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Nimrod MR Mk2 Review of Hot Air System

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Executive Summary

This Hot Air Systems Report forms the response required by Discrete Task 8.7 of the Nimrod Fuel System Safety Case, Phase 4 Work Proposal – Issue 2, January 2008, QINETIQ/EMEA/IX/BID0708836/1-LJRVP (Customer Reference DE&S/Wyt/4/5/2/15) to the Nimrod IPT, Reference [1].

This report presents the results of an assessment of the Nimrod MR2 hot air components and has been developed using zonal analysis, examination of supporting document sets and a physical inspection of the aircraft's hot air components. In addition, briefings from Suitably Qualified Expert Personnel (SQEPs) at RAF Kinloss were used to improve understanding of the Nimrod's operational and maintenance activities. These SQEPs were also utilised as a resource to answer technical queries as they arose throughout the course of the zonal analysis. Additionally, expert advice was sought from Industry to underpin conclusions reached regarding the physical construction and operation of hot air system components.

During the analysis, due consideration was given to the risk mitigation actions already put in place by the IPT. It should be noted that, throughout this report, the term "risk" is used in its broadest sense, and is in no way indicative of any statistical or quantitative risk analysis being performed (as per Section 1.7). As there is no defined hot air "system" for Nimrod and, consequently, no quantitative safety target, this analysis is of a purely qualitative and subjective nature. Furthermore, due to the lack of any safety target, no statement can, or has been, made as to whether the hot air system risks identified in this report have been reduced to As Low As Reasonably Practicable (ALARP) in line with the requirements of JSP 553, Reference [2].

Overall, the analysis of the Nimrod hot air components has resulted in 18 zonal observations and 12 recommendations for the Nimrod IPT. These observations and recommendations are provided in Sections 8.2 and 10 of this report.

The observations made during the review were mainly related to hot air ducting, its insulation and its proximity, and interaction with, other aircraft structures, services and components. This interaction can be separated into two categories:

1. A potential failure of the duct and/or its insulation causing an escape of hot gas, which adversely effects another aircraft structure, system or component.
2. A potential condition where a combustible fluid finds a migratory route to a section of hot air duct, which then acts as a source of auto-ignition.

Currently, there is insufficient information available regarding the hot air ducting and its insulation to draw any demonstrable conclusion on the overall level of risk being carried. Any such conclusion will not be possible until information on the damage limits, tolerances, performance, temperature attenuation, and any damage effects on these parameters, becomes available.

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Abbreviations

AAR	Air to Air Refuelling
A/F	After Flight
APU	Auxiliary Power Unit
BAES	BAE Systems
BBH	Bomb Bay Heating
B/F	Before Flight
CAU	Cold Air Unit
CSDU	Constant Speed Drive Unit
DE&S	Defence Equipment and Support
DPRV	Dual Pressure Regulating Valve
EGR	Engine Ground Run
EIAI	Engine Intake Anti-Icing
HP	High Pressure
IPT	Integrated Project Team
LP	Low Pressure
LPA	Low Pressure Air
MOD	Ministry of Defence
NRV	Non Return Valve
NSG	Nimrod Support Group
POL	Paints, Oils and Lubricants
RAF	Royal Air Force
RTI	Routine Technical Instruction
SCP	Secondary Cooling Pack
SQEP	Suitably Qualified Experienced Personnel
TCV	Temperature Control Valve
UTI	Urgent Technical Instruction
WAI	Wing Anti-Icing

1 Introduction

1.1 Background

Following the loss of Nimrod MR Mk2 XV230, concerns were raised in respect of the risks associated with the fuel system and hot air components of the Nimrod MR Mk2 aircraft. As part of the Nimrod Fuel System Review, there was a requirement under contract NIMES / 8054 to conduct a review of the Nimrod MR Mk2 hot air components, to ascertain the risks associated with these components and, where required, make appropriate recommendations.

1.2 Aim

This report aims to identify the risks associated with the Nimrod MR Mk2 hot air components and, where required, make appropriate recommendations to the IPT for further risk assessment activities and/or the implementation of risk mitigation measures.

1.3 Applicability

This assessment is applicable to the Safety Assessment activities as detailed in the Statement of Work, Reference [1], for the Nimrod MR Mk2.

1.4 Scope

This report covers the Nimrod MR Mk2 hot air components, as defined and agreed within Reference [3] and as detailed in Section 2, within their defined operating environment, and considers the risks posed to the platform. The zonal analysis process reported herein is structured to identify hazards associated with the hot air components, establish potential interaction with hazardous materials, such as fuel, POL etc and detail where there is potential for damage to other aircraft systems and/or equipment.

Whilst every effort has been made to inspect and map the areas defined and agreed within Reference [3], due to physical access restrictions and time constraints, it has not been possible to inspect every part within the defined boundaries. These uninspected areas were limited to the pilot's and engineer's footwarmers, and associated ducting and components and the tail and fin anti-icing ducts to the rear of the APU bay.

1.5 Objectives

The objectives of this report are to:

- Identify areas of risk associated with the hot air system, within the specified boundaries, detailed in Section 2 of this report.
- Recommend actions to remove identified hazards or, where removal is not possible or practicable, suggest mitigation strategies to reduce the associated risk.
- Recommend any additional analyses, tests or other activities, which may be required to provide a sufficiently comprehensive, robust and verifiable representation of the system and its identified risks.

1.6 System Safety Requirements

There is no pre defined Nimrod "Hot Air System" and, this being the case, there are no defined safety requirements for such a system. Additionally, the analyses performed within the scope of this report were not quantitative in nature and, therefore, could not be used as a verification of any quantified safety targets being met.

1.7 Definitions

The usual definition of risk, in safety terms, is the product of the Probability of a Hazard occurring and the associated Severity of the likely result of an ensuing accident. Due to the qualitative and subjective nature of this report, coupled with the lack of any statistical data or safety targets, risk cannot be expressed quantitatively. Therefore, where the word "risk" is used, its meaning is in the broadest sense and in no way implies that a risk calculation has been performed or that any value has been assigned to either expected accident severity or hazard probability.

1.8 Assumptions

The following assumptions are applicable to this report:

- All information reviewed during the assessment activities are considered accurate and correct at the time of issue of this report.
- Trained and competent personnel will operate and maintain the equipment in accordance with the defined operation and maintenance requirements.
- The constituent elements of the defined hot air system within this report are maintained in accordance with the appropriate technical publications.
- The equipment will be operated within all and any limitations imposed by the IPT or other engineering or operating authority.

2 System Definition

2.1 Introduction

There is no pre defined "Hot Air System" for the Nimrod aircraft. For the purposes of this report, "Hot Air System" is used as a general term, covering any ducting, pipes, valves, sensors or other device/mechanism used for the carriage, control or detection of hot pressurised air, associated with the APU, Air Start, Ant-icing or cabin conditioning, deemed to be at a temperature that may be hazardous to the platform and/or crew.

As no POL, grease, other chemical or compound used on Nimrod could be identified that has a lower auto-ignition temperature than fuel, the decision as to what temperature should be considered dangerous was based on examination of the Aircraft Fluid Auto-Ignition Temperature report, Reference [4], and Rolls Royce engine test data, Reference [5] and allowed for a reasonable margin of error. This resulted in a reduction from what was considered the lowest temperature required for auto-ignition of fuel, 200°C, to a cut-off temperature for the review of 180°C. This allowed for a 10% margin of error in the assessment of what are deemed as dangerous hot gas temperatures.

Recognition was given to the fact that auto-ignition of fuel is not the sole risk posed by the hot air system. However, the zonal hazard inspection team were unable to identify a specific item, which, if affected by a lower temperature hot air leak, could directly lead to a significant hazard. Further advice on this matter was sought from the Nimrod IPT during a visit to RAF Kinloss and they were also unable to identify any critical item that could fail as a result of exposure to temperatures lower than 180°C. This rationale was used as a limiting condition when considering the scope of the analysis. Where a temperature in a given area was unknown, expert advice was sought on what temperatures were likely to be experienced. In all circumstances, whatever temperature figure was estimated, engineering judgement was applied to ensure that, with respect to safety, any error was always on the conservative side.

2.2 Defined Boundaries

The following boundaries were agreed, at Reference [3], as the defined boundaries of the Nimrod Hot Air System:

1. The Cross Feed ducting from No1/No2 engines across to No3/No4 engines and inclusive of the additional APU feed ducting up to the NRVs.

   Rationale: This is a clearly identifiable path for very hot air (400°C+) enclosed within a sealed, and easily defined, area.

2. Engine supplies to the wing system pre-coolers, through the pre-coolers and cold air unit and then encompassing all of the controlled pressure system up to the point where it connects with the cabin conditioning air system.

   Rationale: It is assumed that, even if the air within the pressure air system were of sufficient temperature (at some points) to cause auto-ignition of fuel/POL etc, the expansion area and subsequent loss of pressure and temperature within the cabin conditioning system, coupled with the extreme difficulty in physical examination of this ducting, precludes its inclusion within this, limited, review. The review will allow for single-point failures contributing to the hazard conditions, but cannot consider the cumulative effects of multiple system failures. E.g. in this case, the failure of temperature sensors/valves at the TCV for the CAU will be considered in conjunction with no ram - air (engines running on ground) - a single failure condition. The single failure condition assumption for the hot air system was solely used as a defining condition for the migration of potentially hazardous hot gases through the system. It was not used as a limiting factor in the broader analysis.

3. The APU, back to the wing anti-icing cross feed NRV, including the fin and tail anti-icing.

   Rationale: As far as is possible, it must be ascertained what temperatures are emitted from the APU and how high the temperature remains when distributed via the ducting to the NRVs and into the fin and tail anti-icing. This review was limited, from a zonal inspection viewpoint, by physical access.

4. The wing anti-icing system as far as Rib 3 on port and starboard sides.

   Rationale: Temperatures beyond this point (as indicated by the location of the 100°C temperature sensors) are deemed to be below a hazardous level.

   Additionally, the physical disturbance required to review beyond the Rib 3 point is significant, and likely to result in a maintenance burden, which would far outweigh any benefit derived from an inspection in this area.

5. The supply for the bomb bay heating system, from the pre-cooler up to the mixing chamber and associated ducting.

   Rationale: Potentially hazardous temperatures could be experienced in these areas, particularly while no ram air is available (ground running or single point failure).

A graphical representation of the defined system boundaries is included at Annex A to this report.

3 Hot Air System Analysis

3.1 Zonal Inspection Analysis Process

The following steps were taken as the process for the performance of the analysis and the production of this report:

- An initial review of the task requirements, including examination of document sets and schematic diagrams.
- A Phase 1 zonal analysis of the engine HP bleed air cross feed duct, conducted at RAF Kinloss, by [redacted] This visit to RAF Kinloss also allowed the team to be briefed by SQEPs on system operation and maintenance.
- A review of the findings of the initial zonal analysis was performed and assisted with setting the scope for, and boundaries of, the full hot air system zonal analysis.
- A Phase 2 zonal analysis of the remaining hot air system components was conducted at RAF Kinloss by two teams: [redacted]
- The findings of the two teams, along with the initial cross feed zonal analysis, were used in conjunction with SQEP input and technical publications to produce this report.

The physical analysis of the Nimrod hot air system was split into two distinct phases. The first phase was the inspection of the engine HP bleed air cross feed duct, conducted by one team of two personnel. This analysis allowed for a better system understanding and helped to scope the requirements for the broader analysis to follow. The second phase was the inspection of the remainder of the hot air system, conducted by two teams, each comprising two personnel. The structure of this report mirrors the approach used for the zonal inspections.

Throughout this report, many photographs, diagrams and drawings are provided to assist with contextualising the overall view of the analysis and, where applicable, highlighting and clarifying specific issues. However, in an effort to remain concise, these graphical representations have been kept to a minimum. All of the photographs taken during the course of the review have been catalogued and can be viewed on request.

3.2 Limitation of Zonal Inspections

All inspections are liable to limitation due to physical access. The boundaries stated here have been identified through referral to maintenance diagrams and aircrew manuals. Whilst every effort has been made to identify appropriate areas for inspection and review, it was necessary to curtail/limit these inspections where physical access was not possible or practical. Any such limitation(s) will be made apparent within this report.

4 Phase 1 - Engine HP Bleed Air Cross-Feed Duct Zonal Analysis

4.1 Introduction

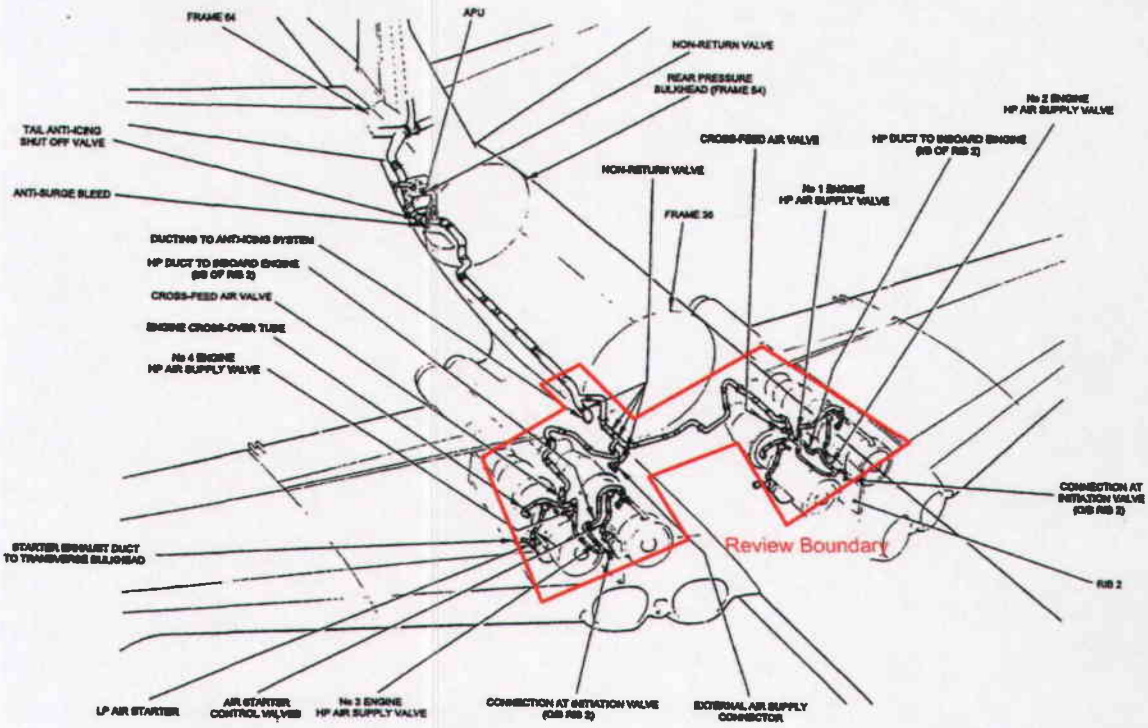
The review of the engine HP bleed air cross feed duct was conducted on 17th and 18th April 2008 by [redacted] on Nimrod MR Mk2, XV235 at RAF Kinloss. Prior to the physical inspection of the aircraft, a brief on the hot air system operation and the indications and warnings provided to the aircrew was provided by [redacted]. This brief was of great value, not only for the review of the engine HP bleed air cross feed duct, but also in assisting with the preparation for the comprehensive system review conducted on the second visit.

Throughout the review, Nimrod IPT assistance was available and the team were able to call upon the expertise of [redacted] as required. [redacted] assistance proved to be invaluable, as he was able to provide detailed knowledge on system operation and also direct the inspection team to the relevant technical publications when necessary. Additionally, [redacted] was able to arrange for the team to visit the Nimrod Support Group (NSG) and thus have the opportunity to inspect closely the hot air ducts and insulation that had been removed from the aircraft as part of major scheduled servicing. The Nimrod IPT were, at all times, extremely helpful and the review could not have been completed in such a timely manner were it not for their assistance.

The primary aim of this zonal analysis was to assess the engine HP bleed air cross feed duct and to document its interactions with the aircraft and its related systems. Secondary aims of the analysis were to familiarise the team with the Nimrod aircraft and to collect documentation and other information to assist with bounding the comprehensive hot air system review.

4.2 Engine HP Bleed Air Cross Feed Duct Review

This assessment considers the HP Bleed Air Cross Feed Duct, as far as the APU NRV, as shown in Figure 1 below:



ENGINE STARTING AIR DUCTING

Figure 1 – HP Bleed Air Cross Feed

4.2.1 Port – Outboard Engine Bay, Zone 2

The cross feed duct shut off valve is located in this area and defines one end of the assessment boundary for the cross feed duct. It was noted that part of the ducting was not protected by an insulation blanket as the duct entered through Rib 2 from the inboard engine bay. Hydraulic pipes, which serve control surface actuators located on the wing, are located across the top of the engine bay. The most notable zonal aspects in this area include:

- Fire extinguisher pipe and nozzle is located in close proximity to the shut off valve.
- Thrust reverse HP air pipe is located in this area.
- Cross feed pipe is located next to the engine.

Figure 2 displays in further detail the zonal interactions described above. For all the zonal diagrams of the engines, Zone 1 is the area forward of the firewall and Zone 2 is to the rear of the firewall.

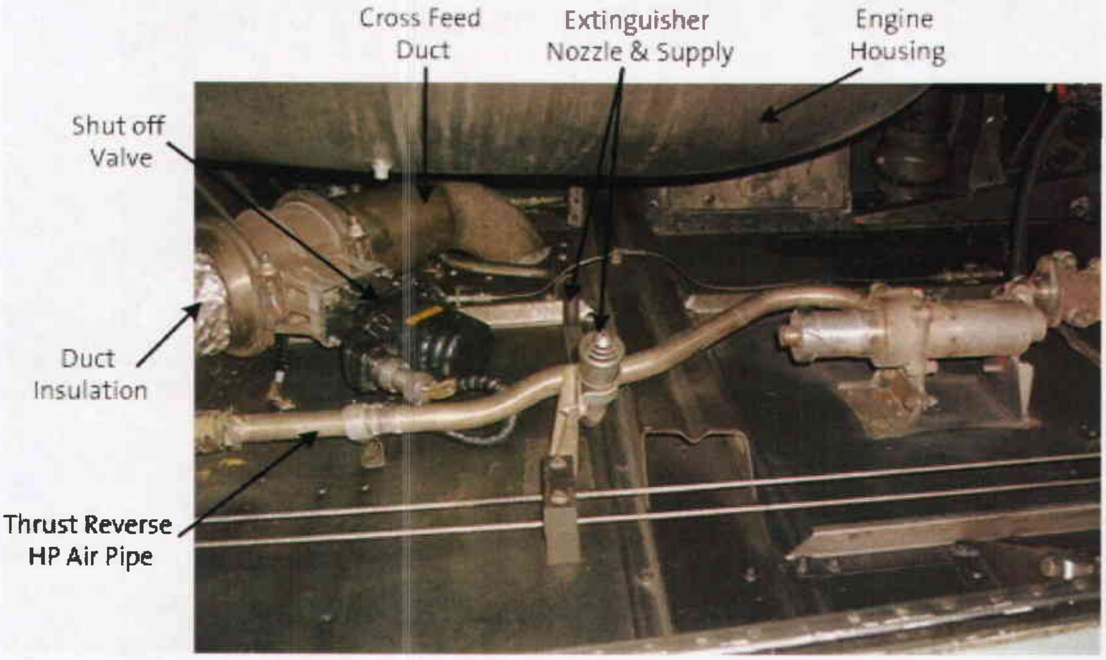


Figure 2 – Port Outboard Engine Zone 2

4.2.2 Port – Inboard Engine Bay, Zone 2

The duct enters through Rib 2 from the outboard engine bay. In this part of the bay, the duct is not completely insulated. Part of the duct is protected and bellows are constructed in the duct to allow for expansion and contraction of the duct. Gaps are present along the duct where the insulation ends and the bellows start. A Graviner overheat sensor is located in this area. Directly above the duct is a refuel gallery that serves the wing fuel tanks. The co-location of this refuel gallery with the hot air duct is considered to be the main zonal risk located within this area.

It is considered that a duct leak would result in local damage to surrounding structure and equipment.

Figure 3 displays in further detail the zonal interactions described above.

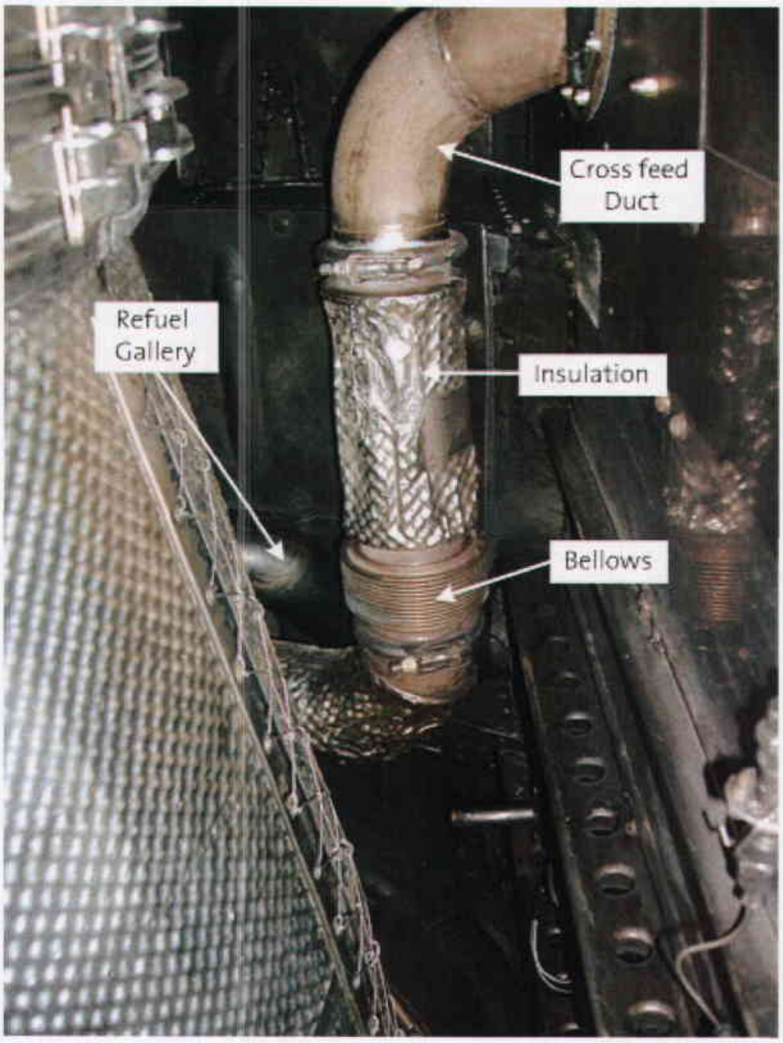


Figure 3 – Port Inboard Engine Zone 2

4.2.3 Port – Tank 7 Dry Bay

Viewed from the top, the Tank 7 vent, electrical wires, control runs, the HP Bleed Air Cross Feed Duct and Tank 7 fuel pipes (feed, refuel and defuel) are visible. A Leak from the duct may result in local damage being sustained. A leak from the fuel pipes could however interact with the duct, presenting a possible ignition source. Hydraulic pipes in this area (not visible in Figures 4 and 5) do not appear to be in close enough proximity to interact or foul with the hot air duct.

Viewed from the bottom a Graviner overheat detector, fuel pipes and control runs are all visible within this area.

Figures 4 and 5 display the zonal interactions described above.

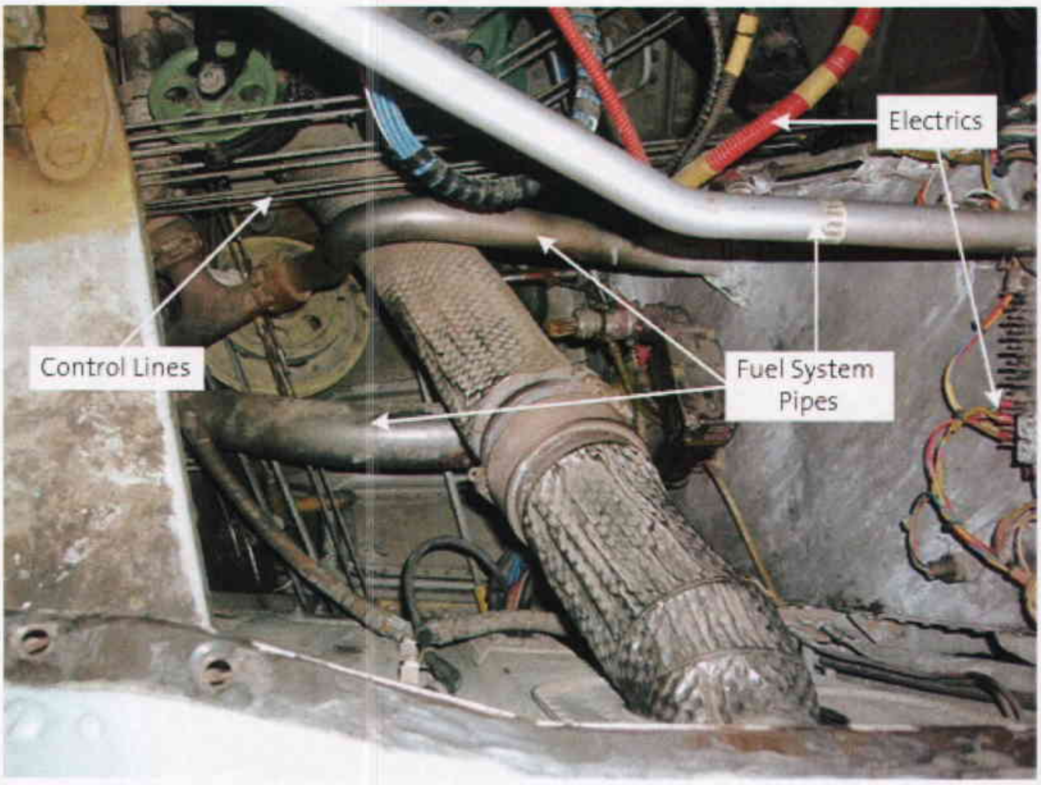


Figure 4 – Port Tank 7 Dry Bay (Top View)

Figure 5 – Port Tank 7 Dry Bay (Bottom View)

4.2.4 Bomb Bay – Centre Section

Services and equipment located within this area include:

- Bomb bay heating.
- Tank 6 refuel.
- Control runs.
- Fuel feed pipes.
- Hydraulic pipes run along rear spar.
- Flap Servodyne.
- Drains.
- Bomb bay door hydraulic pipes.
- Electrical wires.
- Possible interference with structure.

Fuel sources could come into contact with the ducting from various sources including:

- Fuel pipes.
- Hydraulic pipes.
- Drains.

It was noted that liquid was present around the location of the drain, although the type of liquid is not known. It was further noted that the shield over the centre section of the cross feed duct mounting bracket could pool fluid and possibly direct fluid run off towards the laminated mount.

The duct mount is constructed from laminated material that could act as a wick and soak up fluid. The protection shroud could pool and direct fluid run-off towards an unprotected part of the duct.

A T-piece drain is located directly above the duct, and there are gaps in the insulation in this area with exposed duct clearly visible adjacent to the laminated mount. This drain is used to drain liquid from the keel, normally water, although oil and hydraulic fluid residue may also be present.

Insulation over the couplings at the cross feed duct mount has gaps around the ends. Currently, there is a Before Flight (B/F) inspection and test, Reference [6], and an After Flight (A/F) inspection, Reference [7], against these covers. These covers are wire-locked and use worm drive clamps at either end of the cover to hold it in position over the ducting.

Figures 6, 7 and 8 show the zonal interactions described above. In Figure 8, it should be noted that the term "crimping" is only used to describe the observed effect on the duct insulation, and is in no way a statement or assumption of how this effect occurs.

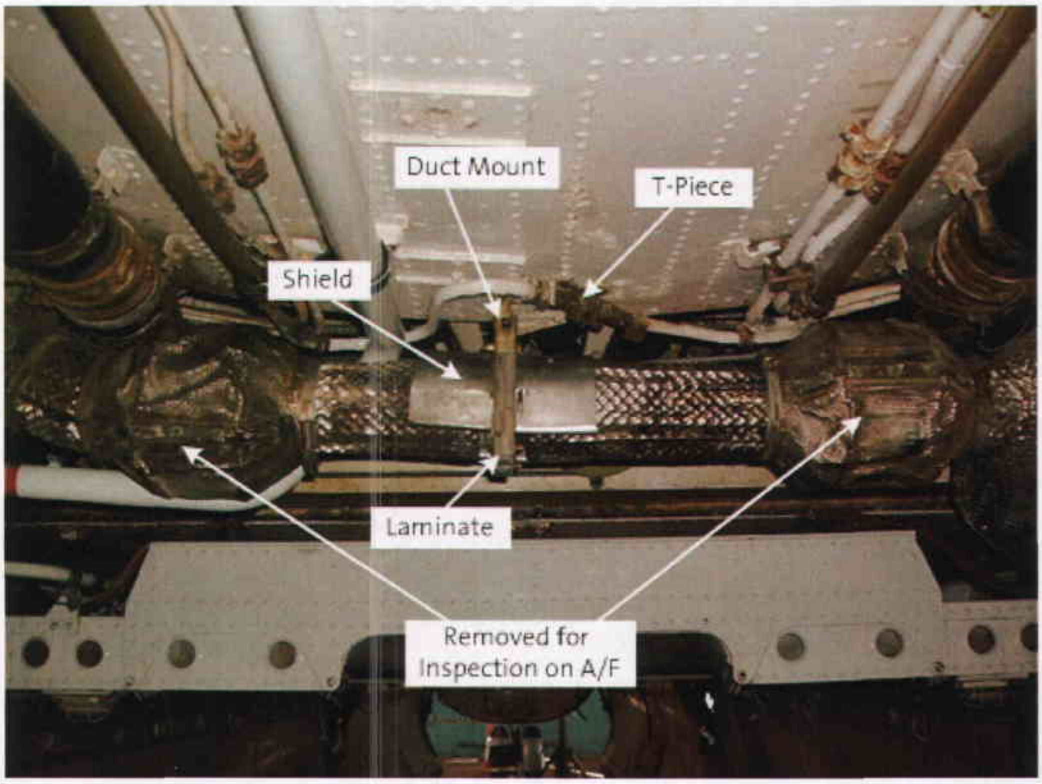


Figure 6 – Bomb Bay Centre Section

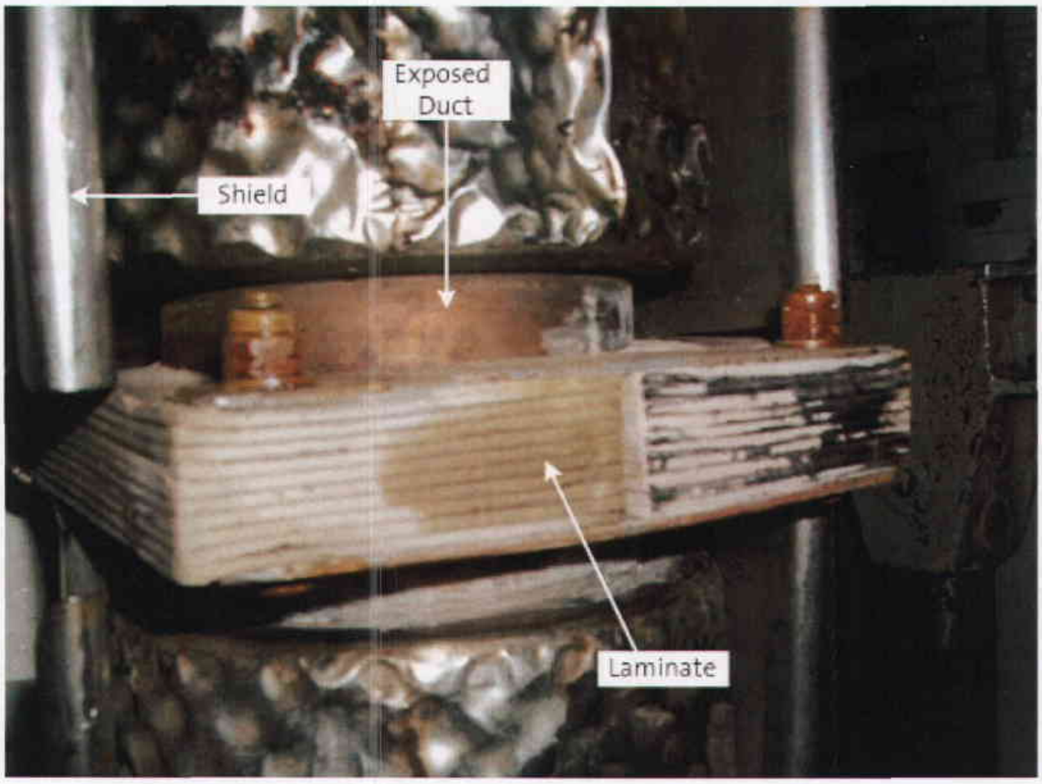


Figure 7 – Duct Mount Construction

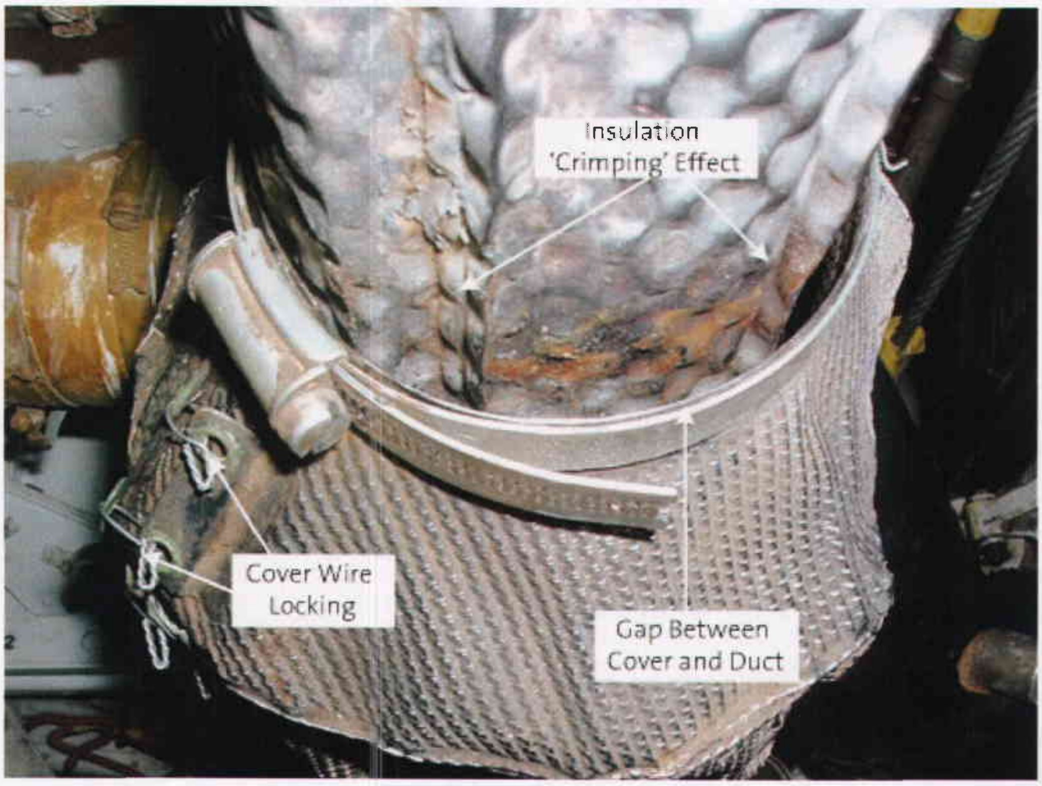


Figure 8 – Shroud and Duct

4.2.5 Starboard – Tank 7 Dry Bay

Viewed from the top, the Hydraulic pipes, fuel pipes and control runs are visible. The hydraulic pipe bracket interference with HP duct is visible. Wiring is located around this area. The duct is in very close proximity to control runs. Assessment is as per the port side although there are more services located on this side of the aircraft. Issues regarding this zone predominately concern the duct interference / close proximity to other services.

Viewed from the bottom the control / pulley housing interference with the insulating blanket is visible. A fuel coupling is directly above the duct. All aircraft services are located in this zone, which makes for a busy and complex area.

Figure 9 displays the zonal interactions described above.

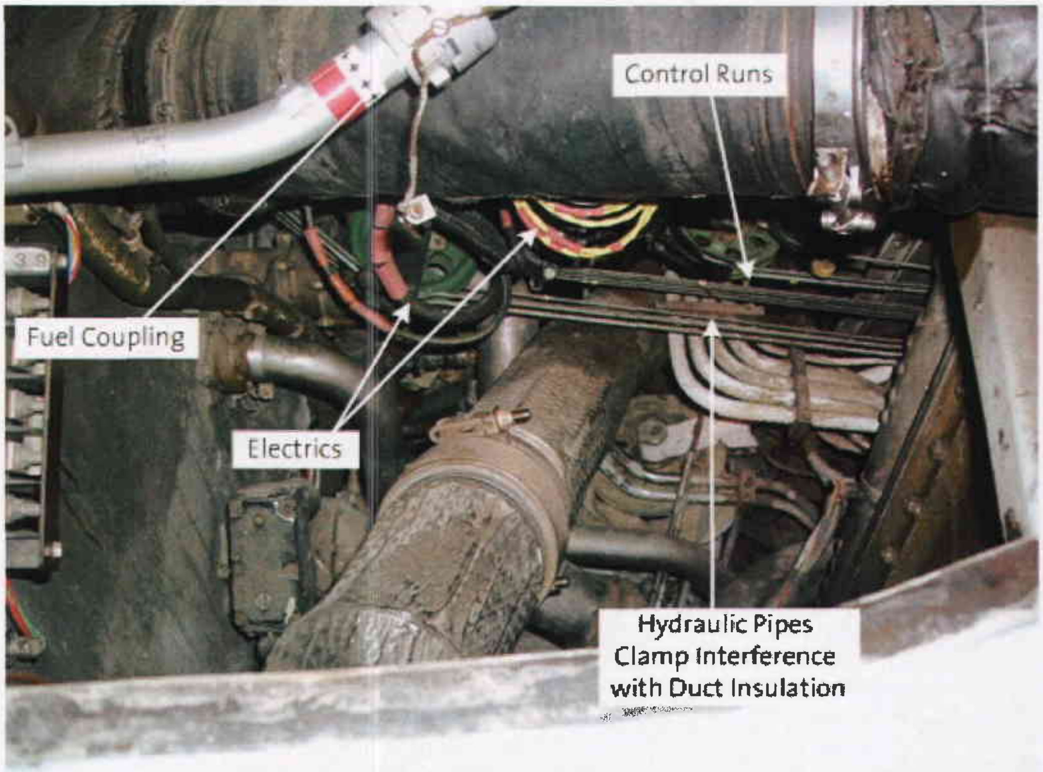


Figure 9 – Starboard Tank 7 Dry Bay (Top View)

4.2.6 Starboard – Inboard Engine Bay, Zone 2

This zone is the mirror image of the port side, as detailed in Section 4.2.2. There are no significant differences from the analysis performed on the port side and the zonal risks are considered as identical.

Figure 10 displays the zonal interactions described above.

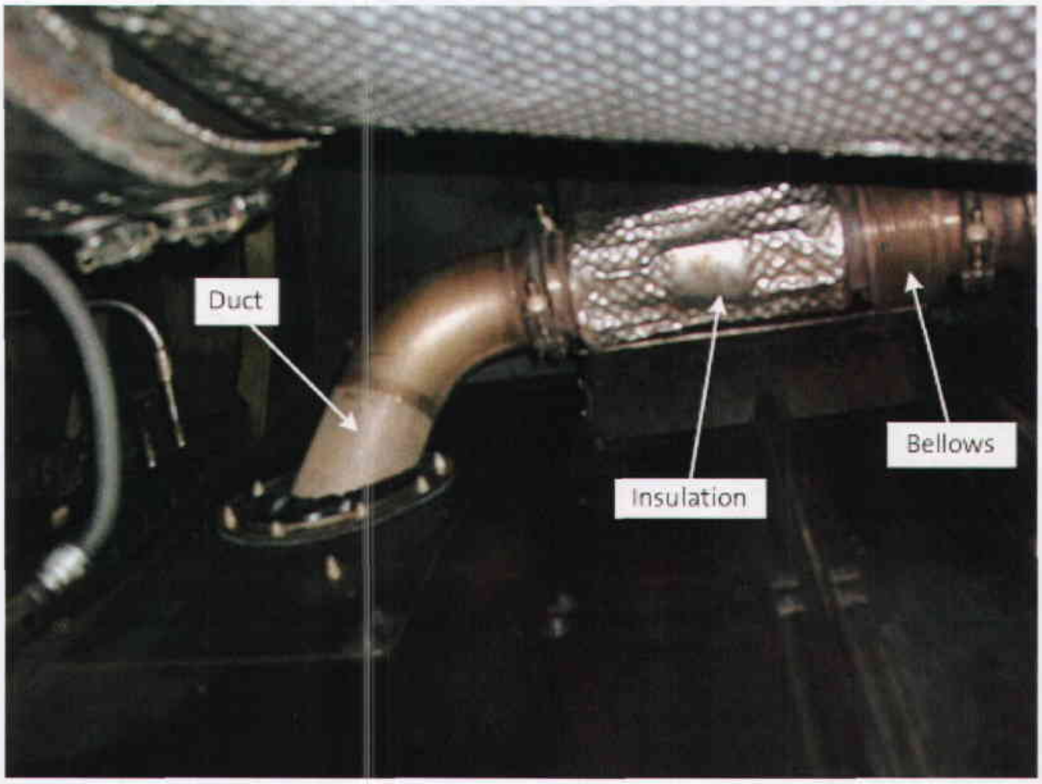


Figure 10 – Starboard Inboard Engine Zone 2

4.2.7 Starboard – Outboard Engine Bay, Zone 2

This zone is the mirror image of the port side, as detailed in Section 4.2.1. Again, there are no significant differences from the analysis performed on the port side, and the risks are also considered to be identical.

Figures 11 and 12 display the zonal interactions described above.

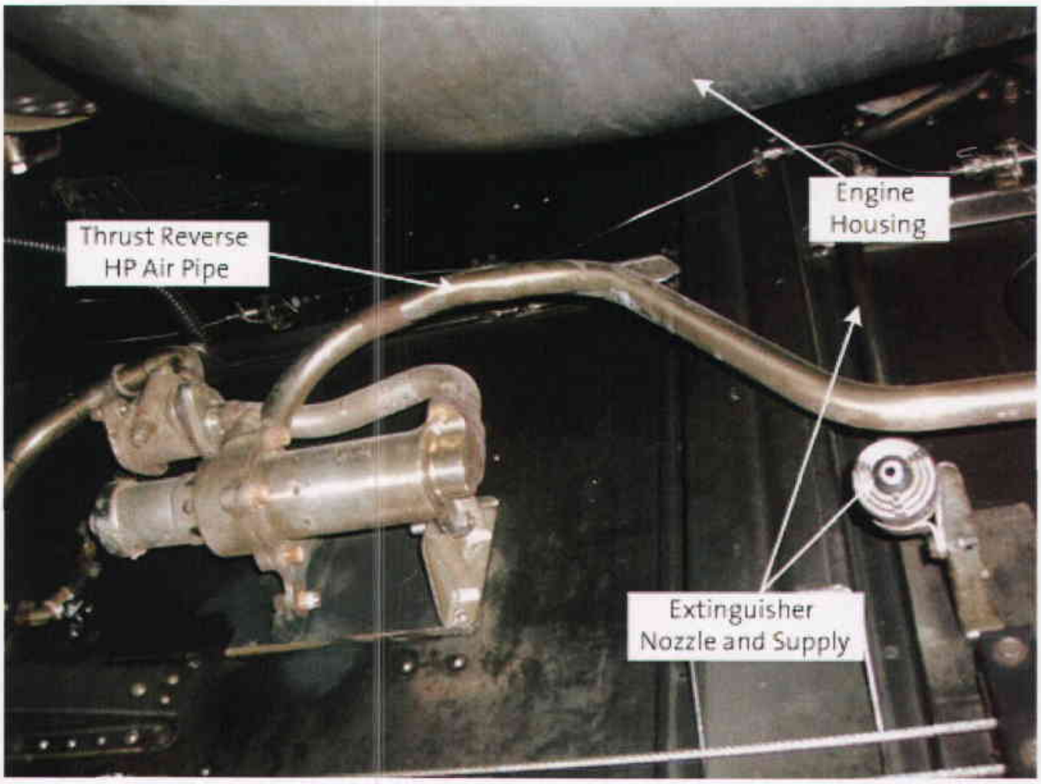


Figure 11 – Starboard Outboard Engine Zone 2 (1)

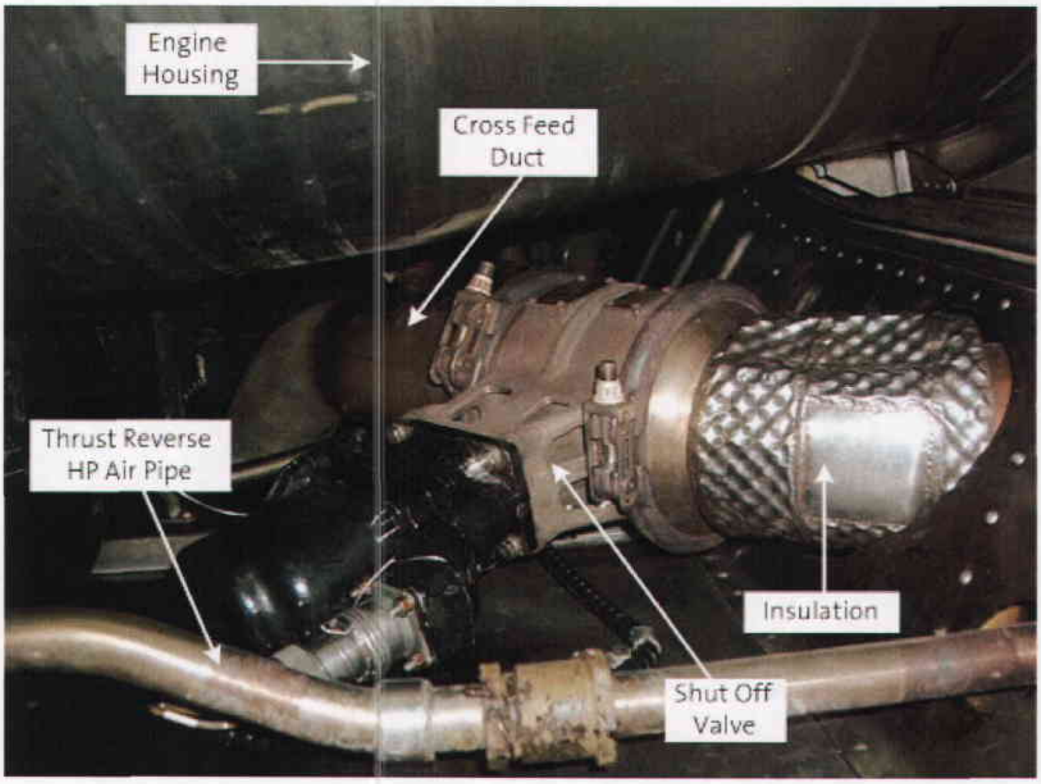


Figure 12 – Starboard Outboard Engine Zone 2 (2)

4.2.8 HP Air Duct and Insulation

During the first visit to RAF Kinloss, the team visited the NSG to view sections of the hot air duct and insulation, which had been removed during major servicing. This presented the opportunity to more closely inspect the construction of, and damage to, the duct and its insulation. The findings from this visit are discussed and presented within Section 6.

4.3 Summary of Observations and Potential Hazards

From the inspection conducted and reported in Section 4 above, the following specific observations and potential hazards have been identified. Each point notes the section where the observation has been highlighted:

a. A keel drain (used to drain any fluid which may accumulate in the keel, normally water, although it may contain oil and hydraulic fluid residue) T-Piece is located directly above the centre mount for the HP bleed air cross feed duct. There are small sections of uninsulated duct located at the position of the centre mount. [Section 4.2.4]

b. The shroud attached to the centre mount for the HP bleed air cross feed duct could pool or direct liquid run off onto the mount laminate material or the uninsulated duct. [Section 4.2.4]

c. The centre mount laminate material could wick and soak up fluid. [Section 4.2.4]

d. It was considered that the periodic inspection of the HP bleed air cross feed duct centre section, which necessitates the removal and refitting of the protective shroud, might be a contributory factor to the insulation damage observed in this area. [Section 4.2.4]

e. It was noted that the direction of the shroud wire locking was not conducive to the prevention of liquid pooling. [Section 4.2.4]

From the inspection conducted and reported in Section 4 above, the following general observations and potential hazards have been identified. The following points have been identified in several of the above sections and are not specific to an individual location.

f. Sections of the HP cross feed duct, which are co-located with fuel lines, electrical and other services, are not entirely covered by insulation.

g. The fuel couplings are in close proximity to the HP bleed air cross feed duct (known to reach temperatures well above that required for auto-ignition of fuel).

h. Where a fuel coupling is located above an insulation-protected piece of ducting, any release of fuel could, due to gravity or aircraft movement, find a path to an exposed piece of duct.

i. There are areas where the clearances between the HP bleed air cross feed duct and other aircraft structures / services are minimal.

j. Areas of the HP bleed air cross feed duct insulation appear to have been damaged. It is not known what effect, if any, this damage has on the protective properties of the insulation.

In identifying these observations, no attempt has been made to quantify the level of risk that they present. However, Section 8 considers mitigation that has been implemented and how it may affect the observations noted. In addition, the following recommendations have been made.

Recommendation [i]: *Consider a re-design of the HP bleed air cross feed duct bracket, where the construction used has led to concerns over wicking and / or pooling of liquids.*

Recommendation [ii]: *Consider applying additional insulation / covers to exposed areas of hot air ducting, particularly where there are significant interactions with other aircraft systems.*