NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C. 20594

October 5, 2022

Group Chairman's Factual Report

POWERPLANTS

DCA21FA174

A. ACCIDENT

Location: Honolulu, Hawaii
Date: July 2, 2021
Time: 0145 Hawaii standard time (HST); 1145 coordinated universal time (UTC)
Airplane: Boeing 737-275C, N810TA, Rhoades Aviation Inc, dba Transair Flight 810

B. POWERPLANTS GROUP

Group Chairman	Carol M. Horgan National Transportation Safety Board Washington, DC
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C. DETAILS OF THE INVESTIGATION

1.0 Engine information

The airplane was powered by two Pratt & Whitney (P&W) JT8D-9A turbofan engines.

1.1 Engine description

The JT8D-9A is an axial flow, dual rotor, low bypass ratio, fully ducted turbofan featuring a 6-stage low compressor driven by a 3-stage low turbine, a 7-stage high compressor driven by a single-stage high turbine, and a can-annular combustor.[1] Both rotors turn in the clockwise direction.[2] A Hamilton Standard JFC60-2 hydromechanical fuel control unit (FCU) governs the high pressure rotor speed and schedules fuel flow to provide the thrust demanded by the thrust lever setting in the cockpit. The JT8D-9A is takeoff rated at 14,500 pounds thrust. See Figure 1.

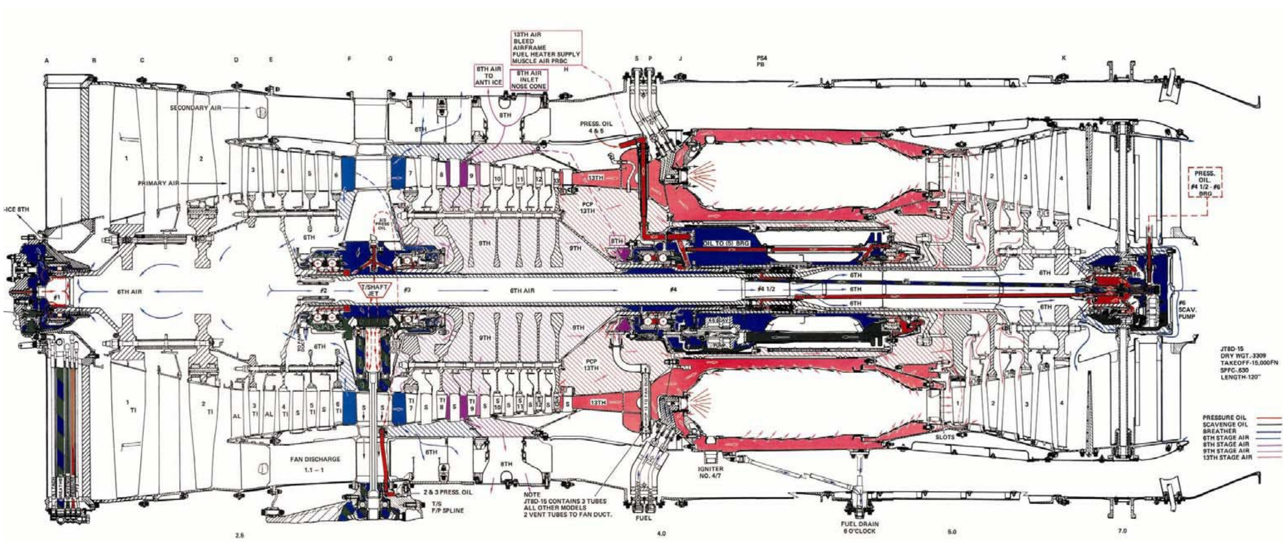

Figure 1 JT8D-9A engine cross-section

1.2 Engine data

See Table 1.

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[1] The low compressor stages are referred to as C1, C2, C3, C4, C5, and C6. The high compressor stages are C7 through C13. The high turbine stage is T1. The low turbine stages are T2, T3, and T4.

[2] References to direction or position are as viewed from the rear of the engine looking forward unless otherwise noted.

Table 1 Engine data

position	engine serial number (ESN)	date of manufacture	time since new (TSN)	cycles since new (CSN)	time since last shop visit
No. 1	674548	06/24/71	32,305	33,670	1,055
No. 2	657227	01/10/68*	70,827	101,368	1,055

*Engine S/N (ESN) 657227 was manufactured as a JT8D-7

The engine dataplates were not recovered. Serialized parts were matched with engine repair station records and airplane service records to confirm ESNs and installed positions. See Attachment 1, Serial Number Identification.

1.3 Engine service history

1.3.1 ESN 674548

A review of the operator's service records found that the last shop visit for ESN 674548 was in 2019, for compliance with Airworthiness Directive (AD) 2003-12-07[3] and life limited component replacements. During this visit, the T1, T2, T3 and T4 disks were replaced with serviceable disks and all modules except the low compressor were disassembled and inspected. The low compressor was replaced with a serviceable module. The post-shop visit test cell run demonstrated that ESN 674548 met engine manual requirements. The exhaust gas temperature (EGT) takeoff power margin was +18F. ESN 674548 was returned to service on September 19, 2019.[4] It was installed in the No. 1 engine position of N810TA on October 28, 2019.

1.3.2 ESN 657227

Review of the ESN 657227 service records found a 2019 shop visit for compliance with AD 2003-12-07. A hot section inspection (HSI) was performed during this visit. The HSI did not include disassembly of the T1 disk assembly. Nine T1 nozzle guide vanes were replaced and the T1 rotor was balanced. The low compressor and low turbine modules were approved for continued service. The post-shop visit test cell run demonstrated that ESN 657227 met engine manual requirements. The exhaust gas temperature (EGT) takeoff power margin was +5F. The engine was returned to service

[3] AD 2003-12-07 is a repetitive inspection of the high compressor disk for corrosion.

[4] APECS Engine Center, LLC Repair Station No. E13R628Y, Work Order 193000

on April 5, 2019[5] and was installed in the No. 2 position of N810TA on September 20, 2019.

The records showed that ESN 657227 underwent a HSI in May 2014. A used-serviceable T1 disk was installed at that time.[6] The engine was sold following the 2014 work and was later acquired by Transair.

A search was made for the inspection details from the T1 blade inspection/disk assembly work performed in 2014. Of particular interest were details concerning an engine manual T1 blade internal sulfidation inspection (Task 72-52-01-24-001). A summary shop visit record (engine records mini pack) from this shop visit was available. However, detailed records of shop inspections are not typically included in a mini pack. The records had exceeded the FAA-required retention period and were no longer available.

A review of the aircraft logbooks and the Federal Aviation Administration Service Difficulty Report database for the six months preceding the accident found no pertinent engine discrepancy reports.

For further details about engine maintenance, see the Maintenance Group Chairman's Factual Report, NTSB public docket DCA21FA174.

1.3.3 Engine performance trending

Engine health monitoring (EHM) post-maintenance performance baselines were established on October 30, 2019. The engines remained on wing until the accident flight. The final airplane EHM status report showed no faults detected and NORMAL status for both engines. See Attachment 2, Camp Systems EHM Fleet Status Report for June 30, 2021.

The raw EHM data were submitted to P&W for review. P&W reported that the No. 1 engine EGT averaged 18F higher than the No. 2 EGT, and that, for most flights, both engines had operated slightly below, but close to, the engine manual cruise limit of 977F.

2.0 Evidence identification

A wreckage debris field was located on a sloped shelf approximately 350 feet below the ocean surface about five nautical miles southwest of HNL.

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[5] APECS Engine Center, LLC, Work Order 181000

[6] Turbine Engine Services, Inc. Repair Station No. Q6GR293Y, Work Order 1473

The engine components were identified in video images recorded on July 8, 2021. The engine that was later confirmed as the No. 1 engine appeared intact from the inlet case to the turbine exhaust case (TEC) and exhaust cone.[7] A thrust reverser lying nearby was identified by its stang fairing configuration as the No. 1 thrust reverser. The thrust reverser was in the unactuated (closed) position. See Figure 2.

Figure 2 No 1 engine and thrust reverser

The engine later confirmed as the No. 2 engine was missing its inlet case, forward fan case, and rear fan case, exposing the fan (C1, C2) stages. The C1 blades were fractured near the platform. Visible C2 blades were bent in the direction opposite rotation. The main accessory gearbox (MGB) was visible, indicating that the engine was inverted. The engine was otherwise intact from the fan rotor to the TEC and exhaust cone. See Figures 3 and 4.

[7] The use of "intact" when describing the condition of hardware indicates that a part or assembly is entire, complete.

Figure 3 No. 2 engine, inverted, showing exposed fan and MGB

Figure 4 No. 2 engine, rear view

The liberated No. 2 engine inlet/fan casing section, the No. 2 engine thrust reverser and both nose cowls were also identified. The No. 2 engine thrust reverser was in the closed, unactuated position. See Figure 5.

Figure 5. Unactuated No. 2 engine thrust reverser

3.0 Fuel test

Transair reported that airplanes N809TA and N810TA were fueled from its No. TAC2 fuel truck on the day of the accident. Transair and FAA representatives witnessed a fuel sample being taken from a Transair N809TA sump tank on July 3, 2021. The fuel sample was submitted to the Naval Supply & Systems Command (NAVSUP) fuel laboratory at Pearl Harbor for evaluation. The lab determined that the fuel met ASTM D1655 specifications. See Attachment 3, NAVSUP Fuel Lab Report, July 7, 2021.

4.0 Evidence recovery

The powerplant and nacelle components were recovered from the ocean October 16, 2021. Members of the Powerplants Group received the evidence at the Port of Honolulu on October 17, 2021. The components were rinsed with fresh water and their external condition was documented.

4.1 Nose cowls

4.1.1 No. 1 engine nose cowl

A missing fragment of No. 2 engine fan case nose cowl forward attach flange was found attached to one of the nose cowls, identifying it as the No. 2 nose cowl.

The No. 1 nose cowl inlet lip was creased at 3 and at 9 o'clock, crushed aftward and axially split at 6 o'clock, and crushed aftward between 3 and 9 o'clock.[8] Most of the structure aft of the lip was missing between 4 and 8 o'clock. The nose cowl attach flange was missing between 3 and 11 o'clock. Intact areas of the inlet lip displayed no notable soft body impact damage. See Figure 6.

Figure 6 No. 1 engine nose cowl, front view

[8] O'clock positions refer to approximate circumferential locations as viewed from the rear of the engine looking forward.

4.1.2 No. 2 engine nose cowl

The No. 2 engine nose cowl inlet lip was axially split at 6 o'clock and creased at 9 o'clock. The lip was crushed aftward between 4 and 8 o'clock and most of the structure aft of the lip in this area was missing. Intact areas of the inlet lip displayed no notable soft body impact damage. The aft bulkhead was cracked and split at 12 o'clock. The aft flange was fractured and missing between 1 and 9 o'clock. See Figure 7.

Figure 7 No. 2 nose cowl, front view

5.0 Engine shipment

The engines and components of interest were crated and transported by boat to San Diego, and then by truck to Flight Engine Services (FES), a repair station in

Ramona, California. Members of the powerplants group met at FES for engine disassembly examinations on December 1, 2021.

6.0 No. 1 engine

6.1 External inspection

Material consistent with nose cowl sheet aluminum structure was compressed across the No. 1 engine inlet guide vane (IGV) leading edges (LEs) from 2 to 7 o'clock. The nose bullet assembly was missing.

Only remnants of the fan discharge front compressor outer duct and the fan discharge duct remained. The fan discharge outer rear duct was present although the aluminum showed a gray color consistent with corrosion and appeared to be disintegrating. The MGB and MGB-mounted accessories[9] were missing.[10] The pressure ratio bleed control remained installed. All cases were present and there were no indications of fire, uncontainment or case rupture. See Figures 8 and 9.

Figure 8 No. 1 engine as recovered, right side view

[9] The fuel pump and FCU were recovered separately.

[10] The MGB housings are magnesium castings and were destroyed by seawater immersion.

Figure 9 No. 1 engine at Ramona, left/rear view

A hard, glass-like deposit coated all engine surfaces that were exposed to seawater.[11]

6.2 Disassembly observations

6.2.1 Inlet/fan and low compressor

The low compressor front support (No.1) bearing was disassembled. The cage was intact and the roller elements appeared full diameter. The cage exhibited some rust that obscured areas of silver plate; the visible plate showed no discoloration or blistering suggesting exposure to excessive temperatures.

The inlet and fan cases were not significantly ovalized or deformed. The IGVs were straight and undamaged and with no LE or trailing edge (TE) impacts. The C1 blades were full length. See Figure 10.

[11] The coating was identified as coral encrustation, a surface layer formed from the calcium carbonate exoskeletons of organisms that grow on metal objects in subtropical ocean waters.

Figure 10 No. 1 engine, inlet view showing IGVs and C1

Adjacent C1 blade midspan shrouds were overlapped (shingled) at two locations. See Figure 11. There were small LE cusps on several adjacent C1 blades just outboard of the midspan shrouds. Clashing damage was observed on the inboard five inches of C1 blade TEs. See Figure 12.

Figure 11 No. 1 engine showing shingled C1 shrouds

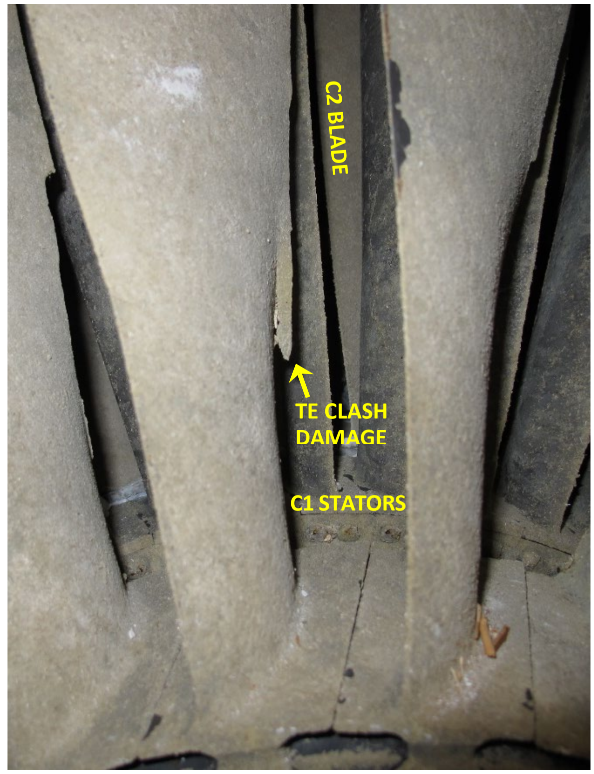

Figure 12 Example of C1 TE clash damage

The C1 stator airfoils were in place and were full length. An eight-stator arc centered on 12 o'clock exhibited light inner span LE clashing damage. The C2 blades were intact and full length, with no notable damage.

The low rotor was seized. Static borescope inspection of the C3 and C4 blades at six evenly spaced locations showed full-length C3 and C4 blades with no obvious distortion. There appeared to be 360° clash damage to the C4 and C5 stator TEs. See Attachment 5, No. 1 Engine Compressor Static Borescope Images.

The C5 and C6 were documented as viewed through the back of the low compressor. The C6 blades were full length and straight between 8 and 11 o'clock, full length and bent opposite the direction of rotation between 11 and 12 o'clock and fractured at the platform between 12 and 8 o'clock.[12] See Figure 13.

[12] The clock positions used in describing the low compressor rotor damage reflect its arrested/seized condition.

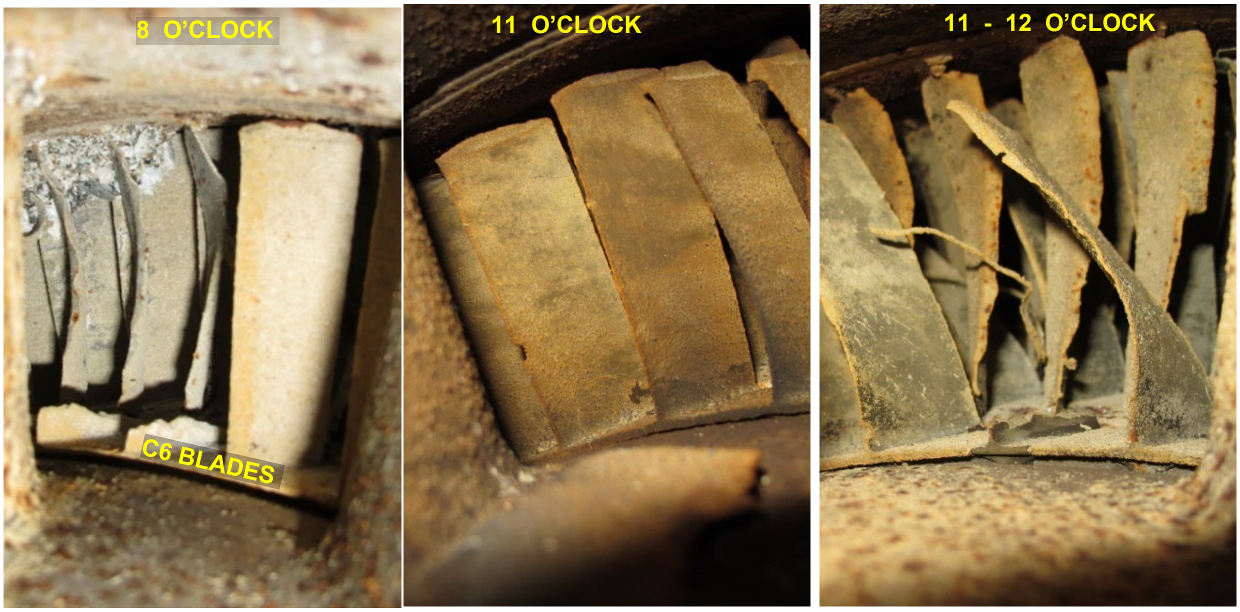

Figure 13 Three views through the aft end of the low compressor showing the last in the arc of fractured C6 blades at 8 o'clock, the last of the straight, intact C6 blades at 11 o'clock and the full-length but reverse-bent C6 blades between 11 and 12 o'clock.

The C5 blades were full length except two that were fractured off at 6 o'clock. The full-length blades were straight between 7 and 11 o'clock and bent opposite the direction of rotation between 11 and 7 o'clock. See Figures 14 and 15.

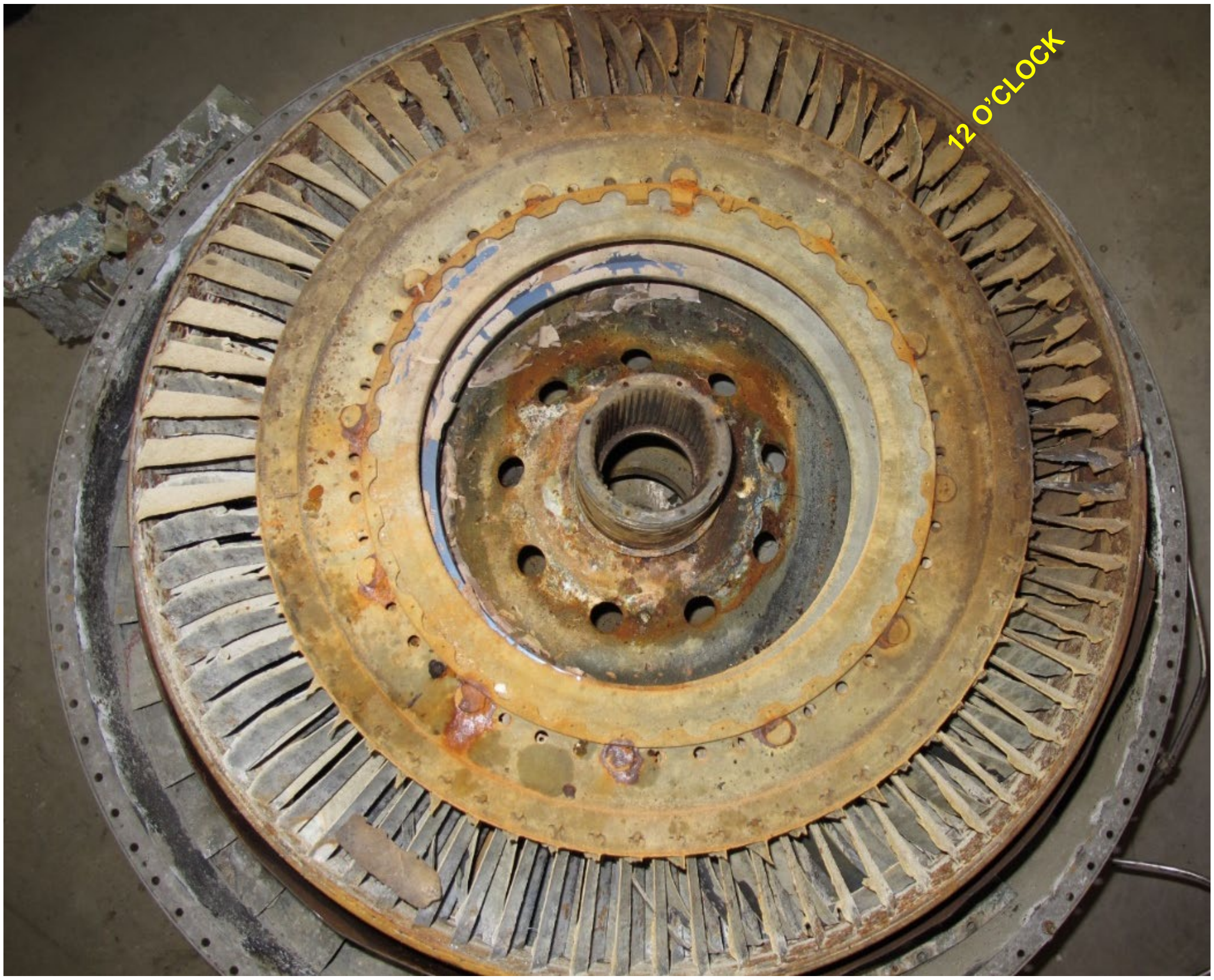

Figure 14 Low compressor viewed from the rear. The clock reference indicates the arrested rotor position

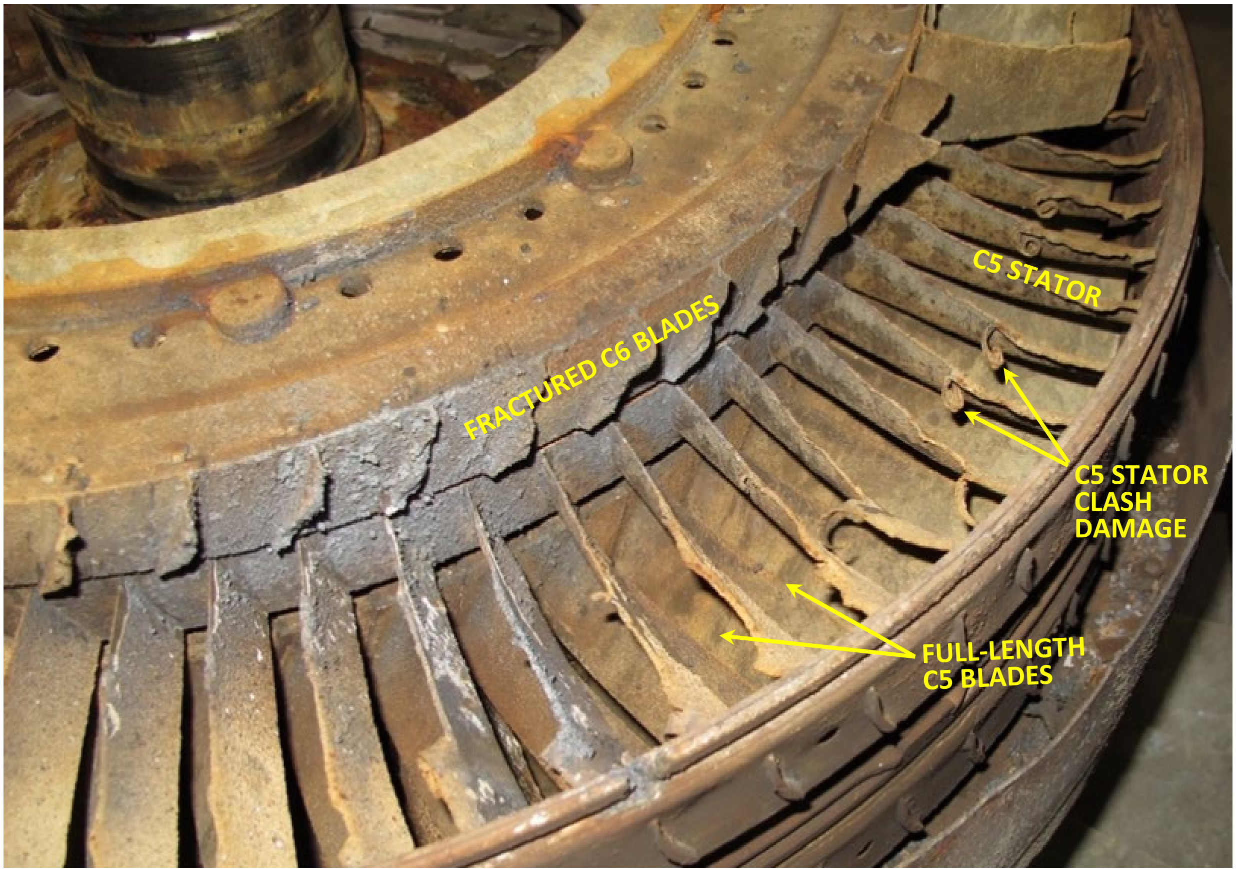

Figure 15 Detail of Figure 14 showing No. 1 engine low compressor C6/C5 damage

Disassembly of the low compressor aft support (No. 2) duplex bearing found intact cages and ball elements. The ball elements appeared full diameter. Rust was observed on the steel components. The silver plating not obscured by rust deposits showed no discoloration or blistering.

The fan exit guide vane case was dented inward between 11 and 12 o'clock and between 12 and 1 o'clock. The vanes were intact; they were coated with a white powder consistent with aluminum corrosion byproduct.

6.2.2 Intermediate case

The intermediate case (IMC) front mount rail was fractured and a segment between 10 and 12 o'clock was missing. The 12 o'clock IMC strut TE was deformed in the clockwise direction. The front mount rail and the strut were rolled forward from 12 to 3 o'clock and the rear skirt was torn forward. See Figure 16.

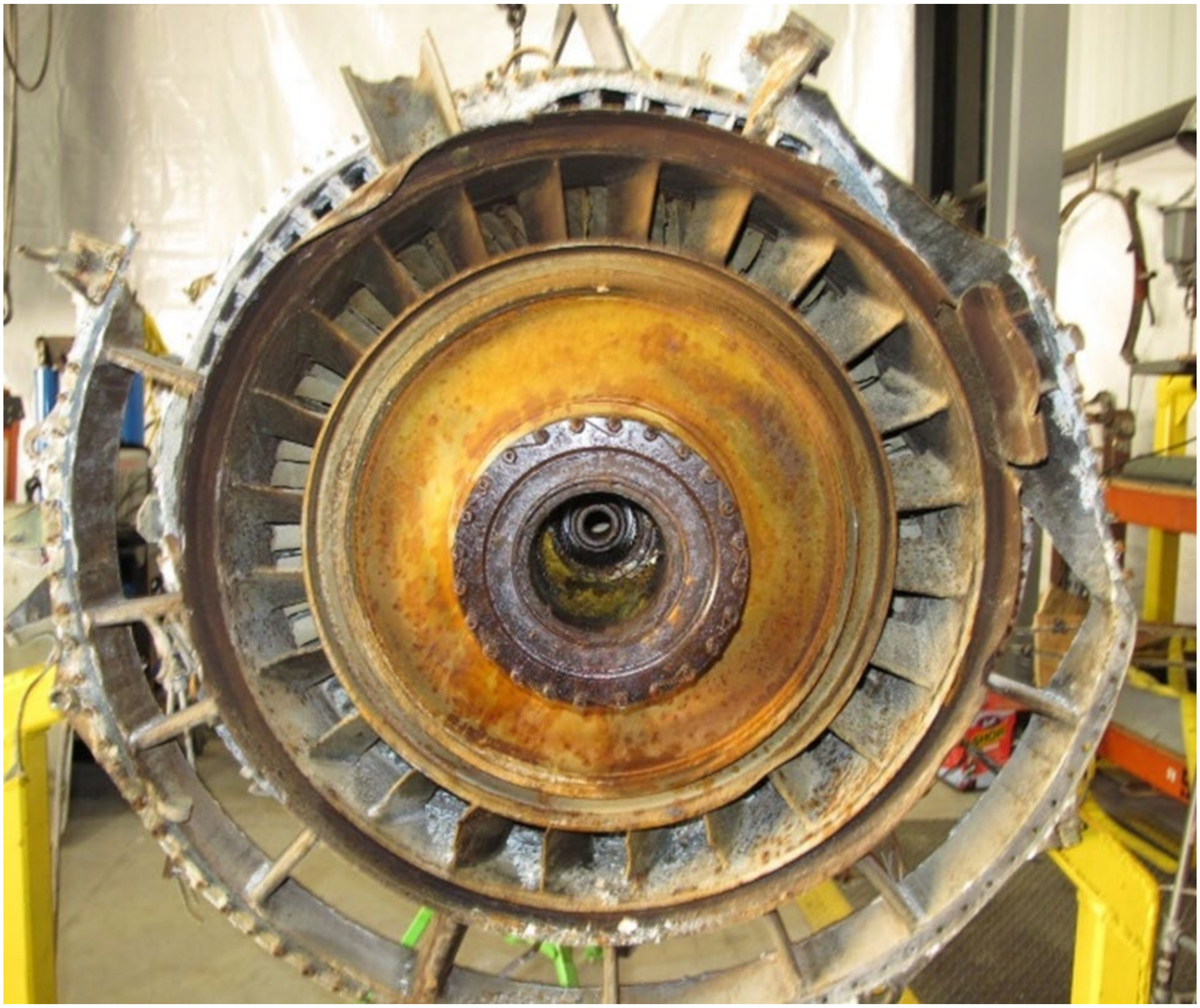

Figure 16 No. 1 engine low compressor aft view showing missing/displaced IMC rail section

Consistent with the IMC front mount rail damage, there was a deep inward dent and case deformity in the IMC front skirt over the aft low compressor stages (C5 and C6). The dent was centered on the strut below the right mount cone bolt, between 1 and 2 o'clock. See Figure 17.

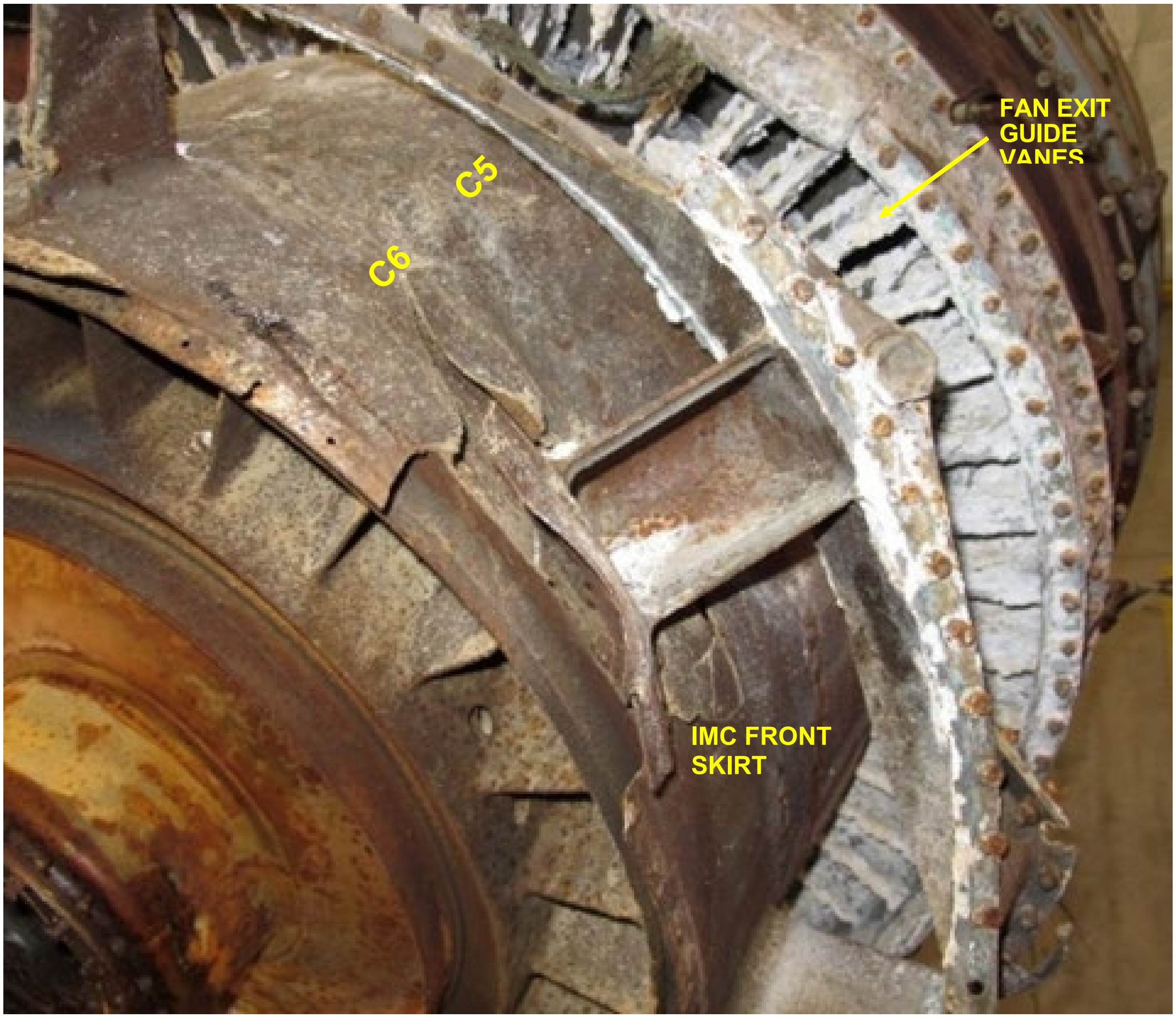

Figure 17 No. 1 engine showing front skirt deformation from 1 to 2 o'clock

The right front mount cone bolt remained attached to the mount rail at 1 o'clock but the threaded tip portion was missing. The IMC front skirt displayed light denting and deformation, but no torn material, between 4 and 6 o'clock. The IMC core struts between 4 and 8 o'clock were buckled.

The N2 power takeoff shaft (tower shaft) inboard bearing rotated smoothly by hand and the outboard bearing could be twisted slightly by hand (no looseness). Visual inspection of the assembled bearings found evenly spaced roller elements that appeared full diameter. The visible silver plate was not blistered or discolored. Steel bearing components were rusted.

6.2.3 High compressor

The high compressor was not disassembled. The high rotor was seized. The C7 was inspected through the high compressor front end. All C7 blades were present, with most exhibiting LE tearing, random bending, and deformation in the direction opposite of rotation. Four random C7 blades were fractured with fracture surfaces deformed opposite the direction of rotation. The C7 stators exhibited TE clashing damage that was deformed in the direction of rotation. See Figure 18. C8 blades viewable past C7 were full length. See Figure 19.

Figure 18 No. 1 engine high compressor front view showing C7 damage

Figure 19 Detail of Figure 18 showing C7 blade LE damage and full-length C8 blades

A limited borescope inspection of high compressor stages C8 through C11 was performed. The observable C8 blades were full length with LE nicks but no obvious bending, the C9 blades were either fractured at the platform or missing from their slots, and the C10 and C11 blades were bent opposite the direction of rotation. See Attachment 4.

The C12 and C13 blades were viewed through the back of the high compressor. All blades were present, and all were bent/deformed opposite the direction of rotation. FES reported that the high rotor front support (No. 3) bearing wiggled in the assembled condition but would not rotate by hand. The bearing was cut, exposing ball elements evenly spaced in the cage and exhibiting local flattening. There was no evidence of bearing seizure. The steel components were rusted. Silver plating not obscured by rust deposits showed no discoloration or blistering.

The high compressor rear support (No. 4) duplex bearing was not disassembled. The aft bearing roller elements appeared evenly spaced and full diameter. The cage exhibited some rust that obscured areas of silver plate. The visible plating showed no discoloration or blistering.

6.2.4 Diffuser/combustor

The diffuser case was rusted. The left and right primary and secondary fuel manifold supply tubes were fractured at the manifold fittings and missing at the Nos. 5 and 6 fuel nozzles. The fuel manifolds were intact except for the right manifold primary fuel feed tube, which was fractured inboard of the B-nut. The diffuser struts displayed areas of advanced corrosion with missing material. The fuel nozzles were coated with rust and coral encrustation but were otherwise unremarkable.

The nine combustion chambers were intact and appeared in good condition, with no evidence of thermal distress. No metallization was observed on the chamber domes in areas free of coral deposits. See Figures 20 and 21.

Figure 20 No. 1 engine exemplar combustion chamber showing no thermal distress

Figure 21 Visible combustor dome surface showing absence of metallization

6.2.5 T1 nozzle guide vanes (NGVs)

Two of the T1 NGVs were bowed; one of these was cracked mid-span. Eight vanes displayed TE cracks near the root. There were no burn-throughs or missing material. A smooth, blue-gray coloration was observed beneath the coral encrustation on several of the vanes. See Figure 22.

Figure 22 No. 1 engine T1 nozzle aft face, showing typical in-service T1 vane condition

6.2.6 High turbine

The T1 blades were intact with no obvious damage. The tip shrouds showed no abnormal wear. See Figure 23.

Figure 23 Aft face of the No. 1 engine T1 disk assembly showing intact airfoils and tip shrouds

The T1 blade outer air seal (BOAS) was unremarkable.[13] The high turbine front support (No. 5) bearing was not disassembled. The roller elements appeared evenly spaced and full diameter. No discoloration or blistering was observed on areas of silver plate not obscured by rust. The air seals appeared in good condition.

6.2.7 Low turbine

The low turbine shaft was bent but intact. Areas of circumferential rub were noted at three axial locations. The turbine intershaft (No. 4 ½) bearing turned smoothly by hand. The roller elements appeared evenly spaced and full diameter. The silver plate showed no discoloration or blistering. There was no acrid oil odor. The carbon seals appeared intact. See Figure 24.

[13] The JT8D-9A BOAS is a one-piece construction.

Figure 24 No. 1 engine low turbine and shaft and closeup view of No. 4 ½ interstage bearing roller elements and rotating seal components

The low turbine was not disassembled. Stages T2 and T3 were inspected through the front. The T2 vanes were intact and undamaged. The T2 blades viewable past the T2 vanes were full length and appeared undamaged. Viewable T3 blades and vanes were undamaged.

The T4 was inspected through the TEC. The T4 vanes were in place with no damage noted. The T4 blades and their tip shrouds were intact and in good condition. See Figure 25.

6.2.8 TEC

The aft end of the TEC was dented radially inward, and the turbine exhaust cone was flattened and partially separated from its flange. The TEC struts were straight. No tactile check of the case was performed based on the intact condition of the turbine blades. All exhaust gas temperature (EGT) Tt7 and the engine pressure ratio system (Pt7) probes were full length. See Figure 26.

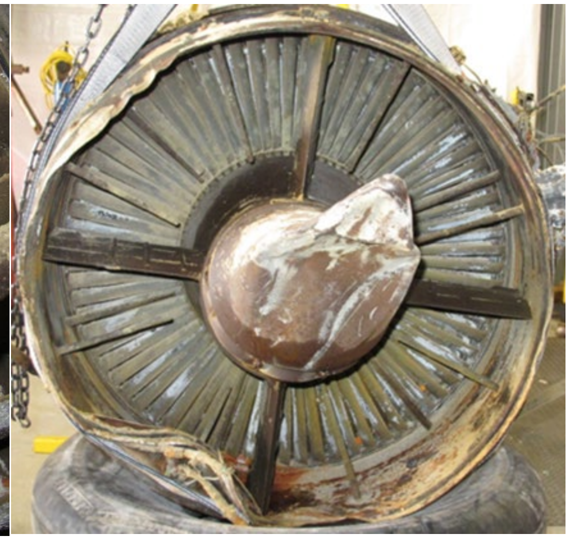

Figure 25 Detail view, T4 blades

Figure 26 Aft view of No. 1 engine showing T4, and Tt7 and Pt7 probes

The low turbine rear support (No. 6) bearing roller elements appeared full diameter and evenly spaced. Areas of the silver plating not obscured by rust showed no blistering or discoloration. The bearing was not disassembled.

6.3 No. 1 engine fuel system investigation

The No. 1 engine fuel pump was examined at Eaton Corporation, Cleveland Ohio on April 4, 2022. The fuel control was disassembled at Collins Aerospace at Windsor Locks, Connecticut on April 13, 2022. The examinations found no condition that would have prevented normal operation. For details of the teardowns, see Attachment 5, No. 1 Engine Fuel System Component Examinations.

7.0 No. 2 engine examination

7.1 External inspection

7.1.1 Inlet/fan case section

The engine inlet/fan case section was liberated from the No. 2 engine and was recovered separately. See Figure 27.

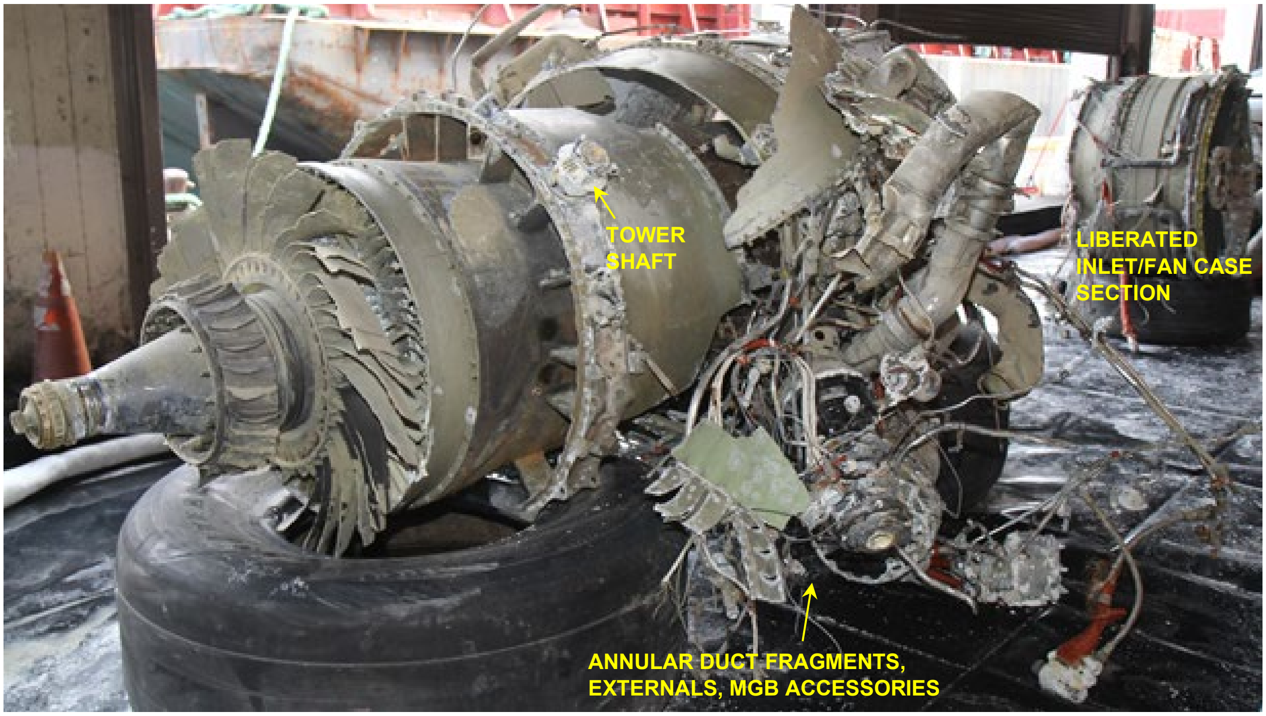

Figure 27 No. 2 engine and liberated inlet/fan section at Honolulu recovery location

The IGVs were intact and straight. Material consistent with nose cowl aluminum sheet metal was wrapped around the IGV LEs from 5 to 7 o'clock. The nose bullet assembly was not recovered. See Figure 28.

Figure 28 No. 2 engine inlet/fan case section, forward view

The C1 stators were missing between 6 and 10 o'clock except for two that were bent/folded in the direction of rotation. The C1 stators between 10 and 6 o'clock were full length and were deformed in the direction of rotation. See Figure 29.

Figure 29 No. 2 engine inlet/fan case section, rear view

The C1 stator TEs exhibited clashing damage. The C2 blade path was circumferentially scored from 3 to 7 o'clock, tracking out of plane from 6 to 7 o'clock. See Figure 30.

Figure 30 No. 2 engine C1 stator TE clash and C2 blade path scoring

7.1.2 Engine annular ducting

The No. 2 engine fan discharge compressor front duct aft flange was missing between 3 and 10 o'clock

The fan discharge outer rear duct was missing except for a fragment between 4 and 7 o'clock. Most of the fan discharge duct was present with the exception of the aft flange. All casings aft of the fan case were intact. There were no indications of fire, uncontainment or case rupture.

The front accessory drive cover was missing.[14] The ignition exciter, pressurization and dump valve and pressure ratio bleed control valve remained attached to the engine. The MGB was missing. The MGB-mounted hydraulic pump, air turbine starter, and the generator were attached by tubing/electrical harness. The FCU and the fuel pump were recovered separately.

Coral encrustation coated the external and gas path surfaces. Rust was observed on the steel components. See Figure 31.

[14] The front accessory drive cover is a cast magnesium casting and was destroyed by saltwater immersion.

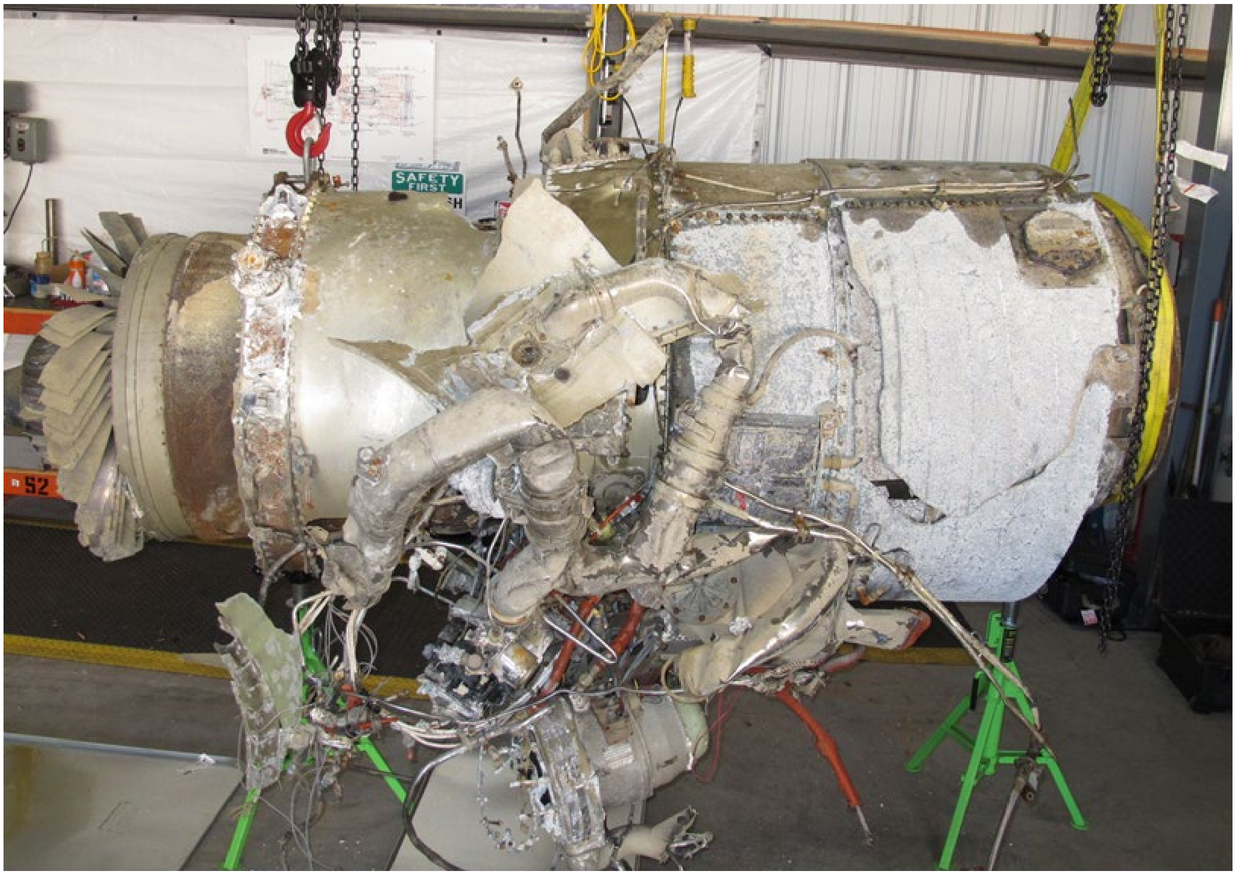

Figure 31 No. 2 engine bottom view, showing missing annular duct pieces and inlet/fan case section. The MGB cases has disintegrated, and MGB-mounted accessories are attached by tubing and electrical harness

7.2 Engine disassembly observations

7.2.1 Low compressor rotor

The No. 1 bearing lock nut, inner race, and cage were present on the fan hub cone. The roller elements were missing. Visible silver plate was not discolored or blistered.

All C1 blades were fractured close to the platform. The C2 blades were full length and bent opposite the direction of rotation except for seven that were fractured within two inches of the platform. See Figure 32.

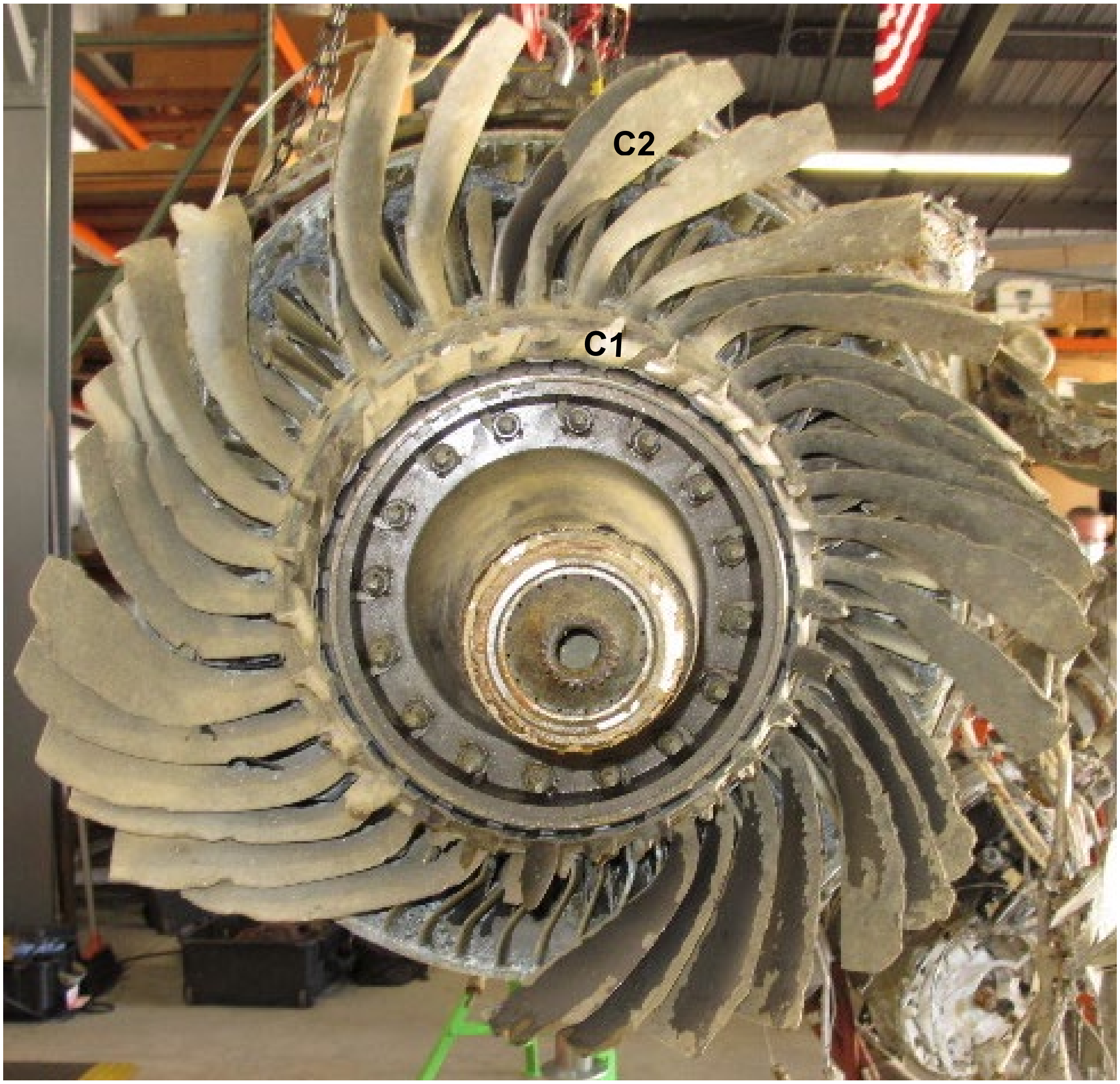

Figure 32 No. 2 engine as received, front view

Low compressor stages C3 through C6 were inspected as assembled. The viewable blades in these stages were entire and were bent opposite the direction of rotation.

7.2.2 IMC

The IMC front mount rail was fractured between 10 and 3 o'clock.

7.2.3 High compressor

The high compressor was not disassembled. Rust was observed on the steel components. The high rotor was seized.

Static borescope images were taken of stages C7 through C12. All C7 blade images showed near-platform fractures. The C8, C9, C11 and C12 images showed full length blades that were bent/deformed opposite the direction of rotation. See Attachment 6, No. 2 Engine Static Compressor Borescope Images.

Visual inspection of the C12 and C13 blades through the back of the compressor found that all blades were deformed in the direction opposite rotation. The C13 blade leading and TEs exhibited clashing damage.

The Nos. 3 and 4 bearings were not viewed.

7.2.4 Diffuser and combustor

The diffuser case was rusted. The left and right primary and secondary manifold fuel supply tubes were fractured at the manifold fittings and were missing at the Nos. 5 and 6 fuel nozzles.

The diffuser case struts exhibited advanced corrosion. The fuel nozzles were unremarkable other than heavy rust and coral encrustation. See Figure 33. Inspection of the nine combustion chambers found no evidence of metallization on the dome surfaces unobscured by deposits. All chambers were intact with no burn-through or other thermal damage. See Figure 34.

Figure 33 No. 2 engine diffuser case and fuel nozzle

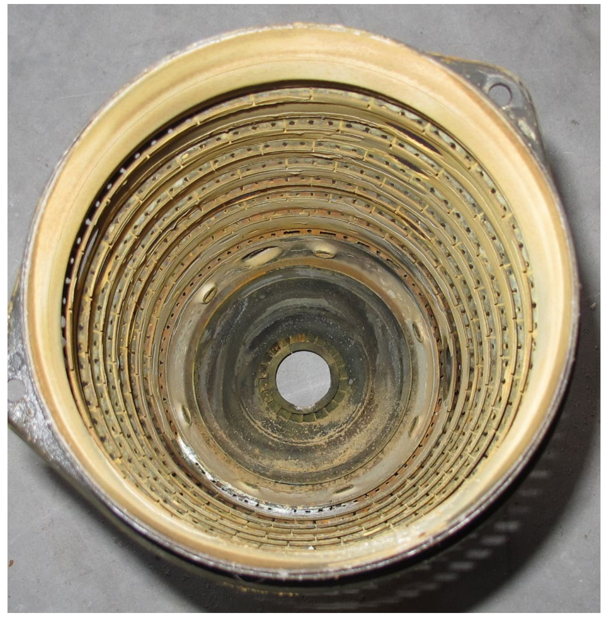

Figure 34 Exemplar combustion chamber inside surfaces, showing no thermal distress

7.2.5 T1 nozzle

The T1 nozzle vanes were in place and exhibited no leading or TE damage. See Figure 35. Where coral encrustation was absent, the vane surfaces were smooth and uniformly steel blue-gray in color. One vane at 7 o'clock was cracked; the crack was open mid chord and wrapped around the airfoil LE. See Figure 36.

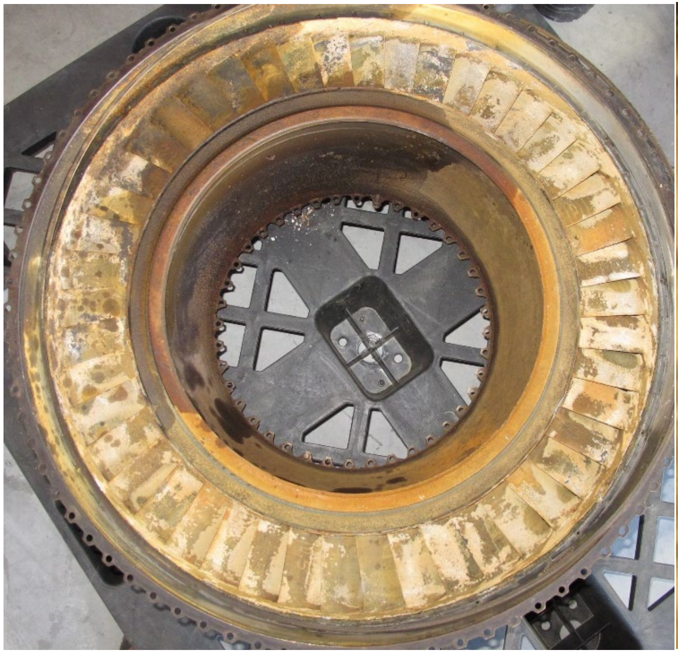

Figure 35 No. 2 engine NGV in good condition

Figure 36 Chordwise vane crack

The T1 BOAS was not obviously ovalized or bulging and exhibited no impact damage. Its honeycomb cell pattern was visible underneath coral encrustation along the blade path. According to FES, this was typical wear for in-service hardware.

The No. 5 bearing could not be rotated by hand. The inner race was centered on the outer race and the ends of the roller elements were evenly spaced, were not discolored, and appeared full diameter. The bearing was not disassembled.

7.2.6 High turbine

The T1 disk was intact and the blades were heavily encrusted with coral. All T1 blades and blade retention rivets were secure. The outer spans of two T1 blades were missing.

The blades were numbered clockwise from 1 to 80, with the trailing fractured blade designated blade 1. Blade 1 was fractured transversely approximately 2.4 inches above the platform TE. Blade 6 was fractured transversely approximately 2.7 inches above the platform TE. Blades 79, 80, 3 and 4 exhibited TE outer diameter impact damage toward the outer span. There was random TE damage to other blades with missing material up to 0.04 inch radially. See Figure 37.

Figure 37 No. 2 engine T1 showing the two fractured blades. TE impact damage is indicated by arrows

There was no T1 blade LE impact damage. The intact tip shrouds appeared full height and exhibited no evidence of rub. The tip shroud of the blade following blade 6 (blade 5) had a normal appearance. The tip shroud of the blade following blade 1 (blade 80) was missing material on the convex side and had an eroded appearance. See Figure 38. The blade fracture surfaces were heavily coated with deposits. See Figure 39.

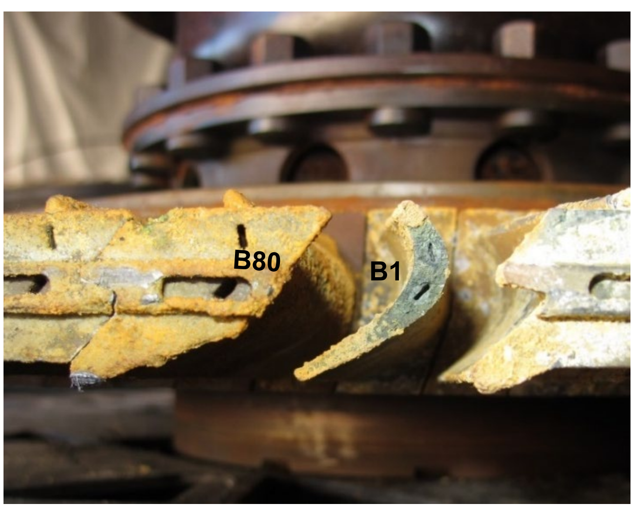

Figure 38 T1 showing B1 and B80 shroud

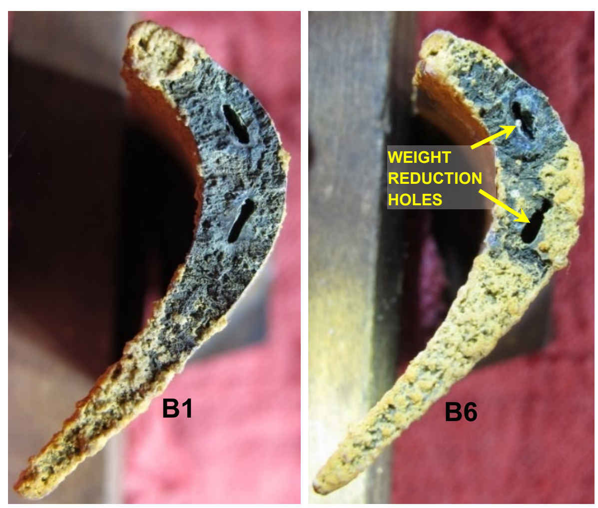

Figure 39 Fractured T1 blades B1 and B6

7.2.7 Low turbine and TEC

The low turbine module was not disassembled. A tactile inspection of the low turbine case found no bulging or other deformity. The T2 was inspected through the front. Three T2 vanes at 5 o'clock exhibited LE damage. All T2 vanes exhibited TE breakout damage. All T2 blades exhibited outer span fractures. See Figures 40 and 41.

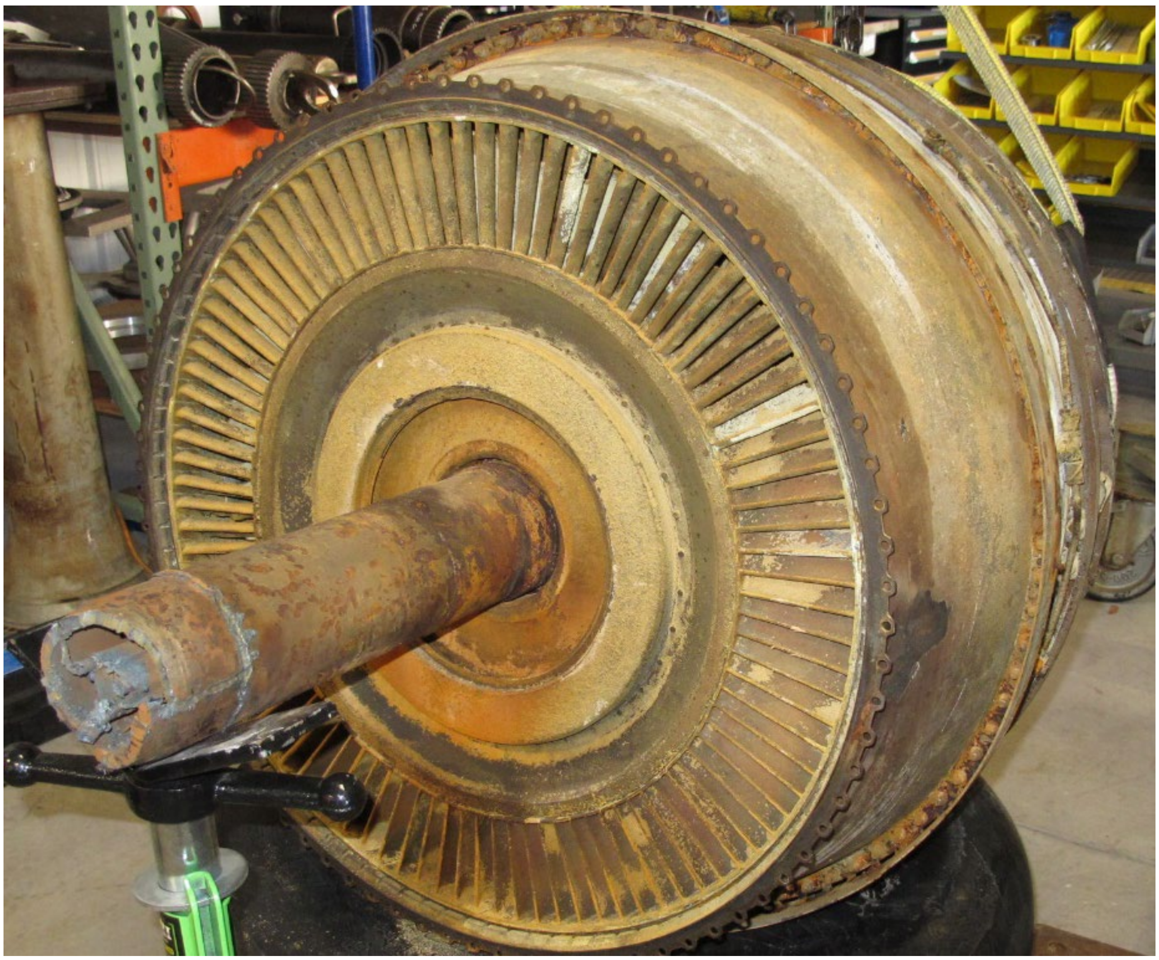

Figure 40 Front view of No. 2 engine low turbine. The shaft was cut to aid disassembly

Figure 41 Detail view of No. 2 engine T2 blade outer span damage

The T3 and T4 were inspected through the back of the TEC. The T3 exhibited outer span blade fractures and TE stator breakout damage similar to the T2 damage. Up to three inches of outer span material was missing from all T4 blades. The T4 vane airfoil breakout damage was most pronounced over the outer 50% span. See Figure 42.

The low turbine to TEC flange hardware was secure. The TEC struts were intact and straight. The Tt7 and Pt7 probes were full length. A tactile inspection of the TEC front skirt found no deformities. See Figure 43.

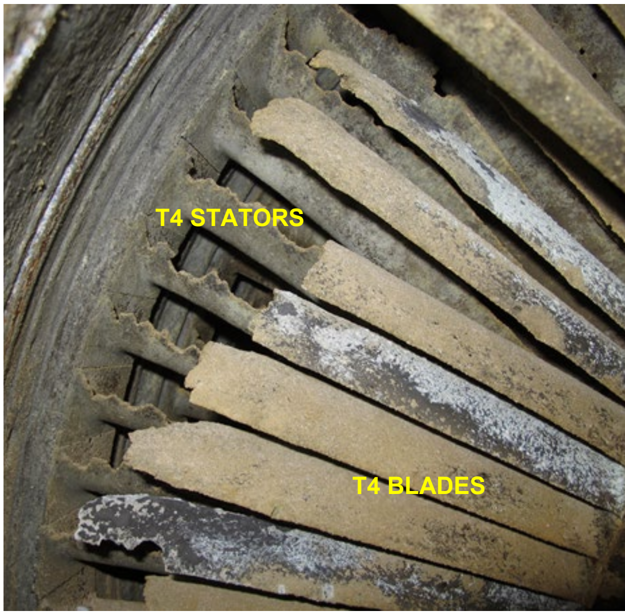

Figure 42 View through the No. 2 engine TEC showing T4 vane TE breakout damage and T4 blade outer span fractures

Figure 43 No. 2 engine rear view, showing the TEC struts and full-length Tt7, Pt7 probes

The No. 6 bearing was not disassembled. The bearing roller elements appeared full diameter and evenly spaced.

7.3 T1 blade metallurgy

The T1 blade set was shipped to the P&W Materials & Processes Engineering Lab in East Hartford, Connecticut for materials investigation.

Metallurgical and fractographic examination of blade 1 and blade 6 found that regions of the chordwise fracture surfaces not covered with ocean deposits were predominantly rough textured (intergranular) except for regions around the two internal spanwise weight reduction holes, which were mostly flat.

Metallographic examination of blade 6 determined that the flat textured regions were in oxidation /corrosion scale and not sound base metal. Extensive oxidation /corrosion through the blade cross-section and secondary intergranular cracks were observed around the internal hole profile and near the plane of the fracture. Gross plastic deformation was not evident visually.

It was determined that the most probable failure mode was internal oxidation/corrosion that led to the loss of load-bearing cross section, resulting in stress rupture fracture. It was inconclusive which of the two blades failed first.

See Attachment 7, Pratt & Whitney DCA21FA174 Metallurgical Investigation Report.

D. ATTACHMENTS

ATTACHMENT 1. Serial Number Identifications

ATTACHMENT 2. Camp Systems EHM Fleet Status Report, June 30, 2021, pgs. 20-21

ATTACHMENT 3. Naval Supply & Systems Command Fuel Lab Report, July 7, 2021

ATTACHMENT 4. Flight Engine Services Static Borescope Images, ESN 674548 High Compressor, December 7, 2021

ATTACHMENT 5. No. 1 Engine Fuel System, Disassembly Examinations

ATTACHMENT 6. Flight Engine Services Static Borescope Images, ESN 657227 High Compressor, December 8, 2021

ATTACHMENT 7. Pratt & Whitney DCA21FA174 Metallurgical Investigation Report, July 29, 2022

Submitted by:

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