This is to certify that this investigation report has been compiled as per the provisions of ICAO Annex 13 for all concerned.

The report has been authenticated with a view to ensuring prevention of aircraft accident and that the purpose of this activity is not to apportion blame or liability.

The AAIG-BD will reopen the investigation if new and significant evidence becomes available in future.

Contact:
Head of Aircraft Accident Investigation Group of Bangladesh
4th Floor, CAAB Headquarters, Kurmitola, Dhaka, Bangladesh
E-mail: Head.AAIG@caab.gov.bd

1. TITLE

1.1 Name of Operator	Biman Bangladesh Airlines
1.2 Name of Manufacturer	Boeing
1.3 Aircraft Model	Boeing 777 300ER
1.4 Aircraft Nationality	Bangladesh
1.5 Aircraft Registration Marks	S2-AFP
1.6 Place of Occurrence	Hazrat Shah Jalal International Airport, Dhaka, Bangladesh
1.7 Date of Occurrence	07 June 2016

2. SYNOPSIS

2.1 Notification of accident to national and foreign authorities	Notified to the following: a) CAA Bangladesh (State of Registry); b) NTSB, USA (State of Manufacturer); c) ICAO; d) Biman Bangladesh Airlines (Operator).
2.2 Accident investigation authority	Aircraft Accident Investigation Group of Bangladesh (AAIG-BD)
2.3 Accredited representation	None
2.4 Organization of the investigation	CAA Bangladesh
2.5 Authority releasing the report	AAIG-BD
2.6 Date of publication of report	07 June 2018
2.7 Brief résumé of the circumstances leading to the accident	a) Biman Bangladesh Airlines Ltd. is the National Flag carrier of Bangladesh. Its main base is located at Hazrat Shah Jalal International Airport (HSIA), Dhaka. All its engineering and operational establishments are also located here.

	b) On the day of the occurrence, the 07th June, 2016, Biman's Flight BG-049, bound for Dammam, Saudi Arabia was scheduled to operate at 1115 UTC, with Boeing 777-300ER aircraft, Reg. S2-AFP with 02 Cockpit Crew & 10 Cabin Crews with 241 Passengers. c) Take-off clearance was issued to the aircraft at 1143 UTC from Dhaka Control Tower and the take-off roll was started at 11:44:23 UTC. d) During take-off roll, just before reaching V1, as per crew statement, at approximately 150 kt, "ENGINE FAIL" warning came on the PFD along with 'Master & "Aural Warning". e) As per let down procedure in the SOP, the crew initiated take-off abort action at an indicated air speed (IAS) of 149 kt at 11:44:54 UTC f) The aircraft came to a stop on the runway. g) After stopping the aircraft on the RWY crew communicated with the ATC Tower and informed about the aborted take-off. h) Tower instructed to vacate the RWY and taxi back via taxiway. i) During taxi back crew asked permission to stop on High Speed taxiway. Tower permitted and wanted to know what the problem was. Crew informed that they had "ENGINE PROBLEM". Tower instructed them to change over to Ground Control. j) Then the aircraft taxied back and the Engines were shut down approximately at 12:05 UTC. k) Ground Engineers checked the cockpit parameters for any abnormal indications. They found no abnormalities except "ENGINE FAIL RIGHT" in the Engine Maintenance Page. Visual inspection of the right engine revealed that the rear part of the engine turbine section was severely damaged. l) During Runway Inspection many FODs in the form of metallic pieces were found scattered on the RW. m) Collected debris was of granular sizes of few millimeters in diameter and up to 5-6 inches in length and up to 2 inches in width. Number of pieces could be to the extent of few hundreds and the overall weight of the received debris were 13. 56 kg.

3 BODY

3.1 FACTUAL INFORMATION

3.1.1 History of the flight:

3.1.1.1 Flight number	BG-049
3.1.1.2 Type of operation	Commercial Passenger operation
3.1.1.3 Last point of departure	Hazrat Shah Jalal International Airport, Dhaka, Bangladesh
3.1.1.4 Time of departure (local time or UTC)	1115 UTC
3.1.1.5 Point of intended landing	Dammam International Airport, Saudi Arabia
3.1.1.6 Description of the flight and events leading to the accident	Take off from Dhaka. Right Engine Fail Indication resulted rejected take off.
3.1.1.7 Reconstruction of the significant portion of the flight path	On the Runway
3.1.1.8 Location (latitude, longitude, elevation),	N23 50.6 E090 23.9; Elevation: 27 Feet
3.1.1.9 Time of the accident (local time or UTC),	11:44:54 UTC
3.1.1.10 Whether day or night.	Day

3.1.2 Injuries to persons:

Injuries	Crew	Passenger	Others
3.1.2.1 Fatal	None	None	None
3.1.2.2 Serious	None	None	None
3.1.2.3 Minor/None	None	None	None

3.1.3 Damage to aircraft (Brief description)

3.1.3.1 Destroyed	No
3.1.3.2 Substantially damaged	Yes to Right Engine only
3.1.3.3 Slightly damaged	No
3.1.3.4 No damage	No
3.1.3.5 Other damage	None

3.1.4 Personnel information

3.1.4.1 Pertinent information concerning each of the flight crew members regarding age, validity of licences, ratings, mandatory checks, flying experience (total and on type) and relevant information on duty time	Pilot in Command: a) Age: 60 years; ATPL: Valid; b) Ratings: Current on B-777 300ER; c) Mandatary Checks: Done; d) Flying Experience (Total): 23, 512.00 Hrs; e) Flying Experience (On type): 3, 637.00 Hrs; f) Duty time: Rested more than 24 hours.

	Co Pilot: a) Age: 38 years; CPL: Valid; b) Ratings: Current on B-777 300ER; c) Mandatary Checks: Done; d) Flying Experience (Total): 6, 951.00 Hrs; e) Flying Experience (On type): 1, 869.00 Hrs; f) Duty time: Rested more than 24 hours.
3.1.4.2 Brief statement of qualifications and experience of other crew members	Not applicable
3.1.4.3 Pertinent information regarding other personnel, such as air traffic services, maintenance, etc., when relevant.	Not relevant

3.1.5 Aircraft information

3.1.5.1 Brief statement on airworthiness and maintenance of the aircraft (indication of deficiencies known prior to and during the flight to be included, if having any bearing on the accident)	Aircraft was airworthy; No deficiency was detected prior to release.
3.1.5.2 Brief statement on performance, if relevant, and whether the mass and centre of gravity were within the prescribed limits during the phase of operation related to the accident. (If not and if of any bearing on the accident give details.)	a) Performance status: Satisfactory; b) Mass & Centre of gravity: Within limit;
3.1.5.3 Type of fuel used.	JET A-1

3.1.6 Meteorological information

3.1.6.1 Brief statement on the meteorological conditions appropriate to the circumstances including both forecast and actual conditions, and the availability of meteorological information to the crew.	a) Meteorological condition (Actual): Surface Wind Calm, Temp: 26, QNH: 1003, Present Wx: Light Rain; b) Meteorological condition (TAF): Rain & Thunderstorm.
3.1.6.2 Natural light conditions at the time of the accident (sunlight, moonlight, twilight, etc.)	Sunlight (Cloudy)

3.1.7 Aids to navigation

3.1.7.1 Pertinent information on navigation aids available, including landing aids such as ILS,	Not relevant

MLS, NDB, PAR, VOR, visual ground aids, etc., and their effectiveness at the time.	

3.1.8 Communications.

3.1.8.1 Pertinent information on aeronautical mobile and fixed service communications and their effectiveness.	Not relevant

3.1.9 Aerodrome information

3.1.9.1 Pertinent information associated with the aerodrome, its facilities and condition, or with the take-off or landing area if other than an aerodrome.	a) Runway Surface – Hard Bitumen; Runway Direction – 14 and 32; b) Length: 10500 ft plus stop-way RW14: 902 ft, RW 32: 476 ft; Width: 148 ft with exit marking at both ends; c) RWY Surface Condition during Incident: Wet to Damp.

3.1.10 Flight recorders.

3.1.10.1 Location of the flight recorder installations in the aircraft, their condition on recovery and pertinent data available therefrom.	a) Location in the aircraft: Tail area; b) Condition: Intact; c) Data: Available.

3.1.11 Wreckage and impact information

3.1.11.1 General information on the site of the accident and the distribution pattern of the wreckage, detected material failures or component malfunctions. Details concerning the location and state of the different pieces of the wreckage are not normally required unless it is necessary to indicate a break-up of the aircraft prior to impact. Diagrams, charts and photographs may be included in this section or attached in the appendices.	a) Occurrence Site: On the Runway; b) Wreckage: Not relevant; c) Component Failure: Right Engine; d) Material failure: Inside Right Engine; e) Debris: Collected debris was of granular sizes of few millimeters in diameter and up to 5-6 inches in length and up to 2 inches in width. Number of pieces could be to the extent of few hundreds and the overall weight of the received debris was 13. 56 kg.

3.1.12 Medical and pathological information

3.1.12.1 Brief description of the results of the investigation undertaken and pertinent data available therefrom.	Not relevant

3.1.13 Fire

3.1.13.1 If fire occurred, information on the nature of the occurrence, and of the firefighting equipment used and its effectiveness.	Not relevant

3.1.14 Survival aspects

3.1.14.1 Brief description of search, evacuation and rescue, location of crew and passengers in relation to injuries sustained, and failure of structures such as seats and seat-belt attachments.	Not relevant

3.1.15 Tests and research

3.1.15.1 Brief statements regarding the results of tests and research.	a) Fuel: Fuel sample was taken from Fuel Filter Bowl which was tested by INTERTEK in UK and all test parameters were found within limit. The detail fuel test report is attached herewith. b) Affected Engine: Starboard Engine

3.1.16 Organizational and management information

3.1.16.1 Pertinent information concerning the organizations and their management involved in influencing the operation of the aircraft. The organizations include, for example: the operator; the air traffic services; airway, aerodrome and weather service agencies; and the regulatory authority. The information could include, but not be limited to, organizational structure and functions, resources, economic status, management policies and practices, and regulatory framework.	a) Operator: Biman Bangladesh Airlines is the national flag carrier of Bangladesh, established in January 1972. It started its operations as a Government enterprise, changed into a public limited company in 2007. Yet, Biman remained fully under the Government control. All key position appointments and major decision makings are made by the support of the Government. Since its inception, Biman had operated different types of aircraft including F-27, B-707, F-28, ATP, DC-10, AB-310, B-737 and B-777. And B-787 is under order due to be delivered from 2018. Biman has a world class Hangar in its main base at HSIA, which can house two large sizes wide bodied and two medium size wide bodied aircraft at a time. The Hangar is equipped with facilities which can perform basic maintenance of aircraft. It lacks expertise and equipment to do any major maintenance work, hence needs to depend on others assistances for major works.

	b) Air Traffic Control Services: Not relevant; c) Airway: Not relevant; d) Aerodrome services: Not relevant; e) Weather Services: Not relevant; f) Regulatory Authority: Not relevant;

3.1.17 Additional information

3.1.18.1 Relevant information not already included in 3.1.1 to 3.1.18.	Aerodrome Fire Fighting (AFF) section is equipped with multi-frequency radio set. As per set procedures, the AFF monitors Ground Frequency only. AFF does not monitor Tower Frequency, thus remains dependent on other communication system for any vital traffic movements. Also, the AFF vehicles do not possess any discrete frequency to be able to directly communicate with the aircraft in time of necessity.

3.1.19 Useful or effective investigation techniques

3.1.19.1 When useful or effective investigation techniques have been used during the investigation, briefly indicate the reason for using these techniques and refer here to the main features as well as describing the results under the appropriate subheadings 3.1.1 to 3.1.19.	Investigation has been carried out, as far as possible, following the ICAO Annex 13, associated Docs 9756 Part I, II and III generally. Part IV has been used meticulously as much as practicable to develop the final report. Human factor Doc 9683 has also been used for the analysis purposes. Few other documents have also been consulted.

4. ANALYSIS

[Analyzed below, as appropriate, has been made with the information documented in 'Factual information' and which is relevant to the 'Determination of conclusions' and 'Causes and/or contributing factors']

4.1 Bore-scope Inspection (BSI):

a) The initial post event inspection revealed that the N2-rotor system was freely rotating, whereas the rotation of the N1-rotor system was restricted to about 120 degrees and resulted in "metallic sounds". Hence, limited bore-scope inspection (BSI) of the LPT was carried out which detected severe airfoil damage beginning from the stage 4 rotor and affecting the ensuing stages. Of the all the engine's magnetic chip detectors (MCD), the one related to the B-sump only was found to be loaded with catch, being metallic burrs (Rough edge on material such as metal after it has been cut or drilled).

b) The propulsion was inducted and set up in the MTU-H shop for the incoming inspection. During this in coming inspection, a BSI was performed excluding the LPT. The low pressure compressor (LPC), high pressure compressor (HPC) and HPT did not reveal any unusual findings.

c) A continued BSI revealed severe LPT stage 3 and 4 airfoil failures, yet no obvious damage within the HPT and HPC module. The presence of an LPT stage 1 rotor seal verified.

4.2 Visual Inspection:

a) No findings were apparent on the fan rotor, the fan case and its abradable shroud.

b) However, at MTU, during the removal of the EGT probes, to get access to the turbine center frame (TCF) for bore-scope inspection, it was found that the sensors of the EGT probes # 4 and # 5 (located at about 5 o'clock) were burned, probe # 4 being more affected than probe # 5. It may be mentioned that according to the L.05138 shop visit records in Dec' 2015, both probes were installed in new condition at that time. The insulation test, circuit resistance test and polarity test were performed at probes # 4, # 5 and # 7 i.a.w. Component Maintenance Manual (CMM) 77-21-40. Only probe # 4 failed all three tests, the two others passed all tests. Except the visual heat damage on probe #5, other 6 EGT probes did not show any unusual finding. The continued BSI revealed that LPT stage 1 stator showed significant damage to the airfoils via EGT probe port # 4 and # 5 in about 5 o'clock position. The airfoils in that area were molten with their center section partially missing. The remaining LPT stage 1 vanes did not show any abnormality.

c) The general visual incoming inspection of the propulsor's external at MTU showed a heat discoloration on the LPT active clearance control (ACC) manifold in about 5 to 6 o'clock position. Furthermore several bulges were detected on the complete circumference of the LPT case. The primary nozzle and forward center body were provided with the propulsor. Their visual inspection revealed minor delamination in different areas on the circumference of the primary nozzles rear edge and a major dent on the forward center body in about 6 o'clock position.

4.3 Engine and Module Disassembly (in Presence of Joint Investigation Team)

a) The disassembly of the propulsor was subsequently initiated on July 26th 2016 in the presence of the joint investigation team. The inspection of the external propulsor hardware did not show any abnormal condition deviating from the OEM buildup requirements. All tubing of the air, oil and fuel systems were found in place and in conformity with the OEM assembly requirements. There were no indications on the propulsor's external hardware appeared causative for the internal damage.

4.4 LPT Module

Note: The LPT module was handled on minimum work-scope level per the applicable GE work-scope planning guide (WPG) during the L.05138 shop visit, only the stage 6 blades had been replaced i.a.w. with SB72-0616 and release certificate was issued on 14 Dec' 2015.

(a) LPT as first module was removed from the propulsor. The view on the LPT's forward split line revealed no obvious damage on the stage 1 rotor beside a light contamination with dust like deposits. Still the view through the stage 1 blades on the stage 2 stator revealed a sector of discolored and obviously damaged vanes within the engine's 5 o'clock position. In addition, a major amount of apparently airfoil debris was found within the hub of the forward seal support.

(b) After removal of the LP mid shaft and the LPT ACC manifolds an almost uniform discoloration of the LPT case was visible. Beside several bulges, an outward directed puncture of the case in the engine's 9 o'clock position, at the axial position of the LPT stage 3 rotor was detected. The LPT ACC manifolds within the engine's 4, 5 and 6 o'clock position featured a distinct blue to purple heat discoloration, which was not apparent on the other manifold segments.

(c) The turbine rear frame (TRF) was removed from the LPT module, and it was confirmed that all of its flow path surfaces were covered with multiple impact indentations, and several skin punctures were visible on the convex side of the struts, near the outward end of their leading edges.

(d) The exposed LPT stage 6 rotor featured the systematic liberation of its outer airfoil segments and platforms, the remaining airfoils featured excessive mechanical damage on their leading and trailing edges. Similar systematic damage to the edges of the stage 5 and 6 stator vanes were also detected, equally around the stator's perimeter.

(Point may be noted that stage 6 blades were replaced at MTU and declared serviceable on 14 Dec' 201 5).

(e) All stage 4 rotor blades had liberated shortly outward of their root platforms, apparently resulting in systematic trailing edge damage on the stage 4 vane airfoils, although not so pronounced as for the two most rearward stages. In contrast the 5 o'clock sector of this stator showed a singular discolored, apparently heat affected appearance, with several axial vane airfoil separation. An area of the trail vane of segment # 10 and of the lead vane of segment # 11 had liberated, thus forming a coherent hole in the stator. A closer view on the affected segments after their disassembly from the module confirmed their bluish-green discoloration and deformation and especially the appearance of the airfoil remains were typical for a thermal damage.

(f) Also the stage 3 stator featured a distinct discolored and thermally damaged area within its 5 o'clock position, in this case the lead and trail vane of a singular segment (# 13) had failed. The coating on the convex airfoil surrounding this damage appeared blistered, whereas the coating on the concave airfoil surfaces had apparently been greenish discolored, partly stripped from the airfoils and subsequently deposited on the leading edges.

(g) After its exposure the stage 2 rotor was found affected by random smaller airfoil impact damage, yet on a consecutive segment of about 60 degrees its airfoils had liberated near their outer platforms.

(h) Also the stage 2 stator featured the singular thermally damaged area in its 5 o'clock position, in this case all three airfoils of two adjacent segments (#18 and #19) had been removed, together with the lead vane of segment #10. As a consequence the inner platforms of these segments had been liberated, one of those was still present at that location, and the other one was missing. The removed segments showed again the discolored and thermally affected appearance.

(i) Similar to its forward side, the aft side of the stage 1 rotor showed an almost unharmed appearance, yet a systematical damage was apparent on the trailing edges, close to the outer platforms. Subsequent inspection of the slot bottom clearance between the LPT stage 1 blade dovetails and the disk revealed values well below the maximum acceptable limit of 1. 27 mm.

(j) So in summary conclusion the LPT module showed a thermal damage affecting its stage 2 to 4 stators locally within its 5 o'clock position, lessening from front to aft, and a mechanical damage starting from its stage 2 rotor and increasing from front to aft.

4.5 Fuel Nozzles Removal and Visual Inspection

(a) All nozzles got an initial visual inspection and the condition of the outer and inner spray tips were documented. Special attention was given on the nozzles # 11 through # 16 that were located in about 5 o'clock position, where major LPT damage had occurred. The nozzles were in a good condition compatible with the short time of operation of the engine (213 cycles), i.e. no severe coking or leakage of any kind was visible. No noticeable visual differences were apparent during the comparison of all fuel nozzles. Almost all fuel nozzles shown slightly discoloration on their tip surfaces, which appeared like fuel deposits. The complete set of the fuel nozzles were sent to OEM-Parker Aerospace for further investigation (see para. "4.10: Investigation of Fuel Spray Nozzles at Parker-Glendale, August 9th to 12th 201) of this report).

(b) All the four segments of the fuel manifolds and the two fuel tube hoses connecting the hydro-mechanical unit with the fuel manifolds were visually and by bore-scope inspected, but no defects or contamination could be established.

(c) The main fuel oil heat exchanger (MFOHE) was removed from the engine.

4.6 TCF Module

Note: The TCF module had been handled on minimum work scope level during the L.05138 shop visit, the modification i.a.w. with SB72-047620 had been accomplished.

(a) The view on the aft split line of the TCF confirmed the findings of the BSI conducted through the EGT probe ports. Only within a sector near the engines 5 o'clock position a thermal damage of the LPT stage 1 vanes could be established, affecting segment #16 to #18, whereas the vanes appeared normal around the remaining perimeter . A closer view revealed that in total seven airfoils had been separated, mostly the vanes inner half had been removed, and the trailing edge was more affected than the leading edge. Within the TCF hub multiple airfoil fragments could be detected, this finding matching the findings within the LPT forward seal support.

(b) The TCF's external cooling air tubes were removed, none of them featured a sign of blockage, and their check valves were all freely moveable. Also within the TCF's cooling cavity no contamination or blocking could be detected by BSI.

(c) The view on the forward split line of the TCF revealed a distinct discoloration of the 5 o'clock, i.e. the #6 strut fairing and the adjacent inner and outer flow path panels. It appeared that the hot spot of this discoloration was in the 158 degrees engine position and in line with the center of the damage of the LPT stage 1 vane airfoils. The outer flow path panel featured a bulge in the position of its hot spot.

(d) After removal of the external tubing a discoloration of the TCF case to pink color was observed, matching the position of the internal hot spot. The LPT stage 1 vane segments were removed, their heat affected appearance resembling the condition of the aft stages 2 to 4. All three airfoils of the segment #17, being in the center of the damage, were separated. The damaged area was in the middle of the two EGT probes # 4 and # 5, the airfoil aft of probe #4 (belonging to segment # 15) was lightly discolored only, whereas the airfoil aft of probe #5 (segment #18) was more degraded with an open leading edge.

Note: All LPT stage 1 vane segments had been inspected serviceable and re- installed during the L.05138 shop visit.

(e) The outboard surface of the outer platform of the most affected vane segment #17 appeared faultless, the inlets and outlets for cooling air flow appeared intact and unblocked. Also the partially exposed cooling air inserts within the airfoil remains appeared intact, their cooling holes still open and permeable.

(f) Subsequently it was agreed with the operator to send the TCF module to the OEM for evaluation of its reparability. Although all dimensional inspection were satisfactory within serviceable limits, GE reported several bulges and discoloration in the skin of the TCF case, most affecting the area at the #6 strut. Bulges were also detected on the # 6 strut fairing and the adjacent outer panels. As a result GE declared the TCF case and the mentioned fairing and panels as unserviceable and un-repairable.

4.7 HPT Module

(a) The view from aft on the HPT module revealed an unremarkable condition of the HPT stage 2 rotor, whereas a distinct heat discoloration of the HPT aft seal was apparent. A closer view on the stage 2 shrouds in the 5 o'clock position revealed light grey discoloration, unique to this area. In addition the intermittent edges of the two affected shrouds appeared heat degraded as well.

(b) After removal of the stage 2 blades a light discoloration of two adjacent HPT stage 2 vane airfoils within the 5 o'clock position (segment #9 trail vane and #10 lead vane) was visible, this being directly in front of the affected stage 2 shrouds. After removal of the HPT module from the combustor/diffuser/nozzle assembly, it was apparent that these two segments only featured a partial release of their leading edge thermal barrier coating (TBC). Because of this finding the two affected vane segments were subsequently declared un-repairable. In addition both segments featured a beginning cracking of their inner platform braze joints and a thermal degradation at the circumferential edges between each other.

Note: All HPT stage 2 vane segments had been installed as new during the L 05138 shop visit.

(c) The inspection of the HPT rotor blades detected rub damage, on the forward seal lips of the stage 2 blades, and on the tips of the stage 1 blades. For both stages two each blades with two tip notches were detected. Several blades of the stage 1 featured in addition a partial TBC loss on their leading edge, this finding was apparently randomly distributed on the rotor. The inspection of the cooling air supply to the HPT case and stage 2 stator, especially the condition of the case's flapper valves, revealed no findings.

Note: All HPT stage 1 blades had been installed as new, the stage 2 blades in overhauled condition during the L.05138 shop visit.

4.8 Combustor – Diffuser - Nozzle Module

(a) The view on the aft split line of the combustor-diffuser-nozzle module (CDN) revealed a uniform and unremarkable appearance of the HPT stage 1 stator vanes, in contrast to the stage 2 stator. No anomalies could be detected around the engine's 5 o'clock position. After the removal of the HPT stage 1 stator the inspection of the leading edges and the concave airfoils resulted in the same finding, only a beginning of darkening of the leading edge coating could be detected. The inspection of the airfoil cooling holes and the outer platform baffles revealed no blockage or contamination.

Note: All HPT stage 1 vanes had been overhauled during the L.05138 shop visit.

(b) Also the review of the combustion chamber revealed no significant findings. A systematic uniform soot pattern was apparent around all flare cones of the inboard and outboard fuel spray nozzle positions. Also the soot patterns on the outer liner surface appeared homogeneous around the whole perimeter.

Note: The combustor dome and outer liner had been installed in overhauled condition, the inner liner as new during the L.05138 shop visit, so all visible soot patterns originated from the recent operation on S2-AFP.

(c) Singular flare cones featured a beginning of thermal degradation of their outer diameter, and some venturi showed a limited amount of coking. Minor braze residues could be found on flare cone witness holes, yet these findings were all randomly distributed and not associated with an anomalous soot pattern.

(d) Also the inspection of the forward side of the combustion chamber after its removal from the diffuser case did not feature any significant findings; all ferrules (Protective caps) appeared undamaged and moveable within their retainers. The review of the combustor's outer skin revealed no findings such as cracking, thermal degradation or blocking of dilution holes. After disassembly of the combustor, its dome and in particular the primary and secondary swirlers were inspected, but again no significant anomaly could be established.

(e) The inspection of the diffuser case's front and aft side displayed no unusual condition. This included the undamaged conditions of the HPC outlet guide vanes, the HPC W-seal and leaf seal segments.

(f) Finally the inspection of the HPC module's aft split line remained without significant findings.

4.9 Investigation of Fuel Spray Nozzles at Parker-Glendale, (August 9th to 12th 2016)

a) All fuel nozzles were sent to Parker-Glendale and unpacked in presence of all participants of the investigation. In accordance with the investigation work-scope from AA Tech-Clyde, the fuel nozzles were visually inspected under a stereoscope with a varying magnification. This examination was performed without knowledge of the nozzles location during engine operation to ensure an objective evaluation. The detailed findings are listed in a report of Parker-Glendale. The general appearance of the nozzles did not show obvious signs of distress, heat influence or other obvious findings.

b) A few of the nozzles were found with tiny white (as referred in 4.9.C) residues (as described in 4.9.C) in their inlets which were sampled. Furthermore very small particles were taken from a few nozzles on different locations, i.e. the inner tip air gap, outer tip, inner orifice, secondary orifice and or the inner tip boat tail. The samples were collected in corresponding containers and they were sent to an independent lab (IMR Test Labs) for evaluation. All detailed results can be found in the IMR Test Labs report.

c) It was established that not all samples taken were adequate in size for an evaluation. Those samples taken from the inlets of the nozzles (white residues) appeared not to have identifiable particles in the sample containers and therefore were not analyzed. The other samples, mostly the ones from the inner tip air gap (taken from nozzle #1, #9 and #17) and a sample from nozzle #8 (taken at the location of the secondary orifice), as well as a sample from nozzle #25 (taken from the inner tip boat tail) were of brownish, white and dark colors. Those samples were inspected in the scanning electron microscope (SEM) and the electron dispersive x-ray spectroscopy (EDS) results indicated that the majority of the debris showed a higher amount of sodium (Na), sulfur (S) and oxygen (O), yet carbon (C) and calcium (Ca) were also present. Furthermore small amounts of additional elements such as iron (Fe), potassium (K), nickel (Ni), copper(Cu), cobalt (Co), chromium (Cr), manganese (Mn), silicon (Si), magnesium (Mg) and aluminum (Al) were also detected. The spectra of the following Fourier transform infrared spectroscopy (FTIR) on those samples confirmed the EDS results by revealing that most of the debris contained sodium sulfate. The differences between the individual spectra could be due to the additional elements, which indicated iron sulfate.

d) Following the investigation work-scope all fuel nozzles were subsequently x- rayed. Those x-ray images were reviewed for any significant forms of distress, unusual visual conditions, obvious contaminates and any valve(s) stuck in an abnormal position. All valves were located in their correct position, none of the flow passes were damaged or broken and no foreign material was detected.

e) For the following positional gaging inspection the flanges of the fuel nozzles were mounted onto the mounting surface of the fixture. The position gages were then pushed over the inlet or manifold connector, the outer tip and the inner tip to check the conformance. The orientation and position of all nozzles regarding the inlet, outer and inner tip were without any findings. The measured depth of all three features was without findings on 29 nozzles; only the inner tip depth of nozzle #23 was slightly longer than the tolerance allowed.

f) After visual and dimensional inspection of the flow test of all fuel nozzles was performed with a few deviations from the CMM procedure. The typical cycling prior to the flow test was omitted as recommended in the CMM task 73-11-49-810-843-A01 and by the investigation work-scope in order not to change the condition of the fuel nozzles after the event and not to dislodge any possible contamination inside the nozzles.

g) In addition, the maximum pressure of the flow test was limited to 360 psig because the data of the event engine during take-off showed that the highest total fuel flow was 25.856 pph. Dividing that value by 30 each fuel nozzles it could be determined that the highest fuel flow per nozzle had been about 862 pph.

The fuel flow from about 980 pph to 1105 pph (even higher than the fuel flow during the event) corresponds to about 360 psig. Furthermore the 550 psig point is only representative of an extreme max power (red line) fuel flow rate. Since testing at this high pressure had the risk of removing potential contamination within the valves, therefore it was decided to exclude the 550 psig point during the flow test.

h) The work-scope specification to flow into a filter paper to catch any foreign material during the flow test could not be implemented and therefore, the test fluid was caught in buckets, from which samples were taken and sent for evaluation to an independent lab. At the time of the release of this report no results of these evaluations have been returned to MTU-H. However, this method required to cover the fuel nozzle tips with tubes, which made it impossible to measure the spray angle and quality.

i) The fuel nozzles were mounted on a fixture in the manual test stand and before the production testing was done, the pressure was set to 5 – 10 psig to verify the check valve function of the fuel nozzles. Subsequently the flow test was continued as described in the CMM. The nozzles were manually flowed and the total flow was documented at different pressure values. In addition the total flow was documented during increasing and decreasing pressure at 165 psig. The difference between the two total flow values at the 165 psig pressure point is defined as the value of hysteresis.

j) Analyzing the results, it was noticed that 2 nozzles (# 15 and # 18) showed total flow values that were out of limit at 165 psig and 1 nozzle (# 16) with an out of limit value at 360 psig. Furthermore, 4 nozzles were out of the ±15 pph limit regarding the hysteresis value: #8 20.2; # 14 15.3; # 18 42.0; # 23 15.5.

k) As mentioned above, with the tubes covering the nozzles tips the fuel spray angle and quality could not be tested, therefore the flow test had to be repeated to record those values. This time the set of fuel nozzles was divided into two halves: One half included the nozzles that were located opposite of the area of the LPT damage (nozzle # 1 – # 4 and # 20 – # 30), which were also tested at 550 psig during this second flow test to meet the CMM standard. The other half included the nozzles that were located in the area of the LPT damage (nozzle # 5 – # 19). Reviewing the documented results, only one total flow value was detected out of limit (nozzle # 18 at 165 psig). Again 4 nozzles were out of the ±15 pph limit regarding the hysteresis value: # 6 26.6; # 11 30.3; # 14 20.5; # 18 64.9.

l) After the second flow test it was noticed that not only the magnitude of the values changed in both directions from flow test 1 to flow test 2, but also the nozzles themselves that were out of limit. The spray quality was considered as slightly streaky on several nozzles during the testing as to be expected and commonly observed on fielded fuel nozzles. All x-ray images and more detailed data regarding the flow tests can be found in the report from Parker- Glendale.

m) Finding of shifting hysteresis values during the flow tests prompted the investigation of the valves inside the nozzles with suspicion of contamination. To gauge their condition 4 representative nozzles # 1, # 2, # 19 and # 20, located distant from the area of the LPT damage, were selected, called “group A”. Those 4 nozzles were connected to the four different manifolds. The nozzles # 1 and # 2 were located in 12 o’clock position and nozzle # 19 and # 20 were located nearest 6 o’clock, but without being within the nozzles that were defined as in the area of LPT damage. These nozzles could provide visual standards for differences due to their position on the engine, e.g. potential evidence that the nozzles on the top experienced more heat than the nozzles on the bottom or signs of contamination.

4.10 Investigation at AA Tech-Clyde, NY (Sept 12th to Sept 15th 2016)

Note: History of the last shop visit at Parker-Glendale of all subject fuel nozzles: The fuel nozzles were numbered, looking forward from aft, clockwise and then removed. Out of total 30 fuel nozzles 28 were of P/N 6000290E 02 and 2 fuel nozzles (located adjacent to the igniter plug positions) of P/N 6000290E 01. These fuel nozzle set originated from 5 different engines. Four of these engines were operated by MTU customers including this event engine 907-021 and only one fuel nozzle came from a non-MTU customer engine (i.e. nozzle #18 in the engine's 7 o'clock position). All engines and their corresponding fuel nozzles showed different times of operation. Inner and the outer sleeves of all nozzles and in addition valves of 4 nozzles were replaced by Parker Aerospace in accordance with the CMM 7311-49 before reinstallation on engine 907-021.Engine sets of nozzles with different operational hours is common and all nozzles were certified before being returned to field use.

a) Subsequently, these four nozzles were cut open and the valves as well as the strainers were sent to AA Tech-Clyde for disassembly and investigation. Once received, the S/Ns of the nozzles and valves as well as the S/Ns of the sleeves and spools were checked for matching parts. The visual inspection of the strainers revealed the presence of a few residues. The valves were then disassembled from their rear side not to destroy any traces of any possible contamination in the following sequence: removed the retaining ring - removed spring seat - removed shim - removed spring - collected remaining fuel in a container for further evaluation - removed the front retaining ring - removed the valve seat - removed the front shim - removed the spool.

b) During this disassembly it was noticed that the spools of all 4 valves did not slide out of the sleeves by gravity as they generally do. They were able to move a short distance only, but then got stopped somehow and had to be pushed or pulled out of the sleeves.

c) The shiny inner diameter surface of all sleeves showed several dull circumferential lines on different axial distances in a varying degree. The outer diameter surface of all spools appeared dull on several areas in different degrees and especially on the grooves' edges smeared particles were detected. One area of each spool showed a circle like dull appearance on the large undercut of the spool. Inspecting those areas under the stereoscope they appeared like sand paper. The re- inspection of the components after drying revealed that the mentioned dull contaminations had become even more distinct. The residues on the strainer, sleeves and spools were analyzed in the independent IMR Test Labs and their results were compiled in a report[25]. The IMR report stated that almost all residues had the same optical coloration, i.e. translucent amber color during the inspection under a stereoscope. In addition they mostly had the same shape, i.e. small bead-like or spherical particles, except where they had been smeared due to valve movement at locations of very close tolerances between spool and sleeve.

d) For further analyses the samples of the contaminant were analyzed with the EDS and with only minor deviations all spectra were similar, containing C, O, Na and S and often chlorine (Cl) as the major elements. Furthermore, the strainer of valve # 20 revealed larger, amorphous contaminants which were higher in carbon content compared to the samples taken from the sleeve and spool of this valve. In addition some reddish brown deposits were detected on the spool of nozzle # 19, which contained a high percentage of Fe and O.

e) Due to the high non-metal content according to all EDS analyses a Fourier transform infrared spectroscopy (FTIR) was initiated for further identification purposes of the contaminant. These analyses of the residues from the various sampled locations produced similar FTIR spectra. Comparisons of these spectra with the library database at the IMR Test Labs did not provide an exact match to a specific reference material. However, the absorption bands in the residue spectra suggested that this material contained a polyacrylate salt, polyacrylic acid and an inorganic sulfate. The elevated presence of sodium in the EDS spectra indicated the polyacrylate salt is sodium polyacrylate, and the sulfate component is sodium sulfate. The minor differences between the residue spectra of the different components from the respective valves appeared primarily to be due to variations in the relative proportion of sodium sulfate in the residue. Furthermore, the combined spectrum of the three named components resembles that of a super absorbent polymer (SAP) which had been analyzed during previous investigations by the IMR Test Labs (2.3.5.2). The somewhat different looking contaminants found in the strainers of nozzle #1 and # 20 could be identified as an epoxy material. Furthermore, a trace amount of fluid was associated with the residue that was collected from the spool of nozzle # 2. The spectrum of this fluid indicated it is an ester oil type substance. The infrared absorption peaks in the oil spectrum suggested that this fluid may contain multiple constituents.

f) Due to the combustion and transfer of the gas stream across the HPT it was considered that one or a small number of the nozzles # 8 to # 14 could have caused the LPT damage. Therefore the further investigation concentrated on those nozzles and in addition on nozzle # 6 and nozzle # 18 that were out of limit at the hysteresis values. Those nozzles are in the following called "group B".

4.11 Investigation at AA Tech-Clyde, (Sept 26th to Sept 30th 2016)

a) Of this group B, nozzle # 6, # 8 to # 11, # 14 and # 18 were sent to AA Tech – Clyde, whereas only the valves of nozzle #12 and #13 were sent. The nozzles were cut open to remove the strainer and the valve. Checking the condition of both components right after removal, a contaminant was visible on most of the strainer caps and on the outside of most of the valves.

b) The disassembly of the nozzle valves of group B was performed in the same procedure as of group A. As mentioned before it was noticed on group A valves that the spools did not slide out of the sleeves by gravity and therefore during this disassembly a drag force measurement was added. The values varied from valve to valve, for details see AA Tech report. Furthermore, all components were checked visually for any kind of damage which could have caused the engine damage.

c) 2.3.7.3 All 9 strainers and valve components were sent to the IMR lab again for visual, SEM and FTIR inspections and analyses. The visual inspection under the stereoscope of the strainers, sleeves and spools showed the same residues like those detected on the components of the group A valves. As an example for all see strainer and spool of nozzle #11.

d) The EDS was performed on the spools of nozzle # 8, # 11, # 13 and # 18. The EDS results of the contaminant were the same like those found on the group A spools. The particles revealed the bead like shape or were smeared on the edges of the spool due to its movement with its tight tolerances.

e) All 9 spools showed that circle like area of residues again and therefore samples for the FTIR analysis were taken from this area of all spools. It was found that all spectra were similar, yet not identical to the electronically generated addition spectrum of the sodium polyacrylate, polyacrylic acid and sodium sulfate reference spectra. The minor spectral differences appear to be due to the relative proportion of the sodium sulfate.

f) Further FTIR analyses were done on the traces of fluid residue that were also found on the spool of nozzle # 11 and # 18, similar as found on spool # 2 of nozzle group A. The FTIR spectra of this substance were similar for all three spools and the suggestion of the FTIR library was again primarily phthalate ester oil. The retained fuel from the valves #11, #18 and #19 during disassembly was analyzed for the presence of the same substance and the spectra showed peaks consistent with those of phthalate ester oil, as well as jet fuel and a small amount of turbine oil. Detailed results see IMR report.

g) Finally two more tests i.e. color change test and absorption test were performed on the previously analyzed FTIR specimen of the circle like deposits from the spools #8 and #10. It was stated that only a few seconds after getting in contact with water, the volume of the residues expanded significantly. Furthermore, the aqueous solution of the color change test turned them into that typical bluish-turquoise color.

h) The visual inspection of all valve components did not reveal any findings other than the described contamination and discoloration.

4.13 Investigation on Hydro-mechanical Unit 29

a) The hydro-mechanical unit (HMU) was removed from the propulsor and identified as of P/N 1962M80P04 (OEM P/N 8061-694) – S/N WYGC9704. The review of the history of 907-021 revealed that this unit was originally installed to this engine at new production and had been sent to an outside vendor for repair during the L.05138 shop visit, including modification in accordance with SB73-0083 and SB73-0085, the former requiring in part number change from 1962M80P03 (8061- 693) to 1962M80P04 (8061-694). The HMU was returned serviceable from the vendor and reinstalled to 907-021 prior to its pass-off test and shipment to the customer.

b) On MTU-H's inquiry a special work-scope for the investigation of the subject HMU was recommended by the GE Aviation Fleet Support, stating that the unit should be disassembled and inspected for any contamination without prior testing. The unit was subsequently shipped to the vendor Woodward Aircraft Engine Systems (Prestwick, UK), and its investigation was carried out in the presence of one representative of MTU-H and the MTU Maintenance Canada Ltd. Accessory Repair Centre (MTU-C ARC) respectively from September 13th to 15th 2016.

c) The repeated visual inspection at the vendor's facility revealed that the HMU was in good and clean condition, as to be expected after the limited operation since the last repair, and all required lock wires were in place. All electrical connectors were visually checked and found in good condition. Fuel dripping out of the unit during the visually inspection was collected for subsequent analysis. The inlets and outlets of the unit were visually examined and – as far as possible - inspected by bore-scope. Minor contaminations were detected and collected, e.g. brownish granular objects within the heated servo pressure (PHS) port inlet screen. The screen was subsequently removed and the microscopic analysis revealed that the contamination consisted out of flat, brittle brownish particles. Later on, fuel analysis was done by UK based organization "Intertek". The fuel analysis report is attached herewith the report.

d) The typical external cleaning was waived, and subsequently the HMU was disassembled to piece part level, whereas no increased resistance was found for any component. Several components, e.g. the bypass valve assembly or gear train components, featured a darker contamination similar to fuel lacquering, which appeared unusual after the short time of operation. Various smaller contamination (e.g. fibers, granular objects) were found in different locations.

e) Based on the experiences from the fuel spray nozzle investigations all critical parts were re-inspected after drying: So for example on the bypass valve piston a whitish surface contamination was detected, together with small white objects in a recessed area. A sample of the latter was retrieved, revealing to consist of white flakes of about 0.25 mm diameter. This sample was collected in aluminum foil (sample II) and later on sent by MTU-H to a laboratory for identification by FTIR. The resulting spectrum[34] could not be identified by the FTIR device, but showed certain similarity to the spectra identified for the fuel spray nozzle contamination,

f) The visual inspection of the staging valve piston after drying revealed that its grooves were partially filled with a granular substance of ivory color. A sample of this contamination was retrieved as sample. Contamination of similar appearance was identified on the staging electro-hydraulic servo valve (EHSV) (retrieved as sample III) and the shut-off shuttle valve piston.

g) The findings established within the HMU's joint investigation were consistently summarized in a comprehensive report by Woodward[35]. This report stated that the unit itself was found faultless during the investigative disassembly and passed its outgoing test satisfactorily. However the whitish contamination found in the mentioned location after drying was reported.

4.14 Investigation on Main Fuel Pump and Fuel Filter (Bowel Assembly)

a) The main fuel pump (MFP) was removed from the propulsor and identified as of P/N 838000-2 and S/N ATC95950. The review of the history of 907-021 revealed that this pump was originally installed to this engine at new production and had been sent to an outside vendor for overhaul during the L.05138 shop visit and reinstalled to 907-021 prior to its pass-off test and shipment to the customer.

b) The initial visual inspection at MTU-H revealed no obvious damage. The inspection of the unit's fluid inlets and outlets revealed some smaller contamination identified as fibers and rubber seal debris only.

c) On MTU-H's inquiry a special work-scope for the investigation of the subject fuel pump was recommended by the GE Aviation Fleet Support, stating that the unit should be disassembled and inspected for any contamination without prior testing. The unit was subsequently shipped to the vendor Triumph Accessory Services (Grand Prairie, TX), and its investigation was carried out in the presence of one representative of the MTU Maintenance Canada Ltd. Accessory Repair Centre (MTU-C ARC) from September 22nd to 23rd 2016.

d) This investigation revealed no defects beside minor cavitation on both gears and fuel pump bore, the pump was found in good condition as to be expected by its operation time since overhaul. No contamination was found within the strainer assembly and no evidence of fuel lacquering was detected. Also the re-inspection after drying of the internal components did not reveal any whitish contamination comparable to the findings within the fuel nozzles or the HMU.

e) The fuel filter bowl assembly was removed from the main fuel pump, and the filter element assembly (P/N ACC153F3235) retrieved for investigation. The filter element appeared visually clean. The microscopic inspection of its outer lamella did not reveal any significant finding. Subsequently the filter element was back washed with cleaning solution and the solid particle share was retrieved. This contamination consisted of a light brown powdery matter with singular minor metallic flakes.

f) A sample of this matter was subjected to an analysis by a scanning electron microscope (SEM). The low magnification image of the SEM's secondary electron detector confirmed the powdery composition; a higher magnification revealed that this substance consisted of an agglomeration of very fine particles.

g) A sample was retrieved from the remaining fuel within the filter bowl assembly and subsequently sent to Intertek Farnborough Fuels and & Lubricants Centre for chemical analysis. Their report stated that the sample was identified by gas chromatography – mass spectrometry to be consistent with a standard Jet A-1 jet fuel sample. The analysis revealed content of fatty acid methyl esters (FAME) were identified as below 1.3 ppm and hence below the recommended threshold of 5 ppm. The analysis further revealed elevated contents for various metals, particularly phosphorous (P), which was later identified to be a contamination by the sample container.

h) Subsequently the fuel sample was filtrated and the retrieved solid particles were analyzed by EDS, resulting in the detection of mainly inorganic/organic deposits of differing composition, and an amount of very small to medium irregular shaped particles, mainly from aluminum alloys, with few stainless steel, carbon steel, lead and tin particles.

i) On request of MTU-H, Intertek returned 50% of the filter tissue for a continuative analysis. The microscopic examination revealed mainly grayish/brownish particles, their bigger share had deposited at the edge of the exposed part of the filter tissue. The filter tissue was subsequently exposed to a 0.5% copper sulfate pentahydrate-solution, and after drying the discoloration of several apparently spherical particles into a turquoise color was observed. This color-change test is referred to as an evidence for the presence of super absorbent polymers (SAP).

j) In 2011 the OEM informed all GE90-94B and GE90115B operators about two GE90-94B in-flight shut down events in the year 2010, (Ref. to GE90-94B IFSDs related to Fuel Contamination: ATTACHMENT-J) for which the subsequent investigation detected the presence of super absorbent polymers (SAP) within the main fuel filter, the HMU and the fuel nozzles of both engines, together with a "sticking of the valves within the fuel system within the HMU and the fuel nozzles". The investigation concluded that the contamination with SAP was the most likely cause for both events.

k) It should be noted that both engines of the 2010 event were initially operated at the same aircraft, yet after the first event the second engine was transferred to another aircraft and suffered an apparently similar IFSD event two operation cycles thereafter. This scenario indicates that an SAP contamination mostly likely induced during fueling does not necessarily result in an immediate event, but this could also happen an unknown number of cycles later. Since the second affected engine was operated at another aircraft indicates that the SAP contamination was present within the engine's fuel system (and not the aircraft's systems) at least for two cycles before causing the reported failure.

4.15 Investigation on HPT ACC Valve

a) The installed HPT ACC valve was identified as of P/N 5910500-106, S/N PFBAUV89. The review of the history of 907-021 revealed that this valve was originally installed to this engine at new production and had been visually inspected during the L.05138 shop visit and reinstalled to 907-021 prior to its pass-off test and shipment to the customer.

b) On MTU-H's inquiry a special work-scope for the investigation of the subject fuel pump was recommended by the GE Aviation Fleet Support, stating that the unit should be disassembled and inspected especially for any contamination. The unit was subsequently shipped to the vendor Parker Aerospace Customer Center (Irvine, CA). This investigation did reveal wear groove on the shaft and arm only, but no detected contamination was reported.

4.16 Flight Recorder

a) Analysis of the DFDR showed no abnormal data during engine start, taxi or during initial part of acceleration. However, N1 vibration value up to 5 and nominal EGT rise were recorded preceding the initiation of the abort take-off, of the event engine (Engine No. 02).

4.17 Investigation of the Fuel Dispenser at HSIA, Dhaka

a) After receiving the initial investigation report from MTU on 17th August 2016, immediately, the AAIT investigated the fuel supplier Padma's equipment and procedures of refueling at HSIA. Padma aviation fuel division is technically supervised and supported by Shell and complied with the Shell standard. Responsible officials and technical personnel of the organization was interviewed, implementation status of its existing procedures of the organization was also observed and the following information was noted:

b) Fuel Dispensing Equipment Used:

Fuel Dispenser : No. D-8;
Vehicle Manufacturer : Bossserman Aviation Equipment Inc

Type of Filter : Filter Monitor;
Edition : El – 1583
Brand of the filters : FACET;
Model No. : FG 230 – 6.

c) Differential pressure recorded for the month of June 2016: 5/6 PSI.

d) Last Filter changed date: 17/02/2016; next due to change date: 17/02/2017.

e) Routine and periodical Inspections of the filter element: Regularly done and recorded OK.

f) Fuel dispensed by this filter element from 01/06/2016 to 14/06/2016 amounted to 16753420 liters, supplied to about 20 different air carriers with no adverse report.

g) Differential Pressure of the fuel dispenser on 05/01/2017 has been found to be 10 PSI.

5. CONCLUSIONS

[Listed below are the findings, causes and/or contributing factors established in the investigation. The list of causes and/or contributing factors include both the immediate and the deeper systemic causes and/or contributing factors]

5.1 Findings (Aircraft)

a) The a/c was certified, equipped and maintained in accordance with existing regulations and approved procedures.

b) The a/c had a valid certificate of airworthiness and had been maintained in compliance with the regulations.

c) The aircraft was airworthy when dispatched for the flight.

d) The maintenance records and the recent ECTM analysis revealed no defect existed prior to the dispatch of the aircraft.

e) The load and balance was within the limit and had no relevance with the occurrence.

f) There was no known of defect or malfunction in the aircraft that could have contributed to the occurrence.

g) The fuel sample was tested abroad by accredited agencies and all test parameters were found within limit.

h) Fuel dispensing system including fuel hydrant used for refueling the aircraft by the fuel supplier was found in order maintaining standard procedures, supported by Shell.

5.2 Fuel filter

a) Fuel filter element was found visually clean. The microscopic inspection did not reveal any significant findings. Subsequently, the filter element was back washed and the solid particle contamination consisted of a light brown powdery matter with singular minor metallic flakes were found.

b) A sample of this matter was subjected to an analysis by a scanning electron microscope (SEM). A high magnification revealed agglomeration of very fine particles.

c) A sample was also analyzed by Intertek Farnborough Fuels and & Lubricants Centre for chemical analysis. The analysis revealed content of fatty acid methyl esters (FAME) were identified as below 1.3 ppm and hence below the recommended threshold of 5 ppm

d) Further analysis of the filter tissue by MTU-H revealed grayish/brownish particles, deposited at the edge of the exposed part of the filter tissue. The filter tissue was subsequently exposed to a 0.5% copper sulfate pentahydrate-solution, and after drying the discoloration of several apparently spherical particles into a turquoise color was observed. This color-change test is referred to as an evidence for the presence of super absorbent polymers (SAP).

5.3 Hydro-mechanical Unit (HMU)

a) The hydro-mechanical unit (HMU), P/N 1962M80P04 (OEM P/N 8061-694) – S/N WYGC9704, was originally installed to this engine at new production and repaired by a vendor during the L.05138 shop visit, and reinstalled to 907-021.

b) The inspection of the unit's various fluid inlets and outlets discovered some unusual whitish spots within the servo actuator variable bleed valve return (VBV RET) port.

c) A special work-scope for the investigation of the subject HMU was recommended by the GE Aviation Fleet Support· The unit was analyzed by Woodward Aircraft Engine Systems (Prestwick, UK. The visual inspection revealed that the HMU was in good and clean condition. The inlets and outlets of the unit were visually examined and minor contaminations were detected and collected. The screen was subsequently removed and the microscopic analysis revealed that the contamination consisted out of flat, brittle brownish particles

d) The findings established within the HMU's joint investigation were consistently summarized in a comprehensive report by Woodward. This report stated that the unit itself was found faultless during the investigative disassembly and passed its outgoing test satisfactorily.

5.4 Combustor – Diffuser - Nozzle Module (CDN)

a) All HPT stage 1 vanes had been overhauled during the L.05138 shop visit.

b) A systematic uniform soot pattern was apparent around all flare cones of the inboard and outboard fuel spray nozzle positions.

c) The combustor dome and outer liner had been installed in overhauled condition, the inner liner as new during the L.05138 shop visit; so all visible soot patterns originated from the recent operation on S2-AFP.

d) Singular flare cones featured a beginning of thermal degradation of their outer diameter, and some venturi showed a limited amount of coking.

5.5. Investigation of Fuel Spray Nozzles at Parker-Glendale, (Aug 9th to Aug 12th 2016)

a) The general appearance of the nozzles did not show obvious signs of distress, heat influence or other obvious findings.

b) A few of the nozzles were found with tiny white residues in their inlets.

c) Samples from the inner tip air gap taken from nozzle # 1, # 9 and # 17, and a sample from nozzle #8 as well as a sample from nozzle # 25 were of brownish, white and dark colors. Those samples were inspected in the scanning electron microscope (SEM) revealing that most of the debris contained sodium sulfate.

d) For the following positional gaging inspection the flanges of the fuel nozzles, measured depth of all three features (the inlet, outer and inner tip) was without findings on 29 nozzles; only the inner tip depth of nozzle # 23 was slightly longer than the tolerance allowed.

e) To determine hysteresis of the nozzles, 2 nozzles (# 15 and # 18) showed total flow values that were out of limit at 165 psig and 1 nozzle (# 16) with an out of limit value at 360 psig. Furthermore, 4 nozzles were out of the ±15 pph limit regarding the hysteresis value: # 8 20.2; # 14 15.3; # 18 42.0; # 23 15.5.

f) Fuel spray angle and quality analysis revealed only one total flow value was out of limit (nozzle # 18 at 165 psig). 4 nozzles were out of the ±15 pph limit regarding the hysteresis value: # 6 26.6; # 11 30.3; # 14 20.5; #18 64.9.

g) The finding of shifting hysteresis values during the flow tests prompted the investigation of the valves inside the nozzles with suspicion of contamination.

5.6 Investigation at AA Tech-Clyde, September 12th to 15th 2016

a) During visual inspection of the strainers of the above mentioned nozzles after disassembly revealed the presence of a few residues.

b) The spools of 4 representative valves (of nozzles # 1, # 2, # 19 & # 20; Group- A) did not slide out of the sleeves by gravity as they generally do.

c) Area of each spool showed a circle like dull appearance which under the stereoscope appeared like sand paper. After drying the mentioned dull contaminations had become even more distinct.

d) The residues on the strainer, sleeves and spools were analyzed in IMR Test Labs. IMR reports stated that almost all residues had the same optical coloration, i.e. translucent amber color. In addition they mostly had the same shape, i.e. small bead-

e) like or spherical particles.

f) According to Fourier transform infrared spectroscopy (FTIR) the absorption bands in the residue spectra contained a polyacrylate salt, polyacrylic acid and an inorganic sulfate. The elevated presence of sodium in the EDS spectra indicated the polyacrylate salt is sodium polyacrylate, and the sulfate component is sodium sulfate. The combined spectrum of the three named components resembles that of a super absorbent polymer (SAP). The somewhat different looking contaminants found in the strainers of nozzle # 1 and # 20 could be identified as an epoxy material. A trace amount of fluid was associated with the residue, collected from the spool of nozzle #2 indicated it is an ester oil type substance.

g) The epoxy found in some strainers of the nozzle was not an unusual finding, because it is used in the manufacturing process of the strainer. In addition the epoxy was found on locations, where they could not have an effect on the movement of the valves.

h) It was estimated that the presence of the ester oil(s) found on some of the spools and in the retained fuel most likely did not have an effect on any of the valves e.g. sticking of the spool or any other malfunction. Those oils are soluble in the fuel and would not decrease the lubricity of the fuel. The source of the oils could not be determined, because it could originate from any fluid that passed through the fuel nozzle, like test stand fluids, preservation oils and aircraft fuel.

i) Due to the combustion and transfer of the gas stream across the HPT it was considered that one or a small number of the nozzles # 8 to # 14 could have caused the LPT damage. These and nozzle # 6 and # 18 are grouped in B.

5.7 Investigation at AA Tech-Clyde, September 26th to 30th 2016

a) Of Group B, contaminant was visible on most of the strainer caps and on the outside of most of the valves of nozzle #6, # 8 to # 11, # 14 and # 18.

b) All 9 strainers and valve components of group B under IMR lab visual inspection under the stereoscope of the strainers, sleeves and spools showed the same residues like those detected on the components of the group A valves.

c) The EDS results on the spools of nozzle # 8, # 11, # 13 and # 18 of the contaminant were the same like those found on the group A spools. The particles revealed the bead like shape or were smeared on the edges of the spool due to its movement with its tight tolerances.

d) All 9 spools showed that circle like area of residues spectra were similar, yet not identical to the electronically generated addition spectrum of the sodium polyacrylate, polyacrylic acid and sodium sulfate reference spectra. The minor spectral differences appear to be due to the relative proportion of the sodium sulfate.

e) FTIR analyses on the traces of fluid residue of spool nozzle # 11 and # 18 were found similar as on spool # 2 of nozzle group A, primarily phthalate ester oil.

f) Finally, color change test and absorption test on the spools # 8 and # 10 was found a few seconds after getting in contact with water, the volume of the residues expanded significantly and the aqueous solution of the color change test turned them into that typical bluish-turquoise color.

5.8 Aircraft Damage

a) Aircraft made an aborted take-off at approximately 150 kt while departing for Dammam due to "ENGINE FAIL" warning came on the PFD along with 'Master & "Aural Warning".

b) A limited bore-scope inspection was carried out at Dhaka due to restriction of N1 rotor at about 120^0 which detected severe airfoil damage beginning from the stage 4 rotor and affecting the ensuing stages. Of all the engine's magnetic chip detectors (MCD), the one related to the B-sump only was found to be loaded with catch, being metallic burrs (Rough edge on material such as metal after it has been cut or drilled). A continued BSI at MTU-H revealed severe LPT stage 3 and 4 airfoil failures, yet no obvious damage within the HPT and HPC module. The presence of an LPT stage 1 rotor seal rub was falsified[6]. Further BSI revealed that LPT stage 1 stator showed significant damage to the airfoils in about 5 o'clock position. The airfoils in that area were molten with their center section partially missing [. The remaining LPT stage 1 vanes did not show any abnormality.

c) At MTU, it was found that the sensors of the EGT probes # 4 and # 5 (located at about 5 o'clock) were burned, probe # 4 being more affected than probe # 5. Probe # 4 failed the insulation test, circuit resistance test and polarity test.

d) The general visual inspection at MTU showed a heat discoloration on the LPT active clearance control (ACC) manifold in about 5 to 6 o'clock position. Several bulges were detected on the complete circumference of the LPT case. Minor delamination in different areas on the circumference of the primary nozzles rear edge and a major dent on the forward center body in about 6 o'clock position were detected.

e) There were no indications on the propulsor's external hardware appeared
f) causative for the internal damage.

g) No obvious damage on the stage 1 rotor of LPT. Stage 2 stator revealed a sector of discolored and obviously damaged vanes within the engine's 5 o'clock position.

h) LPT case had an almost uniform discoloration. An outward directed puncture of the case in the engine's 9 o'clock position, at the axial position of the LPT stage 3 rotor was detected. The LPT ACC manifolds within the engine's 4, 5 and 6 o'clock position featured a distinct blue to purple heat discoloration, which was not apparent on the other manifold segments.

i) The turbine rear frame (TRF) flow path surfaces were covered with multiple impact indentations, and several skin punctures were visible on the convex side of the struts, near the outward end of their leading edges.

j) The exposed LPT stage 6 rotor featured the systematic liberation of its outer airfoil segments and platforms, the remaining airfoils featured excessive mechanical damage on their leading and trailing edges. Similar systematic damage to the edges of the stage 5 and 6 stator vanes were also detected, equally around the stator's perimeter.

k) All stage 4 rotor blades had liberated shortly outward of their root platforms, with several axial vane airfoil separation. An area of the trail vane of segment # 10 and of the lead vane of segment # 11 had liberated, thus forming a coherent hole in the stator. A bluish-green discoloration and deformation of the remaining airfoils were typical for a thermal damage.

l) Stage 3 stator featured a distinct discolored and thermally damaged area within its 5 o'clock position. The lead and trail vane of segment (# 13) had failed. The coating on the convex airfoil surrounding this damage appeared blistered, whereas the coating on the concave airfoil surfaces had apparently been greenish discolored.

m) Stage 2 rotor was found affected by random smaller airfoil impact damage, yet on a consecutive segment of about 60 degrees its airfoils had liberated near their outer platforms. Also the stage 2 stator featured the singular thermally damaged area in its 5 o'clock position and all three airfoils of two adjacent segments (# 18 and # 19) had been removed, together with the lead vane of segment # 10. The removed segments showed again the discolored and thermally affected appearance.

n) The Slot bottom clearance between the LPT stage 1 blade dovetails and the disk revealed values well below the maximum acceptable limit of 1. 27mm.

o) Therefore, in summary the LPT module showed a thermal damage affecting its stage 2 to 4 stators locally within its 5 o'clock position, lessening from front to aft, and a mechanical damage caused by the liberated vanes starting from its stage 2 rotor and increasing from front to aft.

5.9 Crew/Pilot

a) The flight crew were licensed and qualified for the flight in accordance with the existing regulations.

b) The flight crew were medically fit and adequately rested.

c) The flight crew were in compliance with flight and duty time limitations.

d) The flight crew had taken correct and appropriate abort actions.

e) The flight crew actins/inactions did not contribute towards the occurrence.

5.10 Operations of Aircraft

a) Debris from the aircraft damaged engine on the RWY posed hazard for the operations of aircraft.

b) No flight crew of 12 flights that had taken off and landed over the debris noticed or reported debris to the ATC.

c) Radio Telephone phraseology used by the flight crew following the abort action was not proper.

d) SOPs of the operator have different terms used for an abort take-off for different aircraft of the fleet.

5.11 Air Traffic Service

a) ATCO failed to assist the crew following the aborted take-off.

b) ATCO also failed to assess the consequences of a heavy aircraft of the statute of B 777-300 ER, aborting take-off of at a high speed.

c) Use of improper phraseology by the crew following the abort take-off might have negated an effective response from ATC.

d) ATS did not have any abort take-off procedure to handle situations after an abort take- off.

e) Aerodrome Fire Fighting did not proceed to the event site in spite of the abort take-off and that the aircraft had held on the RWY for about 2 minutes.

6. CAUSES

6.1 Discussion of Operational Data

a) The analysis of the engine condition trend monitoring data, being stable and similar to the sister engine, did not show any trend shifts or fluctuations prior to the attempted event flight on June 7th 2016. According to the operator’s information, no relevant faults existed on the aircraft or engine systems. Also the maintenance records did not show relevant entries for the subject engine.

6.2 Flight Recorder

a) Analysis of the DFDR showed no abnormal data during engine start, taxi or during initial part of acceleration. Temporary N1 vibration up to 5 units and nominal EGT rise was recorded preceding the initiation of the abort take-off. This recorded spontaneous increase of the N1-vibrations and nominal EGT rise was most probably resulting from the beginning of the thermal and mechanical damage.

b) It appeared unclear why this thermal degradation was not reflected within the recorded data, particularly since the LPT stage 1vane thermal degradation happened in the ultimate vicinity of two EGT probes, i.e. # 4 and # 5.

c) So in the summary, it appeared that both thermal and mechanical damage had occurred spontaneously prior to the aborted take-off roll.

6.3 Hardware

a) The mechanical damage within the LPT module is understood to have caused by the conflict of rotating and static engine parts. It is concluded that it was mainly caused by the conflict of the LPT stage 2 vane segments # 18 and # 19 inner platforms, which had been liberated after the thermal caused disintegration of the related airfoils. Thus the mechanical damage is secondary to the observed thermally induced damage.

b) The thermally induced damage starting at the HPT stage 2 stator and affecting only a limited engine sector around the 5 o'clock position indicated that the affected components were exposed to a temperature distinctively higher than foreseen by the design. The combustion of fuel appeared to be the only potential heat source responsible for the thermal damage, so it appeared conclusive that a portion of the fuel injected into the combustion chamber had not been burned within the chamber as per design, but in the axial station of the TCF transition duct respectively LPT stage 1 stator, yet also well affecting the LPT stage 2 to 4 stators more aft.

c) A necessary requirement for the complete combustion of the fuel within the chamber is its atomization and dilution with the oxygen contained within the engine gas stream, in order to develop an ignitable mixture. Based on the subject damage pattern it appears that this process was somehow disturbed. The fuel atomization and mixing with air are accomplished by the combination of the fuel spray nozzle and the surrounding components of the combustor, being first of all the venturi and the swirlers. Since none of the latter components was found conspicuous during this investigation, the fuel nozzles themselves appeared the most likely cause of the potential hot streak.

d) The fact that the thermal damage is limited to that small sector of the engine only indicated that a single or a small number of adjacent fuel nozzles were responsible. Due to an assumed yet unknown swirl of the gas stream (and also of a potential liquid fuel jet) it is not possible to identify a single fuel nozzle as the cause, but a region of nozzles, extending from 3 o'clock (i.e. nozzle #8) to 5 o'clock (i.e. nozzle #14) could be considered to most probably contain the causing component.

e) It appeared most likely that a temporary incapability of the nozzles moveable components, i.e. its valve was apparent during the event. The IMR analyses found indications that the contaminant consisted amongst others of sodium polyacrylate, a super absorbent polymer. This assumption was furthermore supported by the beadlike appearance of the substance, its positive reaction to the color change indicator and its swelling when in contact with water, so that the presence of SAP was concluded. Due to the very small size of the SAP particles (in general from 5µm to 20µm) the engine fuel filter and fuel nozzle strainer were unable to catch that contaminant completely. The SAP particles were able to make their way into the fuel nozzles valves. Since the SAP is a soft plastic material it could easily be drawn into the gap between the spool and sleeve during the movement of the spool. This situation subsequently most likely caused hampering of the valves.

6.4 Super Absorbent Polymers and Contamination of Aircraft Fuel

a) The relevant contamination detected within the fuel nozzles was identified as super absorbent polymers. The contaminations present within the HMU (by its similar FTIR analysis) and the fuel sample (by the color change test of the filtered particles) were with high probability of the same type. This fact led to the conclusion that this contamination had affected the complete fuel system and therefore must have been introduced by the fuel supply.

b) Super absorbent polymers (SAP), typically consisting of sodium or potassium poly acrylate can absorb and retain large amounts of liquids, e.g. water. It is commonly used in filter monitors installed in airport fuel handling systems (e.g. refueling vehicles, hydrant dispensers and other mobile fueling equipment) to remove free water from fuel and thus minimize the risk of ice formation within the engine's fuel system. The SAP particles are typically globules ranging from 5 to 20 µm diameter, but could also be as big as 750 µm in diameter. Once in contact with water the globules turn into an amorphous gel.

7. SAFETY RECOMMENDATIONS

[Stated below is the safety recommendation made for the purpose of accident prevention. The safety recommendation has been implemented.]

a) Operators should investigate their refueling operations at the airports where uploads are accomplished to ensure proper maintenance and monitoring programs are being conducted in accordance with usage of filter monitors which contain SAP.

8. APPENDICES

[Included and preserved in the file, as appropriate, all the pertinent information considered necessary for the understanding of the Final Report]

Systematically documented in file.

END