



**NATIONAL TRANSPORTATION SAFETY BOARD**  
**Office of Aviation Safety**  
**Washington, D.C. 20594**

**April 12, 2023**

**POWERPLANT GROUP CHAIRMAN'S FACTUAL REPORT**

**NTSB No: ENG22LA049**

**A. INCIDENT**

Location: Riyadh, Kingdom of Saudi Arabia

Date: March 31, 2022

Time: 19:05 UTC

Aircraft: Vistajet, Bombardier Global 7500 Business Jet, Registration number 9H-VIG

On March 31, 2022, at 19:05 universal coordinate time (UTC), a Bombardier Global 7500 Business Jet, registration number 9H-VIG, powered by two General Electric (GE) Aviation Passport 20-19BB1A turbofan engine and operated by Vistajet, experienced a right (No. 2) engine fire during the takeoff climb from the King Khalid International Airport, Riyadh, Kingdom of Saudi Arabia (OERK). After the right engine fire warning annunciated, the pilots disengaged the autothrottles and retarded the right engine throttle to idle. When the right engine throttle was reduced, the fire warning annunciation ceased. With the fire warning annunciation out, the pilots incrementally increased the right throttle and the fire warning annunciated again. The pilots shutdown the right engine, performed an in-flight air turn back to OERK, and made an uneventful landing with no injuries reported.

The Kingdom of Saudi Arabia Aviation Investigation Bureau (AIB) informed the NTSB of this event on April 14, 2022, and the investigation was ultimately delegated to the NTSB. Due to the similarities with an on-going NTSB investigation (ENG22LA020), a joint Powerplant Group Chair Factual Report was created to document the findings for these two events. Details for this event can be found in Section 3.0 of this report.



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**POWERPLANT GROUP CHAIRMAN'S FACTUAL REPORT**

**NTSB No: ENG22LA020**

**A. INCIDENT**

Location: Palm Beach, Florida

Date: April 3, 2022

Time: 09:06 eastern standard time

Aircraft: Wing Aviation Charter Services LLC, Bombardier Global 7500 Business Jet,  
Registration number N63RP

**B. POWERPLANT GROUP MEMBERS**

Safety Board Group Chairman: Jean-Pierre Scarfo  
Powerplant Lead Engineer  
Washington D.C.

General Electric Aviation: Sam Farmiga  
Product Safety Engineer  
Commercial Flight Safety  
Cincinnati, Ohio

Dale Dennis  
Product Safety Engineer  
Commercial Flight Safety  
Cincinnati, Ohio

Federal Aviation Administration Members: David Keenan  
Air Accident Investigator  
Washington D.C.

Scott Stevenson  
Continued Operation Safety  
Engine Certification Office  
Burlington, Massachusetts

Kingdom of Saudi Arabia Accredited  
Representation Member:

Tawfik Alkeshi  
Technical Investigator  
Accident Investigation Bureau  
Jeddah, Kingdom of Saudi Arabia

Malta Accredited Representative:

John Barbara  
Inspector Investigations Unit  
Bureau of Air Accident Investigation  
Floriana, Malta

Canadian Accredited Representative:

Jerome Ouellet  
International Operations and Major  
Investigations  
Transportation Safety Board of Canada  
Quebec Canada

Canadian Technical Advisor:

Michael Lemay  
Chief Air Safety Investigator  
Bombardier Aviation  
Quebec Canada

## C. SUMMARY

On April 3, 2022, at 9:06 eastern standard time, a Bombardier Global 7500 Business Jet, registration number N63RP, powered by two General Electric (GE) Aviation Passport 20-19BB1A turbofan engines and operated by Wing Aviation Charter Services LLC, experienced a left (No. 1) engine fire during takeoff climb from the Palm Beach International Airport (PBI), West Palm Beach, Florida. After the left engine fire warning was annunciated, the pilots reduced power and leveled off at 4,000 feet above ground level (AGL) at which time the fire warning annunciation ceased. The pilots notified air traffic control (ATC) that the fire warning was intermittent, and they were going to proceed with the planned flight. A subsequent climb with the engines at high power caused the left engine fire warning to annunciate again. The pilots performed an in-flight turn back to PBI and made an uneventful landing with no injuries reported to the three crew members and 15 passengers on board. The incident flight was a 14 *Code of Federal Regulations* (CFR) Part 135 non-scheduled domestic passenger flight from PBI to Teterboro airport (TEB), Teterboro, New Jersey.

Post-event engine inspection found light thermal distress on the outside of the engine core compartment near the top of the engine from the 10:00 to 11:00 o'clock position, aft looking forward, in the vicinity of the fuel manifolds and the fuel nozzles. Localized discoloration was observed on the inside of the core cowls consistent with the general location of fuel nozzle No. 16 and a thermally distressed engine air duct sleeve. At fuel nozzle No. 16, the fuel nozzle-to-fuel manifold b-nut connection appeared shiny and lacked the sooting that neighboring fuel nozzle-to-fuel manifold b-nut connections exhibited.

The engine was shipped to the GE Peebles Test Operations facility in Peebles, Ohio, to perform a series of leak checks, torque checks, and alignment checks. A nitrogen check, using soapy liquid at all the fuel manifold b-nut connections was conducted; no leaks were found. A torque check of all the fuel nozzle-to-fuel manifold b-nut connects found that four had very low torque values, less than 200 inch-pounds, when compared to the other b-nut connection locations and the required installation torque of 285 inch-pounds nominal. One of the four low torque locations was fuel nozzle No. 16.

After completing the on-engine checks, the fuel manifolds and fuel nozzles were removed and shipped to the GE failure analysis laboratory in Cincinnati, Ohio for additional component evaluation. Detailed examination of the fuel nozzle No. 16 location revealed: 1) galling on the outer diameter of the fuel manifold ferrule sealing surface consistent with the b-nut running onto the tube outer diameter, 2) signs of galling and grooving on the fuel manifold female ferrule inner conical sealing surface that mates with the fuel nozzle male bullnose sealing surface, and 3) elliptical and intermittent contact marks around the fuel nozzle male bullnose conical surface, consistent with misalignment contact with the fuel manifold female ferrule; the wear mark was not in the same plane around the entire surface. According to GE, this observed female ferrule sealing surface damage is indicative of misalignment and relative movement within the connection due to high load and low cycle contact and not vibratory wear. Visual examination found no other fuel manifold b-nut connections or fuel nozzle male bullnoses exhibiting similar ferrule sealing surface damage.

During the investigation into this event, three additional GE Passport 20-19BB1A engines experienced fuel manifold leaks, two of which resulted in an in-flight undercowl fire. This factual report documents the findings from all four GE Passport fuel leak events, the testing conducted to determine the causes, and the corrective actions taken by GE and the Federal Aviation Administration to prevent further occurrences. GE performed similar leak, torque, and alignment checks on all those engines along with visual examination of the fuel nozzle and fuel manifold sealing surfaces to determine if there were common causes/anomalies for all the observed fuel manifold leaks. Additionally, GE conducted a series of acceptance test procedure engine runs, developmental engine runs, and component static rig tests to: 1) better understand the effects of fuel nozzle-to-fuel manifold pigtail misalignment, 2) gather assembly and operational loads/stresses on the fuel manifolds under a variety of installation sequence scenarios, 3) validate and develop fuel manifold and fuel nozzle installation best practices and procedures, 4) gather operational data on torque (clamp) relaxation on the fuel manifold b-nut connections, and 5) develop methods to minimize the amount of relaxation experienced in operation.

Based on all the data gathered from the event engines, the test engines, and component rig tests, several cumulative factors were found to have contributed to the fuel manifold leaks. Fuel manifold pigtail and fuel nozzle dimensional variation, combined with a given assembly sequence, can create potential misalignment between fuel manifold female ferrule and fuel nozzle male bullnose sealing surfaces, resulting in high resistance in the threads, low effective clamping force, and a false (high) torque reading. This low effective clamped connection can relax/loosen during engine operation as the manifold geometry normalizes and the connection shifts. All the leaking fuel manifold b-nut connections were found on connections with lower than expected torque values. Since no fuel leaks occurred during the development engine tests, and leaks could be induced and stopped with slight variations in torque during the component rig tests, GE concluded that relaxation of the fuel manifold b-nut connection torque and misalignment were insufficient to induce a leak on their own; therefore, an aggravating factor such as surface distress, like what was observed in the event engines, was also necessary. GE also concluded that multiple factors can be present to create a leak and they are false (low) torques due to misalignment, higher than anticipated assembly loads due to dimensional variation, and poor/distressed sealing surface condition.

Several corrective actions were taken by GE and the Federal Aviation Administration to address and mitigate the risk of GE Passport 20-19BB1A engines fuel manifold leaks. GE issued service bulletins to borescope the engine compartment for signs of an undercowl fuel leak or fire damage (72-00-0141-00A-930A-D-001), and to retorque the fuel manifold b-nut connections as well as the fuel manifold-to-fuel manifold b-nut connection (72-00-0142-00A-930A-D-001); the Federal Aviation Administration followed up with Airworthiness Directive AD 2022-13-12 requiring a visual inspection of the core compartment, a retorque of the core compartment coupling nuts, a ground power assurance check, and a follow-up borescope inspection to ensure that there were no leaks before the airplane was returned to service. GE reviewed the fuel manifold and fuel nozzle installation and assembly procedures and made several changes to provide more specific guidance. The changes focused on eliminating possible ambiguities in the written procedures and to minimize any misalignments or unintended installation loads based on the results from the static rig and engine tests. In

addition, feedback from the assembly mechanics were included to improve the overall effectiveness of the proposed installation and assembly changes. GE issued a "change in design" to finalize and clarify the optimum fuel nozzle and fuel manifold installation and assembly procedure using the best practices developed during testing.

## TABLE OF CONTENTS

|                                                                                     |    |
|-------------------------------------------------------------------------------------|----|
| A. INCIDENT .....                                                                   | 2  |
| B. POWERPLANT GROUP MEMBERS .....                                                   | 2  |
| C. SUMMARY .....                                                                    | 4  |
| TABLE OF CONTENTS.....                                                              | 7  |
| TABLE OF PHOTOS.....                                                                | 8  |
| TABLE OF FIGURES .....                                                              | 8  |
| TABLE OF TABLES .....                                                               | 8  |
| TABLE OF ACRONYMS.....                                                              | 9  |
| D. DETAILS OF THE INVESTIGATION .....                                               | 10 |
| 1.0 ENGINE AND AIRPLANE INFORMATION – N63RP .....                                   | 10 |
| 1.1 Airplane and Engine History.....                                                | 10 |
| 1.2 Engine Description .....                                                        | 10 |
| 1.3 Fuel Distribution Core Component Description.....                               | 12 |
| 1.4 Engine Nacelle and Fixed Duct Description .....                                 | 13 |
| 2.0 GE PASSPORT 20-19BB1A ESN 904265 EVALUATION – PALM BEACH EVENT .....            | 14 |
| 2.1 On Scene Examination at PBI .....                                               | 14 |
| 2.2 Leak Checks at GE .....                                                         | 15 |
| 2.3 Gap and Torque Checks at GE.....                                                | 16 |
| 2.4 Fuel Nozzle-to-Fuel Manifold B-nut Interface Connection Examination at GE ..... | 17 |
| 2.5 GE Laboratory Exam of the Fuel Nozzles and Fuel Manifolds .....                 | 18 |
| 3.0 GE PASSPORT 20 – ADDITIONAL FUEL MANIFOLD LEAK EVENTS .....                     | 19 |
| 3.1 ESN 904292 Fuel Leak – Operation Event – Saudi Arabia .....                     | 19 |
| 3.2 ESN 904365 Fuel Leak – Found During B-Nut Retorque at Bombardier.....           | 25 |
| 3.3 ESN 904238 Fuel Leak - Found During B-nut Retorque at Bombardier.....           | 26 |
| 4.0 COMPARISONS BETWEEN THE FUEL LEAK ENGINES .....                                 | 29 |
| 5.0 TESTING - ENGINE ACCEPTANCE, DEVELOPMENT ENGINE, AND COMPONENT RIG.....         | 30 |
| 5.1 Acceptance Test Procedure for Return-to-Service of ESN 904365 .....             | 30 |
| 5.2 Development Engine Test - Replicate Misalignment and Wear Damage .....          | 31 |
| 5.3 Component Rig Testing .....                                                     | 32 |
| 6.0 ADDITIONAL VISUAL DATA GATHERED .....                                           | 34 |
| 6.1 Fuel Nozzle Female Ferrule Sealing Surface Deformation.....                     | 34 |
| 6.2 Visual Comparison of The Right and Left Fuel Manifolds.....                     | 35 |
| 7.0 TESTING AND DATA GATHERING FINDINGS.....                                        | 37 |
| 8.0 CORRECTIVE ACTION .....                                                         | 38 |
| 8.1 Changes to the Fuel Nozzle and Fuel Manifold Assembly Procedure.....            | 38 |
| 8.2 All Operators Wires and Advisor Wires .....                                     | 39 |
| 8.3 Service Bulletins and Airworthiness Directives .....                            | 40 |
| ATTACHMENTS .....                                                                   | 43 |

## TABLE OF PHOTOS

|                                                                                                                                     |    |
|-------------------------------------------------------------------------------------------------------------------------------------|----|
| PHOTO 1: LOWER FAN COWL DISCOLORED .....                                                                                            | 14 |
| PHOTO 2: THERMAL DISTRESS AND NO. 16 FN LOCATION AS POSSIBLE LEAK LOCATION .....                                                    | 14 |
| PHOTO 3: POSSIBLE FUEL AND THERMAL IMPINGEMENT LOCATIONS.....                                                                       | 15 |
| PHOTO 4: FUEL LEAK CHECK WITH DEVELOPER.....                                                                                        | 15 |
| PHOTO 5: B-NUT GAP CHECK AND TORQUE MEASUREMENT .....                                                                               | 16 |
| PHOTO 6: FUEL MANIFOLD FERRULE DAMAGE AT FUEL NOZZLE NO. 16 LOCATION .....                                                          | 17 |
| PHOTO 7: ELLIPTICAL GALLING ON THE FUEL NOZZLE MALE BULLNOSE SEALING SURFACE .....                                                  | 18 |
| PHOTO 8: CORE FIRE HARNESS THERMALLY DAMAGE (6:00-7:00 O'CLOCK POSITION ALF) .....                                                  | 20 |
| PHOTO 9: TURBINE CENTER FRAME (TCF) DRAIN TUBE SOOTED.....                                                                          | 20 |
| PHOTO 10: FUEL MANIFOLD B-NUT WETTED (12:00-1:00 O'CLOCK POSITION ALF).....                                                         | 20 |
| PHOTO 11: FUEL MANIFOLD B-NUT WETTED (12:00-1:00 O'CLOCK POSITION ALF).....                                                         | 20 |
| PHOTO 12: FUEL MANIFOLD B NUT WETTED (6:00-1:00 O'CLOCK POSITION ALF) .....                                                         | 20 |
| PHOTO 13: FUEL MANIFOLD B NUT WETTED (6:00-1:00 O'CLOCK POSITION ALF) .....                                                         | 20 |
| PHOTO 14: THERMAL DISTRESS AND POSSIBLE LEAK LOCATION .....                                                                         | 21 |
| PHOTO 15: FN NO. 18 FLUID FLOW PATTERN.....                                                                                         | 22 |
| PHOTO 16: FN NO. 16 FLUID FLOW PATTERN.....                                                                                         | 22 |
| PHOTO 17: FUEL MANIFOLD FERRULE DAMAGE AT FUEL NOZZLE NO. 18 LOCATION.....                                                          | 23 |
| PHOTO 18: NO. 18 FN MALE BULLNOSE WITH ABRASIVE MARKS AND PARTICLE IMPRESSION .....                                                 | 24 |
| PHOTO 19: HIGH MAGNIFICATION OF SIMILAR SHAPED DEBRIS DAMAGE ON FUEL NOZZLE MALE BULLNOSE SEALING<br>SURFACE ON NOS. 13 AND 16..... | 24 |
| PHOTO 20: M26 MALE BULLNOSE FLAT SPOT/DENT AND MATERIAL REMOVAL .....                                                               | 25 |
| PHOTO 21: SUSPECTED FUEL LEAK FROM FUEL NOZZLE NO. 1 LOCATION .....                                                                 | 26 |
| PHOTO 22: FN NO. 1 FERRULE DAMAGE AND FEMALE SEALING SURFACE GALLING .....                                                          | 27 |
| PHOTO 23: FN NO. 1 MALE BULLNOSE DAMAGE AND MALE SEALING SURFACE GALLING.....                                                       | 28 |
| PHOTO 24: EXAMPLES OF DIFFERENT ALIGNMENTS/MISALIGNMENTS.....                                                                       | 32 |
| PHOTO 25: INSTRUMENTED COMPONENT RIG TEST .....                                                                                     | 33 |
| PHOTO 26: THERMAL RIG TEST .....                                                                                                    | 33 |
| PHOTO 27: NON-DEFORMED SEALING SURFACE .....                                                                                        | 34 |
| PHOTO 28: SLIGHT DEFORMED SEALING SURFACE.....                                                                                      | 34 |
| PHOTO 29: FUEL MANIFOLD PIGTAIL ALIGNMENT TEMPLATE .....                                                                            | 35 |
| PHOTO 30: SEMI-FREE STATE MISALIGNMENT ON ESN 904265 FUEL MANIFOLD .....                                                            | 36 |
| PHOTO 31: SEMI-FREE STATE MISALIGNMENT ON ESN 904292 FUEL MANIFOLD .....                                                            | 36 |
| PHOTO 32: PIGTAILS ON ESN 904238 NOT FLUSH WITH TABLE .....                                                                         | 37 |

## TABLE OF FIGURES

|                                                                       |    |
|-----------------------------------------------------------------------|----|
| FIGURE 1: GE PASSPORT 20 BASIC VIEW .....                             | 10 |
| FIGURE 2: GE PASSPORT 20 BASIC CROSS-SECTION.....                     | 11 |
| FIGURE 3: FUEL NOZZLE/FUEL MANIFOLD MOUNTED ON COMBUSTION CASE.....   | 12 |
| FIGURE 4: FUEL NOZZLE AND FUEL MANIFOLD DIAGRAM.....                  | 12 |
| FIGURE 5: NACELLE COMPONENTS.....                                     | 13 |
| FIGURE 6: FAN COWLS OPEN.....                                         | 13 |
| FIGURE 7: FIXED FAN DUCT AND CORE COWL PANELS .....                   | 13 |
| FIGURE 8: FUEL MANIFOLD B-NUT LOW TORQUE AND FUEL LEAK LOCATIONS..... | 30 |
| FIGURE 9: FERRULE SEALING SURFACES .....                              | 34 |

## TABLE OF TABLES

|                                                                            |    |
|----------------------------------------------------------------------------|----|
| TABLE 1: FUEL MANIFOLD B-NUT GAP AND INSTALLATION TORQUE MEASUREMENTS..... | 16 |
| TABLE 2: PASS 20-19BB1A FUEL MANIFOLD LEAKS EVENTS .....                   | 19 |
| TABLE 3: FEATURES OF ALL FUEL MANIFOLD LEAKS .....                         | 29 |

**TABLE OF ACRONYMS**

|       |                                       |        |                                           |
|-------|---------------------------------------|--------|-------------------------------------------|
| °C    | Degree Celsius                        | GE     | General Electric                          |
| °F    | Degree Fahrenheit                     | HPC    | High Pressure Compressor                  |
| 3D    | Three-Dimensional                     | HPSOV  | High Pressure Shutoff Valve               |
| AD    | Airworthiness Directive               | HPT    | High Pressure Turbine                     |
| AGL   | Above Ground Level                    | ICAO   | International Civil Aviation Organization |
| AIB   | Aviation Investigation Bureau         | In.    | Inch                                      |
| ALF   | Aft Looking Forward                   | lb.(s) | Pound(s)                                  |
| AOW   | All Operators Wire (GE Aviation)      | LEC    | Low Emission Combustor                    |
| ATB   | Air Turn Back                         | LPC    | Low Pressure Compressor                   |
| ATC   | Air Traffic Control                   | LPT    | Low Pressure Turbine                      |
| ATP   | Acceptance Test Procedure             | N1     | Low Pressure Rotor Speed (in percent)     |
| AW    | Advisory Wire (Bombardier)            | N2     | High Pressure Rotor Speed (in percent)    |
| BAAI  | Bureau of Air Accident Investigation  | NTSB   | National Transportation Safety Board      |
| BSI   | Borescope Inspection                  | OGV    | Outlet Guide Vane                         |
| BTU   | British Thermal Unit                  | PBI    | Palm Beach International Airport          |
| CC    | Core Cowl                             | PN     | Part Number                               |
| CCW   | Counterclockwise                      | PSID   | Pounds Per Square Inch Differential       |
| CFR   | Code of Federal Regulations           | PSIG   | Pounds Per Square Inch Gage               |
| CID   | Change In Design                      | PSIGA  | Pounds Per Square Inch Gage Absolute      |
| CSN   | Cycle Since New                       | PTO    | Peebles Test Operations                   |
| CW    | Clockwise                             | RPM    | Revolution Per Minute                     |
| EASA  | European Union Aviation Safety Agency | SB     | Service Bulletin                          |
| ESN   | Engine Serial Number                  | SN     | Serial Number                             |
| FAA   | Federal Aviation Administration       | TCCA   | Transport Canada Civil Aviation           |
| FADEC | Full Authority Digital Control        | TCDS   | Type Certificate Data Sheet               |
| FEI   | Field Engineering Instruction         | TCF    | Turbine Center Frame                      |
| FFD   | Fixed Fan Duct                        | TEB    | Teterboro Airport                         |
| FN    | Fuel Nozzle                           | TSB    | Transportation Safety Board (Canada)      |
| FPI   | Fluorescent Penetrant Inspect         | TSN    | Time Since New                            |

## D. DETAILS OF THE INVESTIGATION

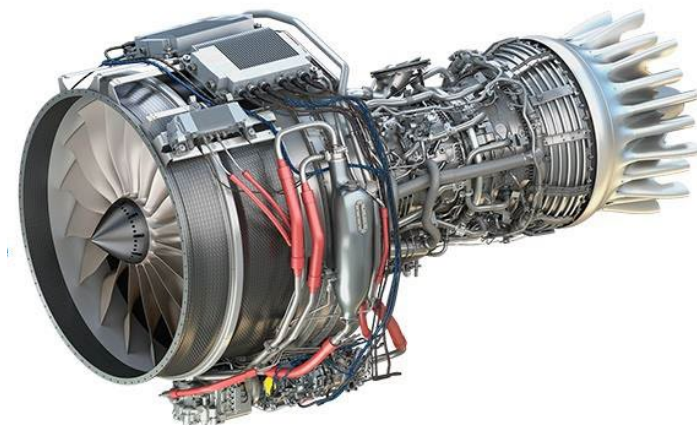
### 1.0 ENGINE AND AIRPLANE INFORMATION - N63RP

#### 1.1 AIRPLANE AND ENGINE HISTORY

The incident airplane was a Bombardier Global 7500 Business Jet, registration number N63RP, serial number (SN) 70079, produced in 2021, and operated by Wing Aviation Charter Services LLC, United States. The airplane was equipped with two General Electric (GE) Aviation<sup>1</sup> Passport 20-19BB1A turbofan engines. The left (No. 1) engine, engine serial number (ESN) 904265 had accumulated 211 hours time since new (TSN) and 119 cycles since new (CSN) at the time of the event. The right (No. 2) engine, ESN 904264, had accumulated 196 hours TSN and 110 CSN at the time of the event. Neither engine had undergone an overhaul or shop visit prior to the event. The engines were delivered new with the airplane.

#### 1.2 ENGINE DESCRIPTION

The GE Aviation Passport 20 engine is a high bypass dual-rotor, axial-flow turbofan (**FIGURE 1**). The bypass ratio of the engine is 5.6:1 with an overall pressure ratio of 45:1. The high pressure compressor (HPC) is driven by a two-stage high pressure turbine (HPT). The 10-stage HPC includes five blisk<sup>2</sup> stages for weight reduction. The integrated front fan and three-stage low pressure compressor (LPC) is driven by a four-stage low pressure turbine (LPT) (**FIGURE 2**). A low emission combustor (LEC) is used for weight and emissions advantage. Combustor case has integrated outlet guide vanes (OGVs) diffuser for weight reduction. The accessory drive system extracts energy from the high pressure high speed rotor to drive the engine accessories and the engine-mounted aircraft accessories. The engine is equipped with a dual channel Next Generation Full Authority Digital Engine Control (FADEC) control system which provides enhanced fault isolation and capability for engine functionality and diagnostics.

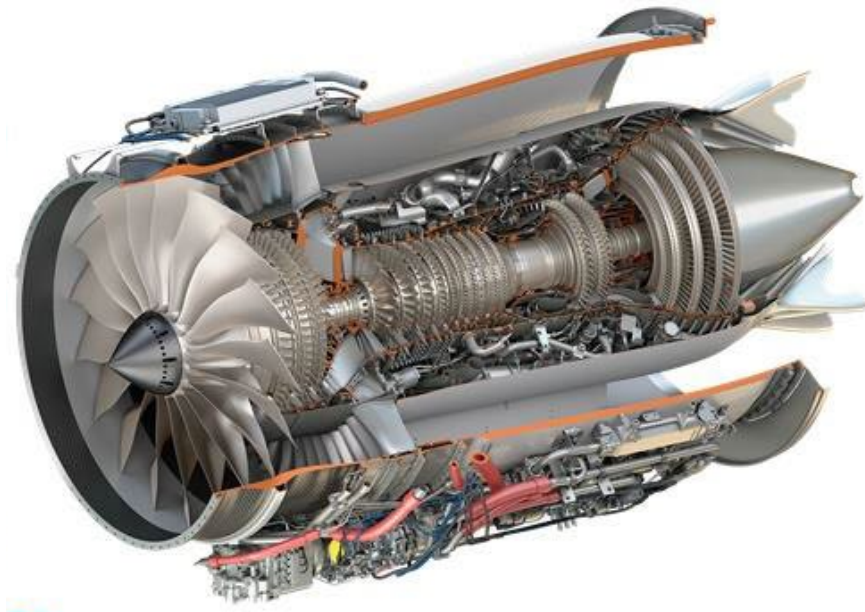


**FIGURE 1: GE PASSPORT 20 BASIC VIEW**

Figure courtesy of GE

<sup>1</sup> For the remainder of this report GE Aviation may simply be referred to as GE.

<sup>2</sup> A one-piece bladed disk that eliminates individual separate blades and attaching hardware.



**FIGURE 2: GE PASSPORT 20 BASIC CROSS-SECTION**

Figure courtesy of GE

According to the engine's FAA Type Certificate Data Sheet (TCDS) E00091EN, Revision 2, dated March 18, 2019, the GE Passport 20-19BB1A turbofan was issued a FAA type certificate on April 29, 2016. The engine has a maximum takeoff (5 minutes) at sea level static thrust rating of 18,920 pounds at a fan speed of 5,761 revolutions per minute (RPM), flat-rated<sup>3</sup> to 86°F (30°C) and a maximum continuous at sea level static thrust rating of 17,565 pounds at a fan speed of 5,611 RPM, flat-rated to 77°F (25°C). The maximum permissible main rotor and output shaft speeds<sup>4</sup> are as follows: 1) 100% N1 speed is 6,032.4 RPM, 2) 100% N2 speed is 19,680.1 RPM, 3) maximum permitted fan shaft speed is 6,260 RPM, i.e., 103.7% of N1, and 4) maximum permitted core shaft speed is 22,625 RPM, i.e., 114.9% of N2.

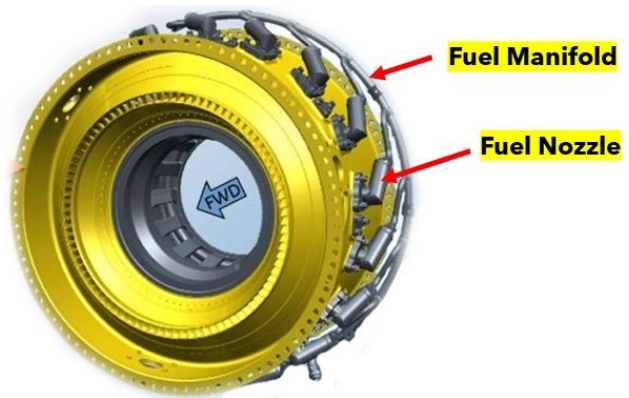
All directional references to front and rear; right and left; top and bottom; and clockwise and counterclockwise are made aft looking forward (ALF) as is the convention. All numbering is in the circumferential direction starting with the No. 1 position at the 12:00 o'clock position or immediately clockwise from the 12:00 o'clock position and progressing sequentially clockwise ALF. The fan and core rotate clockwise ALF.

<sup>3</sup> Flat-rated to a specific temperature indicates that the engine will be capable of attaining the rated thrust level up to the specified inlet temperature. Engine ratings for all three versions of the engine are based on calibrated test stand performance under the following conditions: 1) sea level static, standard pressure (14.696 pounds per square inch absolute (psia), 59°F, 2) no customer bleed or customer horsepower extraction, 3) ideal inlet, 100% ram recovery, 4) production aircraft flight cowling, 5) production instrumentation and 6) fuel lower heating value of 18,400 British Thermal Unit (BTU)/pound (lb.).

<sup>4</sup> N1 is the low rotor speed given as a percentage and N2 is the high rotor speed given as a percentage.

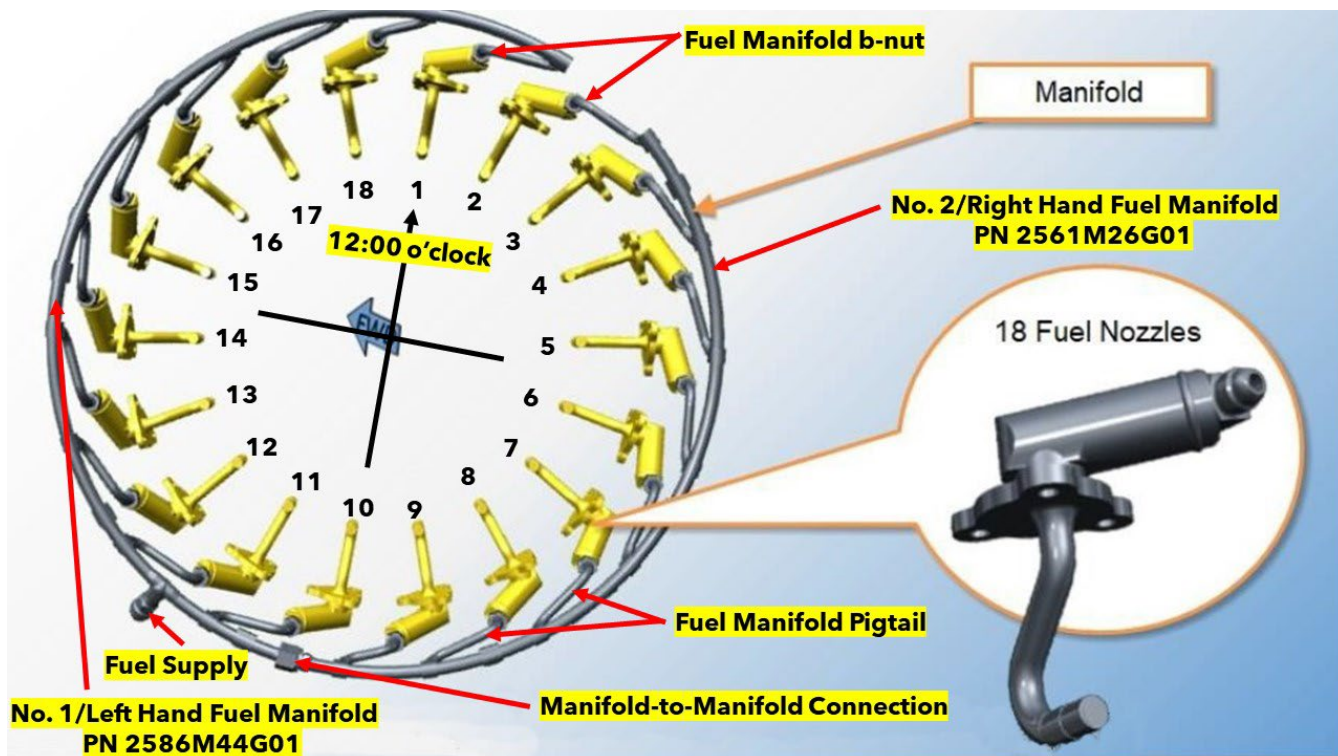
### 1.3 FUEL DISTRIBUTION CORE COMPONENT DESCRIPTION

The engine has 18 fuel nozzles (FN) with a primary and secondary flow distribution. Fuel is provided to the FNs by two fuel manifolds (**FIGURES 3 and 4**) mounted on the outside of the combustion case. Ten FNs are attached to the left fuel manifold, FNs Nos. 1, 10-18, ALF. The remaining eight FNs are attached to the right fuel manifold, FNs Nos. 2-9, ALF. The two fuel manifolds are connected at a common manifold-to-manifold connection at the 6:00 o'clock location. The FNs are equipped with two check valves, one each for the primary and secondary flow circuits; the check valve opens at a cracking pressure of about 50 pounds per square inch gage (psig) for the primary circuit and at a cracking pressure of about 250 psig for the secondary circuit.



**FIGURE 3: FUEL NOZZLE/FUEL MANIFOLD MOUNTED ON COMBUSTION CASE**

Figure courtesy of GE (modified by NTSB)



**FIGURE 4: FUEL NOZZLE AND FUEL MANIFOLD DIAGRAM**

Figure courtesy of GE (modified by NTSB)

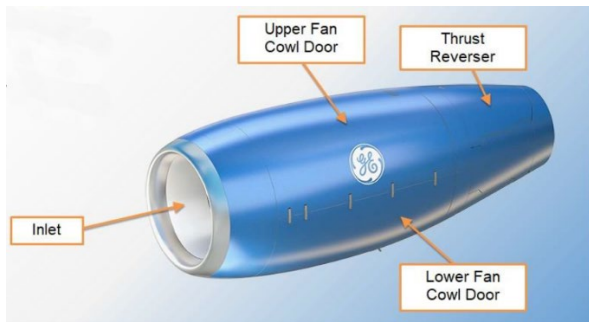
The fuel manifolds (aft looking forward) will be referred to as follows:

Left fuel manifold will be referred to as the No. 1 or M44 fuel manifold, PN 2586M44G01

Right fuel manifold will be referred to as the No. 2 or M26 fuel manifold, PN 2561M26G01

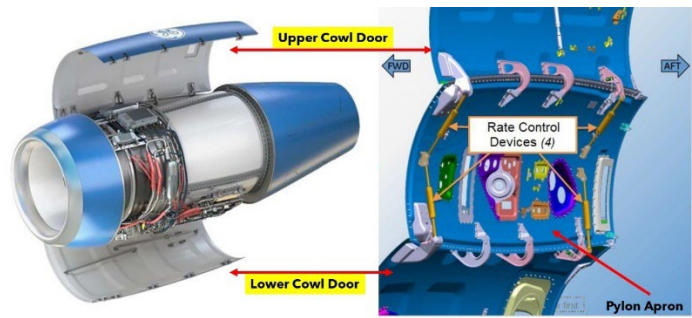
## 1.4 ENGINE NACELLE AND FIXED DUCT DESCRIPTION

The engine is housed in an aerodynamic nacelle (**FIGURES 5** and **6**). The nacelle is made up of the inlet, upper and lower fan cowl doors, pylon apron, and the thrust reverser. The fan cowls are a clam shell design and are mounted to the pylon apron between the inlet and thrust reverser. They enclose the engine in an aerodynamic fairing, creating a fire barrier for the accessory compartment, and providing ventilation for the accessory compartment. The pylon apron completes the cowlings between the upper and lower fan cowl doors.



**FIGURE 5: NACELLE COMPONENTS**

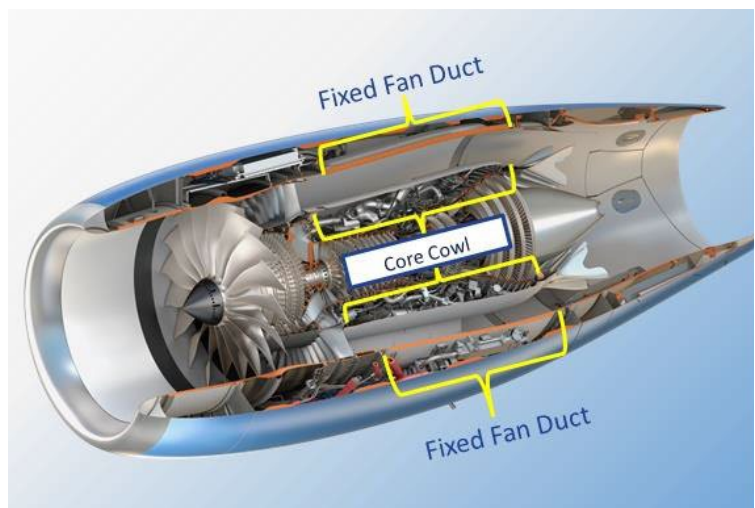
Figure courtesy of GE



**FIGURE 6: FAN COWLS OPEN**

Figures courtesy of GE

The engine is equipped with a fixed fan duct (FFD) and the core cowl (CC) panels to provide an aerodynamic flow path for the fan air bypasses from the fan exit to the exhaust mixer and thrust reverser nozzles (**FIGURE 7**). The FFD is comprised of four panels split at the 4:00, 6:00, 8:00, and 12:00 o'clock positions while the CC is comprised of 4 handed panels sized and positioned for access to the core compartment.



**FIGURE 7: FIXED FAN DUCT AND CORE COWL PANELS**

Figure courtesy of GE

## 2.0 GE PASSPORT 20-19BB1A ESN 904265 EVALUATION - PALM BEACH EVENT

The NTSB did not travel to PBI to examine the airplane and engine on-scene, or to the GE facility for the engine and hardware exams; the information in this report was provided by the operator, GE, and Bombardier (See **ATTACHMENT 1** for details).

### 2.1 ON SCENE EXAMINATION AT PBI

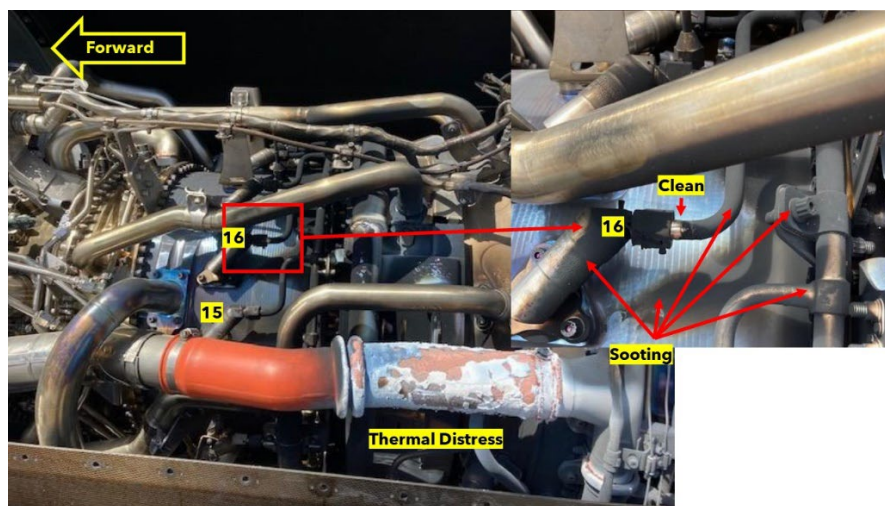
GE and Bombardier fleet support engineers met at the airplane to document the airplane and engine damage; a team from GE Strother was also there to provide maintenance assistance. A borescope inspection (BSI) of the core of the left engine, ESN 904265, through the core cowl vent revealed no unusual findings around the bottom on the engine. The upper fan cowl door was opened, the pre-cooler rope seals and insulation blanket were damaged, and slight discoloration of the lower fan cowl paint (**PHOTO 1**) was noted.



**PHOTO 1: LOWER FAN COWL DISCOLORED**

Photo courtesy of GE

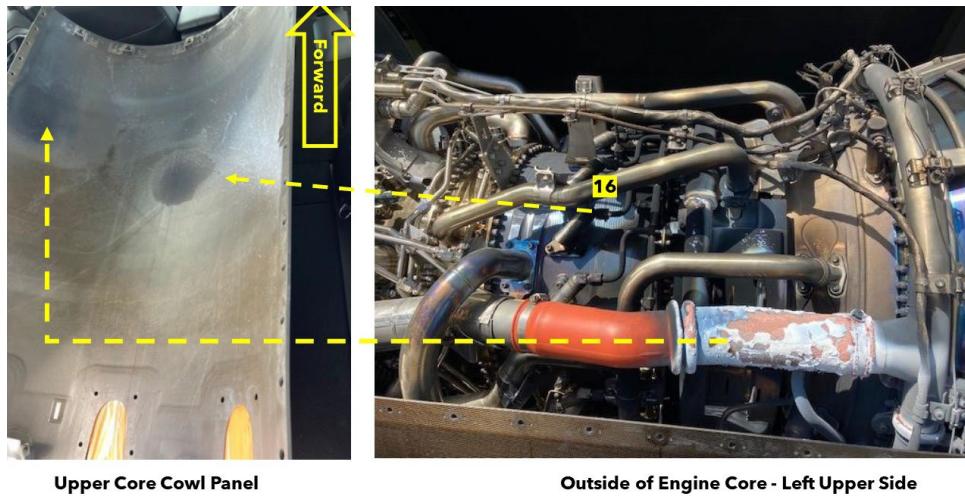
The engine FFD and CC panels were removed to expose the outside of the engine core compartment. Evidence of light thermal distress was found at about the 10:00-11:00 o'clock position, aft of the FNs, comprised of sooting and damage to an air duct thermal sleeve (**PHOTO 2**). All the fire detection loops appeared normal and undamaged. At FN location No. 16, the FN-to-fuel manifold b-nut connection appeared shiny and lacked the sooting that neighboring FN-to-fuel manifold b-nut connections exhibited; this was thought to be a possible fuel leak location. All the visible FN-to-fuel manifold b-nut connections were safety cabled, and the cable was in the correct orientation. For brevity, the FN-to-fuel manifold b-nut connection will be referred to simply as the "fuel manifold b-nut connection" for the remainder of the report.



**PHOTO 2: THERMAL DISTRESS AND NO. 16 FN LOCATION AS POSSIBLE LEAK LOCATION**

Photo courtesy of GE (modified by NTSB)

Localized discoloration was observed on the inside to the upper core cowl consistent with the general location of FN No. 16 and the thermally distressed air duct sleeve (**PHOTO 3**). The possible fuel spray impingement location on the FFD appeared to be at an angle aft of FN No. 16.



**PHOTO 3: POSSIBLE FUEL AND THERMAL IMPINGEMENT LOCATIONS**

Photo courtesy of GE (modified by NTSB)

## 2.2 LEAK CHECKS AT GE

ESN 904265 was removed from the event airplane and shipped to the GE Peebles Test Operations (PTO) facility in Peebles, Ohio to perform a series of leak checks. The FN and fuel manifold areas were covered with white leak developer (**PHOTO 4**) and the engine was wet motored<sup>5</sup>; no leaks were found. The wet motoring was conducted at a fuel pressure much lower than what was experienced during the event. The low fuel pressure used during the wet motor simulated fuel start pressures and not the high fuel pressures the engine experienced during the event; maximum fuel pressure at high power is about 1,000 pounds per square inch differential (psid). A nitrogen check, with soapy liquid at the fuel manifold b-nut connections, was also conducted and again no leaks were found.



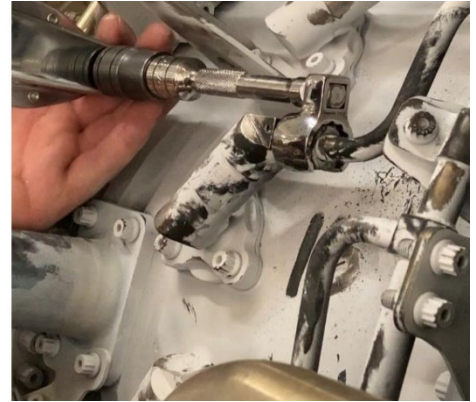
**PHOTO 4: FUEL LEAK CHECK WITH DEVELOPER**

Photo courtesy of GE

<sup>5</sup> Wet motoring is when the core of the engine is rotated to engage the engine driven fuel pump with the high pressure shutoff valve (HPSOV) open to allow fuel to flow to the FNs with the ignitors disabled so that the fuel cannot ignite.

### 2.3 GAP AND TORQUE CHECKS AT GE

Gap checks on each fuel manifold b-nut connection were measured in the as-received condition using a pin gage at two locations 180° part - they were referred to as the clockwise (CW) and counterclockwise (CCW) sides of the b-nut connection. The intent was to measure and access the overall gap and any tilting (misalignment) of the fuel manifold b-nut connection (**PHOTO 5**, left side). The FN and fuel manifold assembly instructions do not



**PHOTO 5: B-NUT GAP CHECK AND TORQUE MEASUREMENT**

Photo courtesy of GE

provide or specify a minimum or maximum gap between the fuel manifold b-nut and the FN shoulder; this measurement was taken solely for investigative purposes to identify any possible assembly anomalies. The fuel manifold b-nut connection installation torque is  $285 \pm 8\%$  inch-pounds (in.-lbs.). A dial torque wrench was used to measure the installation torque and the recorded value was when the b-nut first begins to move in the tightening direction.

**TABLE 1** provides the gap and installation torque measurements at each location.

| <b>TABLE 1: FUEL MANIFOLD B-NUT GAP AND INSTALLATION TORQUE MEASUREMENTS</b> |                        |                    |                    |                      |                                                        |
|------------------------------------------------------------------------------|------------------------|--------------------|--------------------|----------------------|--------------------------------------------------------|
| Fuel Nozzle Position                                                         | Gap ALF CW Side (inch) | Gap ALF CCW (inch) | Average Gap (inch) | Fuel Manifold Number | Installation Torque In Tightening Direction (in.-lbs.) |
| 1                                                                            | 0.12                   | 0.122              | 0.121              | 1 (M44)              | 96                                                     |
| 2                                                                            | 0.107                  | 0.109              | 0.108              | 2 (M26)              | 216                                                    |
| 3                                                                            | 0.1                    | 0.105              | 0.1025             | 2 (M26)              | 252                                                    |
| 4                                                                            | 0.101                  | 0.102              | 0.1015             | 2 (M26)              | 230                                                    |
| 5                                                                            | 0.099                  | 0.099              | 0.099              | 2 (M26)              | 280                                                    |
| 6                                                                            | 0.107                  | 0.107              | 0.107              | 2 (M26)              | 220                                                    |
| 7                                                                            | 0.103                  | 0.103              | 0.103              | 2 (M26)              | 240                                                    |
| 8                                                                            | 0.103                  | 0.105              | 0.104              | 2 (M26)              | 230                                                    |
| 9 <sup>7</sup>                                                               |                        |                    |                    | 2 (M26)              | 245                                                    |
| 10                                                                           | 0.121                  | 0.122              | 0.1215             | 1 (M44)              | 230                                                    |
| 11                                                                           | 0.117                  | 0.117              | 0.117              | 1 (M44)              | 190                                                    |
| 12                                                                           | 0.123                  | 0.121              | 0.122              | 1 (M44)              | 215                                                    |
| 13                                                                           | 0.125                  | 0.123              | 0.124              | 1 (M44)              | 132                                                    |
| 14                                                                           | 0.126                  | 0.123              | 0.1245             | 1 (M44)              | 240                                                    |
| 15                                                                           | 0.124                  | 0.122              | 0.123              | 1 (M44)              | 240                                                    |
| 16A                                                                          | 0.127                  | 0.125              | 0.126              | 1 (M44)              | 120                                                    |
| 16B                                                                          | 0.123                  | 0.126              | 0.1245             | 1 (M44)              | 285                                                    |
| 17                                                                           | 0.121                  | 0.125              | 0.123              | 1 (M44)              | 228                                                    |
| 18                                                                           | 0.122                  | 0.122              | 0.122              | 1 (M44)              | 204                                                    |

<sup>6</sup> This works out to be 262-308 in.-lbs.

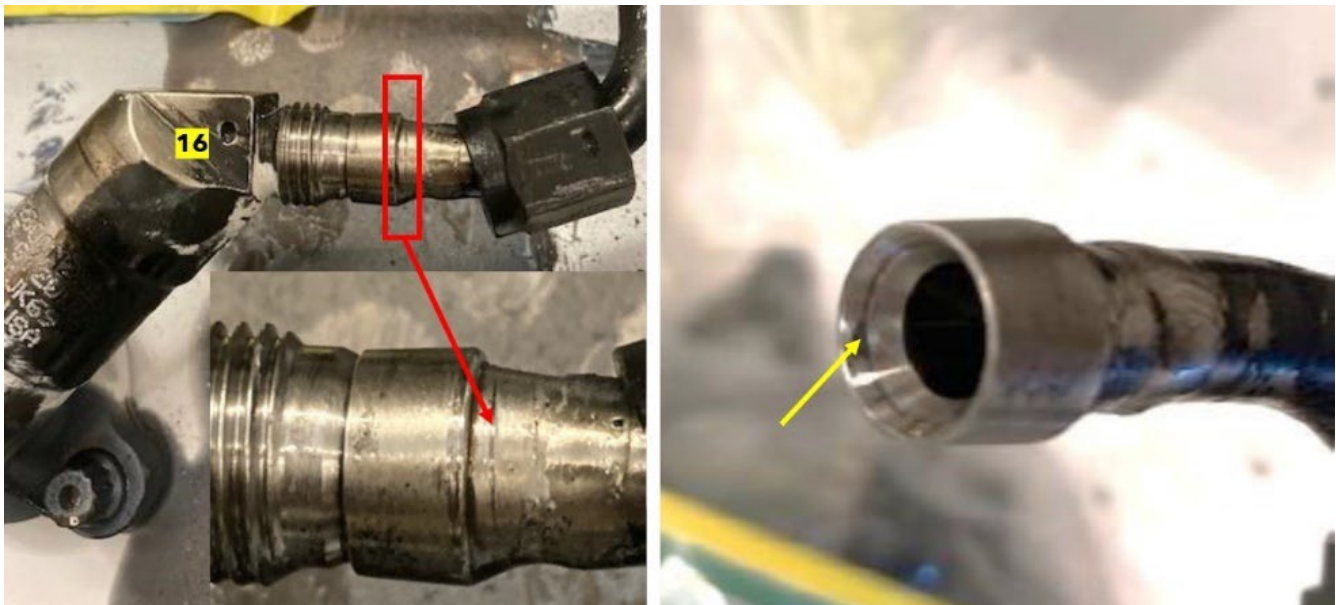
<sup>7</sup> The torque value was obtained; however, due to the engine being in the test stand there was insufficient/inadequate space to access the FN No. 9 ferrule location to perform the pin gage measurement.

According to GE, the gap values were within expected dimensional ranges. All the torque values were lower than the nominal value of 285 in.-lbs.; however, four fuel manifold b-nut connections had significantly lower torque values and are highlighted in red in **TABLE 1**. The fuel manifold b-nut connection for FN No. 16 was retorqued to the nominal value and the gap remeasured; highlighted in yellow in **TABLE 1**.

#### 2.4 FUEL NOZZLE-TO-FUEL MANIFOLD B-NUT INTERFACE CONNECTION EXAMINATION AT GE

After the gap and torque checks were completed, the fuel manifold b-nut connections were loosened and then retightened by hand; the fuel manifold b-nut connection for FN No. 16 location was the only one where the b-nut could not be fully run down onto the FN threads. Subsequently, all three attachment bolts that secure FN No. 16 to the combustion case were loosened. The FN moved/rotated slightly, and the fuel manifold b-nut ran freely by hand onto the FN threads, indicative of a slight misalignment between the fuel manifold and the FN.

Removal of the No. 1/left (M44) fuel manifold revealed that the fuel manifold female ferrule sealing surface for the FN No. 16 location exhibited: 1) galling on the outer diameter consistent with the b-nut running onto the tube (**PHOTO 6**, left side see inset) and 2) signs of galling and grooving on the female inner conical sealing surface that mates with FN male bullnose sealing surface (**PHOTO 6**, right side, yellow arrow). According to GE, the observed female ferrule sealing surface damage is indicative of misalignment and relative movement within the connection due to high load and low cycle contact and not vibratory wear. Visual examination found no other fuel manifold b-nut connections exhibiting similar ferrule sealing surface damage.



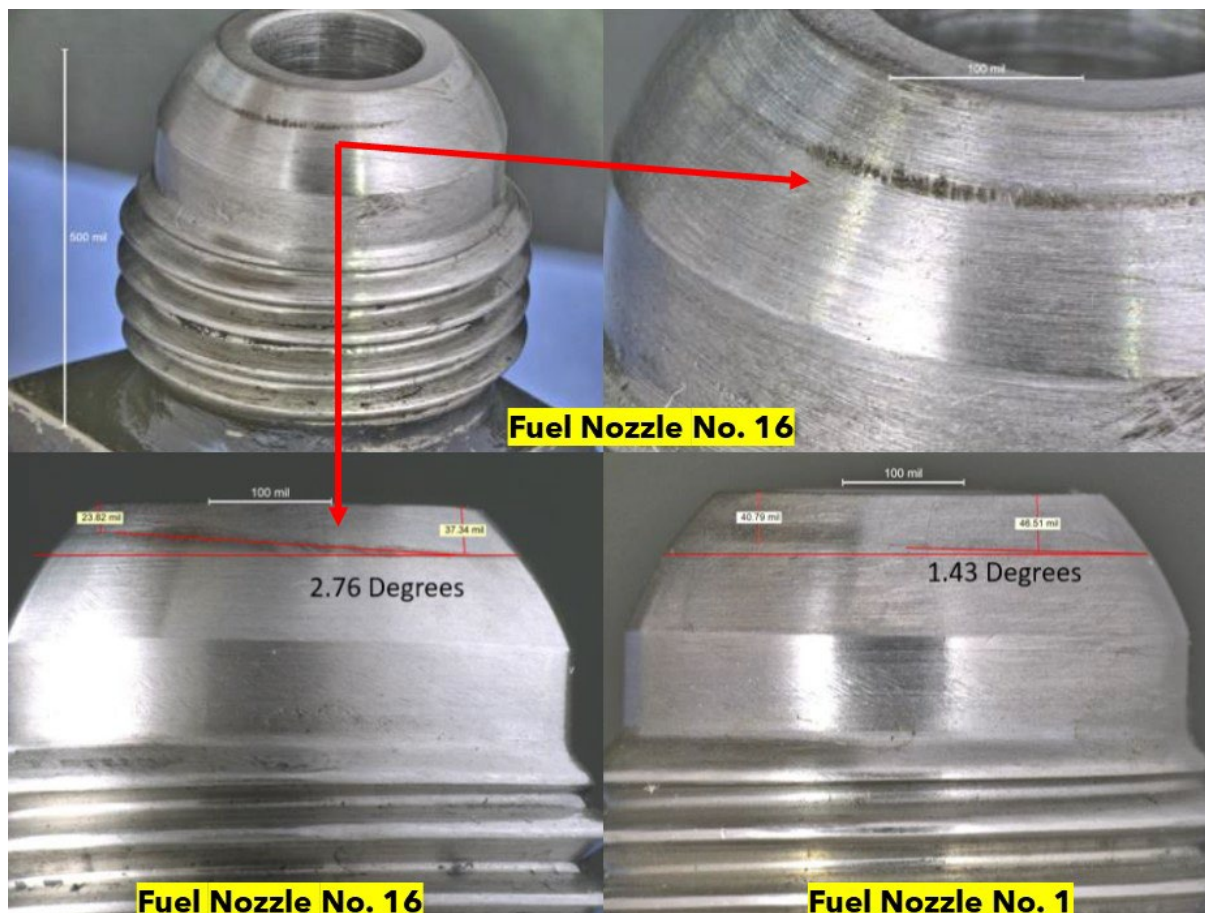
**PHOTO 6: FUEL MANIFOLD FERRULE DAMAGE AT FUEL NOZZLE NO. 16 LOCATION**

Photo courtesy of GE (modified by NTSB)

## 2.5 GE LABORATORY EXAM OF THE FUEL NOZZLES AND FUEL MANIFOLDS

The FNs and fuel manifolds were shipped to the GE failure analysis laboratory in Cincinnati, Ohio, for additional component evaluation. A fluorescent penetrant inspection (FPI) was performed on the fuel manifolds and no cracks were found. The FN male bullnose-to-fuel manifold female ferrule sealing surfaces were examined in detail for contact patterns.

Closer examination of the contact mark on the FN No. 16 male bullnose sealing surface showed indications of galling that according to GE was indicative of high contact stress and relative motion between the two components (**PHOTO 7**, top row). The FN male bullnose sealing surface contact mark was elliptical and intermittent around the sealing conical surface consistent with misalignment contact with the fuel manifold female ferrule sealing surface; the wear mark was not in the same plane around the entire surface. Comparing the witness marks on the FN male bullnose sealing surfaces for positions Nos. 1 and 16 (both had significantly lower measured b-nut installation torques - see **TABLE 1**) revealed that the FN No. 16 position had more angular offset misalignment (**PHOTO 7**, bottom row) than the FN No. 1.



**PHOTO 7: ELLIPTICAL CONTACT PATTERN ON THE FUEL NOZZLE MALE BULLNOSE SEALING SURFACE**

Photo courtesy of GE (modified by NTSB)

### 3.0 GE PASSPORT 20 – ADDITIONAL FUEL MANIFOLD LEAK EVENTS

During the investigation into the GE Passport 20-19BB1A engine fuel manifold leak at PBI on April 3, 2022 (ESN 904265), three additional engines were found to have similar fuel manifold leaks. **TABLE 2** provides a complete list of all the known GE Passport 20-19BB1A engines fuel manifold leaks as of the issuance of this report. The following sections provide details and findings for those additional events.

| <b>TABLE 2: PASS 20-19BB1A FUEL MANIFOLD LEAKS EVENTS</b> |                     |                                                                 |                 |            |
|-----------------------------------------------------------|---------------------|-----------------------------------------------------------------|-----------------|------------|
| ESN                                                       | Location            | Leak Occurred/Found During                                      | Date Found      | Engine CSN |
| 904265                                                    | Palm Beach          | Flight - Operational                                            | April 3, 2022   | 119        |
| 904292                                                    | Saudi Arabia        | Flight - Operational                                            | March 31, 2022  | 121        |
| 904365                                                    | Bombardier Assembly | Retorque per Service Bulletin (SB)/Airworthiness Directive (AD) | April 28, 2022  | 3          |
| 904238                                                    | Bombardier Assembly | Retorque per SB/AD                                              | October 6, 2022 | 290        |

#### 3.1 ESN 904292 FUEL LEAK – OPERATION EVENT – KINGDOM OF SAUDI ARABIA

A few days prior to the PBI Bombardier Global 7500 Business Jet fuel manifold leak and subsequent fire event (NTSB case number ENG22LA020 - ESN 904265), the NTSB was informed of a Global 7500 Business Jet in the Kingdom of Saudi Arabia that experienced a fire warning annunciation during takeoff. The Kingdom of Saudi Arabia Aviation Investigation Bureau (AIB) informed the NTSB of the event and delegated the investigation in accordance with International Civil Aviation Organization (ICAO) Annex 13 protocols to the airplane state of registry, Malta. Due to the similarities with the PBI NTSB investigation (ENG22LA020), the Malta Bureau of Air Accident Investigation (BAAI) delegated the event to the NTSB and the NTSB accepted. Representatives from the Kingdom of Saudi Arabia AIB and the Malta BAAI as well as the Transportation Safety Board (TSB) of Canada as the state of design and manufacture of the airplane, participated in this investigation and have been afforded Accredited Representative status. Bombardier Aviation served as a Technical Advisor to the TSB and GE Aviation served as a party member to the NTSB. The NTSB investigation number for the Global 7500 Business Jet fuel manifold leak in the Kingdom of Saudi Arabia is ENG22LA049.

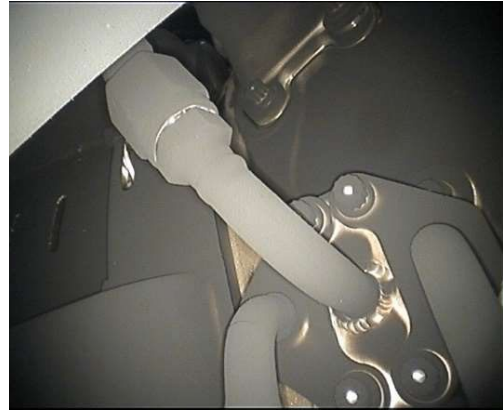
On March 31, 2022, a Bombardier Global 7500 Business Jet experienced a right engine, ESN 904292, fire during the takeoff climb from King Khalid International Airport, Riyadh, Kingdom of Saudi Arabia (OERK). After the right engine fire warning annunciated, the pilots disengaged the autothrottles and retarded the right engine throttle to idle. When the right engine throttle was reduced, the fire warning annunciation ceased. With the fire warning annunciation out, the pilots incrementally increased the right throttle and the fire warning annunciated again. The pilots shut down the right engine and performed an in-flight air turn back (ATB) to OERK and made an uneventful landing with no injuries reported. Post-BSI of the right engine by GE on-wing support revealed indications of an undercowl fire and

potential leak locations (**PHOTOS 8-13**). At the time of the event, ESN 904292 had accumulated 388 hours TSN and 121 CSN.



**PHOTO 8: CORE FIRE HARNESS THERMALLY  
DAMAGE (6:00-7:00 O'CLOCK POSITION ALF)**

Photo courtesy of GE



**PHOTO 9: TURBINE CENTER FRAME (TCF)  
DRAIN TUBE SOOTED**

Photo courtesy of GE



**PHOTO 10: FUEL MANIFOLD B-NUT WETTED  
(12:00-1:00 O'CLOCK POSITION ALF)**

Photo courtesy of GE



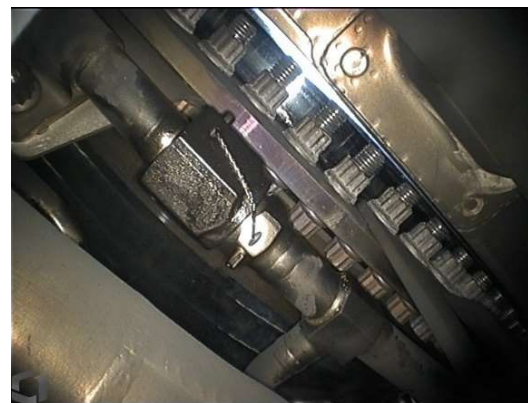
**PHOTO 11: FUEL MANIFOLD B-NUT WETTED  
(12:00-1:00 O'CLOCK POSITION ALF)**

Photo courtesy of GE



**PHOTO 12: FUEL MANIFOLD B-NUT WETTED  
(6:00-7:00 O'CLOCK POSITION ALF)**

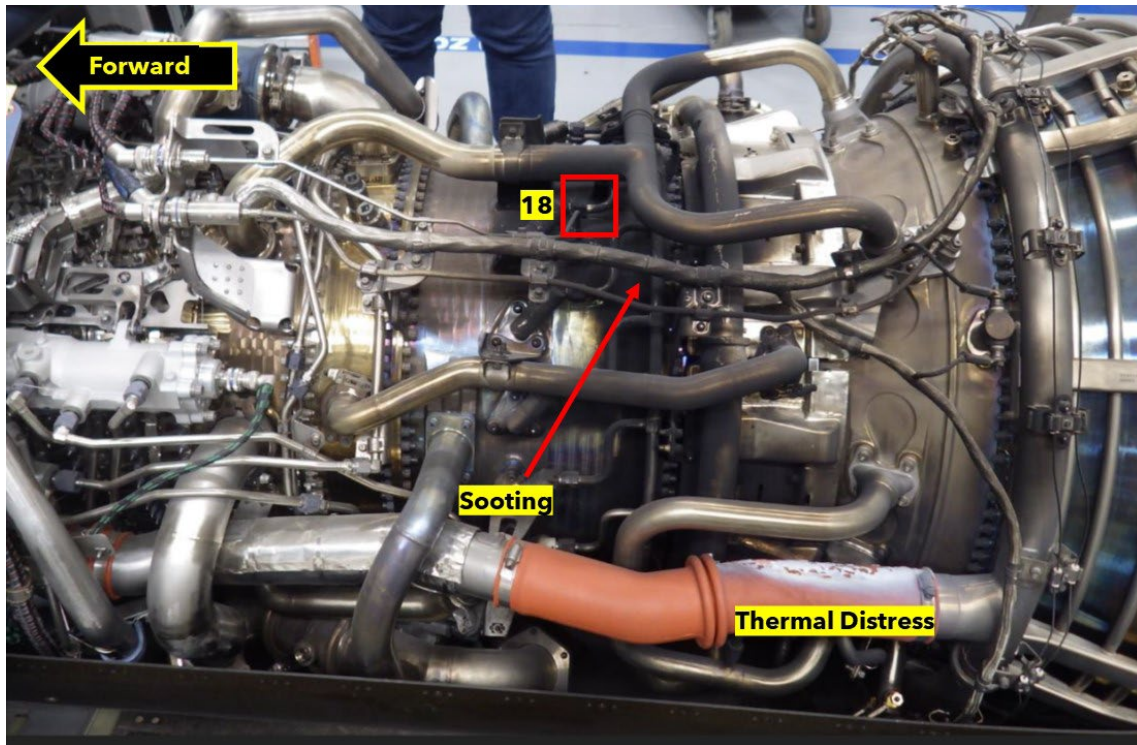
Photo courtesy of GE



**PHOTO 13: FUEL MANIFOLD B-NUT WETTED  
(6:00-7:00 O'CLOCK POSITION ALF)**

Photo courtesy of GE

ESN 904292 was shipped back to GE Cincinnati to be evaluated. Light sooting, aft of the FNs, along with minor thermal damage to an air duct thermal sleeve was observed (**PHOTO 14**). All the fire detection loops appeared normal and undamaged. At FN No. 18, the fuel manifold b-nut connection appeared shiny and lacked sooting; it also exhibited a fluid flow pattern emanating from the connection (**PHOTO 15**). FNs Nos. 12, 14, and 16 were wetted but only FN No. 16 exhibited a fluid flow pattern (**PHOTO 16**). All the visible fuel manifold b-nut connections were safety cabled, and the cable was in the correct orientation. A leak check using nitrogen at just under 30 psig was performed; pressure held for an hour with no decay. The fuel leak was not reproduced just like the testing results of ESN 904265 (Palm Beach).



**PHOTO 14: THERMAL DISTRESS AND POSSIBLE LEAK LOCATION**

Photo courtesy of GE (modified by NTSB)

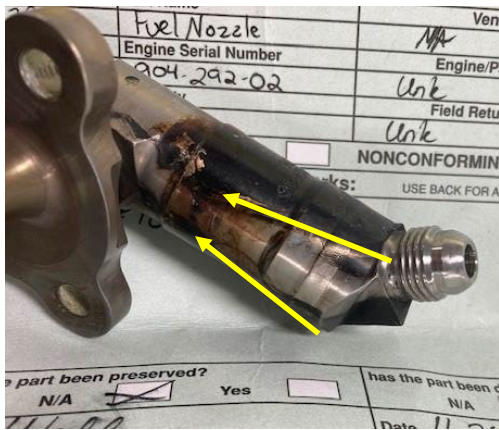
**PHOTO 15: FN No. 18 FLUID FLOW PATTERN**

Photo courtesy of GE (modified by NTSB)

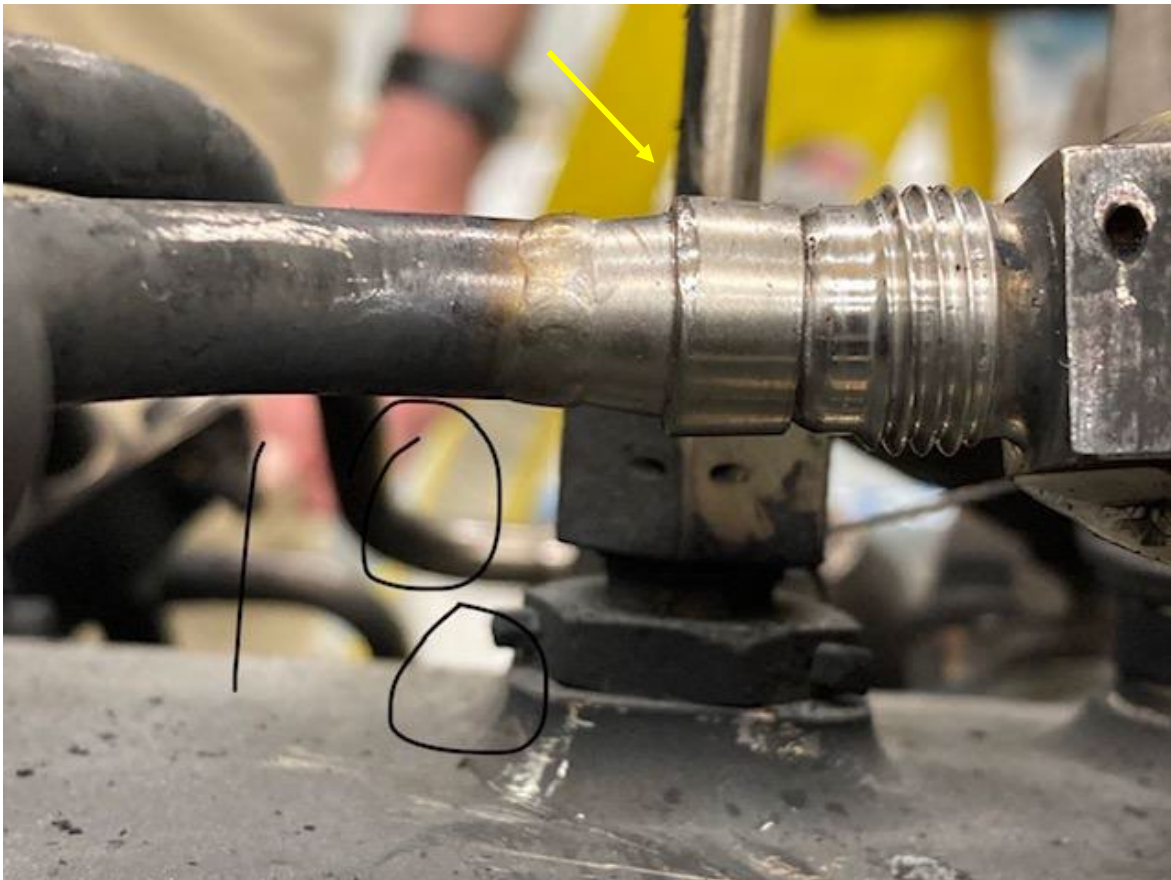
**PHOTO 16: FN No. 16 FLUID FLOW PATTERN**

Photo courtesy of GE (modified by NTSB)

A torque check was performed on the fuel manifold b-nut connections like what was performed on ESN 904265 (Palm Beach). Low torque values, below 200 in.-lbs., were measured at FNs Nos. 10, 13, 16, 18, and 1; all five FN locations are on the No. 1/left (M44) fuel manifold. All the other fuel manifold b-nut connection torque values ranged between about 200-300 in.-lbs. The torque and gap data between ESN 904265 (Palm Beach) and ESN 904292 (Kingdom of Saudi Arabia) were consistent with one another and confirmed a statistically significant difference in torque and gaps between the No. 1/left (M44) fuel manifold (M44) and the No. 2/right (M26) fuel manifold. On both engines, the leaks only appeared on the No. 1/left (M44) fuel manifold.

After the fuel manifold b-nuts were loosened, an attempt was made to retighten them by hand. All b-nuts were run down onto the FN threads by hand on the right (M26) fuel manifold while four (Nos. 12, 13, 14, and 18) b-nuts on the left (M44) fuel manifold could not be run down using normal force. Subsequently, all three attachment bolts that secure the FN No. 18 to the combustion case were loosened, the FN moved slightly, and the b-nut ran freely by hand onto the FN threads. This was the same result that was observed on ESN 904265, FN location No. 16; indicative of a slight misalignment between the fuel manifold and the FN.

The fuel manifold female ferrule outer diameter at location FN No. 18 exhibited contact/witness marks consistent with the b-nut threads wearing onto the shoulder (**PHOTO 17**).



**PHOTO 17: FUEL MANIFOLD FERRULE DAMAGE AT FUEL NOZZLE No. 18 LOCATION**

Photo courtesy of GE (modified by NTSB)

ESN 904292 FN No. 18 fuel manifold ferrule outer diameter surface exhibited galling, and elliptical and intermediate contact marks indicative of misalignment contact with the fuel manifold female ferrule sealing surface. However, along with the intermittent galling, there were signs of contaminants (hard particles) on the FN male bullnose sealing surface in the form of craters, indentations, and imbedded material on the sealing surface. Diagonal orientated abrasive material marks/material removal, consistent with what appears to be previous repair (**PHOTO 18**), was also observed.<sup>8</sup> According to GE, there was no record of a repair operation being performed on this specific nozzle at the fuel nozzle manufacturer<sup>9</sup> or at the engine assembly site; GE concluded that this possible repair may have occurred sometime during engine assembly. The engine manual does not allow for any nicks or scratches but does allow for blending. However, blending is only allowed in the circumferential direction for conical/cylindrical parts; the blend/abrasive material removal marks on FN No. 18 male bullnose sealing surface were in the diagonal direction along the axis of the part. Therefore, the blending in the area would be inconsistent with the engine manual blending instructions.

<sup>8</sup> ESN 904265 FN No. 16 did not experience the hard particle impression marks nor the abrasive material removal.

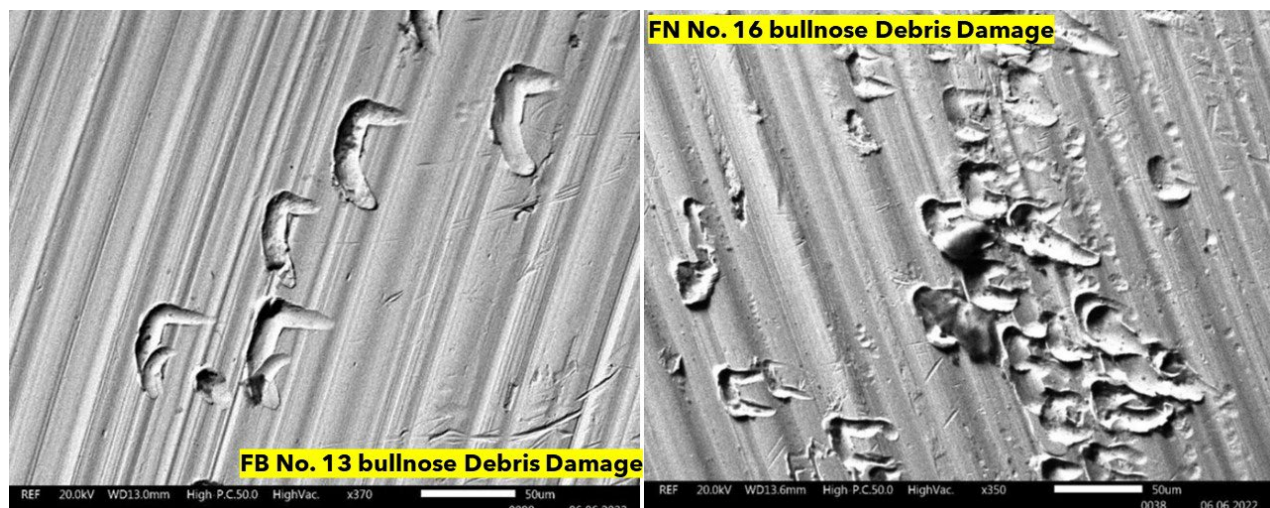
<sup>9</sup> The fuel nozzle manufacturer is Advanced Atomization Technologies (AA TECH), Clyde, New York and is a joint venture between Parker Aerospace and GE Aviation.



**PHOTO 18: No. 18 FN MALE BULLNOSE WITH ABRASIVE MARKS AND PARTICLE IMPRESSION**

Photo courtesy of GE (modified by NTSB)

Only the FN No. 18 male bullnose sealing surface showed evidence of rework/repair; however, hard particle damage was also observed on the male bullnose seal surfaces of FNs Nos. 12, 13, and 16 (**PHOTO 19**). GE was unable to confirm the source of the contaminates.



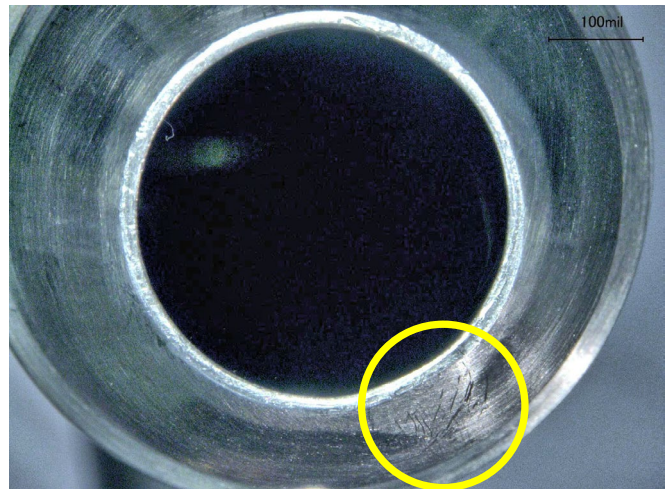
**PHOTO 19: HIGH MAGNIFICATION OF SIMILAR SHAPED DEBRIS DAMAGE ON FUEL NOZZLE MALE BULLNOSE SEALING SURFACE ON NOS. 13 AND 16**

Photo courtesy of GE (modified by NTSB)

### 3.2 ESN 904365 FUEL LEAK – FOUND DURING B-NUT RETORQUE AT BOMBARDIER

Part of GE's initial field containment plan was to inspect all Passport 20 engines, those that were in-service with operators and those at Bombardier for final airplane assembly for signs of an undercowl fuel leak or fire damage. GE developed field engineering instructions (FEIs) to perform an undercowl inspection that became the basis of SB PASSPORT20-A-72-00-0141-00A-930A-D-001 issued to inspect in-service engines.<sup>10</sup> As new information became available, GE's field containment plan included a retorque of the fuel manifold and the fuel manifold-to-fuel manifold b-nut connections; the new retorque operation FEI became the basis of SB PASSPORT20-A-72-00-0142-00A-930A-D-001.<sup>11</sup>

On April 28, 2022, while Bombardier was performing the retorque FEI on their final assembly line, evidence of a fuel leak on the outboard lower cowl and the fuel manifold b-nut connection at the 6:00 o'clock position was found on ESN 904365. All the torque values for the FN attachment bolts, the fuel manifold b-nuts connections, and the fuel manifold-to-fuel manifold b-nut connection were all within the acceptable range. The engine had accumulated 3 hours TSN and 3 CSN when it was removed from the airplane. The engine was shipped to the GE facility in Lafayette, Indiana, for disassembly, and the fuel manifolds were removed and sent to the supplier, GE Hookset, New Hampshire, for dimensional inspection and then to the GE failure analysis lab in Evendale for evaluation; the FNs were also sent to Evendale for evaluation. The male bullnose sealing surface on the No. 2/right (M26) fuel manifold that mates with the female ferrule sealing surface on the No. 1/left (M44) fuel manifold exhibited a flat area/dent that intersected the sealing band and an area of abrasive operations/material removal consistent with what appears to be a previous repair; the leak is thought to have occurred at the flat area (**FIGURE 20**). GE conducted a records search at the supplier, GE Hookset, and the individual assembly router cards at the assembly facility, GE Lafayette, to find any record of a rework/repair<sup>12</sup> having been performed on the No. 2/right (M26) manifold; no record indicating that a rework/repair was performed was found.



**PHOTO 20: M26 MALE BULLNOSE FLAT SPOT/DENT AND MATERIAL REMOVAL**

Photo courtesy of GE (modified by NTSB)

<sup>10</sup> See Section 8.3 SERVICE BULLETINS AND AIRWORTHINESS DIRECTIVES section for details on the engine inspections and corrective actions.

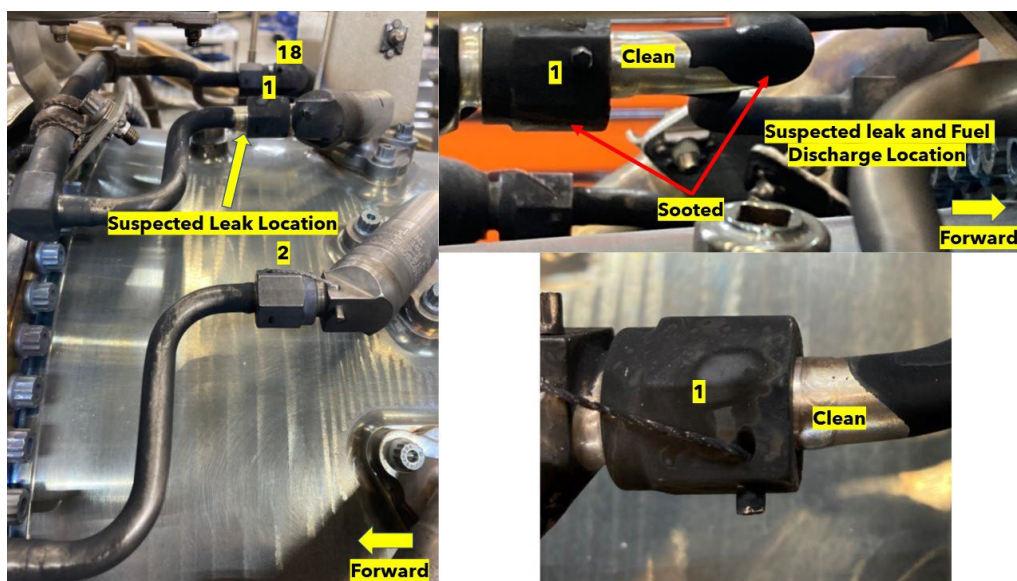
<sup>11</sup> See Section 8.3 SERVICE BULLETINS AND AIRWORTHINESS DIRECTIVES section for details on the engine inspections and corrective actions.

<sup>12</sup> The engine manual does not allow nicks or dents on the sealing surface.

### 3.3 ESN 904238 FUEL LEAK - FOUND DURING B-NUT RETORQUE AT BOMBARDIER

On October 6, 2022, Bombardier was preparing to perform the fuel manifold b-nut connection retorque operation in accordance with GE SB PASSPORT20-A-72-00-0142-00A-930A-D-001 and FAA Airworthiness Directive (AD) 2022-13-12<sup>13</sup> and to address a fire loop fault when they discovered sooting around several fuel nozzles at the 12:00 o'clock position on ESN 904238. There was no report of any fire indications associated with this engine. The engine core compartment had previously undergone a BSI in accordance with GE SB PASSPORT20-A-72-00-0141-00A-930A-D-001 on April 22, 2022, with no anomalies found; the engine had accumulated 322 hours TSN and 173 CSN at the time of the engine core compartment BSI. After the event, GE reviewed the photographs taken during the April 2022 BSI and confirmed the report of no findings. The engine had accumulated an additional 275 hours and 117 cycles from the time the core compartment BSI was performed to the findings of the sooted fuel nozzles; ESN 904238 had accumulated a total of 597 hours TSN and 290 CSN on October 6, 2022, when the sooted FNs were found.

The engine was removed from the airplane and shipped to GE Strother, Strother Kansas, facility for inspection and documentation; unlike the previous fuel leak engines (ESNs 904265, 904292, and 904365) ESN 904238 was assembled at the GE Strother facility and not at GE Lafayette facility. Areas of sooting were found from about the 9:00 to 12:00 o'clock location in the vicinity of the fuel manifolds and fuel nozzles. No thermal distress was noted to any non-metallic components, such as fire loop grommets; the left side of the engine showed no signs of sooting or fuel leaks; no signs of burning, thermal, or fire distress in the core compartment; and the core cowls showed very light discoloration adjacent to the No. 1 FN location. Closer visual examination showed that the FN No. 1 showed heavy sooting on the fuel manifold b-nut connection and along the pigtail but was clean in an area just forward of the b-nut (**PHOTO 21**); soot does not normally adhere to fuel wetted surfaces.



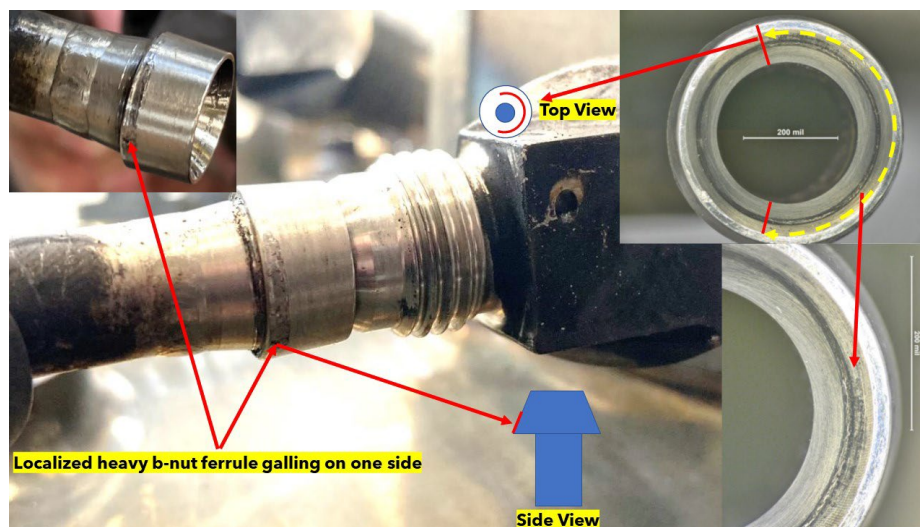
**PHOTO 21: SUSPECTED FUEL LEAK FROM FUEL NOZZLE NO. 1 LOCATION**

Photo courtesy of GE (modified by NTSB)

<sup>13</sup> See Section 8.3 SERVICE BULLETINS AND AIRWORTHINESS DIRECTIVES section for details on the engine inspections.

Similar to the other fuel manifold leak engines, a nitrogen pressure/leak check was performed with leak detector fluid applied at all the FN-to-fuel manifold b-nut connections; no leak was detected. Gap and torque measurements were taken at every FN-to-fuel manifold location. All the FN-to-manifold torque values were above 240 in.-lbs. except for FN No. 1 which was about 145 in.-lbs.; FN No. 1 also had a large gap compared to the other FN locations.

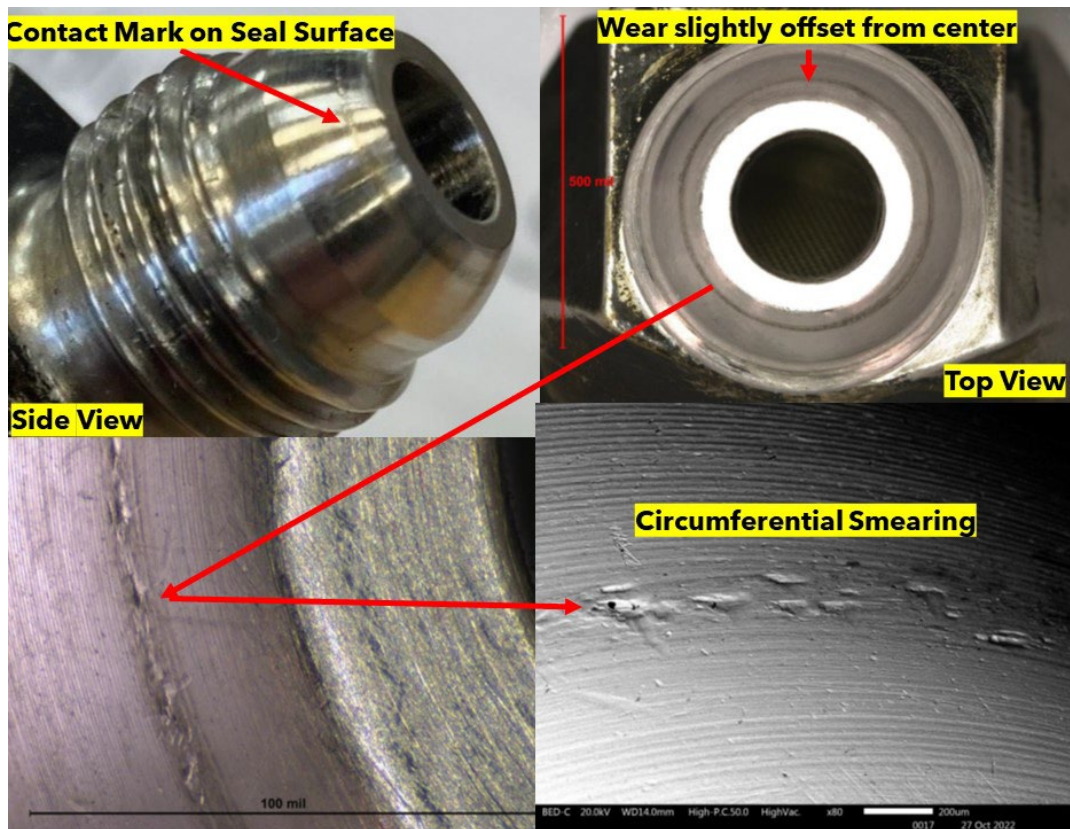
Heavy localized galling was observed on the fuel manifold female ferrule outer diameter (**PHOTO 22**). The female inner conical sealing surface exhibited the normal 360° contact mark from mating with the FN male bullnose seal surface along with heavy galling outboard of the normal contact mark around an arc that was over 180° (**PHOTO 22**, upper right hand).



**PHOTO 22: FN No. 1 FERRULE DAMAGE AND FEMALE SEALING SURFACE GALLING**

Photo courtesy of GE (modified by NTSB)

The FN No. 1 male bullnose sealing surface exhibited the normal 360° contact mark from mating with the female ferrule inner conical sealing surface; however, it was not centered on the male bullnose sealing surface but had shifted slightly upwards. Along with the normal contact wear, heavy circumferential galling/material smearing was observed consistent with the contact mark (**PHOTO 23**). According to GE, the galling observed on the sealing surfaces of the FN No. 1 ferrule and male bullnose are consistent with misalignment of the joint.



**PHOTO 23: FN No. 1 MALE BULLNOSE DAMAGE AND MALE SEALING SURFACE GALLING**

Photo courtesy of GE (modified by NTSB)

#### 4.0 COMPARISONS BETWEEN THE FUEL LEAK ENGINES

A review of the data collected on the fuel manifold leak engines revealed several common factors and trends. **TABLE 3** provides a list of common features/factors and **FIGURE 8** provides a pictorial view of the fuel leak versus low torque locations. All the fuel manifold leaks were considered to have occurred at high power setting based on pilot statements for the operational events and the inability to replicate the fuel leaks during the low pressure test.

| <b>Table 3: Features of All Fuel Manifold Leaks</b> |                                                |                                                                |                                                                 |                                                          |
|-----------------------------------------------------|------------------------------------------------|----------------------------------------------------------------|-----------------------------------------------------------------|----------------------------------------------------------|
|                                                     | ESN 904265                                     | ESN 904292                                                     | ESN 904365                                                      | ESN 904238                                               |
| Leak Location                                       | FN No. 16                                      | FN No. 18                                                      | manifold-to-manifold connection                                 | FN No. 1                                                 |
| Reported Fire                                       | Yes                                            | Yes                                                            | No                                                              | No                                                       |
| Manifold PN at FN leak location <sup>14</sup>       | M44                                            | M44                                                            | NA                                                              | M44                                                      |
| Assembled <sup>15</sup>                             | GE Lafayette                                   | GE Lafayette                                                   | GE Lafayette                                                    | GE Strother                                              |
| Fuel manifold manufacturer <sup>16</sup>            | GE Hookset                                     | GE Hookset                                                     | GE Hookset                                                      | GE Hookset                                               |
| CSN at leak <sup>17</sup>                           | <125                                           | <125                                                           | <125                                                            | >125                                                     |
| Indications of misalignment                         | Yes                                            | Yes                                                            | Yes                                                             | Yes                                                      |
| Low torque value at leak connection                 | Yes                                            | Yes                                                            | No<br>(500 in.-lbs.) <sup>18</sup>                              | Yes                                                      |
| Unique sealing surface damage at leak location      | Yes                                            | Yes                                                            | Yes                                                             | Yes                                                      |
| Type of sealing surface damage                      | Axial ferrule/bullnose sealing surface galling | Male Bullnose abrasive operation (suspected unapproved repair) | Male Bullnose sealing surface dented (possible previous repair) | Circumferential ferrule/bullnose sealing surface galling |

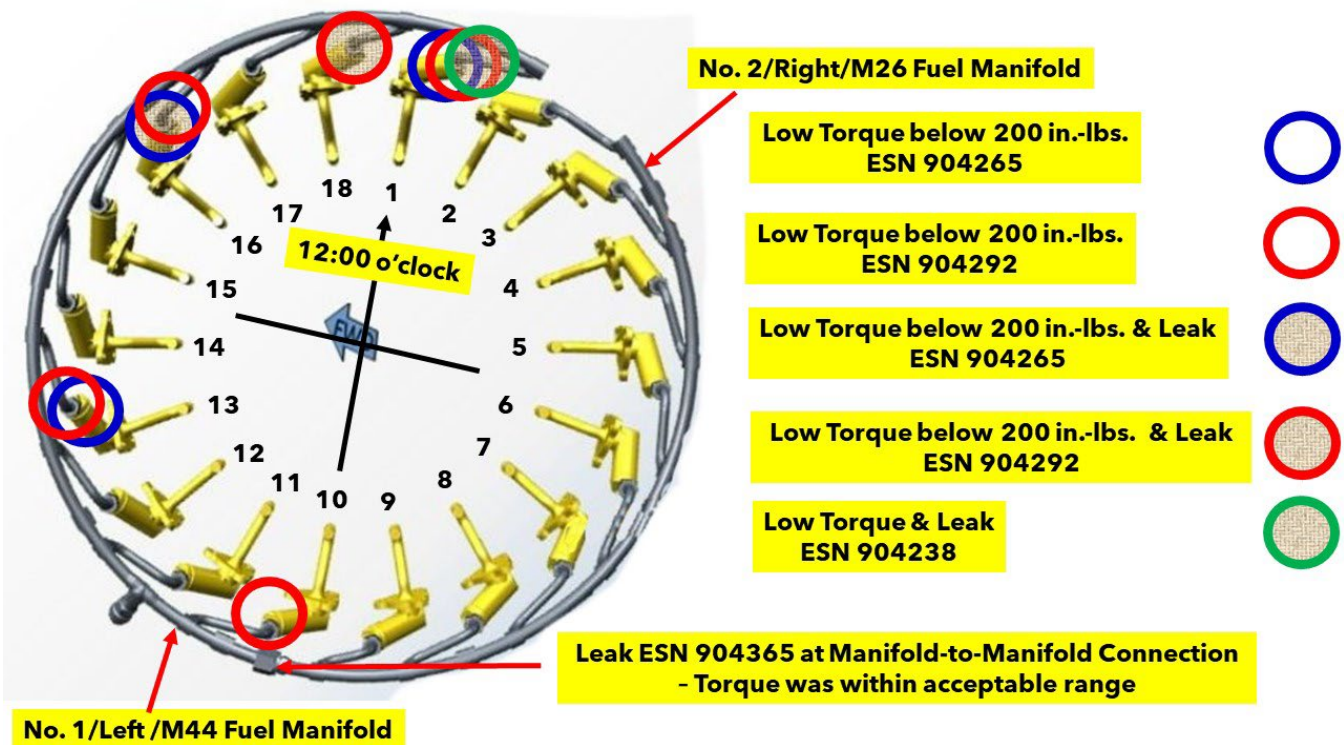
<sup>14</sup> No leaks were observed on fuel manifold M26.

<sup>15</sup> Early in the GE passport engine program, the engine was assembled at two different GE facilities, GE Lafayette and GE Strother, readied to ship to Bombardier for installation into the airplane. Currently, new production engines are only assembled at the GE Lafayette facility.

<sup>16</sup> All engines have fuel nozzle manifolds manufactured by GE Hookset - There is currently only one supplier of both fuel manifolds for the GE Passport engine.

<sup>17</sup> See Table 2 for exact CSN.

<sup>18</sup> The fuel manifold-to-fuel manifold installation torque value (500 in.-lbs. nominal) is much higher than the FN manifold torque installation value (285 in.-lbs. nominal)



**FIGURE 8: FUEL MANIFOLD B-NUT LOW TORQUE AND FUEL LEAK LOCATIONS**

Figure courtesy of GE (modified by NTSB)

## 5.0 TESTING - ENGINE ACCEPTANCE, DEVELOPMENT ENGINE, AND COMPONENT RIG

GE conducted a series of Acceptance Test Procedure (ATP) engine runs, developmental engine runs, and component rig tests to: 1) better understand the effects of FN-to-fuel manifold pigtail misalignment, and operational and assembly loads/stresses on the fuel manifolds under a variety of installation sequence scenarios, 2) validate and develop fuel manifold and FN installation best practices and procedures, 3) gather data on torque (clamp) relaxation on the fuel manifold b-nut connections, and 4) develop methods to minimize the amount of relaxation experienced in operation. The different tests and engine runs were often conducted concurrently and were attempting to gather similar data under varying assembly and operating conditions.

### 5.1 ACCEPTANCE TEST PROCEDURE FOR RETURN-TO-SERVICE OF ESN 904365

ESN 904365 was found to have a fuel leak while at Bombardier (See Section 3.2) and was shipped back to GE for examination and evaluation. Torque checks were performed on all the fuel manifold b-nut connections; five were at or below 200 in.-lbs. (Nos. 13 to 17, which are all on the M44/left manifold). This was an additional data point that confirmed some amount of fuel manifold b-nut connection torque (clamp) relaxation was occurring in operation on Passport 20 engines. GE performed research on several of their legacy engine programs and found that some torque (clamp) relaxation in b-nut connections was normal and expected; however, the amount of M44 relaxation was abnormally high in comparison, mostly in those assembled at the GE Lafayette facility.

All the fuel manifold b-nut connections were retorqued using a revised fuel manifold and fuel nozzle interim assembly procedure to the nominal 285 in.-lbs. and an ATP engine run was performed. GE developed an initial revised assembly procedure as an interim corrective action to provide more specific guidance to remove possible ambiguities and to prioritize minimizing any misalignments or unintended installation loads; the ATP served to determine if the interim corrective action was effective while additional testing and data was being gathered.

An ATP test, which ran for about 4 to 5 hours, was conducted on ESN 904365 as well as additional engines as part of this investigation. Based on the results, GE concluded that: 1) some amount of torque (clamp) relaxation still occurs even after retorque, 2) torque (clamp) relaxation occurs within several engine cycles, 3) the retorquing operation is effective in reducing the amount of torque (clamp) relaxation and misalignment, and 4) the possibility that progressive installation stresses related to the assembly sequence and normal operating loads may contribute to torque (clamp) relaxation.

## 5.2 DEVELOPMENT ENGINE TEST - REPLICATE MISALIGNMENT AND WEAR DAMAGE

GE used a developmental Passport 20 turbfan engine, ESN 904122/01A, to replicate the misalignment wear and loss/relaxation of the fuel manifold b-nut connection torque that was observed on the fire event engines (ESNs 904265 and 904292). New No.1/left (M44) and No.2/right (M26) fuel manifolds were installed along with new FNs<sup>19</sup>, both manifolds were intentionally misaligned consistent with event hardware observations, and the FN and fuel manifolds were assembled using the assembly procedures in effect at the start of the program. The tests were comprised of three 120-cycle engine runs; much longer than the ATP tests discussed in Section 5.1.

The intent of the first 120-cycle test cell run was to replicate the wear anomalies observed on the FN male bullnose sealing surface and the fuel manifold female ferrule sealing surface. During the first 120-cycle run, periodic compartment BSI were performed, and no leaks were detected. After completion of the first 120-cycle run, the engine was removed from the test stand and torque checks of all the fuel manifold b-nut connections were performed. Torque (clamp) relaxation was observed on several of the fuel manifold b-nut connections; however, none were below 200 in.-lbs. Additionally, the data showed that the intentionally misaligned connection did not exhibit significant torque (clamp) relaxation. Since no fuel leaks occurred, GE concluded that relaxation of the fuel manifold b-nut connection torque and misalignment were insufficient to induce a leak; therefore, surface distress like what was observed in the event engines was also needed.

The intent of the second 120-cycle test cell run was to retorque the fuel manifold b-nut connections using the same initial assembly procedures in effect at the start of the program to see if retorquing minimizes the amount of fuel manifold b-nut connection torque (clamp) relaxation; basically confirming the effectiveness of GE SB PASSPORT20-A-72-00-0142-00A-930A-D-001 and FAA AD 2022-13-12. Again, periodic compartment inspections were performed during the test cell run and after completing the 120-cycle test, a torque

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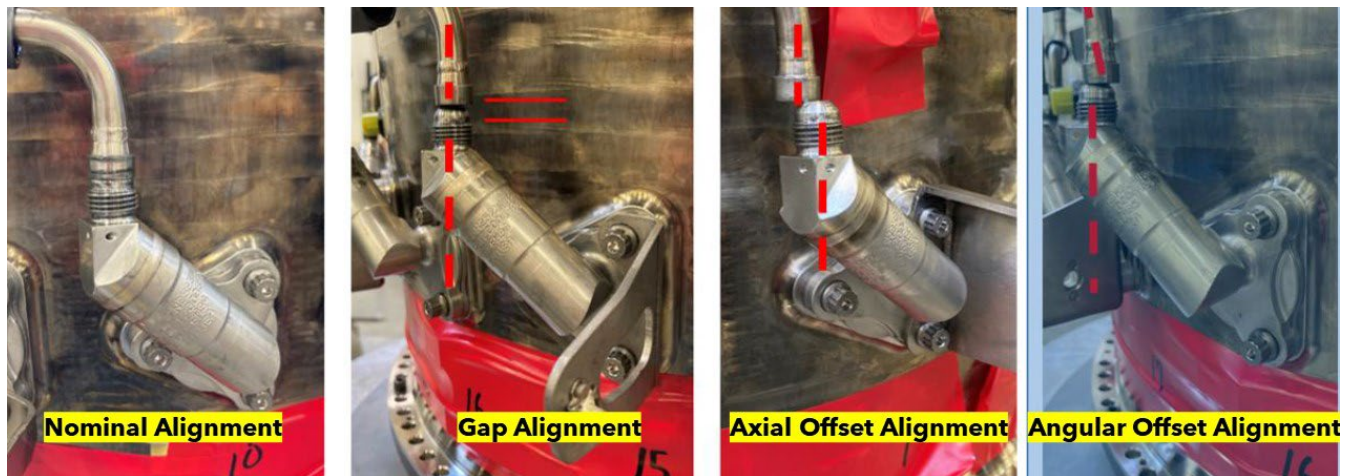
<sup>19</sup> Fuel nozzle No. 10 was from a previous build and was the only fuel nozzle not new for this engine test.

check showed a slight torque (clamp) relaxation of the fuel manifold b-nut connections. Thus, GE concluded that the retorque operation was while effective at preventing leaks, still exhibited more relaxation than anticipated. This was likely attributed to the specific dimensional characteristics of the test manifold.

### 5.3 COMPONENT RIG TESTING

Component rig testing was comprised of essentially two types of tests: an iterative static test to quantify assembly stresses under different assembly procedures and a thermal cyclic test to determine the effectiveness of the retorque procedures under conditions that simulate more closely the engine operating environment.

One of the static component rig tests attempted to bound the amount of FN male bullnose-to-fuel manifold female ferrule/b-nut misalignment as a function of angular offset, axial offset, gaps between fuel manifold b-nut connection and the FN shoulder (**PHOTO 24**), the amount of torque (clamp) relaxation of the fuel manifold b-nut to induce a leak, and captured assembly loads for different FN and fuel manifold b-nut connection torque sequences. The hardware used were a combination of FNs from a previous certification test (the male bullnoses of the FNs are identical to the current production configuration), and new fuel manifolds from current engine production supply.



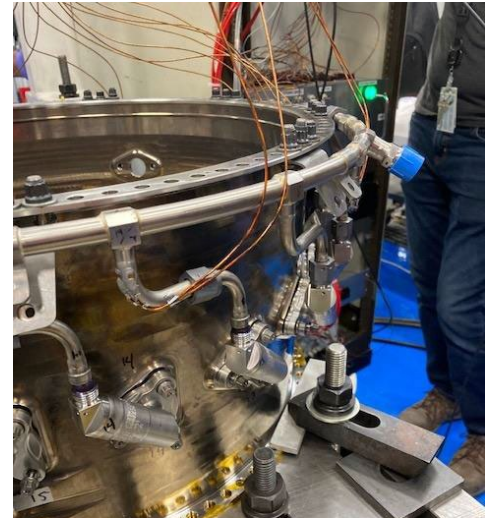
**PHOTO 24: EXAMPLES OF DIFFERENT ALIGNMENTS/MISALIGNMENTS**

Photos courtesy of GE

The values used for the fuel manifold b-nut misalignment were consistent with those observed during the torque and gap checks previously performed on ESNs 904285 and 904292. Variations in angular offset were between 1° to 5° (See **PHOTO 7**, bottom row for example), and the gaps and axial offset ranged from 0.100 to 0.150 inches. All the FN manifold b-nuts were torqued to the nominal installation value of 285 in.-lbs. After a leak was induced, the amount of torque of the fuel manifold b-nut necessary to stop the leak was applied and recorded. The main takeaway was that misalignment between the fuel manifold pigtail and the fuel manifold b-nut connection can induce stresses that can lead to low effective clamping at the fluid seal surface during initial assembly and a reduction of that clamping during operation. Furthermore, when a leak was intentionally induced, the leak

could easily be arrested by adding some additional torque to the joint. GE concluded that along with reduction of the clamping force at the fluid sealing surface, surface distress on the FN male bullnose sealing surface, like what was observed on all three leaked engines, was also a contributor to induce the fuel leak.

Several static component rig tests were performed using production hardware, some of which came from a previous component test, to capture stress data under various iterative FN and fuel manifold installation and torque sequences to: 1) assess assembly effects on the fuel manifold pigtail preload, 2) determine assembly variables that impact fuel manifold alignment and loading, and 3) develop fuel system component installation and torque sequences to minimize factors that may create a condition that could lead to a significant loss/relaxation of torque in the fuel manifold b-nut connection (**PHOTO 25**). The testing showed that the assembly process influenced alignments and that fuel nozzle position relative to the engine case can be modified to reduce in-process assembly stress. All stress values measured were well below yield strength of the materials.



**PHOTO 25: INSTRUMENTED  
COMPONENT RIG TEST**

Photo courtesy of GE

The intent of the thermal cyclic test (**PHOTO 26**) was to match thermal cycles of the engine, for example hot combustion chamber case and lower/cooler fuel manifold temperatures, to: 1) replicate the fuel manifold and fuel manifold-to-fuel manifold b-nut connection torque (clamp) relaxation and the gap effects observed on the No.1/left (M44) fuel manifold on the two event operational engines (ESNs 904265 and 904292), 2) prove the effectiveness of the retorque operation and 3) determine the cyclical capability of the retorqued connection. The thermal rig testing was completed but the test was not able to duplicate the fuel manifold b-nut connection torque (clamp) relaxation. GE hypothesized that more than just thermal induced stresses were needed to cause torque (clamp) relaxation. Therefore, GE proposed a test plan to induce vibration levels consistent with normal operational vibration levels and duration times to determine effect of vibration on the b-nut joint. The vibration testing and pressure cycling on the rig were completed but were unable to replicate the b-nut relaxation.



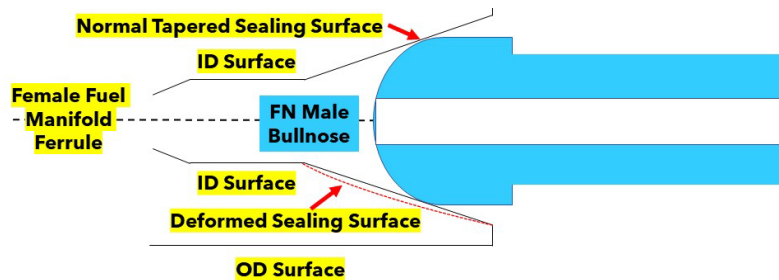
**PHOTO 26: THERMAL RIG TEST**

Photo courtesy of GE

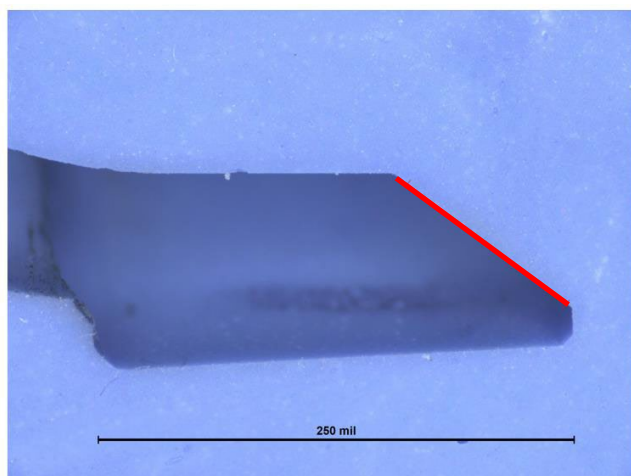
## 6.0 ADDITIONAL VISUAL DATA GATHERED

### 6.1 FUEL NOZZLE FEMALE FERRULE SEALING SURFACE DEFORMATION

**FIGURE 9** is a general representation of the FN male bullnose-to-fuel manifold female ferrule connection and nomenclature. The fuel manifold female ferrule is designed to deform slightly both elastically and plastically during assembly to ensure the proper grip and increase sealing surface area on the FN male bullnose (**PHOTOS 27** and **28**). The conical female ferrule surface is designed to match the spherical male bullnose to ensure a reliable compression seal as the nut that secures the two is tightened to maintain alignment. The relative angle of the female ferrule and the FN male bullnose sealing surfaces will determine the amount of linear (axial) movement that is converted into radial compression of the female ferrule sealing surface. A good and reliable seal is when there is a light, level, and uniform mark around the entire sealing surface and a slight compressive deformation of the sealing. **PHOTOS 6, 7, and 18** showed examples of these marks that were not uniform and level. Examination of all the female and male sealing surfaces found that there was a lack of deformation of the female ferrule sealing surface at the leak locations. There were no examples found of deformed female ferrule sealing surfaces leaking. Furthermore, the plastic deformation was inconsistent amongst on the ferrules examined; some had more than others, even if the installation torque was the same.

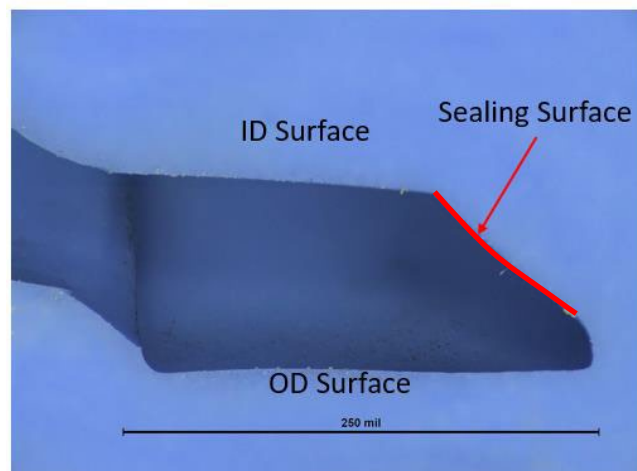


**FIGURE 9: FERRULE SEALING SURFACES**



**PHOTO 27: NON-DEFORMED SEALING SURFACE**

Photo courtesy of GE (modified by NTSB)



**PHOTO 28: SLIGHT DEFORMED SEALING SURFACE**

Photo courtesy of GE (modified by NTSB)

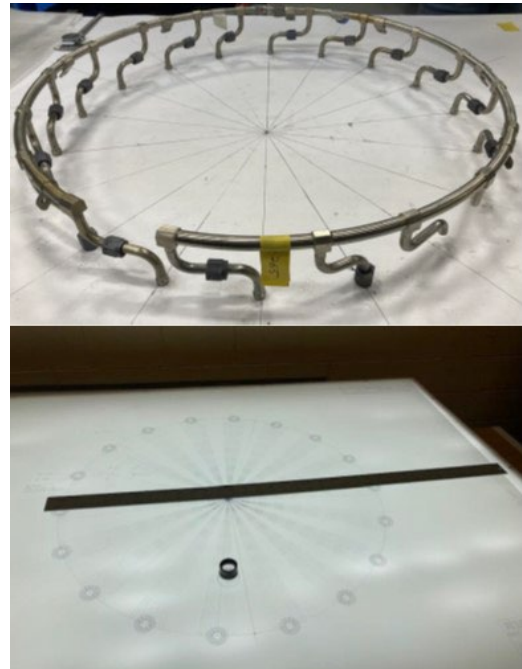
Hardness checks on the fuel manifold female sealing surfaces as well as dimensional inspection for correct sealing surface contact angle were performed to find out

if material variations could have contributed to the inconsistencies observed in the plastic deformation of the female ferrule sealing surfaces. The hardness checks and the sealing surface angles were consistent with manufacturing print and GE suspects that the differences in plastic deformation were not a function of the material property of the ferrule but more likely due to higher clamping forces at assembly.

## 6.2 VISUAL COMPARISON OF THE RIGHT AND LEFT FUEL MANIFOLDS

GE conducted a series of simple visual assessments of the fuel manifold pigtail location in the free state and in a semi-connected state; the fuel manifolds were not attached to the engine or to the fuel nozzles but placed on an examination table. Fuel manifolds from ESN 904265 (Palm Beach), ESN 904292 (Kingdom of Saudi Arabia), ESN 904122/01 (development engine), and ESN 904238 (Bombardier pre-retorque) were evaluated.

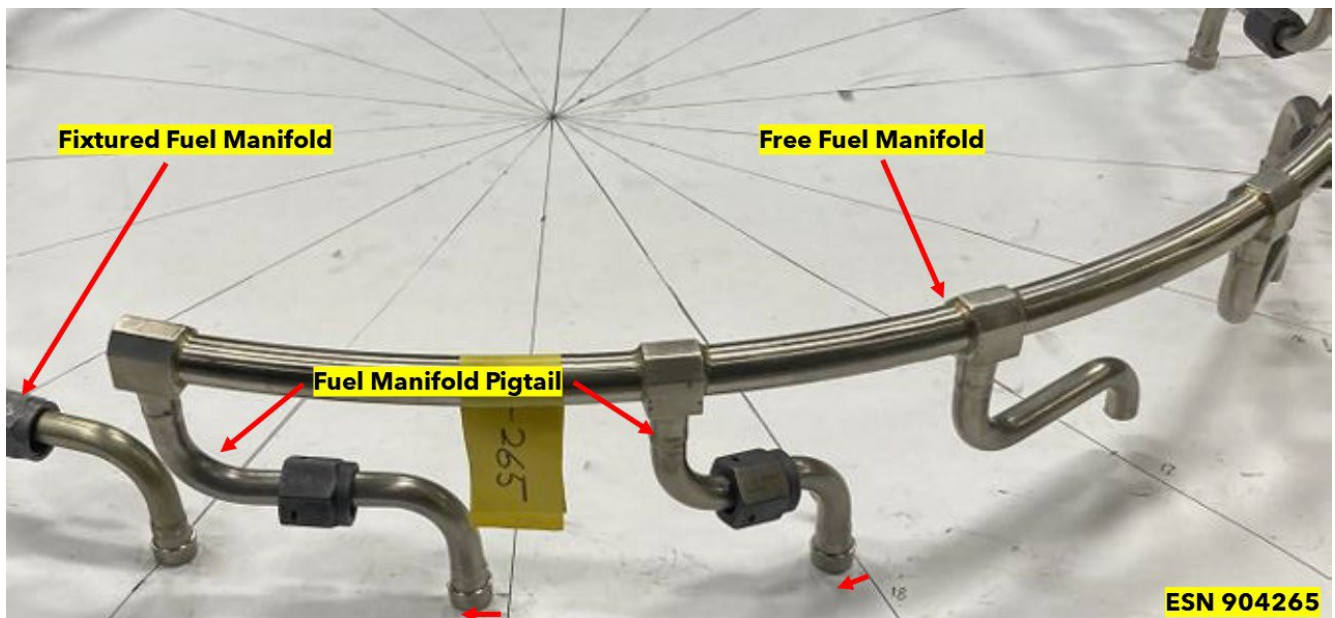
GE created a template to show the relative circumferential and radial displacement/misalignment of the fuel manifold pigtail connections. Lines at 20° angles were drawn from a center point representing the radial centerline locations of the eighteen fuel manifold pigtail ferrule connections (**PHOTO 29**, top). For more accurate angular measurements, a transparent mylar sheet with finer graduated radial lines representing smaller angular displacement from the centerline were created and was backlit for easier interpretation (**PHOTO 29**, bottom).



**PHOTO 29: FUEL MANIFOLD PIGTAIL ALIGNMENT TEMPLATE**

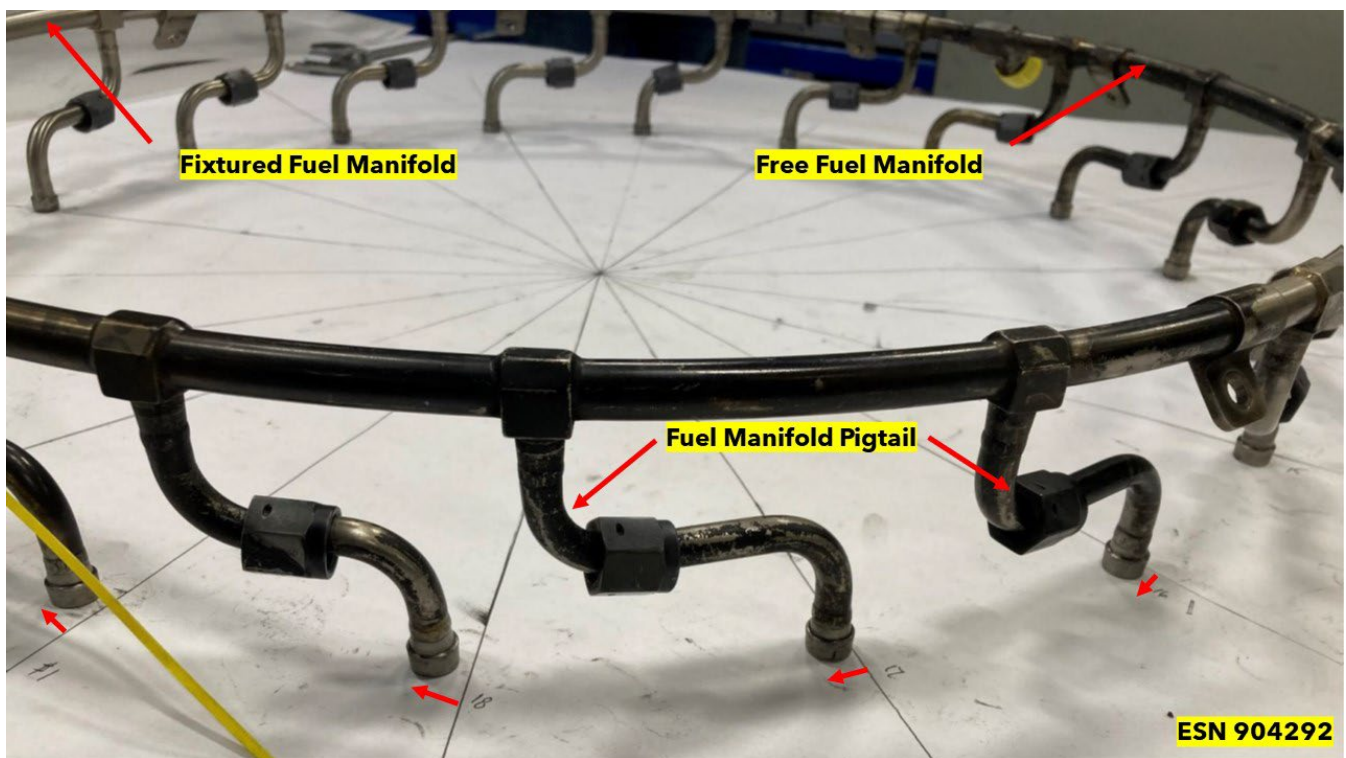
Photos courtesy of GE

In the free state condition where the fuel manifolds are not joined at the manifold-to-manifold b-nut connection, all the fuel manifold pigtails were aligned with the radial lines. None of the fuel manifold pigtails showed any circumferential misalignment circumferentially away from the radial centerlines. With fuel manifolds connected at the manifold-to-manifold connect and holding one of the fuel manifolds fixed so that the pigtails remained on the radial centerlines (semi-free state), a slight shift (circumferential misalignment) in the fuel manifold pigtails on the non-fixed fuel manifold was observed. The direction of the misalignment was consistent on all three engine fuel manifolds evaluated and the shift was in the direction of closing/tightening the circular shape (**PHOTOS 30** and **31**). Although not shown, ESN 904238 fuel manifolds exhibited the same circumferential misalignment. Thus, connections of the fuel manifolds at the 6:00 o'clock fuel manifold-to-fuel manifold b-nut was shown to be a contributor to the system assembly stresses and circumferential misalignments.



**PHOTO 30: SEMI-FREE STATE MISALIGNMENT ON ESN 904265 FUEL MANIFOLD**

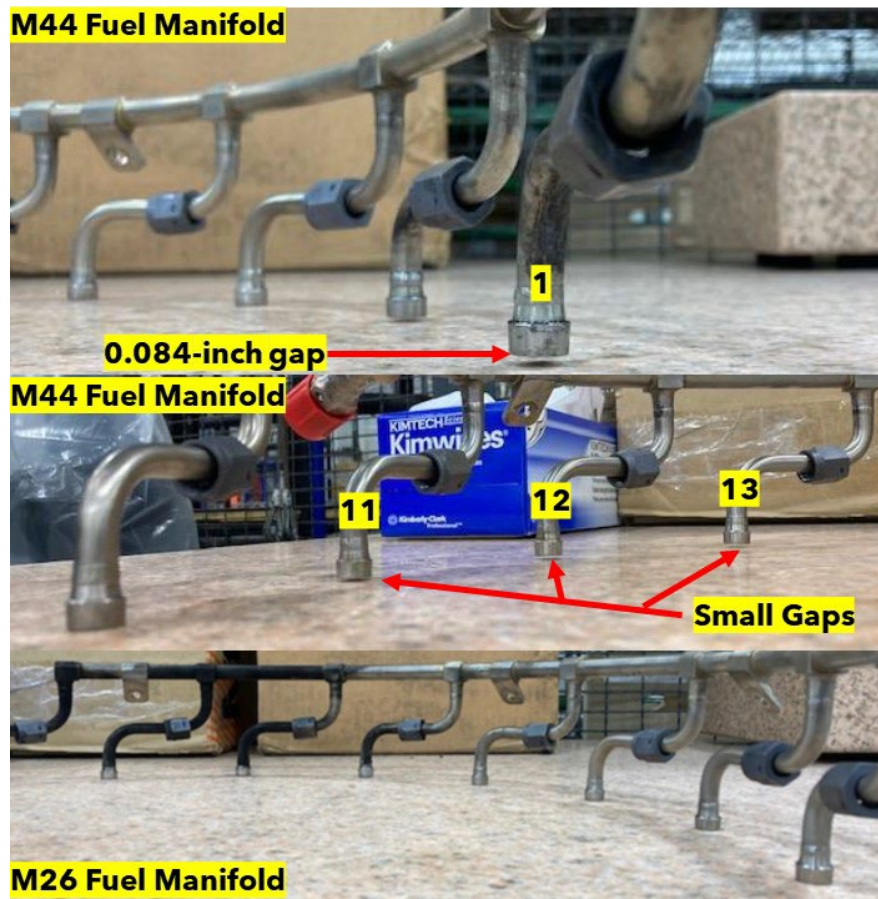
Photo courtesy of GE (modified by NTSB)



**PHOTO 31: SEMI-FREE STATE MISALIGNMENT ON ESN 904292 FUEL MANIFOLD**

Photo courtesy of GE (modified by NTSB)

The fuel manifolds from ESN 904238 showed an additional alignment contributor; some of the fuel manifold pigtails were not flush with the table and were vertically displaced some amount when viewed on the gage table (**PHOTO 32**)<sup>20</sup>. All the vertically displaced pigtails were on the M44 fuel manifold; none of the pigtails on the M26 fuel manifold showed this same anomaly. FN No. 1 pigtail was visibly and dimensionally shorter than the adjacent pigtails (**PHOTO 32**, top picture).



**PHOTO 32: PIGTAILS ON ESN 904238 NOT FLUSH WITH TABLE**

Photo courtesy of GE (modified by NTSB)

## 7.0 TESTING AND DATA GATHERING FINDINGS

Based on all the data gathered from the event engines, the test engines, and component rig tests, several cumulative factors related to the FN and fuel manifold assembly procedures and assembly/operational stresses cumulatively contributed to the fuel manifold leaks.

Fuel manifold pigtail and fuel nozzle dimensional variation, combined with a given assembly sequence, can create the potential for misalignment between fuel manifold female ferrule and fuel nozzle male bullnose sealing surfaces. The misalignment can preload the fuel manifold b-nut connection, creating high resistance in the threads during torquing that promotes low effective clamping and false (high) torque readings when compared to a neutral/well aligned connection. This low effective clamped connection can relax/loosen during engine operation as the manifold geometry normalizes and the connection shifts. All the leaking fuel manifolds b-nut connections were found on those connections with lower than expected torque values.

Additionally, some amount of torque (clamp) relaxation is expected to occur within several engine cycles, even after a retorque; however, the retorque operation effectively

<sup>20</sup> Print allows +/- 0.06 inch in this direction perpendicular to the table.

reduced the amount of overall torque (clamp) relaxation and misalignment. Since no fuel leaks occurred during the development engine tests, and leaks could be induced and stopped with slight variations in torque during the component rig tests, GE concluded that relaxation of the fuel manifold b-nut connection torque and misalignment were insufficient to induce a leak on their own; therefore, an aggravating factor such as surface distress, like what was observed in the event engines, was also necessary.

GE concluded that multiple factors can be present to create a leak, false (low) torques due to misalignment, higher than anticipated assembly loads due to dimensional variation, and poor/distressed sealing surface condition.

## 8.0 CORRECTIVE ACTION

### 8.1 CHANGES TO THE FUEL NOZZLE AND FUEL MANIFOLD ASSEMBLY PROCEDURE

The assembly method used at the beginning of the Passport 20 program was the same procedure used on all four engines with leaks (ESNs 904265, 904292, 904365, and 904238) and was the same procedure used at both GE assembly facilities; the fuel nozzle and fuel manifold assembly procedures are part of the combustor module, PN 2467M45G04, assembly procedures. The original procedure called for installing the FNs and fuel manifolds finger tight. Then the FN were hand-tightened to the combustion case were torqued to the combustion case in sequence clockwise from FN No. 1 to 18, followed by the fuel manifold b-nut connections sequentially clockwise Nos. 1 to 9, the manifold-to-manifold b-nut connection, and then finally the fuel manifold b-nut connections sequentially clockwise from FN No. 10 to 18.<sup>21</sup> The fuel manifold b-nut connections and the fuel manifold-to-manifold b-nut connection were then untorqued in the same sequence to a free running condition and retorqued again as described above (triple-torque procedure). According to GE, the triple torque procedure improves joint integrity and robustness when compared to a single torque.

During the investigation, GE reviewed the fuel manifold and fuel nozzle installation and assembly procedures, paying close attention to the assembly sequence, and made several changes to provide more specific guidance to eliminate possible ambiguities in the written procedures and to prioritize minimizing any misalignments or unintended installation loads. The revised combustion module assembly procedure changed the installation torque sequence slightly for the FNs and fuel manifolds and included additional controls on the 'triple-torque'<sup>22</sup> procedure for the fuel manifold b-nut connections; these changes required GE to issue a "change in design" (CID) and the combustor PN changed from PN 2467M45G04 to PN 2467M45G05 with FAA approval.

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<sup>21</sup> Note that the sequence starts with fuel manifold b-nut No. 1, which is part of the M44/left manifold, then sequentially clockwise ALF to the M26/right fuel manifold, to the fuel manifold-to-fuel manifold b-nut connection, then finally back to the M44/left manifold.

<sup>22</sup> The fuel manifold b-nut connection 'triple torque' involves torquing the b-nut to the required 285 in.-lbs. nominal (torque 1), breaking the torque, torquing again to 285 in.-lbs. nominal (torque 2), then checking the torque (torque 3). The connection is not loosened between torque 2 and torque 3.

GE gathered data from the static rig and engine tests, along with feedback from the assembly mechanics, to determine the overall effectiveness of the revised assembly procedures. GE found that adding oil to the b-nut threads resulted in statistically higher torque values when compared to engines assembled where no oil was added to the b-nut threads, and observable smaller b-nut gaps. In addition, GE modified the fuel nozzle installation position during assembly. GE plans to issue another CID in the first quarter of 2023 for FAA to finalize and clarify the optimum FN and fuel manifold installation and assembly procedure to be used on all further Passport engines to include the use of oil on the b-nuts and a slight change to the FN installation; the combustor PN will change from PN 2467M45G05 to PN 2467M45G06 once it is approved by the FAA. GE considered the installation and assembly procedures associated with PN 2467M45G06 to be the permanent corrective action and the changes will be incorporated in the maintenance manuals.

## 8.2 ALL OPERATORS WIRES AND ADVISOR WIRES

Multiple All Operators Wires (AOWs) and Advisory Wires (AWs) were issued by GE and Bombardier respectively relating to the Passport 20 engine fuel manifold leaks. Those AOWs and AWs related to the issuance of GE SBs and FAA ADs are discussed in Section 8.3 SERVICE BULLETINS AND AIRWORTHINESS DIRECTIVES.

On April 7, 2022, GE Aviation issued to all Passport 20 operators AOW message number 22-PASSPORT-001 Revision 0 informing operators of an ongoing investigation into two recent Global 7500 engine fire warning annunciations in the fire zone; these were the ESN 904265 (Palm Beach) and ESN 904292 (Kingdom of Saudi Arabia). Post-flight inspections of both engines indicated that the fire was contained within the engine core compartment. GE issued additional revisions to 22-PASSPORT-001 informing operators of upcoming GE SBs and FAA ADs; See Section 8.3 SERVICE BULLETINS AND AIRWORTHINESS DIRECTIVES for additional details.

On April 8, 2022, Bombardier issued to all Global 7500 business jet operators AW AW700-72-0864 informing operators of two engine fire warning annunciations shortly after takeoff and to reiterate the importance of following the flight manual procedures for an in-flight fire. Since then, Bombardier has issued several revisions to their AW updating operators of the status of the investigation and any upcoming GE SBs or FAA ADs.<sup>23</sup>

On October 17, 2022, GE Aviation issued to all Passport 20 operators AOW message number 22-PASSPORT-001 Revision 5 informing operators of a recent finding while performing GE SB PASSPORT20-A-72-00-0142-00A-930A-D-001 titled "ENGINE - General (72-00-00) - Fuel manifolds coupling nuts retorqued for containment action Service Bulletin". The engine was removed and shipped to GE for evaluation; this was ESN 904238 and was the fourth Passport engine found to have leaked from the fuel manifold. GE recommended that

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<sup>23</sup> Bombardier issues the following revisions: Revision 1 April 14, 2022; Revision 2 May 2, 2022; Revision 3 May 19, 2022; Revision 4 July 15, 2022, Revision 5 August 8, 2022, and Revision 6 October 17, 2022. Revision 4 stated that FAA AD 2022-13-12 would also be posted on the Transport Canada Civil Aviation (TCCA) and European Union Aviation Safety Agency (EASA) websites. Revision 6 was released to inform operators of a fourth engine finding.

for engines that have complied with FAA AD 2022-13-12, no further action was required. For engines that have not complied with the FAA AD, GE recommended that operators accelerate the accomplishment of GE SB PASSPORT20-A-72-00-0142-00A-930A-D-001 and complete the retorque by November 30, 2022.

### 8.3 SERVICE BULLETINS AND AIRWORTHINESS DIRECTIVES

Part of GE's initial field containment plan was to inspect all Passport 20 engines, those that were in-service with operators and those at Bombardier for final airplane assembly and test for signs of an undercowl fuel leak or fire damage. GE developed field engineering instructions (FEI) to perform an undercowl inspection that would become the basis for a service bulletin (SB) to inspect in-service engines.<sup>24</sup> On April 14, 2002, GE Aviation issued Category 2 SB PASSPORT20-A-72-00-0141-00A-930A-D-001 titled "ENGINE - General (72-00-00) - Visual Inspection of the core compartment with a borescope - Service bulletin" recommending a visual inspection using a borescope of the core compartment in the fuel nozzle zone for indications of a fuel leak or undetected fire; the inspection could be performed on-wing. The GE SB also recommended a reporting back to GE Service Engineering on any findings. To assist in compliance with the GE SB for engines in-service, GE made available field service teams to perform the on-wing inspection. For those engines at Bombardier waiting for customer delivery, the inspections were performed by Bombardier using the FEI provided by GE. Recommended SB compliance was as follows:

- (i) For engines with less than or equal to 150 CSN, perform the SB as soon as possible without effect on revenue service but before 25 flight cycles from the issue date of the service bulletin.
- (ii) For engines with between 151 and 200 CSN, perform the SB as soon as possible without effect on revenue service but before 50 flight cycles from the issue date of the service bulletin.
- (iii) For engines with 201 CSN or greater perform the SB as soon as possible without effect on revenue service but before 75 flight cycles from the issue date of the service bulletin.

As new information became available, GE's field containment plan was adjusted to include a retorque of the fuel manifold b-nut connections as well as the fuel manifold-to-fuel manifold b-nut connection; a new FEI was developed for the retorque operation and that instruction became the basis for a new GE SB.<sup>25</sup> On May 11, 2022, GE Aviation issued Category 2 SB PASSPORT20-A-72-00-0142-00A-930A-D-001 titled "ENGINE - General (72-00-00) - Fuel manifolds coupling nuts retorque for containment action Service Bulletin" recommending a visual inspection of the core compartment for indications of a fuel leak or undetected fire, and providing instructions for retorque of the fuel manifold b-nuts and the fuel manifold-to-fuel manifold b-nut connection. The inspection and retorque operation

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<sup>24</sup> On April 13, 2022, GE Aviation issued AOW message number 22-PASSPORT-001 Revision 1 to inform operators that SB PASSPORT20-A-72-00-0141-00A-930A-D was being issued as part of their field containment plan.

<sup>25</sup> On May 2, 2022, GE Aviation issued AOW message number 22-PASSPORT-001 Revision 2 to inform operators that SB 72-00-0142-00A-930A-D was being issued as part of their field containment plan.

could be performed on-wing. Following the retorque procedure, instructions were provided for a high power engine run followed by BSI of the core compartment to look for fuel leaks.<sup>26</sup> The GE SB also recommended a reporting requirement back to GE Service Engineering on any findings. To assist in compliance with the SB for engines in-service, GE made available field service teams to perform the on-wing inspection and retorque operation. For those engines at Bombardier waiting for customer delivery, the inspection and retorque operation was performed by Bombardier using the FEI provided by GE. The GE SB would prioritize ESNs based on fleet utilization and engine assembly facility. Recommended SB compliance is as follows:

- (i) For ESNs 904257 and up, perform the SB as soon as possible without effect on revenue service but before 30 flight cycles or 12 months from the issue date of the SB.
- (ii) For ESNs 904256 and lower, perform the SB as soon as possible without effect on revenue service but before 100 flight cycles or 12 months from the issue date of the SB.

The FAA issued AD 2022-13-12, with an effective date of July 14, 2022, for all GE Passport 20-17BB1A, GE Passport 20-18BB1A, and GE Passport 20-19BB1A model turbofan engines.<sup>27</sup> The FAA AD requires a visual inspection of the core compartment, a retorque of the core compartment coupling nuts, a ground power assurance check, and a borescope inspection to ensure that there were no leaks before the airplane was returned to service. Depending on the results of the inspections, the AD requires operators to perform applicable maintenance in accordance with their FAA-approved instructions for continued airworthiness. At the time, the FAA considered the AD to be an interim action since the unsafe condition was still under investigation. Based on the results of the GE SBs and FAA AD no further FAA rulemaking action was necessary.

The FAA AD differs slightly from the GE SB PASSPORT20-A-72-00-0142-00A-930A-D-001 in that: 1) the FAA AD splits the inspection and retorque into two separate compliance tasks whereas the SB keeps them together based on ESN and 2) the FAA AD does not require a reporting requirement. The FAA AD compliance is as follows:

Perform a visual inspection of the core compartment for indications of fuel leakage, undetected fire, and heat distress:

<sup>26</sup> The SB is applicable to ESNs 904104, 904108, 904117, 904118, 904123 through 904222, 904224 through 904345, 904349, 904352, 904354, 904356, 904357, 904359 through 904371, and 904373 through 904375. This SB has been introduced into production to these engines: 904346, 904347, 904348, 904350, 904351, 904353, 904355, 904358, 904372, 904376, and up.

<sup>27</sup> On June 30, 2022, GE Aviation issued AOW message number 22-PASSPORT-001 Revision 3 to inform operators that AD 2022-13-12 was being issued that referenced GE SBs PASSPORT20-A-72-00-0141-00A-930A-D-001SBs (borescope inspection) and PASSPORT20-A-72-00-0142-00A-930A-D (retorque SB/ground assurance check). On August 26, 2022, GE issued AOW message number 22-PASSPORT-001 Revision 4 to inform operators that the FAA approved an Alternative Method of Compliance (AMOC) for AD 2022-13-12.

- (i) For engines with less than or equal to 150 CSN as of the effective date of the AD, inspect before exceeding 30 flight cycles after the effective date of the AD.
- (ii) For engines with 151 to 200 CSN as of the effective date of the AD, inspect before exceeding 50 flight cycles after the effective date of the AD.
- (iii) For engines with greater than 200 CSN as of the effective date of the FAA AD, inspect before exceeding 75 flight cycles after the effective date of the FAA AD.

Retorque core compartment coupling nuts as follows:

- (i) For engines with ESN 904257 or higher, before exceeding 30 flight cycles after the effective date of the FAA AD, retorque the core compartment coupling nuts.
- (ii) For engines with ESN 904256 or lower, before exceeding 100 flight cycles after the effective date of the FAA AD, retorque the core compartment coupling nuts.
- (iii) For all affected engines, before further flight after performing the required retorque perform a ground power assurance check and a borescope inspection.

Jean-Pierre Scarfo  
AS40 Engineering Division  
Powerplant Lead

## ATTACHMENTS

1. GE Passport 20 Core Compartment Fires In Service, dated March 14, 2023