Aviation Investigation Final Report

Location:	Orlando, Florida	**Incident Number:**	ENG19IA013
Date & Time:	February 21, 2019, 07:27 Local	**Registration:**	N30401
Aircraft:	Boeing 737	**Aircraft Damage:**	None
Defining Event:	Powerplant sys/comp malf/fail	**Injuries:**	181 None
Flight Conducted Under:	Part 121: Air carrier - Scheduled		

Analysis

The No. 2 engine high pressure compressor (HPC) failure was caused by a stage 2 blade separation. A HPC stage 1 variable stator vane (VSV) trunnion stem, identified as VSV #33, was missing a washer and retaining nut that allowed VSV #33 to rotate independent of the other vanes in the stage. The out-of-schedule VSV created a 1 per revolution pulse on the HPC stage 2 rotor that eventually created fatigue cracks on the HPC stage 2 blade posts that secure the rotor blades in the disk spool. When one of the fatigue cracks transitioned to overload, a section of a blade post separated and allowed a blade to enter the gas path. Titanium fragments created by secondary impact damage as a result of the separated blade were caught between the rotating blade tips of the stage 1 blades and the steel HPC cases. The contact created a brief but intense titanium fire that melted the HPC case material around the HPC stage 1 rotor plane of rotation. The damage observed both immediately upstream of the separated HPC stage 2 blade and through all remaining stages aft was secondary impact damage.

The GE Aviation Materials Laboratory performed a binocular analysis on the HPC VSV #33 trunnion stem and D-head and found wear patterns and witness marks that confirmed that a washer and retaining nut were present at some point. According to engine maintenance records, the last time the HPC VSVs were removed was during an engine overhaul at the GE Aviation- Celma maintenance, repair, and overhaul (MRO) facility, Petrópolis, Brazil in July 2014. When the HPC was assembled during the engine overhaul, the VSV #33 washer and retaining nut were likely either omitted or improperly torqued, which may have allowed the retention nut to back off during engine operation.

Probable Cause and Findings

The National Transportation Safety Board determines the probable cause(s) of this incident to be:

A No. 1 (left) engine high pressure compressor stage 2 blade separation. The blade separated due to a mixed-mode fatigue crack that originated on a blade disk post and was initiated by a misaligned (out-of-schedule) high pressure compressor stage 1 variable stator vane that was missing a washer and retaining nut on the vane trunnion stem.

Findings

Aircraft	Compressor section - Failure
Aircraft	Compressor section - Incorrect service/maintenance

Factual Information

History of Flight

Initial climb	Powerplant sys/comp malf/fail (Defining event)
Initial climb	Engine shutdown

HISTORY OF FLIGHT

On February 21, 2019, about 0729 eastern standard time (EST), United Airlines (UAL) Flight 1768, a Boeing 737-924, N30401, powered by two CFM International CFM56-7B26 turbofan engines, experienced a No. 2 (right) engine failure during initial climb from Orlando International Airport (MCO), Orlando, Florida. At about 7,000 feet altitude, the flight crew reported an "abrupt loud grinding noise and instantaneous boom," followed by a loss of No. 2 engine power and subsequent uncommanded engine shutdown. The crew initiated quick reference handbook procedures, closed the No. 2 engine fuel shutoff valve, declared an emergency, and returned to MCO, where they made an uneventful overweight single engine landing. Airport rescue and firefighting (ARFF) crews met the airplane on the adjacent high speed taxiway, but no fire or smoke was visible, and the airplane was cleared to taxi to the gate under its own power. No passenger or crew injuries were reported. The flight was being operated in accordance with 14 *Code of Federal Regulations* Part 121 and was a regularly scheduled flight from MCO to George Bush Intercontinental Airport (IAH), Houston, Texas.

DAMAGE TO THE AIRPLANE

There was no damage to the airplane structure.

TEST AND RESEARCH

Engine Examination and Disassembly

A preliminary visual inspection of the No. 2 engine was performed by UAL maintenance crews at MCO who reported high pressure compressor (HPC) case burn through. The engine was removed from wing and shipped to the General Electric (GE) Aviation facility in Evendale, Ohio. Party members from United Airlines (UAL), GE Aviation, CFM International, Boeing, the Federal Aviation Administration (FAA), and the National Transportation Safety Board (NTSB) met at GE Aviation to examine and disassemble the engine between February 26 - March 2, 2019.

The engine had no visible indications of undercowl fire or high energy uncontainment. The fan blades were all intact and in good condition, and the fan spun smoothly with concurrent rotation of the low pressure turbine (LPT). HPC case burn through was observed around the case, but was not continuous, and was estimated to have affected approximately 60% of the circumference. HPC case material remained intact around the rub button pads and at the HPC stator case split flanges. The case surfaces and accessories/lines in proximity to the burn through holes were discolored, sooted and coated in metal spray. The forward sump magnetic chip detector (MCD) plug had metal debris ("fuzz") accumulation on

the magnet and in the filter screen. A sample of the debris was collected for analysis and identification by the GE Materials Laboratory.

A visual examination of the HPC stator cases was performed after removal of the external engine components, and in addition to the case burn through, one HPC stage 1 variable stator vane (VSV) trunnion stem was missing a washer and retaining nut at the 1:30 position. The VSV alignment mark, located on the top of the trunnion stem was positioned (clocked) at a different angle relative to the rest of the vanes in the stage.

During engine disassembly, eight HPC stage 2 rotor blades, including the blade dovetails, were found separated and missing. The HPC stage 2 disk blade slots for each of the eight missing blades had one or more separated disk post corners (**Photo 1**). There was secondary impact damage observed throughout the gas path aft of HPC inlet guide vanes. The HPT stage 1 blades and the LPT stage 1 nozzle vanes exhibited thermal damage. Metal flakes and debris were collected in the aft sump, adjacent to the No. 4 bearing.

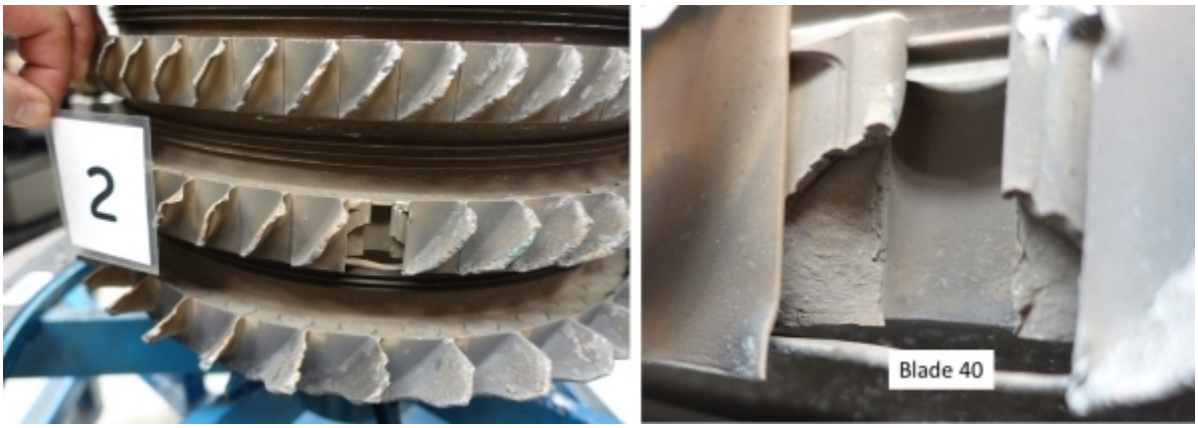

Photo 1- HPC Stage 2 Separated Rotor Blade

Engine Electronic Control Testing

The electronic engine control (EEC) was removed and hand carried by GE Aviation Flight Safety to BAE Systems in Fort Wayne, Indiana for download and acceptance test procedure (ATP) on February 28, 2019. There were no faults recorded during testing, which indicated the EEC was functioning properly during the incident flight.

Engine Maintenance

The last incident engine shop visit was an engine overhaul at the GE Aviation-Celma maintenance, repair, and overhaul (MRO) facility in Petrópolis, Brazil in July 2014. GE Aviation located photographs taken during the overhaul, but the HPC VSV actuation hardware condition could not be evaluated from the photos, because many of the VSV trunnions and lever arms were obstructed by external engine components. According to the shop records, 22 of the 82 HPC S1 VSVs were replaced and the remaining VSVs were overhauled. Installation position of the replaced and overhauled S1 VSVs were not recorded.

Materials Analysis

The HPC rotor assembly, HPC cases, and the metal debris samples collected from the aft sump and the forward sump MCD were moved to the GE Aviation Materials Laboratory in Evendale, Ohio for analysis.

A visual and binocular examination of the HPC stage 1 VSV (identified as VSV #33) trunnion stem confirmed that the missing washer and retaining nut identified during the engine teardown resulted in disengagement of the lever arm from the trunnion D-head allowing the vane to go off-schedule approximately 31 degrees relative to the other HPC stage 1 VSVs. The HPC VSV #33 trunnion stem had a uniform coating of dirt/debris along the full length of the stem consistent with engine operation over an extended period of time without the washer and retaining nut. The laboratory analysis also identified witness marks on HPC VSV #33 indicating that a washer and retaining nut were present at some point, but it could not be determined when the parts were removed or separated (**Photo 2**).

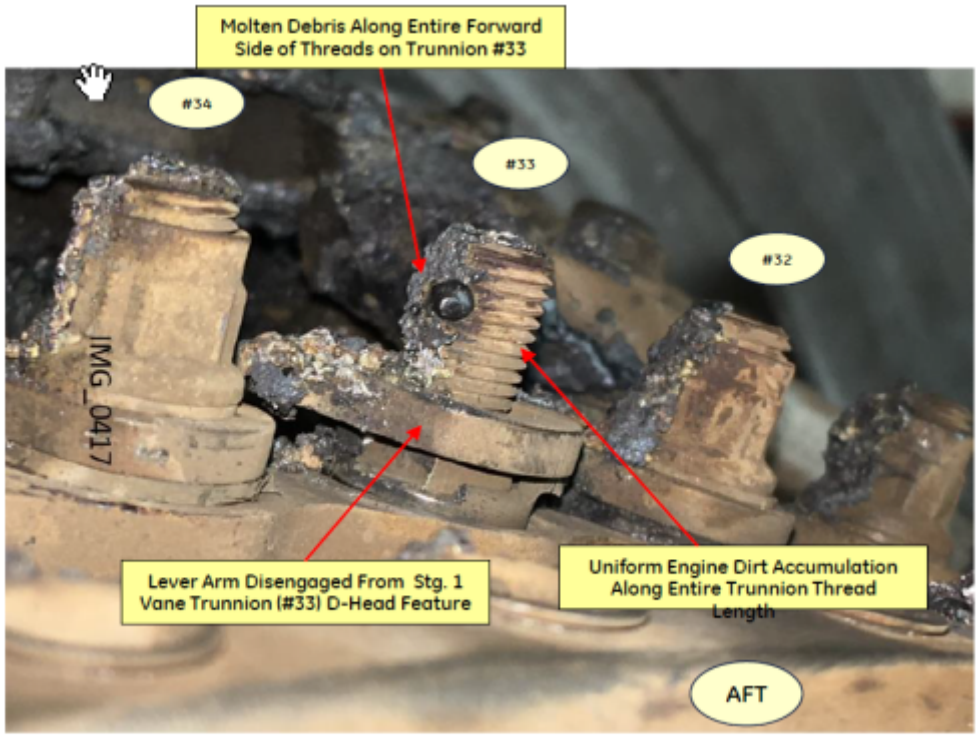

Photo 2- HPC Stage 1 Variable Stator Vane Trunnion #33 (Photo Courtesy of GE Aviation)

The HPC stage 2 disk posts fracture morphology was consistent with a lower alternating stress, high cycle fatigue (HCF) and/or mixed-mode low cycle fatigue (LCF)/HCF mechanisms. The primary initiation occurred adjacent to the forward right corner of the disk posts. A metallographic examination through a crack origin on one of the HPC stage 2 disk posts did not identify any material anomalies or stress risers. The material microstructure was consistent with properly processed beta forged Ti-17 material as specified in the engineering drawing.

The metal flakes collected in the aft sump were identified to primarily consist of RBD modified steel and silver plating. The aft sump is adjacent to the No. 4 bearing and both materials are present in the No. 4 bearing assembly. The metal that was collected on the forward sump MCD was identified as M50Nil, also a bearing material.

The complete Metallurgical Investigation Report is available in the investigation docket. The NTSB Materials Laboratory assisted in development of the metallurgy workscope and concurred with the findings and conclusions in the final report.

ADDITIONAL INFORMATION

Corrective Action

Following the incident event, the GE Aviation-Celma CFM56 maintenance, repair and overhaul (MRO) facility incorporated additional control measures to avoid improper VSV lever arm installation. The revised installation procedure requires a trunnion nut torque verification check by a second technician using a torque wrench. The primary mechanic is then instructed to complete a trunnion nut seating check using a 0.001 inch feeler gauge to prevent false torque indications. The feeler gauge check ensures there is no gap between the nut and the lever arm surface.

The GE Aviation-Strother, Kansas CFM56 MRO facility also revised their VSV lever arm installation instructions to add a mechanic stamp requirement during engine build to confirm proper thread protrusion on each VSV trunnion.

GE Aviation/CFM International notified the NTSB that they are currently evaluating new torque wrench technology that measures torque and angle. The wrench will alert the technician if the pre-set angle is not applied to achieve the torque values specified in the engine manual.

The missing VSV nut and washer finding was reviewed at all CFM56 engine MRO shops and presented at both the June 2019 Operators Symposium in Brussels, Belgium and the November 2019 All Middle East Operators Conference in Muscat, Oman. Finally, the incident findings were featured in the first quarter (Q1) 2020 edition of the GE Fleet Highlites that is available on the GE portal and can be accessed by all operators and MRO shops.

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:**	N30401
Model/Series:	737 924	**Aircraft Category:**	Airplane
Year of Manufacture:	2001	**Amateur Built:**	
Airworthiness Certificate:	Transport	**Serial Number:**	30118
Landing Gear Type:	Retractable - Tricycle	**Seats:**	
Date/Type of Last Inspection:		**Certified Max Gross Wt.:**	174198 lbs
Time Since Last Inspection:		**Engines:**	2 Turbo fan
Airframe Total Time:		**Engine Manufacturer:**	Cfm Intl.
ELT:		**Engine Model/Series:**	CFM56 SERIES
Registered Owner:	Wells Fargo Trust Co Na Trustee	**Rated Power:**	
Operator:	UNITED AIR LINES INC	**Operating Certificate(s) Held:**	Flag carrier (121)
Operator Does Business As:		**Operator Designator Code:**	UALA

Meteorological Information and Flight Plan

Conditions at Accident Site:	Unknown	**Condition of Light:**	Dawn
Observation Facility, Elevation:	KMCO,106 ft msl	**Distance from Accident Site:**	1 Nautical Miles
Observation Time:	07:27 Local	**Direction from Accident Site:**	280°
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:	Orlando, FL (MCO)	**Type of Flight Plan Filed:**	IFR
Destination:	Houston, TX (IAH)	**Type of Clearance:**	Unknown
Departure Time:		**Type of Airspace:**	Unknown

Wreckage and Impact Information

Crew Injuries:	6 None	**Aircraft Damage:**	None
Passenger Injuries:	175 None	**Aircraft Fire:**	None
Ground Injuries:	N/A	**Aircraft Explosion:**	None
Total Injuries:	181 None	**Latitude, Longitude:**	28.431388,-81.308334(est)

Administrative Information

Investigator In Charge (IIC):	Hunsberger, Robert
Additional Participating Persons:	Kate Keogh; United Airlines; Chicago, IL Amy O'Dell; United Airlines; Chicago, IL Ken Wolski; GE Aviation; Evendale, OH Rob Hous; GE Aviation; Evendale, OH Steve Johnson; CFM International; Strother, KS Andrew Fabian; Boeing; Seattle, WA Kyle Gustafson; Federal Aviation Administration; Burlington, MA
Original Publish Date:	April 27, 2020
Last Revision Date:	
Investigation Class:	Class
Note:	The NTSB did not travel to the scene of this incident.
Investigation Docket:	https://data.ntsb.gov/Docket?ProjectID=99006