o. The close proximity of WAI to control runs, wiring looms and fuel pipes in wing root Rib 1. [Stbd – Section 5.2.8; Port – Section 5.2.17]

p. The moveable bracket assembly holding the hot air pipe in the aft bomb bay zone and the close proximity of the Tank 6 fuel line and the Tank 6 Inter-space drain. [Section 5.2.18]

q. The location of the [redacted] S26 routed directly under, and in contact with, the APU Air Start outlet. [Section 5.2.19]

r. The potential for fuel migrating along the external aircraft surface finding a route to ignition sources behind external surface fairings. [Section 5.2.20]

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 [iii]: Consider a re-design of the rear bomb bay SCP duct bracket, where the construction used has led to concerns over wicking and / or pooling of liquids.

Recommendation [iv]: Investigate the qualities of the external hot air duct fairings to prevent liquid ingress and, if necessary, consider the feasibility of sealing these external aircraft fairings.

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

6 HP Air Duct and Insulation

The engine HP bleed air cross feed ducting is for large parts, covered by an insulating blanket, encompassing a thin, steel outer shell and a fibrous material between the shell and duct. A diagram of a typical insulated pipe is shown below as Figure 60.

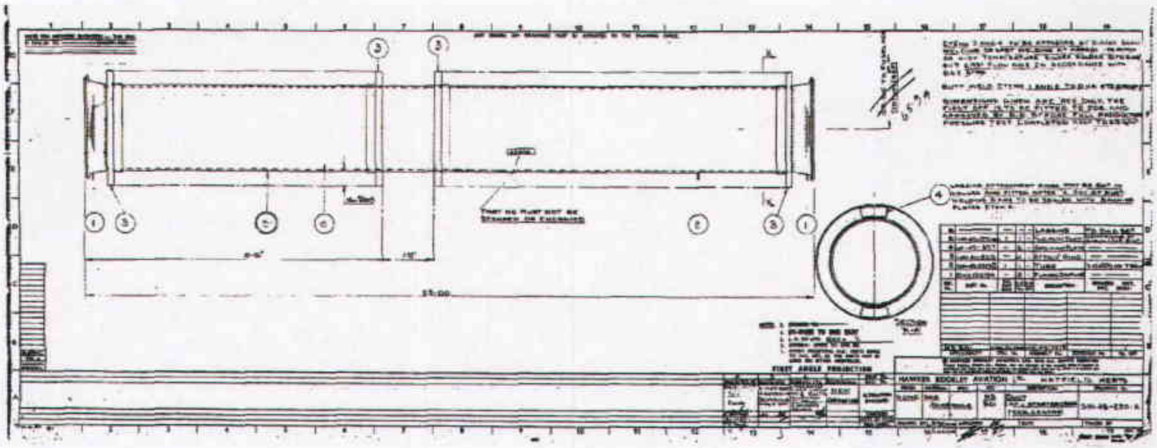

Figure 60 – HP Air Duct Construction Drawing

During the zonal inspection of the aircraft, and while inspecting sections of duct removed from the aircraft, it was noted that many sections showed signs of stress and/or damage. It was not possible to ascertain what the implications of such damage/stress to the ducting would be in terms of the duct integrity or the hazard posed to surrounding structures or components. During the examination of the removed sections of ducting at the NSG, it was possible to discuss the issue with some of the maintenance personnel, who were able to confirm that a pressure equalisation hole was designed into the duct insulation. However, they were also able to show several examples of how the physical construction of these duct sections led to the degraded performance, or complete failure, of these pressure equalisation holes. Figures 61 and 62 show examples of these partially, and completely, blocked holes. It is believed, but not confirmed, that the blocking of these pressure equalisation holes has led to the "crimping" or "crushing" effect observed on many of the sections of hot air duct.

During the visit to NSG, it was much easier to view various pieces of the hot air duct, as they had been removed from the aircraft and, consequently, it was possible to view them clearly without other aircraft structures or components obscuring the view. Many sections showed evidence of impacts that had not breached the integrity of the insulation. However, there were other examples where the outer shell had been ruptured. In either case, it has not been possible to make any meaningful statement as to the effect this damage would have in terms of duct integrity or degradation of the insulation's performance. Examples of these damaged duct sections are shown at Figures 63 – 65.

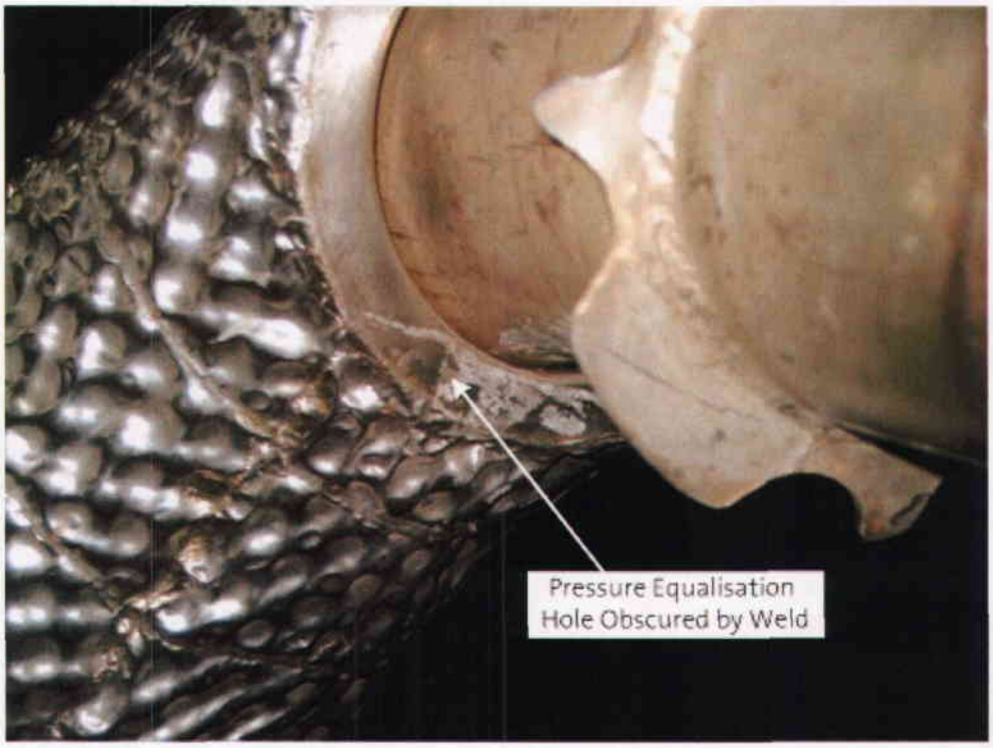

Figure 61 – HP Air Duct Insulation (1)

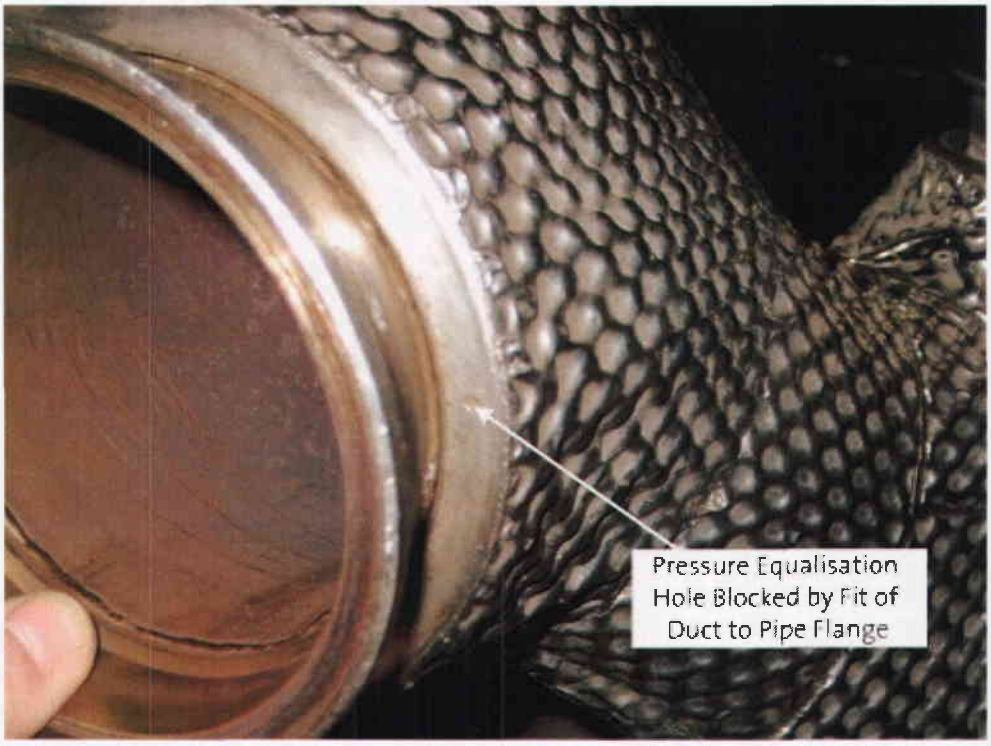

Figure 62 – HP Air Duct Insulation (2)

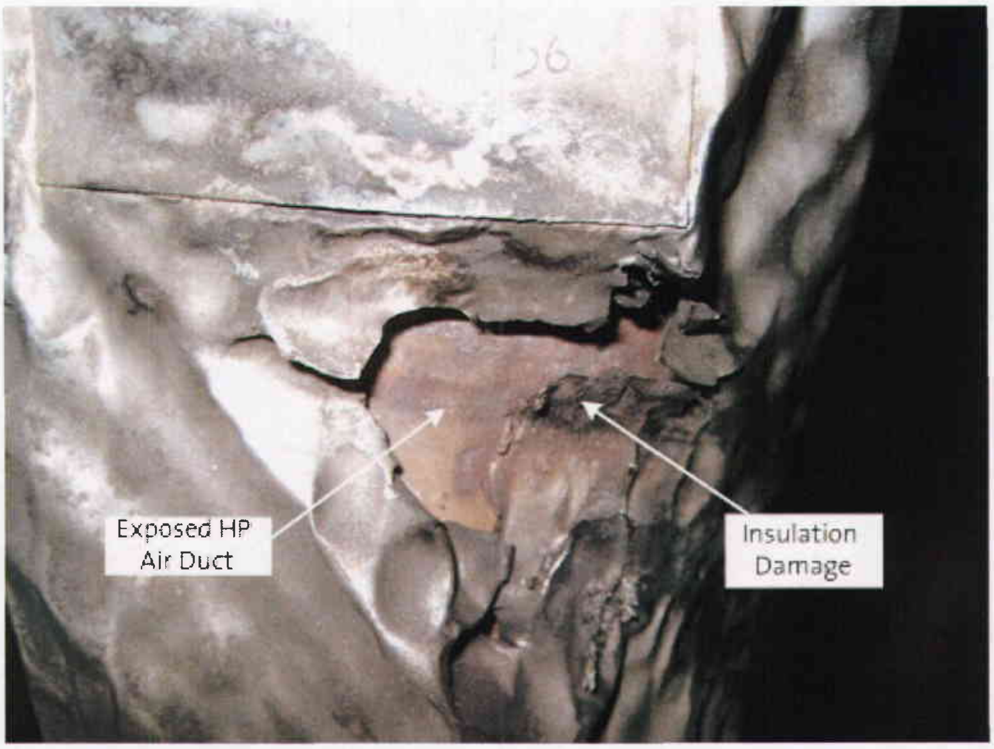

Figure 63 – HP Air Duct Insulation (3)

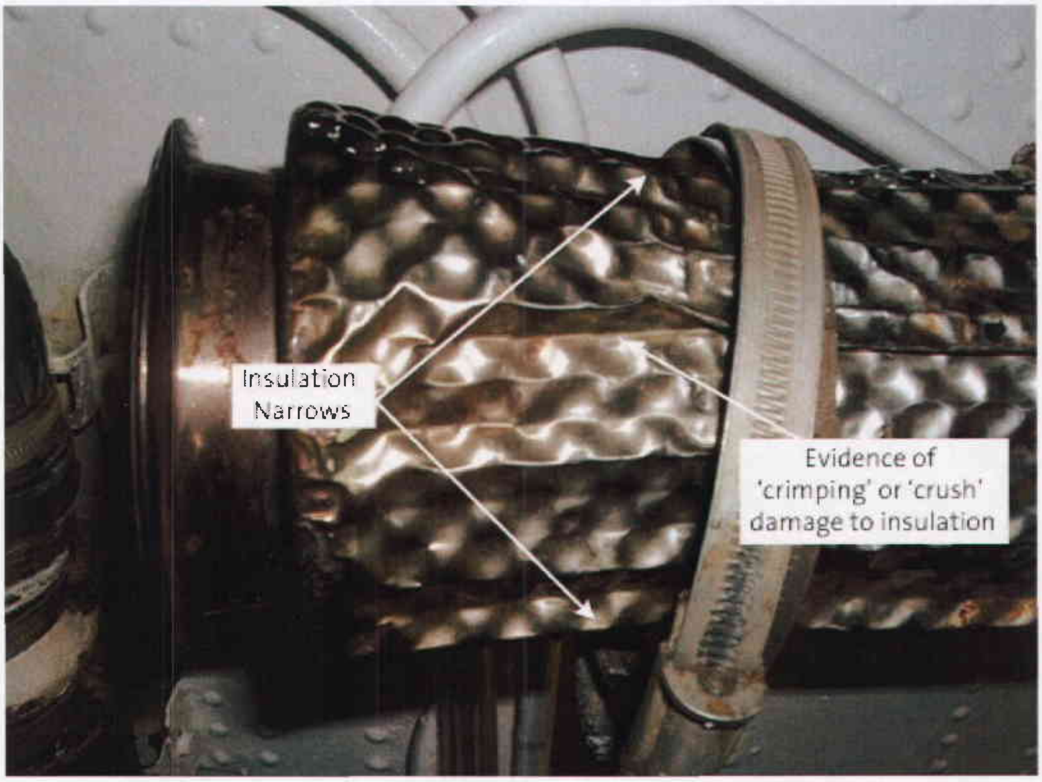

Figure 64 – HP Air Duct Insulation (4)

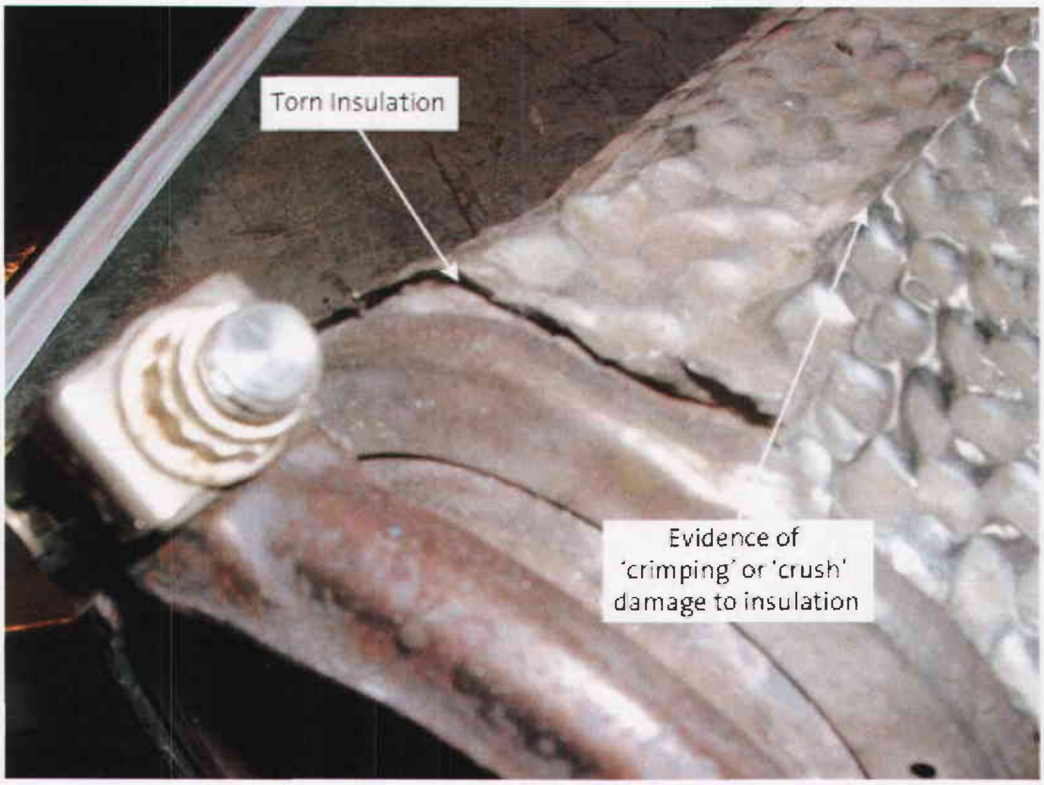

Figure 65 – HP Air Duct Insulation (5)

As a consequence of noting the issues with the ducts, these were discussed with BAE SYSTEMS (BAES) at BAES Chadderton on 6th June 2008.

Regarding the specific discussion surrounding damage tolerances for the duct and its insulation, BAES stated that there was no acceptable level of damage for the insulation. However, they also informed QinetiQ that they are currently conducting tests on the 'crush' or 'crimp' effect observed on the insulation and that they were gathering data on the properties of the insulation. It was intimated that the results from these tests are expected at the end of July 2008.

Recommendation [vi]: Dependent on the information received from Industry on the duct insulation, consider the addition of extra pressure equalising holes in the insulation.

BAES also informed that any damage sustained to a duct would be subject to assessment in order to determine an appropriate course of action. It is anticipated that a significant failure in a duct would be evident as damage would be evident on the insulation, however, minor damage may not be easily identifiable.

Recommendation [vii]: Await the information from Industry on the hot air duct insulation prior to formulating appropriate policies for maintenance, fitment, serviceability assessment etc.

As there was visible evidence on several ducts viewed at NSG of knocks, bumps and abrasions, the question of clearance between components was raised. BAES advised that there is a 'handbook' requirement for clearances, which should have made its way into the technical publications. BAES further advised that the required clearances should also be stated on the drawings.

At this time, the only clearance requirements identified for ducts are those provided by [redacted] of the Nimrod IPT. These are detailed within AP101B-0503-1BJ, Chap 23-12, Para 3.5.7, Reference [8], and state the following minimum clearances must exist:

- Between ducts not at a clipped position – 5.0 mm (0.2 in)
- Between ducts at a clipped position – 2.5 mm (0.1 in)
- Between ducts and structure not at a clipped position – 5.0 mm (0.2 in)
- Between ducts and structure at a clipped position – 2.5 mm (0.1 in)

Recommendation [viii]: Consider issuing a directive for duct clearance requirements and checks to ensure compliance with the clearance requirements mandated by Reference [8].

Clearance around the ducts is important for 2 key reasons, firstly, to prevent physical damage as a result of fouling, and secondly, to prevent heat conduction from the ducts onto other systems and structure. Clearance requirements may vary depending on the installation as different aspects may be subject to different amounts of movement (movement may be caused by expansion and contraction in a system or by bending forces and vibrations).

Recommendation [ix]: Consider vibration monitoring as a method to confirm whether extant clearance requirements are satisfactory.

Clearly, given the observations made during the cross feed duct and hot air system reviews, the condition of the ducting and its insulation are vital components in establishing the risks posed to the aircraft. However, until such time that information becomes available, no firm conclusion regarding the limits, tolerances and clearances for the duct insulation can be made.

It is noted that numerous ducts have limitations of use applied to them, for example, the cross feed duct is only used for ground engine start and emergency in flight engine relight. This is considered an appropriate course of action until additional information (i.e. clearance and damage limits) regarding the ducts and insulation becomes available, at which point the limitations of use may be reviewed.

The matter of air temperatures, pressures and flow rates through the ducts was also discussed. It was considered that the various venturi (flow rate), temperature and pressure sensors located in various positions throughout the air systems would provide a level of understanding of air flow around the system. However, there was no map of air temperatures, flow rates and pressures within the air systems. It was indicated by BAE Systems that a possible source for any such information could be found within the hot and cold weather trials conducted on the Nimrod aircraft. This has been considered further at Section 7.

7 Documentation Review

From discussion with BAES, it was noted that a possible source of information for temperature, pressure and flow rate data for air within the aircraft hot air related systems might be contained within the original hot and cold weather trials reports. Subsequent to this discussion, a search of the Boscombe Down technical library was undertaken for any such trials reports. Four reports were identified and have been reviewed below:

- Nimrod MR Mk1 Engineering Cold Weather Trials, A&AEE/953, 30th April 1971

  This report discusses the findings from cold weather trials conducted on Nimrod MR Mk1 XV226. Whilst it is reported that some temperature mapping of the cabin was undertaken; temperatures, flow rates and pressures of the air within the air systems was not measured or mapped. Discussion of these systems is noted in part where issues were flagged, however, the only significant observation noted against an air system is against the APU, which experienced surge during operation at cold temperatures.

- Nimrod R Mk1 XW665 Hot Weather Trials at SAF Tengah Singapore Summer 1972, A&AEE/953/1, 8 September 1977

  This report discusses the findings from hot weather trials conducted on aircraft Nimrod R Mk1 XW665. The activities conducted and reported include temperature mapping of the pannier bay, rear cabin and flight deck. Issues were identified and reported, however these all relate to the conditioning of the cabin, flight deck and pannier bay with respect to avionic equipment cooling and personnel comfort. No temperature, pressure or flow rate mapping through the air system ducts is presented.

- Nimrod MR Mk2 Cold Weather Trial, 20 June 1980

  This report details the findings from the cold weather trials conducted on aircraft Nimrod MR Mk2 XV229. The activities conducted consider the ability of the aircraft systems to achieve a satisfactory operating temperature for both crew and equipment in cold climates. The effectiveness of the SCP to warm the aircraft is discussed, however, no activities were undertaken to consider the temperatures, pressures or flow rates of air through the air related systems. Where any issues relating to the operation of the aircraft in cold conditions was experienced, notes and recommendations are made.

- Nimrod MR Mk2 Hot Weather Trial 1981, Letter Report E 454, 24 March 1982

  This report details the findings from the hot weather trials conducted on aircraft Nimrod MR Mk2 XV229. The activities conducted considers the ability of the aircraft systems to achieve a satisfactory operating temperature for both crew and equipment in hot climates. The report details temperatures at different locations within the cabin and flight deck measured throughout the trials programme. No information is detailed regarding temperatures, flow rates or pressures within the air ducts.

From the reports reviewed above, it is clear that the information and results obtained during these trials activities relate to the performance of the aircraft in these climatic and environmental conditions. They do not contain information relating to the temperature, pressure or flow rate of air through the air system ducts. Consequently, the above noted reports cannot be used to gauge in any more detail what parts of the hot air system pose a greater or lesser risk to the aircraft or to help further define the hot air system boundary.

8 Risk Mitigation Activities

8.1 Actions Taken

Several risk mitigation actions have already been implemented by the Nimrod IPT, which will have a notable effect on the risks presented by the hot air system. These risk mitigation actions comprise a mix of operational limitations and maintenance activities: most notably the operational limitation on the use of the HP bleed air cross feed duct, Reference [9], which limits the use of the cross feed duct to ground use only; and the electrical isolation of the SCP, Reference [10], which prevents the operation of the SCP at all times. These are discussed further.

8.1.1 Mitigation Summary

Following the accident of Nimrod XV230, numerous actions have been implemented which, in addition to any 'normal' mitigation i.e. as applied through routine maintenance and operation, combine to reduce the level of risk presented by the aircraft and its systems. This suite of additional mitigation is summarised at Annex B. Whilst this mitigation impacts numerous systems, the following are noted as they specifically impact the hot air systems discussed within this report. They are:

- Inhibition of the SCP (RTI/173).
  The SCP has been electrically isolated such that it can not be operated. The air supply to the SCP is taken from the HP bleed air cross feed duct from which it passes through a valve just aft of the cross feed duct. This valve is spring loaded shut and is electrically actuated to open. The valve is electrically isolated preventing the operation of the SCP. Additionally, Modification 1294 is currently in draft, which aims to permanently inhibit the use of the SCP.

- Revised engine start procedure and limitation of use against the HP Bleed Air cross feed duct (RTI/173).
  The ground engine start procedure has been revised and a limit of 80% HP RPM introduced, which consequently limits the air temperature, reached within the HP bleed air cross feed duct. Having started the engines, the HP bleed air cross feed duct Shut Off Valves are closed preventing higher temperature air passing through the duct. A limitation of use has been applied to the cross feed duct such that it is not used in flight.

  A ground trial has been conducted as part of UTI/51 and UTI/52, which has measured the temperatures of the HP bleed air cross feed duct during the revised engine start procedure, the results of which suggest that the duct temperature remains below that of the fuel auto ignition temperature. The report detailing the results and findings of this trial are currently being drafted.

- Use of bomb bay heating is suspended (RTI/173).
  The use of bomb bay heating is currently suspended such that the associated ducts are not exposed to any engine bleed air.

The mitigation introduced aims to reduce the risk presented by the hot air system by introducing operational limitations on systems and by making changes to the maintenance policy against the hot air system.

Other risk mitigation activities include the issue of Urgent Technical Instructions (UTIs) to investigate evidence of smoke and heat damage around a section of cross feed ducting. Reference [11], which mandated a physical examination of the condition of the duct and

References [12] and [13], which required that temperature readings of the duct were recorded every 5 minutes during a 45 minute Engine Ground Run (EGR). Additionally, Routine Technical Instructions (RTIs) have been issued, which call for ongoing inspections of the duct. Reference [6], which requires that an examination of the duct and a functional test of the cross feed valves, is performed on every Before Flight (B/F) servicing, and Reference [7], which requires that a physical examination of the cross feed duct insulation shrouds is performed at every After Flight (A/F) servicing.

8.1.2 Duct Replacement Programme

The Nimrod IPT is currently campaigning a programme to replace a number of hot air ducts on the aircraft as a result of the associated lifing policy for those ducts. Reference [14] details the ducts to be replaced and includes information about the lifing policy of the ducts. Further, it contains advice on an appropriate maintenance regime to follow pending completion of the duct replacement programme.

8.2 Observations

The identified mitigation will impact on the observations highlighted as part of the zonal inspections reported herein. A qualitative assessment of the impact of the mitigation is presented below:

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]

These three zonal observations (a, b and c) consider different aspects of the same potential risk. In this instance, the risk is of fire resulting from a fuel source contacting with a hot surface. The first observation identifies that a leak from the keel drain T-Piece may come into contact with the HP bleed air cross feed duct. The second observation notes that the identified shroud may direct any fuel towards an un-insulated section of duct and the third observation identifies that any fuel in this area may wick into the mount, again resulting in fuel coming into contact with a hot surface.

To mitigate this risk, RTI/173 details that the use of the HP bleed air cross feed duct is only used during ground engine start and that the engine start procedure is limited to 80% HP RPM, the aim of these limitations of use is to limit the temperatures reached by the duct. Providing the un-insulated duct surface temperature does not exceed the fluid auto ignition temperature, the risk of fire will be reduced or eliminated. UTI/51 and UTI/52 have been undertaken which measure the HP bleed air cross feed duct temperature during ground engine start, results from which suggest that the duct temperature will not exceed auto ignition temperature for fuel. AF and BF inspections, References [6] and [7], are conducted on the HP bleed air cross feed duct, which check for signs of leaks. Further, as part of STI/926, the laminated duct mount is being replaced and will be inspected at every equalised maintenance. In addition to this, Recommendations 7, 9 and 10 have been made in order to investigate if further mitigation is possible.

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]

Observations d and e consider the shrouds covering the bellows located on the HP bleed air cross feed duct. The noted shrouds have been identified previously as having a possibility of holding fuel, should fuel track and run down the associated duct. Consequently, inspections have been introduced which check for fuel in these locations. Recommendations 4 and 5 have been made in order to ensure that the inspection method does not adversely effect the duct insulation.

Should fuel be present on the HP bleed air cross feed duct, given the revised engine start procedure (80% HP RPM limitation) and limitation against use of the cross feed duct in flight, UTI/51 and UTI/52 have measured the HP bleed air cross feed duct temperature, results from which suggest that the duct temperature will not exceed auto ignition temperature for fuel.

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. [Section 4.3]

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). [Section 4.3]

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. [Section 4.3]

Zonal observations f, g and h consider the locations on the HP bleed air duct where surface temperatures could be significant. The 80% HP RPM engine start limitation and limitation of use against the cross feed duct in flight have been introduced, iaw RTI/173, which aim to limit the temperatures reached of the duct. Providing the un-insulated duct surface temperature does not exceed the fluid auto ignition temperature, the risk of fire will be reduced or eliminated. UTI/51 and UTI/52 have been undertaken which measure the HP bleed air cross feed duct temperature during ground engine start, results from which suggest that the duct temperature will not exceed auto ignition temperature for fuel. In addition to this, Recommendations 7, 9 and 10 have been made in order to investigate if further mitigation is possible.

Additional inspection regimes have been introduced, iaw RTI/172 to check for fuel leaks which aim to reduce the likelihood of a significant fuel leak. Fuel is also purged from the refuel gallery, using the AAR nitrogen purge function, iaw RTI/297.

i. There are areas where the clearances between the HP bleed air cross feed duct and other aircraft structures / services are minimal. [Section 4.3]

Where separation between systems is minimal or fouling occurs, heat transfers from one system may occur and / or mechanical damage may occur as a result of movement. Consequently, appropriately defined clearances between systems components are necessary to protect against potential fouls. Recommendations 1 and 2 have been made to investigate suitable and relevant clearance requirements between systems components.

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. [Section 4.3]

Damage tolerance of the noted duct insulation is not fully understood. Consequently, Recommendation 4 has been made.

k. The close proximity of the engine intake anti-icing pipe to fuel and hydraulic lines. [Sections 5.2.1, 5.2.4, 5.2.13 and 5.2.10]

l. The close proximity of hot air ducts to fuel lines and other services within both zone 1 engine bays. [Sections 5.2.2, 5.2.5, 5.2.14 and 5.2.11]

m. The location of the vent pipe above the ducts and CAU in the CAU bay. [Sections 5.2.7 and 5.2.16]

Observations k, l and m note specific instances where systems come into close proximity to hot air systems. Whilst increased levels of inspection should aid the identification of leaks, there is currently only limited information available regarding temperatures of the various hot air systems. Whilst it is possible to determine normal system temperatures in certain locations, as a result of temperature control sensors located in the systems, it is not clearly understood what the associated duct temperatures are. Recommendation 7 has been made in order to establish further information to determine whether specific zonal hazards exist.

n. The fouling / interference of the bomb bay heating ducts and fuel lines in the bomb bay centre section. [Section 5.2.9]

Fouling of the identified duct and fuel line may result in mechanical damage to either system. Currently, RTI/173 inhibits the use of bomb bay heating. Consequently, any potential fuel / heat zonal hazards between the fuel system and the bomb bay heating system has been eliminated. Recommendations 1 and 2 have been made in order to determine appropriate clearance requirements of systems components.

o. The close proximity of WAI to control runs, wiring looms and fuel pipes in wing root Rib 1. [Sections 5.2.8 and 5.2.17]

The close proximity between the Wing Anti-Ice and other aircraft systems may present a zonal risk. This will however, be dependant on the temperatures of the WAI duct. RTI/172 requires inspection of this location and aims to identify leaks, which may migrate to a hot surface. Recommendation 7 has been made in order to gain further information to determine the hot air system temperatures, including WAI, to determine if a specific zonal risk exists.

p. The moveable bracket assembly holding the hot air pipe in the aft bomb bay zone and the close proximity of the Tank 6 fuel line and the Tank 6 Inter-space drain. [Section 5.2.18]

Zonal observation p identifies a potential zonal interaction between the fuel system and a hot duct. The hot duct identified is used to feed air to the SCP. Currently, the SCP is inhibited, iaw RTI/173, consequently, the identified duct should not get hot as it is not in use. Additionally, the moveable bracket assembly is constructed of a laminated material and could potentially wick fluid. Recommendation 10 has been made to consider whether a redesign of the bracket is necessary to prevent wicking.

q. The location of the [redacted] routed directly under, and in contact with, the APU Air Start outlet. [Section 5.2.19] S26

Zonal observation q identifies an interaction between an electrical cable and duct. Whilst the cable does not contain a fluid / fuel, depending on the heat of the duct it may result in degradation of the cable. Whilst this is considered to present a minimal safety issue, Recommendation 7 has been made to determine further information of the duct temperatures. This information should be used to determine if a specific zonal hazard exists.

r. The potential for fuel migrating along the external aircraft surface finding a route to ignition sources behind external surface fairings. [Section 5.2.20]

Observation r considers the migration of fuel onto a hot duct. Mitigation introduced, RTI/213, aims to reduce probability of a fuel leak and BOV operation in flight by prohibiting AAR. Additionally, the SCP is also inhibited, iaw RTI/173, so the identified ducts behind the fairings on the outside of the airframe should not get hot. Additionally, Recommendation 11 has been made to determine if sealing the fairings to prevent fluid migration onto the ducts would provide any further mitigation.

8.3 Residual Risk Issues

It is considered that activities have been implemented which will mitigate a number of the observations identified above. Of those activities, the SCP and HP bleed air cross feed duct and 80% HP RPM engine start limitations having the largest mitigating effect. However, the mitigation activities themselves raise some issues:

- The limitation on in-flight use of the cross feed duct still poses a question regarding the risk exposure time from residual heat left in the duct. This is particularly significant where high ambient ground temperatures are experienced. It is unknown how long potentially hazardous hot gas temperatures remain inside the cross feed duct after the valves are closed. Whilst the 80% HP RPM engine start limitation aims to ensure that the temperature of the HP bleed air cross feed duct do not reach the temperature of fuel auto ignition (the results of which UTI/51 and UTI/52 suggest), the report detailing this is currently awaited.

Recommendation [x]: The results obtained from UTI/51 and UTI/52, which measured the temperature of the HP bleed air cross feed duct during engine start with an 80% HP RPM limitation, should be compiled and formally reported.

- The A/F examination of the cross feed duct requires the removal and refitting of the protective shroud. It is noted that Reference 15 Para 5a(6) requires that the shroud assembly seams are orientated as closely as possible to the 12 and 6 o'clock positions, to facilitate fluid drainage. Additionally, the repeated fit and removal of the retaining jubilee clips may be a contributory factor in the observed damage to the cross feed duct insulation.

Recommendation [xi]: Conduct an assessment of the impact of repeated fitting and removal of the insulating shroud on the centre section of the engine cross feed duct during A/F servicing.

It can be seen from Section 8.2 and from the points above that there is a level of residual risk within the Hot Air System. Additionally, it is not possible to quantify the level of risk that remains following the application of mitigating actions. It is however considered that it may not be practical or indeed even worthwhile to expend potentially significant amounts of effort in order to be able to quantify risk levels, when other engineering judgements may result in similar levels of risk reduction. In considering this, the following recommendation is noted which aims to generate a better understanding of those areas of the hot air system which will present greater levels of risk.

Recommendation [xii]: Consider conducting thermal analysis tests for the hot air system ducts; particularly in those areas where there is some ambiguity over the maximum temperatures likely to be experienced. Empirical test data, which specifies the precise maximum temperatures experienced at certain points, would provide some of the information necessary to allow realistic and verifiable risk levels to be established. Additionally, consider the fitment of a permanent temperature sensor to feed the engineer's panel with a real time display of the cross feed duct temperature.

Recommendation [xiii]: Conduct a statistical review of the number, periodicity, location and scale of fuel leaks.

In establishing quantifiable data relating to the hot air systems and fuel system, a targeted approach to risk reduction can be taken.

Recommendation [xiv]: Consider the feasibility of creating run-off tracks or channels to direct leaking fuel away from hot air components.

Whilst no safety target is defined for the hot air system, it would not be possible to determine if any targeted mitigation would or would not achieve an acceptable level of safety, however, it may allow for a qualitative risk assessment and ALARP judgment to be made.

9 Conclusion

9.1 Introduction

There are a total of 18 observations, summarised in Sections 4.3.9, 4.5.22 and 8.2 of this report, derived from the zonal analysis performed at RAF Kinloss. These observed zonal interactions between the hot air system components and other aircraft components, structures and systems can be broken down into 2 distinct areas. Firstly, an uncontrolled escape of hot gas that directly and adversely effects one of those other aircraft components, structures or systems. Secondly, the scenario where a part of the hot air system acts as a source of ignition for a fuel, oil, lubricant or other material or accelerant.

9.2 Escape of Hot Gases

Hot air escaping and causing damage to surrounding structures components is extremely difficult to assess for the following reasons:

1. The pressure, flow rate and temperature vary from location to location.
2. The direction of any uncontrolled escape of hot gas will influence the potential level of any hazardous effect, and the direction of any such escape cannot be predicted.
3. The size and shape of the location where any such leak may occur will influence the effect insofar as there may or may not be sufficient room to dissipate the gas or a channelling effect from the structure may direct the gas away from/toward any vulnerable components etc.
4. Whilst reasonable estimates of the expected gas temperatures can be made, there are many areas where the temperature of the hot gas within a duct is not known. For the purposes of the analysis, the worst credible expected temperature at any given point was considered. This was usually based on the assumption of a single system failure condition e.g. a lack of mixing cool/ram air.

Whilst the zonal analysis did discover several instances where the proximity of adjacent structures, services and components raised concerns that a hot gas escape would have an adverse effect, no evidence of any damage from interference or fouling to these structures, components or services was observed.

The interference issues that were observed during the investigation raised particular concern, as vibration/movement in these locations can lead to damage of the hot air ducting. Where this occurs, the direction of the hot gas escape is more predictable, as it is almost certain that any such escape will be directed toward the component that is moving against the duct. Document examination and discussion with SQEPs did not result in the disclosure of any detail regarding the expected amount of movement experienced due to vibration or aircraft manoeuvring. Consequently, it was impossible to conclude what damage would occur as a result of any interference, or to establish a timescale for any damage to occur. The physical access limitations, particularly in the Tank 7 Dry Bay, the location with the greatest proximity and interference issues, meant it was not possible to check for damage at the locations where interference occurred, thus further frustrating any attempt to quantify the perceived problem.

9.3 Auto-Ignition of Combustible Liquids

Reference [4] established that the liquid with the lowest auto-ignition temperature on the aircraft is fuel (208°C). Although aware that at this relatively low temperature, exposure time is a significant factor as to whether ignition will occur, it was deemed prudent to use this figure, along with a margin of error, as a baseline for the analysis. Fuel is also, by several orders of magnitude, the largest source of combustible liquid on the aircraft and consequently was the focus for the consideration of the hot air system acting as a source of auto-ignition. However, where specific zonal interactions were observed, other combustible fluids, e.g. hydraulic oil, were also considered as potential hazards.

Whilst, theoretically, it is possible for fuel to migrate to almost any part of the aircraft, the analysis was limited to consideration of more credible, zonal interactions and clear migratory paths.

Throughout the analysis – and detailed in Section 4 of this report – several areas were identified where hot air ducting was located in close proximity to fuel pipes. The greatest risk was deemed to be those areas where fuel couplings were located above hot air ducting. It would be more likely, were an uncontrolled escape of fuel to occur, that such an escape would – particularly if it were the result of a system overpressure – be from a point where the system is already broken, i.e. a coupling, as opposed to a single piece of pipe. Even where such couplings were located above insulated ducting, it was readily apparent that it would be very easy, and indeed likely, for any leaked fuel to migrate along the insulation until it reached an exposed section of the duct. Generally, gravity was seen as the force used to drive the migration of fuel, although aircraft manoeuvres and attitude would alter some, more obvious, migration paths and could lead to some unexpected routes to hot air ignition sources being found.

Hot air ducting of sufficient temperature to cause fuel auto-ignition is housed behind fairings external to the main aircraft structure. Witness marks showed that fuel ejected from the aircraft via blow off valves can, due to the boundary layer effect, find a path to these fairings. The protective qualities of these fairings, with respect to preventing fuel ingress, could not be ascertained during the course of this review. Only at the NSG was it possible to view behind one of the fairings and this was only on one aircraft. Examination behind the fairing of this aircraft showed no signs of any fuel or liquid ingress. However, examination of one aircraft is insufficient to conclude that such ingress cannot occur.

Overall the risk posed by fuel auto-ignition is heavily influenced by the number, location and scale of uncontrolled fuel escapes. It will be necessary to acquire verifiable data that provides these details prior to establishing any level of risk.

9.4 General

This review has identified several specific (zonal) and general hazards relating to the hot air system. Mitigating action taken by the Nimrod IPT has, particularly with respect to the centre section of the HP bleed air cross feed duct and the SCP, reduced the risk posed by these hazards.

Quantifying the residual level of risk is, however, impossible. Too many factors – e.g. fuel leak rates and duct temperatures – remain unknown to be able to establish a quantifiable risk figure. Furthermore, as there is no defined aircraft hot air system, and consequently no system safety target, even in the event that the requisite information to quantify the level of risk became available, that risk could not be compared against a defined risk matrix. Establishing a clearer understanding of the risk carried may empower the IPT to make any further airworthiness decisions based on a more definitive and verifiable assessment of the risk posed by the hot air system.

Recommendations have been made in this report, which aim to increase the understanding of potential risks and consider additional mitigation against the risks identified.

10 Recommendations

As a result of the observations made during the course of the review of the Nimrod hot air system, QinetiQ propose the following recommendations to the Nimrod IPT. However, as discussed in Section 8, it is considered that application of any additional mitigation should be targeted; consequently, the recommendations noted are grouped accordingly.

The following recommendations should be considered in any event:

1. Consider vibration monitoring as a method to confirm whether extant clearance requirements are satisfactory.[1]
2. Consider issuing a directive for duct clearance requirements and checks to ensure compliance with the clearance requirements mandated by Reference [8].[2]
3. Dependent on the information received from Industry on the duct insulation, consider the addition of extra pressure equalising holes in the insulation.[3]
4. Await the information from Industry on the hot air duct insulation prior to formulating appropriate policies for maintenance, fitment, serviceability assessment etc.[4]
5. Conduct an assessment of the impact of repeated fitting and removal of the insulating shroud on the centre section of the engine cross feed duct during A/F servicing.[5]
6. The results obtained from UTI/51 and UTI/52, which measured the temperature of the HP bleed air cross feed duct during engine start with an 80% HP RPM limitation, should be compiled and formally reported.[6]

The following recommendations should be undertaken to ensure that the remaining recommendations can be considered with appropriate background information:

7. Consider conducting thermal analysis tests for the hot air system ducts; particularly in those areas where there is some ambiguity over the maximum temperatures likely to be experienced. Empirical test data, which specifies the precise maximum temperatures experienced at certain points, would provide some of the information necessary to allow realistic and verifiable risk levels to be established. Additionally, consider the fitment of a permanent temperature sensor to feed the engineer's panel with a real time display of the cross feed duct temperature.[7]
8. Conduct a statistical review of the number, periodicity, location and scale of fuel leaks.[8]

Completion of the above recommendations should allow for a more considered and informed approach to the follow recommendations:

9. Consider the feasibility of creating run-off tracks or channels to direct leaking fuel away from hot air components.[9]

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[1] Identified from Section 6, Recommendation [ix]
[2] Identified from Section 6, Recommendation [viii]
[3] Identified from Section 6, Recommendation [vi]
[4] Identified from Section 6, Recommendation [vii]
[5] Identified from Section 8, Recommendation [xi]
[6] Identified from Section 8, Recommendation [x]
[7] Identified from Section 8, Recommendation [xii]
[8] Identified from Section 8, Recommendation [xiii]

10. Consider a re-design of the HP bleed air cross feed duct bracket at the centre section and rear bomb bay SCP duct bracket, where the construction used has led to concerns over wicking and / or pooling of liquids.[10]

11. Consider applying additional insulation / covers to exposed areas of hot air ducting, particularly where there are significant interactions with other aircraft systems.[11]

12. Investigate the qualities of the external hot air duct fairings to prevent liquid ingress and, if necessary, consider the feasibility of sealing these external aircraft fairings.[12]

Relevant activities currently being undertaken by the Nimrod IPT are presented at Annex C. Whilst this list of activities is not exhaustive, the identified activities should progress a number of the recommendations identified above.

[9] Identified from Section 8, Recommendation [xiv]

[10] Identified from Section 4.3, Recommendation [i] and Section 5.3, Recommendation [iii]

[11] Identified from Section 4.3, Recommendation [ii] and Section 5.3, Recommendation [v]

[12] Identified from Section 5.3, Recommendation [iv]

11 References

[1] Nimrod Fuel System Safety Case, Phase 4 Work Proposal – Issue 2, January 2008, QINETIQ/EMEA/IX/BID0708836 / 1-LJRVP.

[2] JSP 553, Military Airworthiness Regulations.

[3] Email – Nimrod Hot Air "System" Review, [redacted], 29 Apr 2008.

[4] An Analysis of Available Data to Determine a Surface Boundary for Auto-Ignition of Aircraft Fluids – BAE/W/NIM/RP/164830 R1 V1, 4 Jul 2003.

[5] Rolls Royce Engine Temperature Test Data – Engine No 709, 4 Oct 1996.

[6] RTI/NIMROD/234 – Before Flight Examination of the Cross Feed Dusting Shroud Assemblies and Functional Check of the Cross Feed Valves, date Feb 2008.

[7] RTI/NIM/ROD/235 – After Flight Examination of the Cross Feed Ducting Shroud Assemblies, dated Feb 2008.

[8] AP101B-0503-1BJ, Chap 23-12, Para 3.5.7 – Ducting removal and Installation Instructions.

[9] RTI/NIMROD/173 – Limitations applied to Nimrod systems including NP Bleed Air Cross Feed Duct

[10] UTI/NIMROD/025, Electrical Isolation of Secondary Cooling Pack, 10 Dec 07.

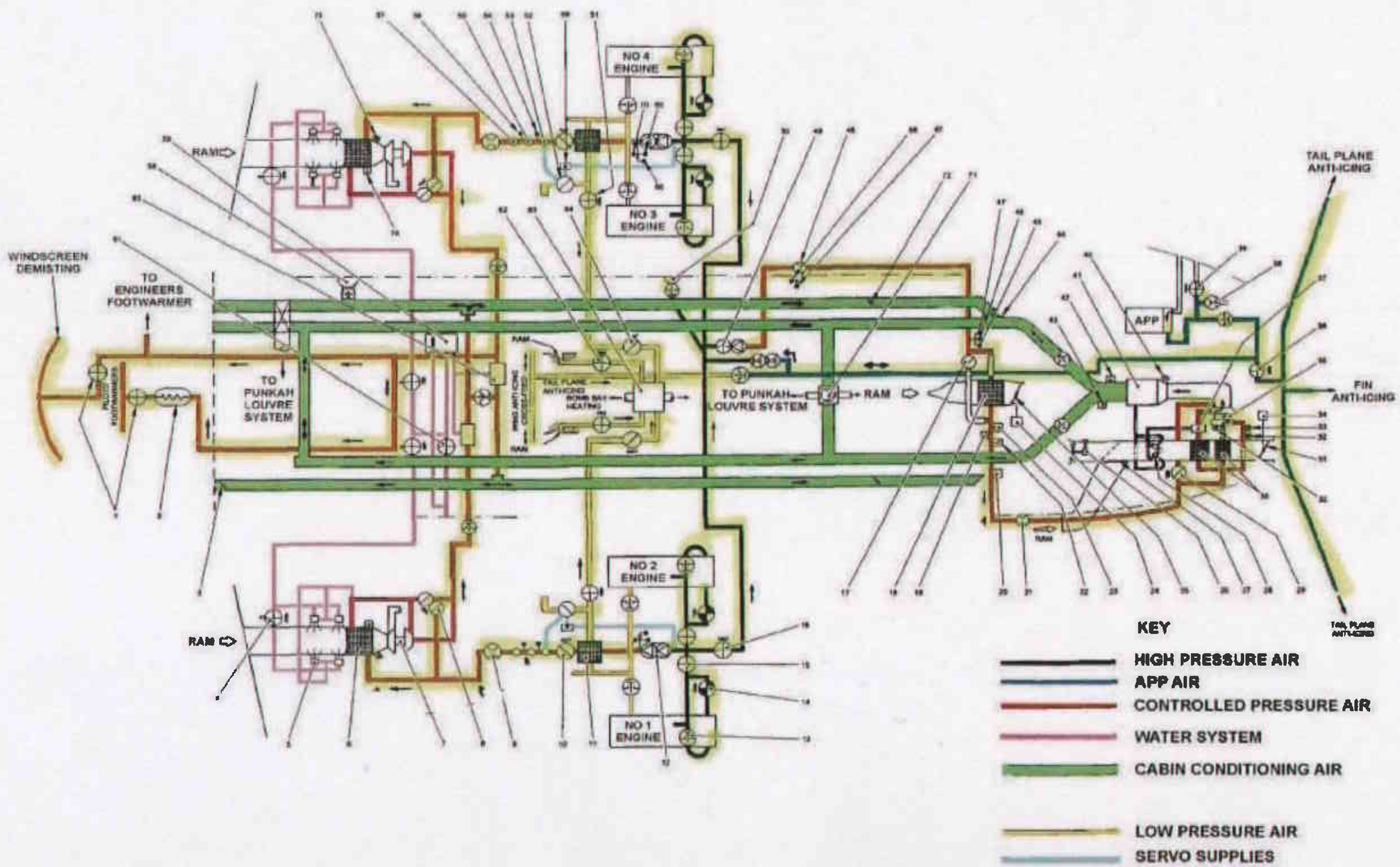
[11] UTI/NIMROD/049 – Examination of ECU HP Air Cross Feed Ducting, 30 Jan 2008.

[12] UTI/NIMROD/051A – Temperature Check of Cross Feed Ducting, 26 Mar 2008.

[13] UTI/NIMROD/052 – Temperature Check of Cross Feed Ducting, 26 Mar 2008.

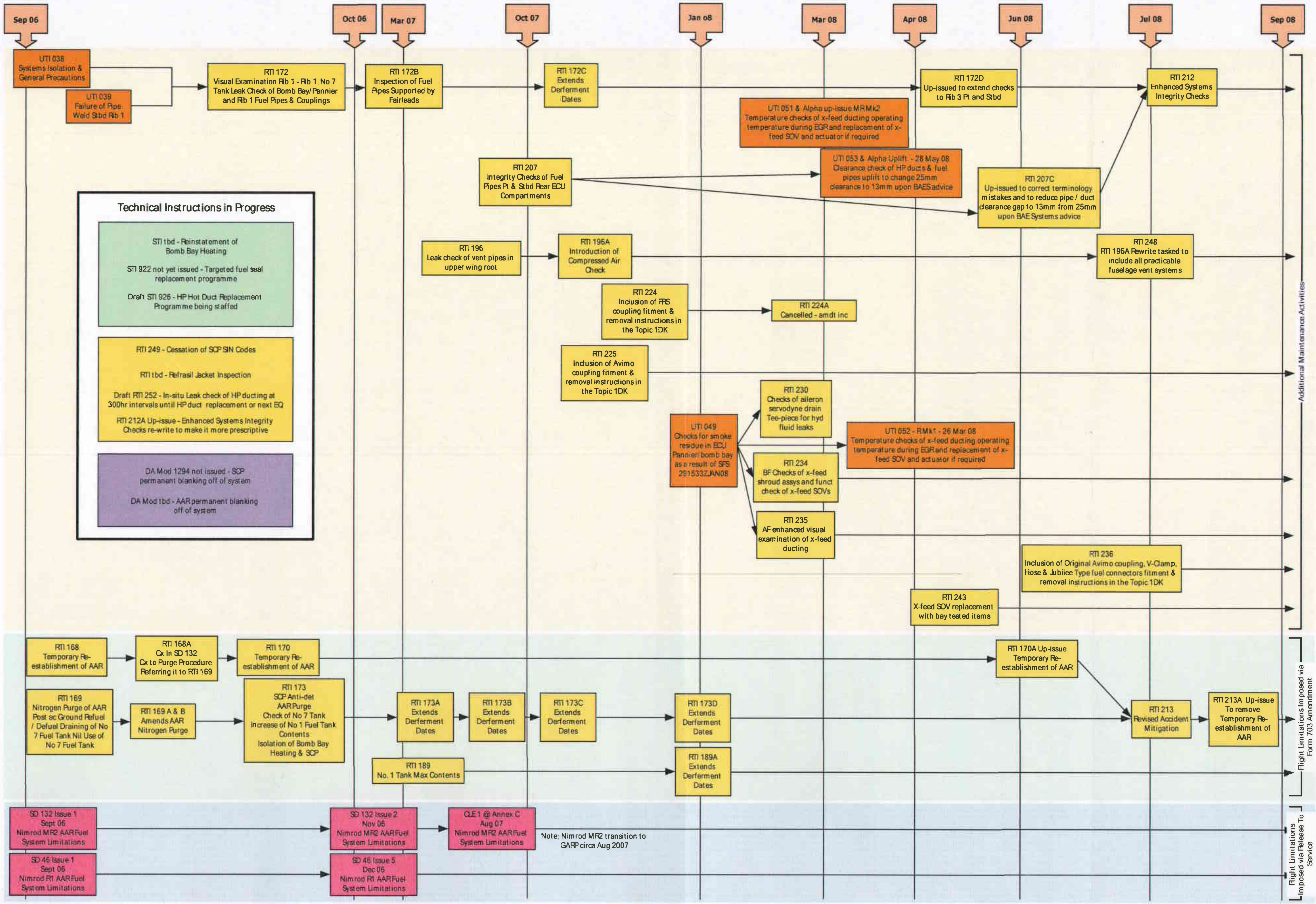
[14] FAT/801R/08/016, Issue 4, 3rd July 2008, Nimrod Structural Integrity of Hot Air Ducts – Final Report and Recommendations

A Annex A: Nimrod MR Mk2 – Hot Air System Review Boundary Diagram



1	Hot air control valve	38	Auxiliary spill valve
2	Foot warmer heater	39	Anti-surge valve
3	Cockpit air supply valve	40	Duct temperature control sensor
4	Shut-off (Unimatic) valve	41	Water extractor
5	Atomizing nozzle	42	Duct temperature bulb
6	Heat exchanger (wing system)	43	Duct over-temperature switch
7	Cold air unit (wing system)	44	Rear cabin air supply valve (frame 50)
8	Temperature control valve (wing system)	45	Low mass-flow pressure switch (tail pack)
9	Flow control venturi (wing system)	46	High mass-flow pressure switch (tail pack)
10	Mass-flow control valve	47	Pre-cooler overpressure switch
11	Pre-cooler (wing system)	48	Flow limiting venturi
12	Dual pressure regulating valve	49	Pressure regulating and shut-off valve
13	Non-return valve	50	Ground start connection
14	Starter valve	51	Bomb bay shut-off valve
15	Manual shut-off valve	52	LP bleed air control valve
16	Cross-feed valve	53	HT control sensor
17	Pre-cooler underheat temperature control valve	54	Cold air unit overspeed pressure switch
18	Pre-cooler (tail pack)	55	HP air overheat switch
19	Pre-cooler over-temperature switch	56	Low mass-flow pressure switch (wing system)
20	Pre-cooler underheat temperature control sensor	57	Pre-cooler outlet temperature bulb
21	Flow control venturi (tail pack)	58	Ground conditioning connection
22	Pre-cooler outlet temperature sensor	59	Water bottle
23	Pre-cooler outlet temperature bulb	60	Water extractor / humidifier
24	Pre-cooler ram air modulation valve actuator	61	Drain cock
25	Pre-cooler ram air modulation valve	62	Bomb bay ram air shut-off valve
26	Ground cooling fan	63	Bomb bay mixing chamber
27	Flap valve	64	Bomb bay temperature control valve
28	Water injector	65	High mass-flow pressure switch (wing system)
29	Temperature control valve (tail pack)	66	Pre-cooler overpressure switch
30	Primary/secondary heat exchanger (tail pack)	67	Duct underpressure switch
31	Tail pack ram air modulation valve	68	Duct overpressure switch
32	Cold air unit over temperature switch	69	Solenoid valve (LP bleed-air control valve)
33	Tail pack ram air temperature control sensor	70	Boost cancel switch
34	Tail pack ram air modulation valve actuator	71	Flap valve (punkah louvre system)
35	Cold air unit (tail pack)	72	Rear cabin air supply valve (frame 37)
36	Tailplane anti-icing shut-off valve	73	Cold air unit fan overheat switch (wing system)
37	Water separator	74	Cold air unit fan temperature control sensor (wing system)

B Annex B: Mitigation Summary



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C Annex C

A review of the Nimrod EMDB has been undertaken to identify activities that are considered relevant to the findings and recommendations of this report. Whilst the Nimrod EMDB contains details on all activities being undertaken by the Nimrod IPT, identified below are those activities that are considered relevant to this report. A number of these activities contribute to the mitigation summarised within Annex B.

Note: The information presented in this Annex is as reflected within the Nimrod EMBD.

RTI / STI / UTI and RTS activities are summarised in Annex B. PDS Tasks raised by the Nimrod IPT (Identified from EMDB Issue 1695):

AV(A)/2846	Raise F714 for designer modification to blank SCP. *Ongoing – letter RJO-NIM-08-04*
AV/2874	Raise F714 for designer modification to blank AAR. *Ongoing – letter MBSY-WRB-250708*
AV/2912	Removal of SCP SINs from 5A1 and cessation of 14 day anti-det as system will be permanently blanked and isolated under DA mod 1294. *Supplied a spreadsheet of SINs to BAE, verbal response agreed between RO and DW that BAE agreed with this. Subsequent RCM analysis conducted to review this.*
AV(A)/2727	Damage limits for engine hot air system pipes. *Letter MBSY/MA/16/11/07/1*
AV/2875	Feasibility study for a Designer Modification to blank the AAR system. *See task 2874.*
AV(A)/2795	Draft an STI – Inhibition of the SCP. *SCP is currently electrically isolated. STI 923 is in draft however not issued.*
AV(A)/2931	Produce an STI to introduce additional drain holes in the No7 Tank dray bay lower skin. *STI/930 (R1) and STI/931 (MR2) now fleet embodied.*
AV(A)/2932	Produce a repair drawing to support task to produce an STI to introduce drain holes in the No7 tank services bay. *Drawings provided as part of Task 2931.*
AV/2970	7 Tank dry bay ducting bellows Refraisal / muff. *Task superseded by task 2991.*
AV/2982	MOD 1294 SCP blank additional queries. *Ongoing, MOD 1294 still in draft.*

PDS Tasks raised by the Nimrod IPT (Identified from EMDB Issue 1948):

AV(A)/2809	Provision of a firm cost for the replacement of all cross feed ducts from the ECU separation points. *Hot duct replacement programme underway.*
AV(A)/2822	Investigate lowering HP air supply temp / pressure in cross feed ducts through the fitment of PRV/TRV, LP air mixer or another device near the cross feed SOVs.

	Task cancelled. It is assumed the task has been cancelled due to the revised engine start procedure, which limits the temperatures and pressures in the HP bleed air cross feed duct.
AV(A)/2837	Temperature measurement of Nimrod MR Mk2 Cross Feed Duct *Trial conducted and results have been compiled however no report has been produced.*
AV(A)/2867	Investigate the feasibility of replacing HP duct Refraisal jackets as an item during EQ maintenance, or alternatively provide advice on a repair scheme to damaged refraisals. *Ongoing, core task superseded by other task.*
AV/2913	Bleed air hole on new ducts *Ongoing. Request for additional work to investigate the cause of Refraisal damage to determine if bleed air holes are suitable.*
AV/2870	Draft STI to enable the duct replacement program to be carried out. *Ongoing, draft STI in progress.*
AV/2991	Draft an STI to fit a Pipe Joint Assy (6M4S8701A or similar) to duct joint 6M4S2209 / 6M4S643 and 6M4S2210 / 6M4S643. *Task rejected.*
AV/3037	Determine the temperatures for the bomb bay heating and anti icing outside of the firezones. *Ongoing.*
AV/2992	Design review of all drawings relating to the design, manufacture and installation of all ducts being replaced under the HADR program. *Task rejected.*

AEDIT Tasks raised by the Nimrod IPT (Identified from EMDB Issue 1948):

1218	ECU starting from STAD instead of ECU bleed air. *Ongoing, awaiting information.*
1216	Investigate the feasibility of starting ECUs without feeding ECU bleed air into the cross-feed duct and drafting the required procedure. *Ongoing, awaiting information.*
1231	Produce an RTI to measure the temperature of the cross feed duct within the bomb / pannier bay. *UTI 51 and 52 produced to measure temperature of the cross feed duct. Ground trials have been completed and results compiled although no report produced.*

In light of the highlighted activities noted above, these activities can be considered against a number of the recommendations made in this report…

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Abstract The system review report presents the results of an assessment of the Nimrod MR Mk 2 Hot Air System and has been developed using a zonal analysis, review of technical documentation and SQEP input to identify hazards associated with the system. Overall, this activity for the Nimrod MR Mk2 Hot Air System has identified 18 significant observations, resulting in a total of 13 recommendations to the Nimrod IPT. Due to the lack of a quantified safety target and statistical system data, no quantified level of system risk has been established. The results of the system review are purely qualitative and subjective in nature.			
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