

National Transportation Safety Board

Office of Aviation Safety

Washington, DC 20594



ENG23LA031

POWERPLANTS

Group Chair's Factual Report

January 13, 2025

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A. INCIDENT

Location: Newark, New Jersey
Date: June 28, 2023
Time: 1019 Eastern Daylight Time
Airplane: Boeing 737 MAX-9, N37516, United Airlines Flight 2376

B. POWERPLANTS GROUP

Group Chair	Robert Hunsberger National Transportation Safety Board Washington, DC
Member	Mehdi Lamnyi Federal Aviation Administration Burlington, Massachusetts
Member	James Easton CFM International Cincinnati, Ohio
Member	Bryan Tinker CFM International Cincinnati, Ohio
Member	Paola Perez CFM International Cincinnati, Ohio
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Member	Joseph Pierce CFM International Cincinnati, Ohio
Member	Ryan Hurling United Airlines Chicago, Illinois

Member	Carlos Moreno United Airlines Chicago, Illinois
Member	Stuart Tanasse Boeing Renton, Washington
Member	Jimmy Dutton Boeing Seal Beach, California
Member	Steve Demko Air Line Pilots Association International Newark, New Jersey

C. SUMMARY

On June 28, 2023, about 1019 eastern daylight time (EDT), a Boeing 737 MAX-9, N37516, powered by two CFM International LEAP-1B28 turbofan engines, operated as United Airlines Flight 2376, experienced a No. 1 (left) engine fire during taxi-in after landing at Newark Liberty International Airport (EWR), Newark, New Jersey. The airplane was operated as a Title 14 *Code of Federal Regulations* Part 121 flight from Fort Lauderdale-Hollywood International Airport (FLL), Fort Lauderdale, Florida to EWR.

According to the flight crew, during taxi-in, they received a No. 1 engine fire warning indication and audible bell. The flight crew shutdown the No. 1 engine, discharged one fire bottle, and the fire warning indication ceased. There was no visible smoke or fire emanating from the No. 1 engine, and the airplane was towed to the gate. Maintenance personnel observed evidence of a fuel leak under the No. 1 engine at the gate. The No. 1 engine thrust reverser doors were opened for visual inspection and heat damage and sooting were observed on the engine cases and external components.

The No. 1 engine was shipped to the GE Aerospace engine shop in Lafayette, Indiana for examination. Investigation party members from the CFM International, Boeing Commercial Airplanes, United Airlines, Air Line Pilots Association, International (ALPA), the Federal Aviation Administration (FAA), and the National Transportation Safety Board (NTSB) completed the examination from July 19-20, 2023.

The left side of the engine exhibited multiple indications of undercowl fire including discoloration and sooting of the engine core from the 6 to 12 o'clock positions, between the high-pressure compressor rear case and the aft flange of the high-pressure turbine case. The discoloration was most concentrated from the 6 to 9 o'clock positions. There was no evidence of engine case burn through or radial uncontainment. The fuel manifold and fuel nozzles were leak checked with pressurized nitrogen and leak detection fluid was sprayed on the fuel nozzle-to-fuel manifold b-nuts and fuel nozzle flange bolts. A leak was identified at the fuel nozzle 17 pilot secondary inlet b-nut connection. Torque measurements of the fuel nozzle b-nuts and flange bolts revealed that the secondary inlet b-nuts of fuel nozzles 17 and 18 had zero torque and backed off with no resistance according to the GE Aerospace mechanics.

UAL revised their AMM fuel nozzle set replacement procedures following the incident to incorporate additional steps and checks to verify proper installation. The revised procedure requires additional external hardware to be removed from the engine to ensure better access to the fuel nozzles and reduce the likelihood of false torque indications. A pressurized nitrogen leak check of the fuel manifold is performed after the fuel nozzles are torqued, prior to external hardware installation. Leak detection fluid is applied to all fuel nozzle connections and each nozzle is visually inspected for leak indications. After the fuel nozzle set replacement is complete, an engine wet motor is performed with the cowl doors open to visually inspect for fuel leaks. A part power leak check is then performed where the engine is started and accelerated to approximately 70% N1 (fan/low rotor speed) to increase fuel pressure above idle speed and actuate fuel system components that are only active above idle conditions. The part power leak check is performed with the cowl doors closed. The cowl doors are subsequently open to visually inspect for leaks after engine shutdown.

CFM International introduced a reverse bleed system on the LEAP-1A engine model in 2024 that is designed to address the root cause of fuel nozzle coking by incorporating a blower to reduce heat soak back following engine shutdown. The reverse bleed system is planned to be introduced onto the LEAP-1B engine model in 2025.

D. DETAILS OF THE INVESTIGATION

1.0 Engine Information

1.1 Engine Description

The CFM International¹ LEAP-1B28 is a high-bypass turbofan engine consisting of a coaxial front fan/booster driven by a multi-stage low pressure turbine (LPT); a multi-stage high pressure compressor (HPC); two-stage high pressure turbine (HPT); twin annular pre swirl combustors; and a full authority digital engine control (FADEC) (**Figure 1**). According to the FAA type certificate data sheet (TCDS) E00088EN, Revision 5, 4 November 2019, the engine has a maximum continuous sea level static thrust rating of 28,690 pounds (lb) and a takeoff (5 minute) thrust rating of 29,317lb². All directional references to front and rear, right and left, top and bottom, and clockwise and counterclockwise are made aft looking forward (ALF).

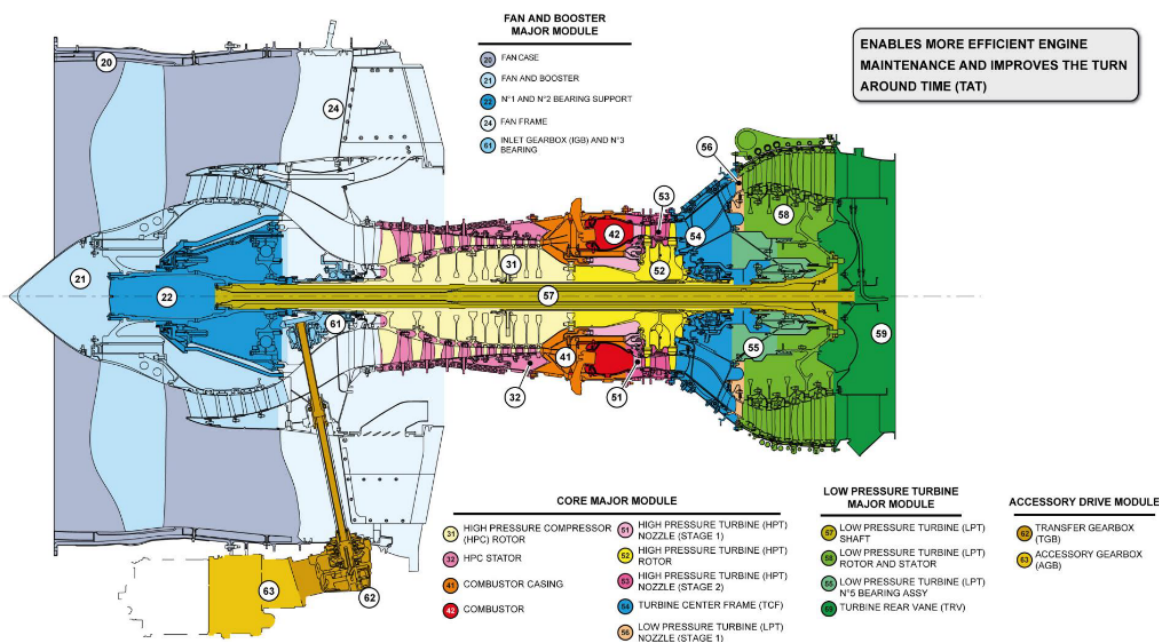


Figure 1- CFM LEAP-1B28 Engine Module Diagram

(Source - CFM International)

¹ CFM International is a joint venture between GE Aerospace and Safran Aircraft Engines.

² Takeoff thrust is nominally independent of ambient temperature (flat rated) up to ambient temperature of: Std + 15°C (30°C, 86°F), except as noted above.

Maximum continuous thrust is nominally independent of ambient temperature (flat rated) up to ambient temperature of Std. + 10°C (25°C, 77°F).

Ratings assume standard sea level conditions with zero customer bleed or power extraction.

The LEAP-1B engine has 18 fuel nozzles with dedicated primary and secondary inlets that are attached to the primary and secondary fuel manifolds with b-nuts (**Photo 1**). The fuel nozzle number positions as viewed forward looking aft are identified in **Figure 2**.

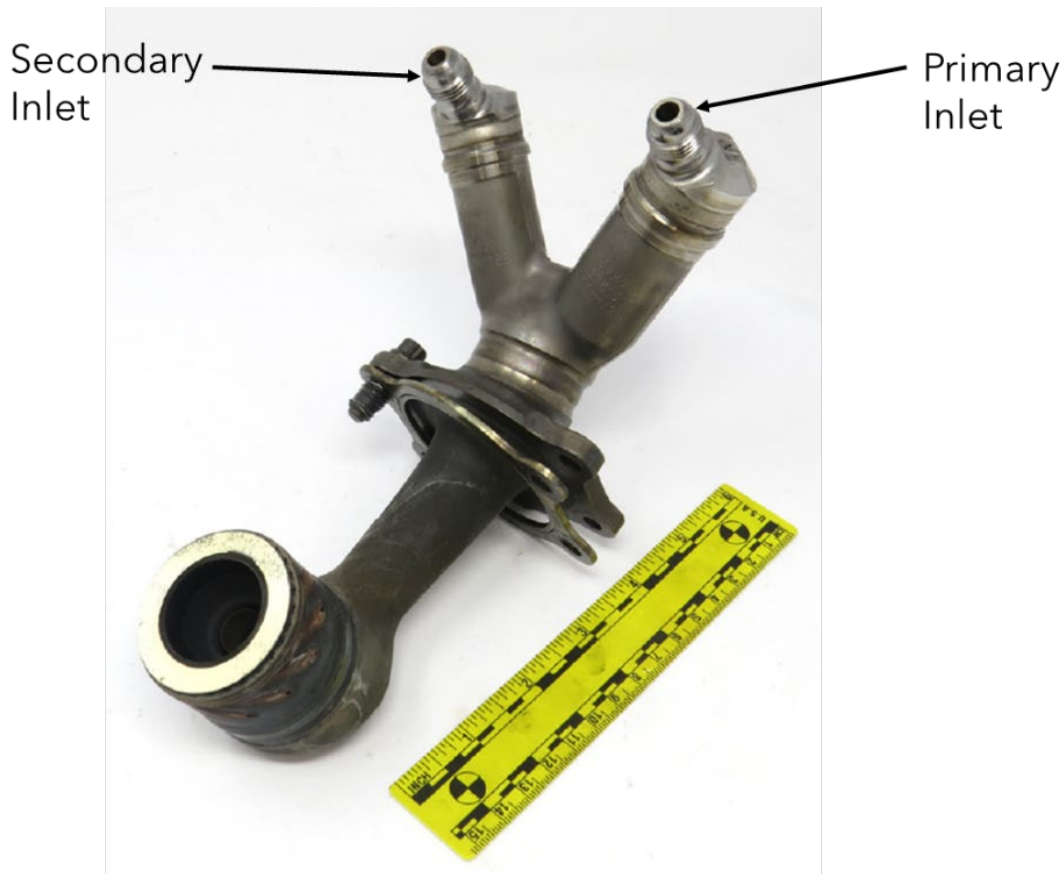


Photo 1- LEAP-1B Fuel Nozzle

(Source- CFM International)

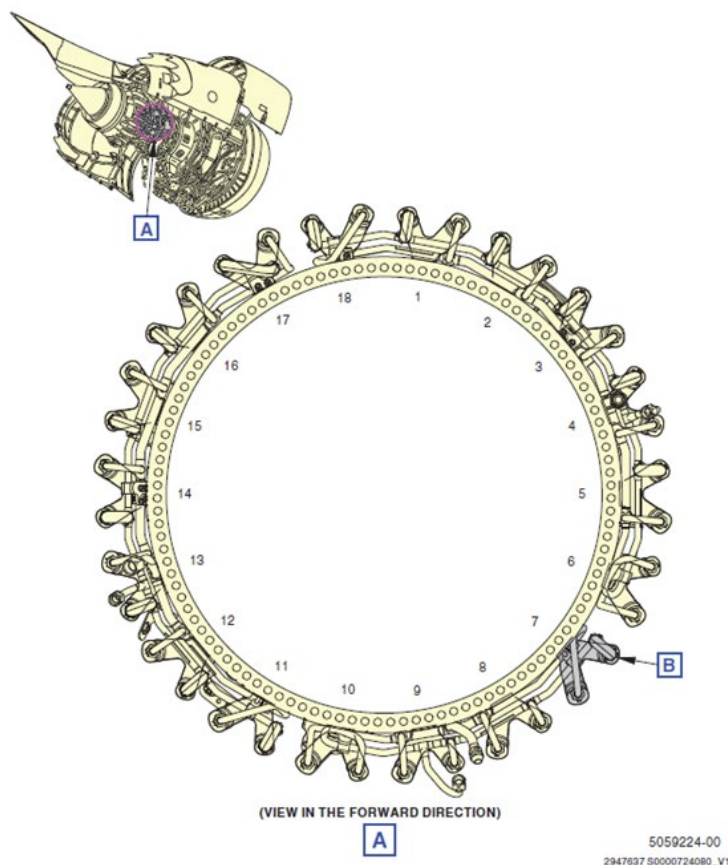


Figure 2- LEAP-1B Fuel Nozzle Numbering

(Source- CFM International)

1.2 Engine Operating History and Maintenance

According to the engine logbook and NTSB Form 6120.1, Pilot/Operator Aircraft Accident/Incident Report, the No. 1 engine, CFM LEAP-1B28, engine serial number (ESN) 60A467, had accumulated 6,384 hours time since new (TSN) and 1,997 cycles since new (CSN). The engine had not undergone any major shop repairs since new. According to United Airlines (UAL), recent ESN 60A467 maintenance is summarized below:

June 27, 2023- Log page was created for a No. 1 engine failure to start - an EEC (Electronic Engine Control) built-in test equipment (BITE) was performed.

June 21, 2023- The engine was water washed and pressure subsystem (PSS) vacuum was accomplished. Regular oil servicing.

June 6, 2023- Fuel sample taken to test for microbial contamination. Test passed.

June 1, 2023- Maintenance gripe for oil debris monitoring system (ODMS) chip count increase. Engine was examined and no anomalies were noted.

January 12, 2023- All 18 fuel nozzles were replaced by UAL mechanics on wing at Cleveland Hopkins International Airport (CLE), Cleveland, Ohio.

UAL provided a copy of the work cards from the January 12, 2023, fuel nozzle set replacement. The UAL procedure was titled "EA7311-01292 REV A, Operation 001- CFM LEAP-1B Fuel Nozzle Full Set Replacement." The installation and inspection of the fuel nozzles was performed in accordance with Boeing 737 MAX-9 aircraft maintenance manual (AMM) 73-11-05-400-802-G00 and were marked completed by a mechanic and inspector. The airplane had accumulated 551 flight cycles / 1,705 flight hours between the time the fuel nozzles were replaced, and the incident engine fire occurred.

2.0 LEAP-1B28, ESN 60A467 Examination and Teardown

The incident No. 1 engine was shipped to GE Aerospace in Lafayette, Indiana for examination and disassembly. The shop was given permission to unbag the engine and secure it in a work gantry prior to the investigation teams' arrival. The engine was shipped with some engine build-up equipment still installed to avoid disturbing external hardware and soot patterns (**Photos 2 and 3**). The engine data plate confirmed the ESN, 60A467, and rated thrust (**Photo 4**). The fan rotated smoothly by hand with concurrent rotation of the LPT. The ODMS plug and oil scavenge screens were removed and were free of debris (**Photo 5**).



Photo 2- Engine Left Side, as Received

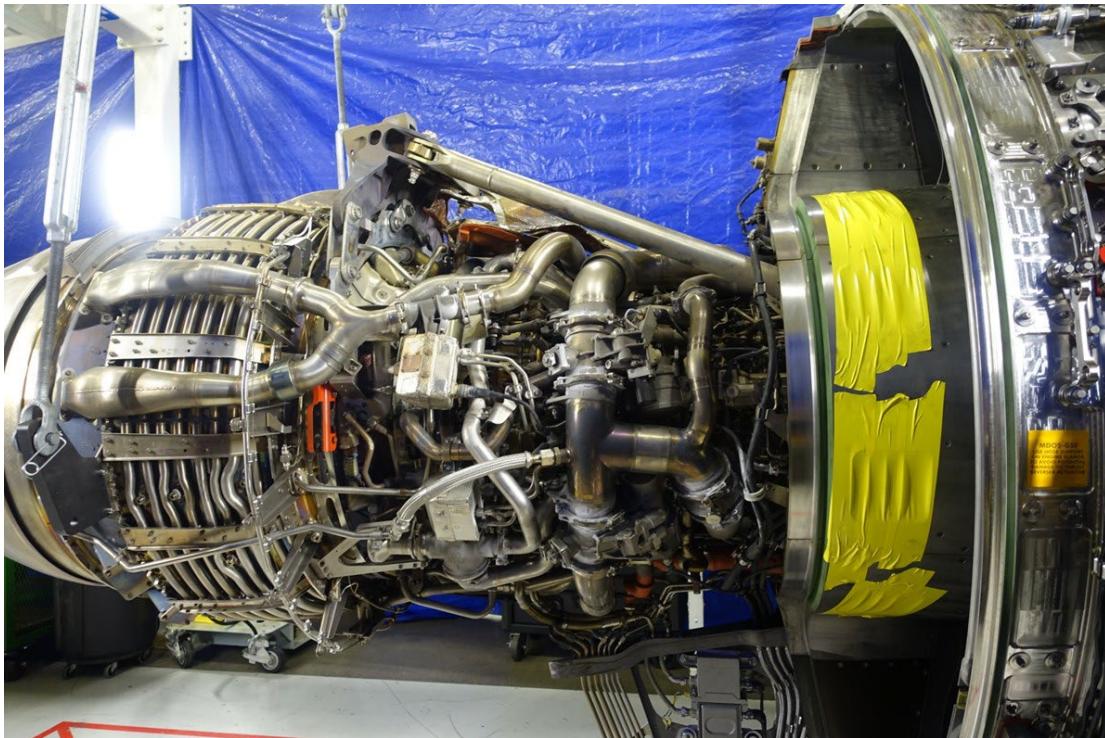


Photo 3- Engine Right Side, as Received

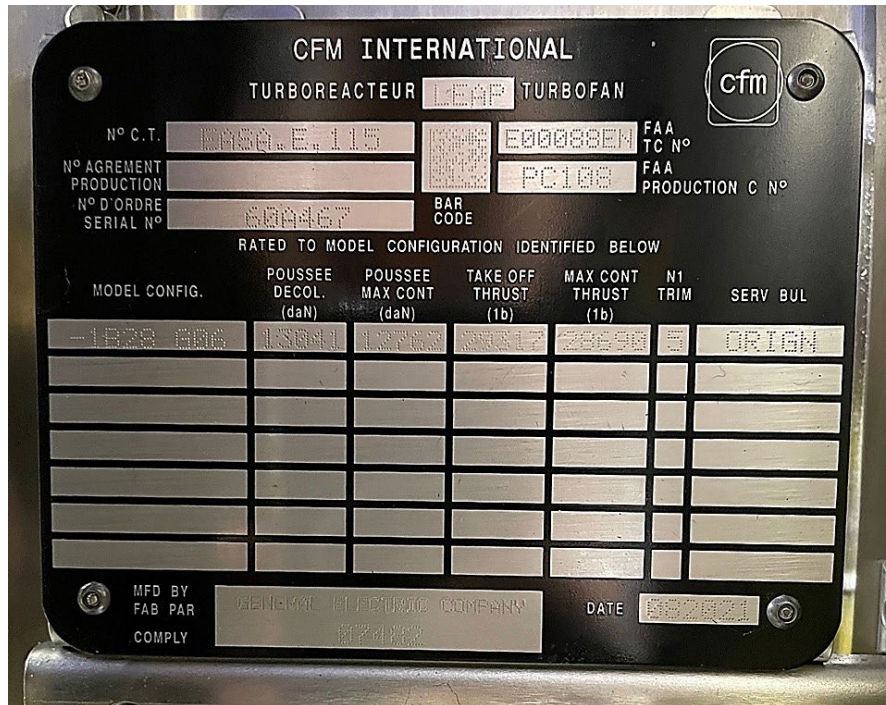


Photo 4- ESN 60A467 Data Plate

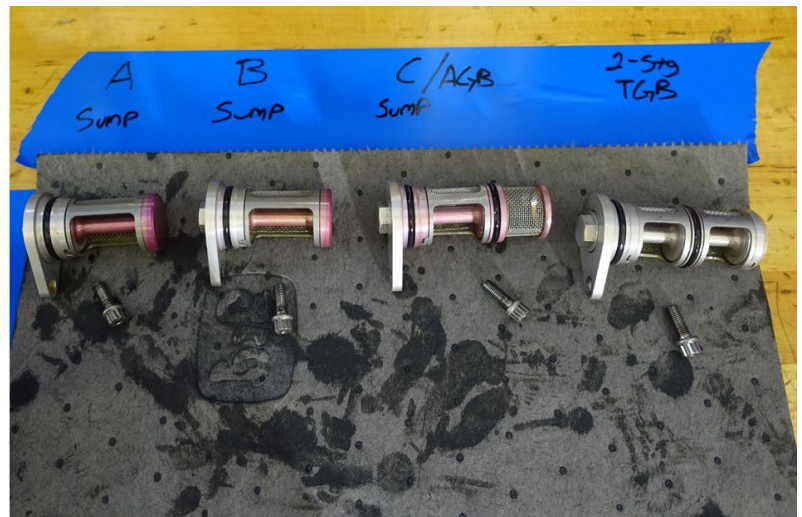


Photo 5- (L) ODMS Detector, (R) Oil Scavenge Screens

The fan blades were all intact and in good condition with minor leading edge wear consistent with similar service run engines (**Photo 6**). The fan case rub strip had light uniform tip rub that was also normal for similar engines according to CFM International.



Photo 6- Fan Blades

The left side of the engine exhibited multiple indications of undercowl fire exposure. The engine core was discolored/sooted from the 6 to 12 o'clock positions, between the HPC rear case and the aft flange of the HPT case. The discoloration was darkest from the 6 to 9 o'clock positions (**Photo 7**). Multiple wire harnesses including the exhaust gas temperature (EGT) and T3³ harnesses were charred, and the wire sleeves were partially consumed. The wire and associated p-clamp thermal damage was mostly localized at the 10 to 11 o'clock position in axial positions coincident to the HPC front and rear cases (**Photo 8**). The silicone coating on the thermal sleeve surrounding the HPT active clearance control (ACC) duct was partially consumed. The left engine core fire detector loop isolator grommets were melted and/or consumed from the 7 to 11 o'clock positions (**Photo 9**).

³ T3 is the compressor discharge temperature.
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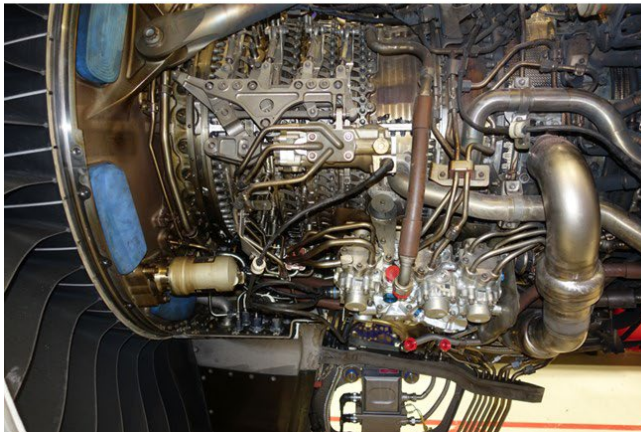


Photo 7- Left Side of Engine, Lower Core Discoloration

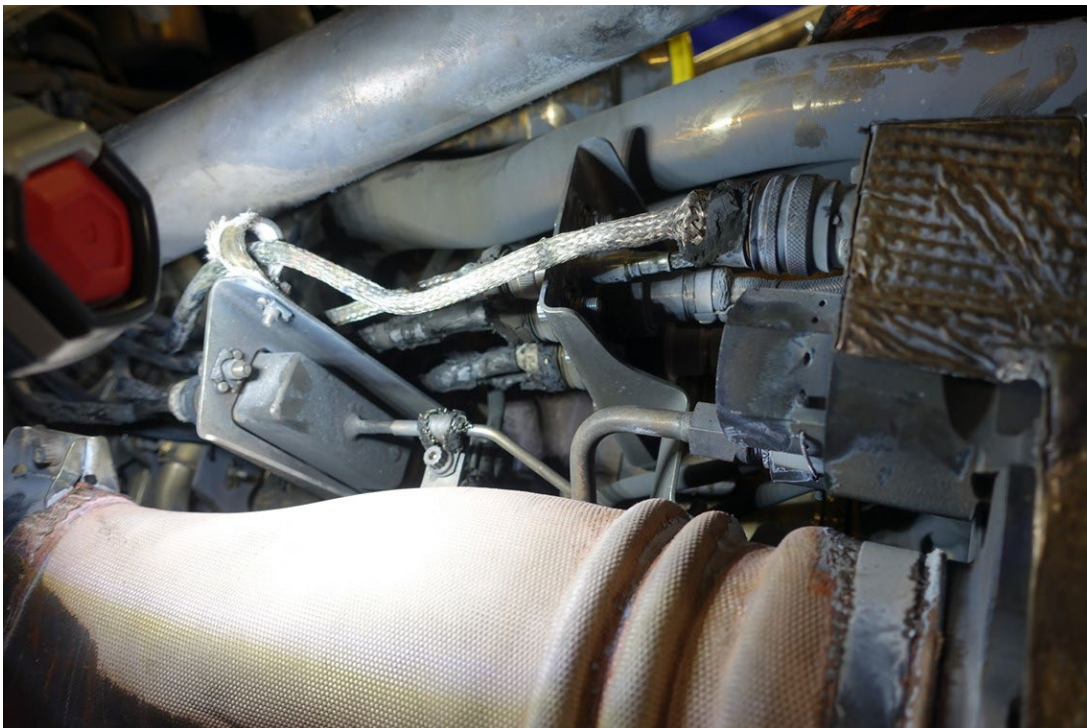


Photo 8- Thermal Damage, 10 o'clock Position

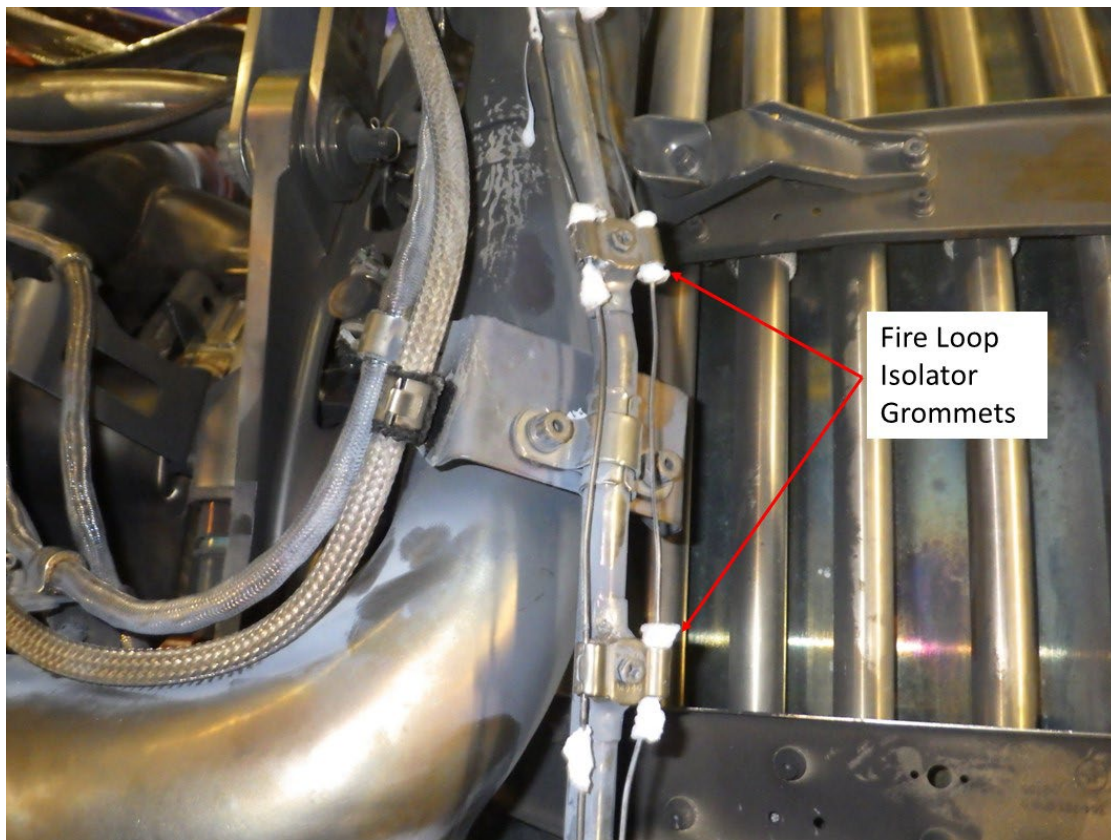


Photo 9- Left Core Fire Detection Loop, Isolator Thermal Damage

The GE-Lafayette mechanics noted that the surface inside and around the 12 o'clock fan frame strut had a bronze discoloration that appeared consistent with varnishing. The variable bleed valve (VBV) panels were removed, and the bronze discoloration extended 360 degrees around the aft side of the fan hub frame. A different LEAP-1B engine in the shop was viewed for comparison (**Photo 10**). Three pressure fuel tubes (identified in the CFM LEAP-1B illustrated parts catalog (IPC) as significant item number 3600B- fuel tube) that are routed down through the 12 o'clock strut were also discolored in areas not shielded by a metal plate bracket and the interior of the 12 o'clock strut around the fuel tube upper braze joints appeared wetted. The fuel lines were capped at the 12 o'clock position on top of the fan hub frame, the engine core connection b-nuts were disconnected, and pressurized nitrogen (45 pounds per square inch (psi)) was connected to the tube on the left side of the engine and shop air (120psi) was ported into the two tubes on the right side of the engine. There were no bubbles observed when leak detection fluid was applied to the braze joints and surrounding areas. The three fuel lines were separated as an assembly and sent for fluorescent penetrant inspection with no crack indication findings (**Photo 11**).

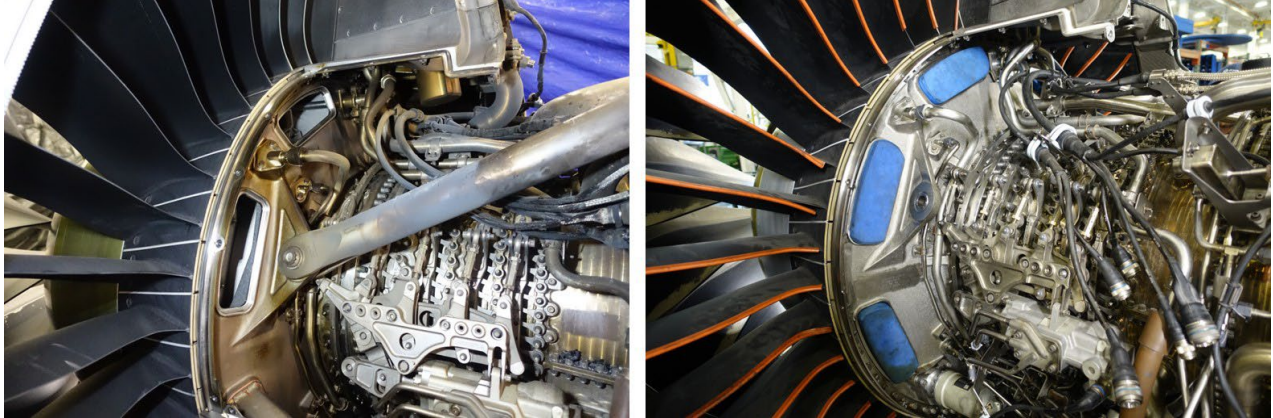


Photo 10- (L) Incident Engine Discoloration Under VBV Panels, (R) Exemplar Engine

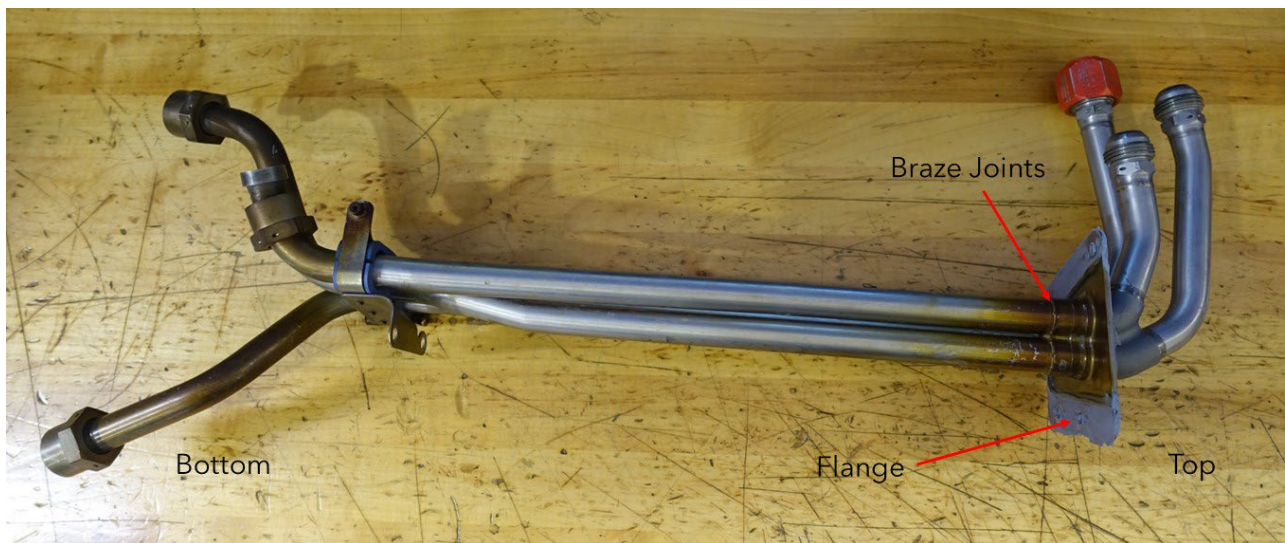


Photo 11- Fuel Tube

The right side of the engine was in good condition and there was no evidence of thermal damage observed.

2.1 Fuel Manifold Pressure Leak Check

The fuel nozzle and fuel manifold were pressure leak checked in accordance with the Boeing 737-MAX 9 AMM (73-11-05-200-801-600- Fuel Nozzle and Fuel Manifold Leak Check). Pressurized nitrogen was connected to the enriched primary fuel hose tube, fuel hose manifold, and fuel hose secondary manifold and pressurized to a regulated pressure of 40 psi. Leak detection fluid was sprayed on all nozzle and b-nut connections. Leak bubbles were visible at the b-nut connection of fuel nozzle 17 pilot secondary inlet (**Photo 12**).

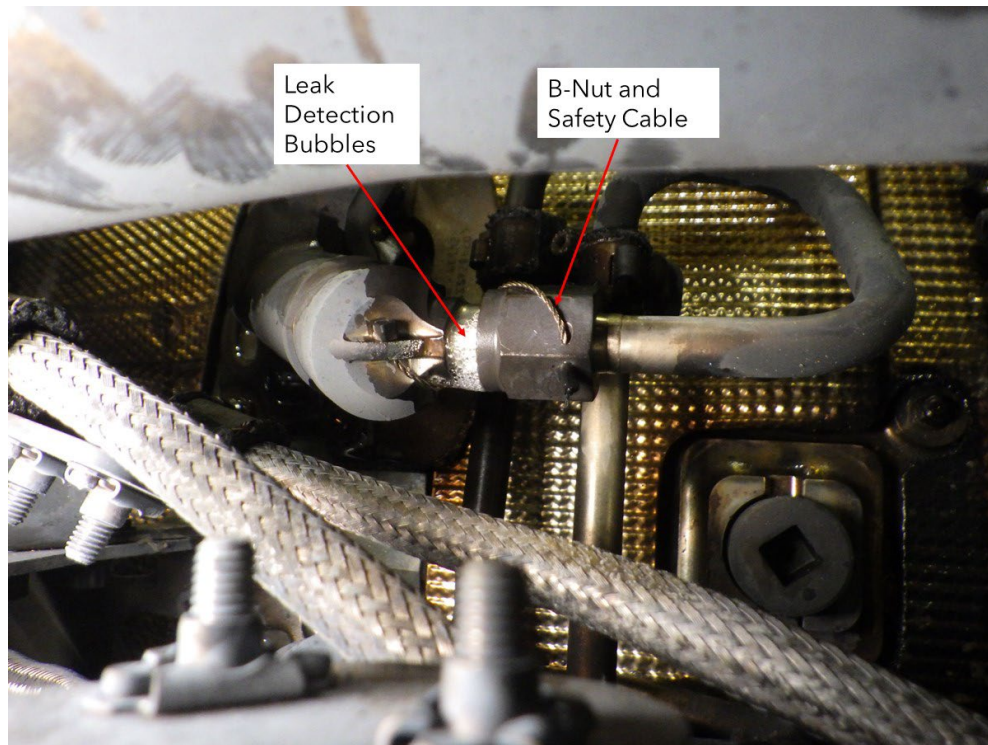


Photo 12- Fuel Nozzle 17 Leak Check

The engine externals were stripped to access the fuel nozzles. A visual inspection confirmed that the primary and secondary fuel nozzle b-nuts were all match marked with a torque stripe and safety cable installation was installed. The breakaway torque was recorded for each fuel nozzle b-nut and the nozzle was subsequently retorqued to 285 inch-pounds (in-lb) (AMM mid-range) specification and photographed. The recorded torques are available in the docket as "Powerplants Attachment #1- ESN 60A467, Fuel Nozzle B-Nut and Flange Bolt Torque Measurements. The secondary inlet b-nuts of fuel nozzles 17 and 18 both had zero torque⁴.

3.0 Materials Analysis

Four fuel nozzles (positions 4, 16, 17, 18) were shipped to the GE Aerospace Failure Analysis (FA) Laboratory in Evendale, Ohio for materials analysis (**Photo 13**). Fuel nozzles 17 and 18 were identified to have zero b-nut torque at the secondary inlet during the teardown examination while fuel nozzles 4 and 16 were found to have b-nut torque that fell within specifications. Fuel nozzle 16 was located

⁴ A Snap-On brand calibrated torque wrench with digital display was used to record breakaway torque measurements. The wrench will not detect or display torque values below 22 in-lbs. The term "zero torque" in this report is used for values below 22 in-lbs. where the mechanics stated that the b-nut backed off with no resistance.

in the fire affected area, and fuel nozzle 4 was located outside the fire affected area. A visual and binocular examination of the four fuel nozzle mating faces and threads did not reveal any mechanical deformation or indications of cross threading. Rubber castings of the secondary manifold ferrules were made for each of the four fuel nozzles. The sealing surfaces of the four ferrules appeared slightly concave, consistent with plastic deformation from installation against the fuel nozzle bullnoses. Coking was observed around the mating surface of fuel nozzles 17 and 18 but was not present on nozzles 4 or 16 (**Photos 14 and 15**). The analysis concluded that there was insufficient evidence to determine how long a fuel leak may have occurred from the fuel nozzles 17 and 18 secondary inlet.



Photo 13- Fuel Nozzles 4, 16, 17, and 18 as Received at the GE Aerospace FA Laboratory

(Source- CFM International)



Photo 14- Fuel Nozzles 4, 16, 17, and 18 Primary and Secondary Inlet Threads

(Source- CFM International)

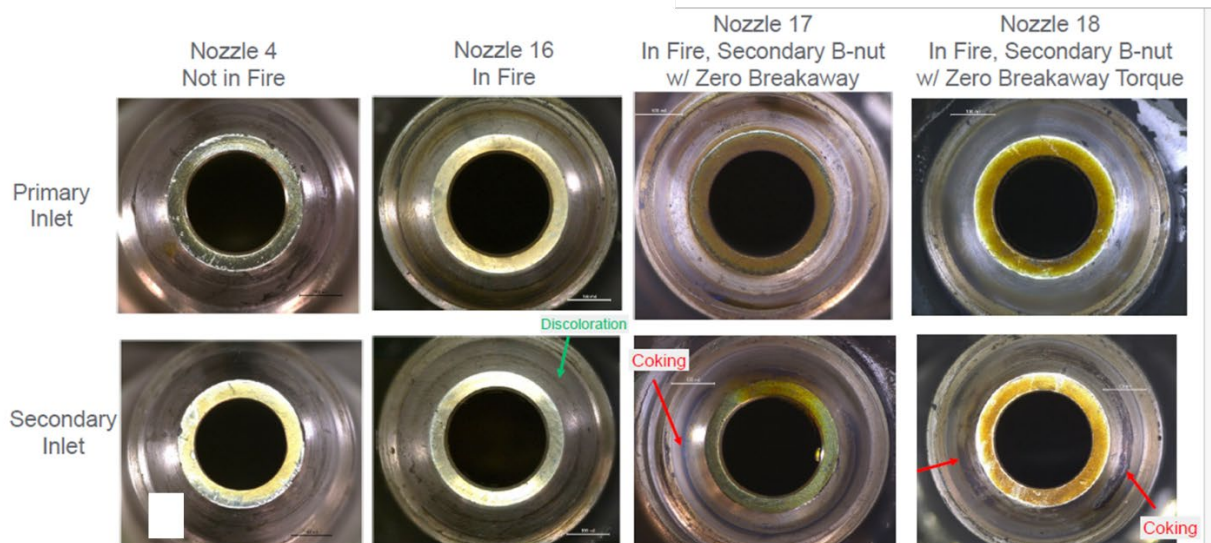


Photo 15- Fuel Nozzles 4, 16, 17, and 18 Mating Surface

(Source- CFM International)

The 12 o'clock fan frame bifurcation heat shield was shipped to the GE Aerospace FA Laboratory to perform a chemical analysis of the discolored varnish like layer observed during teardown on the heat shield and surrounding components. Fourier Transform Infrared Spectroscopy (FTIR) of the surface varnish determined it was a 40% match for coking but did not match to other signatures in the GE Aerospace FA library. The GE Aerospace Failure Analysis report is available in

the investigation docket as "Metallurgical Evaluation of LEAP-1B Fuel Nozzles, Fuel Manifold, and Fireproof Plate."

4.0 CFM LEAP Fuel Nozzle Coking Summary and Event History

CFM LEAP series engine fuel nozzle coking has driven early and repetitive fuel nozzle replacements throughout the fleet. Elevated temperatures in the engine hot section following shutdown, also known as thermal soak back, can heat residual fuel in the fuel nozzles to create coking. Excessive fuel nozzle coking can result in engine start issues, decreased performance, and premature engine wear including loss of thrust and in-flight shutdown. In certain cases, excessive fuel nozzle coking can also result in increased fuel flow through certain fuel nozzles leading to distress of the HPT static structures. Currently, operators need to monitor for fuel nozzle coking and must replace fuel nozzles when coking accumulation reaches unacceptable levels. Coking related issues are generally identified through on-board monitoring systems and/or through CFM Customer Notification Reports (CNR).

The FAA published Airworthiness Directive (AD) 2020-06-01, effective April 16, 2020, to address the unsafe condition due to fuel nozzle coking. The AD requires a revision the Airworthiness Limitations Section (ALS) to perform either fuel nozzle condition monitoring every 125 flight cycles (FC) or repetitive borescope inspections of the HPT for signs of fuel nozzle streaking distress every 600 FC.

According to UAL, they have completed 443 fuel nozzle set replacements on their CFM LEAP fleet as of October 2024. The replacements are primarily performed at UAL engine maintenance shops at CLE and Tampa International Airport (TPA), Tampa, Florida.

5.0 Corrective Actions

5.1 United Airlines

UAL revised their AMM fuel nozzle set replacement procedures following the incident to incorporate additional steps and checks to verify proper installation. The revised procedure requires additional external hardware to be removed from the engine to ensure better access to the fuel nozzles and reduce the likelihood of false torque indications. A pressurized nitrogen leak check of the fuel manifold is performed after the fuel nozzles are torqued, prior to external hardware installation. Leak detection fluid is applied to all fuel nozzle connections and each nozzle is visually inspected for leak indications. After the fuel nozzle set replacement

is complete, an engine wet motor⁵ is performed with the cowl doors open to visually inspect for fuel leaks. During the wet motor, the fuel boost pumps are turned on, the fuel spar valve is opened, and the engine starter is engaged without engine ignition. A part-power leak check⁶ is then performed where the engine is started and accelerated to approximately 70% N1 to increase fuel pressure above idle speed and actuate fuel system components that are only active above idle conditions. The part-power leak check is performed with the cowl doors closed. The cowl doors are subsequently open to visually inspect for leaks after engine shutdown.

UAL also procured and recommend the use of digital torque wrenches like what was used during the incident engine teardown to aid mechanics.

5.2 CFM International

In the 1st quarter of 2021, CFM International provided input to update the Boeing 737 MAX AMM to address potential maintenance errors related to fuel nozzle replacement. The changes include incorporation of the triple torque process which instructs mechanics to torque hardware to specified values, untorque the hardware, torque the hardware again, and then confirm torque a third time. A video of the LEAP triple torque process, "LEAP- B-Nut Torque Best Practices- GE Aerospace" was also uploaded to YouTube in November 2022⁷. Additional AMM changes included a documentation table of torque values, instructions to apply a torque stripe/match mark of the b-nut before the final of torque check, and independent inspection of each b-nut torque following installation.

CFM International introduced a Reverse Bleed System (RBS) to the LEAP-1A⁸ fleet in the 2nd quarter of 2024 to reduce fuel nozzle coking by managing the fuel nozzle thermal environment following engine shutdown, resulting in fewer fuel nozzle replacements. The RBS is activated when the Aircraft Display Processing Computer (DPC) and EEC recognize engine shutdown. The RBS features a blower that pulls air from undercowl and ducts it into the hot section through a reverse bleed valve (**Figure 3**). The RBS runs until the next engine start or a maximum of 60 minutes. The RBS hardware is permanently installed on the engine. CFM International plans to introduce the RBS to the LEAP-1B fleet in 2025.

⁵ The wet motor leak check procedure is performed in accordance with AMM tasks 71-00-00-790-803-G00, Test No. 3- Wet Motor Leak Test and 71-00-00-910-800-G00, Wet Motor Procedure.

⁶ The part-power leak check procedure is performed in accordance with AMM task 71-00-00-710-801-G00, Test No. 5- Part Power Leak Check.

⁷ LEAP- N-Nut Torque Best Practices- GE Aerospace,
<https://www.youtube.com/watch?v=p2ihtdSwRMY>

⁸ The LEAP-1A model variant is installed on the Airbus A320neo family of engines.

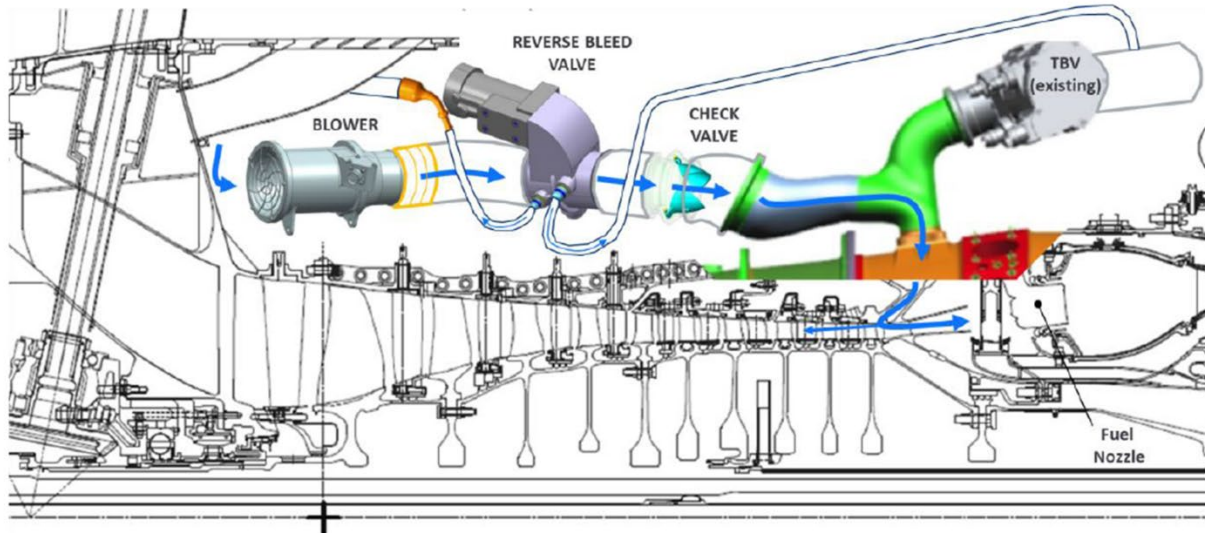


Figure 3- CFM LEAP-1A Reverse Bleed System

(Source- CFM International)

The CFM International best practice guide, including b-nut related tasks were reviewed and updated. The revised guide was released in January 2024.

Boeing 737 MAX AMM updates are planned for the 4th Quarter of 2024 to incorporate UAL's post fuel nozzle replacement idle run leak check as an optional task. The AMM change will also include clarified wording to triple torque the fuel nozzle B-nuts one fuel nozzle at a time.

Submitted by:

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