NATIONAL TRANSPORTATION SAFETY BOARD
Office of Aviation Safety
Washington, D.C. 20594

January 18, 2012

POWERPLANT GROUP CHAIRMAN'S FACTUAL REPORT

NTSB No: ENG-11-IA-051

A. INCIDENT

Location: Denver, Colorado

Date: September 26, 2011

Time: 2237 Universal Coordinated Time (1637 mountain daylight time)

Aircraft: United Airlines, Boeing 757-222, registration number N526UA, Flight 909

B. POWERPLANTS GROUP

Safety Board Group Chairman:	Jean-Pierre Scarfo Powerplant Lead Engineer Washington D.C.
Pratt & Whitney Member:	Bob Bao Flight Safety Investigator East Hartford, Connecticut
United Airlines Members:	Pat Donahue Air Safety Investigator Chicago, Illinois
	Monal Merchant Sr. Powerplant Engineer San Francisco, California
Boeing Members:	Van Winters Propulsion Technology Seattle, Washington
	Michael Germani Propulsion Safety Seattle, Washington

Federal Aviation Administration Member:	Eric West Air Safety Investigator Washington DC

C. SUMMARY

On September 26, 2011, 1637 mountain daylight time, a Boeing B-757-222, registration number N526UA, operated by United Airlines (UAL) as flight 909, and powered by two Pratt & Whitney PW2037M turbofan engines, experienced a left engine (No. 1) bird strike[1] following touchdown on runway 35R at the Denver International Airport (DEN), Denver, Colorado. According to the flightcrew, after initial touchdown and the application of full reverse thrust, two hawks were observed on the centerline of runway 35R and shortly thereafter impacts were felt on the fuselage followed by a 'hot' odor in the cockpit. After the airplane cleared the runway, a No. 1 engine oil pressure light illuminated accompanied by low oil pressure indication. The No. 1 engine was reported to have spooled down on its own while the airplane continued to taxi using the No. 2 engine to taxiway 'EE'. A flight attendant observed smoke coming from the rear of the No. 1 engine and the flightcrew requested that Airport Rescue and Firefighting (ARFF) come to the airplane. The No. 1 engine was shutdown using the Engine Fire or Engine Severe Damage or Separation procedure in the UAL 757 Quick Reference Handbook (QRH) Non-Normals 14.80.10. ARFF inspected the airplane and no signs of fire were observed. The airplane was towed to the gate using a tug where the passengers deplaned normally. Of the 179 passengers and 6 crewmembers on board the flight, no injuries were reported. The incident flight was a 14 *CFR* Part 121 domestic passenger flight from Chicago O'Hare Airport (ORD) to DEN. Day visual meteorological conditions prevailed at the time and an instrument flight rules flight plan was filed.

Examination of the airplane revealed minor gouging of the fuselage and under the left wing, with no through holes, a passenger window was nicked, and a slashed but not deflated left-hand main landing gear forward right tire. The inner barrel of the No. 1 engine inlet cowl exhibited multiple impacts, gouges, and through-holes that penetrated through the outer skin of the inlet at two locations.

Examination of the No. 1 engine revealed that all the fan blades were extensively damaged with three blades fractured transversely across the airfoil at or near the mid-span shroud. The three fractured fan blades were all located within a consecutive group of 5 blades. No penetration or breaches were observed in any of the engine cases but the fan case exhibited several bulges that corresponded to hard impacts and missing fan blade rub strip material (parent material exposed). Examination of the No. 2 engine revealed that several of the fan blades exhibited minor leading edge impact damage primarily located outboard of the mid-span shroud.

A United States Department of Agriculture Wildlife Biologist collected a whole and intact bird and what appeared to be the remains of second bird from runway 35R. The Wildlife Biologist identified the intact bird as a juvenile Red-Tailed Hawk. The remains of the second bird, along with remains collected by the Powerplant group from the No. 1 engine, were sent to the Smithsonian Institution National Museum of Natural History Division of Birds - Feather Identification Laboratory in Washington DC for analysis. The remains of the second bird were identified as coming from a female

[1] Although collisions between aircraft and birds make up about 98% of all wildlife strikes and pose the greatest risk, they are not the only animals involved in collisions with aircraft. Deer, coyotes, and even alligators wandering onto runways can create serious problems for departing and landing aircraft. When aircraft collide with wildlife is it commonly referred to as a wildlife strike and if it is a bird it is referred to as a bird strike.

Red-Tailed Hawk. The Red-Tailed Hawk ranges in weight from about 24.3 to 51.50 ounces (1.52 to 3.22 pounds) with the female larger in size.

D. DETAILS OF THE INVESTIGATION

1.0 ENGINE AND AIRPLANE INFORMATION

1.1 ENGINE HISTORY

The incident airplane was equipped with two Pratt & Whitney (P&W) PW2037M[2] turbofan engines. At the time of the bird strike and ingestion event, the No. 1 engine, serial number (SN) P727118, had accumulated 56,318 hours time since new (TSN); 20,119 cycles since new (CSN); 1,174 hours since last inspection (TSLI); and 436 cycles since last inspection (CSLI).

1.2 ENGINE DESCRIPTION

The PW2037M is a dual-spool, axial-flow, high bypass turbofan engine that features a 1-stage fan, a 4-stage low pressure compressor (LPC), a 12-stage high pressure compressor (HPC), an annular combustor, a 2-stage high pressure turbine (HPT), and a 5-stage low pressure turbine (LPT). According to the TCDS, the engine has a maximum takeoff thrust rating of 37,530 pounds, flat-rated[3] to 87°F (30°C) and a maximum continuous thrust rating of 34,640 pounds flat-rated to 77°F (25°C).

All directional references to front and rear; right and left; top and bottom; and clockwise and counterclockwise are made aft looking forward (ALF) as is the convention. All numbering is in the circumferential direction starting with the No. 1 position at the 12:00 o'clock position or immediately clockwise from the 12:00 o'clock position, and progressing sequentially clockwise ALF. The direction of rotation of the engine is clockwise ALF. Engine flanges are identified in alphabetical sequence from front to rear (**FIGURE 1**).

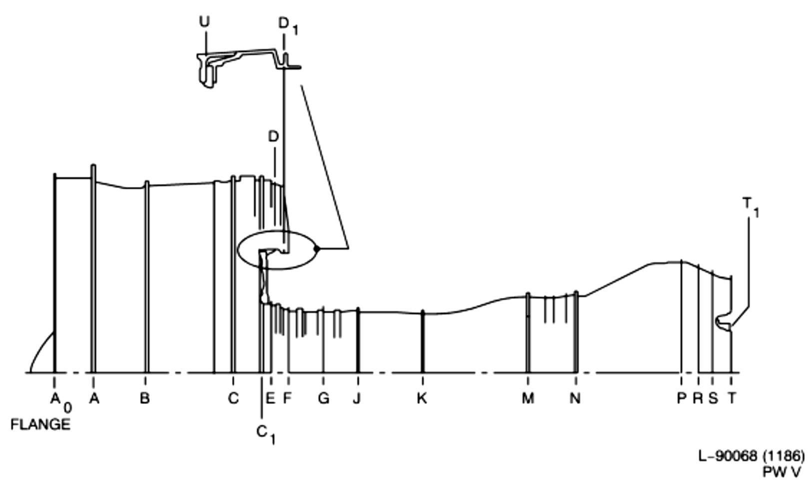

FIGURE 1: ENGINE FLANGE IDENTIFICATION

---

[2] According to the FAA Type Certificate Data Sheet (TCDS), TCDS No. E17NE, revision 13, dated October 10, 2003, the PW2037M is the same as the PW2040, except operated at PW2037 rating via appropriate electronic engine control data entry plug.

[3] Flat-rated to a specific temperature indicates that the engine will be capable of attaining the rated thrust level up to the specified inlet temperature.

2.0 IN-SITU AIRPLANE AND ENGINE EXAMINATION

2.1 FLIGHT DECK

Examination of the aislestand panels and controls revealed that both forward thrust levers (throttles) were at the idle detent position; the reverser thrust levers were in the stowed position; both engine fire handles and the Auxiliary Power Unit (APU) fire handle were in the down position; and both fuel control run/cutoff switches were in the CUTOFF position. According to United maintenance personal, the No. 1 engine fire handle was initially found in the pulled (armed) position consistent with the emergency procedures conducted by the flightcrew but was reset to its normal down position prior to towing the airplane to the hangar to prevent an inadvertent discharging of the fire bottles.

2.2 AIRPLANE DAMAGE AND FINDINGS

The left-hand main landing gear forward right tire exhibited a cut in the tread but the tire did not deflate. The left-hand lower wing skin inboard of the engine at wing station (WS) 130, stringer U23 exhibited what appeared to be three superficial gouges. The forward fuselage body exhibited the following: 1) a gouge at fuselage station (FS) 600, between stringers S-11L and S-13L, 2) three small nicks at FS 879, stringer S-11L, and 3) a passenger window (8^{th} window aft of passenger door 2L) between FS 920 and 940 exhibited a 1.0-inch gouge and 0.5-inch impact on the outer pane (**PHOTO 1**). The left-hand aft fuselage body exhibited superficial gouges at the following locations: 1) FS 1360, stringer S-29L, 2) FS 1400, stringer S-29R; and 3) FS 1420, stringer S-28R.

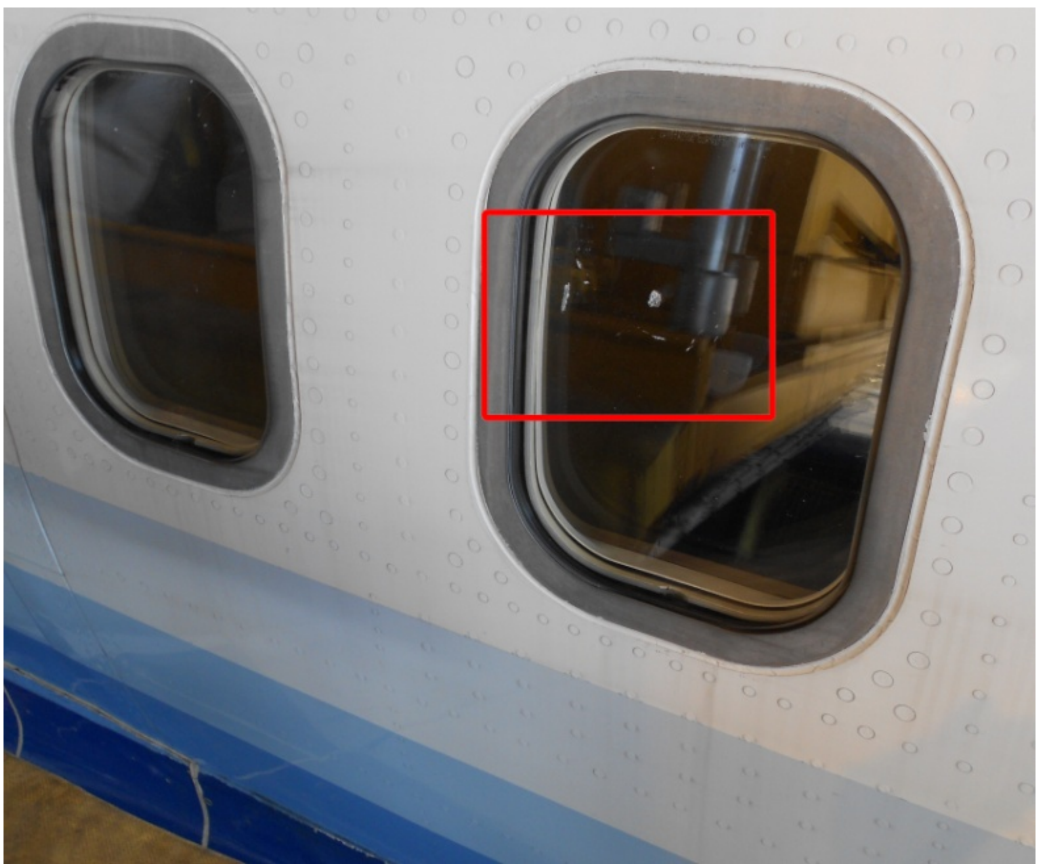

PHOTO 1: IMPACT DAMAGE TO PASSENGER WINDOW

(PICTURE COURTESY OF UNITED AIRLINES)

A smear consistent with possible bird remains was observed at about the 4:00 o'clock position on the inlet cowl outer skin with no associated impact damage observed in the area of the bird smear (**Photo 2**).

Photo 2: Bird Remains on the No. 1 Engine Inboard Inlet Cowl

Impact marks and gouges were observed around entire circumference of the inlet cowl inner barrel, with the majority of the damage located within approximately 12-inches axially of the "A_o" flange (**Photos 3, 4 and 5**). Along with the impact gouges, numerous fan blade fragments were found imbedded in the inlet inner barrel acoustic liner.

PHOTO 3: FAN ROTOR AND INLET COWL INNER BARREL INGESTION DAMAGE - FRONT VIEW

PHOTO 4: INNER BARREL DAMAGE - OUTBOARD VIEW **PHOTO 5: INNER BARREL DAMAGE - INBOARD VIEW**

The No. 1 engine inlet cowl was numbered clockwise location ALF in order to facilitate documentation of the impact damage location. Documentation of the noteworthy inlet cowl damage is provided in **TABLES 1** and **2.**

TABLE 1: NO. 1 ENGINE INLET INNER BARREL DAMAGE

	Clock Position	Distance from "A_o" Flange to Center of Damage (inches)	Impact Axial Length (inches)	Impact Circumferential Length (inches)	Depth of Damage from Inner Liner: **1** – Through acoustic liner **2** – Through the inner wall **3** – Through the outer skin **4** – Blade fragment imbedded in acoustic liner
1	2:15	7.0	4.0	4.5	1 (**PHOTO 6**)
2	3:15	9.25	0.75	9.5	1 (**PHOTO 6**)
3	4:20	8.0	8.5	5	3 (**PHOTO 7**)
4	5:05	6.0	3.0	6.0	2 (**PHOTO 7**)
5	7:45	6.5	4.0	7.0	2 (**PHOTO 8**)
6	10:30	8.0	7.5	4	3 (**PHOTO 9**)
7	9:15 – 10:45	6.0	1.0 to 10	31	1
12	9:45	2.5	2.0	0.5	2
A	12:15	16.0	-	-	4
B	1:00	15.5	-	-	4
C	3:00	4.0		-	4 (**PHOTO 6**)
D	4:15	6.5	-	-	4 (**PHOTO 7**)
E	5:00	12.0	-	-	4 (**PHOTO 7**)
F	6:30	1.0	-	-	4
G	7:30	6.5	-	-	4 (**PHOTO 8**)
H	7:40	9.5	-	-	4 (**PHOTO 8**)
I	9:00	7.0	-	-	4
J	11:00	4.0	-	-	4
K	12:00	5.0	-		4

TABLE 2: NO. 1 ENGINE INLET OUTER SKIN DAMAGE

	Clock Position	Distance from "A_o" Flange to Center of Damage (inches)	Impact Axial Length (inches)	Impact Circumferential Length (inches)
8	10:30	12.0	0.5 AL honeycomb inner backing* 3.0 epoxy graphite outer skin *	0.5 AL honeycomb inner backing 5.0 epoxy graphite outer skin
9	10:25	9.5	0.25 AL honeycomb inner backing 5.5 epoxy graphite outer skin	0.25 AL honeycomb inner backing 4.0 epoxy graphite outer skin
10	10:20	14.0	1.25	1.25 - Note: blade remains stuck in outer skin panel
11	4:30	7.5	4.0 AL honeycomb inner backing 7.0 epoxy graphite outer skin	0.25 AL honeycomb inner backing 2.5 epoxy graphite outer skin

* The aluminum (AL) honeycomb damage measurement represents the hole size in the material while the epoxy graphite outer skin damage measurement represents a tearing measurement. The outer skin exhibited flaps of broken material.

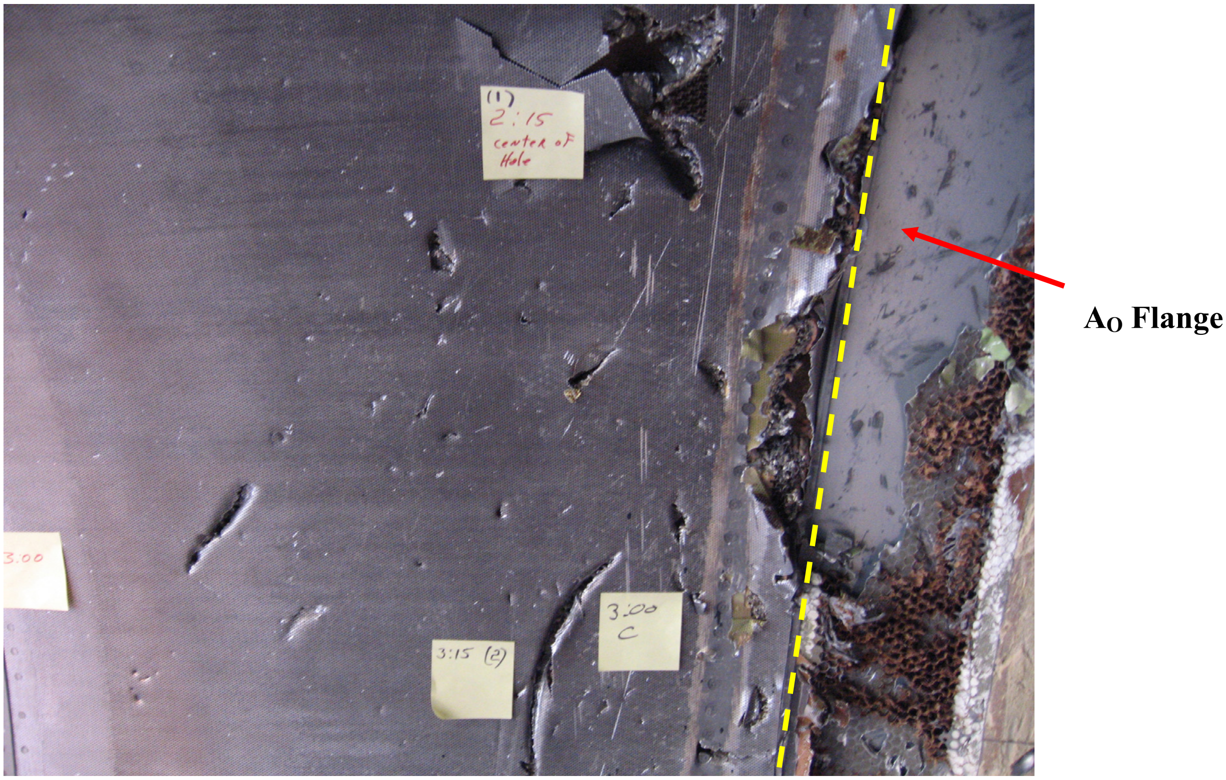

PHOTO 6: INLET COWL INNER BARREL DAMAGE - LOCATIONS 1 AND 2

PHOTO 7: INLET COWL INNER BARREL DAMAGE - LOCATIONS 3 AND 4

Photo 8: Inlet Cowl Inner Barrel Damage - Locations 3 and 4

Photo 9: Inlet Cowl Inner Barrel Damage - Locations 3 and 4

The No. 1 engine fan cowls, the thrust reverser (TR) halves, and the core cowls were each latched and secure. The outboard fan cowl has an engine oil fill and master chip access panel (also referred to as a pressure relief/oil tank access panel) located at about the 8:00 o'clock position. This panel was found in the OPEN position. Looking through the opening at the oil tank, the oil fill cap was found dislodged from the oil fill port but still tethered to the tank by its lanyard (**Photo 10**). No signs of an oil leak were observed. According to United mechanics, the oil level in the oil tank was measured to be about 1 quart low.[4] The pressure relief doors on both the left- and right-hand sides of the core cowl were found in the OPEN position.

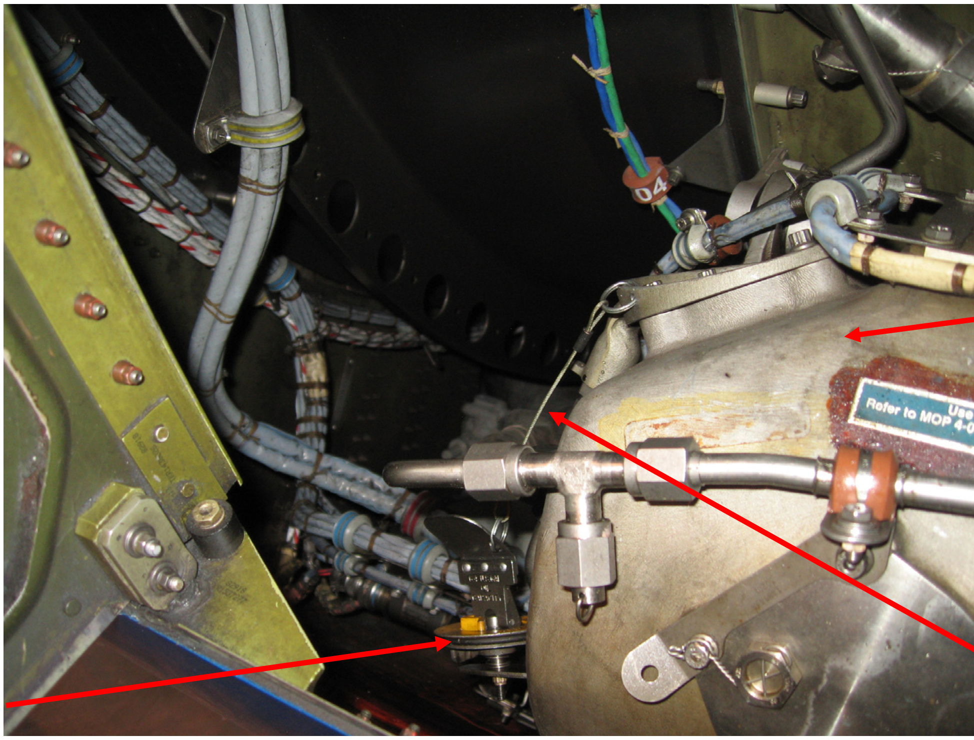

Photo 10: No. 1 Engine Oil Filler Cap Dislodged from Oil Tank

The thrust reverser (TR) was deployed and as it translated to the deployed position, a large quantity of hydraulic fluid poured from the bottom of the TR around the scupper drain and metallic debris consistent with acoustic liner material and fan blade fragments fell to the ground. The fan blade fragments were collected for further examination. All the blocker doors and their associated hardware (drag links, hinges, and spring mechanism) were intact and appeared to be seated properly, except for blocker door No. 9 that had a piece of acoustic liner wedged between the blocker door and the translating sleeve[5]. Several of the blocker doors exhibited minor fragmentation and gouges in the thrust side of the door (side facing forward when the door is deployed). Bird feathers and remains were found on the aft side of blocker doors No. 6 and 7 captured within the spring mechanism (**Photo 11**) and at several hinge locations (**Photo 12**). All the cascades were intact and appeared undamaged. Pieces of metal debris consistent with the acoustic liner material and fan blade fragments were found within several of the cascades outlet slots. Bird feathers and remains were found in cascades between the 5:00 and 9:00 o'clock positions. Bird feathers and remains were also found on the inside of the translating

[4] The oil quantity was measured after the engine was removed from the airplane and placed in an engine stand.
[5] Blocker doors were numbered sequentially clockwise ALF 1 through 12 starting at the 12:00 o'clock position.

sleeves, along the lower bifurcation panel (PHOTO 13), and at the aft end of the translating sleeve. Acoustic panel material and fan blade fragments were found at the rear end of the translating sleeve.

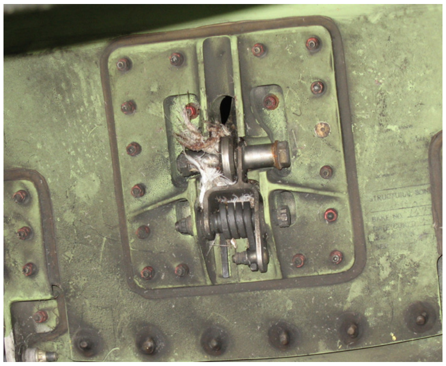

PHOTO 11: REMAINS IN SPRING MECHANISM

PHOTO 12: REMAINS IN HINGE

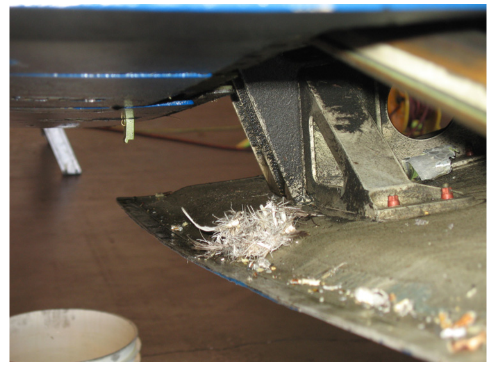

PHOTO 13: REMAINS ON BIFURCATION PANEL

The fan cowls and the TR were opened to expose the engine. Examination of the external components on the engine and the TR actuation system revealed that several parts exhibited damage due to the bird strike and the subsequent imbalance loads. At the 4:00 o'clock position, a 'B'-flange bolt that is also used to secure a support bracket for the anti-ice and starter duct was fractured and the bolt was found resting on the inboard fan cowl ledge. The corresponding rod end bearing, used to attach the anti-ice and starter duct to the support bracket on the 'B'-flange, and the bracket itself were bent. The electronic engine control (EEC) is attached to the left-hand side of the fan exit case by four mounts. The upper and lower forward mounts were found cracked and the upper and lower aft mounts were fractured (PHOTO 14). The support bracket for the starter control valve electrical connector was fractured and the connector plug was loose within the support bracket but remained engaged with the electrical receptacle on the valve. When the TR was deployed a large quantity of hydraulic fluid poured from the bottom of the TR around. The source of the hydraulic leak was identified as coming from the upper right-hand TR actuator (PHOTO 15). The left-hand power door open system actuator rod (PDOS) was found fractured in the threads of the rod end.

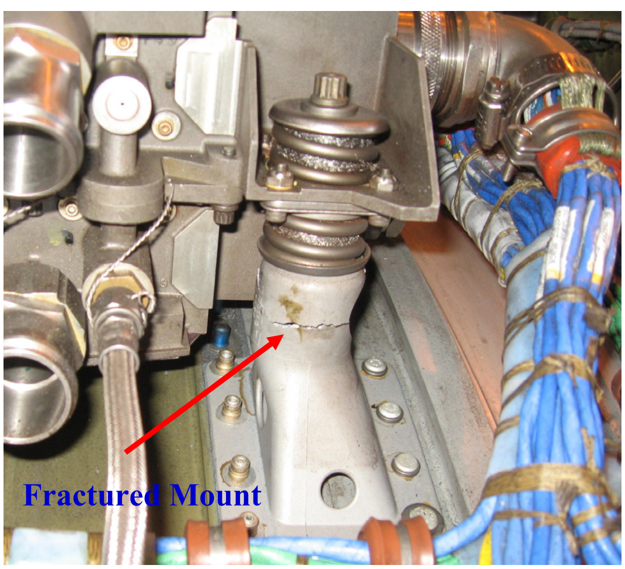

PHOTO 14: FRACTURED EEC AFT MOUNTS

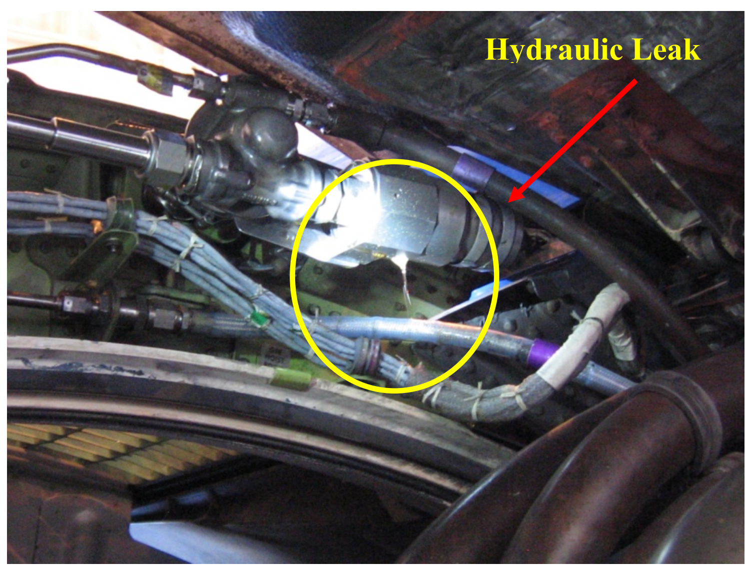

PHOTO 15: LEAKING UPPER RIGHT-HAND TR ACTUATOR

When the No. 1 engine was removed from the airplane and the inlet cowl removed from the engine, two fan blade fragments were discovered between the inner and outer inlet cowl barrels. One blade fragment was a small airfoil section with both mid-span shrouds attached and measured approximately 6.0- x 4.0-inches and weighted 10.88 ounces (0.68 pounds) (identified as blade 21 in **PHOTO 25** and **TABLE 4**) while the other blade fragment was a section of airfoil that measured approximately 5.0- x 4.0-inches and weighted 15.21 ounces (0.95 pounds) (identified as blade 22 in **PHOTO 25** and **TABLE 4**). See Section 3.0 and **TABLE 4** for details.

2.3 NO. 1 ENGINE DAMAGE AND FINDINGS

Both the front and rear inlet cone segments (spinner cones) were intact and present. The front cone appeared to be undamaged while the rear cone exhibited several circumferential surfaces slices, none of which cut completely through the skin thickness.

The fan case and fan exit case did not exhibit any holes, penetrations, or uncontainments. The fan case forward acoustic panels were all missing exposing the fan case from the “A_o” to “A” engine flange locations (See **PHOTO 6 - 9**). The fan case between engine flange locations “A_o” to “A” exhibited no through-cuts or holes, only minor impact damage. The fan blade rub strip was essentially intact and rubbed, with some areas chunked-out exposing the fan case parent material beneath. Several impact marks and outward bulges in the fan case were noted in the areas where the fan blade rub strip had been chunked-out. The bulges were noted at the followings clock positions: 12:00, 12:30, 1:00, 2:00, 4:30, 5:00, 9:45, and 10:45.

The fan rotated easily by hand. All the fan blades were present and installed in the fan disk and were numbered sequential in the direction of rotation (clockwise) for documentation purposes. The No. 1 blade was chosen because it was missing the most airfoil material. All the fan blades exhibited hard-body impact damage, with significant material loss along the length of the leading edge with the greatest amount of impact damage located outboard towards the blade tip portion of the airfoils (**PHOTO 16**). Fan blades Nos. 33, 34 and 35 also exhibited leading edge impact damage consistent with soft-body damage (**PHOTO 17**). Several fan blades exhibited leading edges that were bent in the direction opposite rotation.

PHOTO 16: HARD-BODY FAN BLADE DAMAGE

PHOTO 17: SOFT-BODY FAN BLADE DAMAGE

Three fan blades, Nos. 1, 32, and 34 were fractured transversely across the airfoil (**Photo 18**). The No. 1 fan blade was fractured below the mid-span shroud and was missing approximately 13.5-inches of the outer airfoil (**Photo 19**). The No. 32 fan blade was fractured above the mid-span shroud and was missing approximately 6.5-inches of the outer airfoil (**Photo 20**). The No. 34 fan blade was fractured below the mid-span shroud and was missing approximately 12.0-inches of the outer airfoil (**Photo 21**). The mid-span shrouds of fan blades sets 10 and 11; 11 and 12; 16 and 17; and 22 and 23 were found shingled[6]; however, other fan blade sets exhibited evidence of the mid-span shingling as well but were no longer shingled when examined by the Powerplant Group (**Photo 22**).

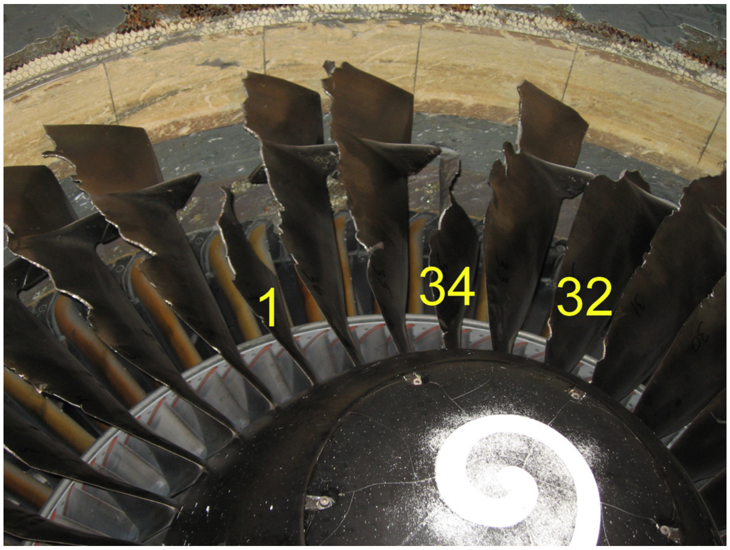

Photo 18: Transversely Fractured Fan Blades

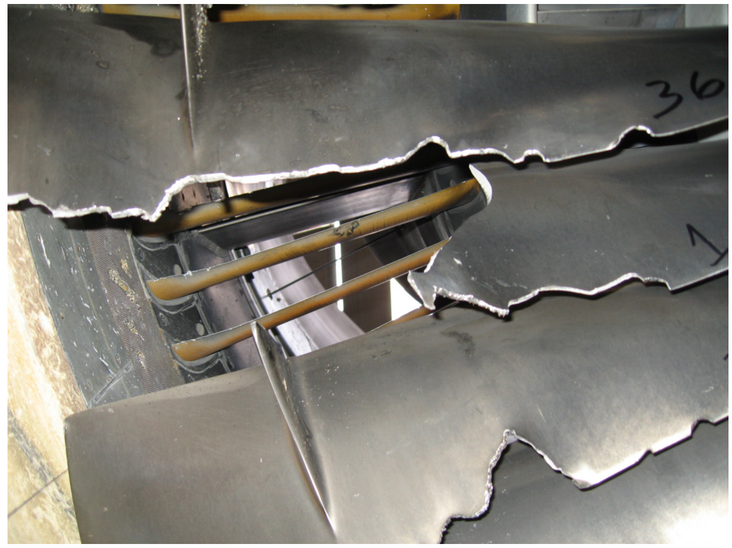

Photo 19: No. 1 Fan Blade Fracture

Photo 20: No. 34 Fan Blade Fracture

Photo 21: No. 32 Fan Blade Fracture

[6] Shingled is the condition of the mid-span shroud overlapping the shroud of an adjacent blade in lieu of abutting at the contact surfaces

PHOTO 22: SHINGLED MID-SPAN SHROUDS

The fan exit case inner liners, located between the fan blade rub strip and the aft acoustic liners, were present, intact and exhibited numerous impact marks and gouges. The aft acoustic liners behind the fan exit case inner liners were present and exhibited numerous impact marks and gouges with one piece of fan blade found imbedded in the liner at about the 9:30 o'clock position. All the exit guide vanes were present and most exhibited minor leading edge impact damage. Looking past the fan blade, the splitter and the booster inlet guide vanes appeared essentially undamaged. Looking past the inlet guide vanes, the 1st-stage LPC blades leading edges appeared undamaged and the abradable 1st-stage LPC blade rub strips (outer air seal) were rubbed away exposing the parent material beneath. Black debris consistent with the rub strip material was observed between the 1st-stage LPC blades.

Looking through the exhaust nozzle at the back end of the engine revealed that all the low pressure turbine blades (LPT) were present and intact. Resting at the bottom of the turbine exhaust case and the exhaust nozzle were small metallic pieces of debris.

2.3 NO. 2 ENGINE DAMAGE AND FINDINGS

Prior to the arrival of the Powerplant Group, the Safety Board authorized UAL to perform a borescope inspection of the No. 2 engine and to report any results. According to UAL, the borescope inspection did not find any internal engine damage beyond what is acceptable by the PW2000 Engine Manual limits.

Both the front and rear inlet cone segments were intact and present. All the fan blades were present, intact and whole. Fourteen fan blades exhibited minor leading edge hard-body impact damage and cuts (**PHOTO 23**). All the impact damage, except for one fan blade – No. 2 – was located outboard of the mid-span shroud.[7] Fan blades Nos. 3 and 4 exhibited the most severe impact damage of all the blades (**Photo 24**). The fan blade rub strip was intact and undamaged. The forward acoustic liner exhibited two minor gouges at the 11:30 o'clock position, with the largest measuring about 1.0-inch, and a 0.25-inch gouge at the 4:00 o'clock position. The inlet cowl inner barrel exhibited 5 minor/superficial impacts scuff marks, none of which passed through the inner acoustic liner.

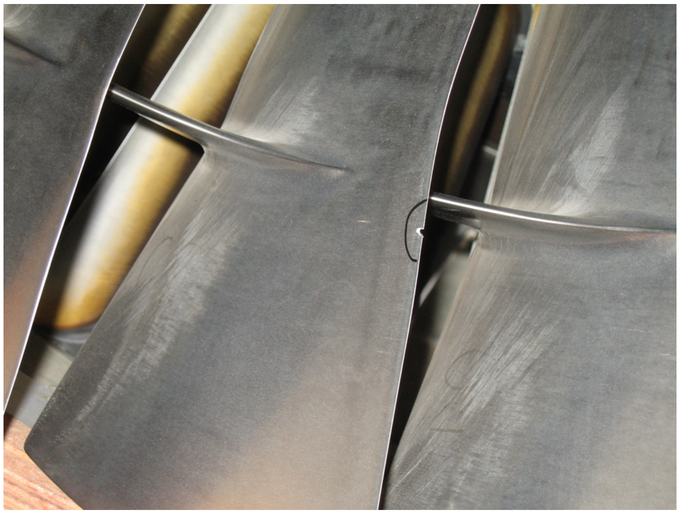

Photo 23: No. 2 Engine Typical Fan Blade Damage

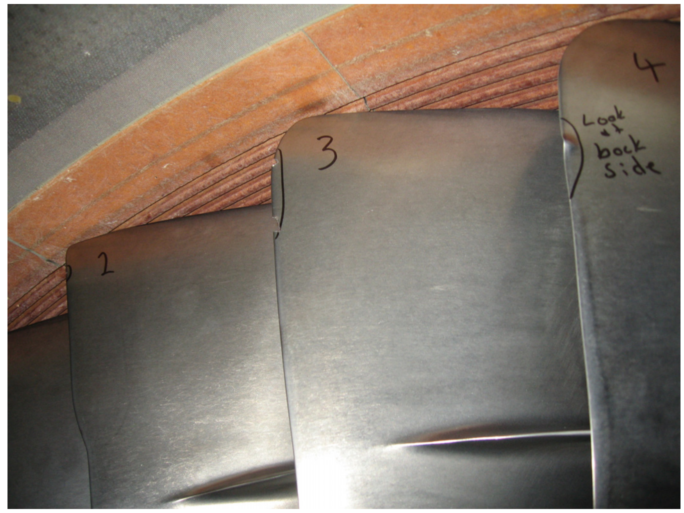

Photo 24: No. 2 Engine Fan Blade No. 3 & 4 Damage

3.0 NO. 1 ENGINE EXAMINATION AT UNITED AIRLINES

The engine was shipped to the UAL Engine Maintenance Center at the San Francisco International Airport (SFO) for removal of the fan blades and to perform some additional inspections and documentation. A workscope was developed and the Safety Board authorized UAL to perform work on the No. 1 engine in accordance with that workscope without the Powerplant Group present. This section provides the information that was collected during the engine exam.

The fan blades were removed and weighed in order to calculate the amount of low pressure (LP) rotor imbalanced induced by the missing fan blade airfoil material. **Table 3** provides the weights[8] of all the fan blades and **Figure 2** is a radar map of those weights. P&W was asked to calculate the amount of rotor imbalance due to the missing fan blade material. Using the fan blade weights and photographic documentation of the fan blade damage, P&W estimated that the amount of rotor imbalance could be a maximum of 4,022 ounce-inches (equivalent to the loss of 1.24 fan blades). The PW2037 engine was certified for the engine mounts and cases to withstand loads generated by the loss of 2.9 fan blades per Part 33.23 (see *Section 6.2 FAA Bird Ingestion Standards When PW2037M was Certificated* for details).

[7] The fan blades were numbered by UAL mechanics. They were numbered clockwise forward looking aft, in the direction opposite fan rotation.

[8] The fan blades weights include the fan blade seals and are in the as-received condition. Four serviceable fan blades from United stock were used to determine the average fan blade weight of 8.74 pounds with the weights ranging from 8.7 to 8.82 pounds.

Table 3: Fractured Fan Blade Weights

Blade No.	Weight (pounds)	Blade No.	Weight (pounds)	Blade No.	Weight (pounds)	Blade No.	Weight (pounds)
1	8.750	10	8.746	19	5.008	28	8.714
2	8.478	11	8.591	20	8.452	29	8.640
3	8.600	12	8.634	21	8.699	30	8.721
4	8.550	13	8.667	22	5.184	31	8.469
5	8.370	14	8.576	23	8.234	32	8.566
6	8.531	15	8.474	24	7.082	33	8.594
7	8.451	16	8.472	25	8.371	34	8.517
8	8.376	17	8.420	26	8.372	35	8.306
9	8.486	18	8.285	27	8.262	36	8.169

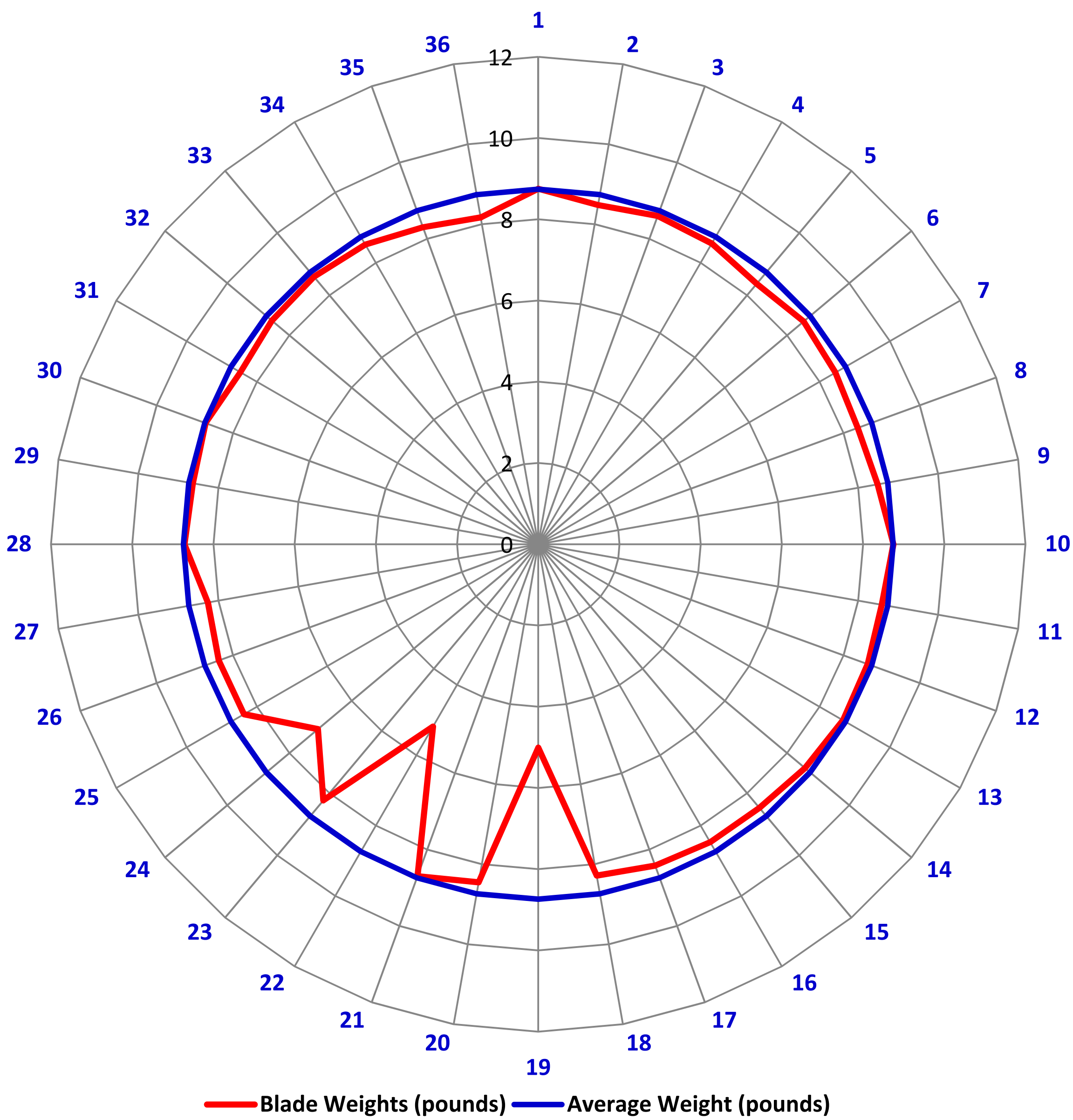

FIGURE 2: RADAR MAP COMPARING FRACTURED FAN BLADE WEIGHTS TO AVERAGE FAN BLADE WEIGHTS

United was requested to collect and weigh any blade material found in the inlet cowl and thrust reverser during the course of the engine disassembly. **Photo 25** and **Table 4** provide the details of the debris collected from the inlet cowl and thrust reverser.

Photo 25: Collected Fan Blade Fragments from Inlet Cowl and Thrust Reverser (courtesy of United Airlines)

Table 4: Blade Debris Found in the Inlet Cowl and Thrust Reverser				
Debris Found Inside Cavity Between Inner Barrel and Outer Barrel Skin of Inlet Cowl				
Debris Number	Width inches	Height inches	Thickness inches	Weight ounces
1	1.040	0.545	0.085	0.0485
2	0.470	0.480	0.070	0.0135
3	0.624	0.311	0.116	0.0370
4	1.250	0.692	0.129	0.1075
5	0.967	0.858	0.193	0.0915
6	0.580	0.233	0.064	0.0070
7	2.440	0.630	0.136	0.3540
8	0.619	0.626	0.094	0.0540
9	1.109	0.582	0.165	0.1125
10	0.475	0.176	0.125	0.0165
11	0.254	0.125	0.113	0.0060
12	2.274	1.423	0.139	0.6475
21	5.677	3.987	0.351	10.8835
22	6.310	4.775	0.325	15.2135
23	2.220	1.304	0.157	0.5040
24	2.070	0.839	0.200	0.5315
25	2.285	0.812	0.135	0.4105
		Total Weight Inside Inlet Cowl Cavity		**29.0385**
Debris Found Imbedding in the Inner Barrel Skin				
Debris Number	Width inches	Height inches	Thickness inches	Weight ounces
13	6.009	4.958	0.268	14.7980
14	1.791	1.510	0.194	0.8330
15	1.802	1.210	0.123	0.6340
16	1.574	0.950	0.106	0.2135
17	1.632	0.808	0.138	0.3105
18	1.500	1.124	0.123	0.2005
		Total Weight in Inlet Cowl Inner Barrel		**16.9895**
Debris Found Inside Thrust Reverser				
Debris Number	Width inches	Height inches	Thickness inches	Weight ounces
19	2.212	1.26	0.16	0.2005
20	2.716	1.93	0.173	0.8515
		Total Weight Inside of Thrust Reverser		**1.052**

4.0 BIRD REMAIN INDENTIFICATION

A local United States Department of Agriculture (USDA) wildlife biologist located at Denver International Airport was informed of the bird strike event and preceded to runway 35R where the bird strike occurred to collect bird remains. Afterwards, the USDA wildlife biologist inspected the airplane to document any bird strike damage and to collect any additional bird remains. A wildlife strike report, No. 2011-9-26-211506, was submitted to the FAA Wildlife Strike Database for this incident. The report can be found on the FAA website at (http://wildlife-mitigation.tc.faa.gov/wildlife/default.aspx). The FAA Wildlife Strike Database contains records of reported wildlife strikes since 1990. Strike reporting is voluntary; therefore, the database only represents information received from airlines, airports, pilots, and other sources.

According to the wildlife strike report, No. 2011-9-26-211506, two separate birds struck the airplane. A whole bird, along with a partially consumed rodent was recovered from the right-hand edge of runway 35R (**PHOTO 26**). The wildlife biologist identified the bird as a juvenile Red-Tailed Hawk (*Buteo jamaicensis*) and the rodent as a thirteen-lined ground squirrel *(Spermophilus tridecemlineatus)*. Remains of a second bird were scattered along the runway along with pieces of the engine. Inspection of the No. 1 engine revealed bird remains in the fan area. The bird remains collected by the wildlife biologist, along with samples collected by the Powerplant Group during their examination of the engine, were sent to the Smithsonian Institution National Museum of Natural History Division of Birds - Feather Identification Laboratory in Washington DC for analysis.

PHOTO 26: ANIMAL REMAINS RECOVERED BY THE WILDLIFE BIOLOGIST

The Smithsonian Feather Identification Laboratory, using feather identification and Deoxyribonucleic acid (DNA) analysis, identified the bird remains as coming from as a Red-Tailed Hawk. The Red-Tailed Hawk ranges in weight from about 24.3 to 51.50 ounces (1.52 to 3.22 pounds) with the female larger in size.[9] From the samples provided, the age of the bird – adult-vs-juvenile – was not possible. Additional DNA examination was able to identify the remains as coming from a female Red-Tailed Hawk. The average weight of the female Red-Tailed Hawk is about 1224 grams (43.2 ounces or 2.69 pounds.

5.0 FLIGHT DATA RECORDER INFORMATION

The digital flight data recorder (DFDR) was sent to the Safety Board's Headquarters in Washington DC and was readout by the Vehicle Recorder Group. A sequence of events timeline was created based on data from the DFDR for the incident flight. See **TABLE 5** for the timeline and also see the DFDR Group Chairman's Report for additional data (**FIGURE 3**). For the timeline, Time (T) equals zero was chosen as the time the airplane touched down and all subsequent events are based on that time.

[9] Data on the red-tailed hawk was gathered from the following sources: 1) The Cornell Lab of Ornithology and can be found at: http://www.allaboutbirds.org/guide/red-tailed_hawk/lifehistory and 2) The National Geographic and can be found at http://animals.nationalgeographic.com/animals/birds/red-tailed-hawk/.

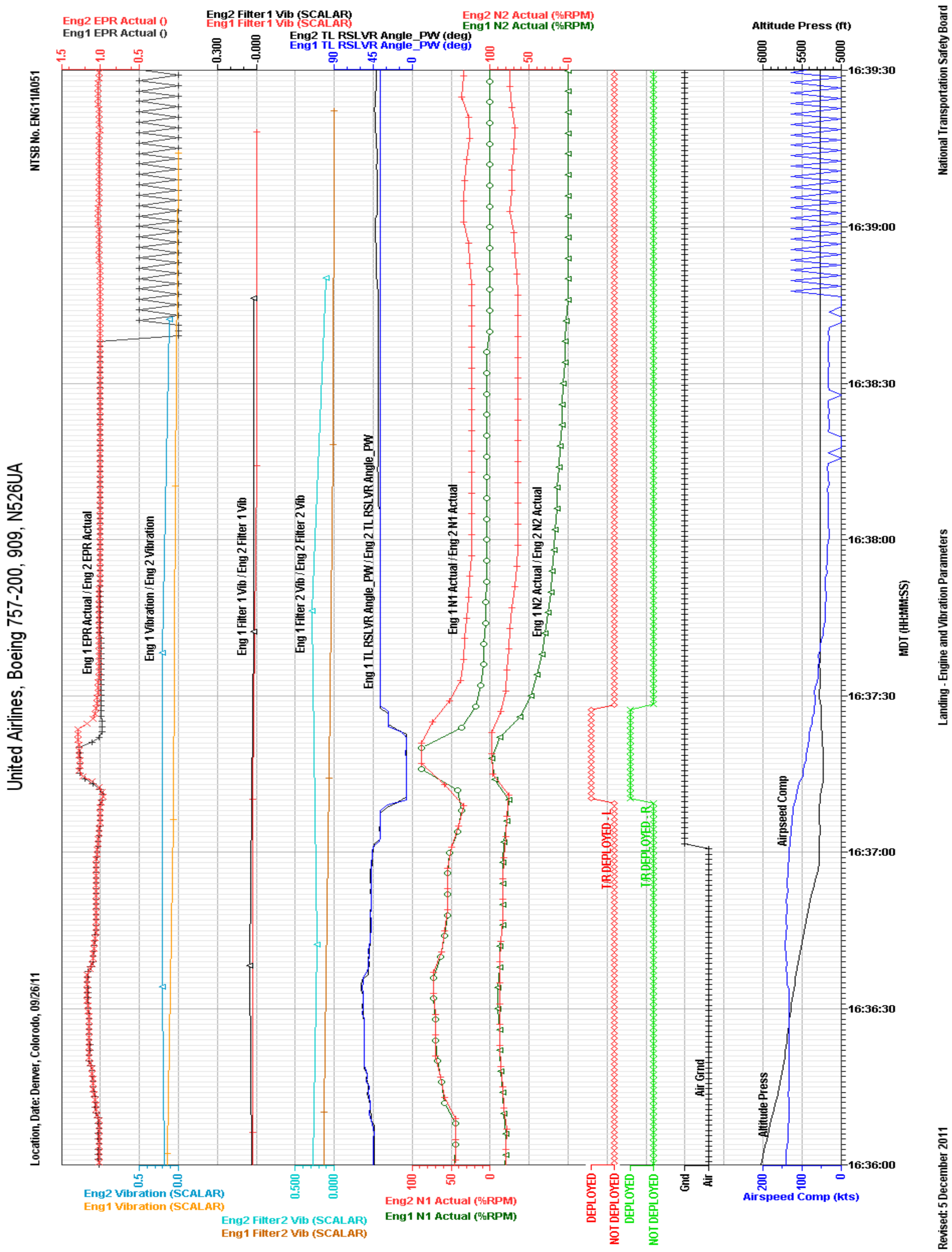

FIGURE 3: FLIGHT DATA PLOT FOR EVENT LANDING

TABLE 5: INCIDENT TIME LINE	
NTSB FDR data time (seconds)	
T = 0	Airplane touchdown ENG1 EPR = 1.04 ENG2 EPR = 1.03 ENG1 Thrust Lever Resolver Angle = 45 deg ENG2 Thrust Lever Resolver Angle = 44.3 deg
T = +1s to 8s	EPR, N1, N2, and Thrust Lever Resolver Angle for both engine move together and are matched
T = +9s	ENG1 TL RSLVR Angle = 7.03 deg ENG2 TL RSLVR Angle = 6.33 deg ENG1 and ENG2 Thrust Reverser Deployed
T = + 10s to 19s	Both engine EPRs move in unison to a value of about 1.27/1.28 Both engine N1 move in unison to a maximum value of about 88 percent Both engine N2 move in unison to a maximum value of about 98 percent Both Thrust Lever Resolver Angles remain at about 7.03 degrees
T = +20s	ENG1 EPR decreases from 1.27 to 1.11 ENG2 engine parameters remain stable **This is assumed to be the time that the bird ingestion occurred**
T = +21s	ENG1 EPR decreases to 1.02 ENG1 and ENG2Thrust Lever Resolver Angle remains unchanged ENG1 N2 decreases to 88 percent ENG2 engine parameters remain stable
T = +22s	ENG1 EPR decreases .98 and remains below 1 for the next 15 seconds until goes to zero ENG1 Thrust Lever Resolver Angle increases to 11.95 degrees ENG2 Thrust Lever Resolver Angle increases to 18.28 degrees
T = +23s	ENG1 Thrust Lever Resolver Angle increases to 27.42 degrees ENG1 N1 decreases to 36 percent
T = + 25	ENG1 N2 decreases to 62 percent
T = +27s	ENG1 and ENG2 Thrust Reverser Stowed ENG1 and ENG2 Thrust Lever Resolver Angle increases to 37.27 degrees ENG1 N1 decreases to 18 percent
T = +29s	ENG N2 decreases to 48 percent
T = +31s	ENG N1 decreases to 12 percent

6.0 ENGINE BIRD IGNESTION REQUIREMENTS

6.1 CURRENT FAA BIRD INGESTION STANDARDS

The airworthiness standards for aircraft engines are contained in Title 14 *Code of Federal Regulations* Part 33 and the bird ingestion standards are found in Subpart E - Design and Construction; Turbine Aircraft Engines, Part 33.76 Bird Ingestion. Amendment 33-23 with an effectivity date of October 17, 2007, includes the current Part 33.76 Bird Ingestion requirements. The bird ingestion testing requirements are divided into essentially the following categories – large single bird, small and medium flocking bird, and large flocking bird – where the bird weight, and the number of birds (in the case of the flocking bird requirements) required for the test are dictated by the size of the engine inlet throat area. Had this engine been certified under the current bird ingestion standards, the following ingestions tests would have applied based on the inlet throat area of 4,359 square-inches (in^2) for the PW2037:

A) Large Single Bird Test:	one 6.05-pound bird
B) Small and Medium Flocking Bird Test:	one 2.53-pound bird plus six 1.54-pound birds
C) Large Flocking Bird Test:	one 2.53-pound bird

Each of these tests demonstrates the engines capability at a different operating condition and based on that operating condition, different post-ingestion operational capability.

For the Large Single Bird test, after the bird is ingested the following engine conditions will not occur:

i. Non-containment of high-energy debris;
ii. Concentration of toxic products in the engine bleed air intended for the cabin sufficient to incapacitate crew or passengers;
iii. Significant thrust in the opposite direction to that commanded by the pilot;
iv. Uncontrolled fire;
v. Failure of the engine mount system leading to inadvertent engine separation;
vi. Complete inability to shut the engine down.

For the Small and Medium Flocking Bird test, after the bird(s) are ingested, the following conditions will not occur:

i. More than a sustained 25-percent power or thrust loss;
ii. The engine to be shut down during the required run-on demonstration prescribed as follows:
    a. Ingestion so as to simulate a flock encounter, with approximately 1 second elapsed time from the moment of the first bird ingestion to the last.
    b. Followed by 2 minutes without power lever movement after the ingestion.
    c. Followed by 3 minutes at 75-percent of the test condition.
    d. Followed by 6 minutes at 60-percent of the test condition.
    e. Followed by 6 minutes at 40-percent of the test condition.
    f. Followed by 1 minute at approach idle.
    g. Followed by 2 minutes at 75-percent of the test condition.
    h. Followed by stabilizing at idle and engine shut down.
    i. The durations specified are times at the defined conditions with the power being changed between each condition in less than 10 seconds

iii. The conditions defined in Large Single bird requirement;
iv. Unacceptable deterioration of engine handling characteristics.

For the Large Flocking Bird test, after the bird(s) are ingested, the following conditions will not occur:

i. A sustained reduction of power or thrust to less than 50 percent of maximum rated takeoff power or thrust during the run-on segment as specified:
   a. Ingestion followed by 1 minute without power lever movement.
ii. Engine shutdown during the required run-on demonstration as specified:
   a. Ingestion followed by 1 minute without power lever movement.
   b. Followed by 13 minutes at not less than 50 percent of maximum rated takeoff power or thrust.
   c. Followed by 2 minutes between 30 and 35 percent of maximum rated takeoff power or thrust.
   d. Followed by 1 minute with power or thrust increased from that set in paragraph c. of this section, by between 5 and 10 percent of maximum rated takeoff power or thrust.
   e. Followed by 2 minutes with power or thrust reduced from that set in paragraph d. of this section, by between 5 and 10 percent of maximum rated takeoff power or thrust.
   f. Followed by a minimum of 1 minute at ground idle then engine shutdown. The durations specified are times at the defined conditions. Power lever movement between each condition will be 10 seconds or less, except that power lever movements allowed within paragraph b. of this section are not limited, and for setting power under paragraph c. of this section will be 30 seconds or less.
iii. The conditions specified in Large Single bird requirement.

6.2 FAA Bird Ingestion Standards When PW2037M was Certificated

The basic PW2037 engine was issued Type Certificate (TC) E17NE by the FAA on December 28, 1983 and on January 30, 1987; the TC was amended to include the PW2037M model (**Attachment 1**). The PW2037 was certified under Part 33, Amendment 6 that had an effectivity date of October 31, 1974. At the time that the PW2037 engine was certificated, neither Part 33.76 Bird Ingestion, nor any other stand-alone engine bird ingestion requirement existed. Instead, the engine bird ingestion requirements were part of a broader ingestion requirement in Part 33.77 Foreign Object Ingestion (**Attachment 2**).

Some major and minor changes were made to the bird ingestion requirement between the time the PW2037 was certificated and the current standard. For the large bird requirement for instance, under Part 33.77, the large bird test required a 4-pound bird if it could fit in the inlet while the current bird ingestion standard bases the bird weight on the inlet throat area, with the maximum bird size of 8-pounds. Also, unlike the current bird ingestion standard that has three separate test categories - large single bird, small and medium flocking bird, and large flocking bird – the bird ingestion standards in effect at the time the PW2037 was certificated had only two, essentially the equivalent of the current large single bird and the small and medium flocking bird, and in both tests, the bird weights were less.

Under Part 33.77, the first bird ingestion requirement was the ingestion of a 4-pound bird that may not cause the engine to:

i. Catch Fire;
ii. Burst (penetrate its case);
iii. Generate loads greater than those specified in Part 33.23; or
iv. Loss of capability of being shut down.

The second bird ingestion requirement under Part 33.77 was divided into two ingestion categories (medium and small bird size) based on whether a 1.5-pound bird could pass through the inlet guide vanes (IGVs).[10] In either case, the ingestion of the bird(s) may not cause more than a sustained 25 percent power or thrust loss or require the engine to be shut down. The small bird test calls of a 3-ounce bird for every 50 in^2 of inlet area up to a maximum of 16 and the large bird test calls for a 1.5-pound bird for the first 300 in^2 and 1 bird for every 600 in^2 thereafter up to a maximum of 8 birds. If the 1.5-pound bird could pass through the IGVs, the small bird test was not required. Based on the PW2037M inlet throat area of 4,359 in^2, sixteen 3-ounce birds or eight 1.5-pound birds would be required for the run-on test. Only the 1.5-pound bird test was performed.

TABLE 6 provides a comparison of the current bird ingestion standard and the one in effect when the PW2037M was certified.

[10] Older generation of jet engines that pre-date the PW2037 turbofan employed static IGVs ahead of the rotating fan blades to direct air into the engine. The IGVs reduced the size of objects that could be ingested into the engine and reduced the effective frontal area exposed to ingestion debris. Today's large transport category turbine-powered airplanes are almost exclusively powered by turbofan type engines that have a large frontal area directly exposed to the oncoming air and long rotating fan blades with no structure ahead of the fan blades which makes them more susceptible to ingestion events.

Table 6: Comparison of Bird Ingestion Requirements						
	Part 33.77 Amendment 6 Foreign Object Ingestion			**Current Part 33.76 Bird Ingestion Standards**		
	Weight (pounds)	Quantity	Post-Ingestion Requirement (will not occur)	Weight (pounds)	Quantity	Post-Ingestion Requirement (will not occur)
Single Bird	4	1		6.05	1	
			Burst (penetrate its case)			Uncontained high-energy debris
			NEW REQUIREMENT ⇨			Toxic engine bleed air
			NEW REQUIREMENT ⇨			Thrust in the opposite direction
			Catch Fire			Uncontrolled fire
			Deformation of Engine Mount			Inadvertent engine separation
			Inability to shut down the engine			Inability to shut the engine down
Small and Medium Flocking	1.5 or 0.1875	8 (1.5 lb) or 16 (3-oz)	Loss of 25% power or thrust	2.53 & 1.54	1 (2.53) + 6 (1.54)	Loss of 25% power or thrust – plus some additional run-on power requirements as a function of run-on time
			Require the engine to be shutdown			Require the engine to be shutdown
			NEW REQUIREMENT ⇨			Uncontained high-energy debris
			NEW REQUIREMENT ⇨			Toxic engine bleed air
			NEW REQUIREMENT ⇨			Thrust in the opposite direction
			NEW REQUIREMENT ⇨			Uncontrolled fire
			NEW REQUIREMENT ⇨			Inadvertent engine separation
			NEW REQUIREMENT ⇨			Inability to shut the engine down
			NEW REQUIREMENT ⇨			Unacceptable deterioration of engine handling characteristics
Large Flocking			**NEW REQUIREMENT ⇨**	2.53	1	Sustained power less than 50% - plus some additional run-on power requirements as a function of run-on time
			NEW REQUIREMENT ⇨			Uncontained high-energy debris
			NEW REQUIREMENT ⇨			Toxic engine bleed air
			NEW REQUIREMENT ⇨			Thrust in the opposite direction
			NEW REQUIREMENT ⇨			Uncontrolled fire
			NEW REQUIREMENT ⇨			Inadvertent engine separation
			NEW REQUIREMENT ⇨			Inability to shut the engine down

6.3 PW2037M BIRD INGESTION CERTIFICATION TESTING RESULTS

P&W successfully conducted the PW2037 engine large bird ingestion test on May 13, 1983 and the medium flocking bird ingestion test on June 23, 1983. The results of large bird ingestion test was published in report PW-5819, dated October 1983, and the results of the medium flocking ingestion test results was published in report PW-5808, dated August 1983. The same experimental engine was used for both tests with a simulated flight inlet.

For the large bird ingestion test, a single 4-pound pheasant was fired at the fan blade mid-span shroud at 250 knots with the engine thrust set in excess of the PW2037 maximum cruise rating. The engine thrust decreased slightly from the maximum cruise thrust level after the ingestion of the 4-pound bird. No engine surge occurred and the engine shutdown was normal. The damage was limited to the fan case and fan blades. No fan case holes or penetrations were reported and the acoustic liners and the fan case rub strip exhibited gouges and missing material. Five fan blades were scrapped because they were damaged beyond repair limits. The scrapped fan blades exhibited blade tip damage and/or loss with all the damage located outboard of the mid-span shrouds. None of the blades were fractured transversely across the airfoil as was observed in the UAL Denver bird ingestion event.

For the medium bird ingestion test, eight 1.5-pound pheasants were distributed across the face of the engine to simulate a flock encounter with some of the birds aimed at critical radial locations. The birds were fired at 180 knots to represent typical initial climb speed and the engine thrust was set at the takeoff rating. The engine thrust after the ingestion was greater than 75 percent of the takeoff thrust and no surge occurred. The acoustic liners and the fan case rub strip exhibited gouges and missing material. Several fan blades sustained soft-body damage with two blades cracked at the mid-span shroud. None of the blades were fractured transversely across the airfoil as was observed in the UAL Denver bird ingestion event. In additional to the fan blade and fan case damage, external component brackets were fractured and the LPC exhibited minor leading edge rub. The fractured brackets were redesigned based on the results of the bird ingestion test.

On December 13, 1983, the FAA issued P&W a letter indicating that the report PW-5819 was reviewed, approved, and satisfied the requirements of Part 33.77 ingestion requirements. On December 27, 1983, the FAA issued P&W a similar letter for report PW-5808.

7.0 ENGINE AND AIRPLANE CONTAINMENT REQUIREMENTS

The engine containment standards are found in 14 *CFR* Part 33 Subpart B - Design and Construction; General, Section 33.19 Durability. Engine manufacturers are required to design compressor and turbine rotor cases for the containment of damage from rotor blade failure. Section 33.19(a) states in part that:

> The design of the compressor and turbine rotor cases must provide for the containment of damage from rotor blade failure. Energy levels and trajectories of fragments resulting from rotor blade failure that lie outside the compressor and turbine rotor cases must be defined.

Engine manufacturers design cases to contain a blade failure and this is substantiated by an engine blade-out test or by analysis based on rig testing, component testing, or service experience. FAA Advisory Circular (AC) 33-5 provides guidance and acceptable methods by which the engine manufactures test and certificate that the engine is in compliance with the containment provisions in *CFR* Part 33. The Part 33.19(a) requirements to define the energy levels and trajectories resulting from a blade failure was intended to address only the initial blade(s) release, not the medium-to-small blade fragments that are created during the subsequent blade failures. Examination of the engine revealed that the fan case sustained some bulging but no exit holes, penetrations or uncontainments were noted.

No containment requirements exist that call for airplane manufacturers (commuter airplanes Part 23 or transport category Part 25) to design inlets or nacelles to contain engine debris. Therefore, the requirement for containment of fan blades stops at the interface between the engine structure, in the case of the PW2037 the "A_o" flange, and the airplane inlet structure. The inlet functions as aerodynamic structure to guide the flow into the engine and was not intended to provide or incorporate structure to prevent fan blade forward liberation. Although the airplane manufacturers are not required to design structure to contain engine debris, they are responsible for the overall safety of the airplane and do have some engine debris uncontainment responsibility as outlined AC 20-128A, "Design Considerations for Minimizing Hazards Caused by Uncontained Turbine Engine and Auxiliary Power Unit Rotor Failure."

The AC describes how to best mitigate the threat of the debris causing a potential hazardous or catastrophic condition to the airplane or harm to the occupants on board by requiring design precautions based on service experience and tests. Currently airplane manufactures use redundancy, separation, and isolation to minimize the hazards from large, single, uncontained engine fragments. Examination of the airplane revealed minor superficial gouging of the fuselage, the left-hand wing, and one passenger window, none of which posed a hazard to the airplane or passengers.

Jean-Pierre Scarfo
Aerospace Engineer
Powerplant Lead