PART 1.4 – FINDINGS

INTRODUCTION

1.4.1 The XZ210 Service Inquiry (SI) was convened on 5 Dec 11 to investigate the circumstances surrounding the loss of a Gütersloh based Army Lynx helicopter and to make recommendations in order to prevent recurrence and enhance air safety. While the main focus for the inquiry's determination of causal factors was on the technical aspects of the accident, a wide range of related issues were investigated to inform the Panel's findings set out in this part of the report. Although the SI Panel was dislocated from the country where the accident occurred throughout the majority of the inquiry, this did not prove a significant hurdle; particularly as the ac remains had been transported to UK for examination.

1.4.2 The controlled nature of the forced landing meant that, other than minor impact on the main rotor blades, damage to the ac was caused primarily by a mechanical failure and resultant fire. This assisted the focus of the subsequent examination of the ac remains. The timeline for the inquiry was driven largely by the detailed forensic technical investigation of the ac engines undertaken by RR under the supervision of MilAAIB Investigators.

METHODOLOGY

Accident Factors

1.4.3 Each finding by the Panel is attributed the following accident factors[1]:

a. **Cause**. Factors that led directly to the accident.

b. **Contributory**. Factors that did not directly cause the accident, but made it more likely.

c. **Aggravating**. Factors that did not cause the accident but made the final outcome worse.

d. **Other**. Factors that were none of the above but could cause, contribute to, or aggravate a future accident.

e. **Observations**. Factors that, whilst not germane to the accident and not thought likely to influence a future accident, were considered important aviation safety-related issues worthy of comment.

Human Factors (HF) Modelling

1.4.4 The Panel has exploited the work of Prof James Reason, Known colloquially as the 'Swiss Cheese' model (Reason, 1997), in its analysis of the accident involving XZ210 by assessing evidence across the following categories[2]:

a. **Unsafe Acts**. Fact-based non-judgemental statements aimed purely at categorising potentially unsafe acts of an individual (or team), whether intentional or unintentional; the aim being to clearly identify specific error types so that a correct assessment can be made of human performance issues relating to cited accident factors. Grouped as[3]:

[1] Aviation Safety Information Management System (ASIMS) User Guide, V3.1.
[2] ASIMS exploits a similar methodology.
[3] Note for the purpose of this SI, the Panel considers an error has occurred when the individual (or team) fails to achieve what a given situation required (whether a consciously planned action or not).

(1) **Unintentional Acts**

(a) **Slips**. Error by commission; where a well practiced skill, requiring little cognition, is carried out incorrectly.

(b) **Lapses**. Error by omission; where a well practiced skill, requiring little cognition, is not carried out.

(2) **Intentional Acts**

(a) **Mistakes**. Deficiencies in judgement and/or failing to formulate the right plan based on flawed knowledge and/or incorrect comprehension of rules.

(b) **Violations**. Deliberate and conscious departures from established rules/procedures, although often with no intent to cause harm.

b. **Error Promoting Condition (EPC)**. The psychological, physical/mental limitations and physiological factors that can influence human performance, i.e. capacity, fatigue, etc.

c. **Organisational Influences**. The broader (often indirect and latent) influences that a higher organisation brings to bear on those involved in an occurrence, and which are beyond those individuals' control in terms of resources, climate, etc.

d. **Breached (or failed) Defences**. Those rules, orders, practices and procedures designed to assure the safe operation of ac, which failed or were breached by those involved.

Causation

1.4.5 Key to the Panel's exploitation of Reason's HF model was a coherent and consistent approach to understanding accident causation. This in turn facilitated a clear understanding of short-comings within each category, for which the Panel could consider appropriate intervention strategies; thereby delivering recommendations targeted at preventing or reducing the likelihood of recurrence.

Available Evidence

1.4.6 The Panel had access to the following evidence:

a. Interviews with the crew of XZ210 and other witnesses.

b. Formal statements from witnesses.

c. CVR data of the sortie.

d. Photography from various sources.

e. Relevant orders, Terms of Reference (TORs) and documentation including flying logbooks, ac documentation, sortie planning, briefing materials and engineering documentation.

f. Wreckage of XZ210.

g. Ac technical report by MilAAIB.

h. Technical reports by 1710 NAS (MIG).

i. A detailed review of XZ210 documentation conducted by the JHC Air Engineering Assurance Team (JAEAT).

j. Reports provided by RAF Centre for Aviation Medicine (RAFCAM).

(1) Medical.

(2) HF.

(3) Aircrew Equipment.

k. Flying (simulated) assessment by the Aircrew Member.

l. All flight safety related material, including ASIMS and Lynx Project Team (PT) reports.

m. Previous Accident Reports.

n. MAA JHC Assurance Audit.

Unavailable Evidence

1.4.7 The Panel did not have access to the following evidence:

a. Those parts of the ac destroyed by fire.

b. All information drawn on crew maps and aircrew notebooks along with the contents of personal nav bags which were destroyed in the fire.

Services

1.4.8 The Panel was assisted by the following personnel and agencies:

a. 1710 NAS (MIG).

b. Agusta Westland (AW).

c. Army Aviation Standards.

d. ATLAS Operational Security.

e. Defence Equipment and Support (DE&S) Helicopter Engines PT.

f. DE&S Lynx PT.

g. Directorate Electrical and Mechanical Engineering (Army) (DEME(A)).

h. INM.

i. JARTS.

j. JHC.

k. MilAAIB.

l. QinetiQ.

m. RAF Benson.

n. RAFCAM.

o. RR.

p. Thales Lynx Simulator.

Factors Considered by the Panel

1.4.9 The following factors were considered by the Panel, from which accident factors have been determined along with relevant categories from Reason's HF model:

a. **Pre-Accident**

(1) Ac Maintenance History & Preparation for Flight.

(2) Crew Composition.

(3) Crew Readiness.

(4) Aircrew Authorisations & Qualifications.

(5) Sortie Details & Preparation.

(6) Aircrew Supervision.

(7) Sortie Execution.

b. **Accident**

(1) Accident Sequence.

(2) Crew Handling of the Emergency.

c. **Post Accident**

(1) Survival Aspects.

(2) Personal Aircrew Equipment Assemblies.

(3) PCM.

(4) Salvage Operations.

(5) SHE.

(6) Costs of Damage to Ac & Civilian Property.

d. **Related Issues**

(1) Low Pressure (LP) Fuel Pipe Modifications.

(2) Other relevant modifications.

(3) 1 Regt AAC Wksp REME Manning.

(4) Early Failure Detection (EFD).

ANALYSIS OF FACTORS

Pre-Accident

Ac Maintenance History

1.4.10 An independent inspection was carried out on XZ210 MF700 series documentation, the primary ac record determining ac airworthiness. The review was carried out by the JAEAT to ascertain the standard of practice/husbandry employed at 1 Regt AAC Wksp REME. No significant issues with the ac documentation were raised. The Panel found that the procedures for maintaining the MF700 were followed correctly and that ac documentation was **not a factor**. Exhibit 139

Crew Composition

1.4.11 During the week when the accident occurred, only one CM was available at 1 Regt AAC to participate in the limited number of sorties planned. When the flying programme was originally constructed, the plan for the QHI check sortie in question had not included a CM as part of the crew. On 1 Dec 11, the sole CM was required to fly on Exhibit 246 Witness 3

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the 1st sortie of the day as it involved trooping serials; however, noting that his ac was programmed to be used for the subsequent sortie, he spoke with the QHI and offered to fly on both sorties.

1.4.12 The crew that flew on the sortie in question was on duty and correctly constituted for the task to be undertaken. The positive role played by the CM in the outcome of this occurrence is detailed later in this report; the Panel found that crew composition was **not a factor**. Exhibit 097 Exhibit 098 Exhibit 099

Crew Readiness

1.4.13 Within the preceding 24 hrs, all 3 crew members were found to have been within crew rest period limits as regulated by the JHC Flying Order Book (FOB); in the previous 30 day period the QHI had flown 21 hrs 35 mins, the LHS Pilot 14 hrs 55 mins and the CM 25 hrs. There was no evidence of any HF issues that might have affected the crew's preparedness. The Panel found that crew readiness was **not a factor**. Witness 1-3 Exhibit 097 Exhibit 098 Exhibit 099

Aircrew Authorisations and Qualifications

1.4.14 The QHI self authorised appropriately for the sortie as ac cdr; he was qualified to do so as shown in the 1 Regt Powers of Authorisation Register. The crew members were correctly qualified on the Lynx Mk7 and were in current flying practice with no outstanding training deficiencies. All crew members were in-date for drills, other than the QHI, who was not current for his Lynx egress drill qualification. Exhibit 245 Exhibit 097 Exhibit 098 Exhibit 099

1.4.15 The QHI had recently arrived from MW after completing the Lynx RTT course, during which time he had not completed an egress drill. Although this qualification was not a programmed activity of the Lynx RTT, the joining instructions stated that individuals were responsible for booking and maintaining their own training relating to flying currencies during the course, including egress drills. These instructions included details of all the required currencies and the relevant contact details for respective training providers. The Panel made the **observation** that there was no staff check of log books on completion of the Lynx RTT to confirm that individuals had maintained / achieved the non-timetabled currencies by the end of the course. Exhibit 243

1.4.16 At 1 Regt AAC, qualification and drill currencies were managed through an intranet hosted stand alone Excel spread sheet, where aircrew entered the details of their currencies. The system was not automated and did not highlight deficiencies. The Panel made the **observation** that other JHC units used the Squadron Training Achievement Recording System (STARS) to help record and monitor aircrew currency.

1.4.17 While the Panel judged that the QHI's lack of egress drill currency had no significant impact on this accident, it did consider that it had been a **breached defence**. In other circumstances this might have influenced the outcome of events, particularly with less experienced aircrew; therefore, aircrew qualification and authorisation was deemed to have been an **other factor.**

1.4.18 Whilst investigating the Lynx egress drill issue, the Panel also made the **observation** that there was no formal egress drill syllabus for the Army Lynx. As a result, content was at individual Search Evade Resist Extract Officer's (SEREO) discretion and therefore it varied from person to person, potentially even between members on the same sqn. Exhibit 238

Sortie Details & Preparation

1.4.19 **Pre-sortie Brief**. A crew brief, following JHC Lynx SOP 18 format, was completed in the Regt briefing facility. Although both pilots were present for the brief, the CM was airborne on another sortie; however, the LHS Pilot ensured that he briefed the CM fully between sorties. The RQHI's Office was in the vicinity of the briefing room and the QHI paused the sortie outbrief on 2 occasions in order to attend to phone calls, which he believed were related to the impending MAA audit; however, there was no evidence to suggest that the brief was compromised or not fully completed. The Panel considered the sortie was adequately planned and briefed and this was **not a factor.** Exhibit 273 Witness 1 Witness 2

Aircrew Supervision

1.4.20 The QHI briefed the DAC, a fellow QHI and qualified authoriser, on sortie content, covering the planned route and his intentions regarding the exercises for which he had self authorised. During the sortie, the DAC undertook flight following responsibility for XZ210, remaining in AIS throughout. He was immediately on hand when the crew of XZ210 telephoned AIS following the forced landing and carried out appropriate subsequent actions. Witness 1 Witness 4

1.4.21 The Panel reviewed the Gütersloh FOB in relation to the supervision and authorisation of sorties and concluded that the regulations were considered appropriate and that they were followed satisfactorily. The Panel found that aircrew supervision was **not a factor**. Exhibit 100

Sortie Execution

1.4.22 Analysis of the CVR indicated that the crew executed the sortie up to the point of the accident events as planned and briefed. The Panel found that sortie execution was **not a factor**. Exhibit 103

Accident

Accident Sequence

1.4.23 The crew all reported a loud bang at the initiation of the emergency, followed by a 10° yaw, coupled with ac instability, after which the cabin and cockpit filled with dense smoke which obscured their vision. Initial examination at the crash site was carried out by MilAAIB investigators and representatives from RR. The early evidence focussed attention on the No2 engine which led to a detailed engineering investigation of the remains. This was carried out on the Panel's behalf by RR, under the guidance of MilAAIB advisors. The full results of the technical investigation are at Annex G. Witness 1-3

1.4.24 **Gem Engine Description**. The Gem engine is a twin spool FPT engine of modular construction. There are 7 interchangeable engine modules:

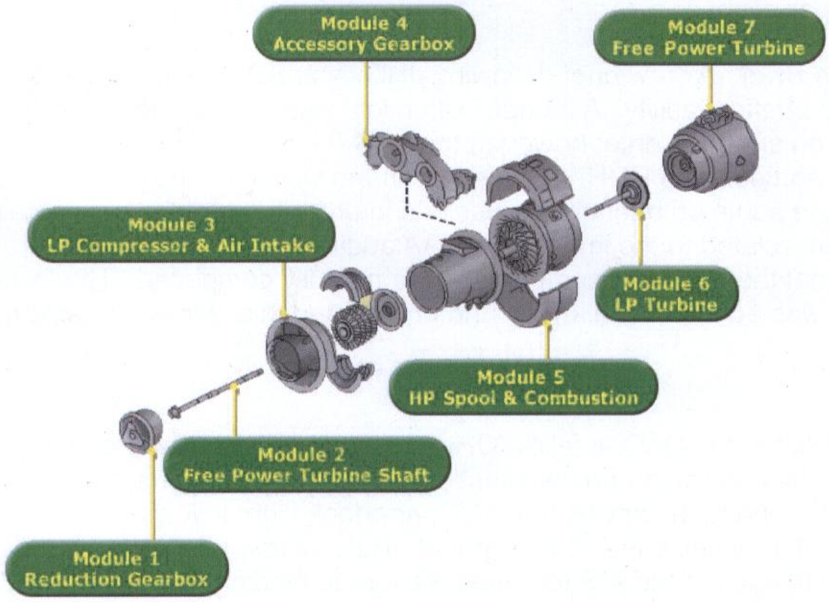

Fig 1 – Gem Engine Modules

a. Module 1 (Reduction Gearbox) - Epicyclic gearbox that reduces the engine output speed and transmits the drive to the main rotor gearbox. It is located at the very front of the engine.

b. Module 2 (FPT Shaft) - A hollow shaft that runs through the middle of the engine, it transmits the drive from both FPT stages to Module 1.

c. Module 3 (Air Intake and LP Compressor) - Behind the annular air intake is the 4-stage axial compressor. The compressor is mounted inside the inter-stage casing.

d. Module 4 (Accessories Gearbox) - Driven by the High Pressure (HP) spool, it is mounted on top of the engine, it provides the drive for the Oil Pump Assembly and High Pressure Turbine (Nh) Tacho, Centrifugal Breather, Fuel Control Unit (FCU), Oil Cooler Fan and Starter Generator.

e. Module 5 (HP Spool and Combustion Chamber) - The HP spool comprises a centrifugal compressor driven by and connected to an un-shrouded turbine. In front of the centrifugal compressor is a bevelled gear that transmits the drive vertically to Module 4. The combustion chamber is a reverse flow annular type. The main fuel supply is via a ring of 17 vaporising nozzles mounted around the combustion casing.

f. Module 6 (LP Turbine and Shaft) - A single stage shrouded turbine and shaft that connects the turbine to the LP compressor.

g. Module 7 (FPT) - The 2-stage shrouded FPT is located inside the exhaust casing at the rear of the engine. It is driven by the hot exhaust gases and transmits the engine power through Module 2 to Module 1. **Module 7 became the main focus of the engineering investigation.**

1.4.25 **Bang**. The first indication of any malfunction that the crew experienced was a loud bang emanating from above and behind them, on the starboard side of the ac. The preliminary conclusion of the subsequent engineering investigation was that the noise was the result of an FPT breakout from the No2 engine. There was a circular cut through almost the entire circumference of the Module 7 casing and the internal components were visible. Annex G

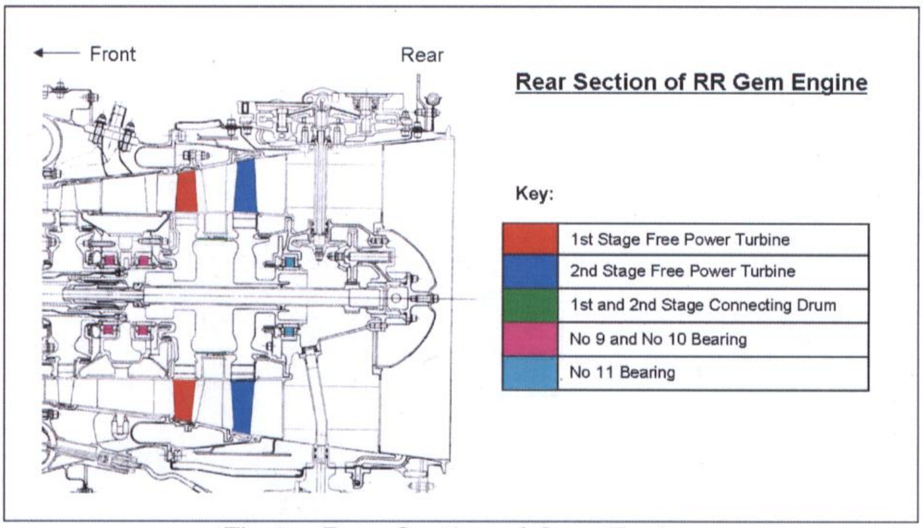

Fig 2 – Rear Section of Gem Engine

1.4.26 Until the FPT failed there had been no indication of impending breakdown of the No2 engine during the sortie. However, the explosive disintegration of the FPT was the final event in the failure sequence which may have started a relatively short time before, perhaps mins or secs. After discounting the possibility of engine control, lubrication system, foreign object damage, Module 1, bearings forward of Module 7 and drive shaft failures as catalysts for the start of the failure sequence, the Module 7 was examined more closely.

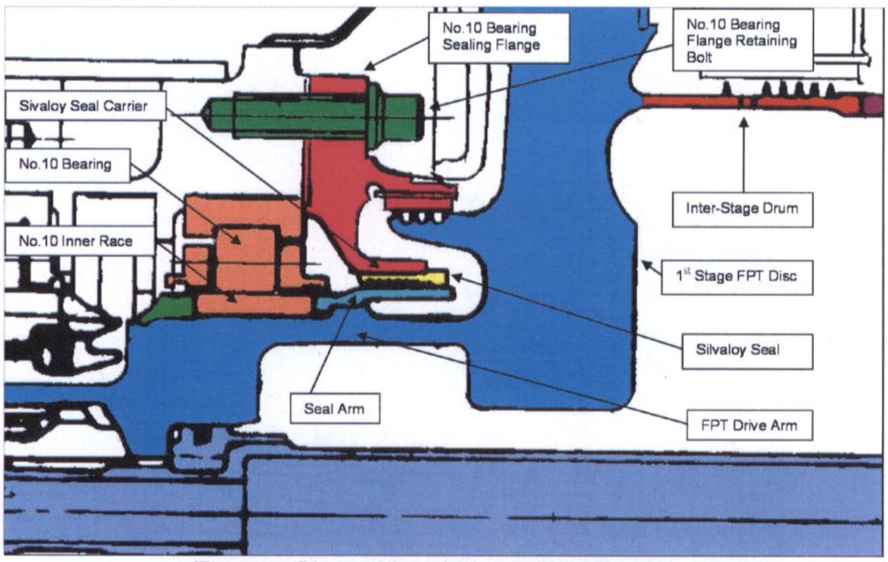

Fig 3 – Close-Up of No10 Bearing Area

1.4.27 The evidence showed that a two part sequence of events within the engine took place: Annex G

a. **No10 Bearing Sealing Flange Retaining Bolts**. The first part of the sequence initiated within the Module 7 whereby all 11 of the No10 bearing sealing flange retaining bolts had loosened over a long period of time (up to 1530 hrs). This allowed a micro-movement of the No10 bearing sealing flange causing a significant contact rub between the silvaloy seal and seal arm. The rub led to the subsequent mechanical failure of the silvaloy seal carrier location welds and an increased frictional distress in this area. This in turn generated significant heating which manifested itself at its most intense where the seal arm was attached to the FPT drive arm in the vicinity of the No10 bearing inner race. As a result, the seal arm and No10 bearing inner race started to slip on the FPT drive arm, generating even more heat, leading to the eventual failure of the FPT drive arm under torsional load, disconnecting it from the Module 2 FPT shaft.

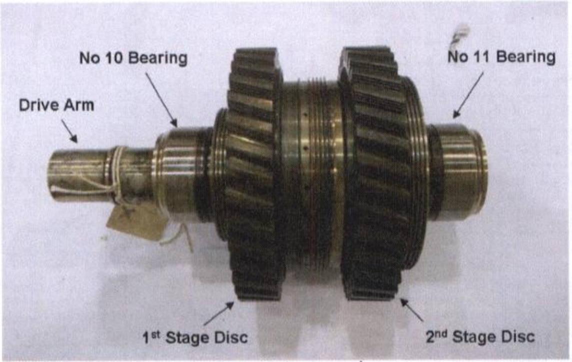

Fig 4 - Example 1st & 2nd Stage Disc (without aerofoils) and Drum Assembly

Fig 5 – No10 Bearing Flange (with Air Baffle removed)

b. **Drive Arm Failure**. The second part of the sequence started immediately after the drive arm failed allowing the now unloaded FPT to rapidly accelerate into an overspeed condition. The centrifugal load on the 2nd stage FPT blades was such that all of the blades failed in the aerofoil section above the fir tree root. They were then released radially outwards with enough explosive energy to cut through the Module 7 casing and further damage components within their trajectory.

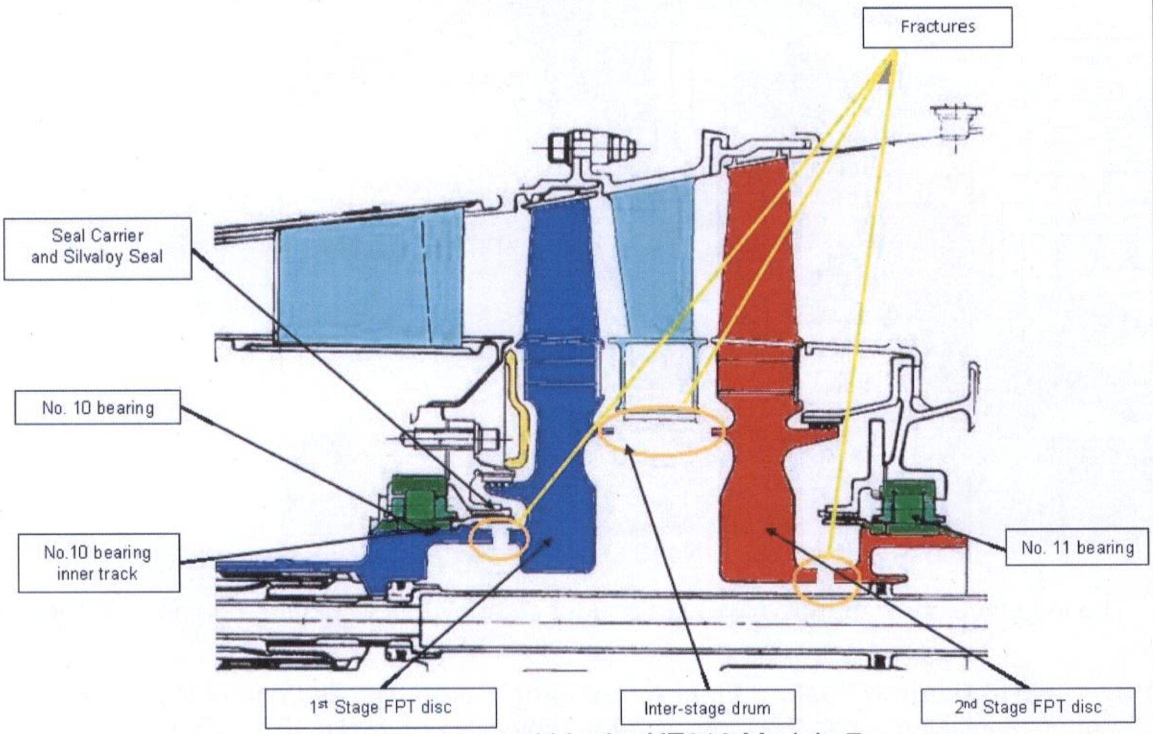

Fig 6 – Fractures within the XZ210 Module 7

1.4.28 The Panel concluded that the bang was caused by the mechanical failure of the FPT assembly on the No2 (starboard) engine and the subsequent 'shedding' of the blades from the 2nd stage FPT disc due to an overspeed. The noise heard in the cabin and cockpit was the 2nd stage FPT aerofoil sections exiting through the circumference of the engine casing. However, this was a symptom of the initiating failure whose origin was traced to a gradual de-torque or loosening of the eleven No10 bearing sealing flange retaining bolts over a period of up to 1530 flying hrs. The Panel found that the loosening of the retaining bolts on the No10 bearing sealing flange which resulted in the failure of the FPT drive arm and subsequent FPT overspeed was the **cause**.

1.4.29 Subsequent action in Jul 12 by RR (under Service Engineering Instruction (SEI) Gem 0125) instigated a torque check of the eleven No10 bearing sealing flange retaining bolts and an inspection for any physical evidence of the silvaloy seal touching or rubbing before any work is carried out on a Module 7. Exhibit 284

1.4.30 As at 16 Oct 12, from a fleet of 213 In-Service engines (166 installed), the Engine Repair Section (ERS) at Royal Naval Air Station Yeovilton had completed 39 Module 7 SEI Gem/0125 assessments (18% of In-Service engines). Of the modules checked only one Module 7 showed significant loss of torque on the No10 bearing sealing flange retaining bolts; this module was dispatched to RR for further investigation. Bearings were routinely changed at 2nd Line and the retaining bolts were checked and torqued as part of the process. Based on the mean time between rejections of 329 engine hrs, the majority of engines would return to 2nd Line repair within a 26 month period. Exhibit 285

1.4.31 **Other Lynx Accidents involving FPT Failure**. The Panel considered other Lynx accidents which involved FPT failures:

a. **Army Lynx XZ205** (14 Jul 82). During ac start-up procedure, with No1 engine in accessory drive, as the No2 engine was being advanced to Min Pitch on Ground, No1 engine was observed to run away with the Nh needle going "off the clock". This was followed immediately by a bang. The Pilot shut down the ac and the ac was evacuated due to fire around the engine and equipment bay. Examination of the No1 engine revealed evidence of an uncontained detachment of the 2nd stage FPT blades and separation of the rear disc section of the power turbine spool [failure of the drum between the 1st and 2nd stages]. The detachment of the 2nd stage FPT blades and separation of the rear disc section of the power turbine spool were considered to have been the resultant effect of the FPT having been over-sped, due to a failure of the fuel control system (FCS). Exhibit 144

b. **Army Lynx XZ667** (10 Apr 94). On the final approach to landing at a forward base, the Handling Pilot experienced what appeared to be a rundown on the No1 engine. The landing was aborted and a climb out was undertaken with the intention of returning to the operational base. During the next 6 mins of flight the crew experienced variations in both engine operating parameters, with instances where the ac rotor speed (and hence Power Turbines) reach 130% speed. As a result the crew had difficulty in identifying which engine was defective (running up or running down) and subsequently elected to carry-out an emergency running landing with the No2 engine retarded. On the approach to the emergency landing site with No1 engine at high power and speed an 'explosion' was heard. The run on landing was completed successfully with little damage to the ac. After normal shut down was completed and the crew had evacuated the ac, a fire was noted in the rear of the ac. Due to the intensity of the fire, with no fire service immediately available, after a period of 20 mins the ac had been destroyed. Subsequent examination of the ac revealed evidence of a uncontained failure of the 2nd stage FPT on the No1 engine. The cause of the FPT overspeed and blade shed was deemed to have been contamination of the FPT Governor. Exhibit 110

c. **Navy Lynx XZ256** (12 Jun 02). Navy Lynx Mk 8 XZ256 from HMS Richmond crashed due to a fire in the No1 engine bay whose combustion Exhibit 269

