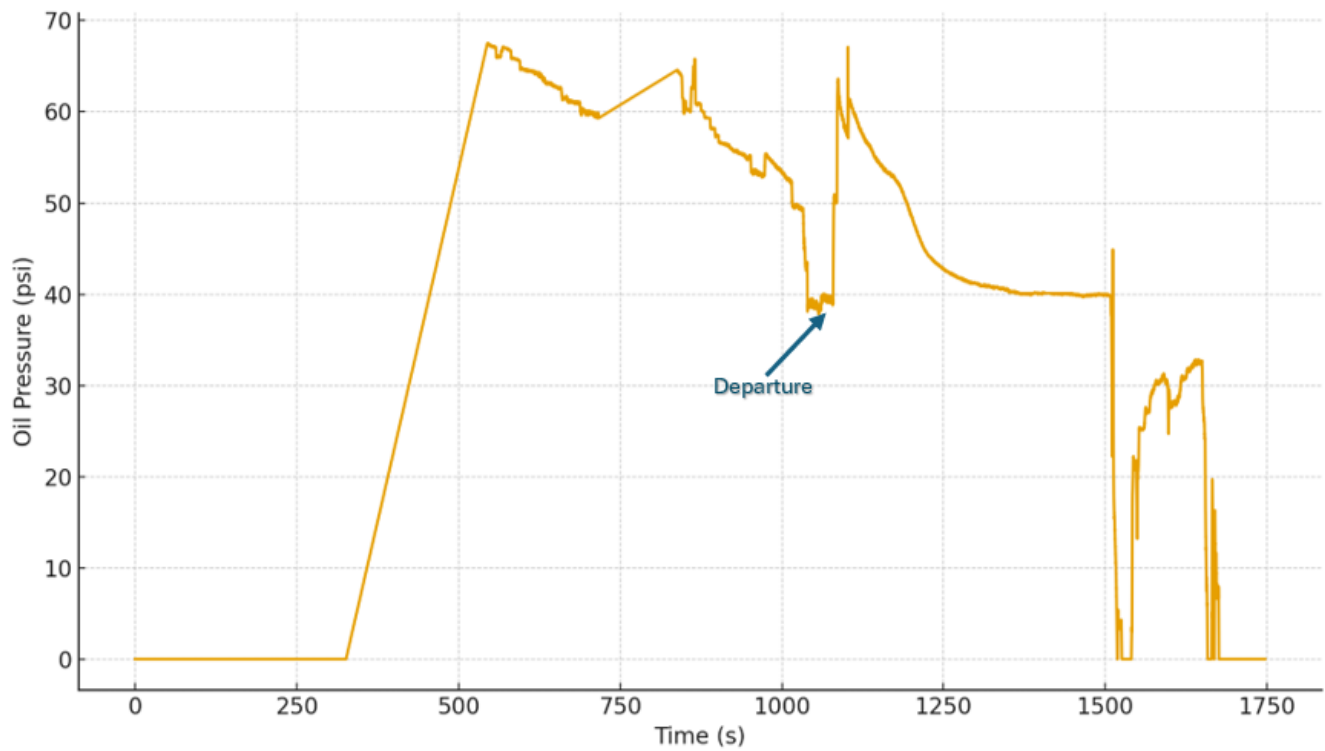


Figure 7: Recorded Oil Pressure Data – Accident Flight