Report on Investigation

Into the

High shop visit cost of PW4090 engines

Reference: Office order 16/2016

Dated 28 March 2016

Investigation Report

1. Introduction:

A. On 05th February 2015 flight no. BG-047 sector DAC – CGP - DXB was scheduled to operate by Boeing 777-200ER aircraft registration S2-AHL, MSN: 32630. Accordingly the aircraft operated DAC - CGP sector with nil defects. After preflight inspection and necessary servicing the aircraft was released at CGP for next leg of the flight i.e. CGP-DXB. But the flight returned to DAC with the defect in the AML (Aircraft Maintenance Log) as "LEFT ENGINE FAIL DURING CLIMB" entered by Flight crew. After arrival at DAC in reference to the AML entry the captain verbally informed the maintenance engineers that after take-off from CGP during climb at about FL 120 they heard a loud bang with " ENGINE FAIL" indication on the PFD associated with #1 engine EGT exceedance. As such inflight shutdown checklist for #1 engine was carried out. Annex-1A1

B. Maintenance Engineers interrogated the MAT (Maintenance Access Terminal) and found maintenance message "71-60431 Left Engine has Surged". Cockpit indication was checked for engine #1 and found oil quantity was zero, hydraulic quantity system-1 was zero. Annex-1A2

C. WAC (Walk Around Check) of #1 engine carried out by maintenance engineers at DAC and found the following: Annex-1A3, 1A4

i. Fan exit fairing aft of fan blade totally detached and blocked 12 O'clock position to 9 O'clock position of the fan discharge area.
ii. Hydraulic was dipping from bottom of the Engine Reverser Cowls.
iii. Trace of oil leak observed through spinner and on the Engine Cowls.
iv. LHS and RHS pressure relief doors on the reverser cowls found in open position.
v. Rear aft center body of Engine exhaust was totally missing.
vi. Burned metal chips & metal dust found in the Low Pressure Turbine exhaust.
vii. Photographs of the visible damaged parts of the engine was taken and attached with the report.
viii. Borescope Inspection carried out through BSI port local area due N2 drive failed to rotate and findings are attached.

D. PW4090 Engine S/N: 222031 was removed following an un-schedule engine surge event and metallurgical failure of HPT Stage 2 blades on 05th February 2015 at TSN/CSN : 43744/10372, TSLSV/CSLSV : 5483/1734. The event caused an In-flight shut down (IFSD) of the engine with a seized rotor and EGT exceedance. The engine was removed on 15th March 2015 and sent to the United Airlines Engine Overhaul shop at San Francisco, USA for necessary repair/ overhaul by the end of April 2015. Annex-1A5 (work order & Airway bill)

E. Due to this sudden engine surge event, Biman Engineering & Material Management became more vigilant and was watching PW4090 Engine parameters for fleet engines. This has resulted detection of second PW4090 Engine S/N: 222166 HPT Blade distress / failure through Borescope Inspection on 04.04.2015 and the engine was removed on 02-06-2015 at TSN/CSN:

36159/8645, TSLSV/CSLSV: 6000/2066 and inducted at United Airlines Engine Overhaul shop for necessary repair/ overhaul on 13-06-2015. Annex-1B1 & 1B2 (work order & Airway bill)

2. Factual information:

A. ESN P222031:

Type of Operation	**Scheduled Flight**
Flight No.	**BG 047**
Sector	**DAC-CGP-DXB**
Date of Incident	**05 February 2015**
Type of Aircraft	**B777-200ER**
Aircraft MSN	**32630**
Aircraft Registration	**S2-AHL**
Place of Occurrence	**In Flight during climb after take-off from CGP at FL 120**
Time of Occurrence	**In flight**
Injury to Crew	**Nil**
Injury to Passenger	**Nil**
Flight Report	**Yes**
Aircraft Damage	**Nil**
Engine Damage	**Yes. Engine #1 (Left hand) Severe HPT Stage 2 Blade Distress**
Engine Model	**PW4090**
Engine Position & ESN	**Position #1 (Left hand), ESN P222031**
Engine removal date	**15 March 2015**
Engine Total Time	**43,744**
Engine Total Cycles	**10,372**
Engine Time Since Last Visit	**5,483**
Engine Cycles Since Last Visit	**1734**
Engine hours used by Biman	**3317**
Engine cycles used by Biman	**917**
Engine hour to cycle ratio	**3.617:1**

B. ESN P222166:

Type of Inspection	**Scheduled Borescope Inspection**
Date of Inspection Findings	**04 April 2015**
Type of Aircraft	**B777-200ER**
Aircraft MSN	**32630**
Aircraft Registration	**S2-AHL**
Place of Occurrence	**During SKD Borescope Inspection found HPT stage 1 total 08 blades found damaged**
Time of Occurrence	**On ground in the Hangar Complex during SKD Borescope Inspection**
Flight Report	**No**
Aircraft Damage	**Nil**
Engine Damage	**Yes. HPT stage 1 total 08 blades found damaged**

	among them 04 blades material liberated and other 04 blades fractured
Engine Model	**PW4090**
Engine Position & ESN	**Position #2 (Right hand), ESN P222166**
Engine removal date	**02 June 2015**
Engine Total Time	**36,159**
Engine Total Cycles	**8,645**
Engine Time Since Last Visit	**6,000**
Engine Cycles Since Last Visit	**2,066**
Engine hours used by Biman	**3484**
Engine cycles used by Biman	**970**
Engine hour to cycle ratio	**3.591:1**

3. Formation of investigation committee:

Pursuant to the decision of Biman Board of Directors in its 158th Meeting held on 08 March 2016 a committee has been constituted by the Biman management vide Office Order No. 16/2016, dated 28 March 2016 with a definite TOR and timeframe of 15 (fifteen) days. The committee constituted as follows in order to investigate into the causes of high shop visit cost of PW4090 engines: Annex-3 office order1

a. Md. Shafiqul Alam Siddique, Chief Engineer (QA) - Convener
b. Md. Ali Naser, DGM Training (Engineering Faculty, BATC) - Member
c. One Official from Bangladesh Air Force (BAF) not less than the rank of Wing Commander. - Member

The Committee may co-opt any officials as member, if deemed necessary.

Note: In response to the Biman request for such nomination in para (c) above, Bangladesh Air Force (BAF) nominated Wing Commander Mr. M Moinul Hasnain, PSC (BD/8597), Engg. BAF on 31st March 2016. Wing Commander Md. Tariqul Islam, PSC (BD/8556), Engg. BAF Base was nominated on 17th April 2016 instead of Mr. M Moinul Hasnain, PSC (BD/8597), Engg. BAF. Annex-3 office order2

Terms of Reference (TOR) of the Committee are as follows:

i) To find out the cause of high shop visit cost of PW4090 Engines S/N 222166 and S/N 222031.
ii) The committee will submit a report to the management within 15 days for submission before the meeting of the Board of Directors.
iii) To identify the person(s) responsible (if any).
iv) To recommend measures for prevention of future recurrence.

4. Methodology:

A. Upon receiving nominations from Bangladesh Air Force (BAF), the complete Investigation Team started the process of reviewing the documentation for the PW4090 Engine Shop Visit process and also had several round of discussions with the Engineering Services and Propulsion Group, they manages repair/overhaul of PW40490 Engines ESN 222031 & ESN 222166. The committee set out the action plan and accordingly collected different information, documents through questionnaires. Consulted relevant manual (WPG), analyzed the actions taken by United Airways shop personnel. Interview the key persons and the persons involved for engine health monitoring on the light of finding the actual facts and information. Responses and comments of each person were analyzed to find out the root cause/reasons for high shop visit cost involved for the repair/overhaul of PW4090 ESN 222031 and 222166 at United Engine Shop and any lapses or ignorance of person(s) involved for the task. Annex-4AB1

B. During the process of Investigation following documents have been reviewed by the Investigation team to determine the cause for high shop visit cost for ESN 222031 & ESN 222166:

1. Engine removal reports for ESN 222031 & ESN 222166; Annex-1A1, 1A2, 1A3,1A4, 1A5 & 1B1, 1B2
2. Interview with the key persons of Engineering Services, Engineering Planning and Insurance and questionnaires; Annex-4AB1
3. AWB for transportation of ESN 222031 & ESN 222166 to San Francisco, USA; Annex-1A5 & 1B2
4. Pictures of damaged parts for ESN 222031 & ESN 222166; Annex-1A4, 5A1 & 6B1
5. Pratt & Whitney Comments on Industry-wide PW4090 Engine HPT Blade Sulfidation issue; Annex-5AB4
6. Work Orders for ESN 222031 & ESN 222166; Annex-1A5 & 1B2
7. Preliminary Shop findings prepared by United Airlines Engine Shop for ESN 222031 & ESN 222166; Annex-5A1 & 6B1
8. Metallurgical Failure Analysis of HPT 2 Blade from ESN 222031 Biman Bangladesh Airlines; Annex-5A2
9. Agreed Work scopes for ESN 222031 & ESN 222166 between Biman, United and EgyptAir; Annex-7A1 & 7B1
10. Preliminary Invoices for ESN 222031 & ESN 222166; Annex-12A1, 12B1
11. Draft Final Invoice for ESN 222031 & ESN 222166; Annex-12A2, 12B2
12. Final Invoice for ESN 222166; Annex-12B4
13. Scrap Reports for ESN 222031 & ESN 222166; Annex-12A3, 12B3
14. Engine Maintenance Agreement between Biman and United Airlines Engine Shop for maintenance of PW4090 Engines operating in Biman fleet; Annex-A & B 13
15. Boeing 777-200ER Aircraft Dry Lease Agreement between Biman and EgyptAir; Annex-5A, 5B & in CD
16. Pratt & Whitney PW4090 Engine Parts Catalog 2015; Annex-8A1, 8B1 in CD
17. PW4090 Engine Workscope Planning Guide; Annex-7AB1
18. Comments from Biman Insurance Underwriter Marsh on the Insurance Claim of ESN 222031; Annex-5A3
19. PW4090 Engine Manufacturer Pratt & Whitney Comments on the HPT Blade failure; Annex-5A5

20. Aircraft Manufacturer Boeing comments on the PW4090 Engine Shop Visit Cost estimate; Annex-14 AB1
21. Minutes of Meeting between Biman and EgyptAir in regards to the Review of Final Invoice for PW4090 Engine S/N: 222166 and other issues; Annex-12B5, 13A4
22. Minutes of Meeting between Biman, Egypt Air and United Airlines in regards to the Review of Final Invoice for PW4090 Engine S/N: 222166 and other issues; Annex-12B6, 13A5
23. Working paper for the 167th meeting of the Biman Board of Directors on Overhaul of PW4090 Engine ESN 222166 at United, USA; Annex-12B7

All the supporting documents are placed in Annex-1A1, 1B1~14 AB1 (237 pages) according to the order.

C. Abbreviations:

AD	Airworthiness Directive
AML	Aircraft Maintenance Log
BSI	Borescope Inspection
CLP	Catalog Price
CSN	Cycle since New
CSLSV	Cycle since Last Shop Visit
DPI	Detail Part Inspection
EA	Engineering Acceptance
EGT	Exhaust Gas Temperature
ESN	Engine Serial Number
FL	Flight Level
FOD	Foreign Object Damage
HPC	High Pressure Compressor
HPT	High Pressure Turbine
IFSD	In-flight shut down
K/E	Knife edge
LHS	Left Hand Side
LPT	Low Pressure Turbine
LLP	Life Limited Parts
MAT	Maintenance Access Terminal
M.I.S	Metal In Screen (Oil)
MRO	Maintenance and Repair Organization
MSN	Manufacturer Serial Number
N2	High Pressure Rotor
NTE	Not To Exceed
OEM	Original Equipment Manufacturer
OSV	Out Side Vendor
PFD	Primary Flight Display
PMA	Parts Manufacturer Approval
PW	Pratt & Whitney
PN	Part Number

SB	Service Bulletins
S/N	Serial Number
SFO	San Francisco, USA
T2	High Pressure Turbine Stage 2
T3	Low Pressure Turbine Stage 4
TAT	Turnaround Time
TSN	Time since New
TSLSV	Time since Last Shop Visit
UA	United Airlines
USD	United State Dollar
US$	United State Dollar
VSV	Variable Stator Vanes
WPG	Workscope Planning Guide

5. Details of first PW4090 Engine S/N: 222031 removal and findings:

A. Biman started operation with two Boeing777-200ER aircraft registration number S2-AHL and S2-AHK under five year Dry Lease arrangement from 02.04.2014 and 18.05.2014 respectively. On 05th February 2015, the first PW4090 engine S/N: 222031 suffered an inflight-shutdown event following a un-schedule engine surge event and metallurgical failure of HPT Stage 2 blades at TSN/CSN: 43744/10372, TSLSV/CSLSV: 5483/1734. The engine was removed due to severe damage both internally and externally. The significant external findings noted immediately after the incident were

- severe damage to the trailing edge of all fan blades,
- Splitter Case torn off, heavy metal deposits observed at the exhaust,
- tail cone was missing,
- severe hydraulic leakage noted at the time of engine cowl opening,
- and the oil tubes were found broken,
- The Inflight shut down (IFSD) event of the engine caused a seized rotor
- and EGT exceedance.

The engine was removed on 13 March 2015 at Dhaka and was sent to the United Airlines Engine Overhaul shop at San Francisco, USA for necessary repair/ overhaul by the end of April 2015.

B. When the engine went to the engine shop and was disassembled, it was also noted that the N2 shaft was not rotating, metal particles visible in tailpipe, metal was also noted on the #1, #1.5 and #2 bearing chip detectors. Disassembly revealed that the engine suffered HPT stage 2 blades failure which resulted in substantial secondary damage, evidence of severe vibration and a gas path flow disturbance. Besides, No. 2 bearing support housing exhibited severe damage and broken metal evidence and No. 2 bearing routed for overhaul, Tower shaft bearings needed to be replaced and 2.5 bleed rings was routed for overhaul. Severe damage noted to all HPT airfoils and air seal duct segments from a liberated HPT stage 2 blades and required replacement. All HPC blades were under severe rubbing due seal dislocation and were

scrapped. All LPT-3 blades were sent for over temperature analysis; T3 blades were found to have over temperature. All T3 blades required replacement. Cracks discovered in main gearbox housing and required full overhaul (Annex-5A1)

C. Summary of Shop findings for ESN 222031(Annex-5A1)**:**

Engine Maintenance Level was Full Disassembly i.e. Heavy Maintenance. Severe damage found to fan, HPC and HPT. At induction, N2 would not rotate, and metal was visible in tailpipe. Metal was noted on the #1, #1.5 and #2 bearing chip detectors. Disassembly revealed the engine suffered a T2 blades failure which resulted in substantial secondary damage, evidence of severe vibration and a gas path flow disturbance (engine surge). See report following. (**United Shop Visit Report for ESN 222031 - attachment)**

Module / Build Group	Major Findings & Repair Disposition
(a) Fan Cases Group – Level of Maintenance: RPR - Repair/Partial Gas path Refurbishment **(b) Fan Blade Group – Level of Maintenance: HM - Heavy Maintenance**	- LPC fan exit "splitter" fairing had liberated from its mounting tangs and caused a non-repairable rub condition with the trailing edges of all fan blades (all fan blades were scrap). (See photos). - Minor damage (repairable in-house) to case's fan blade rub strip and acoustic panel areas.
LPC Group **Level of Maintenance – GPR - Gas Path Restoration**	- Fan Exit Fairing had torn away from its mount tangs. Several tangs bent/damaged. Pieces of composite fairing were found inside LPC. (See photos). - Some LPC blades suffered leading edge damage (see photo). - No. 1 bearing routed owing to engine M.I.S.
Turbine Coupling Group **Level of Maintenance – HM - Heavy Maintenance**	- No. 1.5 Bearing chip detector showed MIS; No. 1.5 bearing removed and routed.
Intermediate Case Group **Level of Maintenance – HM - Heavy Maintenance**	- Intermediate case no. 1.5/2 bearing support flange and adjacent snap diameter exhibited damage (see photos) which required a lengthy PW-Engineering evaluation prior to the issuance of a PW repair EA. Intermediate case required removal from fan case for repair. - No. 2 bearing support housing exhibited severe damage and broken metal evidence (see photos). - No. 2 bearing chip detector showed M.I.S. (No. 2 bearing routed for overhaul). - Tower shaft bearings replaced. - 2.5 bleed ring routed for overhaul.
HPC Group **Level of Maintenance – HM - Heavy Maintenance**	- Extensive Damage to HPC (see photos). Full disassembly (including destack of drums) required. - Several stages of blades exhibited moderate-to-severe (non-repairable) tip rub (see photos). - HPC drum knife edges exhibited moderate-to-severe (non-repairable) rub (see photos).

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Diffuser-Combustor Group **Level of Maintenance – HM - Heavy Maintenance**	- Module routed for disassembly and heavy maintenance. - No. 3 bearing routed owing to engine M.I.S.
Turbine Nozzle Group **Level of Maintenance – HM - Heavy Maintenance**	- Module routed for disassembly and heavy maintenance.
HPT Group **Level of Maintenance – HM - Heavy Maintenance**	- Severe damage noted to all HPT air foils and air seal duct segments from a liberated HPT stage 2 blade (see photos). - T1 and T2 blades sent for over temperature analysis; T1 blades did not over temperature T2 blades were found to have over temperature (LPT-3 blades then sent for analysis). - Engine had suffered a T2 blade failure and IFSD. A separate metallurgical analysis report was generated (dated 6/15/15 and separately provided to BG) for the suspect failed blade. Blade failure was attributed to a hot corrosion failure mode where numerous fatigue cracks unified into a prominent crack front that ultimately resulted in a fracture overload that resulted in a mid-chord air foil section liberation (which also caused substantial secondary damage). - T2 air seal required replacement, regardless of condition, owing to Airworthiness Directive against installed PN.
LPT Group **Level of Maintenance – HM - Heavy Maintenance**	- Initial module-level inspection showed impact damage to T3 vanes and T3 blades (LPT required destack). (See photos). - LPT-3 blades sent for over temperature analysis; T3 blades were found to have over temperature (LPT-4 blades then sent for analysis and found to not have over temperature). All T3 blades required replacement. - Discoloration/Evidence of rub noted on LPT drive shaft outer diameter in several locations (see photos). Condition and photos were reviewed with PW-Engineering, and shaft was determined to be "not repairable". - LPT case exhibited heavy wear to stage 3 vane retention rail wall (see photo).
Turbine Exhaust Case Group **Level of Maintenance – RPR - Repair/Partial Gas path Refurbishment**	- No. 4 bearing, carbon seal and carbon seal spacers were all replaced. - Aft exhaust nozzle plug missing (see photo of forward plug missing nut plates).
Gearboxes Group – Main & Angle **Level of Maintenance of MGB – HM - Heavy Maintenance Level of Maintenance of AGB – HM - Heavy Maintenance**	- Full disassembly of gearboxes required owing to engine's "M.I.S." findings. - Cracks discovered in main gearbox housing (see photos).

D. Insurance Claim filed for ESN 222031(Annex-5A3)**:** Since reason for the engine failure event was unknown, Biman filed an insurance claim for the engine S/N 222031 and invited the lessor, insurance company to participate at the opening of the engine at various levels and to determine the root cause and extent of damage to decide on the workscope level that would be involved for this engine. Due to the facts that the engine had an in-flight-shut-down (IFSD) event followed by Exhaust-Gas-Temperature (EGT) overshoot, the work level and engine parts scrap was set at very high level. After detail review of the internal engine damage and lab analysis, United Airlines submitted a metallurgical report (attachment) that identified the findings on the failed HPT Stage 2 blades was consistent with a hot corrosion failure mode; as a result sulfidation may have contributed to the HPT blade failure. Due to the findings on the suspect second stage HPT blade, the insurance claim was not accepted due to material failure of the engine and is not covered by Biman insurance policy.

Biman Insurance broker MARSH commented on 17 November 2015 that both the Leading All Risks Reinsurer and the Hull Deductible Reinsurer have given this claim further consideration. The Leading Hull All Risks Reinsurer has commented that the proximate cause of the loss is the blade failure (caused by sulfidation over time) and therefore the previous position remains the same, the claim is excluded under Section 1, Exclusion 2 (a) of the policy.

The Hull Deductible Reinsurer has also commented that their interpretations of the policy remains unaltered and have confirmed that coverage is denied.

By way of explanation of this stance, both the hull All Risks and Deductible Reinsurers understand that had the sulfidation been discovered before the blade actually failed, the engine would have been removed (and the claim avoided). However, they both contend that the cause of loss, namely the reason the blade failed, was the sulfidation.

For example, if the same argument was applied to a blade failure caused by the ingestion of a stone, which causes a dent initiating a crack which eventually overloads, if the nick/crack is discovered prior to the failure and the engine is removed, the claim would be also be avoided. However, the cause in this case is not the fact that the nick/crack was not spotted; it is the nick and subsequent crack propagation. Therefore, Reinsurers are resolute in their denial of this claim.

E. PW4090 Engine Manufacturer Pratt & Whitney Comments to the HPT Blade failure incident Annex-5A5**:**

It may be mentioned that there are several HPT Stage 2 blades related incident occurred on PW4090 Engines for other airlines in recent past. Engine manufacturer Pratt & Whitney (P&W) described this event as: "Since January 2009, there have been approximately 50 engine removals due to HPT 2nd stage blade internal hot corrosion reported to P&W. In addition, P&W has concluded there have been **nine In-Flight Shut Down's (IFSD)** resulting from fractured HPT 2nd stage blades caused by internal hot corrosion through February 2015 and in every cases, there has been a huge shop visit cost involved amongst the operators. In July and

August 2015, there have been four IFSD's with damage in the HPT that are under investigation." For all those engines Low Pressure Turbine which is located immediately aft of the HPT 2nd stage blade suffered from severe damage which requires expensive repair/replacement. Moreover, due this sudden surge of LPT damage, a worldwide crisis of PW4090 engine LPT material emerged which also delaying engine build time or prolonged Engine shop visit TAT.

6. Details of Second PW4090 Engine S/N: 222166 removal and findings Annex-6B1:

A. Due to this sudden engine surge event, Biman Engineering became more vigilant and was watching engine parameters for the remaining 03 engines operating in the fleet. This has resulted detection of second PW4090 Engine S/N: 222166 HPT Blade distress / failure and the engine was removed on 01-06-2015 at TSN/CSN: 36159/8645, TSLSV/CSLSV: 6000/2066 and was inducted at United Airlines Engine Overhaul shop for necessary repair/ overhaul on 13-06-2015. After opening the engine HPT section, severely burnt and deteriorated blades were found at HPT Stage 1 blades. The observed blade burning, deterioration and missing material over approximately a 90 degree arc could have resulted liberation of large pieces that could have happened like the first engine, and this findings was discovered only due to the fact that Biman applied reduced Borescope Inspection for all the other PW4090 engines in the fleet.

B. Although the second engine was inducted for HPT airfoil distress but upon disassembly, additional distress and severe wear was found in the HPC VSV system and mating HPC rotor area and sulfidation was discovered on the LPT T3 vanes, which necessitated an LPT, de-stack.

C. Summary of Shop findings for ESN 222166 Annex-6B1**:**

Engine Maintenance Level was Full Shop Visit. Engine was originally inducted for HPT airfoil distress (see HPT blade disassembly photos in Appendix). Upon disassembly, additional distress and severe wear was found in the HPC VSV system and mating HPC rotor area, and sulfidation was discovered on the T3 vanes (necessitating an LPT de-stack). See report following. **(United Shop Visit Report for ESN 222166 - attachment)**

Module / Build Group	**Major Findings & Repair Disposition**
Fan Cases Group – Level of Maintenance: MLI - Module Level Inspection **Fan Blade Group – Level of Maintenance: OH - Overhauled**	- Fan Case rub strip exhibited minor wear, missing areas (local repaired with — "blue putty"). - Fan blades routed for overhaul owing to leading edge surface roughness.
LPC Group **Level of Maintenance – GPR - Gas Path Restoration**	- LPC Stators routed to OSV for re-rubber restoration of rub strips. - Fan hub spinner cone tang exhibited a pre-existing blend (see photo) for which no documentation could be found. - UA worked with local PW office to obtain a PW-Engineering acceptance.

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Turbine Coupling Group **Level of Maintenance – HM - Heavy Maintenance**	- #1.5 Bearing Outer Race Damaged-Full DPI of coupling module required (see photo).
Intermediate Case Group **Level of Maintenance – RPR - Repair/Partial Gas path Refurbishment**	- Tower shaft Bearings replaced. - #2 Bearing overhauled. - #1.5/2 carbon seal upgrade SBs required. - 2.5 bleed valve overhauled.
HPC Group **Level of Maintenance – HM - Heavy Maintenance**	- 5 cracks found in 10-14 drum (C14 disk locking/ loading slots), which necessitated drum replacement. - Severe wear noted in C7 shroud. Wear indications noted between C7 blade platforms and C7 shrouds (i.e.: because of severe wear, shroud was moving axially to the point where it was contacting the spinning rotor, resulting in a — "machining" wear to 6-9 drum blade dovetail area—(see photos). - Extensive wear noted to HPC blade tip coating. - Above items necessitated a full disassembly of HPC including rotor drums. - HPC front case wall exhibited moderate wear from C7 vane contact (caused by worn VSV bushings). - HPC rear shaft exhibited wear on #3 bearing journal which necessitated removal and repair of journal. (See photos in appendix of above items).
Diffuser-Combustor Group **Level of Maintenance – HM - Heavy Maintenance**	- Module was routed for full disassembly and heavy maintenance.
Turbine Nozzle Group **Level of Maintenance – HM - Heavy Maintenance**	HPT-1 Nozzles exhibited burning and erosion (see photo).
HPT Group **Level of Maintenance – HM - Heavy Maintenance**	- HPT-1 and -2 blades exhibited severe burning and erosion (see photos). - T2 Retaining Plate under minimum builds goal and required replacement. - T2 Air seal required replacement with new owing to Airworthiness Directive requirement against installed PN.
LPT Group **Level of Maintenance – RPR - Repair/Partial Gas path Refurbishment**	- LPT-3 Vanes exhibited FOD-type impact damage and leading edge sulfidation (see photos). Destack of LPT required to address T3 vane distress. - LPT case wall vane mounting rail wear was noted (see photo). - T3 blade outer shrouds exhibited wear that necessitated their removal and overhaul (of all T3 blades).
Turbine Exhaust Case Group	- Routed pressure and scavenge oil tubes.

Level of Maintenance – RPR - Repair/Partial Gas path Refurbishment	- Exhaust nozzle missing.
Gearboxes Group – Main & Angle **Level of Maintenance of MGB – HM - Heavy Maintenance Level of Maintenance of AGB – HM - Heavy Maintenance**	- Both gearboxes were routed for full disassembly and overhaul.

7. PW4090 Engine Shop Visit High Cost Driving factors:

Based on the discussion with the respective Propulsion System Group and the Engineering Services management, it was noted that during this shop visit process, following factors that were driving the shop visit cost to a higher value and the same are noted as follows:

A. **Damages of engine major components**. Due to IFSD, more than 290 Line Items (Annex-12 B3) got damaged and declared scraped by United Airlines and Pratt & Whitney for engine serial no 222166 which necessitates purchasing the said quantity of new/used parts items available in the market. The cost of spares procured against the scrap material is approximately USD 16.66 million (Annex-12 B4) including handling charges. For engine serial no 222031, more than 200 line items got damaged (Annex-12 A3) and also declared scrap by United Airlines and Pratt & Whitney. The draft invoice submitted by the United Airlines is approximate USD 18.5 million (Cost of spares against scrap material USD 9.29 million, cost of LLP USD 2.94 million & NTE USD 6.124 million). So price increases considerably for both the engines.

B. **Cost of HPT Blade Set:** This repetitive defect of HPT Blade failure was discussed with the engine manufacturer, and this has been identified as the industry wide problem. Every airline/ operator of PW4090 engine has suffered a number of IFSD events at similar timings due to the HPT blade failure. As a remedy, the engine manufacturer has introduced a modified blade, though not identified as the final solution, but expected to reduce the failure rate with old blades. A set of new HPT Stage 2 blade costs US$ 1,011,880 Catalog Price (CLP).

C. **Non availability of Cost Estimates due to their conditions:** At the early stages of the shop visit process, the engine overhaul agency (United Airlines Engine Shop) usually provides the cost estimate for the engine. The cost estimate provides a guideline for Biman to assess how far the engine repair cost will end up and accordingly takes all technical decisions considering the safe operation of the engine as well as the aircraft. As such Biman requested United Airlines to provide the cost estimate for each engine immediately after framing the workscope and thereafter at every opportunity or even reminded them in several emails. But, due to the fact that the workscope was changing very rapidly because every parts that were sent for inspections and repair, in most of the cases, these parts were rejected for repair and was declared as scrap. And all these scrap replacement costs were continuously added up to the total projected shop visit cost. As such United Airlines was also unable to conclude to a cost estimate, although they were always responding to Biman that the cost estimate is under preparation and would be provided at the following week.

D. **Use of New Parts instead Used Parts:** Biman requested United Airlines for utilising used materials from the open market instead of using new parts from the engine manufacturer Pratt & Whitney to save the cost. As such United Airlines made repeated attempts to search for a used part, and since this model of engine is not very widely used, there were not many used parts available in the market. United Airlines even attempted to find unserviceable parts and send them to Pratt & Whitney for repair of the parts for using in Biman engines, and in many cases those parts were rejected for repair and were scrapped. All these attempts were made just to reduce the engine repair cost at minimum level.

E. **High price for high thrust engines:** As compared to any other engine model parts used for Biman fleet, the catalog price of each of the PW4090 engine parts is at much higher range. This is because mostly, there are not many populations of engines exist in the market, and also these engines are rated for a very higher level thrust and as such they are comparatively expensive parts than any other model of engines.

F. **Preparation of Cost Estimate was unascertainable for United due condition of EgyptAir Engine Parts:** Considering the realities above, United Airlines apparently was unable and as such did not provided the cost estimate for either ESN 222031 or ESN 222166 during this shop visit process to Biman, and as a result the total cost estimate for each of these engines remained at the levels of verbal discussions during initial Workscope preparation between Biman and United Airlines Engine shop to the tune of 15 to 16 Million.

G. **Up gradation of Engine Modules with New Parts due to non-availability of Old Configuration Parts:** During the shop visit process, it is also practiced that whenever there is a part scrap or up gradation of the module, the engine MRO consults with Biman to share the cost impact of the engine overhaul. Sometimes, the decisions are driven by either crack damage or an AD (Airworthiness Directive), and the technical decision has to be taken to overcome the situation either by a new or used parts replacement. But for these engines under repair at United Airlines, there have been many parts which could not be ascertained whether the same would be scrapped or not, even if it was scrapped, whether the same would be replaced by a used part or new. This is due to the failure of most repairable parts during repair process and finally had to replace by purchasing used serviceable parts from market as available or by new parts. As such, United Airlines engine repair system was unable to provide Biman an estimated cost for these two engines, despite the fact that United Airlines has provided an updated Scrap report every week to Biman, but the total cost impact was un-ascertainable.

H. **Replacement of LLP**. As per final invoice of engine serial no. 222166, 16 LLP item parts have been replaced which cost approximately USD 2.37 million (Annex-12 B4).

8. **Following is a brief summary of findings for the two engines under repair at United Airlines Engine shop along with their direct cost impact on those parts** Annex-8A1, 8B1 in CD**:**

ESN 222031 Findings and Observations [Engine damaged due Surge]
1. All Fan Blades damaged beyond repairable limits and scraped. (Replacement cost US$ 3,814,360 per CLP)
2. Engine stall with loud bang resulted Splitter Fairing torn off, Metal debris found at Tailpipe, N2 Rotor seized and Tail Cone was missing. Metal found in front bearing

compartment. These are all very high cost components thus involved huge cost at this shop visit.
3. LPC cases with missing sealant at gap at split line, damage observed to the fan exit case. (Unexpected findings, LPC Case repair alone cost US$ 195,168)
4. Bent splitter fairing attachment flange lugs on the LPC, Damaged HPC rotor. Also 8th and 11th stage HPC vanes scrap. Worn K/E seals and C-6 disk/air seal outer diameter damage. (Unexpected findings due engine surge)
5. HPT vane damage to all stages. All HPT 2 Blades fractured and impact damage to T-2 duct segments. (Replacement cost: US$ 1,115,540 per CLP for vanes)
6. Significant damage to HPT Stage 1 Blades rotating air seal, brush seal lands and airfoil damage. De-bladed all stages (T3-T9) of LPT rotor owing to blade damage noted on all stages. (These extensive workscope incurred additional cost than normal shop visit)
7. Damage to the full set of HPT Stage 1 Blades due to hot corrosion. (Replacement cost US$ 1,348,080 per CLP).
8. Scrap of HPT Stage 2 Air Seal due to Airworthiness Directive (replacement cost US$ 517,220 per CLP).
9. Damage to outer diameter leading edges of LPT Stage 3 nozzle guide vanes. Engine LPT blades damage. (Extensive damage due to surge of engine in flight)
10. Hydraulic lines with protective sleeve worn through by clamps, and note broken electrical connector. (Extensive damage due to surge of engine in flight)
11. Cracks found on Main Gear Box housing for ESN 222031, which scrapped due to major cracks as result of high vibration. (Additional major inspection findings due to surge and incurred cost– replacement cost US$ 331,120.00)
12. All HPT Stage 2 Blades had to be replaced with new set of post SB 72-319 blades. (Extensive damage of high cost items – replacement cost US$ 1,011,880)
13. Total of four (4) Pratt OEM brush seal PN 50K524-01 was replaced due to PMA. (Unexpected findings, replacement cost US$ 413,040 per CLP)
14. Severe Damage on Low Pressure Turbine Hardware which is located immediate aft of the HPT stage 2 (root cause of IFSD) forced replacement of LPT parts amounting US$ 10,000,000 per CLP.

ESN 222166 Findings and Observations

1. Significant damage observed in HPC and LPT modules that required the modules have to be disassembled to access the damage area and address the problem. (High cost materials)
2. HPC stage 7 shrouds have very severe wear. Additionally stage 7 blades exhibit obvious contact wear/rub in the airfoil "Area D" as well as along the aft platform edges. Stage 7 blades will require replacement. (Additional major inspection findings and incurred high cost)
3. Cracking was found in 5 of the loading/locking slots on the 14th stage disk. (Additional major inspection findings and incurred cost)
4. Install the existing 72 T2Bs after repair, remaining 10 T2Bs of the set to be replenished by serviceable blades. (High cost items in hot section of the engine)
5. The amount of existing damage on HPT blades are beyond an initial finding of stress and this engine was operating with burnt and liberated HPT blades. (Replacement cost US$ 1,348,080 per CLP)
6. T3 Vane Sulfidation and Damage. (Industry wide problem of this particular PW4090 engine and incur high cost)
7. LPT module L/E sulfidation observed on 16 T3 vanes, outboard concave side damage observed on 23 T3 vanes and one T3 vane found with material missing (internal cavity

visible). (Industry wide problem of this particular PW4090 engine and incur high cost)
8. Scrap of HPT Stage 2 Air Seal due to Airworthiness Directive (replacement cost US$ 517,220 per CLP).

9. Engine repair delayed at United for Parts shortage due various reasons; It is to be noted on the fact that each of the engine repairs was taking a very long time due to parts shortage for the following reasons:

(a) More and more inspection failure, need to open up the engine parts and modules to meet the Workscope Planning Guide (WPG) requirements; Annex-7AB1
(b) Difficulties to find the appropriate old configuration parts from the used market (as because the engine manufacturer Pratt & Whitney has stopped producing this old configuration);
(c) Sourcing used parts rather than using new parts to keep the cost minimum;
(d) The used parts had a two to three times rejection of repairs;
(e) Delay in parts supply from the engine manufacturer Pratt & Whitney.

10. Module Swap between ESN 222031 & ESN 222166:

A. Due to the fact that two more engines S/N: 222170 and S/N: 222213 were affected further by the HPT Blade Sulfidation, Biman Engineering was pushing United Airlines for an immediate delivery of the engines, or at least one engine at the soonest. Since there was longer time needed to repair the parts as well as waiting for the LPT parts to be delivered by Pratt & Whitney, and since 2 engines were operated under watch, Biman started dialogues with United Airlines to define the Test Schedule followed by an immediate delivery of the engines. On that move, both Biman and United Airlines started communicating on exploring the possibility of immediate build-up of at least one engine, out of the two engines that are waiting for different amount and number of parts. Though there were configuration and part number differences on the various modules and parts between the engines under repair, United Airlines performed side-by-side comparisons between the engine S/N's 222031 and 222166, at the piece part level, looking for exchange opportunities allowing completing one engine in shortest amount of time.

B. After a thorough engineering review, United Airlines proposed Biman on the possibility to build second inducted engine (ESN 222166) first, upon taking completed & usable parts from the first engine (ESN 222031), as most of the parts has been returned from repair or parts supplier vendor. To get the engine back expeditiously, both Biman and United Airlines agreed to build ESN 222166 first and then ESN 222031. The first engine ESN 222166 test was initially scheduled on 26-Dec-2015, but later on delayed further till 22-Jan-2016. Although the estimated completion date for the first engine produced is 26-Dec-2015, utilizing exchanges, United Airlines finally advised that ESN 222166 was tested on 22-Jan-2016, and is ready for shipment subjected to payment from Biman.

11. Issuance of Interim Invoice by United to Biman for ESN 222166 Annex-12B1 & 12B2**:**

A. In the meantime, as because the engine was under preparation for testing, United Airlines submitted their second Invoice for ESN 222166 as US$16,621,321.50 ($16.6 Million) to Biman for payment. Since Biman Engineering never had such an idea of cost impact for any of these two PW4090 engines, United Airlines was asked for explanation for payment of US$ 16.6 Million on top of NTE along with their supporting documents. Biman also made several communications to express the deep concern of such amount, and United Airlines explained the reasons for the cost that UA team members including their leadership have worked very hard to support Biman engines on daily basis and pay special attention to various requirements due to poor condition of engines. The team's goal has been to explore all available options in the industry to support the engine needs.

B. United Airlines also explained that the Technical Operations team continued to experience poor performance of parts and high maintenance cost of PW4090 engines driven by material failure and higher than normal scrap rates. The only solution that United Airlines and other operators have is to manage the problem and overcome the hurdle as a professional and experienced airline and maintenance organization. The conditions of PW4090 engines operated by Biman have proven to be amongst the worse that United Airlines observed to date. United Airlines has also had similar engine conditions as well due to various reasons. As MROs and/ operators try their best in managing the maintenance level and related costs, United Airlines have no control over condition and quantity of parts scrapped as result of engine manual limits. United Airline's initial response to Biman queries are as follows :

I. Majority of points in Biman's email communication are addressed within the contract and can be supported with required documents.
II. Outside vendor charges are estimated and within the NTE price. UA handling fees are limited and capped. Vendor charges are available for review by Biman.
III. All high priced scrap materials such as LLP, frames, cases, major housings and component replacements are available for review by Biman. UA's handling fees are limited and capped.
IV. New parts replacements for scrap material are charged at P&W 2015 catalog price. They are all available for review by Biman. UA handling fees are limited and capped.
V. All Component repairs are estimated and under the NTE price. Repair charges are limited to outline numbers in contract table. Information can be reviewed by Biman.
VI. Used material scrap replacement is agreed at 85% of list price with capped handling fees. Information is available for review by Biman.

C. Based on Biman claim for explaining the extent of ESN 222166 interim Invoice amount of US$16 Million, United Airlines sent following Comments to Biman Annex-12B2:

1. All the cost information under NTE price is limited in amount either as a fixed number or estimated number. Total amount cannot exceed the NTE price of $6.124M.
2. If there are any credits due to customer or estimated numbers are lower than agreed upon price, Biman will receive related credit.

3. More than 80% of engine shop visit cost is related to scrap material replacement. New material or used material.
4. Most costly scrap materials are new HPC, HPT and LPT blades and vanes. Additional scrap report with detail list price information was sent to Biman.
5. Scrap material and reports have the highest priority and were consistently forwarded to Biman. This covered over 290 line items of scrap part numbers for 222031 and more than 200 scrap line items for 222166.
6. Based on written and verbal communications, Biman team has consistently insisted and demanded that UA look for lower price replacement part. Biman also agreed to finding and routing used unserviceable parts with 30 to 45 days lead time in order to manage cost. This strategy worked for some parts but many others were scrapped during repair.
7. Reference written updates, numerous scrap part replacement candidates such as 10-14 stage drum, 15th stage disk, 6-9 stage drum, HPC rear shaft were inspected and sent to P&W shops for repair in order to avoid upgrade of both engine HPC modules. Reports were sent to Biman on number of LLPs scrapped by the OEM during inspection and repair procedure. United Airlines team was encouraged by Biman to continue the search in the market place for used LLPs and other scrap material.
8. Based on so many repairs of high value parts pending at the OEM and other vendor shops with unknown result of repair completion or scrap, it was impossible at the time to estimate a final repair cost. The scrap transaction of a few LLPs or blades and vanes force the requirement for configuration change and major cost fluctuations per module.
9. Biman's demand for exchange of parts and modules between 222031 and 222166 was accepted and welcomed by United Airlines team. The scrap replacement cost of parts related to one engine module as compare to other created another obstacle in producing an accurate or close estimate of final repair costs.
10. During November 2015, United Airlines was able to identify and/or collect all required parts per exchanged modules.

D. As because ESN 222166 has been tested and since the entire vendor Invoices are often comes with the final invoice after each engine delivery to Biman, United Airlines has invested all their efforts to extract as many documents available in the system and submitted to Biman for validation.

12. **Review of ESN 222166 Interim Invoices by Biman** Annex-12B2**:**

A. Upon receiving the documents (which are mostly vendor invoices for material purchase and repair of parts from outside vendors, it revealed that United Airlines USD spent 19 Million for the first engine against the two major driving cost components, like cost for replacement of Scrap materials and cost for repair of recoverable parts (Summery of all material/ parts purchase & repair invoice are attached). It may be mentioned here that due to severe Surging incident of ESN 222031 Parts, majority of the rotating as well as Static parts failed the inspection limits. It is also true that the inspection area for this had to be extended to comply with the manufacturer's recommendation for extensive inspection of the engine parts and modules. Besides this materials cost, there would be an added fixed cost for dis-assembly and

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assembly of the parts and modules, which is yet to be defined by United Airlines, and shall be submitted with detailed breakdown along with the final invoice.

B. And since to expedite the engine repair, both Biman and United Airlines decided to intermix the parts between ESN 222031 and ESN 222166, wherein majority of parts from ESN 222031 has been transferred to ESN 222166, and so as the cost of such parts been also transferred to ESN 222166. Accordingly, United Airlines built ESN 222166 utilizing ESN222031 HPC, HPT and LPT modules. Though the transfer of material cost increased ESN 222166 shop visit cost, but the second engine production had less scrap material cost but the HPC module upgrade (as older version of module is not available in the market) will further increase shop visit cost for second engine production.

C. Due to the module swapping between ESN 222031 and 222166, the major modules including the HPC module been crossed due to the fact that materials for ESN 222031 HPC module were not ready. Because of the HPC module LLP's like 4-10 Drum and HPC Rear Shaft scrapped were of old configuration, both United Airlines and Biman searched for used parts availability in the market after repeated attempts. Then, as there was no hope for finding this old configured LLPs, Biman had to decide to order for complete set of new HPC Module from the engine manufacturer, as it is not allowed to intermix parts between the Old and New configuration of HPC Module. Purchase price of this new HPC Module for ESN 222031 alone would cost US$ 2.1 Million.

D. Upon receiving the Interim Invoice for US$16 Million, Biman Engineering expressed extreme dissatisfaction to United Airlines, as the same is very much beyond the expectation of Biman. After several email correspondences, United Airlines proposed that Biman may review work accomplishment on both the engines versus the invoices submitted towards dealing with the situation, while providing Biman and senior leadership with required flexibility, time for investigation and detail information review to justify or reject any elements of invoice. United Airlines further suggested that there is no secret information or hidden agenda and moving forward further, Biman team and anybody assigned by the Board will have access to the details for work accomplishment and the repair charges involved for both the engines. Also, United Airlines team will be available to support Biman with information and documentation support to the Biman Board and lessor. Based on the situations mentioned above, the below mentioned actions and recommendations may be kindly be reviewed and approved:

1. United Airlines will continue to complete the post-test inspections for ESN 222166 towards preparing the engine for shipment so that, as soon as the payment issue has been resolved, ESN 222166 can be shipped immediately.
2. United Airlines will initiate the process of securing cargo space for shipment of ESN 222166 to Cairo or Dhaka.
3. United Airlines will cooperate closely with Biman Airlines in meeting Biman's desires and requirements for monitoring and reporting of remaining maintenance cost for ESN 222031.
4. Biman request flexibility on invoice partial payment to facilitate release of spare engine 222166 and ongoing maintenance on ESN 222031.

5. Biman will pay US$ 10 Million against the Interim Invoice of US$ 16 Million submitted to Biman, prior to shipment of ESN 222166.
6. Biman request extended time for detail investigation and review of all cost details according to contract for ESN 222031..

E. During the invoice review of ESN 222166, Biman Engineering team reconciled all the invoice items identifying them into following categories:

i) Module-wise fixed cost NTE for assembly/disassembly
ii) Repair of parts, components
iii) Replacement of scrap materials (both new and used)

A summary of the module-wise cost for ESN 222166 are as follows:

S. No	Description	Fixed NTE	Repair	Material	Total
1	Component / Accessory(In House)	$250,071.24		$168,056.09	$456,049.91
2	Component / Accessory(Outside Vendor)	$2,416,636.53	$312,605.99		$312,605.99
3	LPC Module	$50,537.00	$163,913.60	$151,574.54	$366,025.14
	Fan Case	$1,200.00			$1,200.00
4	LPC/LPT Coupling		$25,341.12		$25,341.12
5	Intermediate Case		$32,789.12	$152,459.35	$185,248.47
6	HPC Core		$16,316.16	$1,960,423.92	$1,976,740.08
7	HPC Rotor	$160,541.00	$3,237.92	$1,518,436.82	$1,682,215.74
8	HPC Stator		$158,708.29	$105,145.32	$263,853.61
9	HPC Stator Rear	$133,132.00	$332,520.16	$483,991.86	$949,644.02
10	Diffuser Combustor	$153,220.00	$242,720.64	$39,737.04	$435,677.68
11	Turbine Nozzle		$315,149.30	$336,900.00	$652,049.30
12	HPT Rotor	$64,451.00	$188,110.33	$4,110,191.48	$4,362,752.81
13	LPT Rotor	$259,929.00	$551,479.72	$7,572,117.96	$8,383,526.68
14	TEC	$750.00	$33,606.72		$34,356.72
15	Main GearBox	$114,502.00	$31,744.16	$61,897.67	$208,143.83
16	Angle GearBox	$65,208.00	$8,393.28		$73,601.28
17	LLP	$16299.33		$2,377,055.11	$2,377,055.11
18	Service Bulletins / COAS	$63,576.36	$1,757.50	$123,804.26	$125,561.76
20	Engine Test	$120,000.00			$120,000.00
21	Engine Disassy/ Reassy	$547,937.00			$547,937.00
TOTAL		$4,417,990.46	$2,416,636.53	$19,161,791.42	**$23,581,539.38**

Investigation Report

A summary of the module-wise cost for ESN 222031 are as follows:

S. No	Description	Fixed NTE	Repair	Material	Total
1	Component / Accessory(In House)		$450,000.00	$222,120.60	$672,120.60
2	Component / Accessory(Outside Vendor)		$306,302.07		$306,302.07
3	LPC Module		$536,526.58	$355,731.82	$892,258.40
	Fan Case	$1,200.00	$198,681.60	$70,342.00	$270,223.60
	Fan Blades			$1,348,000.00	
4	LPC/LPT Coupling	$80,909.00	$15,067.36	$8,016.08	$103,992.44
5	Intermediate Case	$90,870.00	$41,892.48	$521,308.22	$654,070.70
6	HPC Core		$903,000.17	$976,822.28	$1,879,822.45
7	HPC Rotor	$160,541.00			$160,541.00
8	HPC Stator				$0.00
9	HPC Stator Rear	$133,132.00			$133,132.00
10	Diffuser Combustor	$153,220.00	$223,736.53	$338,223.45	$715,179.98
11	Turbine Nozzle		$375,220.24	$372,460.00	$747,680.24
12	HPT Rotor	$64,451.00	$539,935.35	$2,375,492.68	$2,979,879.03
13	LPT Rotor	$259,929.00	$761,307.89	$2,157,226.36	$3,178,463.25
14	TEC	$61,144.00	$33,847.52	$6,640.28	$101,631.80
15	Main GearBox	$114,502.00	$892.64	$476,639.74	$592,034.38
16	Angle GearBox	$65,208.00		$67,377.81	$132,585.81
17	LLP			$2,947,921.87	$2,947,921.87
18	Service Bulletins / COAS			$220,553.88	$220,553.88
19	Pratt Engineering Service				$0.00
20	Engine Test	$120,000.00			$120,000.00
21	Engine Disassy/Reassy	$547,937.00			$547,937.00
TOTAL		$1,853,043.00	$4,386,410.43	$12,464,877.07	**$18,704,330.50**

F. As a next attempt, teams from both Biman and Egypt Air visited United Airlines, San Francisco, USA facility during 23~28 May 2016 to review scrap parts and supporting documents to determine the total repair cost payable for Engine S/N 222166. During this review process every amount charged to Biman has been checked and verified in reference to the agreed workscope, provisions of engine maintenance agreement between Biman and United and the Pratt & Whitney Parts Catalog 2015. All the scrap materials were also inspected physically by the teams from Biman and EgyptAir including their scrap reasons and quantity. Annex-12B5

G. After review, the total repair cost for engine S/N: 222166 stands at US$ 23,581,539.38, after adjustment of all valid invoice review claims by Biman and EgyptAir for an amount of US$ 737,567.06. So far Biman paid total US$ 16,124,000.00; therefore total remaining amount payable to United Airlines is US$ 7,457,539.38. Following is the total Invoice status for ESN 222166 Annex-12B6:

Invoice	Number	Date	Amount	Biman Paid	Amount Due
1st	PB00014016	27 July 2015	US$ 6,124,000.00	US$ 6,124,000.00	--
2nd	PB00016608	01 December 2015	US$ 16,621,321.50	US$ 10,000,000.00	US$ 6,621,321.50
3rd	PB00019398	12 April 2016	US$ 1,573,784.94	--	US$ 1,573,784.94
TOTAL			US$ 24,319,106.44	US$ 16,124,000.00	
Credit			(US$ 737,567.06)	--	(US$ 737,567.06)
		NET FINAL COST	**23,575,539.38**	**BALANCE PAYABLE**	**US$ 7,457,539.38**

I. The statement above was also placed in the 167th Meeting of the Biman Board of Directors for appraisal and kind approval of US$ 23,581,539.38 as the total shop visit cost for ESN 222166. Annex-12B7

13. Sharing of Cost for ESN 222031 and ESN 222166 Overhaul between Biman and EgyptAir Annex-12B5 & 13A4:

A. Since the engines (ESN 222031 and ESN 222166) were operated by EgyptAir prior to their delivery to Biman, as such there would be a cost sharing for the total shop visit cost between Biman and EgyptAir as per provisions of the agreement. Besides, during the period of Biman operation, Biman paid the maintenance reserve every month to EgyptAir which is accumulated with EgyptAir. All these cost sharing's shall be reimbursed after appropriate review of all invoices and other shop visit reports and the vendor invoices for material purchase and repair. As part of such Invoice review, Biman already requested EgyptAir for being part of the review so that, both Biman and EgyptAir have a clear understanding to verify all the amounts payable to United Airlines, and necessary preparations for obtaining approvals from the Biman Board can be arranged. Final Invoice payment and reconciliation would be after submission of a complete Final Invoice for both ESN 222031 and 222166, which shall be reviewed by Biman and verified for each material purchase or each vendor repair invoice to be submitted along with the Final invoice for each engine to Biman.

B. Accordingly, a meeting between Biman and EgyptAir was held during 22 – 24 February 2016, and had elaborate discussions on the various technical aspects of the engines (ESN 222031 & 222166) along with the damages noted after open up of these two engines at United Airlines Engine Shop. It was noted during the meeting that damages to the internal Blades, Vanes on all HPT and subsequent LPT Stages and also the associated Disk & Drum LLP's were caused by the severe Surge related in-flight-shutdown event. All the internal parts were finally rejected by

engine manufacturer Pratt & Whitney due beyond repairable limits and therefore had to be replaced with either used or new material, which involved costs for the engine. It may also be mentioned here that ESN 222166 was removed due several HPT Stage 1 Blade mid-chord burnt out and also involved similar cost for all HPT Stages. Besides, due to non-availability of old configured HPC Module LLP, the complete HPC Module had to be up-graded with full set of new LLP's, that alone involved additional cost of US$ 2.1 million.

C. Biman also requested EgyptAir that since there would be a significant amount against ESN 222166 (to the tune of US$ 13 Million) needs to be shared by EgyptAir, and since Biman is also in financial constraints, as such Biman requested for an advance reimbursement of US$10 Million from EgyptAir so that the engine can be released immediately from United Airlines. This advance shall be adjusted with the final portion of EgyptAir sharing of cost on the account of ESN 222166, once the final invoice has been reviewed and the portions for both Biman and EgyptAir has been finalized.

D. In the meantime, United Airlines submitted draft Final Invoices for ESN 222166, where they have charged a total amount of US$ 24,396,949.17 and charged US$ 18,704,331.27 for ESN 222031. Both Biman and EgyptAir shall review these two final invoices in totality and other documents, to determine the amounts payable to United Airlines for ESN 222166 and 222031. Biman and EgyptAir discussed about justification of invoice amount for engines and Egypt Air mentioned that based on their experience, it is not unexpected level of shop visit cost for such extensively damaged engines. Biman and EgyptAir will also determine the amount of cost sharing for each of ESN 222166 and 222031 and will arrange payments accordingly so that the engines can be returned from United Airlines at the soonest.

E. Both Biman and EgyptAir discussed about the Cost Sharing for the first and second engine shop visit in line with the provisions of agreement and per discussion of last meeting held during 05~07 July 2015 at Dhaka. It was also informed by Biman that despite several attempts and initiatives taken by Biman with assistance from EgyptAir, the insurance claim for ESN 222031 was denied by MARSH. Further discussion concluded that EgyptAir will participate in the engine shop visit cost per agreement Clause 6.1 on top of accumulated Maintenance Reserve during both Biman and Egypt Air's operating period. On ESN 222031, EgyptAir used 2767 FH/ 877 FC and Biman used 3,317 FH/917 FC, while on ESN 222166 Egypt Air used 2516 FH/ 1096 FC and Biman used 3484 FH/ 970 FC. EgyptAir agreed to contribute per agreement on pro rata basis to the total shop visit cost on top of accumulated Maintenance Reserve. Besides, per Dry Lease Agreement Clause 6.1.2, the additional amounts after adjustment of Supplemental Reserve shall be paid by both Parties in pro rata if the shop visit cost exceeds the contribution of both the parties.

F. During the meeting with EgyptAir at San Francisco, the following points were discussed and minuted on the sharing of cost for ESN 222166, which are as follows:

1. EgyptAir has received all the supporting documents for ESN 222166 Invoice; EgyptAir will discuss internally to define the cost share amount for ESN 222166.

2. EgyptAir will visit Biman by 06-07 June 2016 to finalize the amount to be shared by EgyptAir for ESN 222166.

3. By 10 June, 2016, cost sharing for ESN 222166 will be finalized between Biman and EgyptAir.

4. EgyptAir will pay their share on cost to Biman including accumulated maintenance reserves on ESN 222166 accordingly.

G. EgyptAir and Biman will review final draft version of the ESN 222031 Invoice and supporting documents and will plan to visit United Air within 3rd week of June 2016. Accordingly Final Invoice will be agreed and approved and cost sharing will be discussed, defined and will be paid. During the visit to United Air to review the final Invoice for ESN 222031, Table Inspection will be carried out and timeline for completion of 3rd Engine will be agreed on.

H. United informed Biman and EgyptAir that PW4090 ESN 222031 has been tested and ready for shipment subjected to the review of Final Invoice and payment of interim invoice. For initiating the intermediate review of the documents for ESN 222031, both Biman and EgyptAir requested United to provide a final draft version of the Final Invoice for ESN 222031 along with their associated supporting documents. United agreed to provide the final draft version of the Invoice for ESN 222031 by early next week. Upon receiving the final draft version of the ESN 222031 Invoice, EgyptAir will start reviewing the Invoice.

14. Boeing provided Cost estimates for repair of PW4090 Engines:

Boeing opined that Boeing Airline Economics group on PW 4090 overhaul costs and received the following info. Please note that these are only estimates since Boeing lacks any real data on this level of work:

1. Cost to overhaul engine with only sulfidation issues: approximately $9-11M (core only)

2. Cost to accomplish PW Engine Heavy Maintenance: approximately $11-14M (depending on work scope)

In addition, a full stack of LLPs is approximately $12.5M. If replacing half the stack during the overhaul, the total shop visit could be approximately $20M. Annex-14 AB1

15. Interview of the personnel concern for Engine Overhaul/Repair:

Series of interviews and open discussions on the high shop visit cost of PW4090 Engines S/N 222166 and S/N 222031 was held with the propulsion group of Engineering Services including Dy. Chief Engineer, Engineering Services and Chief Engineer, Engineering Services. Selective questionaries' were asked to Manager Insurance, Dy. Chief Engineer, Engineering Services, Dy.

Chief Engineer, Engineering Planning, Records and Docs and Chief Engineer, Engineering Services in connection with the investigation (Annex-4AB1).

16. Observation/Findings contributing to the high cost for PW4090 Engine Shop Visit :
The Committee reviewed and observed the following initial observations in respect to the PW4090 engine :

1. IFSD and Turbine Blade crack for both the engines were caused due to Blockage of HPT blades cooling holes by sulfidation. Thus the major components of both the engines were severely damaged and the engine shop visit cost increased enormously.
2. PW4090 Model is a very high thrust engine; max thrust is 90,000 lbs., designed for supporting high payload and long range operations of 777-200 airplanes.
3. Due to high thrust rating, all breakdown engine parts are very expensive as compared to the lower thrust engines (Annex 8A1, 8B1 & also CLP).
4. New Parts from the engine manufacturer are very expensive; the LPT Module alone can cost US$ 10 Million as per PW CLP.
5. Availability of used parts in the market is very limited, as there is only a few numbers of engines that are operating worldwide.
6. EgyptAir engines (ESN 222031 and 222166) are currently at 3rd Run engine operation (TSN 43,744 hours, CSN 10,372 and TSN 36,159, CSN 8,645 respectively) and they can be classified as very old engines, as such they require a full overhaul for all the Modules.
7. Due to EgyptAir engine maintenance policy of Modular maintenance into their own engine shop, they did not send the complete engines to their authorised engine shop.
8. EgyptAir also did not perform full overhaul to all the Modules of these engines during their period of operation.
9. All engines belonging to the leased aircraft from EgyptAir were in Old Configuration of PW4090 parts. In many cases, old configuration parts are not currently available in the market, and also not supplied by the engine manufacturer Pratt & Whitney.
10. Due to the incident of in-flight-shutdown event, ESN 222031 suffered full overhaul at all the Modules and required majority of the parts to be replaced, which had a huge cost impact.
11. Most of the internal parts were finally rejected by engine manufacturer Pratt & Whitney due beyond repairable limits and therefore had to be replaced with either used or new material, which involved costs for the engine.
12. The other engine S/N 222166 also needed to undergo for full overhaul to the major Modules, due to their inspection findings and to comply with the engine manufacturer's recommended workscope level.
13. Biman did not ever dealt with the full overhaul of such bigger and high thrust engine, and never handled shop visit cost to that value.

14. A high level engineering and finance team from Biman and EgyptAir reviewed the Invoice of ESN 222166 to verify every details of the Invoice.
15. Preliminary assessment of the draft final invoices and their associated supporting vendor invoices indicated shop visit cost similar to what United had placed into their draft invoices.
16. For expediting the re-delivery of at least one engine out of ESN 222031 and ESN 222166, both Biman and EgyptAir decided to perform a Module Swap between these two engines, and accordingly the first engine tested was S/N 222166, which is currently awaiting delivery from United Engine Shop at San Francisco.
17. The high cost involvement for repair / overhaul of ESN 222031 and ESN 222166 was on actual basis and of no individual was found directly responsible for any additional cost to the repair of ESN 222031 and ESN 222166.
18. More than 80% of engine shop visit cost is related to scrap material replacement. New material or used material.
19. Most costly scrap materials are new HPC, HPT and LPT blades and vanes. Additional scrap report with detail list price information was sent to Biman.
20. Scrap material and reports have the highest priority and were consistently forwarded to Biman. This covered over 290 line items of scrap part numbers for 222031 and more than 200 scrap line items for 222166.
21. Invoices have been reviewed for the high cost item against PW prize catalog list and found correct.

17. Conclusion : Based on the findings above, the Committee concluded the following :

01. IFSD and Turbine Blade crack for both the engines were caused due to Blockage of HPT blades cooling holes by sulfidation. Thus the major components of both the engines were severely damaged and the engine shop visit cost increased enormously.

02. Nobody is found directly responsible for high shop visit cost to the repair of ESN 222031 and ESN 222166.

18. Recommendations:

A. Necessary advice may be sought from Pratt & Whitney, (OEM of the engine) to stop recurrence of such incident of PW4090 engine.

B. As per lease agreement Repair cost should be settled with EgyptAir.

C. Biman Insurance policy may be reviewed by technical, financial and legal experts to get maximum coverage.

D. Pratt & Whitney should be approached for compensate Biman as an operator for the huge shop visit cost of PW4090 engines due to material failure (Evident by metallurgical failure analysis by United Air Lines).

E. As per Biman operation plan, hour/cycle ratio of Boeing 777-200ER is 3.5:1 which needs to be increased to reduce the shop visit cost of this engine.

F. Concern Biman official (one or two person) may be present to oversee during engine Shop visit, repair work or complete overhaul of PW4090 engine.

14/06/16 Md. Ali Naser, DGM Training (Engineering Faculty, BATC) Member	14/6/16 Wing Commander Md. Tariqul Islam, PSC (BD/8556) Engg. BAF Base Member

14.06.2016

Md. Shafiqul Alam Siddique,
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Quality Assurance
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