

**NATIONAL TRANSPORTATION SAFETY BOARD
OFFICE OF AVIATION SAFETY
WASHINGTON, D.C. 20594**

March 17, 2021

**POWERPLANT GROUP CHAIRMAN'S FACTUAL REPORT
NTSB ID: DCA17LA182**

A. ACCIDENT:

Location: Denver, Colorado
Date: July 2, 2017
Time: 1319 local
Aircraft: CL-0600-2C10 (Regional Jet Series 701), N796SK, S/N 10300

B. POWERPLANTS GROUP:

Group Chairman: Carol M. Horgan
National Transportation Safety Board
Washington DC

Member: Michael Richardson-Bach
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Burlington, Massachusetts

Member: Maurice Montgomery
SkyWest Airlines
Saint George, Utah

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Member: Jeremy Katt
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¹ Bombardier is now Mitsubishi Heavy Industries Regional Jet.

C. ACCIDENT

On July 2, 2017 at 1319 (local) SkyWest Airlines CL-0600-2C10 (Canadair Regional Jet (CRJ) 700), N79SK, powered by two GE CF34-8C5B1 (8C) turbofan engines, experienced a left engine undercowl fire following landing at Denver International Airport, Denver, Colorado (DEN). The airplane was operating as a Title 14 Code of Federal Regulations Part 121 scheduled flight from Aspen/Pitkin County Airport (ASE) to DEN. The flight had landed and the thrust reversers were stowing as the airplane exited Runway 34R when the flight crew observed a L ENG SRG OPEN Caution. The crew reduced engine power to idle and continued to taxi. A L ENG FIRE warning appeared 75 seconds later. Discharge of both left nacelle fire extinguishing bottles did not extinguish the fire. The odor but not the presence of smoke in the cabin was reported. The flight crew stopped the aircraft and shut down the engine. Fire was observed inside the left inlet cowl, at the left pylon, and at a pool of fuel on the ground beneath the airplane. The passengers were evacuated to the taxiway through the main cabin door. There were no injuries. See Figure 1.



Figure 1. Left engine undercowl fire during passenger egress, two views

D. PRECURSORS

There were five previous CF34-8C OBV fuel fitting pullout events, three resulting in undercowl fire. The first three occurred prior to 2014 and involved Honeywell part number (P/N) 4121T67P03 OBVs. Around 2006, Honeywell had noted an increase in loose fitting findings during as-received evaluations of OBVs returned to their repair shops. Honeywell began replacing the upper housings with new whenever they found this condition. Over a five-month period beginning in August 2011, three CRJ 700 airplanes experienced Honeywell OBV supply fitting pullouts, two resulting in undercowl fire, one of these during flight. Manufacture and installation procedure improvements were identified, but there was concern that even with these improvements the OBV supply fitting joint lacked sufficient load-carrying margin for an on-condition valve. GE issued CF34-8C Service Bulletin (SB) 75-0012 (SB 8C 75-0012) and CF34-

8E SB 75-0017 (SB 8E 75-0017)² which directed the replacement of P/N 4121T67P03 OBVs with OBVs manufactured by Parker Aerospace. Federal Aviation Administration (FAA) Airworthiness Directive (AD) 2013-06-06 effective May 8, 2013 mandated SB compliance.

Both the Honeywell and the Parker OBV designs specify Rosán-type (rosan)³ expander fittings with 9/16-inch diameter tube ends. However, the port end of the Honeywell OBV supply fitting, an -04 to -05 expander, was two diameters smaller than the tube end, while the port end of the Parker supply fitting, an -05 to -06 expander, is one diameter smaller than the tube end. See Table 1.

BORE	EXPANDER FITTING	
	Honeywell	Parker
supply	RFG9804-06-19 (0.3125-inch at bore)	RFG9805-06-19 (0.375-inch at bore)
return	RFG9805-06-19	RFG9805-06-19
drain	RFG9804-06-19	RFG9804-06-19

Table 1. Honeywell vs. Parker OBV expander fitting comparison

On March 20, 2014, a return fitting pulled out of a Parker OBV installed on a CF34-8E engine installed on a Republic Airlines Embraer E170. GE's investigation determined that the joint failed due to a maintenance-related over torque. This analysis was reexamined in light of subsequent events, and the calculated over-torque was determined insufficient to have caused the joint failure.

On January 16, 2017, Mesa Airlines CRJ 700, N515MJ, experienced a Parker OBV return fitting pullout and in-flight fire during approach to Nashville International Airport (BNA).⁴ The flight crew noticed that the right engine was consuming more fuel than the left and that auto transfer was ON. The R ENG FIRE message appeared. The crew discharged both right nacelle fire bottles and shut down the right engine, but the R ENG FIRE indication persisted. An emergency was declared and a single engine landing was performed without incident. ARFF met the airplane and extinguished the fire. Passengers and crew evacuated to the runway through the main cabin door. There were no injuries. Post-incident inspection found two ECS links with advanced wear. Metallurgical examination of the OBV found severe port thread wear. The links removed from this engine were used to conduct a modal impact test. OBV frequency response was measured before and after the worn links were installed on a test engine. Installation of the worn links shifted the natural (resonance) OBV frequency of vibration into the engine operating frequency range.

E. DETAILS OF THE INVESTIGATION

1.0 System descriptions

1.1 Engine

² The CF34-8E engine, which powers the Embraer E170/E175, uses the same OBV as the CF34-8C.

³ Rosán was the Alcoa trade name for the two-piece, ring-lock type fluid fitting, now the property of Shur-lok.

⁴ NTSB Case No. ENG17IA011.

The CF34-8C5B1 is a dual rotor, axial flow, high bypass ratio turbofan engine featuring a single-stage fan, ten-stage axial compressor, annular combustion chamber, two-stage high pressure turbine, four-stage low pressure turbine and a full authority digital engine control (FADEC). The CF34-8C5B1 is takeoff rated at 13,790 lbs. thrust.

1.1.1 OBV

The Parker P/N 4123T71P04 OBV is a fuel-actuated, electrically-controlled butterfly valve that increases engine operability margin by unloading the high pressure compressor during engine starts and at higher power settings. The valve opens to bleed stage 10 compressor air into the fan bypass air stream. Three rosan expander fittings are installed in the OBV upper housing (housing cap). Fuel from the engine high pressure pump is routed to the supply port and returned to the pump inlet through a return port.⁵ See Figures 2 and 3.

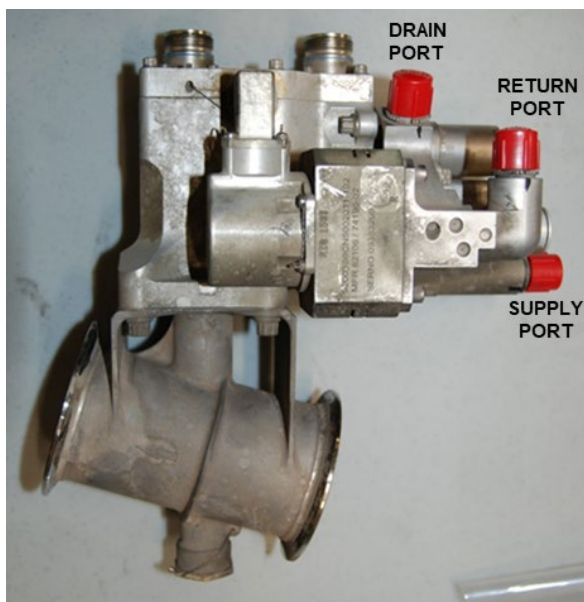


Figure 2. Parker OBV P/N 4123T71P04



Figure 3. P04 housing cap

The P04 OBV housing cap material is 6061T6 aluminum and the fittings are A286 corrosion-resistant steel. Both the supply and the return fittings are rosan -05 to -06 expander-type fittings, having 9/16-inch diameter tube ends with a 270-300 lb-in installation torque range and 3/8-inch diameter port ends with a 100-120 lb-in installation torque range. See Figure 4.

⁵ The drain fitting sees low volume/low pressure fuel. Fuel pressure at the supply fitting is 900 psi.

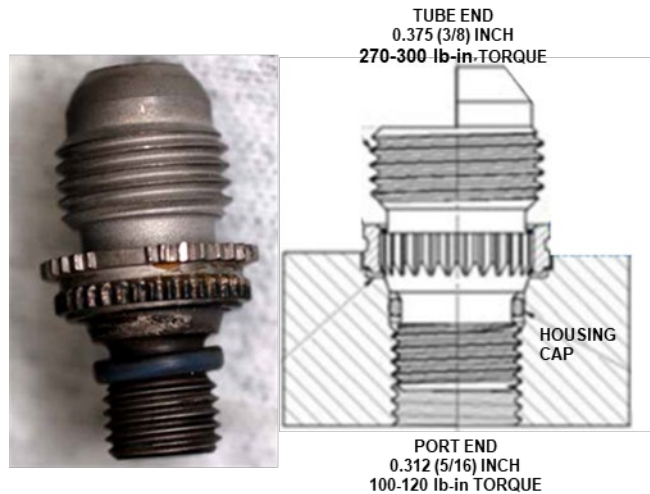


Figure 4. Parker OBV supply rosan (expander) fitting. Fitting threads engage the aluminum housing to develop a preload between the threads and the conical seat

1.2 OBV installation

The CF34-8C OBV is clamped between the 10th stage duct and the 10th stage bleed air manifold at 12 o'clock ⁶ and is not directly attached to the engine. It is part of the engine ECS and extends away from the engine core to mate with an air exhaust port in the forward upper core cowl. The assembly is stabilized by four adjustable link rod assemblies (ECS links). The ECS links are installed between the S10 duct and manifold and the engine combustion chamber frame flanges. See Figure 5.

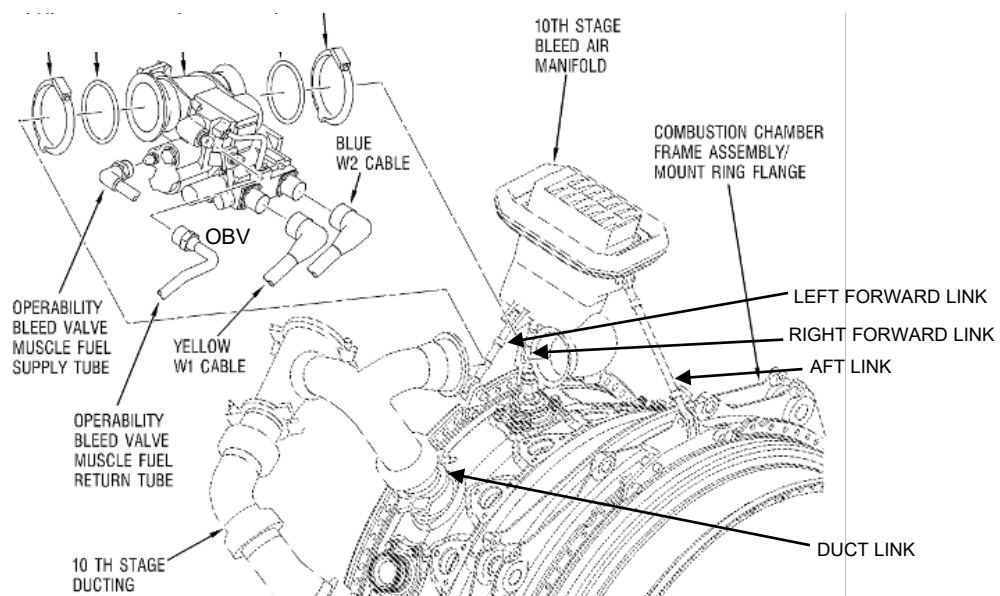


Figure 5. CF34-8C ECS showing OBV installation

⁶ O'clock refers to approximate circumferential locations in a clockwise direction as viewed from the rear of the engine looking forward.

1.3 Engine core compartment

The engine core is enclosed by the forward core cowls (core compartment). See Figure 6. The core compartment is a designated fire zone. High rates of ventilation through the core compartment cool the engine and remove flammable fluids and gases to prevent hot surface ignition due to contact with hot engine surfaces. Core compartment drainage is assisted by gravity drains as ventilation rates decrease.

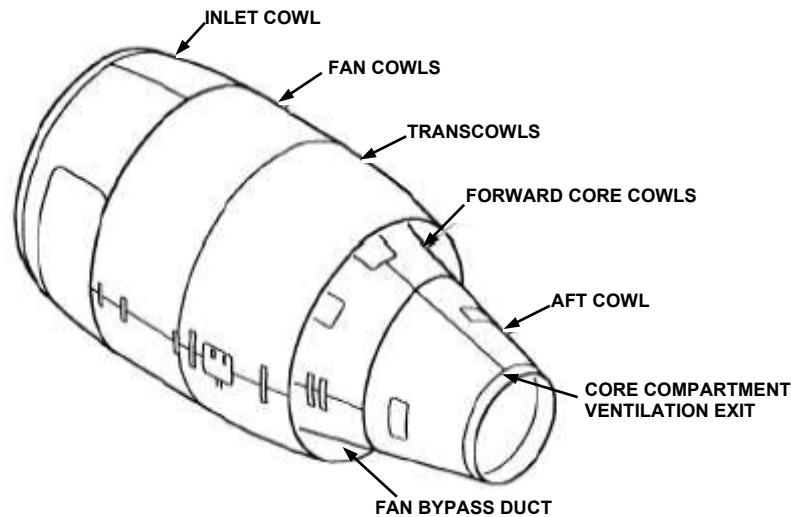


Figure 6. CRJ 700 nacelle, showing the engine forward core cowls, which enclose the engine core section (core compartment)

1.3.1 Core compartment gravity drainage

Fluids not removed by the ventilation airflow collect at the bottom of the core compartment and drain into the fan bypass duct (fan duct) through three 0.25-inch diameter holes, two located in the drain panel near the bottom of the lower forward core cowl and the third hole at the auxiliary cooling inlet panel in the lower forward core cowl. Drained fluids are removed from the fan duct with the fan discharge airstream. With the engine shut down, any fuel draining from the core compartment is no longer removed by fan exhaust and will accumulate in the fan duct. This fuel is routed overboard through two transcowl fluid drains.

Four 0.625-inch diameter vent openings to the fan duct are located in the auxiliary cooling inlet panel. The forward lower core cowl includes a pressure relief door (PRD). See Figure 7.

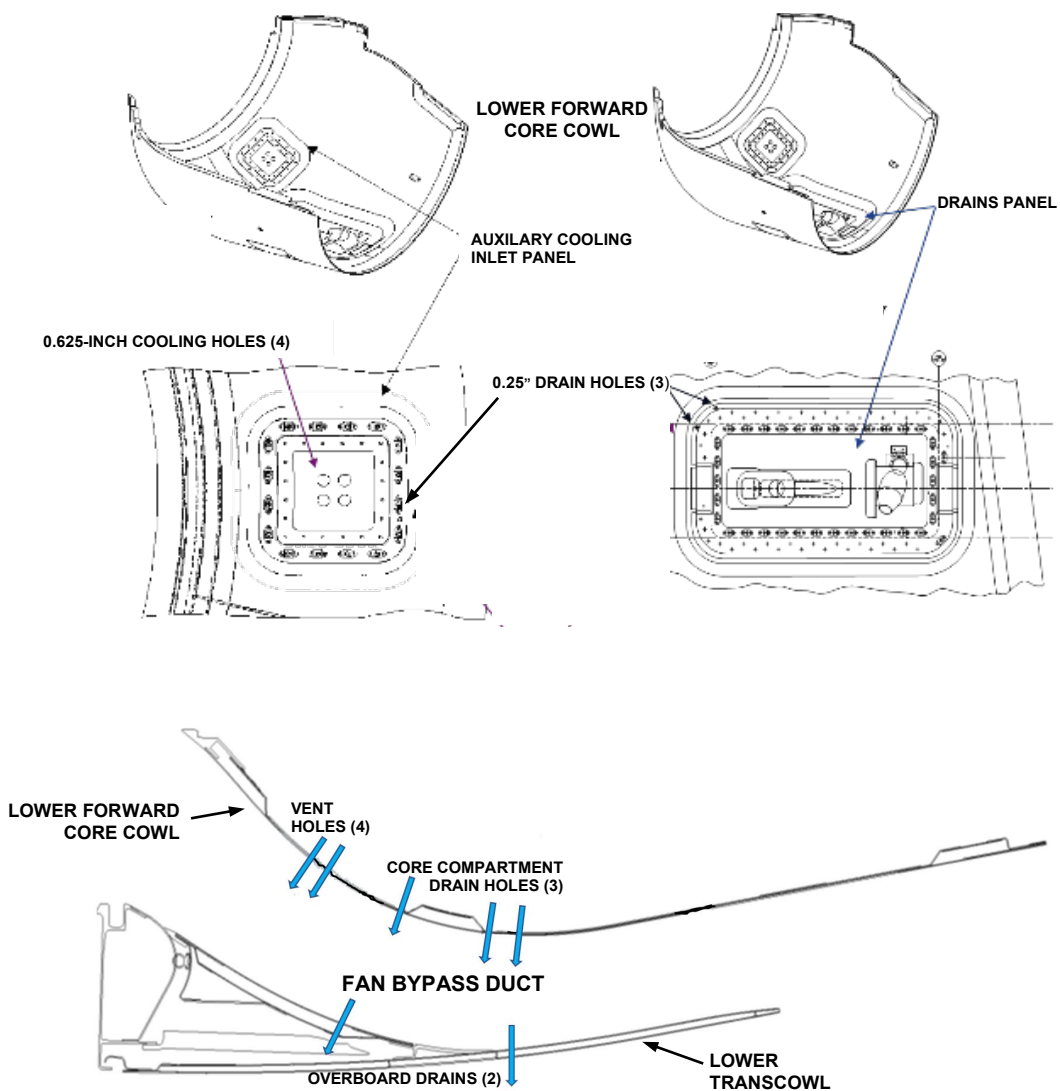


Figure 7. Engine fire zone drainage

The core cowl pressure relief door is designed to open to relieve excess pressure from the core zone in the event of a large air leak from an open bleed air duct or casing hole.

2.0 Engine service history

Review of the operator maintenance records found that both engines were original to the airplane and had never been removed. See Table 2.

Engine position	engine S/N	time since new (hours)	cycles since new	time since last shop visit	cycles since last shop visit
LEFT	194933	22,419	13,157	NA	NA
RIGHT	194932	22,419	13,157	NA	NA

Table 2. Engine data

The maintenance records showed that both OBVs were original equipment and had remained installed since new. See Table 3.

OBV position	OBV S/N	time since new (hours)	cycles since new	time since last shop visit	cycles since last shop visit
LEFT	PFBATJ32	22,419	13,157	NA	NA
RIGHT	PFBATM06	22,419	13,157	NA	NA

Table 3. OBV installation/removal data

A left engine A-check entry indicated that two broken OBV drain tube clamps were replaced on May 19, 2017.

3.0 On site investigation

The Powerplants Group documented the airplane at DEN July 3-7, 2017.

3.1 Airplane fire damage

The left engine nacelle, left engine pylon, local areas of the fuselage and the APU access door were fire damaged. The underside of the left pylon was heat discolored and the paint was blistered and peeling. The pylon surface was severely damaged along the trailing edge and at the outboard edge near the fan discharge. See Figures 8 and 12.

Later maintenance inspection of the pylon determined that the fire caused structural damage to the pylon, requiring major repair or replacement (substantial damage). This resulted in the event being re-classified as an accident.



Figure 8. Thermal damage to left side of the airplane

3.1.1 Inlet cowl

The inlet cowl outer barrel leading edge was heat distressed. The inner barrel surface was heat-deformed between 6 and 1 o'clock. The acoustic liners in this area were buckled between 7 and 11 o'clock and there was a 7-inch crack at 9 o'clock. See Figure 9. The back of the FADEC compartment, which is axially in line with the inner barrel fire damage, was discolored and buckled. See Figure 10.



Figure 9. Inlet cowl inner barrel thermal damage Figure 10. FADEC compartment heat distress

3.1.2 Fan cowl

No damage was noted to the upper fan cowl and the upper translating cowl doors (transcowls). The lower fan cowl outer surface was streaked with fire extinguishing residue and soot. See Figure 11.

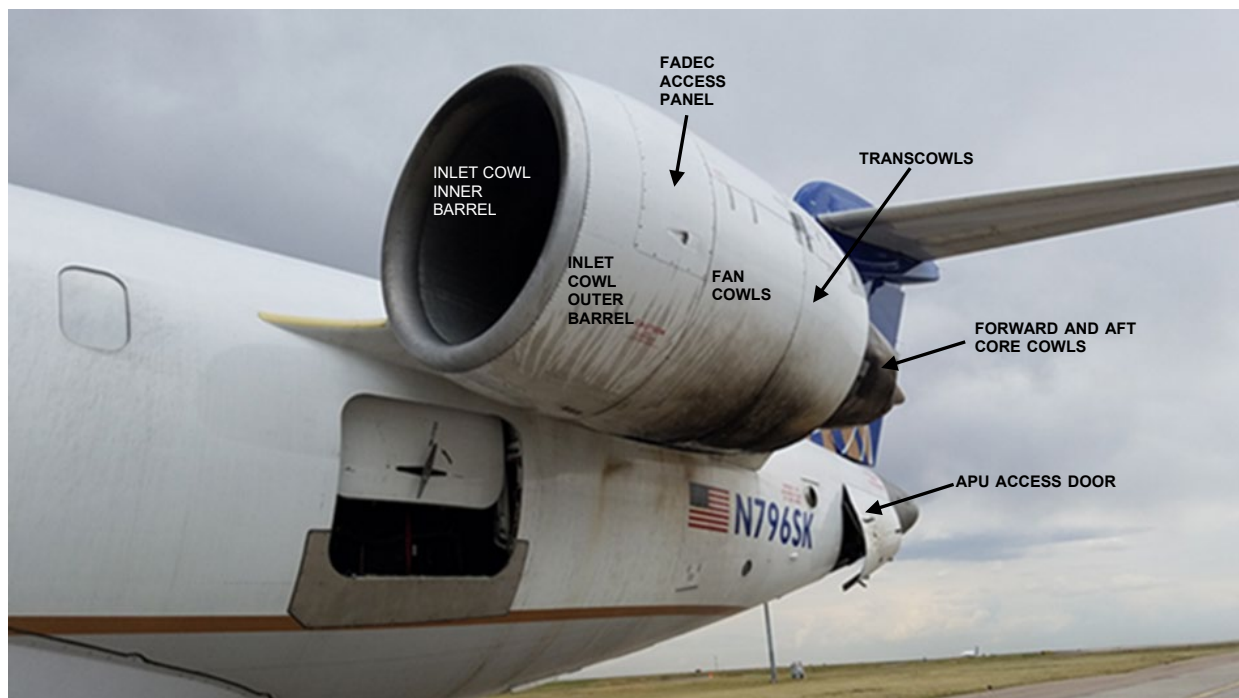


Figure 11. Left nacelle showing thermal damage

3.1.3 Transcowl

The lower transcowl surface was coated with soot between 3 and 9 o'clock except for a small area at 6 o'clock near cowl drain holes. See Figure 12. The reverser was manually deployed with the cowl open to expose the thrust reverser components for inspection. No cascade or translating cowl thermal damage was found.

3.1.4 Core cowl

The upper forward core cowl was undamaged. The lower forward core cowl outer surface was blackened with soot. The PRD was open.⁷ The PRD was covered with soot and a soot trail extended aft. No damage was noted to the engine externals visible through the PRD opening. The aft core cowl was heavily sooted between 3 and 9 o'clock and deformed at 5 o'clock. The primary exhaust (conic) nozzle was inwardly deformed between 7 and 8 o'clock.⁸ See Figure 12.

⁷ The PRD door appeared closed when the emergency vehicles approached the airplane, as observed in an ARFF Go-Pro video.

⁸ It was determined that the aft core cowl and primary exhaust conic nozzle was deformed during the fire mitigation when high pressure spray struck the hot components.

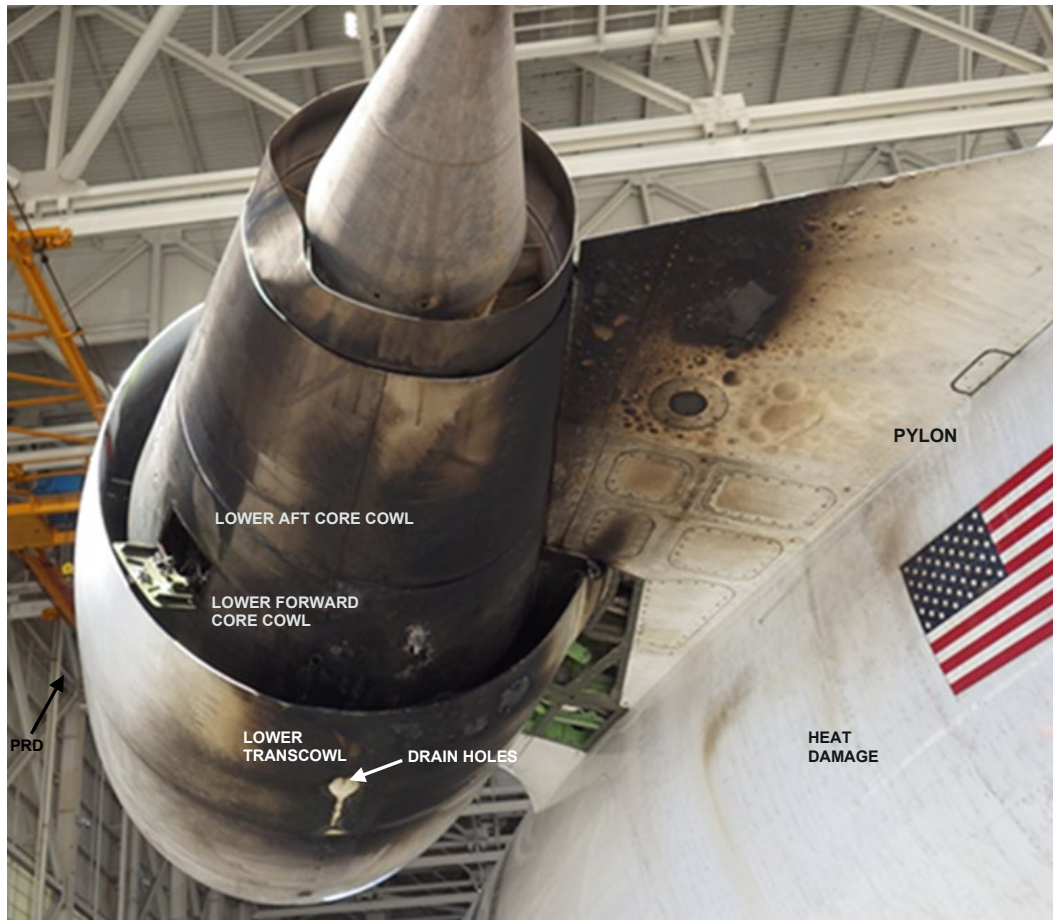


Figure 12. Left nacelle and pylon damage

The core cowl inside surfaces were locally sooted. The lower forward core cowl inside surface exhibited carbon residue near the nacelle drain at 6 o'clock. There was a circular discoloration pattern in this area that encompassed portions of the nacelle drain and gang drain mast, and axial deformation along the 5 o'clock plane. See Figure 13.

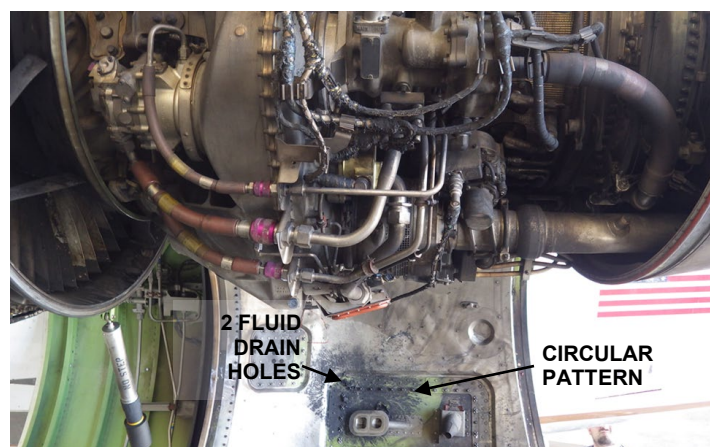


Figure 13. Lower forward core cowl inside surface

Inspection of the forward and aft engine fire zone seals found them in good condition with no evidence of functional failure. See Figure 14.



Figure 14. Open cowling doors and view of pylon damage

An area of intense thermal damage was observed on the lower forward core cowl and lower transcowl between 5 and 6 o'clock, with exposed honeycomb structure at 6 o'clock. The cowling was not penetrated beneath this damage. See Figures 15 and 16.



Fig 15. Lower transcowl and core cowl thermal distress



Fig 16. Exposed honeycomb structure in the lower forward core cowl

Pressure and borescope checks of the fire extinguishing nozzles and lines found no discrepancies. The engine detection loop isolators appeared in serviceable condition.

3.2 Engine assessment

There were no indications of internal engine failure. The low-pressure turbine rotated freely when the fan was turned. Borescope inspections of the high-pressure compressor and high-pressure turbine found no anomalies.

3.2.1 Fan section

The fan blades were locally discolored. The fan blade rub strip was thermally damaged between 4 and 8 o'clock. See Figure 17. The fan frame struts, and the fan outlet guide vane (OGV) surfaces were coated with soot and discolored. The OGVs between 4 and 6 o'clock were fire-damaged (oxidized). See Figure 18.



Figure 17. Fan blade and blade path thermal damage



Figure 18. Fan OGV thermal damage

3.2.3 Core engine

The external engine components between 7 and 5 o'clock were coated with soot. See Figure 19.



Figure 19. Engine core externals

Some of the wiring harness overbraid was consumed and fluid tube fire sleeves displayed areas of white discoloration consistent with exposure to excessive temperature. See Figure 20.



Figure 20. Exemplar engine externals fire damage

3.2.1 OBV fitting pullout

The OBV supply port fitting was found pulled out of the housing. See Figures 21 and 22. Worn threads were observed in the housing supply port bore. The fitting O-ring was blackened and appeared intact. The fuel supply tube was securely attached to the fitting.



Figure 21. Fitting pullout

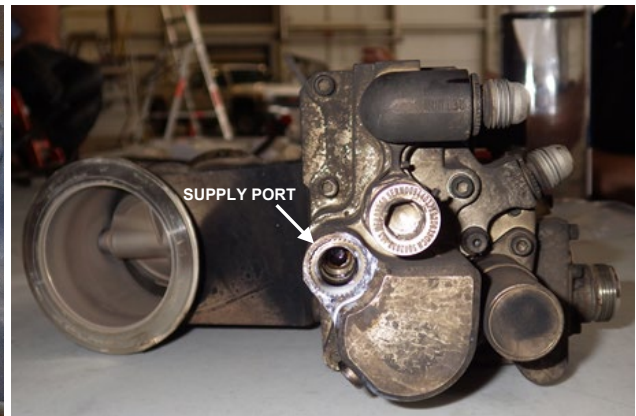


Fig 22. Failure OBV following removal from airplane

An alignment fixture was installed for a partial S10 bleed air manifold installation alignment check.⁹ The alignment was within CRJ 700/900/1000 Airplane Maintenance Manual (CRJ AMM) limits. The OBV return and drain fuel tube B-nuts torque measurements, 20 lb-ft and 22 lb-ft respectively, were slightly below the CF34-8C Line Maintenance Manual (LMM) range (23-25 lb-ft).

The left and right forward ECS links were found loose and heavily worn at their manifold attachment rod ends. See Figures 23 and 24.



Figure 23. Forward left link. The backed-off nut was not as found



Figure 24. Right forward link

⁹ Alignment fixture tool P/N 2C81058G01 is used to position the OBV manifold when it is installed between the OBV and the cowling vent. The measurement was taken after the core cowl was removed.

The aft ECS link showed no obvious wear.

3.3 Right engine OBV and installation

It was decided to inspect the condition of the right engine OBV and installation, given its near identical service history. The alignment fixture was installed prior to opening the cowling to check ECS manifold alignment with the core cowl exhaust port. The alignment was within CRJ AMM limits. A general visual inspection of the ECS manifold and duct found no discrepancies. The OBV appeared in good condition. There was no evidence of fuel leakage, or obvious damage to the ECS links or link support brackets. The OBV supply tube B-nut torque value was within range. The return tube B-nut (21 lb-ft) and drain tube B-nut (17 lb-ft) torque values were below the installation torque range.

3.4 Parts retained

The OBVs, ECS links, left engine ECS manifold assembly, and tubes and hardware of interest were retained for further investigation.

3.5 Recorded data

Flight data recorder (FDR) and FADEC non-volatile memory data showed no indication of abnormal engine operation prior to or in response to the fitting pullout.

3.5.1 Fire timeline

The CRJ 700 nacelle drain capability is approximately 1.5 gallons per minute (GPM) with the engine at ground idle and the PRD closed with assumed undercowl pressure of 0.12 psig and 1.0-inch fluid height.

The OBV supply and return fittings are part of a high-pressure valve actuation circuit. The data review found that approximately 34 gallons of fuel were released into the engine core compartment/fire zone over a 126-second period (fitting pullout to firewall shutoff valve closure) at about 16.2 GPM. Table 4 shows the estimated fuel accumulation in the fire zone as the event progressed.

UTC	Time (T) (seconds)	event	Approximate fuel accumulation (gallons)
20:15:56	T = -33	Touchdown	
20:16:02	T = -27	T/R deploy	
20:16:26	T = -03	T/R in transition to stowed	
20:16:29	T = 0	FITTING PULLOUT, FMU starved, FLAMEOUT	
20:16:30	T = +1	FADEC commands OBV to open FADEC opens FMV to arrest deceleration	0.5
20:16:31	T = +2	T/R fully stowed Both engines commanded to GI OBV does not respond to FADEC command to open FADEC sets OBV SRG CLOSED fault Master CAUTION/ OBV SRG CLOSED message engine relights and accelerates to GI	19.5
20:16:39	T = +10	Master Caution OFF	
20:17:44	T = +75	Left engine FIRE WARNING / Master Warning	
20:18:19	T = +111	Left engine shut down	2.0
20:18:35	T = +126	Left engine fuel firewall SOV closed	
20:18:41	T = +132	Left engine 0 N1	12.0
20:20:02	T = +213	Left engine 0 N2	(TOTAL 34.0)

Table 4. GE fire timeline from FDR, FADEC, and DEN recorded data, ARFF Go-Pro video, and physical evidence, showing sequence of events and estimated fuel leakage against elapsed time

4.0 Component examinations

Members of the Powerplants Group met in Evendale, Ohio on July 26-27, 2017, to document the condition of the accident engine ECS links, attachment hardware and fuel tubes.

4.2 ECS links

4.2.1 Left forward link



Figure 25. Left forward ECS link

The left forward link length was 4.044 inches.¹⁰ The anti-rotation tabs showed some outer surface damage but no evidence of re-bending (re-use). Both rod ends were severely worn. Hammer force and a drift were required to remove the manifold attachment hardware. See Figure 25. The forward bushing was missing material in line with the severe ECS link wear. The aft (welded) bushing was intact. See Figure 26 (a). The rod end housing was worn completely through on one side. An approximate 0.07-inch deep by 0.25-inch long divot of shank material was missing from the (0.25-inch shank diameter) bolt. See Figure 26 (b). The surface texture in the damaged areas of the rod end, bearing, and bolt shank was smooth, consistent with fretting (small displacement amplitude, lower stress) wear. See Figure 26 (c).



Figure 26. Left forward ECS link manifold-attachment hardware, showing (a) wear-through at manifold fork bushing (b) attachment bolt divot and rod end housing wear through, and (c) close up of bolt shank divot

The engine attachment rod end was twisted approximately 15° off center, out of conformance with the requirement. The external diameter of this rod end was 0.809 inch, conforming with the engineering drawing. The entire rod end inner diameter (ID) surface was severely worn and was no longer spherical; profiles were deeply worn into the surface consistent with the uniball bearing dwelling in multiple orientations. The uniball bearing was distorted consistent with having dwelled in various locations. The ball diameter, 0.562 inch, conformed with the engineering drawing.

4.2.2 Right forward ECS link

The forward ECS link length was 4.121 inches. The anti-rotation tabs showed no evidence of re-bending. The nut on the bolt attaching the right forward ECS link at the manifold fork was seized and was freed using lubricant. The forward bushing could be rotated forward and aft. The (welded) aft bushing showed no appreciable wear. General visual inspection of the bolt and nut loading surfaces found no significant wear. The external diameter of the manifold attachment rod end was 0.809 inch, conforming with the engineering drawing. The entire rod end ball ID surface was worn. The entire uniball bearing surface was worn. The ball diameter, 0.562 inch, conformed with the engineering drawing.

¹⁰ The links were measured between estimated bearing centerlines. The drawing requirement for forward links is 3.98 +/- 0.02 inches. The drawing requirement for the aft link is 6.16 +/- 0.02 inches. Adjustments to link length are permitted at installation.

The external diameter of the engine-attached rod end was 0.809 inch, conforming with the engineering drawing. The entire rod end ID surface was worn and the two flat surface features were worn away. A region of 'tiger stripes' was noted. The entire surface of the uniball bearing was worn and showed an area of tiger striping consistent with the marks found on the rod end ID. The ball diameter, 0.562 inch, conformed with the engineering drawing. See Figure 28.

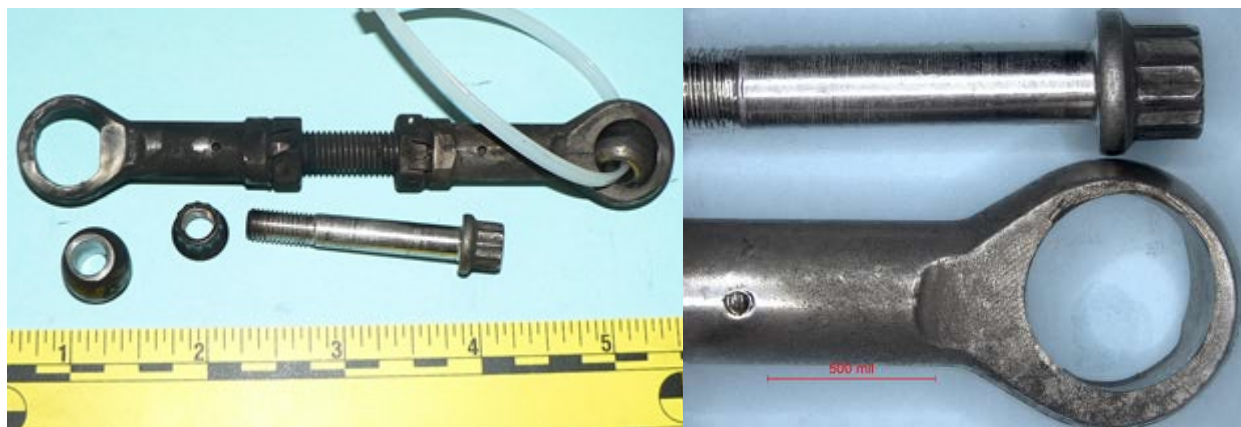


Figure 28. Right forward ECS link

4.2.3 Aft ECS link

The aft ECS link length was 7.047 inches. The anti-rotation tabs showed no re-bending marks. The rod ends were nominally on the same plane as regards twist. The attachment bolt and nut loading surfaces showed no appreciable wear. The external diameter of the rod end attached at the manifold was 0.807 inch, conforming with the engineering drawing. The entire rod end ball ID surface was worn. The uniball bearing exhibited opposing circular wear marks; this wear was superficial except for a step change noted at the base of one of the circular marks. The bearing diameter was 0.562 inch (0.5615 in the worn area), conforming with the engineering drawing. The external diameter of the engine-attached rod end was 0.806 inch, conforming with the engineering drawing. The bearing ID showed superficial wear and fresh circumferential scoring marks. The bearing diameter was 0.562 inch, conforming with the engineering drawing. See Figure 29.



Figure 29. Aft ECS link

4.3 Tubes

The six tube “P” clamps were inspected for unusual wear with no significant damage noted. Fuel tube diameter measurements were taken at two points approximately 90° apart at each of the clamp locations. See Table 5.

Supply	
Clamp location 1	.374 - .380
Clamp location 2	.378 - .377
Clamp location 3	.373 - .378
Drain	
Clamp location 1	.371 - .373
Clamp location 2	.372 - .374
Return	
Clamp location 1	.378 - .380
Clamp location 2	.378 - .378
Clamp location 3	.378 - .379
Clamp location 4	.377 - .378

Table 5. Fuel tube diameter measurements

The supply fitting was removed from the supply tube and sent to Parker Aerospace to be examined with the OBV.¹¹ The tubes were packaged for transfer to GE’s Unison/Elano facility in Dayton, Ohio for 2D mylar build tolerance checks. The tubes met in-service dimensional limits.

4.4 OBVs

The OBVs were shipped to a Parker Aerospace materials lab in Irvine, California after X-ray radiograph and computed tomography (CT scan) images were made at Varex, Inc. in Chicago, Illinois. A disassembly examination of the failure OBV was conducted at Parker on November 13, 2017 with FAA oversight. Scanning Electron Microscopy (SEM) examination of the return port found vertical wear and thread damage consistent with side-to-side vibration or fitting movement. Fractures on the threads showed evidence of beach marks and no signs of overload, indicating that the damage was due to cyclic movement. The final fitting pullout resulted from insufficient remaining threads to hold the fitting in the housing. The A286 fitting and the 6061 aluminum housing materials conformed to print specification and hardness measurements met the drawing requirements.

5.0 Containment actions

A new P/N 4123T71P05 (P05) OBV design with the rosan -05 to -06 expander supply and return fittings replaced with larger rosan -06 to -06 standard fittings was proposed. More data were required to understand fitting pullout root cause.

5.1 Through-the-fleet inspection and data collection

¹¹ No readily available means of removing the fitting was available at the site.

On August 4, 2017, GE issued SB 8C 75-0019, a once-through-the-fleet inspection for loose or leaking OBV fittings and worn ECS links with a request to report findings back to GE. On November 15, 2017 the FAA published Immediate Adopted Rule AD 2017-23-36, mandating compliance with SB 8C 75-0019 within 500 flight hours (FH). The AD cited the four previous pullouts, fires, and the potential for damage to the airplane.

Parker began reviewing OBV repair shop historical records for reports of loose fittings during as-received tests or given as the reason for removal.

5.2 Component Maintenance Manual review

GE and Parker reviewed OBV production line procedures and the CF34-8 Operability Bleed Fuel Actuated Valve Component Maintenance Manual (CMM). On November 17, 2017, the CMM was updated to include the SB 8C 75-0019 OBV fitting inspections, to require housing cap replacement any time the valve is disassembled to piece-part level and revise the rosan fitting installation and removal instructions and OBV parts list.¹²

5.3 Design improvements

GE began validation rotary flex testing¹³ to assess the capability of the rosan -05 to -06 expander and the -06 to -06 standard fittings to withstand system interface loads at multiple external bending moment loads and torques. GE also evaluated several alternative fuel tube designs but they were found ineffective in reducing OBV loading.

An improved-design P05 OBV was expected to be available to production in October 2018 and to the field in December 2018. The P05 OBV and a mandated, repetitive ECS link inspection were discussed as potential final corrective actions.

5.4 Embraer fleet affected

Parker's review of past OBV work files found ten reports of minor leaks at the fitting-to-housing interface. Seven of the ten were OBVs removed from CF34-8E engines. OBVs removed from 8E engines made up roughly 30% of Parker's repair shop inputs, suggesting that fitting leaks were equally likely to occur on OBVs installed on 8E engines.¹⁴ On February 9, 2018, GE issued SB 8E 75-0016, a once through the fleet OBV and ECS link inspection similar in scope to SB 8C 75-0019, recommending that OBVs installed on 8E engines with over 4,000 TSN be inspected within six months.

On October 31, 2018, Task 75-00-00-200-801, Inspection 003, *ECS Visual and Dimensional Inspection* (ECS Inspection 003), a detailed piece part inspection task, was added to 8C LMM 75-00-00. SB 71-0000 was revised to include ECS Inspection 003 with a 16,000 FH inspection

¹² The OBV housing cap is now sold as an assembly with the rosan fittings pre-installed.

¹³ Rotary flex is a standard method of testing the capability of fluid connections.

¹⁴ When installed on a CF34-8E engine, the OBV is mounted at 9 o'clock. Links are installed immediately upstream and downstream of the valve. There are three links and they are not the same design as the 8C ECS links.

interval. CRJ 700 AMM was revised to include ECS Inspection 003 and the inspection was proposed as a CRJ Maintenance Requirements Manual (MRM) task in November 2018.

5.5 Data review and repeat inspection

The incoming SB 8C 75-0019 inspection data included no loose OBV fittings or leaks, however, worn ECS links were found on approximately 16% of the inspected engines. Weibull analysis of the link data identified a vibration-driven wear out failure mode indicating that repetitive flight line inspections were required to control the condition until a long-term corrective action was determined. On February 5, 2018, GE issued Cat 2 SB 8C 75-0020 advising that engines with over 12,800 FH undergo the OBV and ECS link inspections described in SB 8C 75-0019 every 1,600 FH. SB 8C 75-0020R1, published April 15, 2018, aligned the compliance interval with maintenance letter checks (1,680 FH). SB 8C 71-0000, *Powerplant Consolidated On-Wing Inspection Recommendations and Servicing Tasks List* was updated to include the SB 8C 75-0020 repeat inspection.

Parker began measuring the fitting joint residual torque of OBV shop inputs (routine field returns).

5.6 ECS link alignment and best practices

The CRJ nacelle design supplier, Bombardier Shorts (Shorts), advised that ECS link rod end bearings must be properly aligned and securely clamped between the fork bushings to prevent lateral movement and premature wear. A Shorts review of the CF34-8 Maintenance Engineering Sheets and field maintenance documents found they did not control for rod end alignment, and that CRJ 700 AMM 75-31-01 did not include link inspections. GE confirmed that instructions to align the ECS links during installation were missing from the base engine assembly drawing, and that the ECS links were not part of any scheduled airplane maintenance. In October 2017, GE updated 8C LMM 75-00-00 Special Procedure 010, *Environmental Control System Ducting Removal, Inspection and Installation* to include the SB 8C 75-0019 inspections and link installation best practices. Bombardier revised AMM 75-31-01 to reflect the LMM revision in April 2018. The base engine assembly drawings and assembly procedures for new make engines were updated to reflect link installation best practices in June 2018.

6.0 Additional fitting joint failures

6.1 Republic Airlines 8E return fitting pullout

On June 28, 2018, a Republic Airlines Embraer 170 experienced an on-ground OBV return fitting pullout. SB 8E 75-0016 had been complied with 400 hours before the failure. There was no ECS link wear. Metallurgical examination of the OBV return port found heavily worn internal threads with longitudinally oriented wear marks and damaged lock ring slots. The return fitting exhibited thread crest damage. There was no damage to the supply or drain ports/fittings.

6.2 Air North 8E return fitting leak

On July 2, 2018, the investigation of a large fuel leak found an impending OBV return fitting pullout on an AirNorth E170. The residual torque was measured at 55 lb-in. Metallurgical examination found severe return port thread wear damage.

6.3 SkyWest 8C return fitting pullout

On November 5, 2018 a SkyWest CRJ 700 N730SK experienced a return fitting pullout at Medford, Oregon.¹⁵ AD 2017-23-06 had been complied with on November 30, 2017. The AD inspection was performed on the engine. Wear was observed on the visible end of the front plenum link. However, this link wasn't loose, as expected with excessive link wear. The inspection was repeated with the OBV-to-OBV manifold V-clamp disconnected and the link looseness/wear was obvious with the system unloaded. One missing double tube clamp was noted and several clamps were loose around the tubing. Metallurgical examination of the OBV found significant wear on the initially-engaged return port threads and mechanical wear at the thread crest region. The failed OBV had been repaired by HEICO Component Repair Group. Members of the Powerplants Group visited HEICO on February 14, 2019 to review the Medford OBV repair (no anomalies found) and to discuss OBV repair data.

7.0 SB 8C 75-0020 R3 / AD 2019-22-05

7.1 SB 75-0020 inspection interval changes and inspection enhancements

GE revised SB 8C 75-0020 (R3) on December 14, 2018 to lower the initial inspection threshold from 12,800 FH to 6,000 FH and shorten the repeat inspection interval from 1,680 FH to 880 FH. Inspection procedures were revised to include lessons learned from the Medford investigation, including an instruction to remove the V-band clamp when inspecting for link wear and the addition of a fuel tube clamp configuration check.

8C LMM 75-00-00 Special Procedure 007 *Operability Bleed Valve Removal, Inspection and Installation* was updated to provide further detail on tube cold work and visual aids, tube alignment procedures including figures indicating B-nut alignment with fittings, and tube and clamp installation. 8C LMM 72-00-00 and 8E LMM 71-71-00 *Fuel Drain, Return, and Supply Lines Installation and Removal* instructions were revised to reflect the inspection enhancements.

The FAA published AD 2019-22-05 on November 18, 2019 to mandate compliance with SB 8C 75-0020 R3. AD 2017-23-06 was superseded by AD 2019-22-05.

8.0 P05 OBV

The rosan -05 to -06 expander fitting port experienced failures at multiple external bending moment loads and torques during rotary flex validation tests. The standard -06 to -06 fitting port had significantly more wear resistance to external loading. The P05 OBV, with the supply and return port

¹⁵ NTSB case No. ENG19SA003. The Powerplants Group launched on this incident.

-05 to -06 expander fittings replaced with standard -06 rosan fittings was released to production on November 2, 2018. See Table 6.

feature	P02/P03/P04 OBV	P05 OBV
supply fitting	-05 to -06 expander	-06 to -06 standard
return fitting	-05 to -06 expander	-06 to -06 standard
installation torque	100-120 lb-in	180-245 lb-in

Table 6. P05 OBV durability improvements

The P05 OBV was released to the field by SBs 8C 75-0023 and 8E 75-0018 on December 21, 2018. SB 8C 75-0020 was revised to add the P05 to its compliance. The OBV CMM was revised to include the P05 rework and repair instructions.

9.0 Rosan fitting preload variation

GE performed torque tension tests¹⁶ to characterize OBV fitting installation preload using different fitting types, loads, and installations and controlling external bending moment, cyclic loading, and installation torque. The rosan fittings tested showed 68% more preload vs. torque variation than alternate fasteners (30%), with resulting wide distribution of rosan fitting preload at both low and high ends. The preload study demonstrated that uneven conical seat surfaces, uneven application of dry film lubricant and contamination can lower joint preload, further increasing variability, and that increasing fitting installation torque will increase preload. It was demonstrated that limiting the number of retorques during fitting installation increases clamping force and that a rotation angle check prior to final torque application can be used to screen for anomalous fittings. The CMM was revised to include installation refinements identified by the torque tension tests.

A field trial of a procedure to verify adequate joint preload by confirming adequate fitting torque was conducted at GE with several operators. By August 2018, Parker and GE had checked the fitting breakaway torques of 49 valves and found 5 (10%) with below-minimum breakaway torque. The torque verification procedure was issued as limited-release Alert SBs 8C 75-0022 and 8E 75-0017 on Sept 18, 2018. SB 8C 75-0022 was released to two additional operators, SkyWest and Mesa, on December 27, 2018. However, the procedure repeatability was not as expected, and it was not pursued further.

10.0 E170/CF34-8E repetitive OBV inspection

GE issued SB 8E 75-0020 on September 23, 2019 to recommend repetitive inspection of P02/P03/P04 (legacy) OBVs with more than 6,000 TSN for loose or leaking fittings and worn fuel tube clamps every 880 FH until replacement with a P05 or higher OBV. A review of the 8E LMM ECS shop visit link inspection requirements determined that their frequency and piece part nature were sufficient to control for 8E link wear.

¹⁶ Torque tension tests measure the torque required for a joint to achieve a specific preload.

11.0 8E return tube identified as significant contributor

Parker reported that most of the loose fittings detected by their breakaway torque checks were return fittings installed in OBVs removed from 8E engines. Review of the six pullout events found that five of them involved return port fittings. See Table 8.

date	operator	event type	port	installation	link wear
03 20 2014	Republic	pullout, fuel leak	return	8E	unknown
01 28 2017	Mesa	pullout, undercowl fire	return	8C	yes
07 02 2017	SkyWest	pullout, uncontained fire	supply	8C	yes
06 28 2018	Republic	pullout, fuel leak	return	8E	no
07 02 2018	Air North	fuel leak, low torque/wear	return	8E	no
11 05 2018	SkyWest	pullout, fuel leak	return	8C	yes

Table 8. OBV fitting pullouts. Only the SkyWest DEN event involved the supply fitting

A review of service records found that, of the three 8C-engine event OBVs, two had previously operated on 8E engines. Only the SkyWest DEN failure OBV had never been installed on an 8E engine. See Table 9.

date	operator	event type	port	installation	link wear	notes
03 20 2014	Republic	pullout, fuel leak	return	8E	unknown	
01 28 2017	Mesa	pullout, undercowl fire	return	8C/8E	yes	6,049 FH on an 8E
07 02 2017	SkyWest	pullout, uncontained fire	supply	8C	yes	22,419 OBV TSN; severe link wear
06 28 2018	Republic	pullout, fuel leak	return	8E	no	
07 02 2018	Air North	impending pullout: fuel leak, low torque/wear	return	8E	no	
11 05 2018	SkyWest	pullout, fuel leak	return	8C/8E	yes	delivered on an 8E engine

Table 9. OBV fitting pullouts installation information, showing the SkyWest DEN OBV failure as the only supply fitting pullout and the only event OBV without operating time on an 8E engine.

The OBV fuel tubes are 321SS steel with the exception of the 8E return tube, which is Inconel® 625. The tube material was changed during CF34-8E engine certification to meet the fan blade off unbalance requirement.¹⁷ Rotary flex test-to-failure tests were performed to evaluate the effect of the more rigid Inconel 625 tube on the rosan fitting. The tests identified the 8E return tube as a significant contributor to the OBV fitting pullout failure mode.

12.0 Subpopulation identified

The identification of 8C ECS link wear and Inconel 625 8E tube loading as significant contributors to fitting pullouts allowed GE to identify a higher-risk P02/P03/P04 (legacy) OBV subpopulation.

¹⁷ GE CF34-8E CID 529919, introduction of P/N 2036M28G01 tube.

Legacy OBVs that had fittings replaced without housing cap replacement were added to the subpopulation because of the possible weakening of housing caps during rework. On March 7, 2019, GE issued SBs 8C 75-0025 and 8E 75-0019, which provided identification criteria and listed known higher risk OBVs by S/N. See Table 7.

SB	criteria
8C 75-0025	operated with worn links, or operated on an 8E and later installed on an 8C, or rosan fitting replaced without housing cap replacement
8E 75-0019	operated with worn links, or rosan fitting replaced without housing cap replacement

Table 7. Suspect population identification criteria

13.0 OBV wear capability testing

GE used the Inconel 625 tube +Sigma high cycle fatigue (HCF) data from the rotary flex tests to characterize the load capability of the OBV tubes. The Inconel 625 -06 return tube +3 Sigma capability was defined as 35 ksi, or a value greater than or equal to 103 lb-in bending moment. See Figure 30.

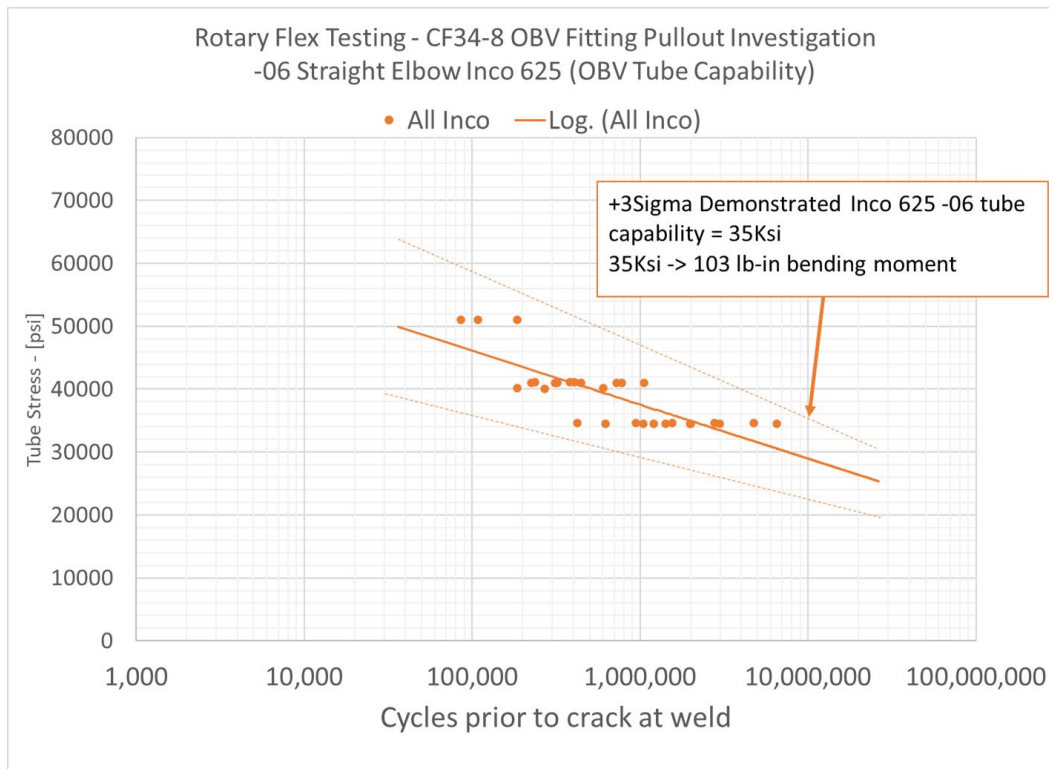


Figure 30. +3 Sigma HCF CF34-8 OBV tube (Inconel 625 -06 90° elbow) capability

Given that GE CF34-8 reliability data showed no in-service OBV tube failures, the load that a +3 Sigma HCF CF34-8 OBV return tube could input into a fitting was designated the worst possible tube-induced vibration loading that OBV fitting joints would experience, and 35 ksi / ≥ 103 lb-in bending force was made the upper load threshold for fitting capability. Rotary flex tests using 35 ksi ≥ 103 lb-in bending force as the upper tube load limit and knowledge gained from the torque tension tests were performed to confirm P04 test findings and to verify P05 OBV capability.

13.1 P04 -05 to -06 expander fitting wear capability

Rotary flex tests of the -05 to -06 expander fitting joint using preload data and the ≥ 103 lb-in bending moment upper load limit found a large region of potential port wear, confirming that the P04 OBV -05 to -06 expander fitting joint was susceptible to port wear due to low preload within worst case engine vibration loads. See Figure 31.

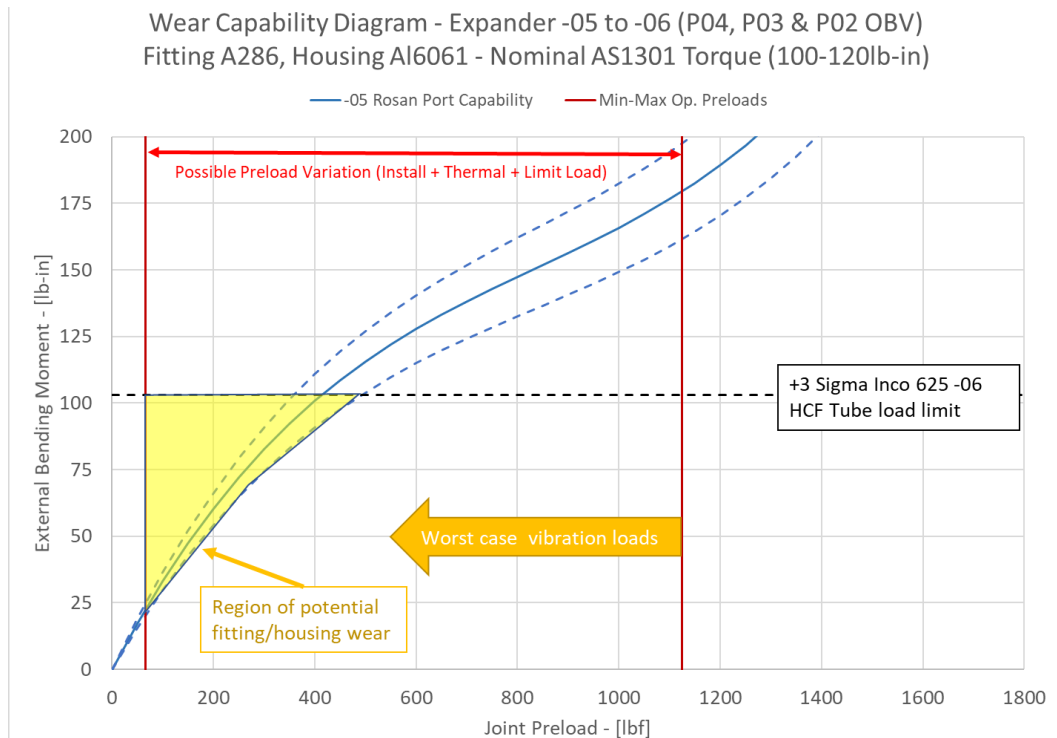


Figure 31. Legacy OBV -05 to -06 expander fitting joint wear capability showing inadequate design margin to withstand system loads

Similar rotary flex tests of the -06 to -06 standard fitting joint verified the P05 OBV as capable of withstanding system loads up to the Inconel 625 HCF capability. The tests revealed a small region of possible port wear should loads exceed the Inconel 625 -06 HCF material capability threshold. See Figure 32.

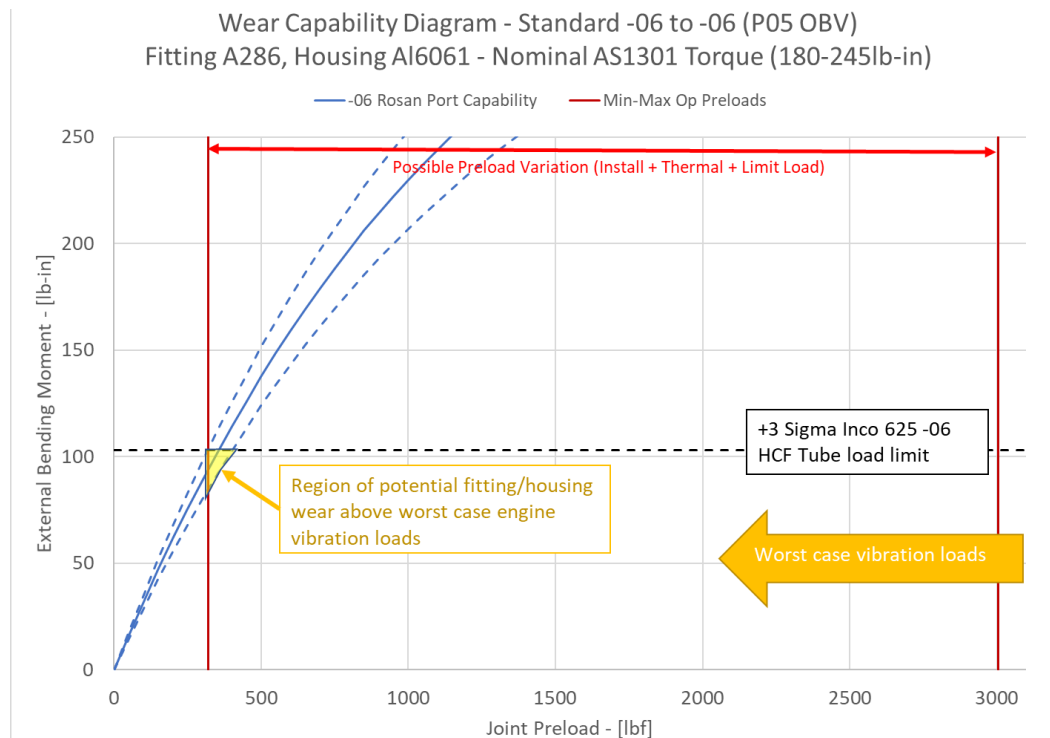


Figure 32. P05 wear capability verified to the Inconel 625 HCF tube load limit. A small region of potential port wear was observed just above worst-case engine vibration loads

14.0 Improved-design (P06) OBV

The P05 OBV housing cap material was upgraded from cast AL6061T6 to forged AL2618 for increased resistance to thread deformation at operating temperatures, and a special thicker-necked -06 to -06 fitting was specified. These upgrades permitted a 260 lb-in to 360 lb-in installation torque range, resulting in a 21% on-average fitting preload increase over the P05 OBV. See Table 10.

feature	P/N 4123T71P02/P03 /P04	P/N 4123T71P05	P/N 4123T71P06
supply fitting	-05 to -06 (expander)	-06 to -06 (standard)	increased-neck -06 to -06 (standard)
return fitting	-05 to -06 (expander)	-06 to -06 (standard)	increased-neck -06 to -06 (standard)
drain fitting (low volume, low pressure fuel)	-04 to -06 (expander)	-04 to -06 (expander)	-04 to -06 (expander)
supply/return fitting installation torque	100-120 lb-in	180-245 lb-in	260-360 lb-in
cap material	AL 6061T6 (cast)	AL 6061T6 (cast)	AL 2618 (forged)

Table 10. CF34-8 OBV configuration differences

The improved-durability P/N 4123T71P06 (P06) OBV was introduced to production by SBs 8C 75-0026 and 8E 75-0021 on February 21, 2020. Rework instructions for upgrade to P06 were

provided by SBs 8C 75-0027 and 8E 75-0022, also published on February 21, 2020. SB compliance (applicable to both 8C and 8E OBVs) is shown in Table 11.

OBV	compliance group	compliance period
P02, P03, P04	Suspect population per SB 8C 75-0025 / 8E 75-0019	6 months
	> 25,000 TSN	16 months
	12,500 – 25,000 TSN	32 months
	< 12,500 TSN	48 months
P05	ALL	10 years or 25,000 TSN/time since upgrade
All	Time since upgrade may be used if reworked to P05 or if housing cap was replaced per CMM 80-12-41 R3 or later	

Table 11. Recommended P06 upgrade compliance periods

F. FINAL CORRECTIVE ACTIONS

1.0 E170 fleet

The corrective action for the CF34-8E fitting pullouts is replacement of legacy OBVs with the P06 OBV per SB 8E 75-0021. SB 8E 75-0021 will be mandated by an AD, currently in process (FAA Reference No. 2021-00631-E).

2.0 CRJ fleet

On January 14, 2020 ECS Inspection 003 at a 16,000 FH interval was made an 8C Engine Manual (EM) Chapter 5 airworthiness limitation by publication of 8C EM Temporary Revision (TR) 05-0145, which added the inspection to Chapter 05-21-00 Table 803, *Mandatory Inspections and Mandatory Maintenance* as a post-SB 8C 75-0026 requirement.

SB 8C 75-0026 was published on February 21, 2020, releasing the P/N 4123T71P06 (P06) OBV to service. Compliance with SB 8C 75-0026 was made contingent on performance of the EM 05-21-00 Table 803 ECS links inspection.

On March 24, 2020 the CRJ Industry Steering Committee & Working Group considered the Chapter 5 Table 803 inspection as a Maintenance Requirements Manual (MRM) task. The inspection was approved for inclusion in the MRM on April 2, 2020.

On May 8, 2020, GE requested approval for an Alternative Method of Compliance of General Applicability (global AMOC) for AD 2019-22-05 paragraph (g), the 880-hour ECS link inspection interval. The global AMOC request proposed that paragraph (g) no longer be required after SB 8C 75-0026 is complied with (P06 OBV upgrade, performance of the 8C EM Chapter 5 Table 803 ECS detailed link inspection, and operator maintenance program compliance with 8C EM Chapter 5-21-00 TR 05-0145 or later). The FAA agreed that SB 8C 75-0026 provides an

acceptable level of safety without the 880 FH repeat inspections mandated by the AD, and approved the global AMOC proposal on July 20, 2020.

The 2021-00631-E AD currently in process will mandate compliance with SB 8C 75-0026. Compliance with the 2021-00631-E AD will be the terminating action for AD 2019-22-05.

Carol Horgan
Powerplants Group Chair