Aviation Investigation Final Report

Location:	San Francisco, California	**Incident Number:**	ENG11IA011
Date & Time:	December 24, 2010, 20:20 Local	**Registration:**	N248WN
Aircraft:	Boeing 737	**Aircraft Damage:**	None
Defining Event:	Powerplant sys/comp malf/fail	**Injuries:**	122 None
Flight Conducted Under:	Part 121: Air carrier - Scheduled		

Analysis

The CFM56-7B24 turbofan engine experienced an inflight fire after departure. The flight crew reported an engine fire warning, discharged a fire suppression bottle and diverted where a successful single engine landing was performed. The airplane taxied to the gate where all the passengers deplaned. There were no reported injuries. Preliminary examination of the engine revealed sooting on the engine cases from the compressor aft flange to approximately six inches beyond the turbine rear frame aft flange, but no significant thermal damage. Detailed examination of the engine revealed that the lower, most forward of the four bolts that secure the fuel manifold cover to the fuel manifold was missing while the other three had low torque values. Due to the missing attachment bolt and low torque on the three remaining bolts a gap between the two surfaces occurred that allowed fuel to leak. A review of photographs taken before the engine was released from the Celma overhaul shop reveals that all four bolts were present at that time, but based on the torque values during the investigation, they were likely not properly torqued at overhaul. These original low torque values allowed the bolts to back out over time until one eventually fell out. Pressurized fuel within the cavity was then able to pry the loose-fitting fuel manifold cover open at the location of the missing bolt and leak past its integral packing, creating the leak and subsequent in-flight fire. Examination of other 737 airplanes with CFM56-7B24 engines revealed no broader field problem.

Probable Cause and Findings

The National Transportation Safety Board determines the probable cause(s) of this incident to be: The probable cause of the undercowl in-flight engine fire was the insufficient installation torque of the bolts that secure the fuel manifold cover to the fuel manifold. Engine vibrations and fuel pressure cycles caused the bolts to gradually loosen further until one bolt lost all its tightening torque and fell out. The internal fuel pressure then forced open the fuel manifold

cover at the location of the missing bolt, causing a gap between the two mating surfaces which allowed fuel to push past the integral packing, resulting in a fuel leak onto the hot engine cases where it ignited resulting in a fire.

Findings

Aircraft	Fuel distribution - Incorrect service/maintenance
Personnel issues	Installation - Maintenance personnel

Factual Information

History of Flight

Enroute-climb to cruise	Fire/smoke (non-impact)
Enroute-climb to cruise	Powerplant sys/comp malf/fail (Defining event)
Enroute-climb to cruise	Engine shutdown

HISTORY OF FLIGHT

On December 24, 2010, a Southwest Airlines (SWA) Boeing 737-7H4, registration number N248WN, powered by two CFM56-7B24 turbofan engines, experienced an in-flight fire after departure from the San Francisco International Airport (SFO), California. The flight crew reported hearing a light pop and noted an engine fire warning on the No. 2 (right-hand) engine. After the No. 2 engine fire handle was pulled, the engine fire warning light switched off. The engine fire, severe / damage / separation / seizure checklist in the quick reference handbook (QRH) was performed and the crew then diverted to the Oakland International Airport (OAK), California, where a successful single engine landing was performed. The airplane taxied to the gate where all the passengers deplaned. There were no reported injuries. The flight was a regularly scheduled 14 CFR Part 121 domestic flight from SFO to Los Angeles (LAX).

ENGINE DAMAGE

Preliminary examination of the engine revealed sooting on the engine cases from the compressor aft flange to approximately six inches beyond the turbine rear frame aft flange, but no significant thermal damage. The engine was removed from the airplane and shipped to the General Electric (GE) Aviation Services Carter Field facility in Fort Worth, Texas where an external evaluation and a series of test cell runs were performed to determine the source of the in-flight fire. At high engine power settings a fuel was found to be leaking from between the fuel manifold and fuel manifold cover. The fuel manifold cover is approximately rectangular in shape and has 4 holes near each corner through which the four retaining bolts are passed, threaded and torqued into the fuel manifold housing, thus locking the fuel manifold cover to the fuel manifold housing. A closer examination revealed that the lower, most forward of the four bolts was missing and the remaining three bolts were insufficiently torqued, leaving the fuel manifold cover loose on the fuel manifold housing.

EXAMINATION OF THE PARTS IN-SITU

A shim check of the gap was performed at the location of the missing fuel manifold cover attaching bolt and a measurement of 0.008 inch was recorded. The gap should be 0.001 inch or less if the bolts are tightened to the correct torque. The three remaining bolts securing the

fuel manifold cover to the fuel manifold were removed and the breakaway torques ranged from 0 to 30 inch-pounds (in-lbs). The installation torque called out in SB 73-0054 instructions is 62-68 in-lbs (See paragraph 'Service Bulletin 73-0054 History' below for more details). The cover was then removed, exposing the integral packing. The packing material was torn creating two flaps with a total length of approximately 0.600 inch. An inspection of the parking bracket mounting hole where the missing bolt was located showed evidence of scoring consistent with the bolt being present at one time. The part number of the remaining installed bolts was AS3237-14, correctly corresponding to the parts catalog.

FLIGHT DATA RECORDER ANALYSIS

Using data obtained from the flight data recorder (FDR) an analysis revealed that there was an increase in fuel flow to the right hand (No. 2) engine but with no corresponding exhaust gas temperature (EGT) or N1 (low pressure rotor rotational speed) increase. This is consistent with an external fuel leak since an increase in fuel flow within the combustor would be associated with an increase in EGT and N1 speed.

TESTS AND RESAERCH

System Description of The Burner Staging Valve (BSV) In The Fuel System

The burner staging valve (BSV) was integrated onto the CFM56-7B24 engine to reduce the likelihood of flameout due to insufficient fuel flow at low engine speeds. The engine has a total of twenty fuel nozzles, ten staged and ten unstaged which supply fuel to the combustor. All 20 nozzles are identical; only the plumbing defines whether they are staged or unstaged. At engine idle conditions, the electronic engine control (EEC) unit sends a signal to the BSV which then shuts off fuel flow to the ten staged fuel nozzles. As a result, the ten unstaged nozzles receive a higher fuel volume resulting in a stronger flame. As the engine accelerates above idle, the EEC signal commands the BSV open, allowing fuel to flow to all nozzles so the engine can operate at higher power settings.

Service Bulletin 73-0054 History

Improvements to the hydro-mechanical unit (HMU) or fuel control unit improved the stability of the idle fuel flow thus rendering the BSV system unnecessary, so it was subsequently removed by service bulletin (SB) 73-0054. Incorporation of the SB requires the removal of only the BSV internal valve but retains the housing – a new fuel manifold cover and parking bracket are installed with four bolts. The parking bracket is required to secure the wire harness leads that previously connected to the BSV. The fuel manifold cover features an integrated seal.

Event Engine Maintenance History

A review of engine maintenance records indicate that SB 73-0054 was complied with by GE Aviation, Engine Services (Celma) on December 17, 2008, which was the last shop visit. Photos

taken during the final inspection at GE Celma showed all four bolts in location but it was not possible to determine from the images if the bolts were properly torqued.

Since the last shop visit, the engine had been in operation for 6,845 hours. A review of Southwest records showed that no maintenance was performed in this area since the last shop visit.

Examination And Findings Of The BSV Hardware On The Engine

To determine if the loose and missing bolt condition was caused by a design, manufacturing, the following parts were examined in detail:

1) The Fuel Manifold Cover and Fuel Manifold
A dimensional examination, using a coordinate measuring machine (CMM), was used to determine if the two mating surfaces had any dimensional anomalies that may have caused an improper fitting of the parts. The fuel manifold flatness was found to be within 0.00102 inch and the flatness of the mating surface on the fuel manifold cover was within 0.00127 inch, both normal values. No faults were found in these components that would affect fitting or clamping ability.

2) The Fuel Manifold Cover Integral Packing
The fuel manifold cover integral packing elastomer was torn and extruded outward at the location of the missing bolt. A microscopic examination by the GE laboratory of the fluorocarbon seal fractures indicated that its tear and propagation were consistent with an unseated seal subjected to pressurized fuel.

3) The Attachment Bolts
A scanning electron microscope (SEM) evaluation of the three remaining attaching bolt threads by the GE laboratory did not identify any abnormalities that would affect clamping ability.

4) The Threaded Inserts in the Fuel Manifold
The threaded inserts in the fuel manifold were sectioned and a dimensional and visual analysis by the GE laboratory of the threads did not reveal any abnormalities that would affect clamping ability.

5) The Self-Locking Features in the Threaded Inserts
The bolt locking feature inside the threaded insert consists of an elastomeric (Vespel, an industry trade name) collar near the end of the thread. An examination of the Vespel collars revealed no unusual condition that would have prevented their self-locking function.

No mechanical abnormalities could be found in any parts leaving the only other source of the loose condition to be human error during assembly.

A sample of Southwest Airlines engines were examined to see if there were any other loose fuel manifold cover bolts. The bolt torques of 20 random engines was measured by Southwest Airlines, which revealed that all 80 bolts (4 per engine) had breakaway torques above the acceptable 62 in-lbs.

To eliminate the concern of a broader field problem introduced by the GE Celma overhaul shop, a field review was done by CFM which revealed that 467 installation kits of SB 73-0054 had been shipped and installed since 2001 with no technical problems reported by any operator. Additionally, the high-time installation was 15,000 hours.

Information

Certificate:	**Age:**
Airplane Rating(s):	**Seat Occupied:**
Other Aircraft Rating(s):	**Restraint Used:**
Instrument Rating(s):	**Second Pilot Present:**
Instructor Rating(s):	**Toxicology Performed:**
Medical Certification:	**Last FAA Medical Exam:**
Occupational Pilot:	**Last Flight Review or Equivalent:**
Flight Time:	

Aircraft and Owner/Operator Information

Aircraft Make:	Boeing	**Registration:**	N248WN
Model/Series:	737 7H4	**Aircraft Category:**	Airplane
Year of Manufacture:		**Amateur Built:**	
Airworthiness Certificate:	Transport	**Serial Number:**	32509
Landing Gear Type:	Tricycle	**Seats:**	139
Date/Type of Last Inspection:		**Certified Max Gross Wt.:**	154500 lbs
Time Since Last Inspection:		**Engines:**	2 Turbo fan
Airframe Total Time:		**Engine Manufacturer:**	CFM
ELT:		**Engine Model/Series:**	CFM56 7B22
Registered Owner:	Southwest Airlines	**Rated Power:**	
Operator:	Southwest Airlines	**Operating Certificate(s) Held:**	Flag carrier (121)
Operator Does Business As:		**Operator Designator Code:**	SWAA

Meteorological Information and Flight Plan

Conditions at Accident Site:		**Condition of Light:**	
Observation Facility, Elevation:		**Distance from Accident Site:**	
Observation Time:		**Direction from Accident Site:**	
Lowest Cloud Condition:		**Visibility**	
Lowest Ceiling:		**Visibility (RVR):**	
Wind Speed/Gusts:	/	**Turbulence Type Forecast/Actual:**	/
Wind Direction:		**Turbulence Severity Forecast/Actual:**	/
Altimeter Setting:		**Temperature/Dew Point:**	
Precipitation and Obscuration:			
Departure Point:	San Francisco, CA (SFO)	**Type of Flight Plan Filed:**	IFR
Destination:		**Type of Clearance:**	IFR
Departure Time:		**Type of Airspace:**	

Airport Information

Airport:	San Franciso SFO	**Runway Surface Type:**	
Airport Elevation:		**Runway Surface Condition:**	
Runway Used:		**IFR Approach:**	None
Runway Length/Width:		**VFR Approach/Landing:**	None

Wreckage and Impact Information

Crew Injuries:	5 None	**Aircraft Damage:**	None
Passenger Injuries:	117 None	**Aircraft Fire:**	In-flight
Ground Injuries:	N/A	**Aircraft Explosion:**	None
Total Injuries:	122 None	**Latitude, Longitude:**	37.779628,-122.419273(est)

Administrative Information

Investigator In Charge (IIC):	Reichel, Harald
Additional Participating Persons:	
Original Publish Date:	August 8, 2013
Last Revision Date:	
Investigation Class:	Class
Note:	
Investigation Docket:	https://data.ntsb.gov/Docket?ProjectID=78108