ARAIB

Report No. ARAIB/AIR-1008

AIRCRAFT SERIOUS INCIDENT REPORT

ENGINE IN-FLIGHT SHUTDOWN

KOREAN AIR

B737-800, HL7786

320 NM NORTHWEST OF BEIJING

3 SEPTEMBER 2010

14 November 2011

AVIATION AND RAILWAY ACCIDENT INVESTIGATION BOARD

MINISTRY OF LAND, TRANSPORT AND MARITIME AFFAIRS

REPUBLIC OF KOREA

According to the provisions of the Article 30 of the Aviation and Railway Accident Investigation Act of the Republic of Korea, 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 this 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 issued as the result of the investigation on the basis of the Aviation and Railway Accident Investigation Act of the Republic of Korea and the Annex 13 to the Convention on International Civil Aviation, 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

Aviation and Railway Accident Investigation Board. Engine in-flight shutdown, Korean Air B737-800, HL7786, 320 NM northwest of Beijing, 3 September 2010. Aircraft Serious Incident Report ARAIB/AIR1008. Seoul, Republic of Korea

Korea Aviation and Railway Accident Investigation Board (ARAIB) is a government organization for independent investigation of aviation and railway accident, and the accident investigation shall be carried out based on the Aviation and Railway Accident Investigation Law of the Republic of Korea and the Annex 13 to the Convention on International Civil Aviation.

The objective of accident or incident investigation of the Korea Aviation and Railway Accident Investigation Board is not to apportion blame or liability but to prevent accidents and incidents.

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Engine In-flight Shutdown

Korean Air
The Boeing Company
B737-800, HL7786
320 NM northwest of Beijing
Latitude: N 44° 47 ′ 00 ″ , longitude: E 113° 15 ′ 00 ″
3 September 2010, at about 04:14[1)]

Synopsis

On 3 September 2010 at about 04:14, a Korean Air B737-800 (Registration HL7786, hereinafter referred to as "HL7786"), performing flight KE2984 from the Irkutsk International Airport, Russian Federation, to the Incheon International Airport, the Republic of Korea, was cruising at 33,000 feet on B339. A few minutes after HL7786 had passed a waypoint POHLO[2)], suddenly the number 1 engine was shut down, so the flight crew declared emergency and landed at the Beijing International Airport, the People's Republic of China. 36 passengers and 8 crew were on board the HL7786, but there was no injuries due to this event.

The Civil Aviation Administration of China was responsible for the conduct of this investigation in accordance with the ICAO Annex 13 5.1, but on 4 November 2010, the whole investigation was delegated to the Aviation and Railway Accident Investigation Board of the Republic of Korea (hereinafter referred to as "ARAIB") in accordance with the ICAO Annex 13 5.1.1.

The ARAIB determines that the probable causes of this serious incident are that 「An axial overload, which was applied to accurately engage a tool into the drive shaft square for the Borescope Inspection (BSI) without knowing that the metallic foreign material was in the drive shaft square, resulted bearing damage in the AGB line 4, such bearing damaging caused a misalignment problem related to the gear shaft offset, the high-pressure compressor rotation RPM (N2 RPM) fluctuated due to gear shaft misalignment resulting from ball bearing damaging, and eventually the Electronic Engine Control (EEC) sensed it and made the engine shut down.」

1) Unless otherwise indicated, all times in this report are Korea Standard Time (KST, UTC+9).
2) About 320 NM northwest of Beijing

As a result of this investigation, the ARAIB make one safety recommendation to the Korean Air and one safety recommendation to the engine manufacturer (CFM International).

1. Factual Information

1.1 History of Flight

The HL7786 with eight crew members and 36 passengers on board departed the Irkutsk International Airport, Russia Federation, on 3 September 2010 at about 02:30 and was cruising at 33,000 feet on B339. At about 04:14, after it had passed a waypoint POHLO (320 nm northwest of Beijing), the lower display unit opened and a "ENG FAIL 1" message was displayed.

When the flight crew carried out the checklist on the “ENG FAIL 1" and checked the engine parameters, the high-pressure compressor rotation RPM (N2 RPM) increased from 88% to about 94% before it returned to 88%, and the “ENG FAIL 1" message disappeared.

But after a while, the parameter values of No. 1 engine including N2 repeated increasing and decreasing, and the “ENG FAIL 1" message was displayed again. The flight crew declared emergency and received a permission by the controller to descend to 29,000 ft, and after taking the relevant abnormal procedures[3)], they landed at the Beijing Capital International Airport.

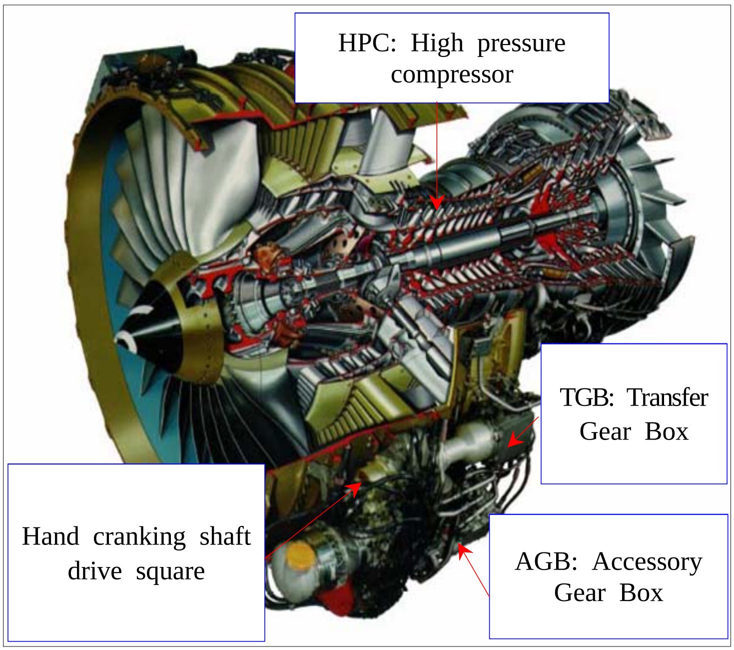
1.2 Injuries to Persons

Injuries	Crew	Passenger	Others
Fatal	0	0	0
Serious	0	0	0
Minor / None	8	36	0

1.3 Damage to Aircraft

As shown in [Fig. 1] and [Fig. 2], the No. 4 line of the accessory gear box of number 1 engine (hereinafter referred to as "AGB") was broken, and due to this the number 1 engine was shut down.

3) "Engine Limit or Surge or Stall" and “One Engine Inoperative Landing" Checklist



[Fig. 1] Illustration of CFM56-7 engine

1.4 Other Damage

None

1.5 Personnel Information

1.5.1 The Captain

The captain (age 57, male) held a valid Airline Transport Pilot License[4], B737 and B747-400 type rating, Class 1 Medical Certificate[5], Radio Operator Certificate[6], and English Proficiency Level 4. His total flying time was 12,347 including 4,417 hours as captain of B737-800/900, 156 hours for the latest three months, and 65 hours for the latest one month.

1.5.2 The First Officer

The first officer (age 30, male) held a valid Commercial Pilot License[7], B737 type rating, Class 1 Medical Certificate[8], Radio Operator Certificate[9], and English Proficiency

4) Qualification number: 1544 (Issued on 24 March 1998)
5) Expiry: 31 July 2011
6) Certificate number: 913400160 (Issued on 13 August 1991)
7) Qualification number: 6262 (Issued on 58 May 2007)

Level 4. His total flying time was 1,480 hours including 1,063 hours on B737-800/900, 103 hours for the latest three months, and 31 hours for the latest one month.

1.6 Aircraft Information

1.6.1 Aircraft History

The HL7786 was manufactured[10)] by The Boeing Company in June 2009 and was introduced and registered[11)] by Korean Air on 15 July 2009. It held a valid Airworthiness Certificate[12)], and its total service time was 3,831 hours and the number of takeoff and landing was 1,570 cycles. C check[13)] was done on 15 July 2009 and A check[14)] on 20 August 2010.

1.6.2 Engine History

The HL7786 was equipped with two CFM56-7B engines[15)] manufactured by CFM International (Commercial Fan Motor International). The engines were mounted at the time of aircraft manufacture in June 2009 and received first[16)] Borescope Inspection (BSI) after the aircraft delivery on 11 April 2010. Its total service time was 3,831 hours and the number of takeoff and landing was 1,570 cycles.

1.6.3 Engine Inspection

1.6.3.1 Magnetic Chip Detector Check

CFM56-7B engine was equipped with three Magnetic Chip Detectors[17)] [hereinafter referred to as "Magnetic Chip Detector (MCD)"] to inspect whether metal chips are detected in the gear box and engine bearing system as shown in [Fig. 2].

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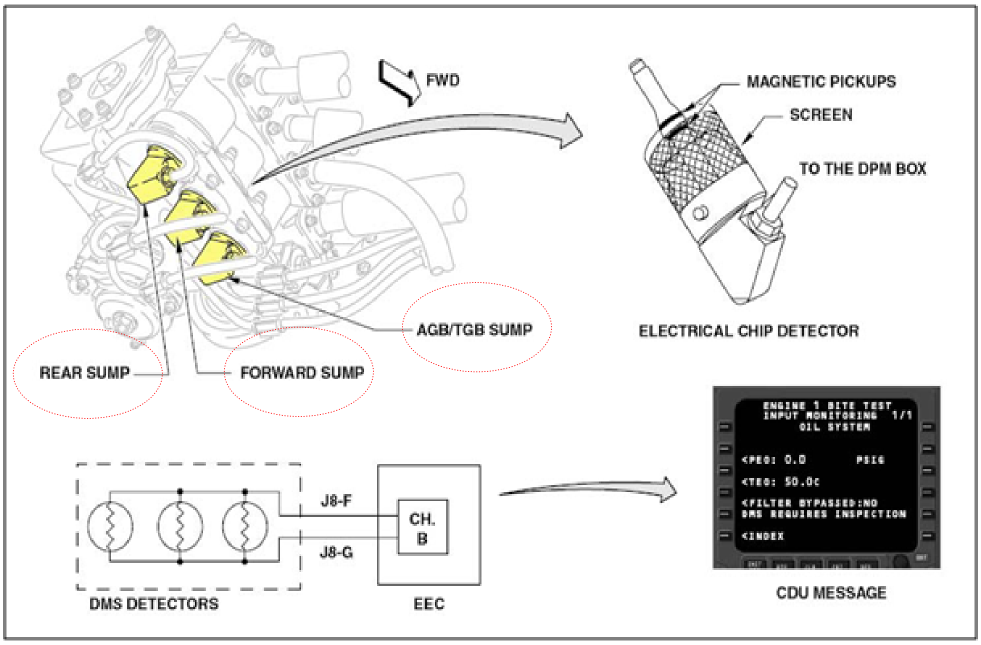
8) Certificate number: Expiry: 30 November 2010
9) Certificate number: 043410094 (Issued on 24 November 2004)
10) Serial number: 37163
11) Registration: 2009-071
12) Certificate number: IS09021 (Issued on 21 July 2009)
13) To be performed at 24th month or 5,500 cycles, chip comes earlier
14) To be performed at every 600 hours
15) Serial number of number 1 engine that was shut down in flight: 802449
16) At that time, total service time was 2,451hours, and conducted by the Korean Air
17) Forward Oil Sump, Rear Oil Sump, AGB(Accessory Gear Box)/TGB(Transfer Gear Box) sump



[Fig. 2] Illustration of the Metal Chip Detector (MCD)

The manufacturer's Maintenance Planning Document provides the Metal Chip Detector (MCD) to be checked at every 500 hours, but Korean Air shortened the period to check at every 250 hours[18].

The latest MCD check on the relevant engine was done on 19 August 2010, and metal chips were not detected in the inspections so far. The incident occurred after 138 hours had passed since the latest inspection.

1.6.3.2 Borescope Inspection

Borescope Inspection (hereinafter referred to as "BSI") is conducted to inspect whether the 2, 4, 6, 8 stage blades of high pressure compressors (HPC) were damaged without disassembling the engine.

This inspection is conducted for the first time in the course of manufacturer's test flight before the aircraft is delivered to the operator. After the aircraft is delivered to the operator, the first inspection[19] is conducted before the engine service time reaches

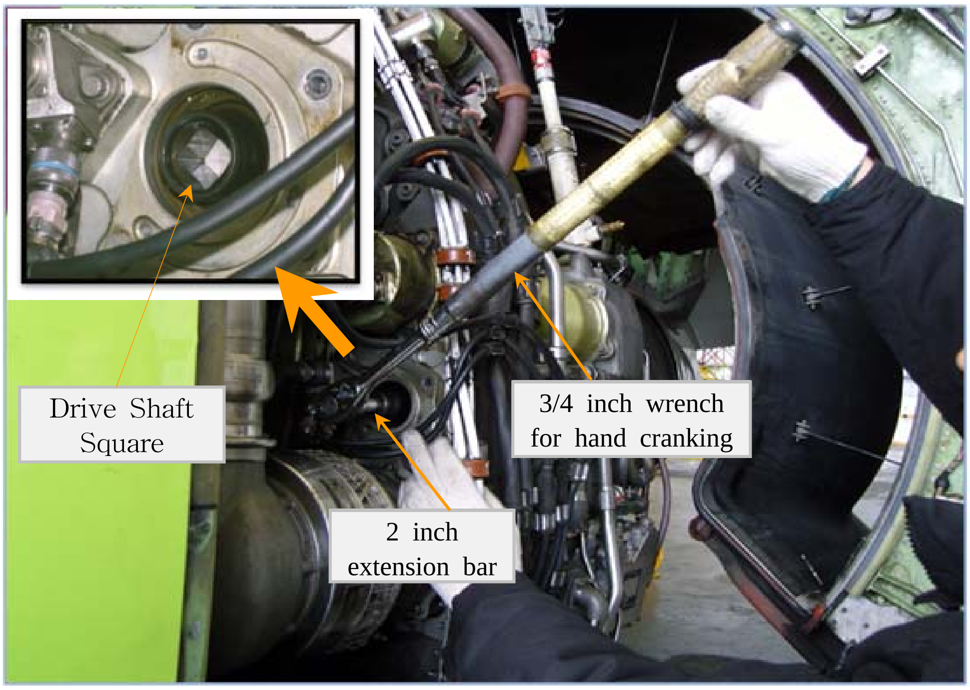
18) Based on the Korean Air's Maintenance Planning Document and CAL CARD No. CL5568LA approved by government

19) On 11 April 2011, the first inspection was conducted by the Korean Air when the engine service time reached 2,451hours

2,500 hours, and subsequent inspection is repeatedly conducted at every 6,000 hours or 6,000 cycles, whichever comes earlier.

As shown in [Photo 1], the Borescope Inspection (BSI) is to inspect blades by using the borescope equipment while rotating the high-pressure compressor, and to rotate this high-pressure compressor, the hand cranking shaft of the accessory gear box should be turned manually.

To turn this hand cranking shaft manually, open the drive shaft square cover and insert a two-inch extension bar into the drive shaft square and then connect the wrench.



[Photo 1] Hand cranking for the engine borescope inspection

1.6.4 Electronic Engine Control

The engine fuel and control system computes the fuel quantity necessary for producing the indicated thrust, and sends the computed fuel quantity to the combustion chamber. The engine fuel and control system is composed of three subsystems[20].

The Electronic Engine Control (hereinafter referred to as "EEC") is a main component of the engine fuel and control system and controls this system. The EEC is

20) Fuel distribution, fuel control and fuel indication systems

in interlock with various engine systems and components, and uses input data received from various engine sensors to compute engine fuel and control outputs.

The major functions of EEC are as follows.

- Input signal validation and processing
- Engine starting, shutdown, and ignition control
- Engine power management
- Reverse thrust control
- Engine core control
- Active clearance control of high-pressure and low-pressure turbines (HPTACC, LPTACC)
- BITE (Built-In-Test Equipment)
- Flight compartment indication

The engine core control function of the EEC's major functions is to maintain the high-pressure compressor rotation speed (N2 speed), HPC static pressure and fuel flow parameters within the limited range.

1.6.5 Weight and Balance

The weight and balance data at the time of takeoff was as follows.

· Zero fuel weight (ZFW)............... 105,029 lbs(Maximum 136,000 lbs)
· Takeoff fuel (TOF)......................... 22,800 lbs
· Takeoff weight (TOW)................. 127,829 lbs(Maximum 174,200 lbs)
· Trip fuel (TIF)............................ 16,799 lbs
· Landing weight (LDW)................ 111,030 lbs(Maximum 144,000 lbs)
· TOW C.G ％ MAC: 14.3 ％ MAC

1.7 Meteorological Information

The weather did not affect this serious incident.

1.8 Aids to Navigation

Not applicable

1.9 Communications

Not applicable

1.10 Aerodrome Information

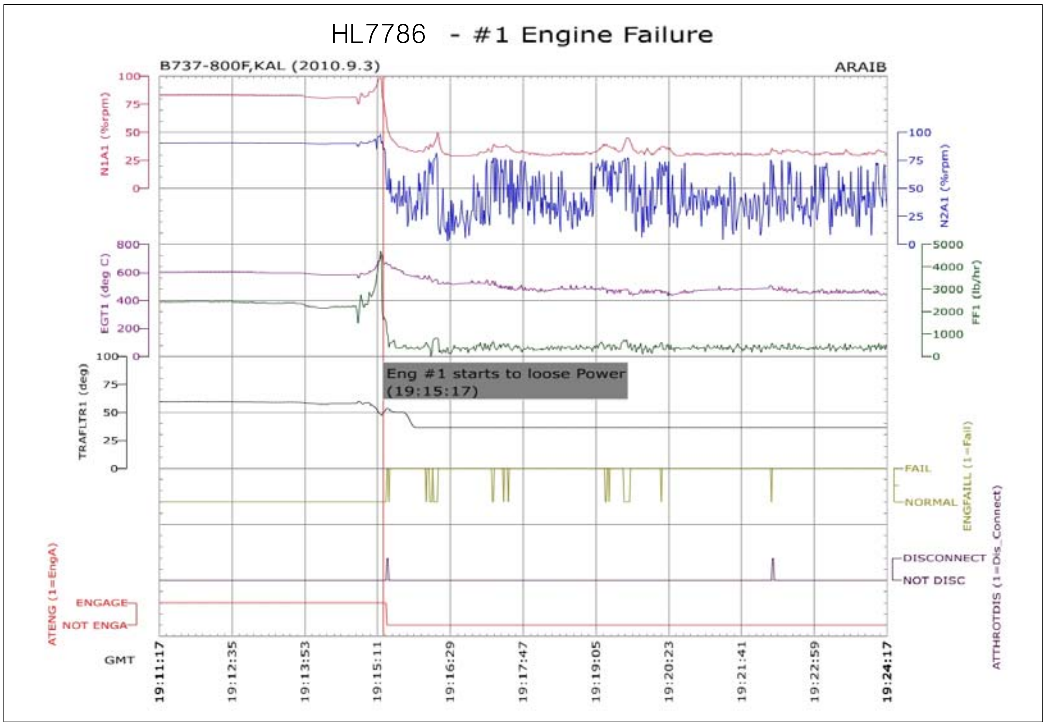
Not applicable

1.11 Flight Recorders

1.11.1 Cockpit Voice Recorder

The HL7786 was equipped with a solid state cockpit voice recorder (SSCVR) which was manufactured[21)] by Honeywell Company and can record for 120 minutes. The ARAIB made a transcript with the voice records at the time when the situation occurred.

1.11.2 Flight Data Recorder



[Fig. 3] FDR major parameters

21) Part Number: 980-6022-011, Serial Number: 12991

The HL7786 was equipped with a solid state flight data recorder (SSFDR) which was manufactured[22)] by Honeywell Company and can record for at least 25 hours. The ARAIB reviewed major parameters at the time of the number 1 engine shutdown.

Referring to the major engine parameters in [Fig. 3] ~ [Fig. 6], we can see that the engine parameters started to fluctuate as engine abnormalities were indicated at 04:14:49, and N1 dropped abruptly from 04:15:17 and the "FAIL" message was displayed at 04:15:21 and the auto throttle was disconnected.

At 04:15:43 “WINDMILL" started and at 04:15:51 the thrust lever was reduced to the idle position, and at 04:24:43 fuel supply to engine was completely cut off.

GMT CLC GMT hh:mm:ss	ALTITUDE ALT FEET	SELECTED N1A1 %RPM	N1 #1 COM N1C1 %RPM	SELECTED N2A1 %RPM	LEFT ENGINE FAIL ENGFAILL	ENGINE PANEL MODE #1 ENGPNLMD1	SELECTED FUEL FLOW #1 FF1 LB/HR	SELECTED TRA TRAFLTR1 DEG
	33098	81,5	81,5	90	NORMAL	N/A	2240	58,01
04 :14:47	33098	81,5		90	NORMAL	N/A	2240	58,01
	33098	81,5	81,5	90	NORMAL	N/A	2240	58,01
	33095	79,3		88,5	NORMAL	ENG OFF	1952	58,01
	33095	75	84	87,3	NORMAL	ENG OFF	1488	59,77
04 :14:51	33098	76		88,4	NORMAL	ENG OFF	1904	59,77
	33100	80,5	84	90,3	NORMAL	ENG OFF	2400	59,77
	33101	84,6		91,5	NORMAL	ENG OFF	2752	58,89
	33100	84,8	80,9	91,1	NORMAL	ENG OFF	2560	57,66
04 :14:55	33098	83,6		90,4	NORMAL	ENG OFF	2352	57,48
	33099	82	80,8	89,8	NORMAL	ENG OFF	2192	57,48
	33099	81,6		89,9	NORMAL	ENG OFF	2224	58,36
	33099	82,5	82,4	90,4	NORMAL	ENG OFF	2368	58,71
04 :14:59	33100	82,5		90,4	NORMAL	ENG OFF	2320	58,71
	33101	82,4	82,6	89,9	NORMAL	ENG OFF	2304	58,71
	33104	83,4		90,5	NORMAL	ENG OFF	2432	58,89
	33102	86,1	82,5	92,4	NORMAL	ENG OFF	2864	58,71
04 :15:03	33100	86,8		92,1	NORMAL	ENG OFF	2784	57,13
	33101	86,4	79,4	91,8	NORMAL	ENG OFF	2656	56,6
	33101	86,1		92	NORMAL	ENG OFF	2688	56,43
	33100	87	78,5	92,4	NORMAL	ENG OFF	2864	56,07
04 :15:07	33100	87,5		92,6	NORMAL	ENG OFF	2880	55,55
	33100	89	76,8	93,5	NORMAL	ENG OFF	3104	54,84
	33101	90		93,5	NORMAL	ENG OFF	3232	53,79
	33100	91,9	72,4	85,3	NORMAL	ENG OFF	3584	52,73
04 :15:11	33100	94,3		95,9	NORMAL	ENG OFF	3792	51,68
	33100	97,4	66,1	96,1	NORMAL	ENG OFF	4208	49,75
	33098	98,5		96,6	NORMAL	ENG OFF	4256	48,87
	33097	98,8	62,9	98,1	NORMAL	ENG OFF	4688	48,34
04 :15:15	33091	97,8		90,1	NORMAL	N/A	4624	47,81
	33088	81	61,9	91,9	NORMAL	ENG OFF	2064	47,99
	33085	79,9		84,5	NORMAL	ENG OFF	1616	49,92
	33082	74,9	68,4	85,8	NORMAL	ENG OFF	1760	50,8
04 :15:19	33081	66,8		83,9	NORMAL	ENG OFF	1632	51,68
	33081	63,9	72,4	60,4	NORMAL	ENG OFF	1552	52,73
	33080	55,9		48,8	FAIL	ENG OFF	1008	53,44
	33081	51,6	74,1	49,1	FAIL	N/A	944	53,44

[Fig. 4] Major engine parameters-1

22) Part Number: 980-4700-042, Serial Number: 17365

GMT CLC GMT hh:mm:ss	ALTITUDE ALT FEET	SELECTED N1A1 %RPM	N1 #1 COM N1C1 %RPM	SELECTED N2A1 %RPM	LEFT ENGINE FAIL ENGFAILL	ENGINE PANEL MODE #1 ENGPNLMD1	SELECTED FUEL FLOW #1 FF1 LB/HR	SELECTED TRA TRAFLTR1 DEG
	33082	74,9	68,4	85,8	NORMAL	ENG OFF	1760	50,8
04 :15:19	33081	66,8		83,9	NORMAL	ENG OFF	1632	51,68
	33081	63,9	72,4	60,4	NORMAL	ENG OFF	1552	52,73
	33080	55,9		48,8	FAIL	ENG OFF	1008	53,44
	33081	51,6	74,1	49,1	FAIL	N/A	944	53,44
04 :15:23	33082	50,3		67,3	NORMAL	N/A	416	52,73
	33082	47,4	71	45,5	FAIL	N/A	576	52,03
	33083	45,4		58,9	FAIL	N/A	640	51,5
	33083	43,8	69,1	37,3	FAIL	N/A	624	51,15
04 :15:27	33085	43,1		42,6	FAIL	N/A	656	50,98
	33088	42,8	67,6	42,1	FAIL	N/A	704	50,45
	33089	41,8		36,6	FAIL	N/A	704	50,1
	33[illegible]9	40,6	67	44,4	FAIL	N/A	432	50,1
04 :15:31	33088	39,6		45,4	FAIL	N/A	384	50,1
	33089	38,4	66,9	27,6	FAIL	N/A	368	50,1
	33088	37,6		48	FAIL	N/A	368	50,1
	33088	37,1	67	56,8	FAIL	N/A	416	50,1
04 :15:35	33088	37,1		33,5	FAIL	N/A	384	50,1
	33088	36,6	67	39,6	FAIL	N/A	368	50,1
	33088	36,4		43,6	FAIL	N/A	400	50,1
	33088	36,4	67	34,1	FAIL	N/A	432	50,1
04 :15:39	33086	36,3		61,6	FAIL	N/A	464	50,1
	33087	36,5	66	41,3	FAIL	N/A	496	49,75
	33087	35,9		36,9	FAIL	N/A	496	48,52
	33088	35,1	62	48,1	FAIL	N/A	368	47,99
04 :15:43	33085	34,9		15,9	FAIL	WINDMILL	336	47,11
	33086	34,4	34,4	20,4	FAIL	WINDMILL	384	45,35
	33086	34,3		51,6	FAIL	WINDMILL	336	43,77
	33084	33,9	33,9	44,1	FAIL	WINDMILL	416	41,84
04 :15:47	33083	33,9		37,1	FAIL	WINDMILL	432	40,43
	33083	33,5	33,4	21,9	FAIL	WINDMILL	352	38,67
	33083	33,3		25,9	FAIL	WINDMILL	368	37,79
	33083	32,9	32,9	31	FAIL	WINDMILL	336	37,44
04 :15:51	33084	32,5		35,1	FAIL	WINDMILL	368	36,39
	33083	32,5	32,5	20,9	FAIL	WINDMILL	368	36,39
	33082	32,6		39,3	FAIL	WINDMILL	368	36,39
	33083	33,1	33,1	31,1	FAIL	WINDMILL	448	36,39
:15:55	33080	34,1		63,6	FAIL	WINDMILL	352	36,39

[Fig. 5] Major engine parameters-2

GMT CLC GMT hh:mm:ss	ALTITUDE ALT FEET	SELECTED N1A1 %RPM	N1 #1 COM N1C1 %RPM	SELECTED N2A1 %RPM	LEFT ENGINE FAIL ENGFAILL	ENGINE PANEL MODE #1 ENGPNLMD1	SELECTED FUEL FLOW #1 FF1 LB/HR	SELECTED TRA TRAFLTR1 DEG
	27862	31,4		48,8	FAIL	WINDMILL	448	36,39
	27786	31,3	31,5	72,9	FAIL	WINDMILL	336	36,39
04 :24:39	27710	32		20,5	FAIL	WINDMILL	576	36,39
	27628	31	31	19,8	FAIL	WINDMILL	224	36,39
	27553	31,4		11,6	FAIL	WINDMILL	496	36,39
	27476	30,5	30,3	53,4	FAIL	N/A	128	36,39
04 :24:43	27395	28,6		38,5	NORMAL	N/A	0	36,39
	27316	27,1	27,1	29,6	NORMAL	N/A	0	36,39
	27239	26,3		20,4	NORMAL	N/A	0	36,39
	27157	26,1	26	60,1	NORMAL	N/A	0	36,39
04 :24:47	27076	25,4		7,4	NORMAL	N/A	0	36,39
	26998	24,9	24,9	57,8	NORMAL	N/A	0	36,39
	26919	24,8		27,3	NORMAL	N/A	0	36,39
	26835	24,1	24	35,6	NORMAL	N/A	0	36,39
19:24:51	26754	23,6		26,1	NORMAL	N/A	0	36,39
	26671	23,3	23,1	8,5	NORMAL	N/A	0	36,39
	XXXXX	XXXXX		XXXXX	XXXXXX	XXXXXXXXXXX	XXXXX	XXXXX
	XXXXX	XXXXX	XXXXX	XXXXX	XXXXXX	XXXXXXXXXXX	XXXXX	XXXXX
XXXXXX	XXXXX	XXXXX		XXXXX	XXXXXX	XXXXXXXXXXX	XXXXX	XXXXX
	26535	22,8	22,8	7	NORMAL	N/A	0	36,39
	26447	22,5		7	NORMAL	N/A	0	36,39
	26365	22,4	22,4	7	NORMAL	N/A	0	36,39
04 :24:57	26286	22,3		44,6	NORMAL	N/A	0	36,39
	26209	22,3	22,3	44,1	NORMAL	N/A	0	36,39
	26133	22,1		43,6	[illegible]RMAL	N/A	0	36,39
	26062	22	22	43,6	NORMAL	N/A	0	36,39
:25:01	25998	21,9		41,8	NORMAL	N/A	0	36,39

[Fig. 6] Major engine parameters-3

1.12 Wreckage and Impact Information

None

1.13 Medical and Pathological Information

The flight crew of the HL7786 held valid medical certificates, and stated that they had not taken any medication or alcoholic beverage that could have affected the flight.

1.14 Fire

Not applicable

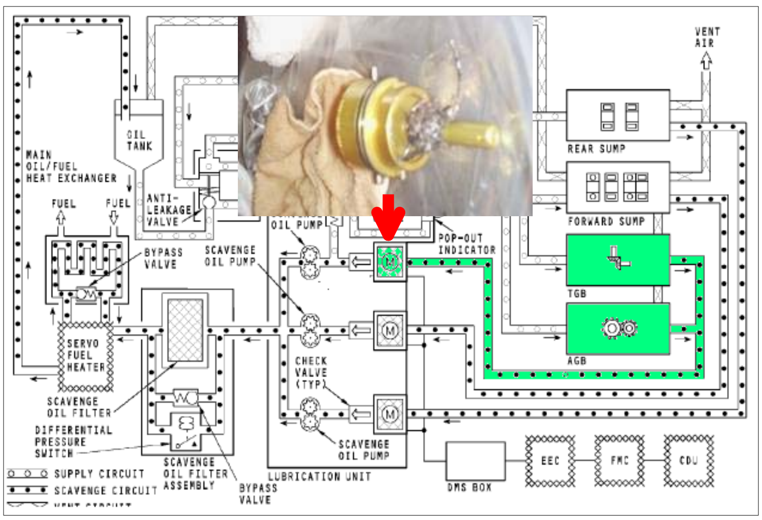
1.15 Survival Aspects

None

1.16 Tests and Research

1.16.1 Engine Inspection after Emergency Landing

In the inspection conducted after the emergency landing at Beijing Capital International Airport was completed, a large quantity of metal chips were discovered in the Magnetic Chip Detector (MCD) that detects metal chips coming out from the oil of the gear box as shown in [Fig. 7].

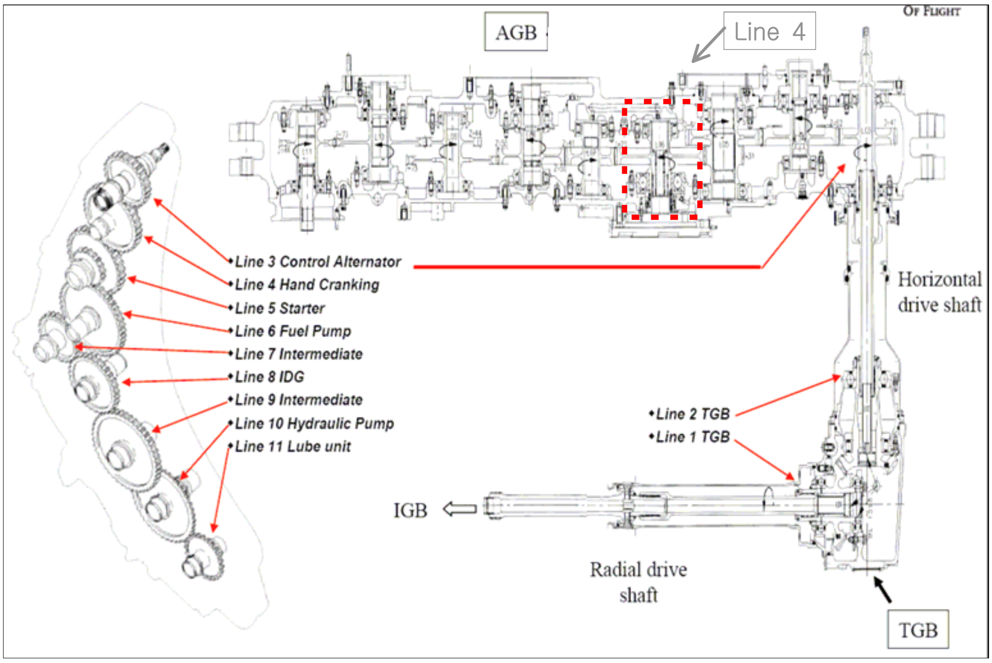


[Fig. 7] CF56-7B engine lubrication system diagram

So it is presumed that the number 1 engine shutdown was caused by the damage to the gear box, and the engine was replaced at Beijing Capital International Airport and was transferred to the Korea Air's Power Plant Maintenance Center.

1.16.2 Accessory Gear Box Teardown Inspection

In the Koran Air's Power Plant Maintenance Center, the relevant gear box was torn down for the inspection to find that the number 4 line of the accessory gear box (AGB) was damaged as shown in [Fig. 8]. The damaged parts were sent to the engine manufacturer for the close inspection on 4 October 2010, and the results of the inspection by the engine manufacturer were as follows;



[Fig. 8] Gear box

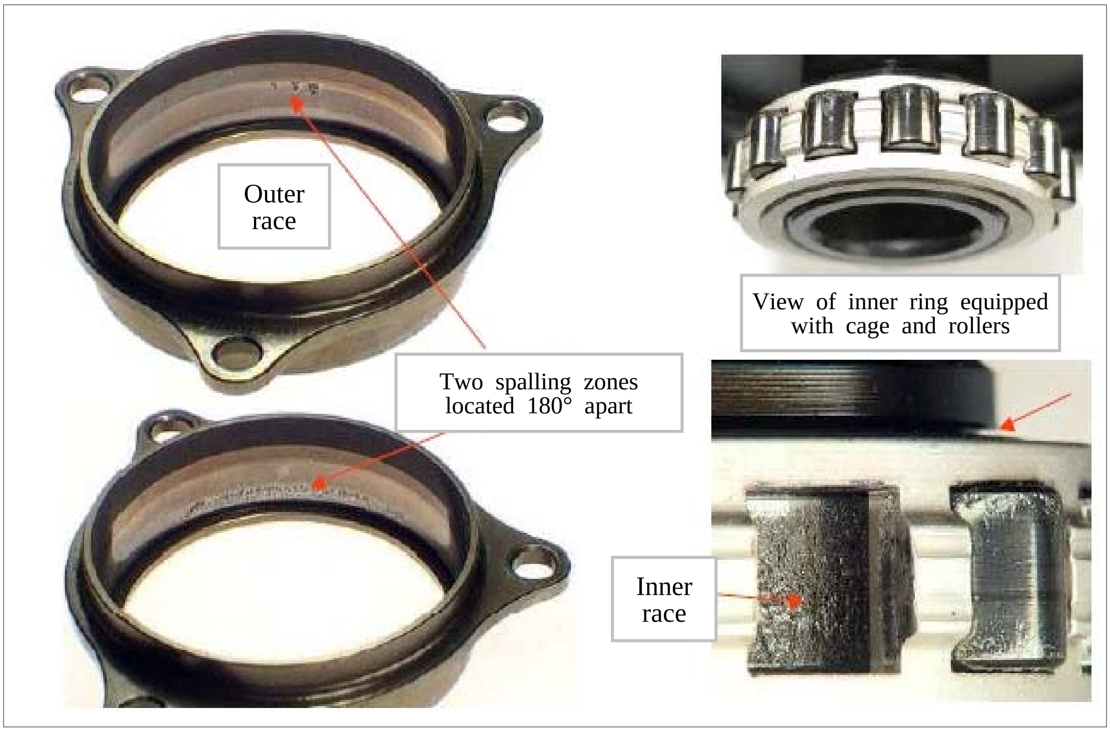
As shown in [Photo 2], the cavity in regard of line 4 ball bearing housing was severely worn down by metallic impacts-rubs related to the fragmentation of both the cage and the inner ring. And line 4 ball bearing outer race journal superficially worn by fretting especially in front of the line securing lugs.

[Photo 2] Starter Pad view

[Photo 3] Gear shaft of No. 4 line

As shown in [Photo 3], the ball bearing journal was worn down deeply by spinning of the inner ring prior to it separated in multiple fragments. The ball bearing was damaged severely and the inner ring and cage of ball bearing were broken into many pieces. The tooth active and non-active flanks severely worn / spalled due to gear shaft misalignment resulting from ball bearing damaging.

All 10 (ten) balls received exhibiting quite same superficial wear condition along with some isolated spalling craters. The residual diameters[23)] were 11.9 mm ~ 12.7 mm. However, heat discoloration which could be due to a lubrication was not found.

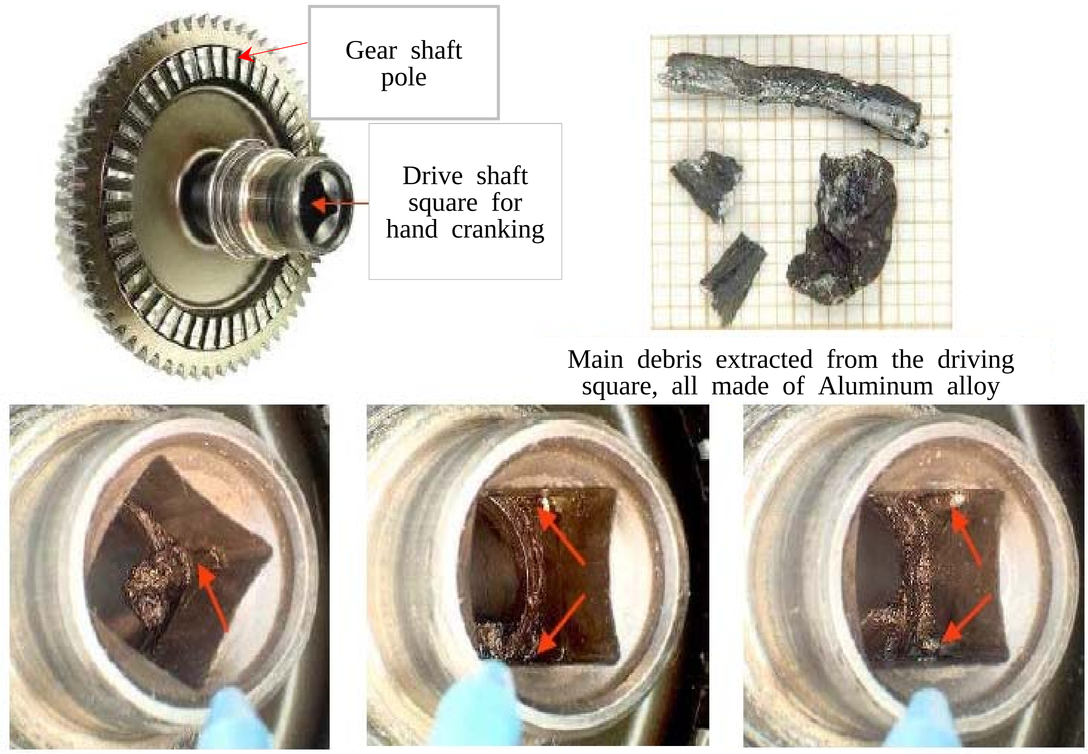


[Photo 4] Roller bearing

As shown in [Photo 4], the outer race way was affected by 2 spalling zones respectively located 180° apart with larger spalling sector close to retaining shoulder and the other one at roller track opposite end. The rollers also were affected by spalling craters mainly developed at each ends of the rolling land.

Inner raceway was exhibits 360° general spalling consistent with the amount of particles trapped on the MCD. Such bearing damaging was indicative of misalignment problem also related to the gear shaft offset resulting from ball bearing damaging.

23) Nominal value: 12.7 mm



Main debris extracted from the driving square, all made of Aluminum alloy

Complementary views of metallic debris found in driving square

[Photo 5] Gear shaft square view

As shown in [Photo 5], Phonic wheel tooth tip also was worn by interference with N2 sensor as a consequence of gear shaft misalignment. Driving square cavity was contaminated by the metallic debris literally crushed at each square inner comers and all identified as made of aluminum alloy (AU2GN)[24].

The metallic debris was introduced during ① AGB manufacturing, ② a borescope inspection prior to the aircraft delivery, or ③ a borescope inspection or maintenance at the airline, but the exact origin and timing of the introduction was known due to various potential sources and lack of evidence.

As shown in [Photo 6], there were two brinelling marks[25] on the outer race way distributed following ball spacing along with two ball impact marks located on rear side

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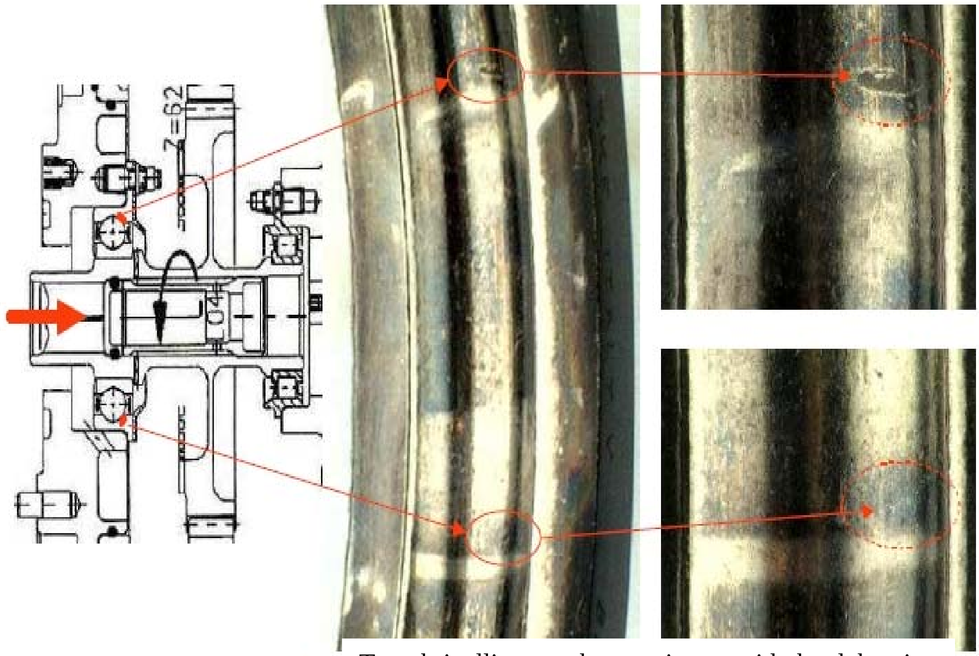
24) The foreign material could have been introduced by the N2 cover or a contaminated tool.

25) Brinelling is a material surface failure caused by contact stress that exceeds the material limit. This failure is caused by just one application of a load great enough to exceed the material limit. The result is a permanent dent or "brinell" mark. It is a common cause of roller bearing failures.

of outer race way. The brinelling marks were induced by axial overload applied through the gear queue to force the inner wrench to enter the gear shaft square cavity.



Two brinelling marks consistent with hard bearing loading during hand crank use

[Photo 6] Ball bearing outer race

1.17 Organizational and Management Information

Not applicable

1.18 Additional Information

None

2. Analysis

2.1 General

The flight crew of the HL7786 were qualified and certified and took a specified rest before the flight. Also, any medical factors that could affect flight were not found.

The HL7786 held a valid airworthiness certificate, and the relevant flight was conducted within the regulatory limitations of the weight and balance.

Any factors that could have affected the failure of the number 4 line in the accessory gear box and number 1 engine in-flight shutdown in the course of conducting the flight procedures were not found.

2.2 Manufacturer's Examination into the AGB

By putting together the results of manufacturer's examination into the damaged parts, it was found that the metal debris were in the hand crank drive shaft square, and it is presumed that the brinelling marks were induced on the ball bearing outer race of accessory gear box (AGB) line 4 line because the inspector applied an axial load to accurately engage the tool for a borescope inspection.

The ball bearing was damaged severely by friction with the brinelling marks on the outer race while it was spinning at high speed, and by this damaged ball bearing, the inner ring and cage of ball bearing were broken into many pieces.

Because the gear shaft rotated shaking due to the misalignment by the damage to the ball bearing cage and inner ring, the sensor sensing the rotation speed (N2 speed) of the high-pressure compressor did not accurately match the pole of gear shaft, so the high-pressure compressor rotation RPM (N2 RPM) fluctuated, and the Electronic Engine Control (EEC) that had this transmitted shut down the engine.

2.3 Engine Preventive Maintenance

2.3.1 Metal Chip Detector (MCD) Check

Since the engine was equipped with a metal chip detector (MCD) for detecting metal chips falling off from the accessory gear box (AGB), it is possible to effectively detect the bearing failure of the AGB in advance through the MCD.

In the case of this serious incident, the gear shaft rotated shaking due to the misalignment by the damage to the ball bearing cage and inner ring, so the roller bearing was damaged, and all the metal chips that broke off at this time remained stuck on the MCD.

The manufacturer's MPD (Maintenance Planning Document) specifies the MCD check to be done every 500 hours, but Korean Air shortened it 250 hours. The latest MCD check on the relevant engine was done on 19 August 2010, and the incident occurred 138 hours after the check.

In the case of this serious incident, if those metal chips had been detected through the MCD check before the damage of AGB, such an in-flight shutdown (IFSD) could have been prevented.

2.3.2 Borescope Inspection

For the borescope inspection, the hand cranking shaft of the AGB should be turned manually. To turn the hand cranking shaft manually, a wrench should be used after an extension bar is engaged into the drive shaft square.

According to the manufacturer's examination results, the inspector applied an axial overload in order to accurately engage the tool without knowing that the metallic foreign material was in the drive shaft square while engaging an extension bar into the drive shaft square for the Borescope Inspection (BSI), eventually, it caused a failure of the AGB line 4.

Therefore, it is necessary to complement the work procedures so as to confirm first whether there is any foreign material inside the drive shaft square and in order not to apply excessive load when engaging a hand cranking tool for the Borescope Inspection (BSI).

A borescope inspection was done first by the manufacturer before the aircraft delivery to the operator, and then, after its delivery to the operator, the first Borescope Inspection (BSI) by the Korean Air was carried out at 2,451 hours on 11 April 2010. But it was not identified which one of the inspections was conducted improperly.

It was presumed that the foreign material found in the hand crank drive shaft square could have been introduced by the N2 cover or contaminated tool, which was introduced during ① AGB manufacturing, ② a Borescope Inspection (BSI) prior to the aircraft delivery, or ③ a Borescope Inspection (BSI) or maintenance at the airline.

But the exact origin and timing of the introduction was known due to various potential sources and lack of evidence. The manufacturer confirmed it with the examination results of the manufacturer that it was unlikely that the foreign material was induced during a Borescope Inspection (BSI) or maintenance at the airline.

3. Conclusions

3.1 Findings

1. The flight crew of the HL7786 were qualified and certified and took a specified rest before the flight. Also, any medical factors that could affect flight were not found.

2. The HL7786 held a valid airworthiness certificate, and the relevant flight was conducted within the regulatory limitations of the weight and balance.

3. The foreign material (aluminum alloy, AU2GN) were left crushed on a corner in the drive shaft square for hand cranking. This was presumed to have been introduced before the delivery of the aircraft to the operator.

4. There were two brinelling marks on the ball bearing outer race, which were presumed by an excessive loads applied axially at the time of engaging a tool into the drive shaft square for the Borescope Inspection (BSI).

5. While the gear was rotating at a high speed, the ball bearing had the surface damaged by friction with the brinelling marks that were on the outer race, and the bearing cage and inner ring were broken into many pieces by the damaged bearing.

6. The high-pressure compressor rotation RPM (N2 RPM) fluctuated due to gear shaft misalignment resulting from ball bearing damaging. The Electronic Engine Control (EEC) sensed it and shut down the engine.

7. Metal chips that fell off from the accessory gear box (AGB) were not detected at the Magnetic Chip Detector (MCD) check which was conducted 138 hours before the event.

8. A Borescope Inspection (BSI) was done first by the manufacturer before the aircraft delivery to the operator, and then, after its delivery to the operator, the first Borescope Inspection (BSI) by the Korean Air was carried out at 2,451 hours on 11 April 2010. But it was not identified which one of the inspections was conducted improperly.

3.2 Probable Cause

The Aviation and Railway Accident Investigation Board determines that the probable cause of this serious incident was that 「An axial overload, which was applied to accurately engage a tool into the drive shaft square for the Borescope Inspection (BSI) without knowing that the metallic foreign material was in the drive shaft square, resulted bearing damage in the AGB line 4, such bearing damaging caused a misalignment problem related to the gear shaft offset, the high-pressure compressor rotation RPM (N2 RPM) fluctuated due to gear shaft misalignment resulting from ball bearing damaging, and eventually the Electronic Engine Control (EEC) sensed it and made the engine shut down.」

4. Safety Recommendations

As a result of an investigation into the serious incident of the HL 7786 occurred on 3 September 2010, the Aviation and Railway Accident Investigation Board makes the following safety recommendations;

To Korean Air

1. Complement the work procedures so as to confirm first whether there is any foreign material inside the drive shaft square and in order not to apply excessive load when engaging a hand cranking tool for the Borescope Inspection (BSI). (AIR1008-1)

=> Korean Air inserted in the check card (CL Card 5535) as of 21 January 2011 the content for first confirming whether there are foreign objects inside the drive shaft square when engaging a hand cranking tool for the Borescope Inspection (BSI) and not applying excessive load to engage the tool, and BSI inspectors were informed of the revised procedures for the Borescope Inspection (BSI). (AIR1008-1 was closed)

To the Engine Manufacturer (CFM International)

1. Complement the work procedures so as to confirm first whether there is any foreign material inside the drive shaft square and in order not to apply excessive load when engaging a hand cranking tool for the Borescope Inspection (BSI). (AIR1008-2)