ARAIB/AIR-F1203

Aircraft Serious Incident Report

In-Flight Engine Shutdown
United Airlines Flight 890
B777-200, N206UA
Approximately 45 km South of Incheon Int'l Airport
31 December 2012

January 2015

AVIATION AND RAILWAY ACCIDENT INVESTIGATION BOARD

This aircraft serious incident report has been prepared in accordance with the Article 25 of the Aviation and Railway Accident Investigation Act of the Republic of Korea.

According to the provisions of the Article 30 of the Aviation and Railway Accident Investigation Act, it is stipulated;

The accident investigation shall be conducted separately from any judicial, administrative disposition or administrative lawsuit proceedings associated with civil or criminal liability.

And in the Annex 13 to the Convention on International Civil Aviation, Paragraphs 3.1 and 5.4.1, it is stipulated as follows:

The sole objective of the investigation of an accident or incident shall be the prevention of accidents and incidents. It is not the purpose of the activity to apportion blame or liability. Any investigation conducted in accordance with the provision of this Annex shall be separate from any judicial or administrative proceedings to apportion blame or liability.

Thus, this investigation report shall not be used for any other purpose than to improve aviation safety.

In case of divergent interpretation of this report between the Korean and English languages, the Korean text shall prevail.

Aircraft Serious Incident Report (Draft)

Aviation and Railway Accident Investigation Board. ***In-Flight Engine Shutdown, United Airlines Flight 890, B777-200, N206UA, Approximately 45 km South of Incheon International Airport, 31 December 2012.*** **Aircraft Serious Incident Report ARAIB/AIR-F1203. Sejong Special Self-Governing City, Republic of Korea.**

The Aviation and Railway Accident Investigation Board (ARAIB), Republic of Korea, is a government organization established for independent investigation of aviation and railway accident, and the ARAIB conducts accident investigation in accordance with the provisions of the Aviation and Railway Accident Investigation Act of the Republic of Korea and Annex 13 to the Convention on International Civil Aviation.

The objective of the investigation by the ARAIB is not to apportion blame or liability but to prevent accidents and incidents.

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Abbreviations

AGB	Angle Gearbox
alt	altitude
AMM	Airplane Maintenance Manual
ARAIB	Aviation and Railway Accident Investigation Board
ARINC	Aeronautical Radio INC.
assy	assembly
ATB	Air Turnback
BMOD	Bill of Material Object Damage
CAM	Cockpit Area Microphone
CAS	Calibrated Airspeed
ch	channel
CVR	Cockpit Voice Recorder
deg.	degree
EEC	Electronic Engine Control
EGT	Exhaust Gas Temperature
EICAS	Engine Indicating and Crew Alerting System
EM	Engine Manual
EPR	Engine Pressure Ratio
FAA	Federal Aviation Administration
FDR	Flight Data Recorder
FF	Fuel Flow
FMU	Fuel Metering Unit
FMV	Fuel Metering Valve
ft.	feet
HPC	High Pressure Compressor
HPT	High Pressure Turbine
ICAO	International Civil Aviation Organization

ICN	Incheon International Airport
I.D	Inside Diameter
IDG	Integrated Drive Generator
IFSD	In-flight Engine Shutdown
IMC	Intermediate Case
in	inch
lbf-in	pound-inch
LPC	Low Pressure Compressor
LPT	Low Pressure Turbine
MCD	Magnetic Chip Detector
MGB	Main Gearbox
Mn	Mach number
N1	rotational speed of the low-pressure rotor
N2	rotational speed of the high-pressure rotor
N2dot	Derivative of N2 speed with respect to time
N.m	Newton.meter
NRT	Narita International Airport
NTSB	National Transportation Safety Board
O.D	Outside Diameter
Pb	Burner Pressure
P&W	Pratt and Whitney
P/N	Part Number
PF	Pilot Flying
PM	Pilot Monitoring
PMA	Permanent Magnet Alternator
pph	pound per hour
psi	pound per square inch
QRH	Quick Reference Handbook
rpm	revolution per minute
SID	Standard Instrument Departure

S/N	Serial Number
SSCVR	Solid State Cockpit Voice Recorder
SSFDR	Solid State Flight Data Recorder
T	tight fit
TCDS	Type Certification Data Sheet
TRA	Thrust lever Resolver Angle
TSN/CSN	Time/Cycle Since New
TSLSV/CSLSV	Time/Cycle Since Last Shop Visit
TSO/CSO	Time/Cycle Since Overhaul
UAL	United Airlines
UTC	Coordinated Universal Time

In-Flight Engine Shutdown

- Operator: United Airlines
- Manufacturer: The Boeing Company, US
- Type: B777-200
- Registration Mark: N206UA
- Location: Approximately 45 km south of Incheon Int'l Airport
  (N 37°19'09", E 126°56'09")
- Date & Time: 31 Dec. 2012, approximately 12:41 KST (03:41 UTC[1])

Synopsis

On 31 December 2012, approximately 12:41, a B777-200 airplane, N206UA, operated as United Airlines flight 890, which took off from Incheon International Airport, Republic of Korea, bound for Narita International Airport, Japan, experienced a pop sound accompanied with a yaw to the left while climbing through about 28,000 ft after takeoff. At this time, the IDG[2] tripped off, and No.1 engine fail EICAS message appeared, followed by fault messages for surge, N2, IDG and FMU. As the engine flamed out, in-flight restart was attempted but unsuccessful. The flight crew who decided to return declared an emergency to air traffic control (ATC), descended, and landed safely at Incheon International Airport, point of departure, about 13:05.

Aboard the airplane were 2 flight crew, 10 cabin crew, and 246 passengers, but there was no personal injury.

The Aviation and Railway Accident Investigation Board (ARAIB) determines

1) Unless otherwise indicated, all times stated in this report are Korean Standard Time (KST, UTC +9).
2) An IDG is a constant speed drive (CSD) and a brushless three-phase AC generator in the same housing/case.

the cause of this serious incident was that the mechanical breakdown of the MB-7 bearing,[3] which supports the front part of the gearbox drive gear shaft at the No. 1 engine MGB, stopped the transmission of the N2 rotor's rotational power to the MGB through the layshaft, which shut down all engine components mounted on the MGB, thereby resulting in the IFSD.[4]

Contributing to this serious incident was that, during the last engine assembly, when the MB-7 bearing was mounted on the MGB driveshaft, the PMA drive retaining nut was tightened with a less torque than that prescribed by the EM, which caused its failure to support the MB-7 bearing inner race, thereby resulting in the mechanical damage of the MB-7 bearing.

Regarding this serious incident, the ARAIB addresses one safety recommendation to United Airlines.

3) The MB-7 bearing is a roller type bearing that supports the forward bearing journal on the MGB drive gear shaft, and bearing numbers are given, for reference, by the engine manufacturer to distinguish bearing locations.

4) In-Flight Engine Shutdown.

1. Factual Information

1.1. History of Flight

On 31 December 2012, approximately 12:30, a B777-200 airplane, N206UA, operated as United Airlines flight 890, took off from runway 33L at Incheon International Airport (hereafter referred to as Incheon Airport), the Republic of Korea, using standard instrument departure (SID), bound for Narita International Airport, Japan.

According to the statement of the captain, when the first officer (FO) manually climbed through 28,000 ft about 12:41, the airplane yawed to the left with the shaking of the control column. The left (No. 1) engine's N1[5] and N2[6] speeds were 20% and 0%, respectively. The IDG tripped off, and ENG FAIL L EICAS message appeared. The flight crew thus declared an emergency to Incheon ATC.

According to the statement of the flight crew, they implemented ENG FAIL L procedures in the QRH and attempted to restart the engine but to no avail. Later, the captain became the PF and landed the airplane at runway 33L in Incheon Airport, using the ILS approach about 13:05.

1.2. Injuries to Persons

There was no personal injuries as a result of this serious incident.

5) N1 speed is the rotational speed of the engine's low pressure spool, which includes the fan, low pressure compressor, and low pressure turbine.
6) N2 speed is the rotational speed of the engine's high pressure spool, which includes high pressure compressor and high pressure turbine.

1.3. Damage to Aircraft

The airframe was not damaged as a result of this serious incident, and damage to the engine was specified in section 1.12 Wreckage and Impact Information.

1.4. Other Damage

There was no other damage.

1.5. Personnel Information

1.5.1. The Captain

The captain (male, age 52) held a valid air transport pilot license[7] issued by the FAA,[8] B777 type rating,[9] a first-class airman medical certificate,[10] an aeronautical audio operator license,[11] and level 6 ICAO English Proficiency Certificate. He had accumulated 20,150 total flight hours, including 12,000 hours as pilot-in-command and 4,100 hours as pilot-in-command in B777 airplanes. He had flown 130 and 80 hours in the last 90 and 30 days, respectively.

The captain received his recurrent simulator training on 14 December 2012 and passed his proficiency check on 15 December 2012.

The captain departed from Los Angeles International Airport, US, on 29 December (Sat), about 02:00 and arrived at Narita International Airport, Japan, about 15:50, then took a rest at a hotel. On 30 December (Sun), he got up at 08:00, departed from Narita International Airport about 18:00, arrived at Incheon

7) License No.: FAA-3186185 (acquired on 11 Mar. 1984).
8) Federal Aviation Administration.
9) Acquisition Date: 20 Feb. 2008.
10) Term of Validity: 2 Oct. 2012 - 31 Oct. 2013.
11) Acquisition Date: 28 Apr. 1978.

Airport about 21:00, and went to bed about 23:00. On 31 December (Mon), he got up at 07:00 and departed from the hotel for United Airlines flight 890 about 10:30.

He stated that he did not drink any alcohol or take any illegal medication in the 24 hours before the event flight and was in good health.

1.5.2. The First Officer

The FO (female, age 38) held a valid air transport pilot license[12] issued by the FAA, B777 type rating,[13] a first-class airman medical certificate,[14] an aeronautical radio operator license,[15] and level 6 ICAO English Proficiency Certificate. She had accumulated 14,782 total flight hours, including 5,782 hours in B777 airplanes. She had flown 210 and 72 hours in the last 90 and 30 days.

The FO received her recurrent simulator training on 13 May 2012 and passed her proficiency check on 14 May 2012.

The FO departed from Los Angeles International Airport, US, on 29 December (Sat), about 02:00 and arrived at Narita International Airport, Japan, about 15:50, then took a rest at a hotel. On 30 December (Sun), she got up at 06:00, departed from Narita International Airport about 18:00, arrived at Incheon Airport about 21:00, and went to bed about 23:00. On 31 December (Mon), she got up at 07:30 and departed from the hotel for United Airlines flight 890 about 10:30.

She stated that she did not drink any alcohol or take any illegal medication in the 24 hours before the event flight and was in good health.

12) License No.: FAA-2853705 (acquired on 19 Feb. 2009).
13) Acquisition Date: 20 Mar. 1999.
14) Term of Validity: 7 Jan. 2012 - 31 Jan. 2013.
15) Acquisition Date: 28 Mar. 1989.

1.6. Aircraft Information

1.6.1. Engine Information

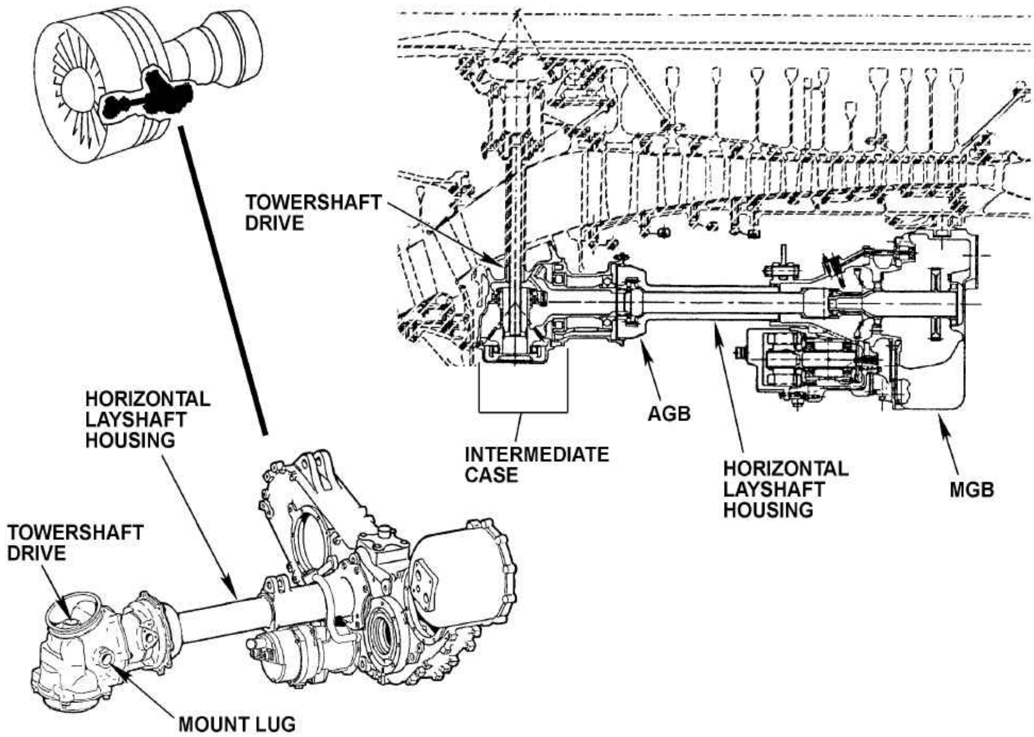
The accident airplane was powered by two Pratt & Whitney (P & W) PW4090 turbofan engines. The PW4090 is a dual-spool, axial-flow, high bypass[16] turbofan engine that features a 1-stage fan, a 6-stage low pressure compressor (LPC), a 11-stage high pressure compressor (HPC), an annular combustor, a 2-stage high pressure turbine (HPT), and a 7-stage low pressure turbine (LPT).

According to the FAA Type Certificate Data Sheet (TCDS) E46NE, Revision 8, dated 23 January 2012, the PW4090 engine has a maximum continuous sea level thrust rating of 74,950 pounds and a takeoff sea level thrust rating of 91,790 pounds flat rated to 59°F (15°C).

1.6.2. Main Gearbox Information

The main gearbox (MGB) is located at the bottom of the HPC rear case and immediately in front of the diffuser case. The angle gearbox (AGB) is located at the bottom of the intermediate case (IMC). A bevel gear on the towershaft in the IMC engages a bevel gear on the front of the HPC shaft. The towershaft drives the bevel gears in the AGB and thereby converts a vertical rotational force into a horizontal rotational force which drives the gearbox drive gear shaft through the layshaft. This force drives the gear shafts of engine components on the MGB, thereby making them function.

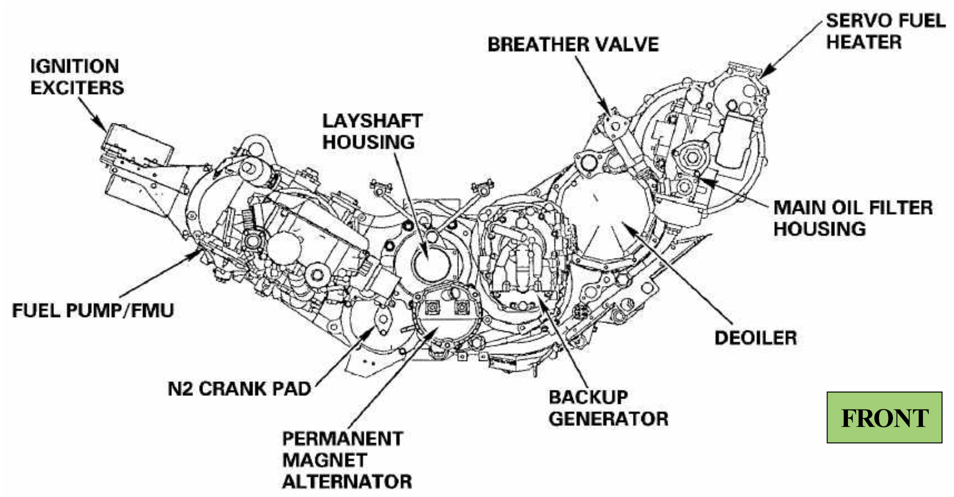
16) The bypass ratio of a turbofan engine is the ratio of the secondary flow rate of air drawn through the fan that bypasses the engine core to the primary flow rate of air that passes through the engine core. The bypass ratio of the PW4090 is 6.4:1.

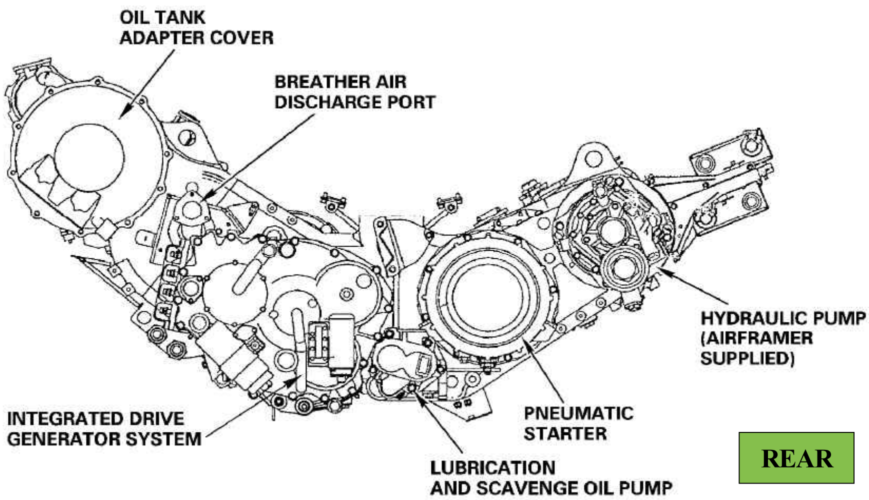


[Figure 1] Gearbox Power Transmission System

The fuel pump/fuel metering unit (FMU), the backup generator, the permanent magnetic alternator (PMA[17]), the deoiler, and the N2 crank pad are installed on the front face of the MGB housing. The IDG, the pneumatic starter, the hydraulic pump, and the lubrication and scavenge oil pump are installed on the rear face of the housing. Main engine components installed on the MGB are located as shown in [Figure 2].

17) The PMA is installed in front of the MGB, the gear of which produces AC electricity by using the rotational force and sends it to the EEC. Also, it sends an analog signal of N2 speed to the EEC.





[Figure 2] MGB Components

1.6.3. Engine History

The serial number of the No. 1 engine (left) was P222172, and its TSN/CSN[18] was 46,715 hours/6,375 cycles. The serial number of the No. 2 engine (right) was P222023, and its TSN/CSN was 62,552 hours/8,786 cycles. The TSLSV/CSLSV[19] of the failed No. 1 engine was 10,499 hours/1,367 cycles. The TSN/CSN and the TSO/CSO[20] of the MGB were 60,361 hours/10,410 cycles

18) Time/Cycle Since New.
19) Time/Cycle Since Last Shop Visit.
20) Time/Cycle Since Overhaul

and 10,499 hours/1,367 cycles, respectively, but the total time of the failed MB-7 roller bearing was not confirmed[21].

1.7. Meteorological Information

Meteorological aspects are not related to this serious incident.

1.8. Aids to Navigation

Not applicable.

1.9. Communications

No communications problems were reported during flight.

1.10. Aerodrome Information

Not applicable.

1.11. Flight Recorders

After the event, United Airlines' aircraft mechanic stationed in Incheon Airport removed the flight data recorder (FDR) and cockpit voice recorder (CVR) from the event aircraft upon direction of the ARAIB. The flight recorders were sent to the analysis lab of the National Transportation Safety Board (NTSB) in Washington DC, US, and the data extracted from the recorders were analyzed by investigators from the ARAIB and the NTSB.

21) United Airlines does not separately manage the service time of each bearing used for the MGB.

1.11.1. Cockpit Voice Recorder

The airplane was equipped with the Honeywell 6032 Solid State CVR (SSCVR)[22] that records approximately 3-hours of cockpit audio separated into four files. Three files and one file contain audio information recorded from three separated HOT microphones and from the cockpit area microphone (CAM), respectively. Each HOT microphone recording contained 2-hours, 10-minutes, and 24-seconds of good-quality audio information, whereas the CAM recording contained 3-hours, 12-minutes, and 45-seconds of poor-quality audio information.

The HOT microphone started recording audio information from the flight crew audio panels when the flight crew referred to the checklist after engine failure and implemented related procedures. The recording continued both during landing and for approximately 1 hour 50 minutes after landing.

1.11.2. Flight Data Recorder

The airplane was equipped with the Honeywell Solid State FDR (SSFDR)[23] that records airplane flight information in a digital format using solid-state flash memory as the recording medium.

The SSFDR can receive data in the ARINC[24] 573/717/747 configurations and can record a minimum of 25 hours of flight data. The FDR recording contained approximately 54 hours of data. The event flight was the last flight of the recording, and its duration was approximately 35 minutes.

Out of the extracted data, main engine parameters relating closely to this serious incident were selected and analyzed as shown in [Table 1].

22) Part No.: 980-6032-001, Serial No.: 01255.
23) Part No.: 980-4700-042, Serial No.: 3475.
24) Aeronautical Radio INC.

Time	Pressure Altitude	EPR		N1 Vib		N2 Vib		BB Vib		N1 RPM		N2 RPM		Oil Pressure		Fuel Flow Rate		Burner Press	
GMT		Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
hh:mm:ss	Feet	EPR		Scalar		Scalar		Scalar		% RPM		% RPM		PSIG		PPH		PSIA	
3:39:11	24695	1.430	1.430	0.56	0.12	0.09	0.07	0.40	0.13	91.8	91.6	87.9	87.9	244	279	14880	14704	280	288
3:39:15	24802	1.434	1.434	0.60	0.11	0.09	0.08	0.39	0.13	91.9	91.8	87.9	87.9			14960	14672	281	288
3:39:19	24909	1.430	1.430	0.58	0.11	0.09	0.09	0.40	0.13	91.8	91.6	87.8	87.8			14816	14688	281	287
3:39:23	25033	1.430	1.430	0.57	0.13	0.07	0.08	0.39	0.14	91.6	91.8	87.8	87.9			14704	14624	279	286
3:39:27	25175	1.434	1.438	0.58	0.15	0.07	0.07	0.40	0.13	91.8	91.9	87.8	88.0			14736	14656	278	286
3:39:31	25328	1.438	1.438	0.57	0.14	0.09	0.09	0.39	0.14	92.0	91.9	87.9	87.9			14752	14624	277	284
3:39:35	25500	1.438	1.438	0.58	0.11	0.10	0.10	0.39	0.15	92.0	92.0	87.9	87.9			14720	14544	276	284
3:39:39	25674	1.441	1.441	0.57	0.11	0.09	0.08	0.39	0.13	92.0	92.1	87.9	87.9			14576	14496	276	283
3:39:43	25845	1.441	1.441	0.57	0.12	0.07	0.08	0.38	0.14	92.1	92.1	87.9	87.9			14496	14448	274	281
3:39:47	26008	1.445	1.445	0.59	0.12	0.09	0.07	0.38	0.13	92.3	92.3	87.9	88.0			14560	14368	273	280
3:39:51	26163	1.449	1.449	0.57	0.12	0.11	0.08	0.41	0.14	92.3	92.4	87.9	88.0			14416	14384	271	279
3:39:55	26312	1.453	1.453	0.56	0.13	0.11	0.09	0.38	0.13	92.4	92.4	87.9	88.0			14384	14320	270	277
3:39:59	26441	1.453	1.449	0.54	0.14	0.10	0.08	0.39	0.12	92.4	92.4	88.0	88.1			14368	14256	270	276
3:40:03	26566	1.453	1.453	0.56	0.12	0.10	0.07	0.39	0.12	92.5	92.5	88.1	87.9			14400	14224	270	276
3:40:07	26694	1.453	1.453	0.59	0.12	0.10	0.08	0.40	0.13	92.5	92.5	88.0	88.0			14352	14160	268	275
3:40:11	26829	1.457	1.457	0.58	0.11	0.10	0.07	0.39	0.11	92.6	92.5	88.1	88.0			14320	14144	267	274
3:40:15	26968	1.461	1.461	0.55	0.10	0.10	0.08	0.40	0.13	92.9	92.8	88.1	88.1	241	278	14320	14096	266	273
3:40:19	27090	1.465	1.465	0.52	0.12	0.11	0.08	0.39	0.11	92.9	92.9	88.1	88.1			14208	14080	265	272
3:40:23	27189	1.465	1.465	0.55	0.10	0.11	0.09	0.39	0.13	92.8	92.8	88.1	88.1			14176	14016	265	271
3:40:27	27278	1.465	1.461	0.56	0.11	0.09	0.07	0.39	0.12	92.8	92.8	87.9	88.1			14112	14000	264	271
3:40:31	27369	1.453	1.457	0.54	0.10	0.10	0.07	0.38	0.11	92.5	92.6	88.1	88.1			14016	13936	263	271
3:40:35	27462	1.461	1.457	0.58	0.10	0.10	0.08	0.41	0.12	92.8	92.6	88.1	88.1			14144	13952	264	271
3:40:39	27562	1.453	1.457	0.61	0.09	0.09	0.08	0.41	0.10	92.6	92.8	88.1	88.1			14112	13968	263	270
3:40:43	27685	1.457	1.457	0.58	0.08	0.11	0.08	0.40	0.11	92.9	92.9	88.3	88.3			14064	13936	262	269
3:40:47	27812	1.465	1.461	0.57	0.08	0.10	0.09	0.42	0.13	92.9	92.9	88.1	88.3			14048	13904	261	267
3:40:51	27939	1.465	1.465	0.57	0.08	0.11	0.08	0.41	0.11	92.9	93.0	88.1	88.3			13904	13840	260	267
3:40:55	28056	1.469	1.469	0.54	0.10	0.11	0.09	0.39	0.13	93.0	93.0	88.3	88.3			13936	13792	259	265
3:40:59	28155	1.473	1.473	0.54	0.10	0.13	0.08	0.39	0.12	93.1	93.0	88.3	88.3			13952	13696	258	264
3:41:03	28232	1.445	1.473	0.59	0.11	0.09	0.08	0.85	0.12	92.6	93.0	86.5	88.1			13344	13664	228	264
3:41:07	28278	1.238	1.469	0.69	0.08	0.01	0.07	0.44	0.11	88.6	92.9	41.6	88.1			10704	13584	44	263
3:41:11	28329	0.699	1.469	0.07	0.08	0.00	0.08	0.10	0.12	33.9	93.4	0.0	88.9			0	13776	16	263
3:41:15	28394	0.699	1.477	0.23	0.09	0.00	0.08	0.23	0.12	26.9	93.4	0.0	88.3			0	14048	14	263
3:41:19	28430	0.699	1.477	0.13	0.10	0.00	0.08	0.14	0.12	25.5	93.3	0.0	88.3	4	277	0	13696	13	262
3:41:23	28449	0.699	1.477	0.14	0.09	0.00	0.08	0.19	0.11	24.9	93.3	0.0	88.3			0	13632	12	261
3:41:27	28462	0.699	1.477	0.12	0.10	0.00	0.08	0.25	0.12	24.5	93.4	0.0	88.4			0	13664	11	261
3:41:31	28475	0.699	1.480	0.14	0.10	0.00	0.07	0.29	0.11	24.1	93.5	0.0	88.4			0	13760	10	261
3:41:35	28486	0.699	1.480	0.18	0.10	0.00	0.08	0.39	0.11	23.8	93.5	0.0	88.4			0	13712	10	261
3:41:39	28496	0.699	1.480	0.08	0.09	0.00	0.07	0.35	0.12	23.5	93.5	0.0	88.4			0	13728	9	260
3:41:43	28506	0.699	1.480	0.13	0.08	0.00	0.08	0.49	0.12	23.3	93.5	0.0	88.4			0	13744	9	260
3:41:47	28514	0.699	1.484	0.12	0.07	0.00	0.08	0.55	0.12	23.1	93.6	0.0	88.3			0	13696	8	260
3:41:51	28523	0.699	1.484	0.16	0.10	0.00	0.07	0.57	0.11	22.9	93.5	0.0	88.3			0	13696	8	259
3:41:55	28532	0.703	1.484	0.12	0.09	0.00	0.08	0.57	0.11	22.8	93.5	0.0	88.1			0	13632	8	260
3:41:59	28540	0.703	1.488	0.11	0.09	0.00	0.08	0.71	0.11	22.6	93.5	0.0	88.1			0	13568	8	259
3:42:03	28547	0.703	1.488	0.08	0.10	0.00	0.08	0.68	0.12	22.5	93.4	0.0	88.1			0	13536	7	259
3:42:07	28551	0.703	1.488	0.09	0.11	0.00	0.07	0.57	0.12	22.5	93.5	0.0	88.1			0	13568	7	259
3:42:11	28538	0.703	1.488	0.11	0.10	0.00	0.08	0.52	0.13	22.4	93.5	0.0	88.1			0	13584	7	259
3:42:15	28464	0.699	1.484	0.11	0.10	0.00	0.08	0.34	0.12	22.4	93.4	0.0	88.0			0	13552	7	259
3:42:19	28340	0.699	1.480	0.11	0.10	0.00	0.08	0.24	0.12	22.4	93.1	0.0	88.0			0	13504	7	260
3:42:23	28185	0.699	1.477	0.11	0.10	0.00	0.08	0.20	0.13	22.4	93.0	0.0	87.4	4	273	0	13520	7	262
3:42:27	28032	0.695	1.184	0.15	0.18	0.00	0.10	0.17	0.12	22.5	84.4	0.0	84.8			0	12240	7	208
3:42:31	27897	0.691	0.922	0.09	0.04	0.00	0.13	0.17	0.12	22.6	70.4	0.0	78.8			0	7472	7	132
3:42:35	27768	0.688	0.777	0.12	0.25	0.00	0.14	0.20	0.20	22.6	52.3	0.0	73.4			0	3040	7	64
3:42:39	27636	0.688	0.754	0.12	0.11	0.00	0.19	0.22	0.19	22.8	45.4	0.0	70.8			0	1888	7	53
3:42:43	27516	0.688	0.754	0.15	0.13	0.00	0.19	0.22	0.19	22.8	43.6	0.0	70.3			0	1856	7	52
3:42:47	27408	0.688	0.754	0.12	0.13	0.00	0.17	0.22	0.18	22.8	43.3	0.0	69.8			0	1856	7	51
3:42:51	27310	0.688	0.750	0.18	0.10	0.00	0.19	0.25	0.19	22.8	43.1	0.0	69.4			0	1856	7	52
3:42:55	27228	0.688	0.754	0.14	0.08	0.00	0.19	0.26	0.20	22.6	43.0	0.0	69.3			0	1872	7	51
3:42:59	27137	0.691	0.758	0.11	0.08	0.00	0.19	0.30	0.19	22.5	42.9	0.0	69.3			0	1888	7	51
3:43:03	27031	0.695	0.758	0.17	0.08	0.00	0.18	0.40	0.18	22.4	42.8	0.0	69.1			0	1904	7	51
3:43:07	26903	0.699	0.762	0.12	0.11	0.00	0.17	0.50	0.17	22.4	42.6	0.0	69.0			0	1920	7	52
3:43:11	26770	0.695	0.758	0.10	0.08	0.00	0.17	0.60	0.17	22.3	42.3	0.0	68.9			0	1888	7	51
3:43:15	26636	0.699	0.762	0.17	0.12	0.00	0.15	0.62	0.16	22.3	42.1	0.0	68.9			0	1904	7	51
3:43:19	26502	0.699	0.762	0.10	0.11	0.00	0.16	0.60	0.16	22.3	42.0	0.0	68.8			0	1920	7	52
3:43:23	26369	0.703	0.762	0.11	0.07	0.00	0.14	0.60	0.14	22.1	41.8	0.0	68.6			0	1904	7	51
3:43:27	26243	0.703	0.762	0.15	0.08	0.00	0.15	0.64	0.14	22.1	41.8	0.0	68.6	4	162	0	1904	7	51
3:43:31	26114	0.703	0.762	0.11	0.10	0.00	0.14	0.63	0.15	22.1	41.6	0.0	68.6			0	1920	7	52

[Table 1] Main Engine Parameters

1.12. Wreckage and Impact Information

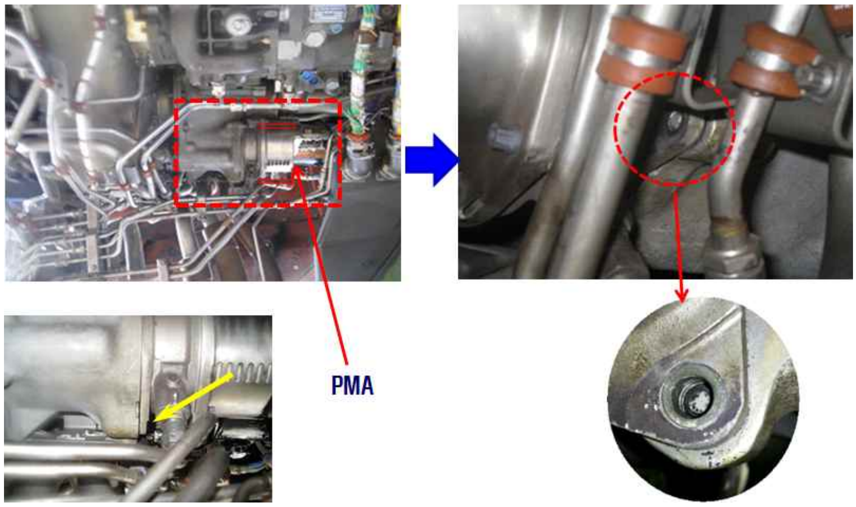
Immediately after the airplane returned to Incheon Airport, United Airlines' aircraft mechanic first performed visual inspection of the No. 1 engine and examined the rotation of the N2 rotor, using the MGB's N2 crank pad. Examination revealed that the N2 rotor failed to rotate.

As shown in [Figure 3], magnetic chip detectors (MCD)[25] installed in the MGB and oil tank exhibited a large quantity of metal chips.

[Figure 3] Magnetic Chip Detector (MCD)

As shown in [Figure 4], out of three permanent magnet alternator (PMA) attachment bolts, one at the 6 o'clock position (yellow arrow) was fractured, and the bolt head part of the fracture was missing.

25) Plugs, at the end of which permanent magnets are attached, attract ferromagnetic particles, mostly metal chips, and provide an early warning of an impending failure of the bearing or oil system.



[Figure 4] PMA Attachment Bolt

1.13. Medical and Pathological Information

The flight crew held a valid first-class airman medical certificate and stated that they did not drink any alcohol or take any illegal medication before the event flight.

1.14. Fire

Not applicable.

1.15. Survival Aspects

Not applicable.

1.16. Tests and Research

1.16.1. General

The No. 1 engine (left) removed from the airplane and sent to United

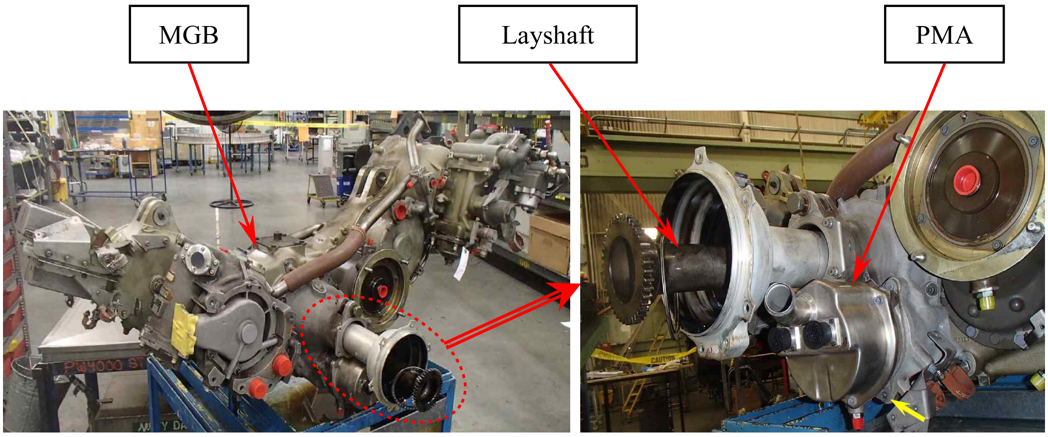
Airlines' Technical Operation Center in California, US, underwent the disassembly examination, which was delegated to United Airlines and P & W by the ARAIB and the NTSB. The examination was carried out in the presence of the investigator from the FAA.

1.16.2. Magnetic Chip Detectors

As shown in [Figure 5], master MCD exhibited a large quantity of metal chips, whereas MCD for AGB, #1/#1.5/#2, #3, and #4 bearings exhibited a small quantity of fines, which were considered to be insignificant in comparison with the service time of the engine.

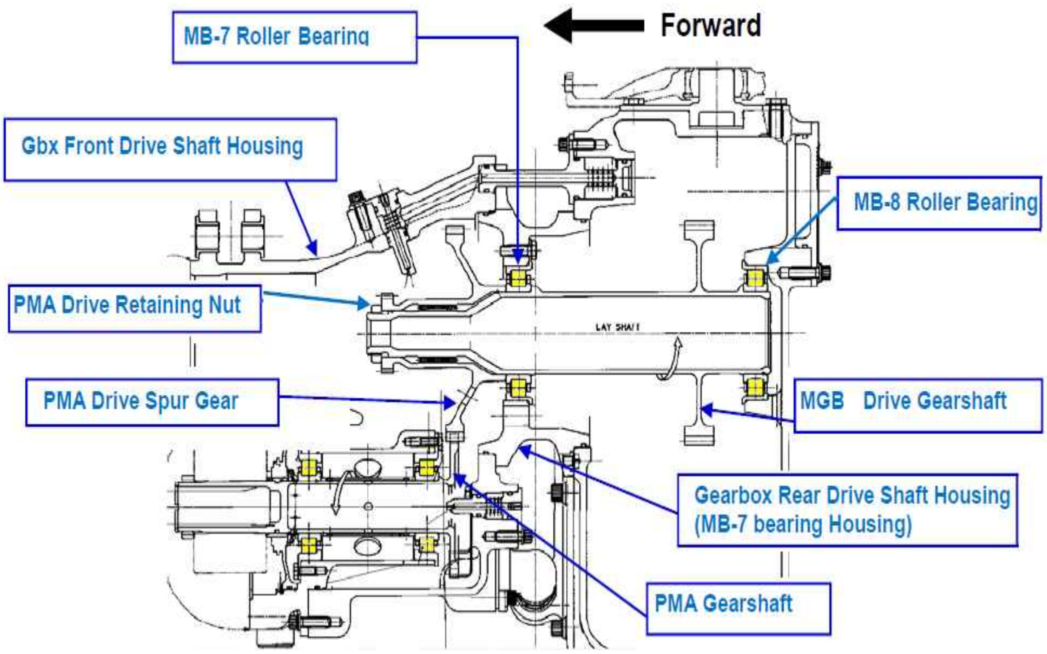
[Figure 5] MCD

As shown in [Figure 6], the gearbox drive gear shaft moved forward from its assembled position, and thereby the gearbox drive gear shaft and the layshaft were disengaged, hanging downwards. One PMA attachment bolt (yellow arrow) was fractured and missing.



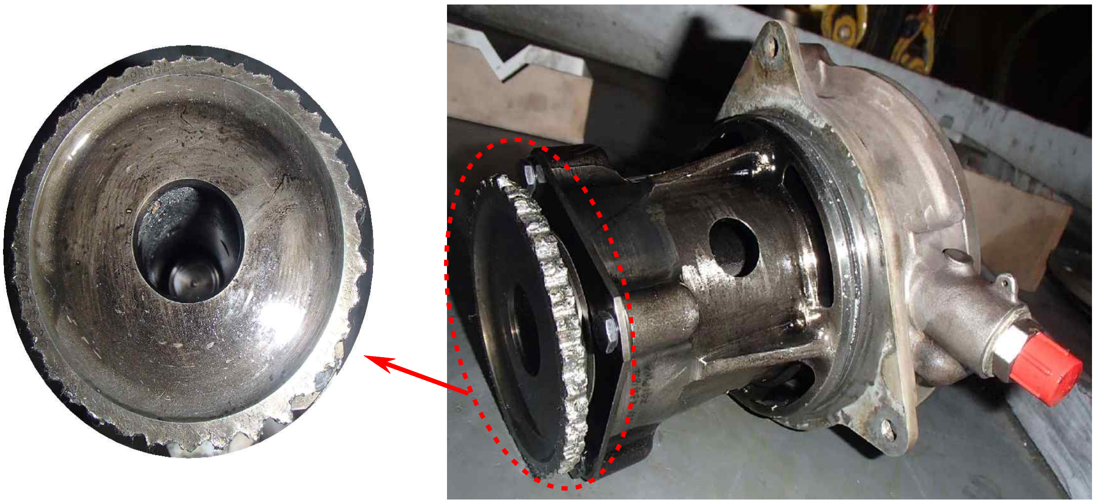
[Figure 6] Removed MGB

1.16.3. Main Gearbox Teardown Inspection



[Figure 7] Overview of Accessory Drive System

The PMA unit removed from the MGB underwent close examination. As shown in [Figure 8], all PMA gearshaft teeth were severely damaged with most of the teeth material was missing. However, the PMA rotor, PMA stator, two PMA shaft roller bearings,[26] and support housing were generally in good condition.

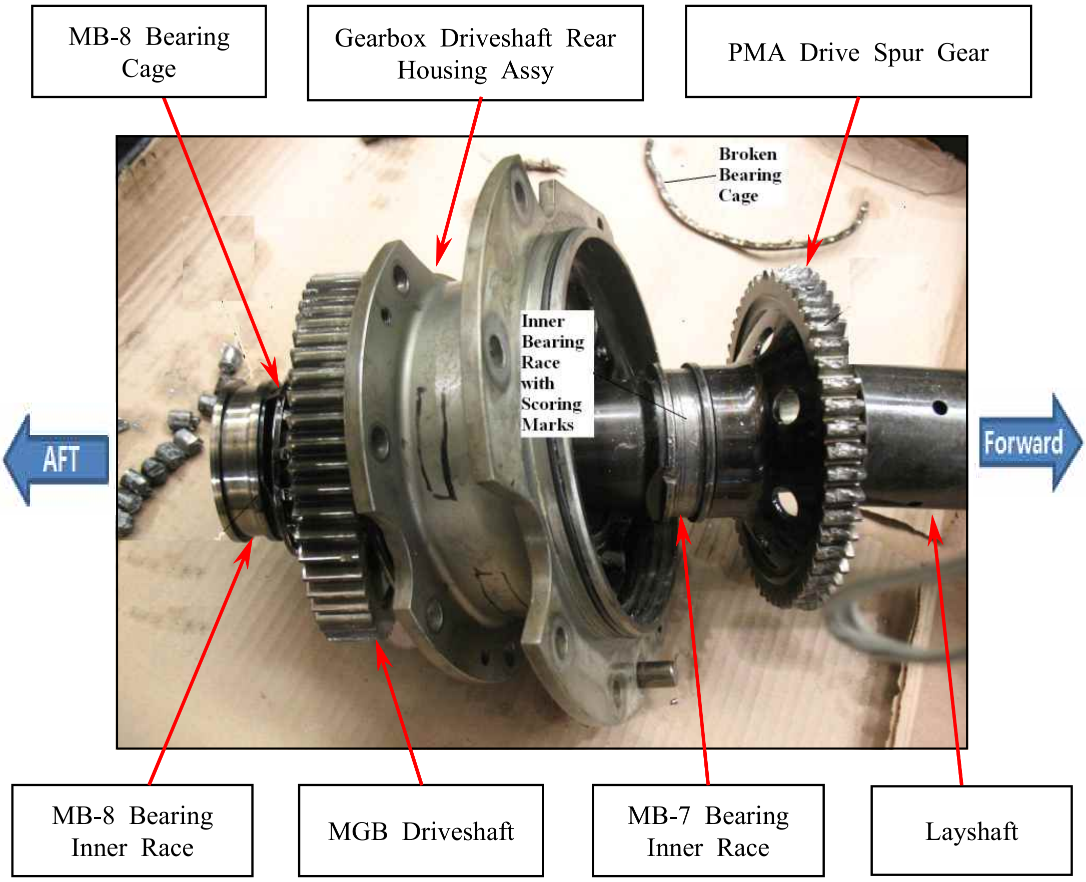


[Figure 8] PMA Gearshaft Teeth Damage

As shown in [Figure 9], the front housing of the gearbox driveshaft at the PMA drive spur gear location exhibited two circumferential grooves (yellow arrows) with circumferential rubbing marks. The aft one appears to be wider and shallower than the forward one.

[Figure 9] Damaged Gearbox Driveshaft Front Housing

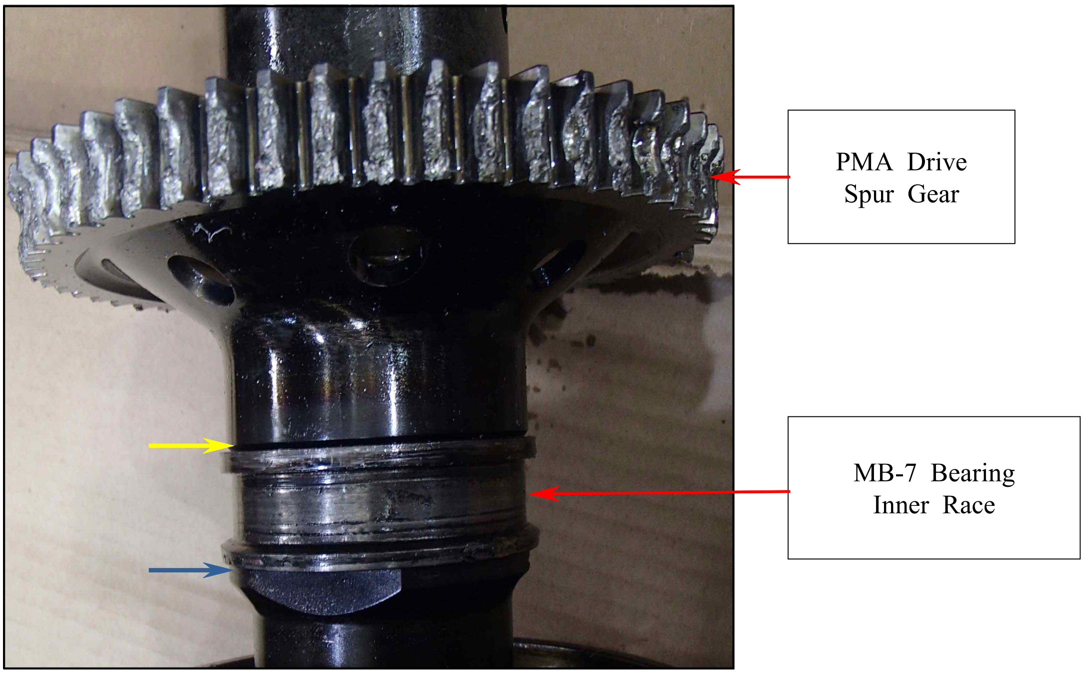
26) One roller bearing each is installed in the front (MB-21 bearing) and at the back (MB-22 bearing), and their part No. is 70R955.



[Figure 10] Gearbox Driveshaft and Bearing

As shown in [Figure 10 and 11], the MB-7 bearing inner race was mounted on the gearbox drive gear shaft. The MB-7 bearing inner race O.D surface exhibited circumferential rubbing and smear. As shown in [Figure 11], The MB-7 bearing inner race appears to be fully seated on the AFT end surface exhibiting no apparent gap (blue arrow) with the gearbox drive gear shaft forward shoulder. The PMA drive spur gear side surface also exhibited no apparent gap (yellow arrow) with the MB-7 bearing inner race side surface.

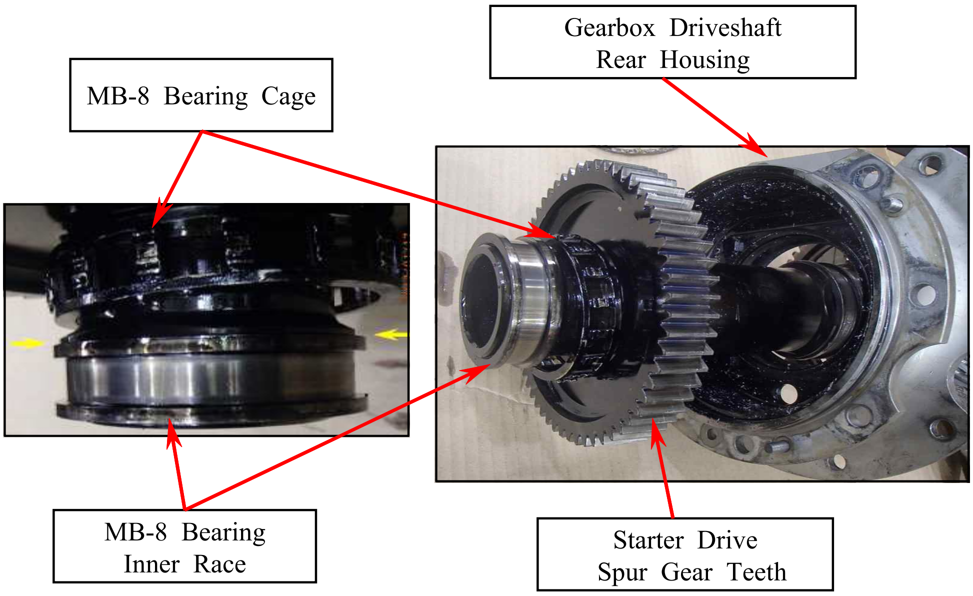
The PMA drive spur gear on the gearbox driveshaft exhibited teeth damage from normal contact pattern on the forward edge to material loss at the AFT edge. This would be consistent with the gearbox drive gear shaft moving forward from its assembled position, with the PMA driveshaft fixed in a normal position.



[Figure 11] PMA Drive Spur Gear and MB-7 Bearing Inner Race

As shown in [Figure 12], the MB-8 bearing rollers and the cage liberated from the assembled positions, but the MB-8 bearing roller cage was intact. The MB-8 bearing inner race was intact and exhibited no apparent damage. The MB-8 bearing inner race forward end surface was fully seated and exhibited no apparent gap with the aft shoulder (yellow arrow) of the MGB driveshaft. Loctite[27)] adhesive appears to have been used at the last shop visit, and a thin layer of Loctite at about 0.003 inch (0.076 mm) was visible on the forward end of the inner race. The starter drive spur gear of the MGB driveshaft exhibited no damage to its teeth which were in good condition.

27) Part No., PWA 549-2 Loctite Grade 640, is used in accordance with Engine Manual (PN 51A751) 72-61-02.

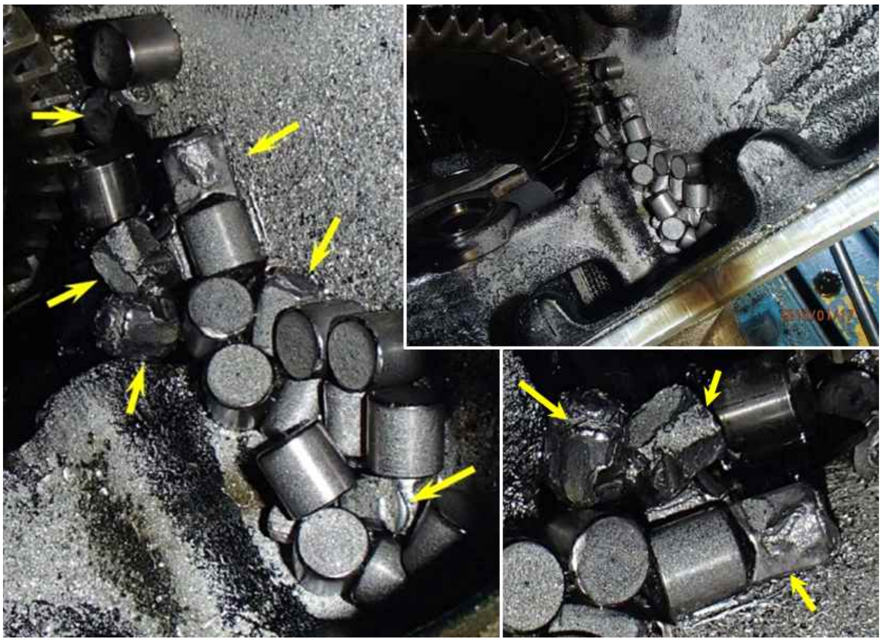


[Figure 12] Gearbox Driveshaft and MB-8 Bearing

As shown in [Figure 13], the MB-7 bearing rollers and cage liberated from the assembled positions and were found in the MGB housing. Severely deformed MB-7 bearing roller cage fragments were retrieved inside the gearbox. Cage fragments were identified as from the MB-7 by default because the MB-8 bearing roller cage was intact. The cage supporting the bearing roller was broken into multiple pieces. MB-7 bearing cage remnants showed that all cross bars and one cage side rail were broken into multiple pieces, and that the other side rail hoop was fractured at one circumferential location and unwrapped into an extended semi-circle shape.

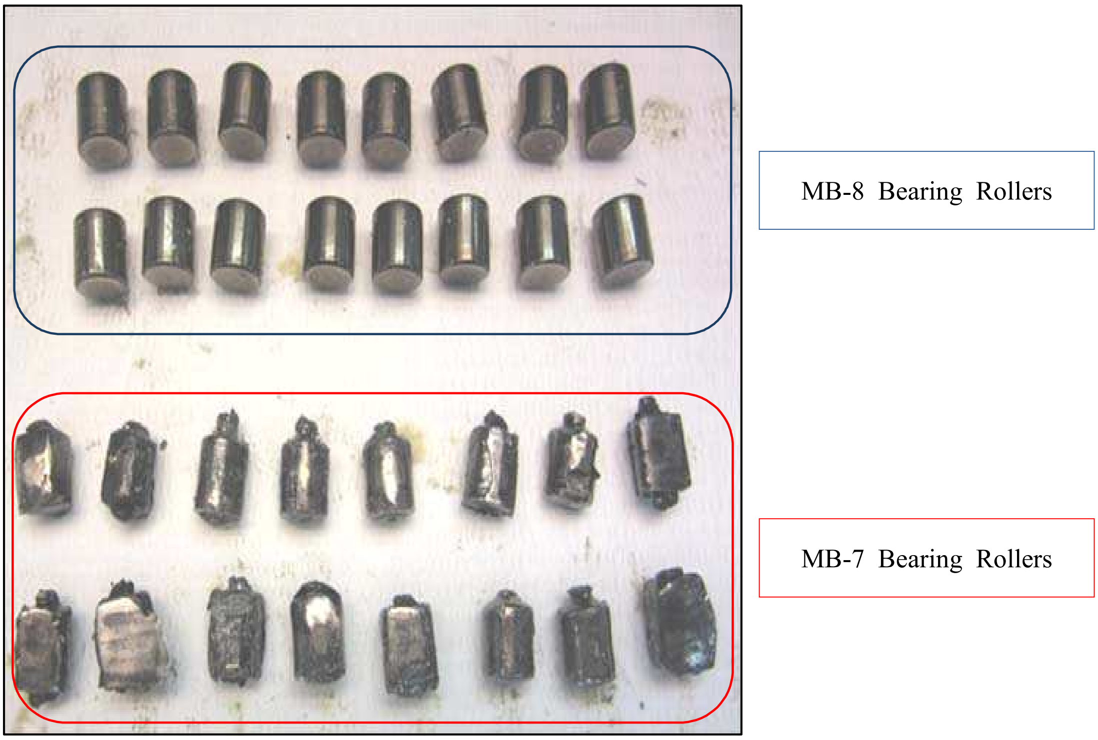
[Figure 13] MB-7 Bearing Cage

As shown in [Figure 14], bearing rollers were retrieved in the vicinity of the gearbox drive gear shaft inside the gearbox. They were mixed with intact bearing rollers and severely damaged bearing rollers with multiple flatten surfaces (yellow arrow).



[Figure 14] Bearing Rollers

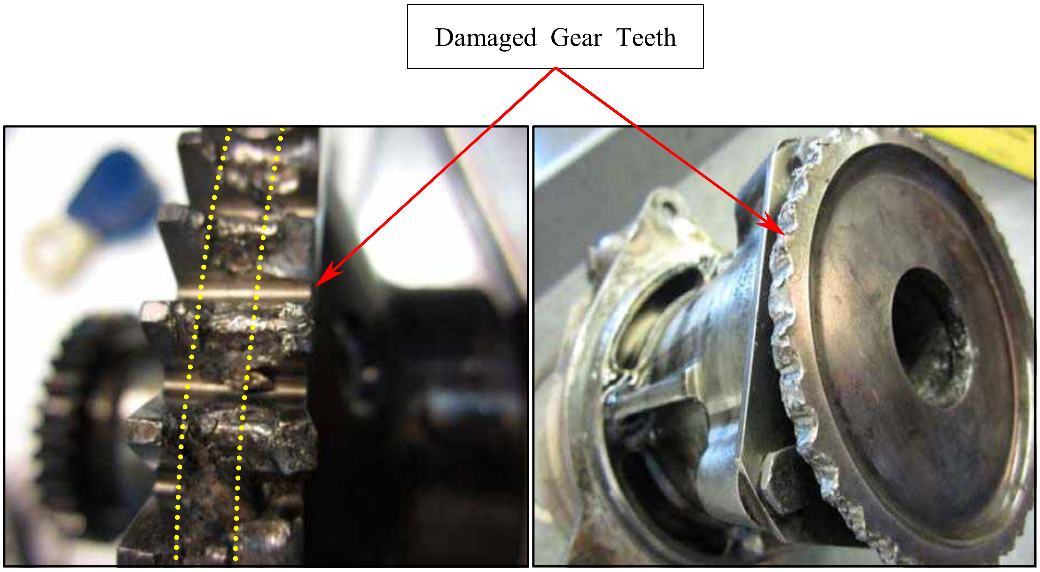
As shown in [Figure 15], rollers in the MB-7 and the MB-8 have the same part number (PN 70R022), and both bearings have 16 rollers. Based on the conditions of the roller cages and inner races of the MB-7 and the MB-8 bearings, the intact rollers were most likely from the MB-8 and the rollers with multiple flattened surfaces were most likely from the MB-7.



[Figure 15] MB-7 and MB-8 Bearing Rollers

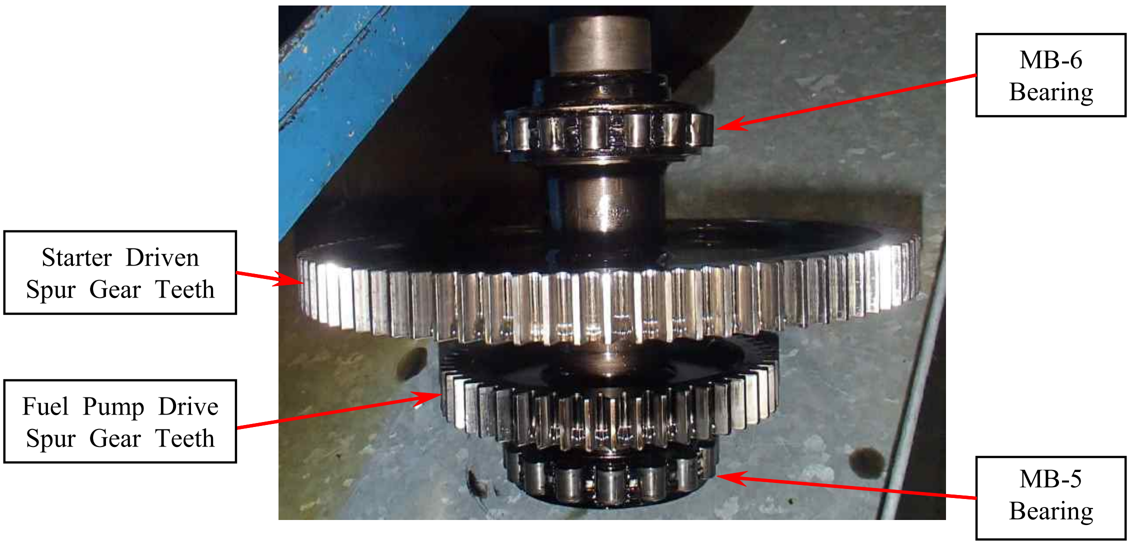
As shown in [Figure 16], there was heavy radial damage to tips of gear teeth on both the PMA drive spur gear (mounted forward of the MB-7 bearing) and the PMA gearshaft. This damage was believed to be secondary to the MB-7 bearing distress which would cause loss of center line and result in tooth tip-to-tooth tip contact of this mesh.

Apart from the damaged teeth of the PMA gearshaft, PMA shaft roller bearings and support housing were generally in good condition. However, damage to the teeth of the PMA gearshaft could have caused vibration in the PMA housing, which could have caused the fracture of one PMA attachment bolt.



[Figure 16] PMA Drive Spur Gear (left) and PMA Gearshaft (right)

As shown in [Figure 17], the starter driveshaft was removed from the MGB for examination. The MB-5[28] and MB-6[29] bearings were in their assembled positions and in good condition. The driven spur gear of the starter and the drive spur gear for the fuel pump exhibited no apparent distress.



[Figure 17] Starter Driveshaft and Bearings

28) Bearing that supports the front part of the starter driveshaft.
29) Bearing that supports the rear part of the starter driveshaft.

1.17. Organizational and Management Information

Not applicable.

1.18. Additional Information

Not applicable.

2. Analysis

2.1. General

To determine the causes of the MB-7 mechanical breakdown, United Airlines selected 24 relevant parts including the MB-7 bearing and sent them to P & W for detailed analysis of each part. The gearbox drive gear shaft was sent to P & W's lab in as-removed condition.

2.2. MB-7 Bearing Distress Analysis

2.2.1. PMA Drive Retaining Nut Inspection

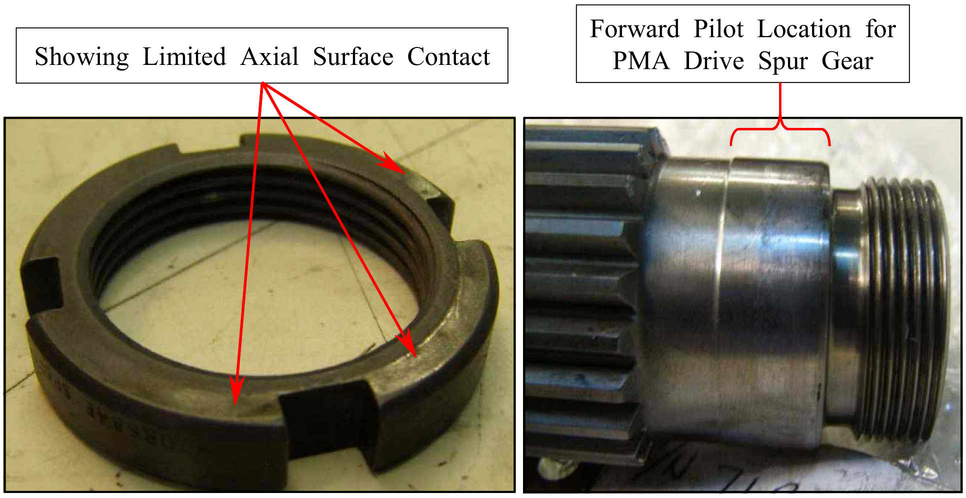
United Airlines found during the engine disassembly examination that the PMA drive retaining nut had an extremely lower breakaway torque than the criteria specified in the EM.[30] Yet the exact breakaway torque could not be measured at disassembly.

According to the EM, the retaining nut assembly torque specification is 650 - 750 lbf-in (73.440 - 84.739 N.m). The retaining nut plays a role as a compressor so that the MB-7 bearing inner race/roller forward of the MGB driveshaft and the PMA drive spur gear cannot be moved in the axial direction.

As shown in left [Figure 18], the PMA drive retaining nut's axial stacking surface had evidence of limited, uneven contact area with the stack, which indicates that the retaining nut was not fully engaged with the MGB driveshaft, but the threads on the MGB driveshaft and retaining nut were undamaged.

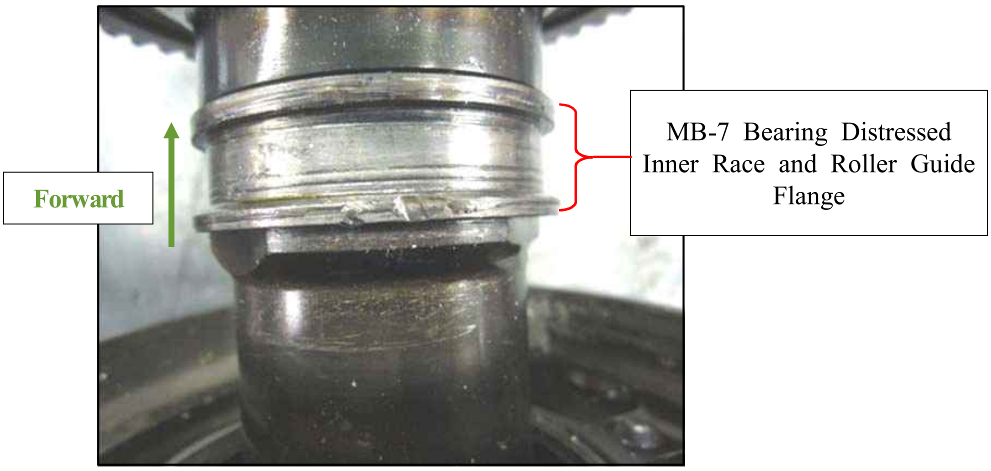
As shown in right [Figure 18], the MGB driveshaft forward piloting surface and its outer spline coupling were undamaged.

30) Engine Manual (PN 51A751) 72-61-00 Assembly-01.



[Figure 18] PMA Drive Retaining Nut (left) and MGB Driveshaft (right)

All of the MB-7 bearing components were found distressed. The MB-7 bearing inner race was still mounted on the MGB driveshaft. As shown in [Figure 19], however, the inner ring raceway, and the forward and aft roller guide flanges exhibited severe circumferential wear.



[Figure 19] MB-7 Bearing Inner Race

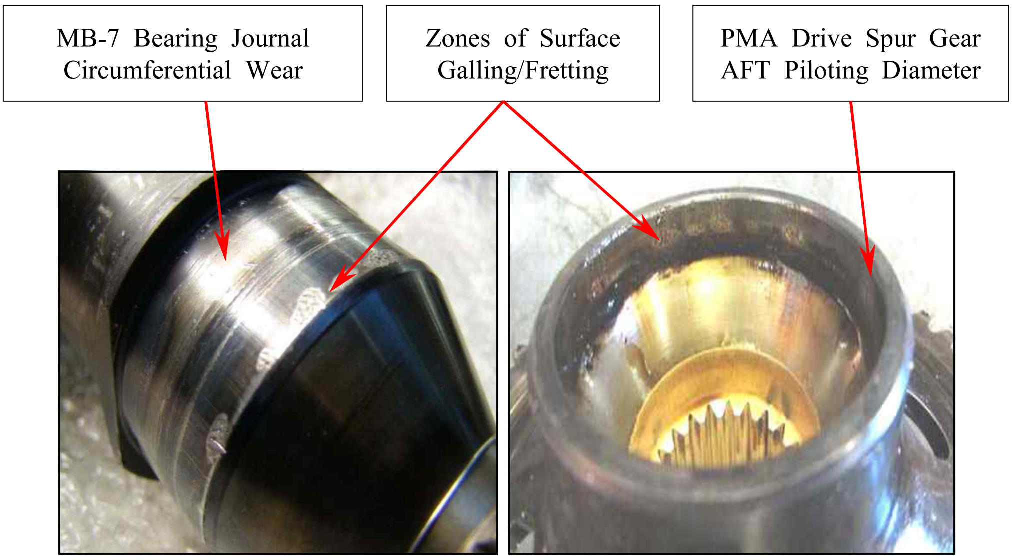
As shown in [Figure 20], zones of galling/fretting[31] with material transfer were observed between the MGB driveshaft MB-7 bearing journal surface and

31) Galling is a form of wear caused when two surfaces compressed by a large amount of force are in sliding contact with each other.

the aft piloting diameter of the PMA drive spur gear, which indicates that there was a fine movement when the two axes rotated although two sliding surfaces were compressed by a large amount of force.

As shown in [Figure 21] and [Table 2], the fit between the forward (location Ⓐ) and the aft (location Ⓒ) of the PMA drive spur gear was tight fits at assembly, but when the PMA drive retaining nut has a low torque, two axes can move in the circumferential direction as much as the clearance between the splines (location Ⓑ), 0.0035 inches (0.089 mm).

As shown in left [Figure 20], the MB-7 bearing journal surface exhibited atypical circumferential wear, which is indicative of MB-7 bearing inner ring rotation relative to the gear shaft and spur gear.



[Figure 20] MGB Driveshaft (left) and PMA Drive Spur Gear (right)

2.2.2. PMA Drive Retaining Nut Torque Procedure

According to the EM's work procedures,[32] the inner race and roller of the

32) Engine Manual (PN 51A751) 72-61-00 ASSEMBLY-01.

MB-7 and MB-8 bearings are heated to extend the I.D, then inserted into the journal of the MGB driveshaft, and compressed by a force of 1,500 lbf (6,672.3 N) with an arbor press so that the inner race can be completely installed on the shoulder. If there is a tiny gap between the MB-7 bearing inner race and the PMA drive spur gear, the inner race can rotate because it is not effectively fixated, but the measurable gap was not found.

As shown in [Figure 21], the MGB driveshaft is assembled as follows: the MB-7 bearing inner race adheres completely to the MGB driveshaft; the PMA drive spur gear compresses the inner race; and the PMA drive retaining nut is finally tightened.

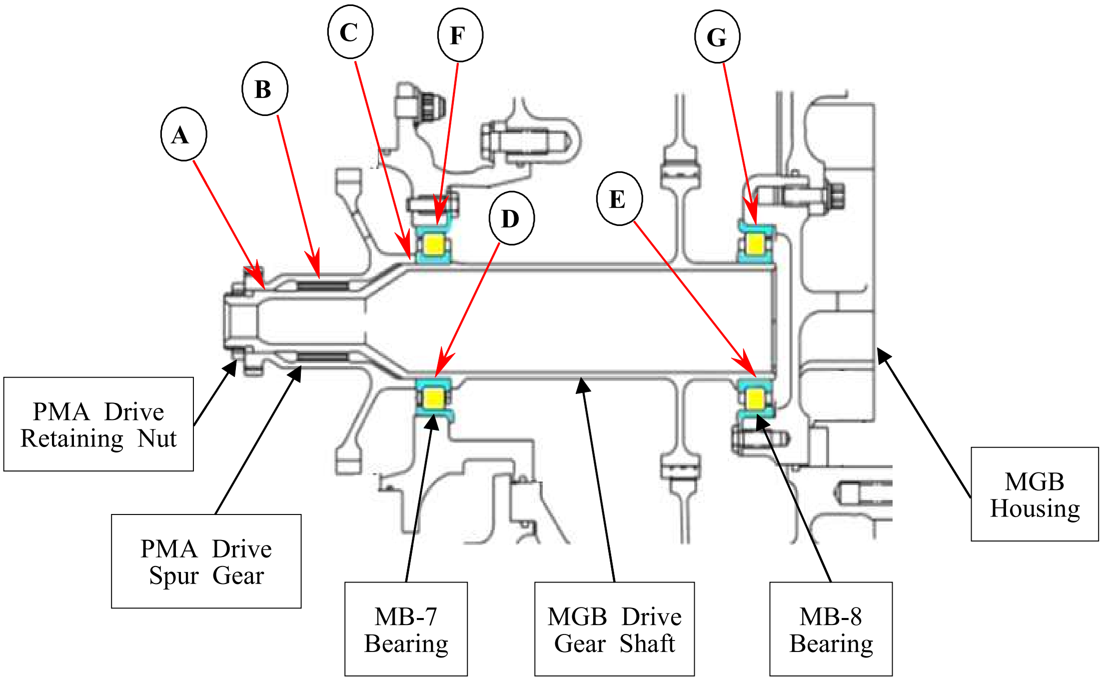
According to the EM's work procedures,[33] the PMA drive retaining nut[34] is assembled as follows:

① The retaining nut is tightened with a torque of 650 - 750 lbf-in (73.440 - 84.739 N.m).
② The retaining nut is loosened to a self-locking torque.
③ The retaining nut is tightened again with a torque of 650 - 750 lbf-in (73.440 - 84.739 N.m).

The cause of the low disassembly PMA drive retaining nut torque United Airlines had found during the engine disassembly examination was that the nut had not been tightened enough. It is highly likely that out of three assembly procedures above, the procedure ③ was implemented with a significantly lower torque than that prescribed by the EM, or that the procedure ③ was omitted after the retaining nut was loosened in the procedure ②.

33) Engine Manual (PN 51A751) 72-61-00 ASSEMBLY-01, Subtask 72-61-00-430-070.
34) A new retaining nut (PN 70R684) should be used to prevent its self-locking function from being weakened.

If the torque is insufficient when the PMA drive retaining nut is assembled into the MGB drivesahft, the retaining nut's clamping force in the axial direction will reduce, which causes not only the material transfer or galling/fretting between the MGB driveshaft and the PMA drive spur gear, but also axial vibration due to the rotation of the MB-7 bearing inner race, thereby damaging the whole MB-7 bearing.



[Figure 21] MGB Driveshaft and Bearing

Ref. No.	Tight Fit Parts		Permitted Limits of Clearances inch (mm)	
	O.D	I.D	Min.	Max.
A	MGB drive gear shaft (forward pilot)	PMA drive spur gear (forward pilot diameter)	0.0016T (0.041T)	0.0009T (0.023T)
B	MGB drive gear shaft (external spline)	PMA drive spur gear (internal spline)	0.0035 (0.089)	-
C	MGB drive gear shaft (aft pilot)	PMA drive spur gear (aft pilot diameter)	0.0016T (0.041T)	0.0009T (0.023T)
D	MGB drive gear shaft (MB-7 bearing journal)	MB-7 bearing (inner race)	0.0019T (0.048T)	0.0010T (0.025T)
E	MGB drive gear shaft (MB-8 bearing journal)	MB-8 bearing (inner race)	0.0021T (0.053T)	0.0012T (0.030T)
F	MB-7 bearing (outer race)	MGB housing (bore)	0.0002 (0.0051)	0.0016 (0.041)
G	MB-8 bearing (outer race)	MGB housing (bore)	0.0002 (0.0051)	0.0016 (0.041)

[Table 2] Fits and Clearances

According to the EM,[35] when assembled as shown in [Figure 21] and [Table 2], the fit between the MGB driveshaft forward (location Ⓐ) and aft (location Ⓒ) pilot location O.D and the PMA drive spur gear I.D has a clearance[36] of 0.0016 - 0.0009 inT (0.041 - 0.023 mmT). In addition, the MB-7 bearing I.D (location Ⓓ) is a tight fit as 0.0019 - 0.0010 inT (0.048 - 0.025 mmT), whereas the MB-7 bearing O.D (location Ⓕ) is a loose fit as 0.002 - 0.0016 inT (0.0051 - 0.041 mm).

As shown above, a tight fit assembly can first prevent the MB-7 bearing inner race from rotating on the MGB driveshaft, make the PMA drive spur gear compress the inner race side surface, and prevent the movement in the axial direction by tightening the PMA drive retaining nut. Yet if the PMA drive retaining nut is not tightened enough, the MB-7 bearing inner race will move, which can cause vibration on the MGB driveshaft, thereby damaging the MB-7

35) Engine Manual (P/N 51A751) 72-61-00 INSP/CHK-04.
36) "T" behind the number indicates a tight fit generated when the connected shaft O.D is larger than the mounted bore I.D.

bearing and subsequently, the MB-8 bearing on the opposite side.

The damage to the MB-7 and MB-8 bearings can cause the gearbox drive gear shaft to move forward from the MGB, which can cause the outer spline to liberate gradually from its connected position with the layshaft's internal spline, thereby stopping power transmission. As the MGB driveshaft is the primary shaft that receives N2's rotational force through the layshaft, linking to many MGB drive gear shafts, the liberation of this driveshaft stopped the operation of all components on the MGB.

2.2.3. MB-7 Bearing Distress Analysis

Additional examination of the MB-7 bearing (P/N 70R022, S/N 16211) distress could not be conducted due to the bearing's serious damage, but the possibility of the damage caused by the bearing's latent BMOD[37] cannot be ruled out.

2.3. FDR Analysis

Among the data extracted from the event aircraft's FDR, major parameters relating to an engine failure were analyzed and displayed graphically as shown in [Figure 22].

The FDR began recording at 03:09:51 UTC and stopped recording at 04:15:08 UTC, approximately 10 minutes after landing. The airplane took off on a runway heading of about 330° at 03:30:02 UTC. Engine parameters started to exhibit a change when the airplane was climbing through 28,000 ft about 03:41:07 UTC.

The No. 1 engine N1 decreased from 88.6% to 22.4%, the level of wind

37) Bill of Material Object Damage.

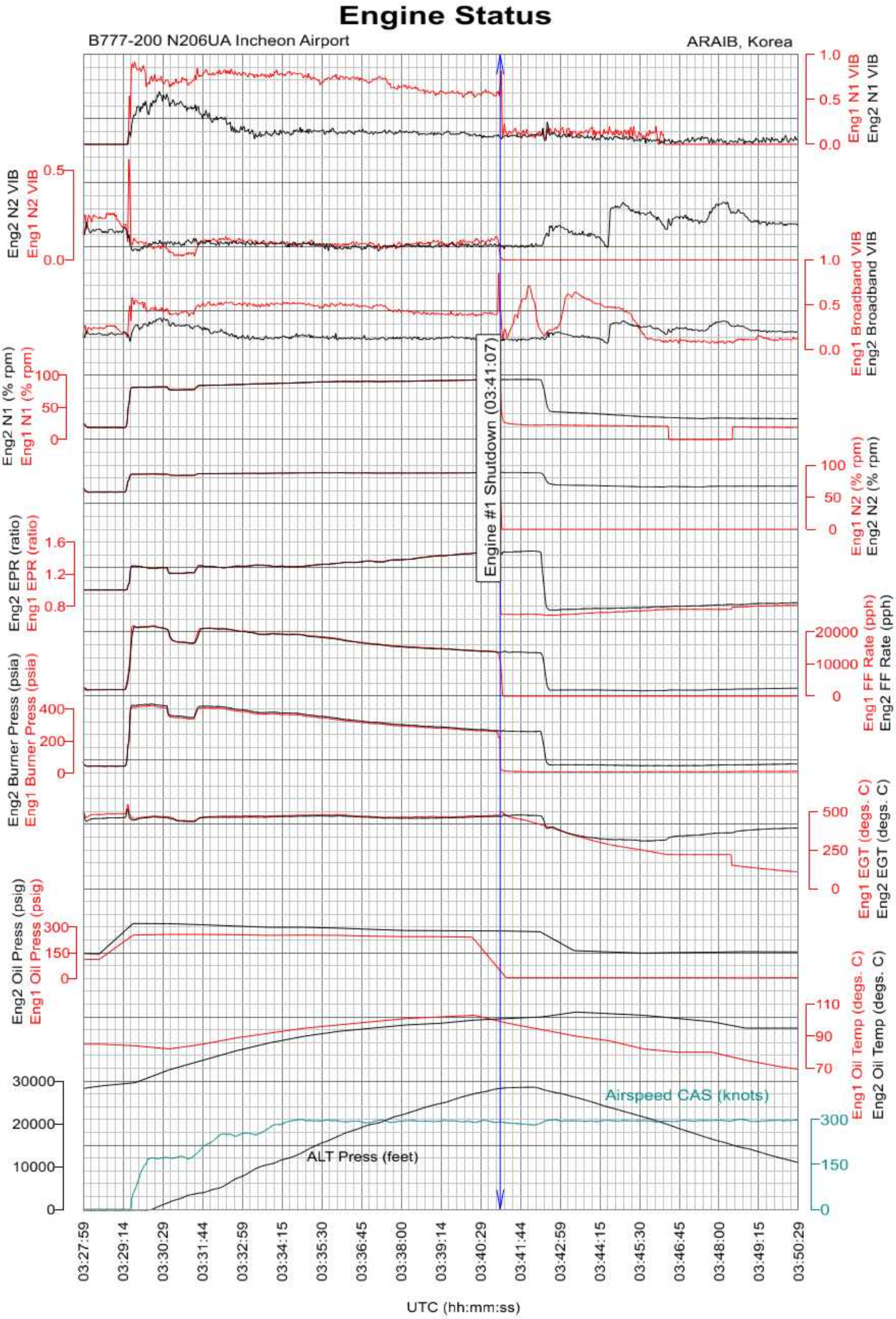
milling, while the No. 1 engine N2 went to zero within 1 - 2 seconds from 88.3%. As N1 and N2 decreased, the engine pressure ratio (EPR) sharply declined from 1.473 to 0.699.

At the same time, oil pressure dropped from 241 psi to 4 psi, outside atmospheric pressure, and oil temperature gradually decreased. The fuel flow rate and burner pressure declined from 13,952 pph to zero and from 250 psi to the minimum 7 psi, respectively. Exhaust gas temperature (EGT) gradually dropped.

The engine vibration levels were relatively lower than the permitted limits specified in the Airplane Maintenance Manual (AMM), but the N1 and broadband vibration levels of the faulty No. 1 engine were relatively higher than those of the No. 2 engine.

At 03:42:38 UTC, the No. 1 engine fail warning was recorded, and the airplane began descending shortly thereafter and landed at 04:05:02 UTC. Meanwhile, all engine parameters of the No. 2 engine were within normal range during the entire flight.

The MB-7 bearing distress caused the MGB driveshaft to move forward and disengage from the layshaft, at the time when the HPC N2 shaft's rotational force could not be transferred to the MGB, thereby shutting down all components on the MGB. Accordingly, the No. 1 engine's N1, N2, EPR, oil pressure, burner pressure and fuel flow rate declined to the minimum and did not recover back to normal until the end of the flight.



[Figure 22] Engine Parameters Analysis Graph

2.4. EEC Fault Memory Analysis

P & W removed the No. 1 engine's electronic engine control (EEC)[38] from the event airplane to extract the fault memory files, which were analyzed. As shown in [Table 3], the EEC's channel A and B contained the same 4 faults that were written to fault memory during the event flight in the following order:

① Surge Detection

The gearbox became disconnected from the layshaft due to mechanical failure within the engine gearbox. In addition, the PMA gear was also significantly damaged. As soon as this failure occurred, the gearbox would no longer be driven by the engine high rotor without the layshaft connection, and all gearbox-driven components would stop turning. This includes the engine fuel pump, the permanent magnet alternator (PMA), the IDG, the oil pump, etc.

With engine fuel flow rapidly decreasing to zero, a combustor flame-out would be expected to occur. As the combustor flame-out caused the burner pressure (Pb) to decrease more sharply than the value predicted by the EEC, surge was detected and the Surge Detection status bit was set.

② FMU FMV Out-of-Position Fault (FMU Track Check Fault)

The FMU would be commanded to a higher fuel flow to attempt to maintain the target EPR, but with fuel flow from the engine fuel pump rapidly decreasing to zero, there would be insufficient fuel pressure to move the FMU Fuel Metering Valve (FMV) to its commanded position, and an FMU Track Check maintenance bit would be expected to occur.

③ N2 Range Fault

38) P/N: 8222830-15-043, S/N: 4171-0416.

The EEC receives the N2 speed analog signal from the PMA and controls the engine's fuel flow. However, with the PMA gear significantly damaged, it is unclear what quality N2 signal would be provided to the EEC, and it is possible that the N2 Range Fault maintenance bit would be set.

④ Starter Control Valve Mechanical

When the No. 1 engine stopped, the flight crew attempted a starter-assisted start. The Starter Control Valve Mechanical maintenance bit would have been set since the engine starter speed would have rapidly spooled up with supplied starter air (from a running APU or from engine crossbleed from the opposite engine), but there would be no increase in engine N2 without a functioning layshaft connection between the gearbox and the high rotor.

Surge Detection (Label 272, bit 26)
Ch A: Alt.= 28276 ft., Mn= 0.74, TRA=75.09 deg., Pb=192.63 psia, N1=2542.75 RPM (=87.7%N1), N2=7014.5 RPM (=64.9% N2), EGT=482.19 deg C, **FF=12914 pph**, N2DOT=-2846.5 RPM/sec., UTC Time=03:41:05.
Ch B: Alt.= 28276 ft., Mn= 0.74, TRA=75.09 deg., Pb=192.63 psia, N1=2542.75 RPM (=87.7%N1), N2=7014.5 RPM (=64.9%N2), EGT=482.19 deg C, **FF=12914 pph**, N2DOT=-2846.5 RPM/sec., UTC Time=03:41:05

FMU FMV Out-of-Position Fault (FMU Track Check Fault) (Label 003, bit 15)
Ch A: Alt=28324 ft., Mn=0.74, TRA=75.44 deg., Pb=16.25 psia, N1= 919 RPM (=31.7% N1), N2=4283.5 RPM (=39.7%N2), EGT=496.06 deg C, **FF=0 pph**, N2DOT=-561.5 RPM/sec., UTC Time=03:41:09
Ch B: Alt=28294 ft., Mn=0.74, TRA=75.07 deg., Pb=19.13 psia, N1=1152.75 RPM (=39.8% N1), N2=5686 RPM (=52.6%N2), EGT=500.72 deg C, **FF=0 pph**, N2DOT=-573 RPM/sec., UTC Time=03:41:07

N2 Range Fault (Label 011, bit 18)
Ch A: Alt=28370 ft., Mn=0.74, TRA=76.08 deg., Pb=14.94 psia, N1=797.75 RPM (=27.5% N1), N2=3055 RPM (=28.3%N2), EGT=487.19 deg C, **FF=0 pph**, N2DOT=-423.5 RPM/sec., UTC Time=03:41:12
Ch B: Alt=28370 ft., Mn=0.74, TRA=76.08 deg., Pb=14.94 psia, N1=797.75 RPM (=27.5% N1), N2=3055 RPM (=28.3%N2), EGT=487.78 deg C, **FF=0 pph**, N2DOT=-456 RPM/sec., UTC Time=03:41:12

Starter Control Valve Mechanical (Label 013, bit 24)
Ch A: Alt=14726 ft., Mn=0.59, TRA=33.52 deg., Pb=9.88 psia, N1=572.75 RPM (=19.8% N1), N2=2742.5 RPM (=25.4%N2), EGT=148.03 deg C, **FF=0 pph**, N2DOT=-36.5 RPM/sec., UTC Time=03:48:33
Ch B: Alt=14726 ft., Mn=0.59, TRA=33.52 deg., Pb=9.88 psia, N1=572.75 RPM (=19.8% N1), N2=2731 RPM (=25.3%N2), EGT=148.03 deg C, **FF=0 pph**, N2DOT=-46.5 RPM/sec., UTC Time=03:48:33

[Table 3] EEC Fault Data

3. Conclusions

3.1. Findings

1. The flight crew held qualification certificates proper for the applicable flight and took the required rest before flight. Also, no medical factors that could have affected the flight were found.

2. The airplane held a valid airworthiness certificate.

3. Magnetic chip detectors (MCD) installed in the MGB and oil tank exhibited a large quantity of metal chips.

4. One of three PMA attachment bolts was fractured and missing.

5. As the MB-7 and MB-8 bearings were damaged, they disengaged from their assembly positions. The MB-7 bearing first sustained a serious damage, thereby resulting in secondary damage to the MB-8 bearing.

6. There was heavy radial damage to tips of gear teeth on both the PMA drive spur gear (on the gearbox drive gear shaft) and the PMA gear shaft.

7. The disengagement of the gearbox drive gear shaft from the layshaft spline stopped the transmission of the N2 rotor's rotational power to the MGB.

8. With no power transmission, all engine components mounted on the MGB stopped turning all at once.

9. Unites Airlines reported the MGB teardown found that the PMA drive

retaining nut had an extremely low breakaway torque at disassembly. The ARAIB concluded this indicated that, at the last shop visit, engine maintenance work was not adequately conducted in accordance with the EM's procedures.

10. Zones of galling/fretting with material transfer were observed between the MGB driveshaft MB-7 bearing journal surface and the aft piloting diameter of the PMA drive spur gear.

11. The MB-7 bearing journal surface exhibited atypical circumferential wear indicative of MB-7 bearing inner race rotation.

12. According to the FDR data, the mechanical breakdown of the No. 1 engine MB-7 bearing shut down all components on the MGB. Accordingly, the No. 1 engine's N1, N2, EPR, oil pressure, burner pressure, and fuel flow rate declined to the minimum and did not recover back to normal until the end of the flight.

13. The fault memory files from the EEC were retrieved and analyzed. There were one status bit and three maintenance bits written to the fault memory during the event flight.

3.2. Causes

The Aviation and Railway Accident Investigation Board determines the causes of this serious incident as follows:

The mechanical breakdown of the MB-7 bearing, which supports the front part of the gearbox drive gear shaft at the No. 1 engine MGB, stopped the transmission of the N2 rotor's rotational power to the MGB through the layshaft, which shut down all engine components mounted on the MGB, thereby resulting in the IFSD.

Contributing to this serious incident were as follows:

During the last engine assembly, when the MB-7 bearing was mounted on the MGB driveshaft, the PMA drive retaining nut was tightened with a less torque than that prescribed by the EM, which caused its failure to support the MB-7 bearing inner race, thereby resulting in the mechanical damage of the MB-7 bearing.

4. Safety Recommendations

As a result of the investigation of the serious incident that occurred to United Airlines flight 890, the ARAIB makes the following safety recommendation:

To United Airlines

1. Improve your quality management procedures and incorporate them into your maintenance program to ensure that the PMA drive retaining nut assembly procedures comply thoroughly with the procedures specified in the manufacturer's EM (AIR-F1203-1).