NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C.

February 2, 2022

Group Chairman's Factual Report

Maintenance Records

1. EVENT DCA21FA085

Operator:	United Airlines
Location:	Broomfield, Colorado
Date:	February 20, 2021
Time:	13:09 Mountain Standard Time
Aircraft:	Boeing 777-222, Registration: N772UA

2. GROUP MEMBERS

Group Chairman:	Gregory Borsari National Transportation Safety Board Washington, D.C.
Member:	James Langsdale Federal Aviation Administration Dallas, TX

Member: Nicolas Genet
Boeing Aircraft Company
Seattle, WA

Member: Elliot Lye
United Airlines
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Member: Jose Portillo
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3. SUMMARY

On February 20, 2021, about 1309 mountain standard time, a Boeing 777-222, United Airlines flight 328, N772UA, experienced an engine failure while climbing after takeoff from Denver International Airport, Denver, Colorado. There were no injuries to the passengers or crew. The flight was operating under 14 *Code of Federal Regulations* Part 121 as a regularly scheduled passenger flight.

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LIST OF ACRONYMS

AD	Airworthiness Directive
AMM	Aircraft Maintenance Manual
ASL	Approved Supplier List
AVM	Airborne Vibration Monitoring
AWL	Airworthiness Limitation
CAMP	Continuous Airworthiness Maintenance Program
CASE	Coordinating Agency for Supplier Evaluation
CASS	Continuous Analysis Surveillance System
CFR	Code of Federal Regulations
CIR	Clean, Inspect and Repair
CMR	Certificate Maintenance Requirement
EA	Engineering Authorization
ECI	Eddy Current Inspection
EICAS	Engine Indicating and Crew Alerting System
ELB	Electronic Logbook
EMS	Engine Maintenance System
ETOPS	Extended Twin Engine Operations
EWIS	Electrical Wiring Interconnect System
FAA	Federal Aviation Administration
FOD	Foreign Object Damage
FPI	Fluorescent Penetrant Inspection
GVI	General Visual Inspection
HNL	Honolulu International Airport
HKG	Hong Kong International Airport
IAH	Houston International Airport
IEN	Internal Engineering Notice
LPC	Low Pressure Compressor
MAC	Mean Aerodynamic Chord

List of Acronyms – Continued

MAT	MAINTENANCE ACCESS TERMINAL
MEL	MINIMUM EQUIPMENT LIST
MIS	MECHANICAL INTERRUPTION SUMMARY
NDT	NON-DESTRUCTIVE TEST
No.	NUMBER
OP SPEC	OPERATION SPECIFICATION
OSV	OUTSIDE VENDOR
P&W	PRATT & WHITNEY
SB	SERVICE BULLETIN
SDR	SERVICE DIFFICULTY REPORT
SFO	SAN FRANCISCO INTERNATIONAL AIRPORT
SN	SERIAL NUMBER
STC	SUPPLEMENTAL TYPE CERTIFICATE
SVA	STATOR VANE ACTUATOR
TAI	THERMAL ACOUSTIC INSPECTION
TC	TECHNICAL CONTROL DOCUMENT
TC	TYPE CERTIFICATE
TCDS	TYPE CERTIFICATE DATA SHEET
UT	ULTRASONIC TEST
XMN	XIAMEN GAOQI INTERNATIONAL AIRPORT

4. DETAILS OF THE INVESTIGATION

A. Air Carrier Certificates

United Airlines, Inc., 233 South Wacker Drive, Chicago, Illinois 60606, Certificate Number CALA014A, was issued by the Federal Aviation Administration (FAA), Great Lakes Region on July 11, 1938 (Amended March 31, 2013).

The FAA Certificate Management Office approved a Repair Station Certificate Number UALR011A, dated July 1, 1953, to United Airlines, San Francisco International Airport, San Francisco, CA 94128 with the following ratings: Airframe, Powerplant, Radio Instrument Accessory, and Limited Non-Destructive Inspection/Testing.

B. Operations Specifications (OpSpecs)[1]

United Airlines, Inc. has a Part 121 Certificate, which included the standards, terms, conditions, and limitations contained in the FAA approved Operations Specifications (Parts D and E) were reviewed.

1) Air carrier was authorized as a 14CFR Part 121 operation.

2) Per section D072 of the OpSpecs, each aircraft must be maintained in accordance with the Continuous Airworthiness Maintenance Program (CAMP) and limitations specified in these Ops Specs. CAMP document for the B777-222 is contained in General Maintenance Manual, subject 05-00-10.

3) Per section D074 of the OpSpecs, United Airlines, Inc. was authorized to use the provisions of a maintenance reliability program on their fleet.

4) Per section D083 of the OpSpecs, United Airlines, Inc. was authorized to use short-term escalations for borrowed Parts subject to overhaul requirements.

5) Per section D085 of the OpSpecs, United Airlines, Inc. had the following airplanes in its fleet 89-A319, 101-A320, 369-737, 72-757, 54-767, 96-777 and 60 -787.

6) Per section D086 of the OpSpecs, United Airlines has a Maintenance Program Authorization for Two-Engine Airplane used in Extended-Range Operation.

7) Per section D090 of the OpSpecs, United Airlines, Inc. was authorized to utilize CASE[2] as a means of qualifying a vendor for services, parts, and materials to satisfy the requirements of 14 CFR Section 121.373.

8) Per section D095 of the OpSpecs, United Airlines, Inc. was authorized to use an approved Minimum Equipment List (MEL).

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[1] Operations Specifications contains the authorizations, limitations, and certain procedures under which each kind of operation, if applicable, is to be conducted by the certificate holder.

[2] The Air Carriers section of the Nonprofit Coordinating Agency for Supplier Evaluations (C.A.S.E.) was organized as a means of sharing non-prejudicial supplier quality approval data among the membership airlines. This increases surveillance coverage of suppliers and thereby upgrades their quality programs. It also has an economic impact on each C.A.S.E. member by decreasing the cost of supplier surveillance and making their surveillance programs more effective.

9) Per section D097 of the OpSpecs, United Airlines, Inc. has an Aging Aircraft Program.

10) Per section E096 of the OpSpecs, United Airlines, Inc. was authorized for a Weight and Balance Program.

United Airlines, Inc. has a Part 145 Certificate, which included the standards, terms, conditions, and limitations contained in the FAA approved Operations Specifications for the Repair Station.

1) Per section D100 of the OpSpecs, United Airlines, Inc. was authorized to perform work at a place other than the repair station fixed locations.

2) Per section D107 of the OpSpecs, United Airlines, Inc. was authorized for Line Maintenance.

C. The Type Certificate Data Sheet (TCDS)

TCDS number T00001SE is for the airplane. TCDS for the engine is E46NE. The TCDS prescribes conditions and limitations under which the product for which the Type Certificate (TC) was issued meets the airworthiness requirements of the Federal Aviation Regulations. According to the document, The Boeing Company is the holder of the TC for the airplane and Pratt & Whitney is the holder of the TC for the engines.

D. Aircraft Information

The Boeing Company manufactured the airplane, dated November 19, 1994, serial number 26930 and it was purchased and delivered to United Airlines on September 29, 1995. The airplane had about 96,975 total flight hours with 17,784 total flight cycles at the time of the incident.

The airplane was equipped with two Pratt and Whitney PW4077. The engines had accumulated the following operating times at the time of the incident.
(see next page)

Engine Information

	No.1 Engine	No.2 Engine
Manufacturer	Pratt & Whitney	Pratt &Whitney
Part Number	PW4077	PW4077
Manufacture Date	May 5, 1995[3]	December 14, 1995[4]
Date Installed on Event Airframe	January 11, 2018	August 15, 2016
Serial Number	777029	777047
Time Since Last Shop Visit	9,311.51	13,924.29
Cycles Since Last Shop Visit	2,022	2,979
Total Time Since New	84,653.22	81,768.51
Total Cycles Since New	15,669	15,262

E. Continuous Aircraft Maintenance Program

United Airlines Air Carrier Maintenance Manual identifies, describes, and defines the maintenance program. The Air Carrier Maintenance Manual includes the technical data that describe maintenance standards, methods, techniques, and procedures for performance of aircraft related maintenance. The Air Carrier Maintenance manual include the manufacturer's instructions for maintaining aircraft, engines, and components. In addition, United utilizes tasks cards that provide detailed instructions for the accomplishment of routine scheduled maintenance. The task cards are part of the air carrier maintenance manual and maintenance program. Task cards are developed, revised, and distributed through an electronic system.

The maintenance program is primarily based upon MSG3 decision logic for scheduled maintenance originally derived from manufacturers maintenance

[3] Source engine data plate
[4] Source 8130 Tag

review board (MRB). Tasks in the maintenance schedule includes (but is not limited to):

1) Airworthiness Directives.
2) Service Bulletins / Service Letters.
3) Replacement of life-limited items.
4) Replacement of components for periodic overhaul or repair.
5) Special Inspections.
6) Checks or tests.
7) Lubrication and servicing.
8) Tasks identified in the Maintenance Review Board Report.
9) Airworthiness Limitations (AWL)
10) Certification Maintenance Requirements (CMR).
11) Supplemental Structural Inspection Documents.
12) Electrical wiring interconnection system (EWIS).

The maintenance schedule for the B777 aircraft is divided into No.1 Service, ETOPS Predeparture check, No.2 Service, A-checks, B checks, C checks, D1 checks, and D2 checks.

1) No.1 Service interval is 3 days /100 hours.
2) ETOPS Pre-Departure Check list accomplished with 3 hours of a ETOPs flight. Resets the No.1 Service.
3) No.2 Service interval is 7days/150 hours. Resets the No.1 Service.
4) A-check interval is 90 days / 1,440 hours / 270 Cycles. Sequenced A1 thru A12. Resets No.1 and No.2 Service.
5) B-check interval is 20 months / 12,000 hours / 2,000 cycles. Resets No.1 and No.2 Service.
6) C-check interval is 36 months / 18,000 hours / 4,000 cycles. Resets No.1 and No.2 Service, and B Check.
7) D1 interval is 72 months / 36,000 hours / 8,000 cycles. Resets No.1 and No.2 Service, B Check, and C Check.
8) D2 interval is 144 months / 72,000 hours / 16,000 cycles. Resets No.1 and No.2 Service, B Check, C Check, and D1 Check.

Check Type	Date	Location	Total Time	Total Cycles
No.1 Service Check	2/19/2021	IAH	96,970:26	17,781

Check Type	Date	Location	Total Time	Total Cycles
No.2 Service Check	2/15/2021	HNL	96,946:22	17,775
A12 Check	1/16/2021	HNL	96,814:41	17,742
B Check	3/2/2020	SFO	95,163:55	17,296
C Check	8/11/2018	HKG	89,394:56	16,094
D1 Check	5/21/2015	XMN	77,873:41	13,868
D2 Check	5/21/2015	XMN	77,873:41	13,868

F. Minimum Equipment List (MEL)[5]

United Airlines was authorized to use an approved MEL on its airplanes per its Op Specs. MEL items were reviewed from August 11, 2020, to February 10, 2021. There were no open MEL items at the time of the incident.

G. Supplemental Type Certificate (STC)

According to United Airlines, there were 15 STCs incorporated on the airplane. None of the 15 STC's were associated to the Engines.

H. Aircraft Flight Logs

Electronic Aircraft Flight Logs were reviewed from October 1, 2020, thru February 20, 2021. The review focused on the No.2 Engine, the No.2 Inlet Cowl and the No.2 engine hydraulic shutoff valve. No discrepancies for the No.2 Engine Fan Blades were noted. One logbook item for a previous attrition liner repair that was missing a section of the repair (measured 0.74" by 2.85") for the No.2 engine inlet cowl was recorded and repaired in accordance with AMM 72-33-01-300-801-N00 on January 6, 2021.

[5] The FAA approved Minimum Equipment List contains a list of equipment and instruments that may be inoperative on a specific aircraft for continuing flight beyond a terminal point.

I. Service Difficulty Reports (SDR) and Mechanical Interruption Summary (MIS)

Service Difficulty Reports and Mechanical Interruption Summary reports were reviewed. The following items are noted.

1) August 30, 2020 – No.2 engine lower acoustic panel 6 O'clock position has damage. Repaired per AMM 72-33-01-300-801-N00.

2) July 21, 2019 – No.2 engine fan case rub strip has damage at the 11 O'clock position looking aft. Damage measures 3.5" x 2.5". Repaired right engine fan case rub strip damage at 11 O'clock per AMM 72-33-01.

J. Aircraft Weight and Balance

Per the Op Specs, United Airlines is authorized to use individual aircraft weights outlined in the empty weight and balance program. The airline is authorized to use fleet airplane weights. Weight sampling interval is 36 months. Individual aircraft not to exceed 18 years. N772UA was last weighed on August 8, 2018.

Basic Empty Weight:	300,209 pounds
Arm:	1,231.35 inches
Center of Gravity (% MAC):	20.41%

K. Major Repairs and Major Alterations

Major repair records were reviewed. None of the 22 major repairs affected the No.2 engine inlet cowl or the No.2 engine.

Records reviewed showed United Airlines incorporated 29 Major Alterations on the incident airplane. One major alteration dated December 4, 1996, accessed the forward bulkhead of the inlet cowl assemblies, removed, and replaced inlet cowl insulation material and remarked the inlet cowls to part number 314W3010-30AA. No discrepancies were noted during the review.

L. Time Limit Components

Time limit components for both airframe and engine components are tracked electronically in a program called SCEPTRE. Within SCEPTRE there is a subsystem specifically for tracking engine component and parts, Engine Parts Monitoring (EPM). United Airlines produced both an airframe and engine component tracking list for review. The review concentrated on the number two engine. All components listed were being tracked including the number two engine fan blades.

M. Continuous Analysis and Surveillance System (CASS)

To comply with requirements of 14 CFR Part 121.373, United Airlines, has a CASS process that forms a continuous loop. The four elements are Surveillance, Analysis, Corrective Action, and Verification. The feedback loop is reviewed at the CASS Review Board and the entire process is monitored for both functional performance and functional effectiveness.

A review of the 4th Quarter 2020 CASS report (February 12, 2021) revealed an airline monitoring the processes and procedures in the maintenance organization. Adjustments and checkpoints are tracked to ensure an effective airline operation.

The 4th Quarter 2020 CASS report did show United was continuously tracking Parts Departing Aircraft. United had defined categories based on the size, weight, and material. There were no reports for the B777 fleet.

N. B777 Fleet Performance

A review of the B777 Fleet Performance Report (February 5, 2021) revealed information (i.e., Delay and Cancellations, Diversions, Reliability Drivers, etc.) intent to show the current status of the fleet compared to its operational intended goals. The report analyzes each of the issues and provides potential solutions. Effectiveness of the corrective actions are tracked on an on-going basis.

The report also provides Powerplant Performance Data. The United B777 fleet uses both Pratt and Whitney (PW4077 and PW4090) and General Electric (GE 90-94B and GE 90-115B) engines. The report monitors the reliability (i.e., aborted takeoffs, air turn back, diversions and inflight shutdowns) of each engine type. According to the report, the PW4077 did not have a major event in the prior three months with only one Unscheduled Engine Removal for a MB7 bearing failure. United reports the unscheduled engine removal was on the No.1 Engine of aircraft 2511, Engine S/N 777026.

O. Approved Supplier List

United Airlines provided an Approved Supplier Listing (ASL) for review. The List identifies providers approved to perform maintenance and provide parts and specialized services to United Airlines fleet of airplanes. The Quality Assurance Department approves, conducts initial and continuing audits and surveillance of maintenance providers. Audit evaluations of active vendors are accomplished on a periodic basis to determine vendor's quality system compliance and effectiveness. United Airlines is also authorized to utilize CASE as means of qualifying a vendor for services, parts, and materials to satisfy the requirements of 14 CFR 121.373. There were no discrepancies

noted in the Approved Supplier List. In addition, United performed a vendor audit of P&W on October 2, 2019. Findings included items such as material shelf life that were corrected.

P. Airworthiness Directives (AD)[6] and Service Bulletins (SB)

A list of ADs (United Airlines and Pratt & Whitney) was reviewed to verify airworthiness of the airplane and engines. All ADs were recorded and tracked for compliance. No discrepancies were noted. The following ADs are noted.

AD 99-15-10 The AD requires replacement of a certain engine-driven pump (EDP) supply shutoff valve, located in the aft strut fairing, with a new shutoff valve. This amendment is prompted by reports of failure of the shutoff valve due to corrosion in the direct current motor in the shutoff valve. Part number S271W741-22 was installed on 8/19/1999 in accordance with the AD.

AD 2018-21-11 requires a fluorescent penetrant inspection (FPI) and an eddy current inspection (ECI) of the low-pressure compressor (LPC) fan hub the next time the engine is separated at the M-flange and the LPC fan hub has accumulated 2,000 or more flight cycles since last FPI and ECI. Pratt & Whitney Alert Service Bulletin PW4G-112-A72-351, dated February 22, 2018, provided the method of compliance per the P&W Cleaning, Inspection and Repair manual. The FPI and ECI was last accomplished on December 2, 2015[7]. Total time 65,628 and total cycles 10,782.

AD 2019-03-01 requires initial and repetitive thermal acoustic inspections (TAI) for cracks in certain 1st stage low-pressure compressor blades and removal of those blades that fail inspection. The AD effective date was March 22, 2019, and the AD referenced P&W Alert Service Bulletin PW4G-112-A72-268 as the method of compliance. The TAI for the set of blades on engine SN 777047 was last accomplished on May 26, 2016[8], at Pratt & Whitney. At that time blade serial number CBDUAU9992 had accumulated 63,903 hours and 12,400 cycles.

After the event the FAA issued AD 2021-05-51 with an effective date of March 24, 2021, which followed the immediate adopted emergency AD 2021-05-51, issued on February 23, 2021, that required, before further flight

[6] Airworthiness Directive (AD) is a regulatory notice sent out by the FAA informing the operator of an action that must be taken for the aircraft to maintain its airworthiness status.
[7] The AD states to comply within the compliance times specified, unless already done. The section of the Cleaning, Inspection and Repair manual that details both the ECI and FPI instructions was last revised March 15, 2014.
[8] Service bulletin A72-268, for the TAI was originally issued July 15, 2004. The AD states to comply within the compliance times specified, unless already done.

to perform a TAI for cracks in the LPC blades and removal of those blades that fail inspection.

The following is a list of Service Bulletins associated with the Fan Blades:

Service Bulletin	Title	Action
PW4G-112-72-66	Engine Fan Blades, LPC - Airfoil Leading Edge Recontour	Superseded by 72-90
PW4G-112-72-90	Engine Blade Assembly, 1ST Stage LPC – Modification of to re-camber the Outer Leading Edge to increase the fan rotor flutter margin	Terminating action for SB 72-66. Project completed 6/4/2013[9]
PW4G-112-72-100	Blade, 1st Stage LPC - Allowed replacement of blade with a more durable blade common with higher thrust engines.	One blade position 18 was installed 8/13/2016
PW4G-112-72-246	Engine Blade Assembly, 1st Stage LPC - Ultrasonic Inspection to Detect Airfoil Cracks	superseded by 72-268
PW4G-112-A72-268 R6	Engine Blade Assembly, 1st Stage, LPC - TAI Inspection to Detect Airfoil Cracks	Initial and repetitive action, AD 2019-03-01

Q. Engine Maintenance and Inspection Program

United Airlines FAA approved Engine Maintenance Program is based on the Pratt and Whitney PW4000-112 Maintenance Planning Document.

1) Fan Blade lubrication every 36 months. Last accomplished August 11, 2018.
2) Perform a detailed inspection of Fan Blades every 3600 flight hours. The inspection includes the fan blade airfoil surface, examine tips for tears, nicks, dents, and other damage. Examine the leading and trailing edges and airfoil surfaces for nicks, dents, cracks, and other damage. Last accomplished on January 14, 2021, no damage noted.
3) Inspection for Leading/Trailing Edge Damage when it exceeds 3,600 hours when in Engine Shop. Last accomplished May 18, 2016, on 19 of the 22 blades including SN CBDUAU9992.

[9] COA D-9248-0 closing date for all fan blades.

4) Fan Blades removed and sent for heavy maintenance when it exceeds 5,000 cycles when in Engine Shop. Last accomplished May 18, 2016.

Note: Fan Blade Thermal Acoustic Inspections are mandated by Airworthiness Directive. See section P.

United Airlines maintenance program includes a Detailed Visual Inspection on the Fan Cases, Acoustic Liners, Fan Exit Fairing and Fan Exit Guide Vanes on each engine with an interval of 27,300 hours. Last inspected August 11, 2018. No findings in the records.

Engine fan case rub strip General Visual Inspection (GVI) required every 3,600 hours. The rub strip was replaced January 6, 2021. The GVI was last accomplished January 14, 2021.

GVI of the fan case Kevlar wrap exposed areas for degradation on each engine with an interval of 27,300 hours. The item is packaged with C-check and last accomplished August 11, 2018. No findings on either No.1 or No.2 engines.

Perform a visual check of the right engine thrust reverser for health per AMM. It is a 24-month item. Packaged with the A-check (600 FH). Last accomplished January 15, 2021, with no findings.

R. Inlet Cowl Maintenance Inspection Program

United Airlines uses the Boeing 777 Maintenance Review Board Report to maintain the airworthiness of the Inlet Cowls. A zonal general visual inspection is accomplished every 1,500 flight hours and is packaged with the 1A1 check. The task was last accomplished on January 16, 2021.

A review of flight logs on the number two engine reported on January 2, 2021, a section of a previous repair to the attrition liner at the 1 o'clock position missing. The repair was intact with a section measuring 0.74" x 2.85" missing. The item was deferred and subsequently the rub strip was repaired on January 6, 2021, at San Francisco, CA.

Service Bulletin 777-71-0002 (Inlet Forward Bulkhead Insulation Inspection and Replacement) was accomplished December 4, 1996, at Denver, Colorado.

S. No.2 Engine Hydraulic Shutoff Valve

The engine hydraulic valve is tested every 18,000 flight hours. The procedure is to pull the fire handle for the engine being tested and to observe the hydraulic shutoff valve position as displayed on the engine indicating and crew alerting system (EICAS) to ensure that the valve has closed. Return the fire handle to the normal position and observe the shutoff valve position as

displayed on EICAS to ensure that the valve has opened. The number two engine hydraulic shutoff valve was last tested on October 30, 2016. Aircraft total time 83,883:23 and 14,962 cycles.

Hydraulic shutoff valve, part number S271W741-22, serial number T50052 was installed August 19, 1999, to comply with AD 99-15-10. Aircraft total time was 17,148 and 3,465 cycles.

T. No.2 Engine Fan Blades

The fan blade set was last overhauled by P&W on May 18, 2016. According to the 8130 tag 19 of the 22 blades including serial number CBDUAU9992 had a total time of 77,827 hours, total cycles 15,379 and time since overhaul of 0.00 hours. The fan blade set was installed on engine serial number 777047 on August 13, 2016. The set of fan blades remained as a set from September 1, 2000, up to the event.

U. Fan Blade Part No. 55A801B-01, SN CBDUAU9992 History

The fan blade was originally installed on engine serial number 777027 on August 25, 1995. The table below shows the engine installation history of the fan blade from initial installation up to the event.

Date Installed	Engine Serial No.	TSN	CSN	Date Removed
8/25/1995	777027	0	0	10/22/1996
10/30/1996	777027	5,332	1,148	8/21/1997
4/24/1998	777027	8,690	1,843	9/17/1998
9/29/1998	777027	10,696	2,226	10/7/1998
11/20/1998	777027	10,851	2,254	9/30/1999
9/1/2000	777026	14,698	3,039	10/30/2000
11/06/2000	777026	15,195	3,135	1/5/2001
2/8/2001	777026	15,874	3,269	2/12/2003
7/10/2003	777026	24,629	4,941	1/15/2004
1/21/2004	777026	26,756	5,323	7/14/2004
4/29/2005	777034	28,602	5,659	3/23/2007
3/26/2007	777034	36,593	7,025	2/12/2008
2/13/2008	777034	40,009	7,756	3/31/2008
7/11/2008	777034	40,556	7,874	9/8/2008
12/22/2008	777034	40,846	7,920	5/16/2014
11/24/2014	777008	59,996	11,685	1/25/2016
8/13/2016	777047	63,903	12,400	2/20/2021 (Event)

According to the 8130-tag dated May 18, 2016[10] the set of fan blades including SN CBDUAU9992 were overhauled in accordance with Pratt & Whitney manual 51A750 Rev 70 dated March 15, 2016, and United Technical Control (TC) document TC 55A901 section 72-31-82/RU03 dated February 21, 2012.

TC 55A901 provides requirement instructions for an outside vendor to clean, inspect, repair and make serviceable PW4000 (112") stage 1 LPC fan blades. At the time of the last shop visit in 2016 the requirement to perform the fan blade TAI inspection was not mandated by the FAA.

Included in the TC was to perform a Phase 1 Ultrasonic Testing (UT) Inspection.

Clean, fully inspect (visual, NDT and dimensional), repair and make serviceable stage 1 LPC fan blades per Pratt & Whitney PW4000 Series Engine Clean, Inspect and Repair (CIR) Manual, P51A750, latest revision, Chapter 72-31-82, and as listed below:

Note: Accomplishment of PW4G-112-A72-268 or CIR 72-31-82 Insp-02 performs the Thermal Acoustic Inspection.

1) The following NDT requirements above and beyond and in addition to those specified in the Pratt & Whitney manuals and Internal Engineering Notices (IENs) referenced herein are also mandatory per the TC document:

a) Fluorescent penetrant inspection (FPI) penetrant dwell times shall be 30 minutes minimum.

b) The following FPI process controls shall be implemented and maintained:

(1) FPI System Performance: PSM-type panels shall be utilized for daily FPI system performance checks. They shall not be processed using NAWD
(non-aqueous wet developer). Only dry powder developers are allowed. The minimum number of indications and background fluorescence requirements shall meet the requirements of ASTM E1417.

(2) Penetrant Brilliance: The use of open, immersion dip tanks, requires a quarterly (every 3 months) penetrant brilliance check and shall be accomplished using a set of Twin KDS (known defect standard) panels manufactured by Sherwin Inc. or equivalent.

[10] The TAI inspection process was first revised June 2017 as Rev A. Rev B, C, & D issued after the HNL event.

2) For PN 55A901 incorporate Service Bulletin PW4G-112-72-90, latest revision. Re-identify parts as PN 55A801

3) For PN 55A801, 55A801-001, 55A901, 55A901-001, 56A201, 56A201-001, 56A221, and 52A241 perform Thermal Acoustic Image (TAI) Inspection per Service Bulletin PW4G-112-A72-268, latest revision.

4) For PN 55A801, 55A801-001, 55A901, 55A901-001, 56A201, 56A201-001, 56A221, and 52A241, perform P&W Phase 1 Ultrasonic Testing (UT) Inspection.

Note: P&W Phase 1 UT Inspection will eventually be replaced by P&W Phase 2 UT Inspection.

5) For PN 55A801, 55A801-001, 55A901, 55A901-001, 56A201, 56A201-001, and 56A221 (except for the serial numbers of PN 56A221 listed in Table 1 of the SB), unless previously accomplished, perform inspection per Service Bulletin PW4G-112-A72-286, latest revision.

6) If applicable, the following Pratt & Whitney IENs/EAs are approved for use as restricted therein. All restrictions and/or additional requirements in this United OSV CIR document still apply:
IEN 97KB418E
IEN 02KC386
IEN 01KB089
IEN 99KZ032A
IEN 02KCW48
IEN 03KB020
IEN 04KC597
IEN 05KC735A Hollow Fan Blade Airfoil Damage Accept As-Is Serial Number CBDUBW7856.
EA11KC320 Incorporation of Thermal Acoustic Image (TAI) Inspection per Service Bulletin PW4G-112-A72-268 for PN 52A241.
EA11KC925D Fan Blade Concave Side, Cavity Sag Accept As-Is, Serial Number CBDUBD4647.

7) The following documentation is required for parts returned to United:

   a) An FAA Authorized Release Certificate certifying conformance to applicable United and non-United specifications.
   PW4077 ENGINE REPAIR MANUAL
   EC7231-01773
   EFF: PW4077, 4090 PW4077 72-31-82/RU03
   EFF: PAGE 4 OF 4

SHOP EFF: MJ, OSV 04/21/21

b) Perform receiving acceptance:

Note: PW4077 Engine Repair Manual dated February 21, 2012, or later is acceptable for the inspection, repair, and receipt of the part.

c) Visually inspect for obvious shipping damage.
d) Examine each fan blade root bottom for presence of A72-286 identification. This confirms that Service Bulletin PW4G-112-A72-286 has been accomplished. If the A72-286 identification is not present, then the part must be returned to the repair vendor.
e) If the part is acceptable, perform all Engine Management System (EMS) transactions and enter the appropriate dimensional data.
f) EMS SB72-268 must be signed off if the 8130-3 shows accomplishment of PW4G-112-A72-268 or accomplishment of CIR 72-31-82 Insp-02. Reference AD 2019-03-01 and AD 2021-05-51.

V. Engine PW4077 Serial Number 777047 History

History for SN 777047 engine shop visits is shown in the table below.

Aircraft	Start Date	End Date	Reason	TSN	CSN
N776UA	9/19/1997	11/14/1997	Chronic 2.5 Bleed	6,007	1,252
N770UA	10/28/1997	9/17/1998	Fail – Compressor Stall	6,076	1,271
N770UA	12/20/1999	5/22/2000	Fan Exit Guide Damage	13,129	2,670
N772UA	9/08/2002	10/11/2002	Fan Case Replace	21,524	4,280
N772UA	08/29/2004	2/25/2005	Performance	28,009	5,490
N214UA	8/23/2005	10/06/2005	Convenience	29,842	5,862
N781UA	6/29/2008	10/28/2008	Performance	41,440	7,807
N210UA	8/22/2010	8/30/2010	Fan Blade Replacement	47,624	9,047
N210UA	9/26/2012	2/12/2013	ECM Parameter Shift	55,460	10,586
N781UA	3/1/2016	8/13/2016	T2 Vane Crack/Erosion	67,844	12,283

W. No.2 Engine Inlet and Cowl Record Review

The number two engine records were reviewed to document any events such as bird strikes, hail damage, high vibration, lightning strikes or damage to the inlet due to ground equipment. The following are noted.

1) August 31, 2020 – Three blades removed from No.2 engine to facilitate other maintenance. Reinstalled blades per AMM 72-31-02-000-801-N00. No vibration run required.
2) May 25, 2020 – High power run required due to N1 vibration has increased to near max guideline. Accomplished visual inspection of the No.2 engine, no discrepancies noted. Accomplished LPC trim balance per AMM 72-31-00-700-801-N00. Verified weights and locations for No.2 engine match AVM stored data. Using balancing solution from flight AVM data reconfigured weights. Accomplished high power engine vibration. Vibration level improved. All well within limits.
3) November 21, 2019 - Engine No.2 High power run required. N1 vibration has increased near max guideline. At next convenient opportunity, visually check engine exhaust for debris and check engine inlet and fan for damage or ingestion. Ensure all accelerometers are secured and connected. Take appropriate corrective action. If visual ok, accomplish a fan trim balance ref AMM 72-31-00 p501. If no maintenance has been done on fan and an average of 6 flight legs available in Maintenance Access Terminal (MAT), pre-balance survey run is not necessary. Try to reduce vibration. May need weights M&E 26-7231-3-0010 thru -0015. Carried by ELB. No.2 engine inspected engine inlet and exhaust for damage or debris. Found none. Performed initial weight vibration calculation. Installed new weights. Vibration improved. Max peak vibration 1.5 @ 1.36 EPR during high power run AMM 71-00-00-720-802 test 8. Accomplished LPC trim balance IAW AMM 72-31-00-700-801-N00. All parameters within limits.
4) September 24, 2019 - Left windshield possible birds strike or very large bug. Needs cleaning. Inspected radome, windshield areas. No evidence of bird strike. Cleaned flight deck windshields.
5) August 3, 2019 – Paper FOD by both engines. No indication of ingestion. Inspected both engine inlets and exhaust and did not find any discrepancies. Okay for service.
6) June 5, 2018 – Bird strike, except at engine inlet. Possible bird strike aircraft left. Possibly gear. Large hawk or eagle. Bird strike at 100 feet, approximately 170 KTS. After accomplishing a walkaround and detailed inspection of both gears, engines, and fuselage. No indication of a bird strike was noted.
7) November 30, 2017 – Engine vibration monitor status message. Accomplished maintenance procedure AMM 31-61-00-800-802. Checked okay.

8) August 17, 2017 – Double bird strike on radome. Occurred during flare. Inspected strike area on radome and no delamination or damage noted. Checked engine inlets and no damage or evidence of ingestion noted, ref. AMM 5-51-18.
9) September 4, 2016 – FOD by right engine. No indication of ingestion. Inspected right engine inlet and outlet for FOD and any damage. No FOD and damage noted.

X. Compressor Stall or Engine Surge

Records were reviewed for each engine when the set of blades were installed to document any reported engine compressor stalls and/or engine surges. The following are noted.
October 17, 2010 – Engine SN 777034, silent surge detected during takeoff. No discrepancies found during visual inspections, no borescope accomplished and no pilot report.
June 6, 2012 – Engine SN 777034, Surge during taxi to gate. No discrepancies found during visual or borescope inspections.

Y. No.2 Engine Thrust Reverser Lower Bifurcation Area

Records for the number two engine thrust reverser lower bifurcation area were reviewed to document any repairs in the area of the fire seal. The following items dated 3/16/2016 are noted.
1) Bifurcation fire sleeve is torn. Replaced sleeve.
2) Drain mast tubing coking lower end. Cleaned and removed coking.
3) Drain mast clamp (1 each) is loose or worn. Replaced clamp.
4) Drain mast tubes chaffed. Removed sharp edges (blended).

Z. Engine Runup Maintenance Training

The United 777-maintenance training student book for engine high power engine runs was reviewed paying particular attention to crosswind precautions. The following training is noted. Wind direction – When possible, the engine must be operated with the inlet pointed into the wind as specified in the figure, "Relative Wind Direction during Engine Operation", reference attachment one. The figure illustrates three zones, with the first zone being 30 degrees maximum wind angle either side of the nose, the second zone up to 90 degrees from the nose, and the third zone for wind direction from the aft 180 degrees. The first zone is the recommended zone for stable winds with a 25-knot maximum wind velocity. Further noted that the wind velocity is for stable wind conditions. Decrease the maximum wind limit 5-knots for gusty wind conditions, or until the SVA indication on the EICAS page becomes stable. Stop the engine run if the SVA indication on the EICAS, EPCS page is not stable. Also, stop the engine run if the inlet noise increases, or the inlet sound changes to a blow torch type sound.

The second zone (up to 90 degrees relative) wind limit is 15-knots maximum is permitted with the same restrictions.

The third zone (tail wind) is limited up to flight idle maximum and a 5-knot maximum wind velocity.

AA. Record of Maintenance Engine Runups

There are five AMM engine runup tasks that require high power settings that accelerate through the do not dwell in ranges while accelerating and decelerating. The five tasks are:

1) Test No.4 Power acceleration / deceleration
2) Test No.8 High power vibration survey
3) Test No.9 Power assurance test
4) Test No.13 Main oil pressure test & adjustment
5) Test No.17 Above idle test

Test No.4 Power acceleration/deceleration procedure is a check for the correct engine acceleration and deceleration operation in the permitted times. There is a caution not to do this test if there is a crosswind or tailwind more than 10 knots. The procedure is to slowly advance the thrust of the engine being tested to 1.25 EPR power setting and once stable for 10 seconds make a record of the following indications: EPR, %N1, %N2, EGT, Oil pressure, Oil temperature, Fuel flow, Total air temperature and Pressure altitude. Next perform a snap deceleration with a stopwatch to measure the time. Quickly move the throttle from 1.25 EPR to idle position and record the time when the engine is at 1.08 EPR. The deceleration time must be less than 4 seconds.

Next is the snap acceleration test. The procedure for the snap acceleration test provides instructions to configure the aircraft so the engine operates at flight idle for 5 minutes prior to performing the snap acceleration. Once stable with a stopwatch prepare to measure the acceleration time. There is a caution if the engine surges during this test you must move the thrust lever to idle position in less than one second. Included in the caution is immediately close the circuit breakers so the engine returns to ground idle. If there is an EGT overtemperature, do an emergency shutdown and motor the engine until the EGT is less than 280 degrees C. Quickly move (one second or less) the thrust lever from idle position to the takeoff position. Make a record of the acceleration time when the engine reaches 1.25 EPR. When the engine gets to 1.25 EPR, quickly move the thrust lever back to idle. The acceleration time must be less than 7 seconds.

Test No.8 High power vibration survey procedure is to examine for satisfactory engine vibration from idle power to 1.36 EPR. The vibration is examined during acceleration and deceleration. There is a caution not to do this test if there is a crosswind or tailwind more than 10 knots. There is also the caution if the engine surges during this test you must move the thrust lever to idle position in less than one second. Once the engine has operated for five minutes at idle and is stable for the engine which will be examined, slowly move the thrust lever forward to 1.25 EPR and the engine become thermally stable for three minutes. Move the thrust lever back to idle power and let the engine stable for six minutes. Look at the performance page on EICAS for the N1 and N2 vibration parameters and prepare to make a record of the vibration values when they peak. Slowly move the thrust lever forward to takeoff power but do not exceed 1.36 EPR. The acceleration should be between 90-120 seconds. During acceleration, make a record of the N1 and N2 speeds at each of the vibration peaks. Slowly move the thrust lever to minimum idle. The deceleration time should be between 90-120 seconds. During deceleration, make a record of the N1 and N2 speeds at each of the vibration peaks. Do the survey again at the peak N1 and N2 vibration points. Use the record that you made before to slowly move the thrust lever forward to each of the N1 and N2 speeds with peak vibration values. Let the engine become stable for 30 seconds at each of the peak vibration speeds. Make a record of the peak vibration values and the N1 and N2 speeds after the engine is stable. Slowly move the thrust lever to the idle position and operate the engine at minimum idle for five minutes.

Test No.9 Power Assurance test procedure to make sure the engine instrumentation, control and secondary systems function correctly. There is a caution for engine surges under certain conditions, that a ground vortex can go into the engine core and a surge can occur. If the engine surges, damage to the engine can occur. Once both engines have been operated for five minutes at idle and are stable make sure all engine parameters are in the permitted limits. Make a record of the EPR, EGT, N1 speed, N2 speed and fuel flow. Operate the engine at flight idle power by opening the radar altimeter circuit breaker and extend the trailing edge flaps to the 25-unit position. Let the engine operate at flight idle for two minutes. After the engine operation becomes stable make a record of the EPR, EGT, N1 speed, N2 speed and fuel flow. Retract the flaps and close the radio altimeter circuit breakers. Operate the engine at 1.25 EPR by slowly advancing the throttle and let stabilize at 1.25 EPR for two minutes. Make a record of the EPR, EGT, N1 speed, N2 speed, and fuel flow. Return the thrust lever to idle position. After completion compare the recorded engine data with the power assurance tables for ground idle, flight idle and 1.25 EPR power assurance.

Test No.13 Main Oil Pressure Test and Adjustment is a check of the main oil pressure at N2 speeds more than idle speed. There is a caution for engine surges under certain conditions, that a ground vortex can go into the engine core and a surge can occur. If the engine surges, damage to the engine can occur. Once both engines have been operated for five minutes at idle and are stable make sure all engine parameters (N1, N2, EGT oil pressure and fuel flow) are in the permitted limits. With the engine at idle make a record of the N2 speed and the oil pressure. Slowly move the thrust lever forward to 1.25 EPR. Let the engine become stable. Make a record of the N2 speed and the oil pressure. Move the thrust lever to the idle position and let idle for five minutes before shutdown. Examine the record of the oil pressure and N2 speed data. If the oil pressure data for the engine is in the permitted limits, the test is done. If not within limits, the oil pressure adjustment is necessary.

Test No.17 Above Idle Test is a check for satisfactory engine operation at more than idle power. There is a caution for engine surges under certain conditions, that a ground vortex can go into the engine core and a surge can occur. If the engine surges, damage to the engine can occur. Once both engines have been operated for five minutes at idle and are stable make sure all engine parameters (N1, N2, EGT oil pressure and fuel flow) are in the permitted limits. Slowly move the thrust lever forward to 1.25 EPR. Let the engine become stable and make a record of the N1 speed, N2 speed, EGT, Oil pressure, and Oil temperature. Move the thrust lever to the idle position and operate at minimum idle for five minutes prior to shutting the engine down. Examine the recorded values against the permitted limits.

The engine run-up records were reviewed from July 2002, which was the earliest available record up to the event. The following table lists each aircraft that had the fan blade installed at the time each of the above tests were conducted including the aircraft, engine serial number, date, and station. The record of maintenance does not include the time of day that the engine run took place, nor does it include high power engine runs performed in the test cell prior to installation on the aircraft.
(See next page)

Aircraft	Position	ESN	Date	Action	Station
2366	2	777026	7/25/2002	"Hi-powered run"	SFO
2366	2	777026	8/8/2002	"Performance assurance test"	SFO
2377	2	777026	7/8/2003	Test No.10 (includes test No.4 and No.9)	SFO
2376	2	777026	1/17/2004	Test No.10 (includes test No.4 and No.9)	SFO
2513	1	777034	2/9/2008	Test No.9	HNL
2372	2	777047	11/27/2019	Test No.8	SFO
2372	2	777047	5/25/2020	Test No.8	DEN

Notes: 1. Dates are based on log page open/close dates.
2. Quoted actions were found in log page text.

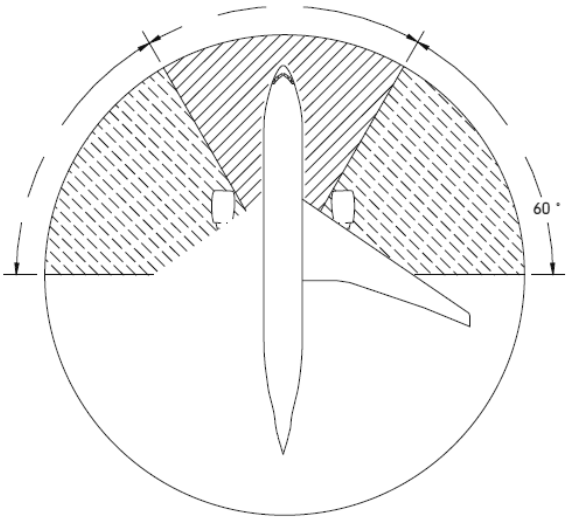
Based on the dates for each high-power engine run the following table shows the engine run date, station, and the winds (direction, speed & gusts) in four-hour increment using UTC observation time.

Date	Station	23:53Z	03:53Z	07:53Z	11:53Z	15:53Z	19:53Z
7/25/2002	SFO	260 16G24KT	250 14KT	240 09KT	240 10KT	240 08KT	280 17KT
8/8/2002	SFO	270 18KT	280 13KT	270 08KT	250 04KT	010 03KT	040 05KT
7/8/2003	SFO	250 20G28KT	260 09KT	270 06KT	260 14KT	290 10KT	290 13KT
1/17/2004	SFO	090 04KT	070 06KT	150 04KT	140 03KT	080 11KT	000 00KT
2/9/2008	HNL	070 12KT	060 09KT	050 10KT	000 00KT	070 08KT	070 1KT
11/27/2019	SFO	150 10KT	250 08KT	270 14KT	190 08KT	290 17G26KT	300 09KT
5/25/2020	DEN	350 13KT	240 06KT	000 00KT	260 06KT	000 00KT	340 06KT

Submitted by: Gregory Borsari
Aviation Accident Investigator

Attachment 1

Engine Runup Wind Limits



RELATIVE WIND

RECOMMENDED (25 KNOTS MAXIMUM WIND VELOCITY) [1]

PERMITTED (15 KNOTS MAXIMUM WIND VELOCITY) [1]

LIMITED UP TO THE FLIGHT IDLE (5 KNOTS MAXIMUM WIND VELOCITY)

[1] THE WIND VELOCITY IS FOR STABLE WIND CONDITIONS. DECREASE THE MAXIMUM WIND LIMIT 5 KNOTS FOR GUSTY WIND CONDITIONS, OR UNTIL THE SVA INDICATION ON THE EICAS EPCS PAGE BECOMES STABLE.

STOP THE TRIM RUN OF THE ENGINE IF THE SVA INDICATION ON THE EICAS EPCS PAGE IS NOT STABLE. ALSO STOP THE TRIM RUN IF THE INLET NOISE INCREASES, OR THE INLET SOUND CHANGES TO A BLOWTORCH-TYPE SOUND. DECREASE THE POWER TO IDLE AND EXAMINE THE RELATIVE WIND DIRECTION AND SPEED. STOP THE ENGINE AND CHANGE THE POSITION OF THE AIRPLANE TO POINT IN THE DIRECTION OF THE WIND, IF IT IS NECESSARY, BEFORE YOU COMPLETE THE ENGINE TRIM RUN.

YOU CAN OPERATE THE APU DURING THE ENGINE OPERATION ON THE GROUND.

Power Plant Operation Limits - Wind Limits