



**FINAL REPORT ON SERIOUS INCIDENT TO M/s EMIRATES  
BOEING 777-300ER AIRCRAFT A6-EBO  
WHILE OPERATING FLIGHT EK 373 (BANGKOK-DUBAI)  
ON 07.11.2012**

**AIRCRAFT ACCIDENT INVESTIGATION BUREAU  
MINISTRY OF CIVIL AVIATION  
NEW DELHI INDIA**

## **Foreword**

This document has been prepared based upon the evidences collected during the investigation, opinion obtained from the experts and laboratory examination of various components. The investigation has been carried out in accordance with Annex 13 to the convention on International Civil Aviation and under Rule 11 of the Aircraft (Investigation of Accidents and Incidents), Rules 2012.

The investigation is conducted not to apportion blame or to assess individual or collective responsibility. The sole objective is to draw lessons from this incident which may help to prevent such future incidents.

## GLOSSARY

AGB	Accessory Gear Box
ACC	Active Clearance Control
ATS	Air Transport Services
ATC	Air Traffic Control
APU	Auxiliary Power Unit
BSI	Borosopic Inspection
CNR	Customer Notification Report
DVOR	Doppler VOR
DME	Distance Measuring Equipment
EEC	Electronic Engine Control
ECS	Environment Control System
EGT	Exhaust Gas Temperature
EICAS	Engine Indication and Crew Alerting System
FMC	Flight Management Computer
FIM	Flight Isolation Manual
GCAA	Gulf Civil Aviation Authority
GE	General Electric
HPT	High Pressure Turbine
HPC	High Pressure Compressor
HPSOV	High Pressure Shut Off Valve
IFR	Instrument Flight Rules
ILS	Instrument Landing System
LPT	Low Pressure Turbine
LVDT	Linear Variable Displacement Transducer
MFD	Multi-Function Display
MCC	Maintenance Control Centre
NTSB	National Transportation Safety Board
PAPI	Precision Approach Path Indicator
QRH	Quick Reference Handbook
RFF	Rescue and Fire Fighting
SB	Service Bulletin
SSFDR	Solid State Flight Data Recorder
SSCVR	Solid State Cockpit Voice Recorder
UTC	Universal Time Co-ordinated
VBV	Variable Bleed Valve
VSV	Variable Stator Vane
VFR	Visual Flight Rules
VHF	Very High Frequency
VOR	VHF Omnidirectional (Radio) Range

# INDEX

Sl. No.	Subject	Page
	Summary	6
<b>1</b>	<b>FACTUAL INFORMATION</b>	<b>7</b>
1.1	History of the flight	7
1.2	Injuries to Persons	9
1.3	Damage to Aircraft	9
1.4	Other Damage	9
1.5	Personnel Information	10
1.6	Aircraft Information	11
1.7	Meteorological Information	13
1.8	Aids to Navigation	13
1.9	Communications	14
1.10	Aerodrome Information	14
1.11	Flight Recorders	15
1.12	Wreckage and Impact Information	15
1.13	Medical and Pathological Information	15
1.14	Fire	15
1.15	Survival Aspects	15
1.16	Tests and Research	16
1.17	Organizational and Management Information	29
1.18	Additional Information	29
1.19	Useful or Effective Investigation Techniques	29
<b>2</b>	<b>ANALYSIS</b>	<b>30</b>
2.1	Operations	30
2.2	Maintenance	30
2.3	Damage to the core engine	30
<b>3</b>	<b>CONCLUSIONS</b>	<b>31</b>
3.1	Findings	31
3.2	Probable Cause of the Incident	33
<b>4</b>	<b>SAFETY RECOMMENDATIONS</b>	<b>33</b>

**FINAL REPORT ON SERIOUS INCIDENT TO BOEING 777-300ER AIRCRAFT  
A6-EBO WHILE OPERATING FLIGHT BANGKOK-DUBAI  
ON 07/11/2012**

1. Aircraft Type	Boeing 777-300ER
Nationality	UAE
Registration	A6-EBO
2. Owner/ Operator	Emirates
3. Pilot – in –Command	GCAA Licence Holder
4. Crew	Cockpit crew – 2 Cabin Crew - 14
5. Extent of injuries	Nil
6. Passengers on Board	190
7. Extent of passenger injuries	Nil
8. Place of Incident	During flight (diverted to Mumbai)
9. Date of Incident	07 <sup>th</sup> November 2012
10. Time of Incident	17:50 UTC
11. Last point of Departure	Bangkok
12. Point of intended landing	Dubai (diverted to Mumbai)
13. Type of operation	Passenger (Scheduled)
14. Phase of operation	Cruise
15. Type of incident	Engine Fire
16. Damage to aircraft	Fire damage localized on Right Engine

(ALL TIMINGS IN THE REPORT ARE IN UTC)

## **SUMMARY:**

On November 7, 2012 a Boeing 777-300 ER powered by General Electric (GE) GE90-115B engines, while operating a scheduled flight declared an emergency due to a fire warning on RH engine during cruise. The flight crew followed engine fire procedures, the engine was successfully shut down, and it was reported that at least one fire bottle was discharged. The airplane was diverted and an uneventful single engine landing was made at Mumbai International Airport. No injuries were reported to the passengers or crew members on board.

After landing, the airplane was stopped on the taxiway for fire crew to inspect. The airplane was cleared to the bay where passengers deplaned.

During a preliminary visual inspection ground crew noted burn marks on the RH engine thrust reverser cowl. Paint blistering was identified on both halves of the engine thrust reverser cowls near the lower pressure relief doors and 'sooting' was seen on engine components. The fuel line to the right Variable Bleed Valve (VBV) actuator was separated at the weld providing a path for fuel to leak.

As per ICAO Annex 13, the occurrence was declared as a serious incident and India being the State of Occurrence, the Government ordered the incident to be investigated by a Committee of Inquiry. In accordance with the ICAO requirements, NTSB and GCAA were requested for appointment of Accredited Representatives and the US NTSB and the GCAA has appointed accredited representatives for the investigation. NTSB was requested to conduct the analytical teardown and to provide a report summarizing the metallurgical analysis and the teardown findings. Both GE Aviation and the Boeing Company were appointed as Technical Advisors to the NTSB in accordance with ICAO Annex 13.

The engine was removed from the aircraft for further investigation / teardown. The power plant group comprising of members of GE, Boeing, the airlines and the NTSB carried out examination of the involved engine at the GE Aviation facility in Cardiff, Wales, United Kingdom. The group released 'engine examination and disassembly field notes' dated January, 18, 2013. A

final engine investigation report was issued in October, 2013 as GE proprietary information. After deliberations by the Committee of Inquiry, it is concluded that Separation of the VBV actuator fuel supply line outside the 'shroud can' to the VBV actuator extend port was caused due to high N<sub>2</sub> vibrations during flight resulting from damage to the HPT (High Pressure Turbine).

M/s GE have incorporated a Service Bulletin (SB) which replaces the subject line with an improved one, thereby precluding the possibility of fracture should there be elevated vibration levels whilst the engine is in service.

## **1. FACTUAL INFORMATION**

### **1.1 History of the flight**

Boeing 777-300ER aircraft was on a scheduled passenger flight from Bangkok to Dubai on November 07, 2012. There were 190 passengers on board in addition to 16 crew members. As per the pilot report, as the airplane approached top of climb it was observed that right engine EGT was 30°C above the left engine EGT. High N<sub>2</sub> vibrations were noted which triggered a display of the engine secondary page on the Multi-Function Display (MFD). Vibration level was monitored for RH engine. This was 4.5 units with all other engine parameters normal. A snap shot of the engine parameters was sent to Maintenance Control Centre (MCC). GE remote diagnostic detected two N<sub>2</sub> rotor vibrations readings(2.98 and 4.45 units) early into the flight and a normal Customer Notification Report (CNR) was issued as the aircraft was on its return to Dubai.

The crew noted a blue 'STATUS' message on the Engine Indication and Crew Alerting System (EICAS) and selected the status page. An 'Engine Control Right' status message was noted with the right engine parameters higher than the left engine parameters, i.e.

EGT	+200°C,
N <sub>2</sub>	+2%
Fuel Flow	+500 kg.

The crew then reduced the speed to decrease the demand from the engine. Discussion was held and briefing carried out among crew members on the Quick Reference Handbook (QRH) procedures for the Engine Limit /Surge/Stall and Engine fail drift down. MCC advised that they had been monitoring the engine; however, could offer no advice other than to continue. The crew then noticed a fuel imbalance message and after discussion completed the 'Fuel Imbalance' checklist. Following fuel balancing the right main fuel tank was noted to reduce and a fuel leak was then considered with a 2.0 tons loss of fuel. Before crew could action the fuel leak check list, they noted 2 or 3 engine bangs, engine surge and an N<sub>1</sub> spike with airframe vibration similar to turbulence followed by EICAS 'FIRE ENG R' activation. The captain took over the control and requested 'Fire Engine Right memory items". The First Officer (F/O) completed the memory items including discharging one extinguisher bottle and the fire warning ceased. In the meantime the purser informed the crew about sparks from the right engine observed from the cabin R3 door area. The aircraft was turned towards Mumbai (VABB) and the single engine drift down was executed in the Flight Management Computer (FMC). The First Officer declared 'Mayday Mayday May-day, (flight number), Engine Fire, descending FL220, request direct Mumbai. ATC initially cleared the flight direct to position POKON. However, crew requested radar vectors to BOM as VABB was entered into the ALT page and no waypoints were visible. The crew observed some traffic at 12 O'clock and stopped the descent. ATC advised that traffic was descending and there was no conflict. The Fire Engine (Right) checklist was completed including starting the Auxiliary Power Unit (APU) with no other abnormal check lists required. The purser was asked to prepare the cabin for landing at BOM. ATC had queried the status of the engine fire and crew informed that it was out but emergency may be maintained. Runway 27 was the active runway at BOM and ATC asked the crew which runway was required by them. Runway 09 was requested and the crew prepared and briefed for the ILS approach to runway 09. Initially no ILS signal was received and ATC were queried if ILS was "ON". In the meantime, Runway 09 ILS signal came alive. The landing gear was lowered early to lose altitude for landing. Following an uneventful landing, the aircraft was initially brought to a near stop on the runway when ATC asked the aircraft to exit via taxiway N1 and hold short of N3. Upon stopping ATC requested for the left engine to be shut down. The crash fire tenders approached the aircraft and observed that the fire was extinguished and it was safe to tow the aircraft. The aircraft was then towed to remote stand R3. The passengers were deplaned through stairs.



On ground, at Mumbai, during preliminary inspection, soot deposits and paint blistering were apparent on fan-cowls and thrust reverser cowls of right-hand engine. Bottom pressure relief doors on both sides were found open, other door-latches were also not flushed. A fuel-leak was observed and identified as coming from the RH VBV actuator, head end fuel-tube which had sheared through 360 degrees at the weld-line.

## 1.2 Injuries to persons

INJURIES	CREW	PASSENGERS	OTHERS
FATAL	Nil	Nil	Nil
SERIOUS	Nil	Nil	Nil
NONE	16	190	

## 1.3 Damage to aircraft.

On walk-around inspection, a fuel-leak was observed from the Right Engine. There were no abnormalities noticed on the engine inlet. Engine Cowlings were opened and burn-marks with blisters were observed mainly on RHS Cowl. The RHS VBV Actuator extend-line was found sheared-off. Following external observations were made before teardown:

- Bottom of rear Thrust Reverser had burn marks (black) and the paint had blisters.
- The aft cowl skin (outer skin) was structurally damaged beyond repairs.
- Back side of thermal insulation blankets (Stainless Steel) was free of any thermal distress.
- Inner surface of the Thrust reverser (under insulation blankets) was in good condition with no sign of thermal damage.
- Heat damage (blisters) was observed on the RH VSV Actuator “ROD” and “HEAD” ends on fire sleeves of fuel lines.

- There was soot deposit throughout LPT and HPT external hardware configuration and the fire was short term, fuel rich and very 'dirty' / 'sooty' fire
- Accessory heat shield was observed with heat discoloration to the aft side.
- Right hand VBV actuator "extend" fuel supply line found separated outside of the drain shroud.

#### **1.4 Other damage: Nil**

#### **1.5 Personnel information:**

##### **1.5.1 Pilot – in – Command:**

Age	: 44 Years
Licence	: GCAA Licence
Valid up to	: 06/10/2019
Class	: Multi Engine Land
Endorsements as PIC	: B-777
Class of Medical	: Class ONE
Med. Exam valid up to	: 31/05/2013
Flying experience on type	: 2524:45
Total flying experience during 30 days	: 94:11
Total flying experience during 24 Hours	: 5:52
Last PPC done on	: 18/09/2012
Last ALC done on	: 08/05/2012
ELPL	: Level 5
Valid till	: 10/3/2014

The Captain had joined the airline as a First Officer on the B-777 and was promoted to commander in May, 2012. He had earlier operated on the Bangkok-Dubai Sector.

### 1.5.2 First Officer:

Age	: 41 Years
Licence	: GCAA Licence
Valid up to	: 18/05/2018
Class	: Multi Engine Land
Class of Medical	: Class ONE
Med. Exam valid upto	: 28/02/2013
Flying experience on type	: 1465:24
Total flying experience during 30 days	: 70:59
Total flying experience during 24 Hours	: 5:52
Last PPC done on	: 17/10/2012
Last ALC done on	: 21/05/2012
ELPL	: Level 6

### 1.6 Aircraft information:

The aircraft details are as follows:

Model	B777-36NER
MSN	32792
Variable No	WD588
Time since New	32311 hrs
Cycles since new	5587

The last 'A' check on the aircraft was carried out on September 02, 2012. It had accumulated 866 hrs/165 cycles since then.

Both Variable Bleed Valve (VBV) actuators and supply tube were originally installed at delivery. Following are the details of broken VBV and its connecting components:

VBV LH actuator	PN 1962M91P03	SN: PFBASM45
VBV RH actuator	PN1962M91P03	SN: PFBASM46
VBV Fuel supply line	PN2165M22P01	
TSN/CSN	18866/3274 Hrs/Cycle	

Last Visual Inspection : 02.09.2012

**ENGINE DESCRIPTION:**

The GE90-115B engine is an ultra-high bypass (8.4:1), variable stator, dual rotor axial-flow turbofan engine with a 9-stage High Pressure Compressor (HPC) driven by a 2-stage High Pressure Turbine (HPT), and a single-stage fan and 5-stage booster driven by a 6-stage Low Pressure Turbine (LPT). The two independently rotating rotors are supported by five bearings, which are housed in three oil sump chambers.

The sea-level static thrust take-off rating is 115,540 pounds and maximum continuous thrust rating is 110,000 pounds.

The involved engine had entered service (on an aircraft with different registration) on February 12, 2009 and was removed on November 14, 2009 for LPT quick turn. It was then installed on the incident aircraft on November 22, 2009. HPT blades were last inspected on September 04, 2012. Since then, it has done 165 cycles.

After the incident, the engine was sent to NTSB for investigation.

**VBV SYSTEM:**

The VBV System has two actuators and ten valves. A unison ring and bell crank linkages connect the actuators to the valves. The actuators turn the unison ring to move the VBVs.

The actuators are on the forward engine core at the 3:30 and 9:30 positions. The VBV actuators attach to the fan hub frame with bolts.

The VBVs are forward of the actuators inside the fan hub frame. They are equally spaced around the engine.

Each actuator has these parts:

- Servo fuel connection
- Drain can
- Rod
- Linear Variable Displacement Transducer (LVDT)

The servo fuel connection has a drain line and a drain can. The drain lines combine into one drain line that goes to the drain mast. The drain can collects fuel leakage.

Each VBV actuator has a rod that attaches to one end of a bell crank linkage. The other end of the bell crank linkage attaches to the unison ring. When the actuator rod moves, the unison ring rotates.

A single channel Linear Variable Differential Transformer (LVDT) in each actuator sends actuator position information to the Electronic Engine Control (EEC). The left actuator LVDT connects EEC to channel 'A' and the right LVDT connects EEC to channel 'B'.

Servo fuel pressure moves the actuator rods forward and aft. The actuators move together to modulate the VBVs. When the rod moves forward, the unison ring turns clockwise. This causes the VBVs to move towards the closed position.

A guide pin is used to install or remove the VBV actuator. The pin goes through a hole in the mounting flange and attaches to the fan hub frame. The pin supports and guides the actuator.

The servo fuel lines attach to the VBV actuators with B-nuts. The fuel line was pre-mod GE 73-0069 and as per the information received from the operator through the accredited representative, the installation of the modified fuel line was communicated to GE as critical, which was turned down by GE as not-critical and replacement to be done during shop-visit. The operator has further requested GE and Boeing to evaluate the risk of fire / stall, if the subject fuel line fails and both of them replied that this is not a concern.

## 1.7 Meteorological information:

The following are the extracts from relevant METARs of the date of incident:

Time	Wind	Speed	Visibility	Clouds	QNH	Trend	Temp
------	------	-------	------------	--------	-----	-------	------

(UTC)	Dir	(kts)	(Km)				(°C)
1710	VRB	04	2.5	Nil	1011	NOSIG	27
1740	030	04	2.5	Nil	1010	NOSIG	27
1810	000	00	2.5	Nil	1010	NOSIG	27

### **1.8 Aids to navigation:**

The aerodrome was equipped with an Instrument Landing System for runway 09, 27 and 14 and DVOR 'BBB' is collocated DME and VOR. Surveillance Radar approach procedures are available 09, 27 and 14 with published missed approached procedures. Radar Vectoring is available.

Minimum Sector Altitude for sector (340 ° - 200 °) is 2400 ft up to 12 nm and 3700 ft from 12nm to 25nm and for sector (200 ° - 340 °) is 2600 ft up to 25 nm. SID, STAR and Radar Vectoring Facilities as published are available.

All the runways are equipped with PAPI lights with 3 degree glide path. Rwy 27, 14 and 32 PAPI lightning system is available on left while for Rwy 09 PAPI lightning system is available on right.

### **1.9 Communications:**

There was two way communications between the ATC and the aircraft.

### **1.10 Aerodrome information:**

Mumbai International Airport Limited is operated by M/s GVK. The airport had two cross runways 09/27 and 14/32, with ARP location 190530 N 0725158 E and elevation of 37 feet from mean sea level. Rwy 27 is 3190 m, Rwy 09 is 3050 m, Rwy 14 is 2774m and Rwy 32 is 2823 m in lengths.

The airport was equipped with ATS communication facilities .Mumbai was Class 'D' airspace with vertical limits from surface to FL 70 and lateral limits of 40 nm from BBB DVOR.VFR/IFR operations and traffic separation were permitted. The aerodrome was equipped with facilities like fueling, cargo-handling and hangar space & repair facilities for visiting aircraft. The aerodrome Rescue and Fire Fighting (RFF) category was 10. Aerodrome was equipped with Primary and Secondary Isolation bay. Pushback facility was available. SID, STAR and Radar Vectoring Facilities as published were available. All the runways were equipped with PAPI lights with 3 degree glide path. Meteorological Information was available throughout 24 hours.

The emergency services of the airport were alerted by the ATC and detailed information about the aircraft i.e. type of aircraft, Runway in use, nature of emergency, etc. was passed-on. The fire-tenders took their position. City fire-brigade and security services were also informed. After 05 minutes, the emergency services were informed about switching off the engine and fire being under-control. The aircraft, after landing was followed by the CFTs on Runway 09. Emergency services monitored the conversation between the aircraft and the ATC, while the aircraft was holding on Taxiway N1 with engine switched off. Full emergency was withdrawn after the aircraft was parked on stand R4, and the emergency services were accordingly withdrawn.

### **1.11 Flight recorders:**

The aircraft was fitted with the SSFDR and SSCVR. Honeywell DFDR Part No. 980-4700-042, Serial No. SSFDR08941 was installed on the aircraft during the incident flight. The removed SSFDR was shipped to GCAA, UAE for downloading. The data was downloaded at the facilities of GCAA, UAE. The accredited representatives were also requested if they wish to be present for the readout of SSFDR. The readout data was provided to the accredited representative of NTSB.

### **1.12 Wreckage and impact information:**

The aircraft had made a single engine landing on runway 09 and vacated the runway via taxiway N4. The other engine was also switched off taxiway N1 (between taxiway N4 and N3). The aircraft was then towed to the parking stand R4.

### **1.13 Medical and pathological Information:**

N/A

### **1.14 Fire:**

The aircraft had diverted to Mumbai due in-flight engine fire. The fire was under control and the engine was shut down in flight. There was no fire other than this.

### **1.15 Survival aspects:**

The incident was survivable.

### **1.16 Tests and research:**

#### **Pre-Induction BSI**

On December 20, 2012, prior to the power plant investigation teams' arrival, authorization was given to GE Aviation Wales product support engineering to perform a Bore Scope Inspection (BSI) of the engine. BSI was carried out and during the inspection, hard body damage was noted on all stages of the HPC and significant thermal damage was identified in the HPT. No damage was noted in LPC or LPT stages that were visible during the BSI.

#### **General Condition of the Engine**

It was decided to carry out the teardown inspection at GE facility in Wales by Power Plant group comprising of members representing GE, Boeing, and Emirates with NTSB as the convener.



Prior to shipment, the fan blade set, fan pace module, lower bifurcation assembly, center body and core nozzle was removed.

The engine exhibited no case breaches, case deformations or un-containment. Sooting was noted on external components and cases over a section of the engine aft of the accessory gearbox (AGB) heat-shield, to the LPT Active Clearance Control (ACC) manifold cover from approximately the 3 to 7 O'clock positions circumferentially. The 'sooting' was most concentrated at the 5 O'clock position, in the general vicinity of the HPT. The aft side of the AGB heat shield was 'sooted' but had no indications of discoloration or thermal damage. The rubber strip around the lower portion of the heat shield was intact and in good condition. The fire detection loop isolators exhibited thermal distress from the 3 to 9 O'clock positions. Rubber elbows on the LPT ACC supply manifold were lightly sooted but remained intact and pliable. An additional area of localized sooting was identified on the external engine components and cases at approximately 2 to 4 O'clock positions from the fan hub frame to the rear HPC Case split line. The main fuel line spray blanket was charred and discolored consistent with thermal exposure. Areas of the main fuel line fire sleeve below the spray blanket showed evidence of light blistering in a few locations. Blistering and charring was also noted on the fire sleeve of the Variable Stator Vane (VSV) actuator rod and fuel supply line. Environment Control System (ECS) ducting on the right hand side of the engine showed evidence of bluing at the weld joints downstream of the high-pressure shutoff valve (HPSOV).

The right hand Variable Bleed Valve (VBV) actuator fuel supply line, was found separated throughout 360 deg. The separation was located at the outboard weld line, outside the 'shroud can' to the VBV actuator extend port. No additional mechanical or thermal damage was noted to any external engine components.

The majority of external engine plumbing was removed to observe the soot pattern followed by disassembly of the engine. Field notes were prepared by the Power Plant group on engine examination and disassembly. It was decided by the Power Plant group to carry-out Metallurgical Analysis of the following components:

- a) VBV Actuator Pressure Fuel Line-Fracture Analysis (NTSB)
- b) HPC Stage 1 Rotor (Blink)
- c) Stage 1 HPT Rotor Blades

- d) Stage 1 HPT Nozzle
- e) Stage 1 HPT Nozzle bolt Cover and Stationery forward Outer Air Seal
- f) Stage 1 LPT Splatter

It was also decided that:

- Snecma would disassemble the booster module and provide a report of findings.
- Parker Aerospace would carry out Component checks of the VBV actuator.
- GE would provide report of similar field events for VBV related fuel leaks.

NTSB was requested to conduct the analytical teardown and to provide a report summarizing the metallurgical analysis and the teardown findings. Both GE Aviation and the Boeing Company were appointed as Technical Advisors to the NTSB in accordance with ICAO Annex 13. The engine was removed from the aircraft for further investigation / teardown. The power plant group comprising of members of GE, Boeing, the airline and the NTSB carried out examination of the involved engine at the GE Aviation facility in Cardiff, Wales, United Kingdom. The group released 'engine examination and disassembly field notes' dated January, 18, 2013. A final engine investigation report was issued in October, 2013 as GE proprietary information.

The SSFDR was removed from the aircraft and was downloaded at GCAA facilities. A copy of the read out was provided to the Accredited Representative of NTSB. The above stated final engine investigation report was prepared utilizing all the available evidences including DFDR readout. The following pages are the factual extracts from the report. The information is concerning:

- General time line of key event points. (flight)
- Plot of the QAR data for the entire event flight. (N<sub>2</sub> vibrations, fuel flow for both engines)
- Event summary » take off, climb & cruise (TLA, CAS, Air/ground mode, N<sub>2</sub>, Pressure Altitude.
- Fuel flow and EGT for the last two flights.
- Tables showing the GE experience of the 8 occurrences of the leaking VBV fuel supply tubes. The 3 locations of leak are inside drain shroud; crack in tube bend outside drain shroud; and crack at weld outside drain shroud. Vibrations levels and aircraft effect for these instances is also documented.

***Factual  
General Time Line of Key Event Points***

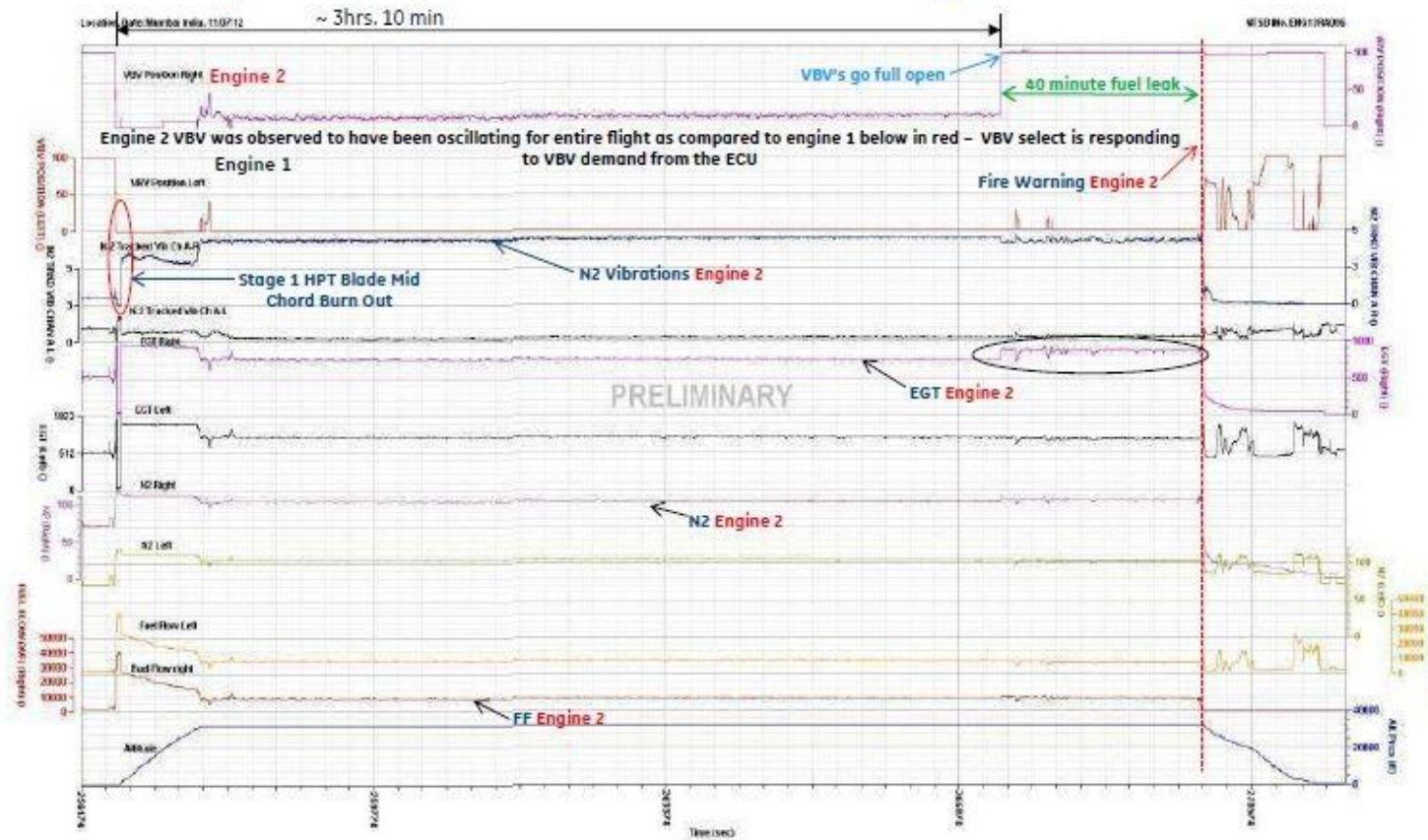
- Takeoff: 14:00
  - N2 Vibe Exceedance: 14:01
- Climb 10K: 14:04
- Climb 20K: 14:09
  - N2 Vibe Exceedance: 14:17
- Cruise Begin: 14:17
  - Notified FSE and Emirates of Climb Exceedance 14:30
- Cruise 2Hr: 16:17
  - Issued CNR for Core Vibration 16:35
  - Fault VBV Actuator does not follow command: 17:03
- Cruise ACARS: 17:41
  - Engine 2 Shut down:
  - Fire Handle Pulled: 17:44
- Cruise End: 17:46
  
- Fuel Loss Estimate: ~ 600 gallons (2 tonnes) in 38 minutes



**32,000 feet  
0.76 Mn  
80-85% N1**

Factual

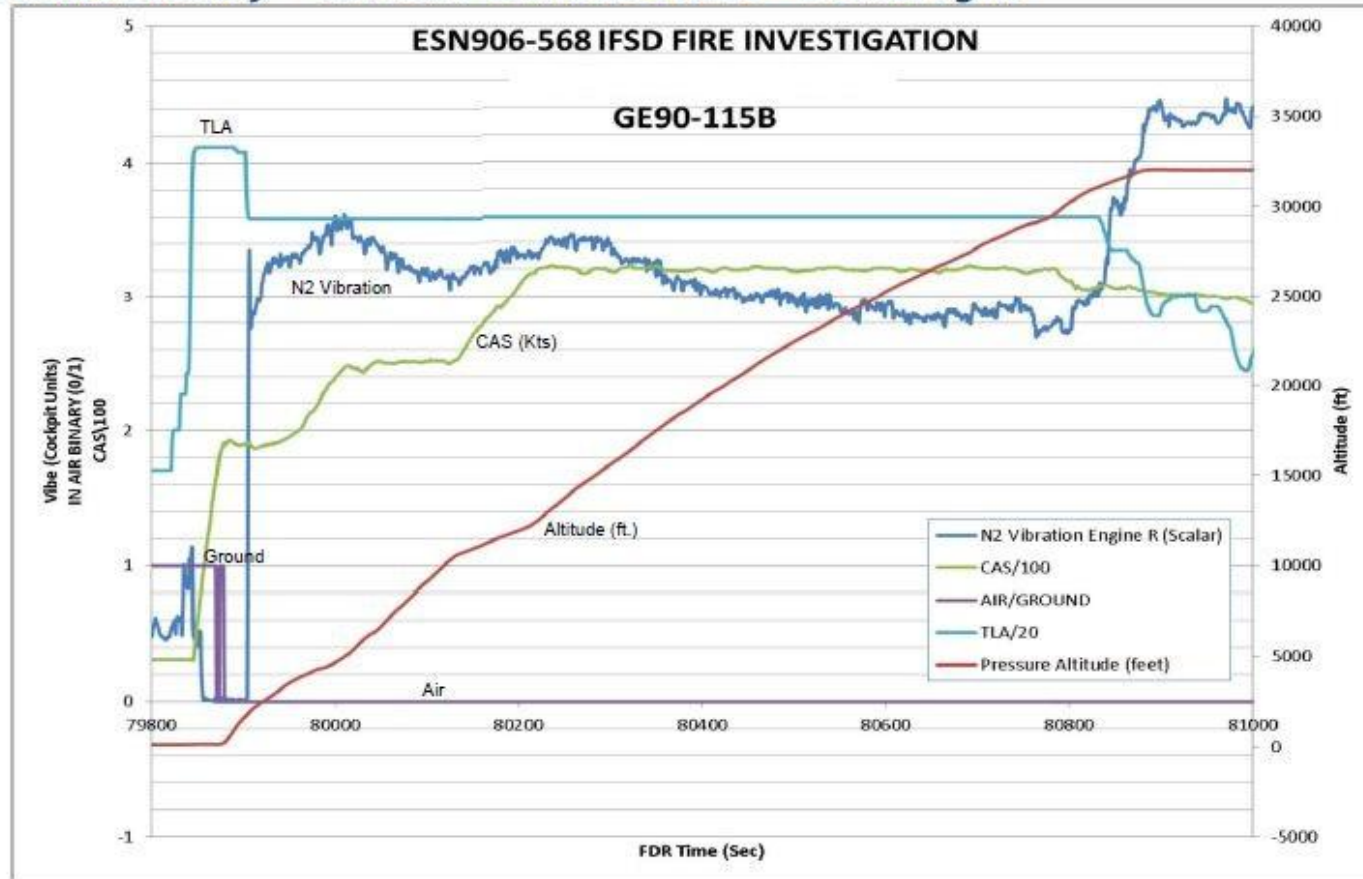
## QAR Data (NTSB Plots) - Entire Event Flight



Revised 16 January 2012

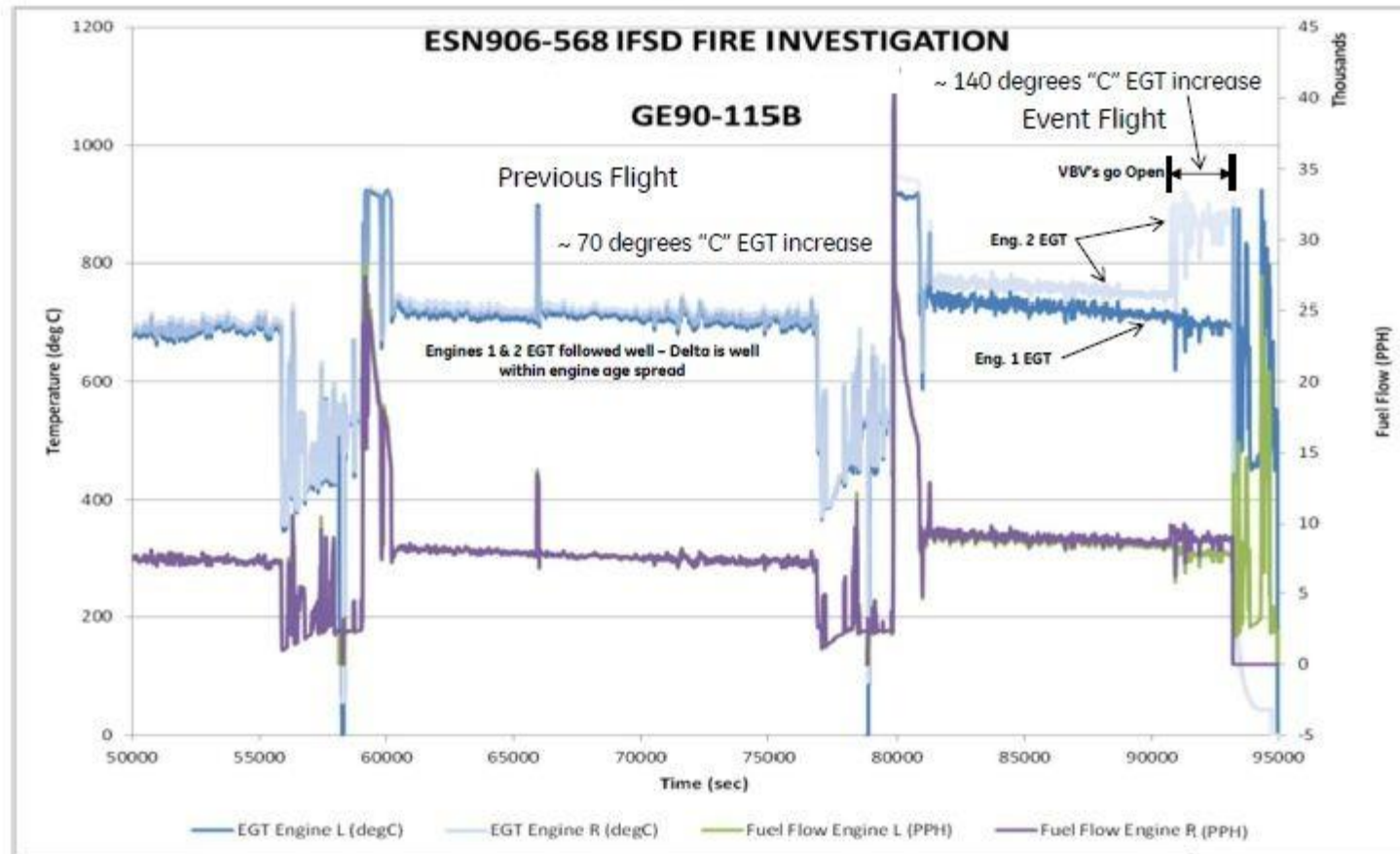
National Transportation Safety Board

**Factual  
Event Summary - Takeoff / Climb to Cruise - Event Flight**



*Factual*

### ESN 906-568 Last Two Flights





***Factual  
Flight Crew Statement***

- The flight was unremarkable to Top of Climb with the first officer as Pilot Flying
- Shortly thereafter the crew noted the right engine EGT 30 degrees "C" above the left engine
- Crew noted that the right engine vib was about 4.4 units N2 with all other parameters normal other than EGT
- A snap shot of the engine parameters were sent to MCC
- The engine page was left open to monitor with parameters remaining constant
- The engine parameters remained unchanged for about 3.5 hours at FL320
- An "Engine Control Right" status was noted with the right engine EGT +200 degrees "C", N2 +2%, and Fuel Flow +500 kg/left engine
- MCC advised that they had been monitoring the engine however could offer no advice other than to continue
- The crew then noted a fuel imbalance message and after discussion completed the "Fuel Imbalance" checklist
- Consideration was given to a possible fuel leak; however as one engine had a higher fuel consumption and sufficient fuel on-board the balancing would allow a base to time fuel burn / total
- **Following fuel balancing the right main fuel tank was noted to reduce and a fuel leak was then considered with a 2.0 tonne loss of fuel**
- **Before crew could action the fuel leak check list they noted 2 or 3 engine bangs, engine surge and an N1 spike with airframe vibration similar to turbulence followed by an EICAS "FIRE ENG R" activation**

*Factual*

*VBV Fuel Supply Tube P/N 2165M22P01 Experience*

- Total of eight (8) leaking VBV fuel supply tubes
  - 2 in 2009
  - 3 in 2011
  - 3 in 2012
- Location of tube damage was to the right hand “EXTEND” fuel supply tube of the VBV Actuator
  - Location 1
    - Crack and separation inside drain shroud at weld
    - 5 of the 8 (62%) were welds cracked inside the shroud drain which allowed the leaking fuel to pass through the drain mast
  - Location 2
    - Crack in tube bend, outside the drain shroud
    - 1 event
  - Location 3
    - Crack and separation at weld, outside drain shroud
    - 2 events
    - 3 of the 8 (38%) fuels leaks were outside the shroud drain system which allowed the leaking fuel under cowl
    - 1 of the 3 (33%) under cowl fuel leaks resulted in an under cowl fire



*Factual*

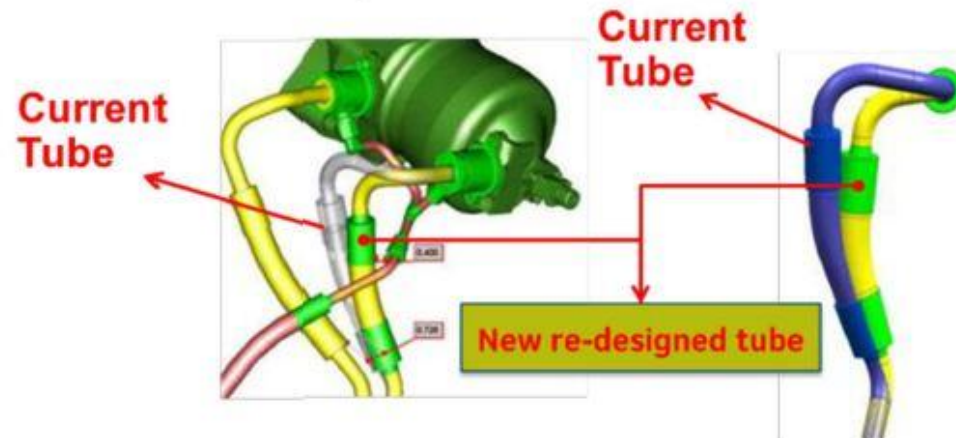
*VBV Fuel Supply Tube P/N 2165M22P01 Experience (Continued)*

- Vibration levels
  - 4 of the 8 (50%) events occurred with normal core (N2) vibration range of 1.4 to 2.5 cockpit units
  - Other 50% of events occurred at high core vibration levels from High Pressure Turbine distress
    - 3 of the 4 (75%) events were above 4.0 cockpit units (Turbine Distress)
    - 1 of the 4 (25%) were high vibration levels above 4.0 cockpit units and was leaking fuel outside of the shroud drain
- Aircraft effect
  - 4 of the 8 events (50%) were found by ground maintenance
  - Remaining 50% were found by the flight crew
    - 2 Fuel Imbalance
    - 2 High Core Vibrations
      - 1 of the 2 resulted in an under cowl fire

*Factual*

***VBV Fuel Supply Tube P/N 2165M22P01 Experience (Continued)***

*Root Cause and Corrective Action Summary*



- The root cause of observed cracks is a tube mode shape excitation within the engine cruise frequency range exacerbated by
  - High stress sensitivity of the welding at the tube end
  - High core vibration
  - Pre-existing condition on the inner surface of the tube end
- The tube was redesigned to move the mode-shape out of the cruise frequency range
  - The shortened hose results in stiffer tube end (higher frequency mode)
- New tube P/N 2483M12P01 was introduced by SB 73-0069 (Cat. 3) issued May 3, 2012
  - Next shop visit of the engine

## Analysis Engine 906-445 and 906-568

Event #	Date	Symptoms	Findings	Phase of Flight	Vibration Trend Data	Under Cowl Fire	ESN	Airline
1	June 2009	Fuel leak observed at engine drain mast VBV port, 72 drops per minute	Found tube crack along the <u>inner # 1</u> weld bead of the O-ring shroud	Post engine shutdown, drain mast leak on ground.	Trend pt. 1.43	No Fire	906-160	A
2	December 2009	Flight crew reported a fuel imbalance during flight. Maintenance noticed fuel leaking from LH Engine cowl overboard.	Found tube crack in the tube bend section – <u>Outside # 2</u> shroud drain	Fuel imbalance noticed during cruise. Leaking cowling on ground	Trend pt. 1.7	No Fire	906-804	D
3	January 2011	Flight crew reported high N2 vibration at climb & cruise [HPT Shroud] – VBV control lost after 2.5 hours – Some time later multiple stalls and fuel imbalance detected	Found tube separation at the <u>outer # 3</u> weld bead	High vibration during climb/cruise. VBV failure during cruise	Trend 4.4 & Event pt. 5.0+	No Fire	906-445	K
4	May 2011	Flight crew reported high N2 vibration [HPT Shroud] & excessive fuel burn. Airport Maintenance observed fuel leaking from drain mast on taxi-in	Found tube crack <u>inside # 1</u> the drain can at the weld bead	Squawk; excessive fuel burn. Taxi after landing drain leak	Trend pt. 3.73	No Fire	906-441	D
5	June 2011	Fuel leak observed at engine drain mast VBV port	Found tube crack along the <u>inner # 1</u> weld bead of the O-ring shroud	Engine off, leak on the ground	Trend pt. 1.8	No Fire	906-821	A2
6	July 2012	High N2 vibration at prior SV from HPTB impact. Post SV test cell fuel leak observed at drain mast	Found tube crack along the <u>inner # 1</u> weld bead of the O-ring shroud	Test Cell Engine Run	Trend pt. 4.2	No Fire	906-579	E
7	August 2012	Fuel leak observed at engine drain mast VBV port	Found tube crack along the <u>inner # 1</u> weld bead O-ring shroud	Taxi out, Aircraft return to gate, Drain mast leak	Trend pt. 2.55	No Fire	906-569	E
8	November 2012	Flight crew reported high N2 vibration at climb & cruise – Engine Fire Warning – VBV fault maintenance message	Found tube separation at the <u>outer # 3</u> weld bead	High vibration during climb / cruise. Tube & VBV failure during cruise	Event pt. 4.2 & peak 5.0	Fire	906-568	E



## ***Recommendations***

### ***VBV Fuel Supply Tube Re-Design***

#### ***Changes to Corrective Action Program***

- SB 73-0069 was originally issued May 3, 2012, Category 3 Compliance
  - Releases new VBV Fuel Supply Tube P/N 2483M12P01
- SB 73-0069 was revised (Revision 1) October 8, 2012
  - Revised Planning Information section, Material Information section and Accomplishment Instructions
- SB 73-0069 Revision 2 issued April 1, 2013
  - Raises compliance category from level 3 to level 2
    - SB to be accomplish within 24 months of the issue date of Revision 2
    - April 1, 2015
  - Tube vendor (Parker) to supply 600+ VBV Supply Tube assemblies / year
  - Current recommendation to operators is for new tube incorporation at shop visits, quick turns and heavy maintenance checks
  - Includes detailed on-wing accomplishment instructions
- SB 73-0069 Revision 3 issued September 24, 2013
  - Three fuel tube separations in 2013 resulting in fuel leakage via drain mast
    - Revises compliance end date to April 1, 2014
- FAA NPRM released July 25, 2013
  - Docket Number FAA-2013-0499
  - Closed date September 23, 2013

GE issued Service Bulletin 73-0069, on 03 May 2012, calling for the replacement of VBV actuator fuel supply tube, P/N 2165M22P01, at the next shop visit of the engine or module. The tube has experienced multiple instances of cracking at the weld due to a mode shape within the operating frequency range. New tube, P/N 2483M12P01 changes the radius of bends to increase stiffness and move the mode shape out of the operating frequency. The event engine was equipped with the pre-service bulletin configuration.

#### **Actions taken during course of investigation**

The VBV fuel supply tube design and its installation programme were changed. SB 73 – 0069 was originally issued on May 03<sup>rd</sup>, 2012 with category-3 compliance wherein the new VBV fuel supply tube was released. As per the first revision to the SB on Oct 08, 2012, the Planning Information Section, Material Information and Accomplishment Instructions were revised. In revision – 2, issued on April 01, 2013, the compliance category was raised from level 3 to level 2, with instruction that it is to be accomplished within 24 months of the issue of revision – 2. This revision also included recommendations that the new tube incorporation be accomplished during shop-visits, quick turns and heavy maintenance checks. Revision – 3 to the SB was issued on September 24, 2013 in view of three fuel tube separations in 2013 resulting in fuel leakage via drain mast.

#### **1.17 Organizational and management information:**

The aircraft was operated by a scheduled airline of the contracting State.

#### **1.18 Additional information: NIL**

#### **1.19 Useful or effective investigation techniques: NIL**

## **2. ANALYSIS**

### **2.1 Operations**

The crew held valid GCAA licences with proper valid endorsements and was qualified to undertake the flight. The crew followed appropriate procedures and took action as per the non-normal check-list after observing the abnormality in the fuel-flow. Advice of MCC was taken and followed. The weather was fine and has in no-way contributed to the incident.

During the period of concern, proper two-way communication was maintained between the aircraft and ATC. The ATC gave priority to the aircraft once emergency had been declared and proper assistance was provided for exigent landing. All the airport emergency services were deployed for catering fire or any other urgency.

The crew has not reported any abnormality with the aircraft operation except the above.

### **2.2 Maintenance**

The aircraft was maintained as per the GCAA requirements and no maintenance action was pending.

### **2.3 Damage to the core engine**

As per the report by “Commercial Flight Safety & Reliability, GE Aviation” the physical evidence/ damage indicates that **one likely scenario** is that the abnormal operating conditions during the last flight (P-9 of the above mentioned report) caused twelve consecutive aft inner rails to crack and move aft into the stage 1 HPT blades. This would create the conditions necessary to sustain a nickel-fire. The twelve rails would be of sufficient mass to confine the metal spray of the high speed mechanical rub inboard around the bolt cover causing them to burn then release the mass of molten material onto the leading edge root of the stage 1 HPT blades.

## **CONCLUSIONS:**

### **3.1 Findings:**

- The crew held valid GCAA licenses with proper valid endorsements and was qualified to undertake the flight.
- The aircraft was maintained as per the GCAA requirements and no maintenance action was pending.
- The crew followed appropriate procedures and took action as per the non-normal check-list after observing the abnormality in the fuel-flow.
- The weather was fine and has in no-way contributed to the incident.
- During the period of concern, proper two-way communication was maintained between the aircraft and ATC.
- The ATC gave priority to the aircraft once it had declared emergency and proper assistance was provided for landing. All the airport emergency services were deployed for catering fire or any other urgency.

### **The following is the sequence of events resulting in the incident:**

- 1) During take-off on incident flight N2 vibration increased due to HPT Distress/ Damage. (Stage 1 HPT Blade mid chord burnout). HPT deterioration was noticed.
- 2) As the airplane approached top of climb and commenced cruise, right engine N2 vibrations were steady at 4.4 units with higher EGT.
- 3) The right engine EGT was observed to be 30°C higher than the left engine EGT.
- 4) Flight continued at FL320 for 2.5 hours and crew monitored engine parameters.
- 5) Crew were alerted by an “Engine Control Right” status on Engine Indication and Crew Alerting System (EICAS) – Right engine EGT was observed to be 200 degrees C more than the left engine; N2 was 2% more than the left engine; and Fuel Flow was 500 kg higher than the left engine.
- 6) ‘ENG CONTROL R’ was the status message with a correlated Maintenance Message 75-14102. On the Fault Isolation Manual (FIM), this message translates into ‘VBV actuator R Eng CH A does not follow command.’
- 7) The VBV Fuel Supply Line had separated resulting in VBVs going to full open.

- 8) When VBVs went open, an additional EGT shift of approximately 140 °C was observed.
- 9) There was an associated increase in Fuel Flow due to the deterioration of core flow and HPT.
- 10) Stage 1 HPC blisk experienced blade tip rubs and liberation of blade leading edge material as a result of the high N2 vibration levels (4.4+)
- 11) Evidence of rubbing between stage 1 HPT nozzles and stage 1 HPT blade forward 'angel wing' was observed.
- 12) Indications of rubbed induced metal fire were noticed.
- 13) Normal Engine Operating performance (Core Operating Line) could not continue with the amount of HPT distress – Engine experienced 2 to 3 stalls (surges).
- 14) Engine experienced three stalls. This corroborated with the flight crew statements.
- 15) The first stall had occurred approximately 13 seconds prior to the fire warning.
- 16) Corresponding parameter oscillations in Fuel Flow, PS3, T25 and VSVs were noticed. T25 was observed rising.
- 17) Documentary evidence confirmed that no under cowl condition existed external to the engine, which could have ignited the leaking fuel.
- 18) When the core engine stalled, the stall front flame went forward through the HPC, passed the HPC IGVs and T25 sensor, following the path of least resistance and passed through the opened VBVs through to the VBV cavity. The flame passed through the "Locked Open" CCC valve into the under cowl area.
- 19) The CCC air exits through the piccolo tube near the right hand VSV actuator fuel actuation lines which were being sprayed with leaking fuel from the separated VBV fuel supply line which is located just below the VSV actuator fuel lines.
- 20) The under cowl vent air entrained with fuel was ignited from the stall front coming through the VBV cavity via the core cooling compartment valve piccolo tube located near the right hand side.
- 21) Thrust reverser over pressurization doors opened as a result of the surge front entering the under cowl cavity.
- 22) VSV actuator fuel lines fire sleeves were found with thermal damage (blistered).
- 23) The fire was very rich and sooty which left a soot trail following the under cowl vent flow lines moving aft and down to 6 o' clock position.




### 3.2 Probable cause of the incident

Separation of VBV actuator fuel supply line outside the 'shroud can' to the VBV actuator extend port was caused by high N<sub>2</sub> vibrations during flight resulting from damage to HPT.

### 4.0 SAFETY RECOMMENDATIONS

NIL

M/S GE have incorporated a Service Bulletin (SB) which replaces the subject line with an improved one, thereby precluding the possibility of fracture should there be elevated vibration levels whilst the engine is in service.

  
30/7/2015  
(R.S. Passi)

Chairman, Committee of Inquiry



(Sh. Anil Menon)

Member, Committee of Inquiry



(Capt. M. Ghadiyali)

Member, Committee of Inquiry

30.7.2015  
DELHI