National Transportation Safety Board

Office of Aviation Safety

Washington, DC 20594

ANC21LA006

SYSTEMS

Group Chair's Factual Report

August 18, 2023

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A. ACCIDENT

Location: Hilo, Hawaii
Date: November 6, 2020
Time: 1600 Pacific Standard Time
2300 UTC
Airplane: PC-12/47E, N400PW, serial number 2003

B. SYSTEMS GROUP

Group Chair	John Flynn National Transportation Safety Board Washington, D.C.
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Advisor to Accredited Representative	Markus Kohler Pilatus Aircraft Stans, Switzerland
Accredited Representative	Beverley Harvey Transportation Safety Board of Canada Ottawa, ON, Canada
Advisor to Accredited Representative	Michel Pitsikoulis Pratt & Whitney Canada Corporation Saint-Hubert, QC, Canada

C. FACTUAL INFORMATION

1.0 Production Fuel Distribution System Description

The fuel distribution system is shown in Figure1. Fuel is stored in two integral wing tanks that are each subdivided into two portions, a main tank, and a collector tank. Drain valves are located in both the main and collector portions of each fuel tank. Refueling is accomplished using over-wing filler caps, located on the upper side of the main portions of both fuel thanks. Each wing tank has a usable fuel capacity of 201gallons. Fuel venting is accomplished through the use of both inward and outward vents.

The fuel distribution system transfers fuel from the left and right main wing tanks into the respective collector tanks through one way valves located between the two fuel tanks. The transfer is facilitated by a transfer ejector pump located in each main tank. Fuel is fed from the collector tanks, through a common manifold, toward the engine primarily via delivery ejector pumps. The nominal output pressure of the delivery ejector pumps is approximately 10 pounds per square inch (psi). The ejectors are energized by heated, high pressure, regulated motive flow from the engine fuel system. The delivery ejector pumps have a flap valve installed in the outlet to prevent reverse flow through the delivery ejector pumps. An electric fuel boost pump, located in each collector tank, is used to provide fuel in the event that either of the delivery ejector pumps cannot supply the required fuel pressure. The nominal output pressure of the boost pumps is 31psi. The boost pumps are also used to provide fuel pressure for engine start, and to laterally balance the fuel load.

From the wing tanks, fuel flows forward through a firewall shutoff valve, a low pressure engine driven pump, an oil/fuel heat exchanger, a fuel filter, and a high pressure engine driven pump to the fuel control unit. See Figure 2. The fuel filter incorporates a bypass valve, and in the event the fuel filter becomes blocked, a spring loaded valve will open and allow fuel to bypass the fuel filter. The valve is calibrated to operate at a differential pressure of 30 psi (+/-1 psi). The fuel system also incorporates a fuel filter differential pressure (FFDP) transducer (ref. "FFDP transducer" in Figure 2) that measures the difference in pressure between the oil/fuel heat exchanger inlet and the fuel filter outlet. In the event of a restriction in this area, the FFDP transducer will trigger a Crew Alerting System (CAS) annunciation for the three thresholds listed in Table 1. The differential pressure is not visible to the pilot while in flight unless a threshold is achieved and the annunciation set.

Table 1. Fuel filter differential pressure thresholds

Description	FFDP value	CAS message
Fuel filter maintenance	> 14.5 psid for 10 seconds and fuel temp > 0°C	Fuel Filter Replace (Status) (ground only)
Fuel filter impending bypass	> 16.5 psid for 10 seconds	Fuel IMP Bypass (Caution)
Fuel filter bypass	> 40.5 psid for 10 seconds	Fuel Filter Blocked (Caution)

A fuel pressure sensor is installed in the fuel line. If the fuel system pressure falls below 2 psi (and the fuel boost pump switches are set to the AUTO position), both the left and right fuel boost pumps will activate and attempt to restore fuel pressure. The boost pumps will automatically turn off 10 seconds after the fuel system pressure has reached 3.5 psi. A single boost pump is capable of supplying the engine with fuel in the event of a low pressure engine driven fuel pump failure.

Fuel quantity is determined using four capacitance-type fuel probes located in each fuel tank. Information on fuel quantity is computed by the Fuel Control Monitor Unit (FCMU) and displayed to the pilot on the FUEL window of the Multi-Function Display (MFD), segmented into 28 'bars' of fuel quantity for each tank. Fuel symmetry is automatically maintained by a fuel balancing device whenever the fuel pump switches were positioned to AUTO. The left and right fuel quantities are monitored to detect fuel asymmetry exceeding 5 percent of each wing's total fuel capacity (about 10.5 gallons, or 2 bars on the pilot's fuel quantity display) and will activate the fuel boost pump in the tank with the higher fuel quantity. Activation of the applicable fuel boost pump is delayed one minute to avoid pump cycling during flight in turbulence. The boost pump will continue to operate until the fuel levels equalize. The fuel balancing system will normally attempt to correct fuel imbalances up to 40 gallons (6 bars), beyond which, the system will no longer operate automatically. In the event of a system failure, fuel symmetry can be maintained by selecting the fuel boost pump to the ON position for the tank with the greater fuel quantity.

According to the Airplane Flight Manual (AFM), the airplane was limited to utilizing JET-A, JET-A-1, JP-5, F-35, JET A-50, JP-8, and JP-8+100 fuels. On this model Pilatus PC-12, the aircraft was certified without an air-separator in the engine fuel feed line. An air-separator in the engine fuel feed line was included on previous models of the PC-12. In addition, the production fuel system design of aircraft N400PW was such that a Fuel System Icing Inhibitor (FSII) was not required.

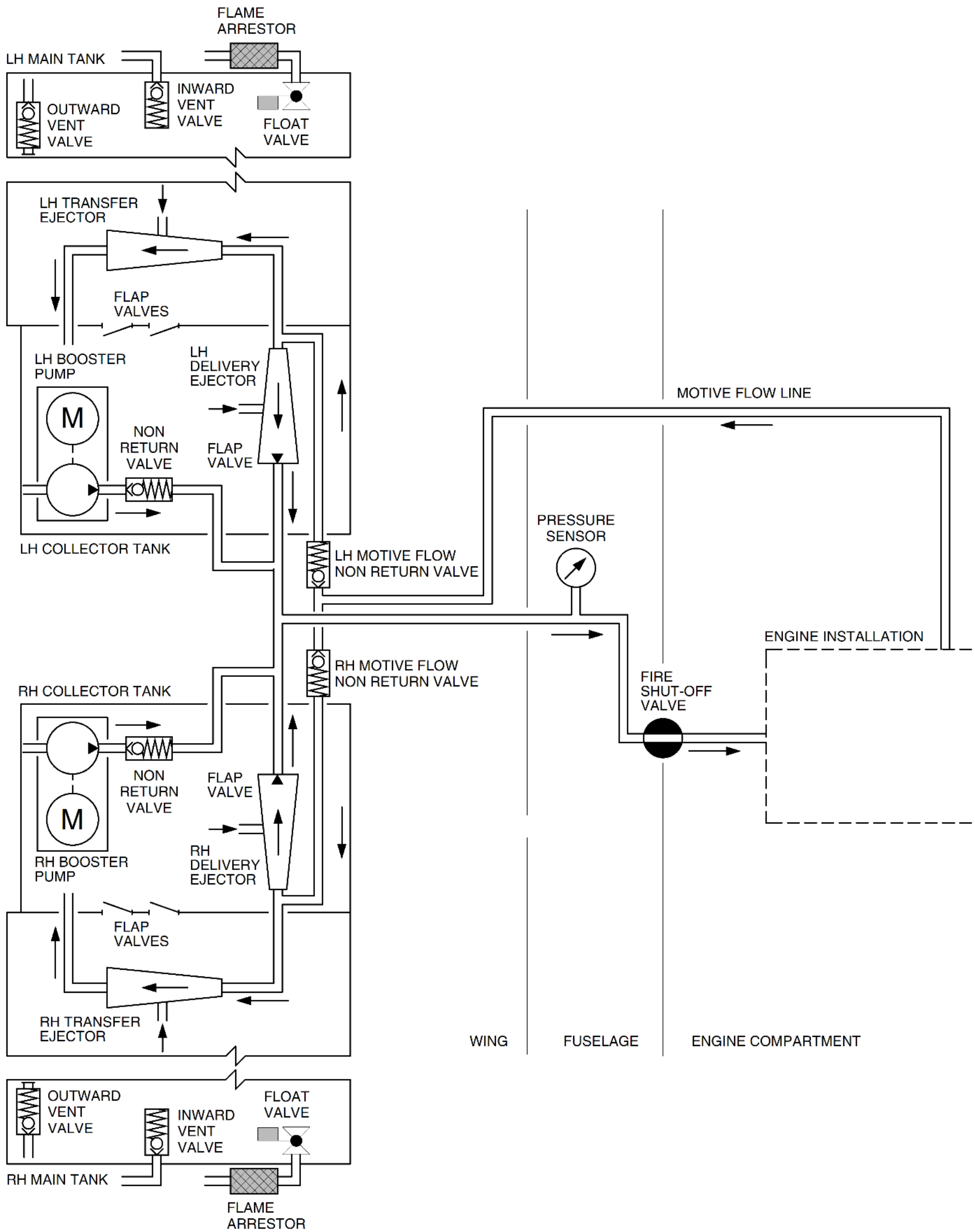

Figure 1. Aircraft production fuel distribution and vent system schematic. (Courtesy of Pilatus)

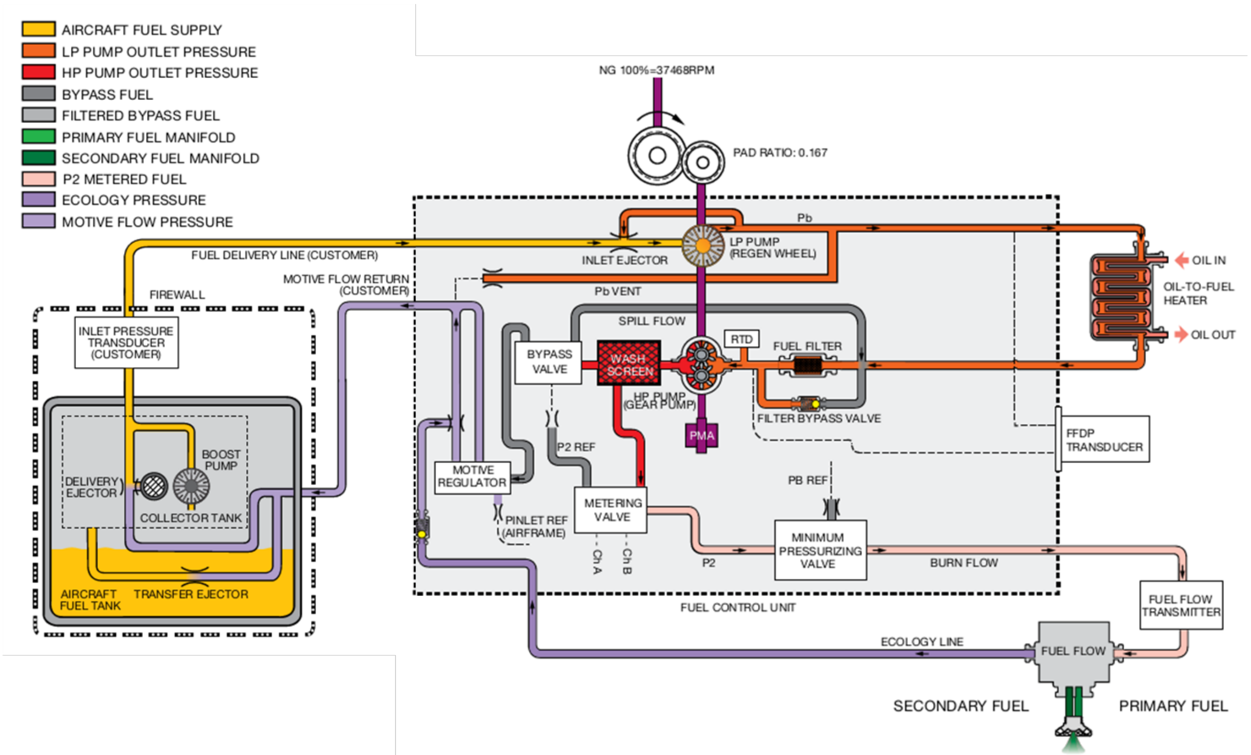

Figure 2. Engine fuel system schematic. (Courtesy of Pratt & Whitney Canada Corp.)

2.0 Ferry Fuel System Provisions

The ferry fuel system provisions were designed and installed by Pilatus Business Aircraft, LTD[1] on June 9, 2020, as a major alteration per FAA Form 337. The fuel system was modified by installing a tee fitting (PN AN824-10D), check valve (PN 869A-10TT), fuel line assemblies (PN 2X-2000-30-0002), a fuel line bracket (PN 2X-2000-32-0003) in the left wing in accordance with Pilatus Business Aircraft, LTD drawings 2X-2000-30-0003 and 12-1305-32-0005, and a fitting elbow feed through (PN AN837-10D) in accordance with Pilatus Business Aircraft, LTD drawings 2X-2000-30-0002 and 2X-2000-30-0003 and document 2X-2000-61-0000. The fitting through the fuselage was capped and the fuel lines leak checked. A schematic of the provisions is shown in Figure 3.

The Pilatus Business Aircraft, LTD Form 337 that installed the ferry system provisions stated, “Ferry tank installations should ensure that no air is introduced into the fuel system.”. This model PC-12 did not have an air-separator in the engine fuel feed line.

[1] Pilatus Business Aircraft Ltd, Broomfield, Colorado, USA, is a wholly owned subsidiary of PILATUS Aircraft Ltd, Stans, Switzerland.

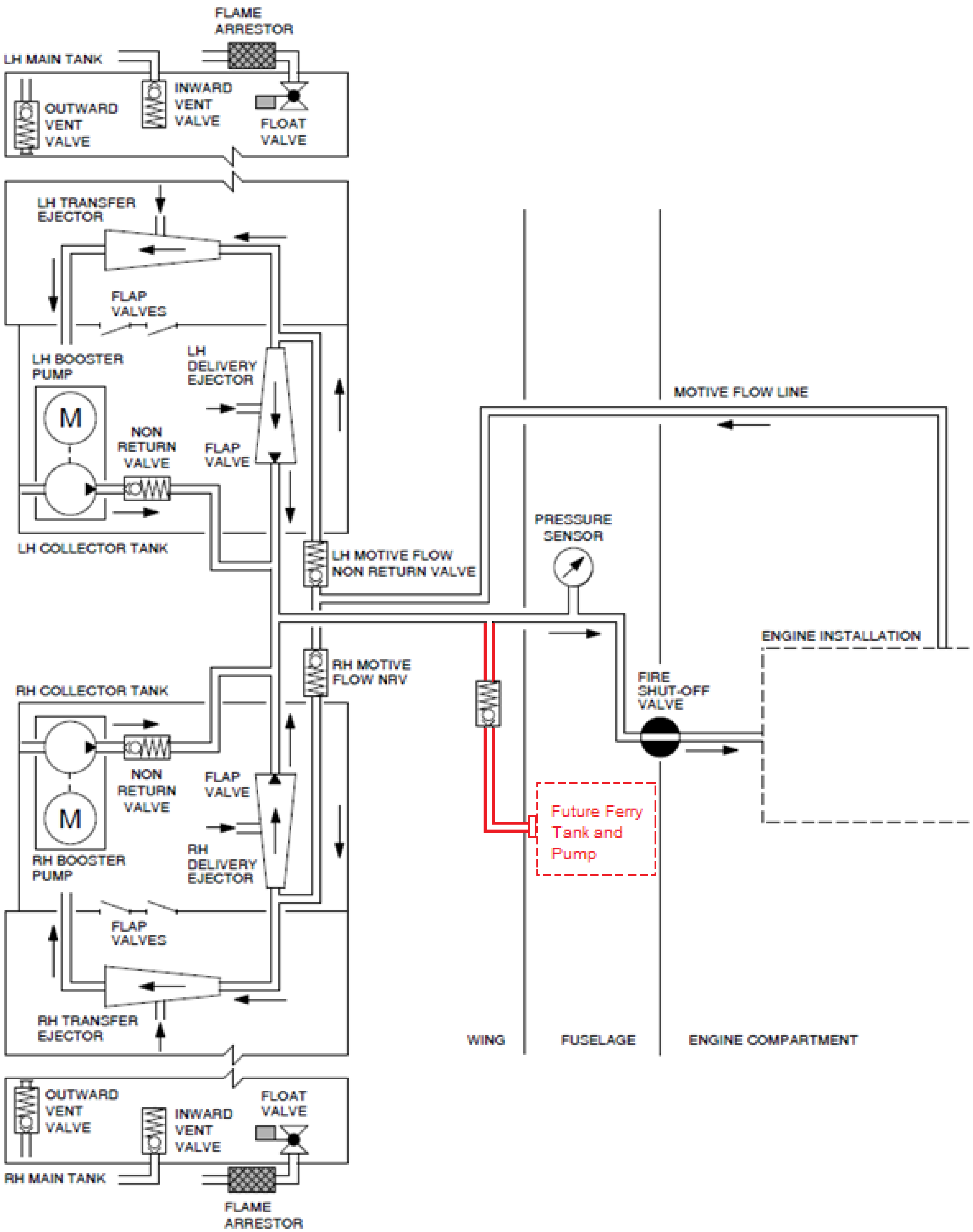

Figure 3. Fuel distribution and vent system schematic with ferry system provisions shown. (Courtesy of Pilatus)

3.0 Ferry Fuel System Installation

October 28, 2020, Flight Contract Services, Inc. modified the aircraft fuel system by installing two auxiliary aluminum 120 gallon ferry fuel tanks in the cabin. The tanks included fuel level sight gages. The number one tank was located at station 255 and was limited to 100 gallons and the number two tank was located at station 275 and was limited to 60 gallons. The tanks were vented to the cabin. The breather vent contained a 0.5 psi check valve and a 3.5 psi relief valve. It would take a 0.5 psi pressure difference to vent to the tank. If the tanks over pressurized to +3.5 psi, the relief valve would let air out. The emergency backup for the breather vent was to loosen the fuel caps. The tanks were electrically grounded and mounted on ½ inch plywood pallets. Pallets were secured with four 2,000 pound straps to eight points of the cargo tie down rings located in the existing seat rails. The ferry fuel system was connected to the existing post-production installed AN837-10D bulkhead fitting in the left-wing root area. See Figure 4. The ½ inch, FLEXTRAL J3-8 fuel line, connected the fuel tanks to a ½ inch on/off in-line ball valve for each tank, then to the fuselage bulkhead fitting and through a one-way check valve to the main fuel supply line.

The FAA Form 337 submitted by Pilatus Business Aircraft, LTD for the ferry system provisions described in section 2.0, states "The ferry tank provisions feed directly into the engine's fuel supply line.". In addition, the drawings and schematics showed the ferry system connected directly to the engine's fuel supply line. The FAA Form 337 submitted by Flight Contract Services, Inc. for the ferry system installation described in section 3.0, states "The ferry fuel feed is directly to the left main tank.".

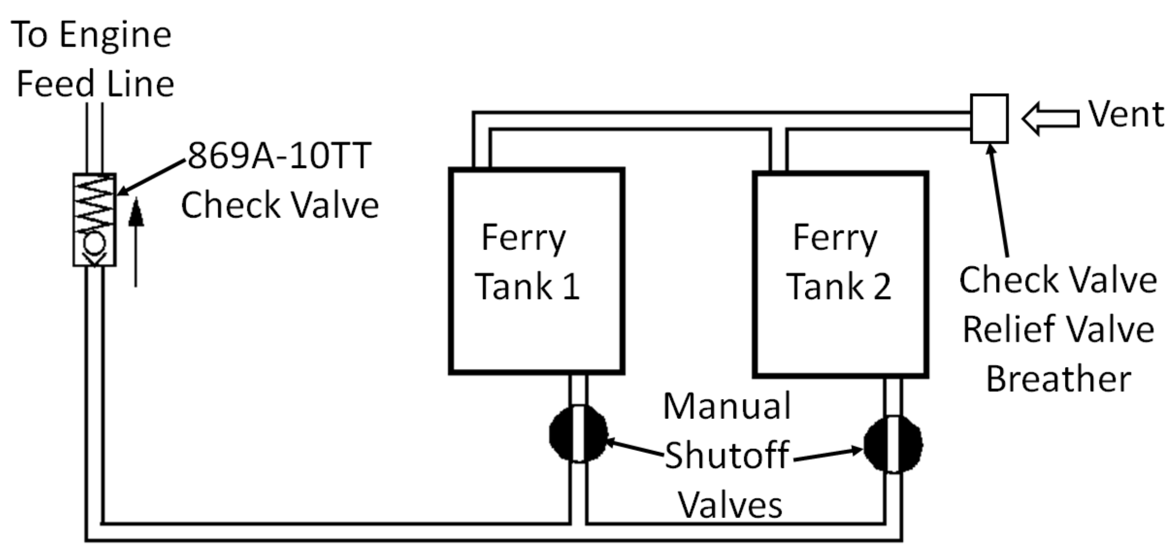

Figure 4. Schematic of ferry fuel system installed on 28 October 2020. (Created by NTSB)

During a positioning flight on 01 November 2020 and an attempted ferry flight on 02 November 2020, the ferry fuel system would not transfer any fuel from the ferry tanks. Between 02 and 05 November 2020, Gateway Air Center along with assistance from Flight Contract Services further modified the ferry fuel system by installing two FASD08100G[2] pumps to provide enough fuel pressure to overcome the delivery ejector pump pressure and supply fuel to the engine fuel supply line. The pumps were installed so that either pump could transfer fuel from either ferry tank. See Figures 5 and 6.

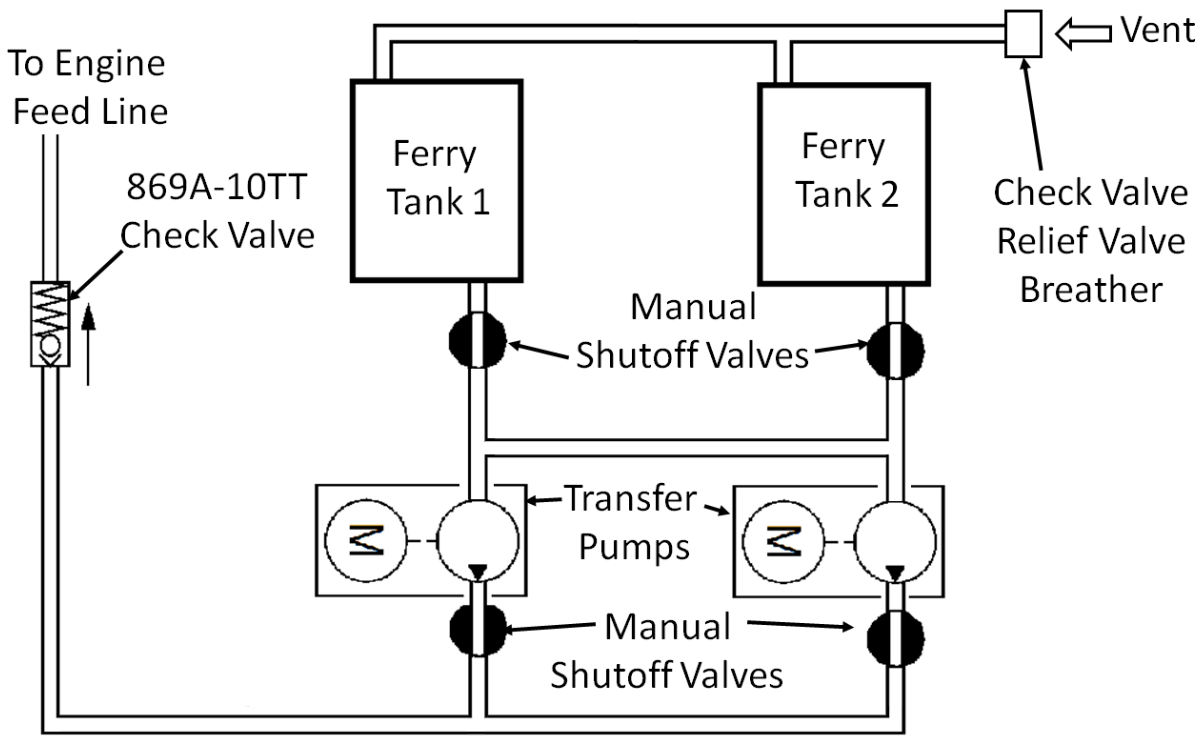

Figure 5. Schematic of ferry fuel system as modified on 05 November 2020. (Created by NTSB)

The ferry fuel system moves fuel to the engine feed line from ferry tanks through the 869A-10TT check valve. The ferry system transfer pump provides fuel at a higher pressure than the delivery ejector pumps which results in the closing of the flap valve in the delivery ejector pumps. The ferry system provides fuel to the engine. The excess fuel is then returned to the wing tanks through the motive flow circuit. The left and right transfer ejector pumps would operate as normal (transferring fuel to their respective collector tank). The motive flow fuel going to the delivery ejector pumps would flow out the pump inlet because the flap valve is closed. The ferry system flow rate would be what the engine burns plus the motive flow. The motive flow would be what refills the wing tanks. See Figure 7.

[2] The FASD08100G pumps are FASS Fuel Systems Signature Series Adjustable Diesel Fuel System 100GPH 1998.5-2004 Dodge Cummins 5.9 pumps.

Neither a new nor revised Form 337 was produced to document the installation of the ferry system pumps. The installation and operation of the ferry system changed the operating characteristics of the production fuel delivery system. No testing or evaluation was completed on how the ferry system would impact the expected system operation.

Figure 6. Photo of transfer pump installation. (Courtesy of Flight Contract Service)

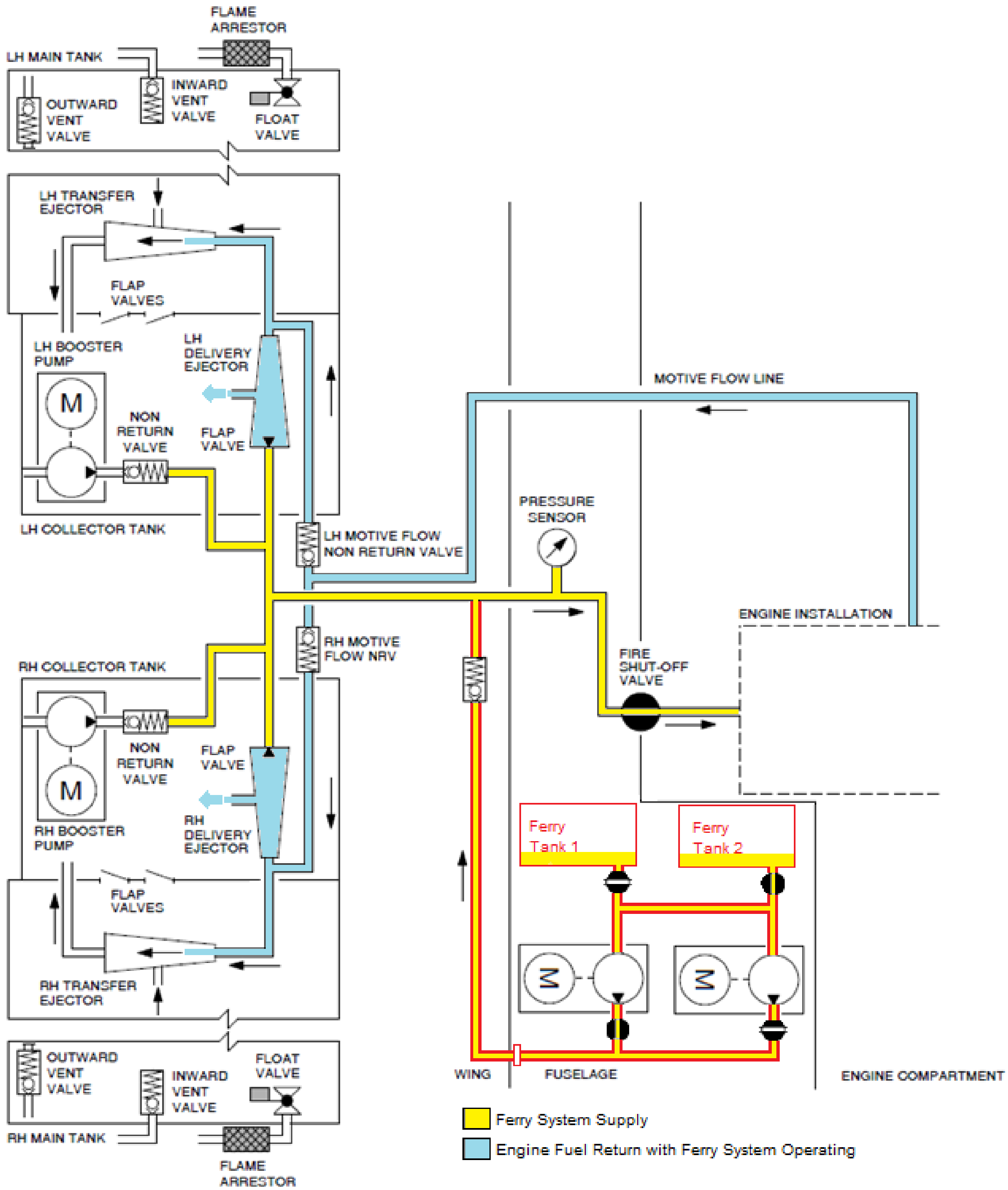

Figure 7. Schematic showing ferry system operation. Note: Source was Figure 3 and then modified by NTSB.

4.0 Advisory Circular 23-10 "Auxiliary Fuel Systems for Reciprocating and Turbine Powered Part 23 Airplanes"

Advisory Circular 23-10 "Auxiliary Fuel Systems for Reciprocating and Turbine Powered Part 23 Airplanes" states the following:

> "The requirements for a direct feed auxiliary fuel system are considerably more stringent than those for a transfer auxiliary fuel system. In general, these requirements ensure that an uninterrupted flow of fuel at the required pressure and flow rate is provided to each engine for all operating conditions of the airplane. For turbine engine airplanes, these provisions should be automatic to meet the requirements of§ 23.955(f)(2). These requirements also address altitude performance effects and low and high temperature fuel aspects as well as providing fuel system independence in at least one configuration. Failure Mode and Effects Analyses (FMEA) are needed to ensure that no hazardous conditions exist due to a failure of the auxiliary system. Continuous engine operation should be verified when the auxiliary tank system is depleted of fuel in order to prevent engine flameout or other unacceptable operating conditions."

There is no evidence that Pilatus Business Aircraft, LTD or Flight Contract Services, Inc. 1) addressed altitude performance effects and low and high temperature fuel aspects on the production system due to the ferry system operation; 2) completed a failure mode and effects analyses (FMEA) to ensure that no hazardous conditions existed due to a failure of the auxiliary system; or 3) verified continuous engine operation when the auxiliary tank system is depleted of fuel in order to prevent engine flameout or other unacceptable operating conditions as required in Advisory Circular 23-10. Neither Pilatus Business Aircraft, LTD or Flight Contract Services, Inc. evaluated 1) if a FSII should be required; and 2) if not having an air-separator would impact the system.

Advisory Circular 23-10 also states the auxiliary tank depletion characteristics should also be evaluated to ensure that air entrainment, etc., do not alter main tank performance. There is no evidence that Pilatus Business Aircraft, LTD or Flight Contract Services, Inc. evaluated the depletion characteristics. Flight Contract Services, Inc. did provide instructions to turn the ignitors ON if there was a chance of air getting into the system.

5.0 Pratt & Whitney Canada FAST™ Data Monitoring System

The aircraft was equipped with a Pratt & Whitney Canada (P&WC) FAST™ Data Monitoring System (DMS). The PT6E-67XP Engine and Propeller Electronic Control System (EPECS) also included a Data Collection Transmission Unit (DCTU) which collected the full flight data from the engine Electronic Engine Control (EEC) for every aircraft flight or engine ground run. When the aircraft lands and the engine is shut down, the data is transferred via cellular connection (SIM Card) to the P&WC FAST DMS Server. This data was available for all flights prior to the actual ferry flight to Hilo. The data from 06 October 2022 through 06 November 2022 was provided to the NTSB. The list of available parameters is in Table 2.

Table 2. P&WC FAST DMS data file parameters

Parameter Name in Data file	Description	Units
FDP(1A)	Fuel Differential Pressure Transducer (1A)	PSID
WF_SELECTED(1A)	Fuel Flow (1A)	PPH
FP(1A)	Fuel Pressure (1A)	PSID
IPS_DOOR_REQUEST_POS(1A)	Inertial Particle Separator Door Request Position (1A)	DISC
IPS_DOOR_SWITCH(1A)	Inertial Particle Separator Door Switch (1A)	DISC
ITT(1A)	Inter Turbine Temperature (1A)	DEG C
MOP(1A)	Main Oil Pressure (1A)	PSIG
MOT(1A)	Main Oil Temperature (1A)	DEG C
NG(1A)	Gas Generator Rotor Speed (1A)	%NG
NP_CCPU(1A)	Propeller speed Control Central Processing Unit (1A)	RPM
P3(1A)	Compressor output pressure	PSIA
WOW(1A)	Weight On Wheels (1A)	DISC
CAS(1A)	Calibrated Airspeed (1A)	KNOTS
MN(1A)	Mach Number (1A)	MACH
NP_PCPU(1A)	Propeller speed Protection Central Processing Unit (1A)	RPM
OAT(1A)	Outside Air Temperature(1A)	DEG C
AC_PALT(1A)	Aircraft Pressure Altitude (1A)	FEET
TQ(1A)	Torque (1A)	PSID
FDP(1B)	Fuel Differential Pressure Transducer (1B)	PSID
WF_SELECTED(1B)	Fuel Flow (1B)	PPH
FP(1B)	Fuel Pressure (1B)	PSID
IPS_DOOR_REQUEST_POS(1B)	Inertial Particle Separator Door Request Position (1B)	DISC
IPS_DOOR_SWITCH(1B)	Inertial Particle Separator Door Switch (1B)	DISC
ITT(1B)	Inter Turbine Temperature(1B)	DEG C
MOP(1B)	Main Oil Pressure (1B)	PSIG
MOT(1B)	Main Oil Temperature (1B)	DEG C
NG(1B)	Gas Generator Rotor Speed (1B)	%NG
NP_CCPU(1B)	Propeller speed Control Central Processing Unit (1B)	RPM
P3(1B)	Compressor Discharge Pressure (1B)	PSIA
WOW(1B)	Weight On Wheels (1B)	DISC
CAS(1B)	Calibrated Airspeed (1B)	KNOTS
MN(1B)	Mach Number (1B)	MACH

Parameter Name in Data file	Description	Units
NP_PCPU(1B)	Propeller speed Protection Central Processing Unit (1B)	RPM
OAT(1B)	Outside Air Temperature(1B)	DEG C
AC_PALT(1B)	Aircraft Pressure Altitude (1B)	FEET
TQ(1B)	Torque (1A)	PSID
PLA(1A)	Power Lever Angle (1A)	DEGREE
PLA(1B)	Power Lever Angle (1B)	DEGREE
TF(1A)	Temperature of Fuel (1A) (at high pressure pump inlet)	DEG C
TF(1B)	Temperature of Fuel (1B) (at high pressure pump inlet)	DEG C

6.0 Ferry Fuel System Operation During Positioning Flight

On the morning of 06 November 2020, the aircraft was flown from Merced Airport (KMCE) to Santa Maria Airport (KSMX). The ferry fuel system was operated and successfully transferred fuel to the aircraft fuel system. After switching off the ferry system transfer pump(s), the aircraft experienced a low fuel pressure condition at the same time as the fuel differential pressure increased. Twice the aircraft boost pumps cycled ON for 10 seconds before the fuel pressure returned to motive flow fuel pressure. See Figures 8-10. Neither pilot mentioned the cycling of the boost pumps in their statements. The fuel temperatures at the high pressure pump inlet remained above 40°C during the ferry system operation. The fuel temperatures upstream of the firewall shutoff valve was not measured.

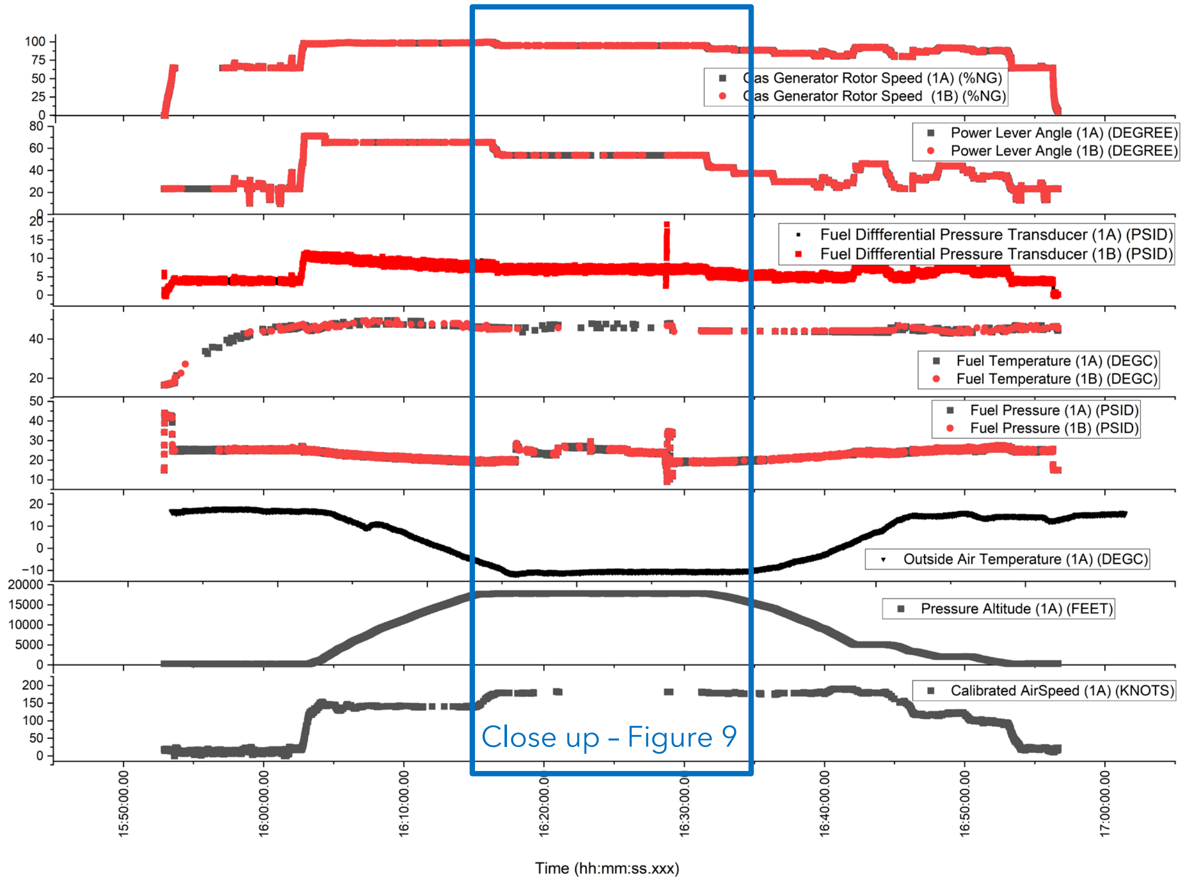

Figure 8. Data plots of selected parameters during flight from Merced to Santa Maria on 06 November 2020. (This data is from the Pratt & Whitney Canada FAST™ DMS.)

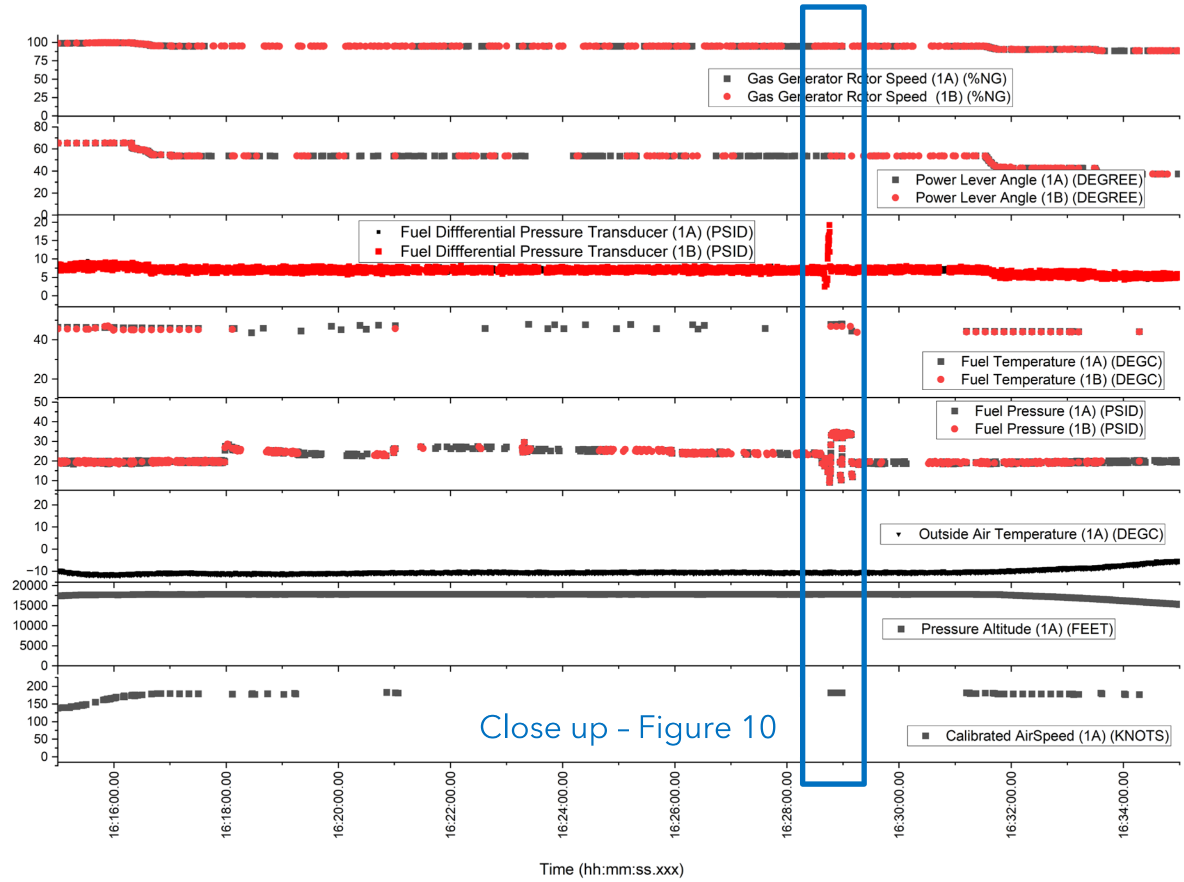

Figure 9. Data plots of selected parameters during ferry fuel system operation on the flight from Merced to Santa Maria on 06 November 2020. (This data is from the Pratt & Whitney Canada FAST™ DMS.)

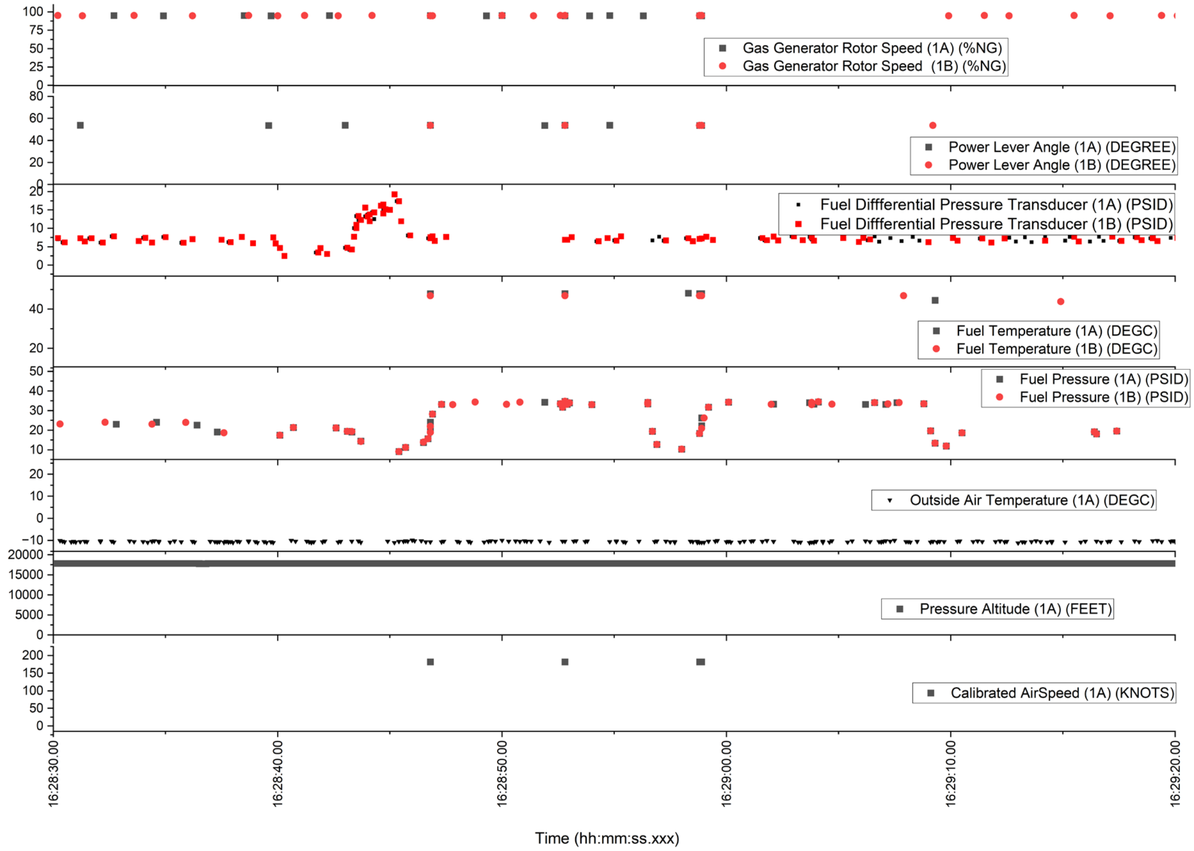

Figure 10. Data plots of selected parameters during transition from ferry fuel system operation to production system operation on the flight from Merced to Santa Maria on 06 November 2020. (This data is from the Pratt & Whitney Canada FAST™ DMS.)

7.0 Accident Flight

The following information is taken from the pilots' statements since no other factual information is available from the accident flight. The fuel load for the accident flight was main tanks full (402 gallons), ferry tank number one at 100 gallons and the ferry tank number two at 60 gallons. The fuel utilization procedure for the flight was 1) Use main tanks until their quantity decreased to 300 gallons; 2) Transfer half of ferry tank number two or when the main tanks reach 350 gallons; 3) Use main tanks until their quantity decreased to 300 gallons; 4) Transfer half of ferry tank number one or when the main tanks reach 350 gallons; 5) Repeat until ferry tanks are empty. The first halves of the ferry tanks were transferred without any issues except occasionally a "FUEL IMBALANCE" caution light occurred, but that was expected as excess transfer fuel was sent back to the main tanks after passing through the engine. Then the ferry system was used to transfer the remaining fuel from ferry tank number two.

About 5 hours into the flight, the number two ferry tank was almost empty. The pilots prepared to stop transferring fuel from the number two tank. The ignition switch was placed ON. The non-flying pilot stated that the transfer pump was turned OFF with fuel still visible in the supply line. The CAS "FUEL LOW PRESSURE" light illuminated. The pilot flying had already placed the IGNITION switch to ON during the ferry transfer, and now set the two aircraft BOOST PUMPs to the "ON" position for the end of transfer process and confirmed the pumps were ON with the green "L PUMP" and "R PUMP" lights on the Fuel System Status Window and green "IGNITION" message on the Primary Flight Display (PFD) Engine Window. About 5 seconds after the low pressure light illuminated, the engine surged and then completely shut down and feathered. The pilots estimated that the engine lost power about 20 seconds after turning the transfer pump off. The fuel quantity in the main tanks and ferry tank number one was about 450 gallons at the time. Fuel temperature in the wing tanks was unknown.

The engine stopped while the aircraft was at FL 280 but the pilots could not recall what altitude the air start procedures were performed, but they knew that 20,000 ft was the maximum altitude for restart in the Pilot Operating Handbook. The pilots used the checklist to perform an air start. The engine started and the propeller unfeathered; however, the engine never reached idle rpm and manipulation of the power control lever did not affect the engine. The engine did not fully start. The crew shut off the engine per the checklist and then attempted another air start. During the next start sequence, the engine made a loud grinding noise and then a loud catastrophic "bang." There was no evidence of smoke or flames from the exhaust on either side of the aircraft. The CAS panel had numerous messages. At some point, the EPECS FAIL light illuminated, but the pilots could not recall exactly when. As the airplane descended, the crew attempted multiple air starts, including the procedures for an EPECS FAIL light on. The propeller never moved, and the engine never started. About 8,000 ft, the crew committed to ditching the airplane and they commenced the ditching checklist.

The pilots, one at a time, went to the back of the airplane to prepare the survival gear. They each donned a life vest. They had a 6 man raft onboard and they prepared it for deployment. The pilot performed a gear up, full flap landing at an angle to the direction of the ocean swells, roughly into the wind. The swells were about 5 to 10 ft high with 20 ft between the crests. The airplane touched a crest with the tail, then it impacted the next crest with the tail first. They finish securing the airplane and then opened the right over wing exit. They deployed the raft and put the survival pack in it. They had a satellite phone, and marine Very High Frequency (VHF) radio, and Personal Locator Beacon/Emergency Position Indicating Radio Beacon (PLB/EPIRB), and life raft Emergency Locator Transmitter (ELT), thermal blankets, food, and water. The airplane stayed upright floating on the surface. They pushed away from the airplane and it stayed insight for about 30 minutes.

Submitted by:

John Flynn
Aircraft Systems Investigator