Ministry of Land, Infrastructure and Transport

ARAIB/AIR-1206

Aircraft Serious Incident Report

In-Flight Engine Shutdown

Eastar Jet Flight 223

B737-700, HL8207

Approximately 77 km South of Gimpo Int'l Airport

5 October 2012

June 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

Aviation and Railway Accident Investigation Board. *In-Flight Engine Shutdown, Eastar Jet Flight 223, B737-700, HL8207, Approximately 77 km South of Gimpo International Airport, 5 October 2012.* Aircraft Serious Incident Report ARAIB/AIR-1206. 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

alt	altitude
AMM	Airplane Maintenance Manual
ARAIB	Aviation and Railway Accident Investigation Board
ATB	Air Turnback
BSI	borescope inspection
℃	degree Celsius
C	cycle
CAS	Calibrated Airspeed
CCV	concave
CDP	(HP)Compressor Discharge Pressure
CFMI	CFM International
ch	channel
CSN	Cycle Since New
CVR	Cockpit Voice Recorder
CVX	convex
deg.	degree
DME	Distance Measuring Equipment
EDM	Electro Discharge Machine
EDS	Energy Dispersive Spectroscopy
EEC	Electronic Engine Control
EGT	Exhaust Gas Temperature
EPR	Engine Pressure Ratio
FAA	Federal Aviation Administration
FAF	Final Approach Fix
FCOM	Flight Crew Operation Manual
FCTM	Flight Crew Training Manual
FDR	Flight Data Recorder
FF	Fuel Flow

ft	feet
GE	General Electric
H	hour
HPC	High Pressure Compressor
HPT	High Pressure Turbine
HQ	High Quality
IAF	Initial Approach Fix
ICAO	International Civil Aviation Organization
ICN	Incheon International Airport
IFSD	In-flight Engine Shutdown
ILS	Instrument Landing System
in	inch
KST	Korean Standard Time
lb	pound
lbf-in	pound-inch
LPT	Low Pressure Turbine
mb	millibar
mil	1/1000 inch
N1	rotational speed of the low-pressure rotor
N2	rotational speed of the high-pressure rotor
NGV	Nozzle Guide Vane
NNC	Non-Normal Checklist
NTSB	National Transportation Safety Board
Pb	Burner Pressure
P/N	Part Number
PF	Pilot Flying
PM	Pilot Monitoring
pph	pound per hour
Ps3	HPC discharge static pressure
psi	pound per square inch

psid	pound per square inch differential
QRH	Quick Reference Handbook
rpm	revolution per minute
SEM	Scanning Electron Microscope
S/N	Serial Number
SID	Standard Instrument Departure
SM	Shop Manual
SQ	Standard Quality
TB	Turbine Blade
TCDS	Type Certification Data Sheet
TEC	Turbine Exhaust Case
Temp.	Temperature
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
TV	Turbine Vane
TZ	Transition Zone
UTC	Coordinated Universal Time
Vib	Vibration

In-Flight Engine Shutdown

- Operator: Eastar Jet
- Manufacturer: The Boeing Company, US
- Type: B737-700
- Registration Mark: HL8207
- Location: Approximately 77 km South of Gimpo Int'l Airport (N 36°51'03", E 126°47'00")
- Date & Time: 5 Oct. 2012, approximately 17:08 KST (08:08 UTC[1])

Synopsis

On 5 October 2012, approximately 17:08, a B737-700 airplane, HL8207, operated as Eastar Jet flight 223, which took off from Gimpo International Airport, bound for Jeju International Airport, experienced an IFSD with the sound of bang and all engine parameters shifting while flying at an altitude of 22,500 ft. The captain declared an emergency, performed engine shutdown procedures, then returned to and landed at Gimpo International Airport, point of departure.

Aboard the airplane were 2 flight crew, 3 cabin crew, and 146 passengers, but there was no personal injury.

The Aviation and Railway Accident Investigation Board (ARAIB) determines the cause of this serious incident was that the liberation of one HPT blade of the right (#2) engine caused severe damage to the engine interior, thereby resulting in the IFSD.

Regarding this serious incident, the ARAIB addresses one safety recommendation to Eastar Jet.

1) Unless otherwise indicated, all times stated in this report are Korean Standard Time (KST, UTC+9).

1. Factual Information

1.1. History of Flight

On 5 October 2012, approximately 16:56, a B737-700 airplane, HL8207, operated as Eastar Jet flight 223 (hereafter referred to as HL8207), took off from runway 32L at Gimpo International Airport (hereafter referred to as Gimpo Airport) and was climbing, using SID BULTI[2)] 1J procedures.

According to the statement of the captain, when HL8207 was climbing through about 22,500 ft near BULTI following the Seoul Approach Control (SEL APP)'s instruction to climb to 24,000 ft, the airplane yawed to the right with the sound of bang.

The flight crew, operating the airplane in the autopilot mode, checked out a pressure altitude and engine indications, which were within normal range, but they confirmed that the right (#2) engine's N1 speed[3)] dropped to 30%, and that the EGT[4)] indicator displayed the ENG FAIL message. The flight crew thus determined that the right engine failed, declared an emergency to SEL APP due to engine failure, and requested a descent and a return to Gimpo Airport.

According to the engine failure non-normal checklist specified in the QRH, the flight crew disconnected the autothrottle, decreased the thrust of the right engine, and shut it down. Then, under the air traffic control of SEL, they notified the flight's emergency return due to engine failure to Eastar Jet on the radio.

Returning to Gimpo Airport, the flight crew were instructed by SEL APP to

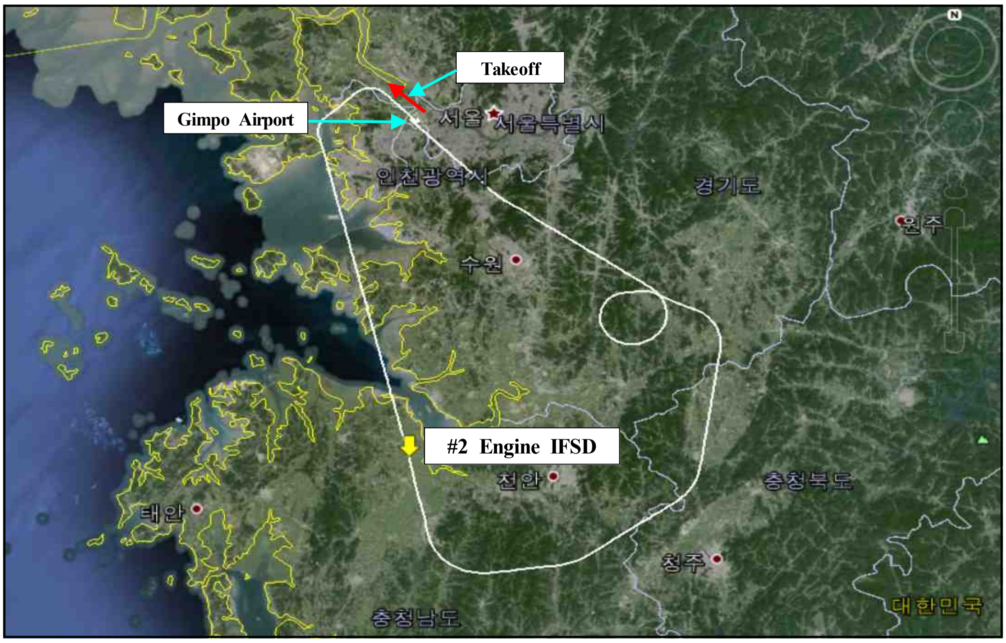
2) A mandatory reporting point where the control of the flight is transferred from SEL APP to ICN ACC.
3) N1 speed is the rotational speed of the engine's low pressure spool, which includes the fan, low-pressure compressor and low-pressure turbine.
4) Exhaust Gas Temperature.

gradually descend to 20,000, 18,000, then 13,000 ft, and obtained a clearance for an ILS runway 32R approach at Gimpo Airport. While descending, they ran the one engine inoperative landing checklist specified in the QRH and made an in-flight announcement about the flight's return to Gimpo Airport due to engine failure.

As the flight crew expected that their altitude would be higher than 7,000 ft of HOKAN, an IAF for an ILS runway 32R approach, they decreased an altitude by making one circle, given radar vector of SEL APP, and followed ILS approach procedures.

Before arriving at KENJA, a FAF, the flight crew lowered the landing gear and set the flaps at 15° according to the one engine inoperative procedures. Also, they ran the before-landing checklist. Descending through about 800 ft, they disengaged the autopilot and took manual control of the airplane, and landed at Gimpo Airport about 17:35, maintaining an appropriate approach speed of 138 knots.

After arrival, the airplane taxied to the assigned gate 22 on its own and about 17:42, the engine was shut down and passengers deplaned. HL8207's flight path is shown in [Figure 1].



[Figure 1] Flight Path of HL8207

1.2. Injuries to Persons

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

1.3. Damage to Aircraft

The airframe was not damaged as a result of this serious incident, and damage to the engine can be found 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 45) held a valid air transport pilot license,[5] an aeronautical radio operator license,[6] and a first-class airman medical certificate.[7]

The captain had accumulated 6,699 total flight hours, including 1,988 hours in the same type aircraft, of which 1,954 hours had been flown as pilot-in-command.

The captain had accumulated 4,712 total flight hours as second-in-command in B767 and B747 airplanes operated by Asiana Airlines, and was hired by Eastar Jet in January 2010. Since promoted to captain in the same type aircraft in early June 2010, he had accumulated an average of about 75 flight hours every month. He passed his line check and CAT-Ⅱ flight simulator training (low visibility CAT-Ⅱ ILS procedures) in June and August 2012, respectively.

In the 72 hours before the event, the captain stayed at a hotel in Phuket (crew hotel) in the morning and went sightseeing in the afternoon on 2 October 2012. On 3 October, he took a rest at the hotel and on 4 October, had a flight from Phuket International Airport to Incheon International Airport, went home about 13:00, and went to bed about 21:30.

On the day of the serious incident, he went to work about 14:40 and prepared for his afternoon flight. 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 first officer (FO) (male, age 34) held a valid air transport pilot license,[8]

5) License No.: 11-002539 (issued on 9 Mar. 2011).
6) License No.: 99-34-1-0021 (acquired on 24 Dec. 1998).
7) Expiration Date: 31 Jan. 2013.
8) License No.: 12-007749 (issued on 3 Nov. 2011).

an aeronautical radio operator license,[9] and a first-class airman medical certificate.[10]

The FO had accumulated 580 total flight hours, including 280 hours in the same type aircraft. Before hired by Eastar Jet, he received his flight training in a small airplane for 300 hours, and after hired in February 2012, completed his FO training in a B737 airplane in July 2012. In addition, he had accumulated an average of about 75 flight hours every month.

The FO had his flight simulator training and related test in May 2012 and passed his line check in July 2012, thereby maintaining his FO status.

In the 72 hours before the event, he had a day off on 2 and 3 October 2012, so he took a rest at home. On 4 October, he was on a roundtrip from Gimpo Airport to Jeju International Airport back. He did not drink any alcohol or take any illegal medication in the 24 hours before the event flight and was in good health.

1.6. Aircraft Information

1.6.1. General

HL8207 was a B737-700 airplane manufactured by the Boeing Company on 20 August 2002. The aircraft was delivered to Eastar Jet on 13 September 2009, which registered it with the Ministry of Land, Transport and Maritime Affairs (current Ministry of Land, Infrastructure and Transport). The history of the aircraft and its major specifications are shown in [Table 1] and [Table 2], respectively.

9) License No.: 10-34-1-0486 (acquired on 9 Dec. 2010).
10) Expiration Date: 2013. 7. 31.

HL8207 was powered by two CFM56-7B20 engines manufactured by CFM International.[11] The right (#2) engine had accumulated 30,285 hours and 23,491 cycles since new (TSN/CSN), with 7,502 hours and 8,516 cycles since the last shop visit (TSLSV/CSLSV) in April 2009.

Registration Mark	HL8207	Type	B737-73V
Rating	MEL	Manufacturer	US Boeing Company
Airworthiness Category	Airplane (Transport)	Manufacturer S/N	32413
Airworthiness Certificate No.	AS10070	Airworthiness Certificate Issue Date	9 Sep. 2010
Operational Role	Air Transport	Airworthiness Certificate Reissue Date	21 Sep. 2012
Engine Type	CFM56-7B20	Engine S/N	891160, 890196

[Table 1] Aircraft History

Category	Airplane	Max. Takeoff Weight	60,781 kg
Type	B737-700	Max. Zero Fuel Weight	54,657 kg
Airworthiness	Transport	Empty Weight	38,295 kg
Endurance	10 hr 12 min	Max. Fuel Carrying Capacity	22,137 kg
Landing Roll Distance	1,280 m	V_{ne}	Mach 0.82
Payload	5,179 kg	Cruising Speed	Mach 0.75
Fuel Consumption/hr	4,960 lb/hr	Takeoff Roll Distance	1,640 m
Max. Operating Alt	12,496 m	Range	6,037 km

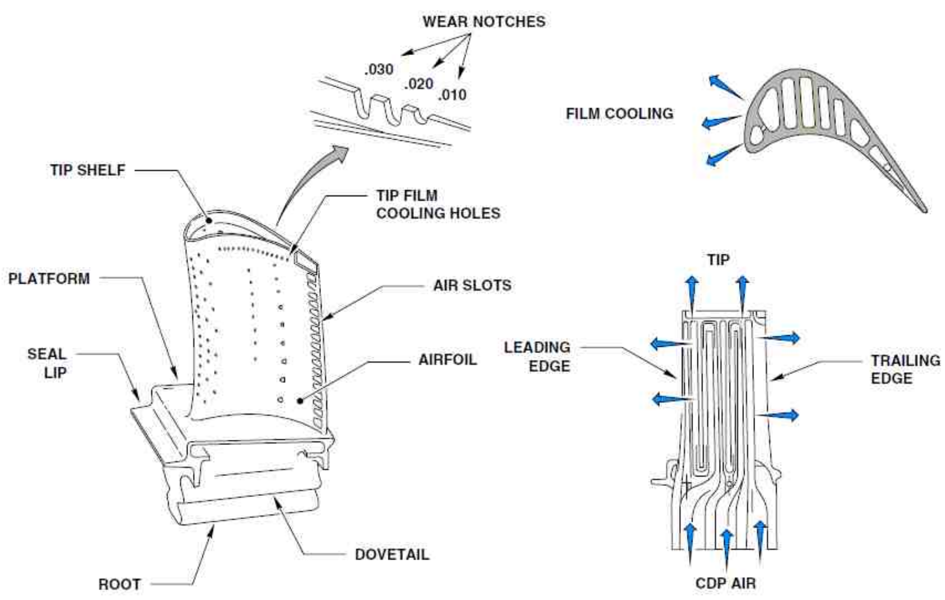
[Table 2] Aircraft Specifications

11) A joint venture between GE Aviation of the US and Snecma of France.

1.6.2. HPT Blades

The HPT of the CFM56-7B engine mounted on HL8207 consists of stage 1 with a total of 80 blades. The HPT blades are made of high temperature single-crystal nickel alloy to gain high strength at a high temperature in comparison to material's weight. Four of the 80 blades are marked with three wear-notches at their tip to show their wear status and identify their positions during borescope inspection. The dovetail root sections of the blades are slidingly received and captured into the disk slots.

The interior of the blades are cooled by CDP[12] air to protect against high temperature. This CDP air flows into the interior of the blade through three cavities at the blade root and cools the blade, then flows out of small holes on the leading edge, trailing edge, and tip, thereby forming a cooling film on the surface of the blade.



[Figure 2] HPT Blade

12) Air which flows into the combustion chamber after it flows into the engine inlet and is compressed until the last 9th stage of the HPC.

1.7. Meteorological Information

A METAR weather report filed when the airplane landed is as follows: wind 4 kt at 340, visibility 10 km, broken at 20,000 ft, temperature 22℃, pressure 1017 mb.

1.8. Aids to Navigation

The airplane landed, using the ILS/DME approach to runway 32R at Gimpo Airport. No anomalies were recorded by the airplane and the ground equipment.

1.9. Communications

No communication problems were reported during flight.

1.10. Aerodrome Information

Not applicable.

1.11. Flight Recorders

1.11.1. Cockpit Voice Recorder

The airplane was equipped with the Honeywell Solid State cockpit voice recorder (SSCVR) (P/N 980-6022-001, S/N 120-2644). On the day of the serious incident, the CVR was retrieved from the site and transported to the ARAIB's analysis lab.

The CVR records, to its IC memory card, the audio information, which is recorded by four channels (captain and FO seats, cockpit area, and backup microphone) and stored as six stream files, four of which and two of which contain 30-minute HQ and 120-minute SQ audio information, respectively.

The CVR recorded audio data for the two hours before the engine shutdown, and the pilots first recognized a sign of engine failure after about 01:23:12 elapsed time of the 120-minute stream file. The ARAIB transcribed a segment of the CVR data between the captain's initial recognition of engine failure and engine shutdown in the ramp after landing and used the CVR transcript in the course of the investigation.

1.11.2. Flight Data Recorder

The airplane was equipped with the Honeywell Solid State flight data recorder (SSFDR) (P/N 980-4700-042, S/N 2951). The FDR was retrieved from the site and transported to the ARAIB's analysis lab on 5 October 2012.

Visual inspection revealed that the FDR was free from damage. The FDR recorded flight data for the 25 hours before the engine shutdown. The ARAIB retrieved this 25 hours worth of raw data, from which the Board collected about 1,100 parameters.

Out of the extracted data, main parameters relating closely to this serious incident were selected and analyzed as shown in [Table 3].

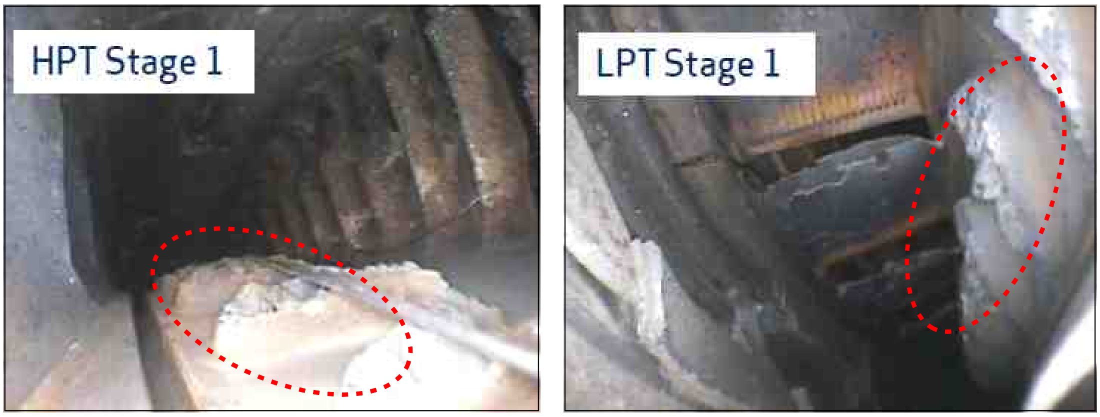
Time(UTC)	ALT	N1		N2		EGT		PS3		FF		Oil Press		Oil Temp		N1 Vib		N2 Vib	
hh:mm:ss	FEET	Left %RPM	Right %RPM	Left %RPM	Right %RPM	Left DEG C	Right DEG C	Left PSIA	Right PSIA	Left pph	Right pph	Left Scalar	Right Scalar	Left DEG C	Right DEG C	Left Unit	Right Unit	Left Unit	Right Unit
8:07:52	21848	96.1	96.3	98.3	98.4	799	813	224	222	5712	5776					0.3	0.8	0.2	0.2
	21902	96.1	96.3	98.3	98.4	800	814	224	222	5712	5776	58	57			0.3	0.8	0.2	0.2
	21957	96.3	96.3	98.3	98.4	801	814	224	222	5696	5776			91	90	0.3	0.8	0.2	0.2
	22007	96.3	96.4	98.3	98.5	801	815	224	222	5696	5776					0.3	0.8	0.2	0.2
8:07:56	22056	96.4	96.4	98.3	98.5	802	816	224	222	5696	5776					0.3	0.8	0.2	0.2
	22110	96.5	96.5	98.4	98.5	803	817	224	222	5696	5776	58	57			0.3	0.8	0.2	0.2
	22156	96.5	96.5	98.3	98.5	803	817	224	222	5696	5776					0.4	0.8	0.2	0.2
	22199	96.6	96.6	98.3	98.5	804	818	222	220	5696	5760					0.4	0.8	0.2	0.2
8:08:00	22245	96.6	96.6	98.4	98.5	805	819	222	222	5696	5760					0.4	0.8	0.2	0.2
	22287	96.8	96.8	98.4	98.5	806	820	222	222	5696	5776	58	57			0.4	0.8	0.2	0.2
	22327	96.8	96.8	98.4	98.5	806	820	222	220	5696	5760			90	89	0.4	0.8	0.2	0.2
	22369	96.8	96.9	98.4	98.5	807	821	222	220	5680	5760					0.4	0.8	0.2	0.2
8:08:04	22409	96.9	96.9	98.4	98.5	808	822	222	220	5680	5760					0.4	0.8	0.2	0.2
	22450	96.9	96.9	98.4	98.5	808	822	222	220	5680	5760	58	57			0.4	0.8	0.2	0.2
8:08:06	**22461**	**96.9**	**45.6**	**98.4**	**81.1**	**809**	**843**	**222**	**24**	**5664**	**5296**					**0.4**	**0.8**	**0.2**	**0.2**
	22516	96.9	34.9	98.4	72.9	809	860	222	26	5664	1360					0.3	1.0	0.2	0.2
8:08:08	22554	96.3	30.3	97.9	66.5	809	866	220	20	5664	752					0.3	1.4	0.2	0.2
	22587	94.8	27.5	97.3	61.6	799	869	204	18	5376	560	58	25			0.3	1.4	0.2	0.2
	22616	94.8	25.4	97.4	58.0	799	867	208	12	5200	384			89	88	0.2	1.5	0.2	0.3
	22638	94.8	23.8	97.4	55.0	799	839	206	12	5216	272					0.2	1.4	0.2	0.3
8:08:12	22655	94.8	22.9	97.4	52.3	798	836	206	10	5200	288					0.2	1.4	0.2	0.3
	22666	94.8	22.3	97.4	49.9	797	833	206	10	5184	400	57	16			0.2	1.3	0.2	0.3
	22670	94.8	21.9	97.4	47.6	796	830	206	10	5184	432					0.2	1.3	0.2	0.3
	22671	94.8	21.6	97.3	45.8	796	827	206	10	5184	368					0.2	1.3	0.2	0.3
8:08:16	22672	94.8	21.4	97.3	44.0	796	824	206	10	5200	368					0.2	1.3	0.2	0.3
	22674	94.8	21.4	97.3	42.4	795	821	206	10	5184	368	58	12			0.2	1.6	0.2	0.3
	22679	94.8	21.3	97.3	40.9	795	818	206	10	5184	368			89	88	0.2	1.6	0.2	0.3
	22683	94.8	21.3	97.3	39.5	795	815	206	10	5184	368					0.2	2.0	0.2	0.3
8:08:20	22692	94.8	21.1	97.3	38.1	795	812	206	8	5200	368					0.1	2.0	0.2	0.3
	22699	94.8	21.1	97.3	36.9	795	809	206	8	5200	368	58	9			0.2	2.3	0.2	0.2
	22707	94.8	21.1	97.3	35.8	795	806	206	8	5200	352					0.2	2.6	0.2	0.2
	22716	94.8	21.1	97.3	34.5	795	804	206	10	5200	352					0.2	2.6	0.2	0.2
8:08:24	22725	94.8	21.1	97.3	33.4	795	803	206	10	5200	336					0.2	2.9	0.2	0.1
	22732	94.8	21.1	97.3	32.4	795	801	206	8	5200	320	58	6			0.2	3.0	0.2	0.1
	22737	94.9	21.0	97.3	31.4	795	799	206	8	5184	320			89	88	0.2	3.0	0.2	0.1
	22742	94.9	21.0	97.3	30.4	795	798	206	8	5184	304					0.2	3.1	0.2	0.0
8:08:28	22747	94.9	20.9	97.3	29.5	795	796	206	8	5184	288					0.2	3.1	0.2	0.0
	22750	95.0	20.5	97.3	28.5	795	794	206	8	5184	272	58	4			0.2	3.1	0.2	0.0
	22755	94.8	20.6	97.4	27.6	796	791	204	8	5200	256					0.2	2.7	0.2	0.0
	22756	94.8	20.6	97.3	26.8	796	788	204	8	5200	256					0.2	2.7	0.2	0.0
8:08:32	22757	94.8	20.6	97.3	26.0	796	786	204	8	5184	288					0.2	2.2	0.2	0.0
	22758	94.8	20.6	97.3	25.4	796	784	204	8	5168	288	58	3			0.2	2.0	0.2	0.0
	22757	94.8	20.6	97.3	24.6	795	782	204	8	5168	304			89	88	0.2	2.0	0.2	0.0
	22753	94.6	20.8	97.3	24.0	795	780	204	8	5152	304					0.2	1.9	0.2	0.0
8:08:36	22745	94.6	20.8	97.1	23.5	795	779	204	8	5168	320					0.2	1.9	0.2	0.0
	22733	94.6	20.8	97.3	22.9	795	777	204	8	5168	320	58	3			0.2	1.9	0.2	0.0
	22716	94.8	20.8	97.3	22.3	795	776	204	8	5168	320					0.2	2.1	0.2	0.0
	22695	94.6	20.8	97.1	21.8	794	774	204	8	5168	320					0.2	2.1	0.2	0.0
8:08:40	22669	94.6	20.8	97.1	21.3	794	773	204	8	5168	320					0.2	2.4	0.2	0.0
	22643	94.6	20.8	97.1	20.6	794	771	204	8	5152	304	58	2			0.2	2.4	0.2	0.0
	22618	94.5	20.8	97.1	20.1	794	769	204	8	5168	320			89	88	0.2	2.6	0.2	0.0
	22598	94.5	20.6	97.1	19.8	793	766	204	8	5152	336					0.2	2.7	0.2	0.0
8:08:44	22582	94.5	20.6	97.1	19.3	794	764	204	8	5152	336					0.2	2.7	0.2	0.0
	22572	94.4	20.6	97.1	18.8	794	762	204	8	5168	336	58	1			0.2	2.7	0.2	0.0
	22561	94.4	20.6	97.1	18.3	793	760	204	8	5168	320					0.2	2.8	0.2	0.0
	22555	94.4	20.8	97.1	17.9	793	759	204	8	5168	320					0.2	2.8	0.2	0.0
8:08:48	22548	94.4	20.8	97.1	17.4	793	758	206	8	5168	336					0.2	2.9	0.2	0.0
	22540	94.4	20.6	97.1	17.0	793	757	204	8	5168	336	58	1			0.2	3.0	0.2	0.0
	22536	94.4	20.6	97.1	16.6	793	757	206	8	5168	336			89	88	0.2	3.0	0.2	0.0
	22528	94.4	20.6	97.1	16.3	793	756	206	8	5168	336					0.2	3.0	0.2	0.0
8:08:52	22524	94.4	20.6	97.1	15.9	793	755	204	8	5168	320					0.2	3.0	0.2	0.0
	22517	94.4	20.6	97.1	15.6	793	754	206	8	5168	304	58	1			0.2	3.0	0.2	0.0
	22515	94.0	20.6	96.8	15.3	792	754	204	6	5168	320					0.2	3.0	0.2	0.0
	22513	91.0	20.5	95.4	14.9	779	754	188	6	4784	320					0.2	3.0	0.2	0.0
8:08:56	22511	90.9	20.5	95.5	14.6	776	754	186	6	4496	320					0.3	3.0	0.2	0.0
	22506	90.8	20.5	95.5	14.3	774	754	186	6	4496	320	56	0			0.3	3.0	0.2	0.0
	22503	90.8	20.5	95.5	13.9	771	753	186	6	4480	304			89	88	0.3	3.0	0.2	0.0
	22499	90.6	20.5	95.5	13.6	769	753	184	6	4480	304					0.3	3.0	0.2	0.0
8:09:00	22495	90.6	20.5	95.5	13.3	768	753	184	6	4480	304					0.4	3.0	0.2	0.0
	22491	90.8	20.5	95.5	13.0	766	753	186	6	4480	304	56	0			0.4	3.0	0.2	0.0
	22486	90.8	20.4	95.5	12.8	765	753	186	6	4480	320					0.4	3.0	0.2	0.0
	22482	90.8	20.4	95.5	12.5	764	753	186	6	4480	304					0.4	2.9	0.2	0.0
8:09:04	22475	89.0	20.4	94.5	12.1	759	754	182	6	4432	304					0.4	2.9	0.2	0.0

[Table 3] Main Parameters Recorded on the FDR

1.12. Wreckage and Impact Information

1.12.1. Preliminary Engine Inspection

After the airplane was transported to the maintenance facility, Eastar Jet's aircraft mechanic performed borescope inspection of the engine gas path. As shown in [Figure 3], all HPT stage 1 and LPT stage 1 blades of the right (#2) engine had missing airfoils.



[Figure 3] Inside of HPT and LPT

As shown in [Figure 4], a lot of metal debris were found at the bottom of the turbine exhaust nozzle at the 6 o'clock position. Damage of LPT stage 4 rotor blades and stator vanes was observed through the struts of the TEC.

The affected engine was immediately removed from the airplane and sent to ST Aerospace, an aviation maintenance, repair and overhaul company, in Singapore for investigation and repair.

Engine disassembly examination was carried out at ST Aerospace's maintenance facility in the presence of the investigators from the ARAIB and the mechanics from Eastar Jet and ST Aerospace.

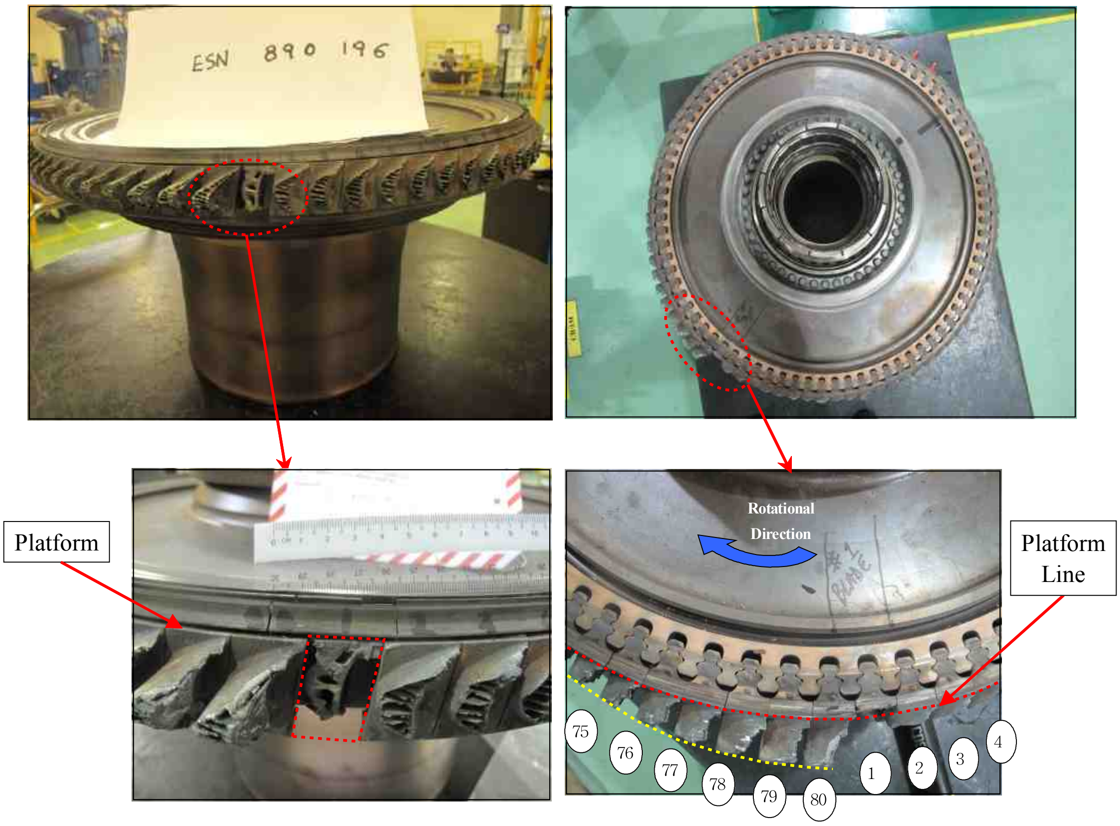
[Figure 4] Turbine Exhaust Nozzle

1.12.2. Engine Disassembly Inspection

As shown in [Figure 5], HPT blades mostly had missing airfoils whose root sections only remained captured into the disk slots. One HPT blade (#1) was liberated under the platform, whereas the remaining 79 blades in the set had airfoil liberation above the platform.

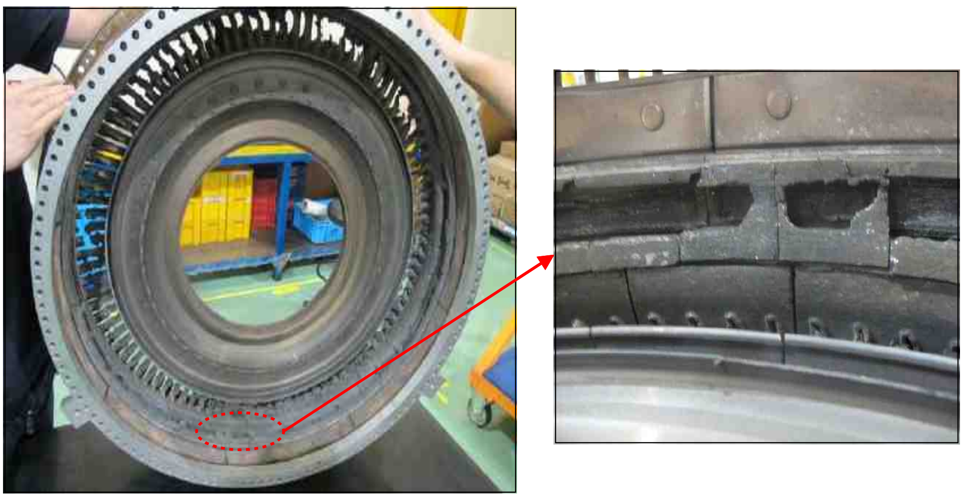
When viewed from the rotational direction of the HPT rotor, #1 blade was the shortest of all, and the remaining blades were getting longer counterclockwise, with the last #80 blade being the longest. This indicates that #1 blade was initially liberated, and that the liberated fragments of #1 blade continued to impact neighboring blades by circumferentially rotating due to centrifugal force, thereby resulting in secondary damage.

Internal engine damage initiated from the HPT blades, some fragments of which were shot forward to the upstream engine modules, thereby resulting in the damage to the trailing edge of the NGVs. The blades of some HPC stages were curled at the tip of the airfoil, but the fan, booster, and combustion chamber were intact.



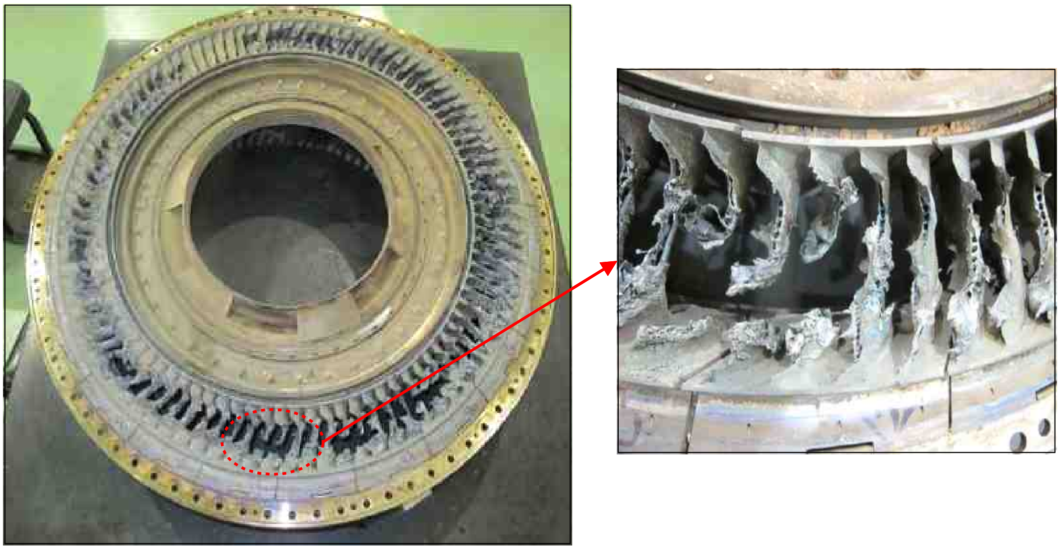
[Figure 5] HPT Rotor Disk and Blades

As shown in [Figure 6], a total of 42 shroud segments attached to the HPT shroud assembly melted away or had large holes in all directions.



[Figure 6] HPT Shroud Assembly

As shown in [Figure 7], most airfoils of the LPT stage 1 NGVs were melted by high temperature.



[Figure 7] LPT Stage 1 NGVs

As shown in [Figure 8], all stages, 1 to 4, of the LPT sustained serious damage. Earlier stages were damaged much more than later ones. All airfoils of the LPT stage 1 blades were missing, and about 80% of the LPT stage 2 blade airfoils were liberated. The LPT stage 3 blades exhibited about 30 to 40% loss of the airfoils, some of which were missing right above the platform. About 10 to 20% of the LPT stage 4 blade airfoils were liberated along the outboard circumference.

[Figure 8] Stage-by-stage Damage of the LPT Blades and Vanes

1.13. Medical and Pathological Information

Any of the flight crew's medical and pathological evidence that could have affected their performance was not found. They stated that they did not drink any alcohol or take any illegal medication in the 24 hours before the event flight.

1.14. Fire

Not applicable.

1.15. Survival Aspects

Not applicable.

1.16. Tests and Research

1.16.1. General

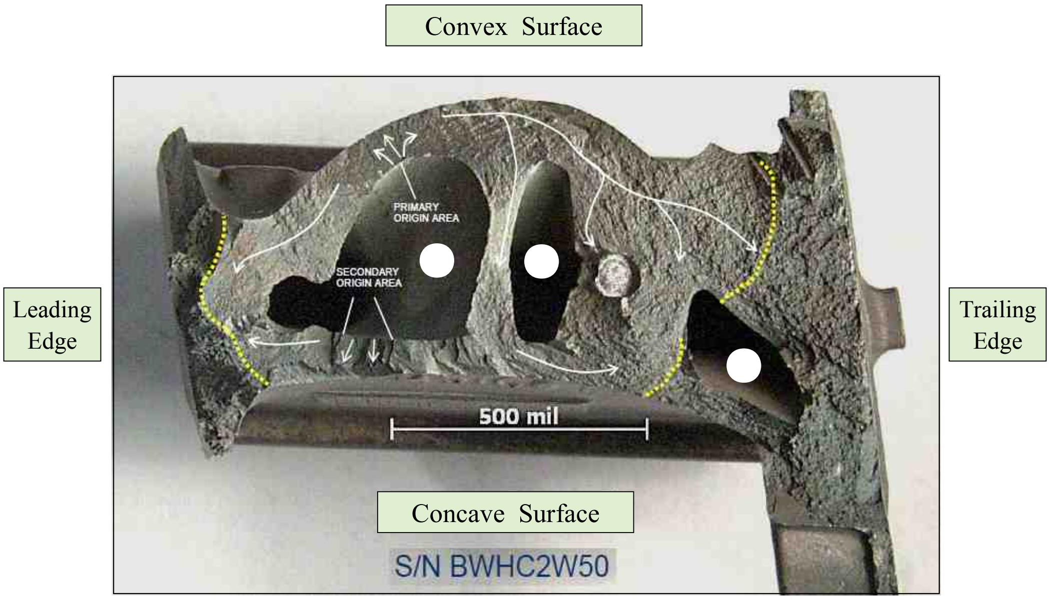
The right (#2) engine removed from the airplane underwent the disassembly examination at ST Aerospace in Singapore in the presence of the investigators from the ARAIB. A set of 80 HPT blades was separated and sent to GE Evendale Lab in Ohio, US, for metallurgical examination.

1.16.2. Metallurgical Examination of the HPT Blades

Primary fatigue crack initiation of the HPT blade with S/N BWHC2W50 occurred from internal convex (CVX) surface located within cavity #1 shank transition zone.[13] Evidence of secondary fatigue crack initiation was also observed from internal concave (CCV) surface of cavity[14] #1 shank transition zone. As shown in [Figure 9], white arrows show the direction of the fatigue crack propagation. Yellow dotted lines show a transition from fatigue crack growth mode to tensile overload mode. This indicates the crack location at the time of liberation and the engine event.

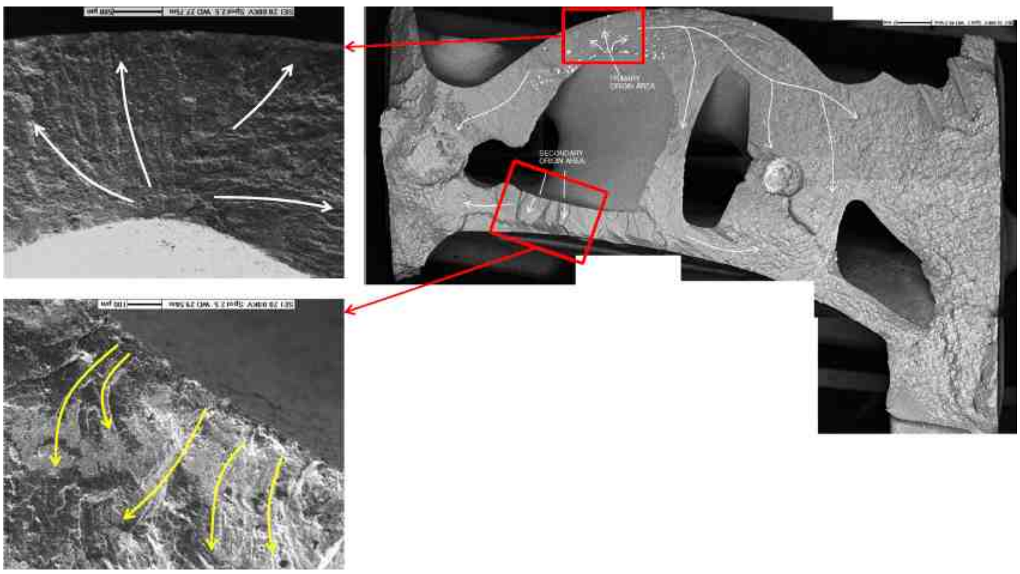
13) Part of the blade body between the airfoil and the root attached to the disk.

14) Inner passages of the HPT blade, into which CDP air flows to cool the blades. There are 3 holes from #1 on the leading edge (LE) to #3 on the trailing edge (TE).



[Figure 9] HPT Blade Fracture Surface

As shown in [Figure 10], the fracture surface is heavily oxidized, but there is enough interpretable evidence to identify the primary crack origin area on the convex wall (white arrows). There is also evidence of a secondary crack origin area on the concave wall with multiple interacting initiation sites (yellow arrows).

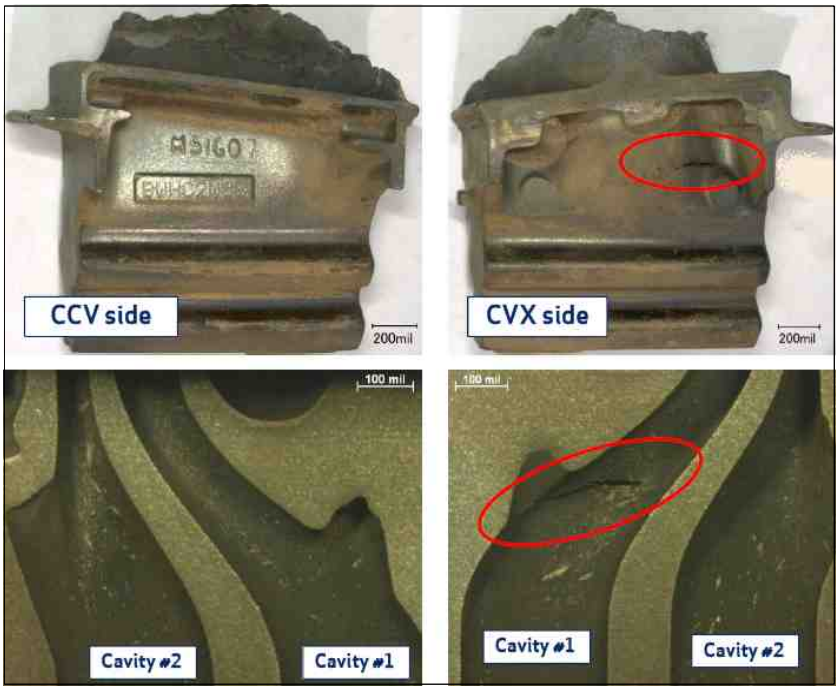


[Figure 10] HPT Blade Fracture Surface

HPT blades attached to HL8207's engine had two different P/Ns: 61 blades with P/N 1957M10P01 and 19 blades with P/N 1957M10P03. The latter blades are new products whose crack defect in the transition zone was improved more than the former. Two blades are physically and functionally interchangeable.

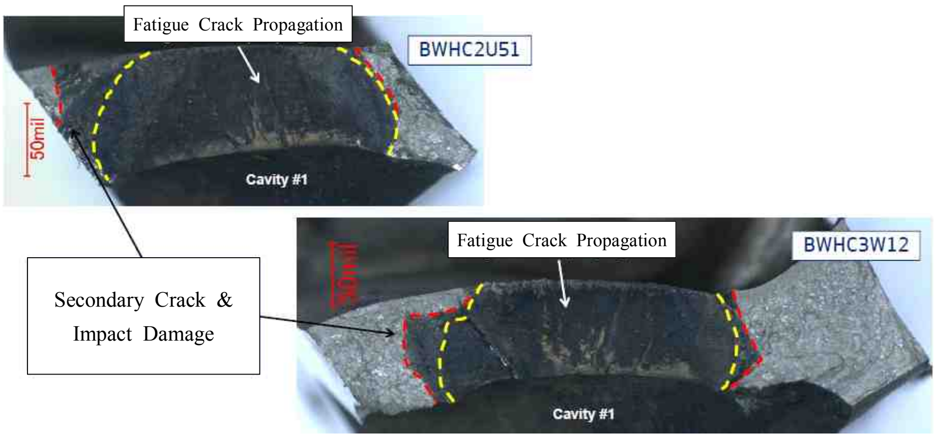
Visual inspection of the remaining 79 blades revealed seven blades with through wall transition zone cracks visible on the external convex wall. As shown in [Figure 11], these cracks were found only on the convex wall of cavity #1 on the leading edge of the blade, with no cracks on the concave wall of cavity #2 and #3. Also, all the blades with cracks had the same P/N, 1957M10P01.

These seven blades were cut using the EDM to split shank concave and convex walls for inspection of transition zone cracks from internal cavity surfaces. Afterwards, two of these blades were lab fractured for metallographic evaluation of transition zone crack surface.

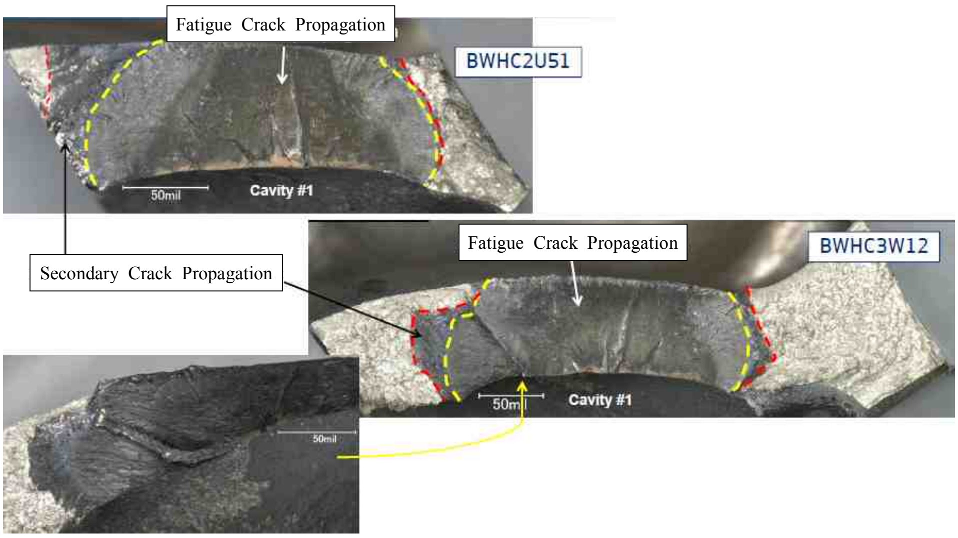


[Figure 11] Through Wall Transition Zone Crack

[Figure 12] and [Figure 13] show lab fractured through wall transition zone cracks of the two out of seven affected blades. [Figure 13] is a macro photo showing lab fractured convex through wall transition zone cracks of the blades after ultrasonic cleaning. Yellow dotted lines show the initial crack region where fatigue cracking initiated from the internal convex surface within cavity #1 and propagated. Red dotted lines exhibit the secondary crack region where cracking was induced by impact damage: tensile overload mode which occurred due to impact during the engine event.

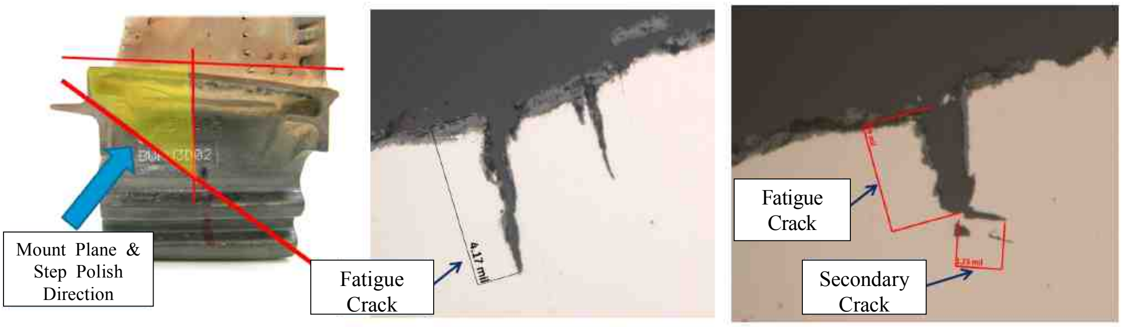


[Figure 12] Through Wall Transition Zone Crack (before cleaning)



[Figure 13] Through Wall Transition Zone Crack (after cleaning)

As shown in [Figure 14], the remaining 72 blades, except seven with through wall transition zone cracks, were all sectioned in the shank transition zone per the diagram shown and step polished four times in the upward direction for measuring transition zone crack depth and internal coating thickness. The secondary cracking induced by impact damage during the engine event was not included in the maximum fatigue crack depth measurement.



[Figure 14] Evaluation of TZ Cracks and Internal Coating Thickness

1.17. Organizational and Management Information

Not applicable.

2. Analysis

2.1. General

The HPT of the CFM56-7B engine mounted on HL8207 consists of stage 1 with a total of 80 blades. As in this serious incident, because transition zone cracks right under the platform were hidden by the platform, the borescope inspection alone could not find them beforehand easily. Meanwhile, on 4 July 2011, CFM International, engine manufacturer, issued the Service Bulletin (SB),[15] which recommended removing the engine and replacing the blades before those with P/Ns 1957M10P01 and 1957M10P03 accumulate 25,000 cycles.

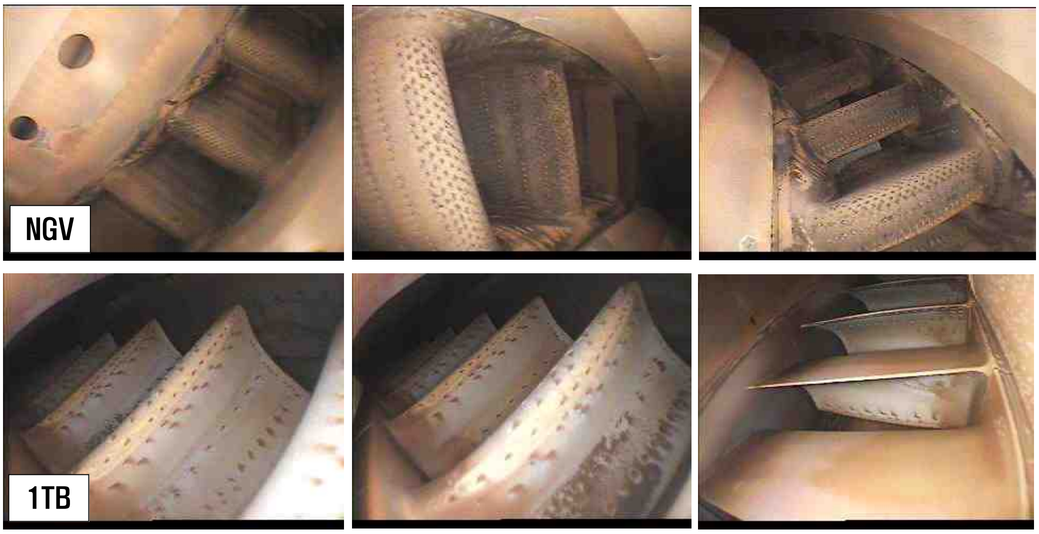
The HPT blade with an initial crack (P/N: 1957M10P01, S/N: BWHC2W50) had accumulated 22,792 hours and 14,975 cycles since new with 7,502 hours and 8,516 cycles since the last overhaul, totaling 30,294 hours and 23,491 cycles, which indicates that this blade had a defect before it reached 25,000 cycles permitted by the SM, with 1,509 cycles to go. Thus, it did not exceed the life limit time recommended by the manufacturer.

2.2. Analysis of the HPT Blades

2.2.1. Monitoring of the HPT Blade Condition

Eastar Jet regularly performed borescope inspection of the HPT blades for any defects. The condition of the HPT blades was to be inspected every 1,600 cycles according to the work sheet,[16] and the last inspection was performed on 8 July 2012, about three months before the event. As shown in [Figure 15], a work log written at that time showed that the HPT blades and NGVs were generally in good condition, with no signs of thermal damage or cracking.

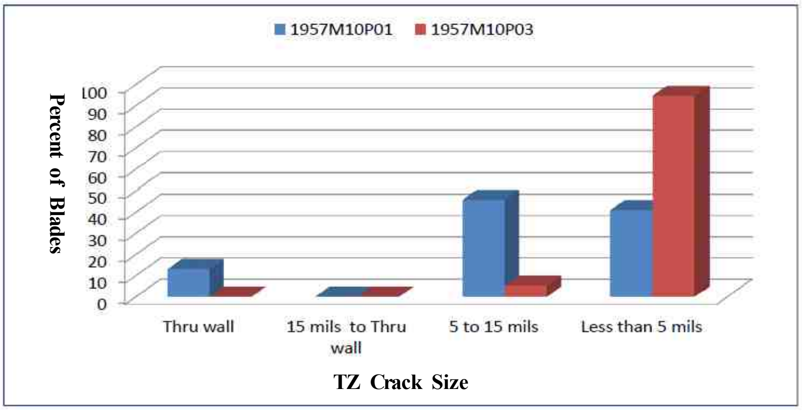
15) Service Bulletin: 72-0821.
16) Work Sheet No.: 72-210-02-01.



[Figure 15] Borescope Photos of HPT NGV (up) & Stage 1 Blades (down)

2.2.2. Measurement of TZ Crack Size

The HPT blades were all sectioned in the shank transition zone to measure the TZ crack depth, and the measurement data is presented in a graphical format by P/N as shown in [Figure 16]. The blades with P/N 1957M10P01 have more severe TZ cracks than those with P/N 1957M10P03. The latter were new when installed, accumulating 8,516 cycles since new, whereas the former were reused after the overhaul, accumulating 23,491 cycles, which indicates that, as cycles accumulate, occurrences of TZ cracks and their size increase.

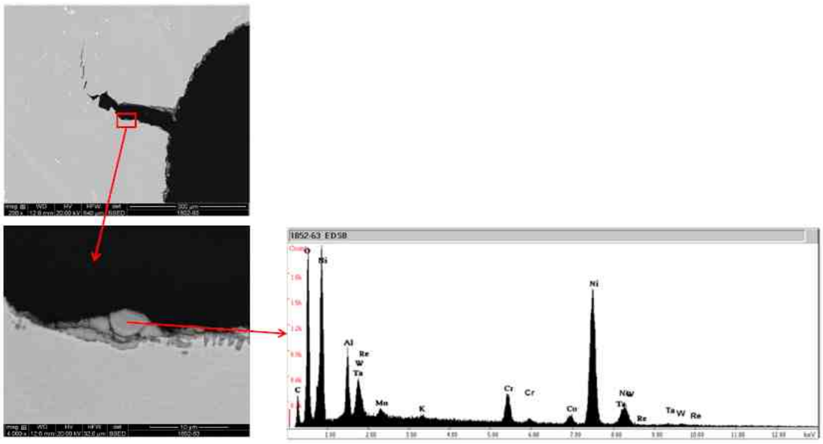


[Figure 16] TZ Crack Size

2.2.3. Analysis of Internal Coating Thickness

All blades with P/N 1957M10P03 had internal coating of about 1 mil thickness in the shank transition zone, but as the coating of P/N 1957M10P01 was not left at all, the inside of the blades were not protected.

The blade with the largest exposed TZ crack (P/N: 1957M10P01, S/N: BWHC0U69) was submitted to SEM for EDS[17] analysis to evaluate oxidation inside the crack, but because the oxidation inside the crack contained no sulfur, this is the evidence that the crack was not driven by corrosion.



[Figure 17] SEM Analysis of TZ Crack

2.2.4. Defects in the HPT Blades of the CFM56-7B

According to the material presented in the joint technical meeting[18] between the Boeing Company and CFM International in May 2012, types of the CFM56-7B's HPT blade defects below the platform root are classified by each P/N as shown in [Table 4]. As shown in [Figure 18], cracks below the platform root of the blades are generally divided into the following three cases: minimum

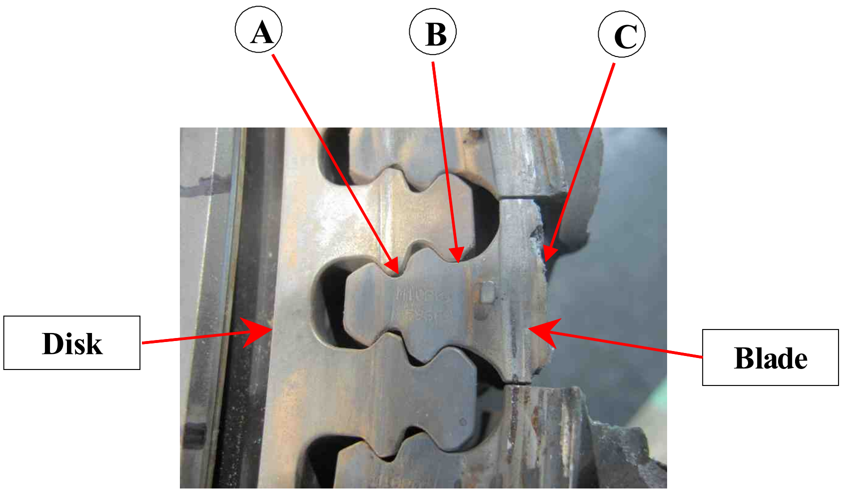
17) One of the atomic analytical equipment, which is installed on the SEM to quickly analyze the elements or chemical characterization of a sample.
18) 22 - 24 May 2012 737NG/CFM56-7 WTT in Charleston.

neck crack; edge of contact crack; and transition zone crack.

In the meantime, the worldwide fleet using the CFM 56-7B engine has seen a total of 30 blade defects below the platform, 16 of which were already widely known TZ cracks, consisting of more than half the cases. In addition, out of 16 defects, 15 and the remaining one were related with P/N 2002M52P09/P11/P14 and P/N 1957M10P03, respectively. Most of the defects were observed in the old model blade with P/N 2002M5209/P11/P14, whereas a defect in the improved blade with P/N 1957M10P01 was found for the first time on HL8207.

Category	P/N	2002M52 P09/P11/P14	1957M10P01	1957M10P03
	Commencement of Blade Manufacture	2001, Q3	2002, Q2	2004, Q2
A	Minimum Neck Crack	2	2	-
B	Edge of Contact Crack	4	6	-
C	Transition Zone Crack	15	-	1

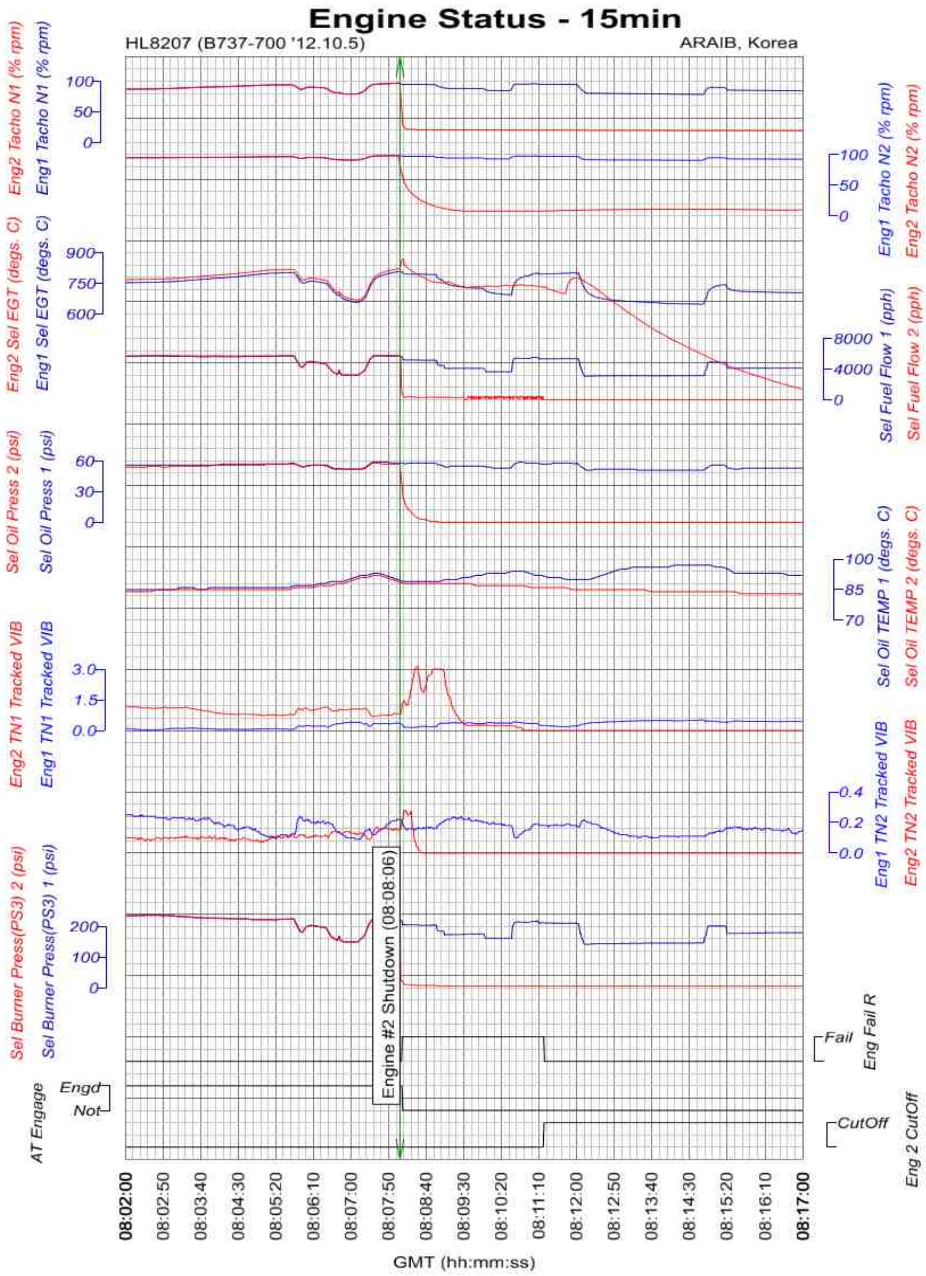
[Table 4] Number of HPT Blade Root Cracks



[Figure 18] Types of HPT Blade Root Cracks

2.3. FDR Data on the Engine

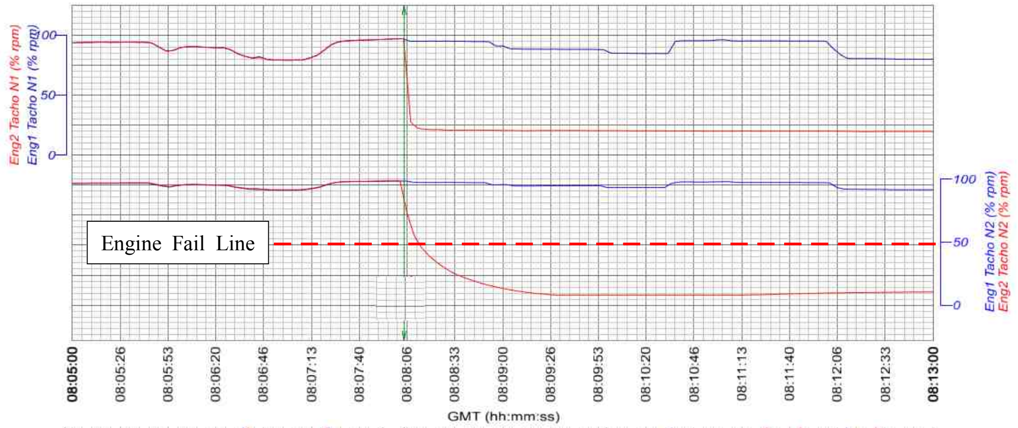
Among the data extracted from the FDR, major parameters relating to the engine failure, with the focus on Eastar Jet flight 223 on 5 October 2012, were selected and analyzed as shown in [Figure 19].



[Figure 19] Engine Parameters Analysis Graph

The FDR installed on HL8207 contained data for about 50 minutes from 07:49:41 UTC to 08:40:49 UTC. Major parameters of the right (#2) engine started to change drastically when the airplane was climbing through about 22,460 ft at 08:08:06 UTC.

As shown in [Figure 20], upon engine failure, the right engine's N1 speed sharply dropped from 96.9% to early 20% just within 3 to 4 seconds, and N2 speed also went down to less than 30% from 98.5%, which indicates that, although the flight crew put the thrust lever in the close position, the engine failed to maintain idle thrust.[19] If N2 speed decreases to less than 50%, the cockpit EGT indicator will display an "ENG FAIL" message.



[Figure 20] N1 and N2 Speeds

As shown in [Figure 21], the right engine's fuel flow (FF) was about 5,760 pph before the event but, upon engine failure, drastically dropped. However, fuel did not completely stop flowing. Instead, it was flowing at 250 - 400 pph for about 3 minutes until the flight crew took action.

As N1 and N2 speeds dropped, Ps3 rapidly decreased from 220 psi to about 1/10 of 220 psi within just a second, which indicates that the combustion

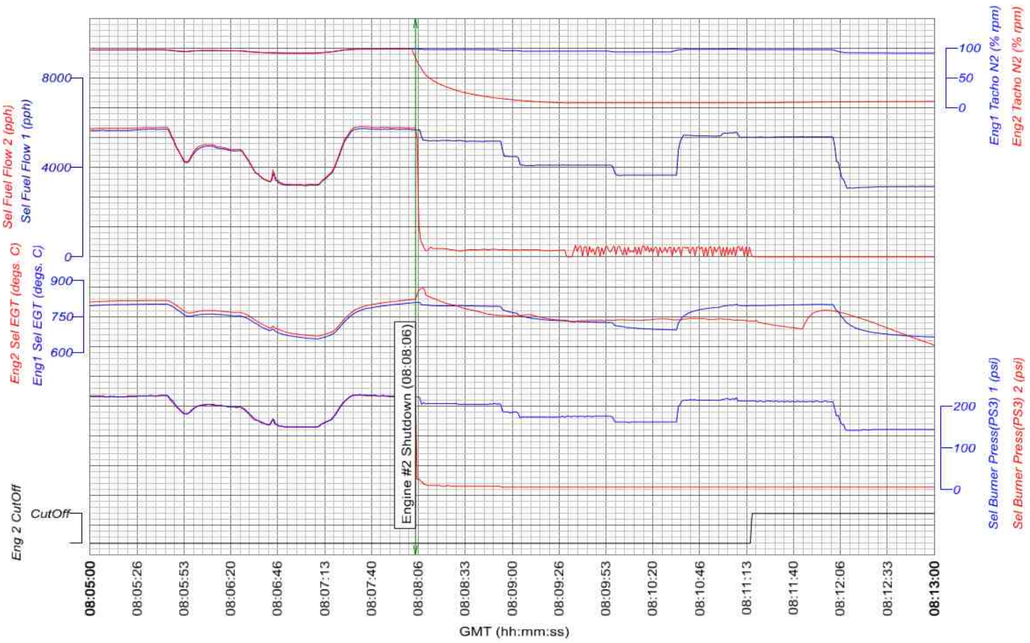
19) In case of the normal engine at flight idle, N1 and N2 speeds are about 31% and 76%, respectively.

chamber flamed out almost at the same time when the event occurred.

The EGT reached its highest temperature 869℃, then started to decrease very slowly, which was caused by the fact that N1 and N2 speeds became lower than engine-windmilling speed due to damage to the blades of the HPT and LPT, thereby failing to cool the engine interior. It was not until about 4 minutes after the event that the EGT started to drop below the EGT start redline, 725℃.

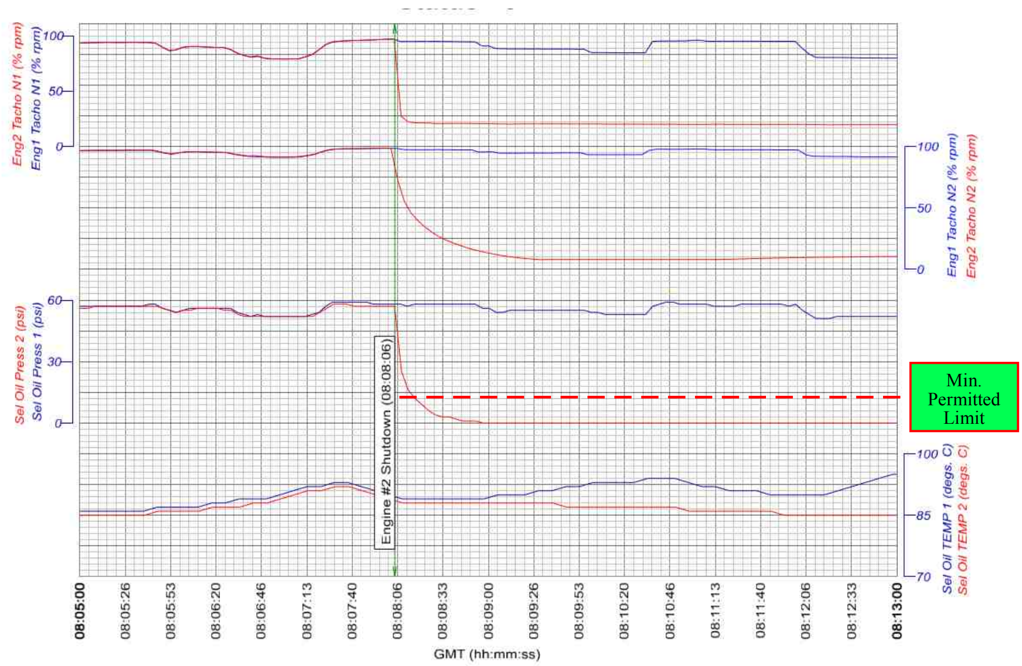
The flight crew disconnected the autothrottle 3 seconds after the event, when the "ENG FAIL" message was displayed. This message disappeared after the flight crew put the engine starter lever in the cutoff position.

A small amount of fuel which was supplied when the combustion chamber flamed out flew into the HPT and LPT and was burned at a high temperature, thereby increasing the temperature of the engine interior. Also, as the compressor shaft's low rpm weakened the cooling function of the engine, the LPT blades and vanes sustained secondary thermal damage.



[Figure 21] N2, FF, EGT, and Ps3

As shown in [Figure 22], 10 seconds after the event, the right engine's oil pressure that had been 57 psid dropped to less than the minimum permitted limit, 13 psid, then 40 seconds after the event, further to 0. This was because the function of the oil pump was lost as N2 speed that was the driving force of the oil pump was too low. In the meantime, oil temperature[20] started to decrease from 88℃ very slowly without rising again since the system was not cooled due to the failure of oil to be circulated within the system.



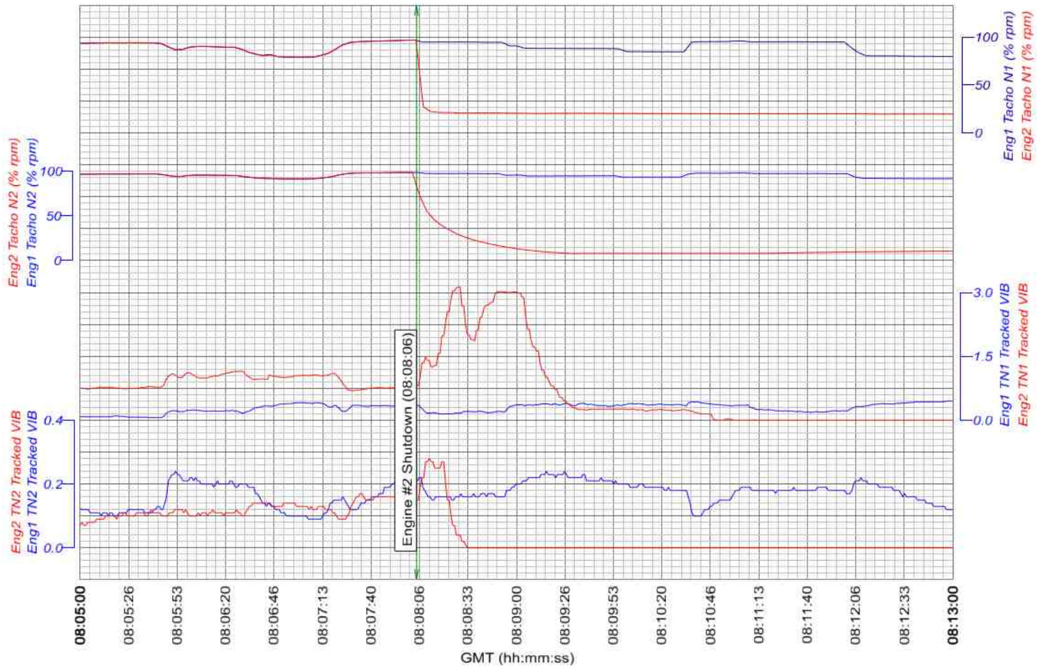
[Figure 22] N1, N2, Oil Pressure and Oil Temperature

As shown in [Figure 23], before the event, the engine vibration level was in good condition, much less than the maximum permitted limit, 4 units.[21] After the event, the N1 vibration level jumped to the maximum 3.1 units and after the engine shutdown, dropped back to less than 1.0 unit, which indicates that, after vibration levels temporarily increased due to the liberation of the LPT blades

20) The maximum permitted limit of oil temperature is 140℃.

21) A unit of the engine vibration displayed on the cockpit instruments. A value obtained by dividing a full scale at regular intervals according to the manufacturer's design concept. In case of a B737 airplane, the engine vibration level's maxium permitted limit is 4 units, which is actually equivalent to 10 mils.

and vanes, they gradually became stable due to a decrease of the shaft's rpm caused by the liberation of all the LPT stage 1 and 2 blades. The N2 vibration level did not exhibit a big change after the engine failure, which is because small loads applied to the HPT shaft (N2) as the HPC sustained a minor damage and all the HPT blades had airfoil liberation almost above the platform.



[Figure 23] Engine Vibration

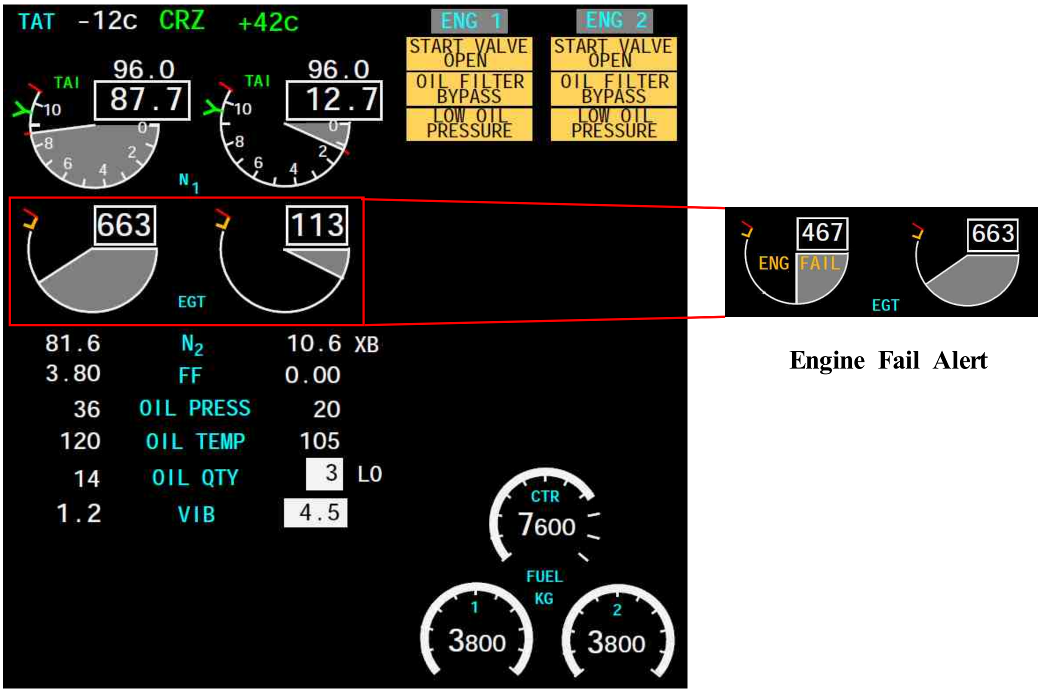
About 08:08:33(UTC), the airplane started to descend at about 22,758 ft, and about 08:37:28(UTC), landed at Gimpo Airport, point of departure. During the whole flight leg, all engine parameters of the left (#1) engine were within normal range.

2.4. Procedures for Engine Failure of a B737-700 Airplane

2.4.1. QAR Procedures for Engine Failure

As shown at the left of [Figure 25], Eastar Jet's B737 FCOM/QRH specifies that procedures for in-flight engine failure should be applied when an ENG FAIL alert shows, and that the captain and the FO should run the NNC by confirming mutually.

As shown in [Figure 24], however, the ARAIB concludes that the flight crew adequately performed the procedures for engine failure after confirming the ENG FAIL alert displayed on the EGT indicator and a decrease of N1, N2, and oil pressure levels.



Engine Fail Alert

[Figure 24] Cockpit Instrument Panel (example)

In case of engine fire, or engine severe damage or separation, the procedures at the right of [Figure 25] should be performed. First of all, the flight crew should perform the procedures from items 1 to 5, trusting to their memory and confirming mutually, then run the NNC from the beginning again.

Engine severe damage is applicable to the second of the three conditions shown at the right of [Figure 25], airframe vibrations with abnormal engine indications, which is different from the condition that occurred in the event.

BOEING 7.15
737 Flight Crew Operations Manual

Engine Failure or Shutdown

Condition: One of these occurs:
- An engine failure
- An ENG FAIL alert shows
- An engine flameout
- Another checklist directs an engine shutdown.

1 Do an engine shutdown only when flight conditions allow.

2 Autothrottle (if engaged). . . . . .Disengage

3 Thrust lever
(affected engine) . . . . . . Confirm . . . . Close

4 **If** conditions allow:

Run the engine for three minutes at idle thrust.

5 Engine start lever
(affected engine) . . . . . . Confirm . . . . . CUTOFF

6 PACK switch (affected side) . . . . OFF

This causes the operating pack to regulate to high flow in flight with flaps up.

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March 27, 2009 D6-27370-683-ESR 7.15

8.2 BOEING
737 Flight Crew Operations Manual

ENGINE FIRE or Engine Severe Damage or Separation

Condition: One or more of these occur:
- Engine fire warning
- Airframe vibrations with abnormal engine indications
- Engine separation.

1 Autothrottle (if engaged). . . . . .Disengage

2 Thrust lever
(affected engine) . . . . .Confirm . . . . . Close

3 Engine start lever
(affected engine) . . . . .Confirm . . . CUTOFF

4 Engine fire switch
(affected engine) . . . . .Confirm . . . . . . Pull

To manually unlock the engine fire switch, press the override and pull.

5 **If** the engine fire switch or ENG OVERHEAT light stays illuminated:

Engine fire switch . . . . . Rotate to the stop and hold for 1 second

If after 30 seconds the engine fire switch or ENG OVERHEAT light stays illuminated:

Engine fire switch. . . . . . . .Rotate to the other stop and hold for 1 second

▼ Continued on next page ▼

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8.2 D6-27370-683-ESR September 25, 2009

[Figure 25] Procedures for Engine Failure and Engine Severe Damage

2.4.2. Flight Crew's Response to Non-normal Situation

When HL8207 was climbing to 24,000 ft near BULTI, the airplane yawed to the right with the sound of bang at an altitude of 22,461 ft at 17:08:06. At this time, the captain checked out a pressure altitude and engine indications which were within normal range, but the right engine's N1 speed dropped to 30% and the EGT indicator displayed the ENG FAIL message, so the ARAIB concludes that the captain adequately determined the right engine failure.

As shown in [Figure 26], according to Autothrottle Use specified in Eastar Jet's FCTM, Chapter 1, page 43, during engine out operations, Boeing recommends disconnecting the autothrottle and keeping the throttle of the inoperative engine in the close position, so the captain appropriately disengaged the autothrottle and put the throttle in the close position before running the NNC.

Autothrottle Use

Autothrottle use is recommended during takeoff and climb in either automatic or manual flight. During all other phases of flight, autothrottle use is recommended only when the autopilot is engaged in CMD.

During engine out operations, Boeing recommends disconnecting the autothrottle and keeping the throttle of the inoperative engine in the CLOSE position. This helps the crew recognize the inoperative engine and reduces the number of unanticipated thrust changes.

[Figure 26] Autothrottle Use

The captain instructed the FO to perform the non-normal procedures for engine failure and requested SEL APP to clear HL8207 for an ascent to 22,000 ft and a return to Gimpo Airport, then operated the airplane following the instructions of SEL APP. He concluded that there was no need to climb since he decided to return due to the right engine's failure, so he requested SEL APP to allow HL8207 to maintain 20,000 ft instead of 22,000 ft. Further, after he confirmed the throttle was in the close position, he adequately put the engine starter lever in the cutoff position at 17:11:16.

3. Conclusions

3.1. Findings

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

2. The airplane held a valid airworthiness certificate.

3. Eastar Jet regularly performed borescope inspection of the HPT blades, and the last inspection performed before the event found no signs of defects.

4. The borescope inspection performed right after the event revealed that all HPT and LPT stage 1 blades of the right engine had missing airfoils, and that a lot of metal debris were found at the bottom of the turbine exhaust nozzle.

5. Engine disassembly examination revealed that one HPT blade was liberated under the platform, whereas the remaining 79 blades in the set had airfoil liberation above the platform.

6. A total of 42 shroud segments attached to the HPT shroud assembly melted away or had large holes in all directions due to impact and high temperature.

7. All LPT blades and vanes from stages 1 to 4 were damaged by impact and high temperature, with relatively more damage in earlier stages.

8. Although the affected HPT #1 blade was once overhauled and has been

used within the maximum permitted cycles recommended by the manufacturer, metallurgical inspection revealed that its fracture surface exhibited transition zone fatigue crack caused by long service hours.

9. Transition zone cracks of the HPT blades were not driven by corrosion.

10. The engine manufacturer issued the SB, which recommended replacing the HPT stage 1 blades with P/Ns 1957M10P01 and 1957M10P03 before they accumulate 25,000 cycles.

11. Eastar Jet has never used the HPT stage 1 blades exceeding 25,000 cycles, maximum permitted cycles recommended by the manufacturer.

12. The flight crew adequately determined the right engine's failure not only because the airplane yawed to the right with the sound of bang, but also because they observed the ENG FAIL message on the EGT indicator.

13. Aware of the right engine's failure, the flight crew immediately started to return to Gimpo Airport, with the autopilot engaged, performed the engine failure procedures specified in the QRH, and safely operated the airplane.

3.2. Causes

The Aviation and Railway Accident Investigation Board determines the cause of this serious incident was that the liberation of one HPT blade of the right (#2) engine caused severe damage to the engine interior, thereby resulting in the IFSD.

4. Safety Recommendations

As a result of the investigation of the accident that occurred to HL8207 at Gimpo Airport on 5 October 2012, the ARAIB makes the following safety recommendation:

To Eastar Jet

1. In case the HPT blades with P/Ns 1957M10P01 and/or 1957M10P03 are installed on the CFM56-7B engine, seek measures, including borescope inspection at a shorter interval, to identify a defect in the blades beforehand and incorporate them in your maintenance program (ARAIB/AIR1206-1).