RAF FORM 412 (ADP)
(Revised 2/97)

ROYAL AIR FORCE
PROCEEDINGS OF A BOARD OF INQUIRY
INTO AN AIRCRAFT ACCIDENT

PART 1

DETAILS OF THE BOARD

Assembled on 3 Sep 06 at Headquarters No 2 Group

By order of the AIR OFFICER COMMANDING No 2 GROUP

To inquire into an accident involving NIMROD MR2 XV230 on 2 SEP 06.

1. **Composition of the Board**.

Duty	Rank, Name, Service No & Decoration	Branch	Unit
President		GD	DCDC
Members		WSO(ENG) ENG	RAF KINLOSS RAF KINLOSS
In Attendance (QR 1269)			

2. **Full Terms of Reference**.

a. Investigate the circumstances of the accident to Nimrod MR2 XV230 near Kandahar, Afghanistan on 2 Sep 06.

b. Determine the cause or causes of the accident and examine related factors.

c. Ascertain the degree of injury suffered by persons both Service and civilian.

d. Ascertain if Service personnel involved were on duty.

e. Ascertain if all relevant orders and instructions were complied with.

f. Ascertain if aircrew escape and survival facilities were fully utilised and functioned correctly.

g. Ascertain extent of damage to aircraft, public property and civilian property.

h. Assess any human factors.

i. Investigate the loss of all classified material carried on or in the aircraft at the time of the accident.

j. Determine whether the age of the Nimrod MR2 fleet was a contributory factor.

k. Determine whether operational pressure was a contributory factor.

l. Make appropriate recommendations.

PART 2

CONCLUSIONS OF THE BOARD

NARRATIVE OF EVENTS

(All times ZULU. Afghanistan Local Time = ZULU + 4 ½ hrs. All times are from source documents. Correlation of identical events on the Kandahar ATC transcript, the aircraft mission tape (transcript version 12) and the C2 agency transcript indicates that while the latter 2 usually agree within seconds, the former is approximately 48 seconds divergent. Thus the C2 Agency's times have been taken as the master and a correction applied to other times where possible. The times quoted in the AAIB report and the QinetiQ combustion study differ in some areas by a few seconds from those contained in this report; the differences are the result of independent interpretation of source data and are not significant.)

(Exhibits 2 and 10 are classified SECRET. To allow the main report to remain at RESTRICTED-STAFF these exhibits are held separately.)

INTRODUCTION

1. On 2 Sep 06, No 120 Sqn Crew 3, supplemented by 2 Witness 4
, was tasked with the support of NATO and Afghani forces
engaged in Operation MEDUSA in Southern Afghanistan. Allocated
Nimrod MR2 XV230, the crew departed at 0913 hrs.
Although the initial stages of the mission appear to have gone according to Exhibit 1
plan, at 1111:33 hrs, approximately 90 seconds after receiving 22 000 lbs
of fuel from a Tristar tanker, the crew experienced almost simultaneous
bomb bay fire and elevator bay smoke/ hydraulic mist warnings; smoke
was observed in the cabin, coming from both elevator and aileron bays, and
shortly afterwards the aircraft depressurised. The crew commenced
emergency drills and at 1114:10 hrs transmitted a MAYDAY, heading for
Kandahar airfield. The Nimrod was subsequently observed by a Harrier Witness 27/
GR7 pilot, at 1116:54 hrs, in an apparently controlled descent, with flames Exhibit 82a-c
emitting from the starboard wing root and the starboard aft fuselage.
Shortly thereafter several members of A Sqn Royal Canadian Dragoons Witnesses
(RCD) observed the aircraft as it passed to the south of their position; the 37&38/
fire appeared to them to be on the port side of the aircraft. At 1117:39 hrs Exhibits 9&73
the Harrier GR7 pilot reported that the aircraft had exploded, at what he Exhibit 2
believed to be 3000ft agl, and he observed wreckage striking the ground.
The RCD also witnessed the explosion, although they reported it as being
at a lower altitude. A Scene of Action Commander was established over
the crash site and a Combat SAR team was deployed. However, there were Exhibit 3
no survivors. Shortly after the crash, the RCD unit, subsequently
supplemented by members of 34 Sqn RAF Regt from Kandahar airfield, Exhibit 4
secured the area. The crash site was in an area of known Taliban activity
and proximate to Operation MEDUSA combat operations: it was

anticipated that the area could only be held for a limited period of time. Thus, initial priorities were the recovery of the crew's bodies, personal effects, classified documentation and equipment. The Canadian unit was withdrawn the following day and, in an increasingly unstable situation, the remaining RAF Regt personnel were withdrawn shortly thereafter.

CREW BACKGROUND

2. Crew 3 had arrived at Deployed Operational Base (DOB) from the UK on 21 Aug 06 and had flown 3 sorties since their arrival, the last being on 27 Aug 06. — Witness 4

the crew had achieved combat ready (CR) status on 1 Aug 06, after a work-up period following the appointment of the CR (Advanced) Flt Lt Squires as Captain. — Exhibit 5

Witness 4

Full details of the crew are contained at Annex B. — Annex B

AIRCRAFT BACKGROUND

3. Nimrod MR2 XV230 deployed to theatre on 3 Aug 06. In the previous 2 years it had received a Major maintenance between 24 Sep 04 and 23 May 05 (at 17 954 flying hours (fg hrs)), a Primary maintenance between 21 Nov 05 and 24 Mar 06 (at 18 445 fg hrs) and was the first Nimrod MR2 to undergo Equalised 1 maintenance between 18 May and 26 Jul 06 (at 18 568 fg hrs); under the previous maintenance regime, replaced by Equalised maintenance, XV230 would have been due a Minor maintenance at 18 854 fg hrs. Examination of the aircraft's documentation revealed that no significant faults were found during the Major or in the period up to the aircraft's loss. Although a number of fuel leaks were identified during the Primary maintenance, lengthening the Primary, these were confined to the wing areas and were successfully repaired (see para 39d). — Compiled from maintenance documentation held by the Board

The ground crew servicing XV230 in theatre reported that it had been a particularly serviceable aircraft. The complete technical details of XV230 are recorded at Annex C. — Witnesses 7-18; Annex C

PRE-CRASH EVENTS

4. **Previous 24 Hours**. The crew had no specific duties during the 24 hours prior to the incident and none booked themselves off DOB during this period. Aircrew accommodation was in air-conditioned single rooms and the standard of food provided by civilian contractors is described as excellent. There is no evidence to suggest that the crew were — Witness 4

other than adequately rested for their mission.

5. **Mission Preparation**. The pre-flight brief was issued to the crew by the briefing officer, , on the morning of 2 Sep 06 and, in accordance with standard practice, they briefed themselves prior to collecting their equipment and walking to the aircraft. Flt Lt Squires self authorised the mission. No difficulties were encountered as the crew prepared the aircraft for flight and they departed at 0913 hrs, only 3 minutes later than originally planned. This scale of delay is not unusual and was probably caused by the need to conform to air traffic departure timings at the combined military/ civil airport.

Witness 6
Exhibit 6
Witnesses 7-18

6. **Pre-Incident Events**. The reconstruction of events prior to the incident is based on information from the Digital Acquisition and Recording Unit (DARU) – the aircraft's accident data recorder, the aircraft's mission tape and the testimony of the Tristar crew who refuelled XV230 immediately prior to the incident. Crew intercom and positional information was extracted from the mission tape, which was recovered from the crash site in a badly damaged state; the DARU does not record cockpit voice, audio or positional information. The evidence from the mission tape covers the period 1000 hrs to 1115:43 hrs, but the damage sustained in the crash rendered some areas of data irrecoverable, despite extensive restoration. Nothing abnormal was reported by Crew 3 in the transit prior to rendezvous with a Tristar tanker for Air-to-Air Refuelling (AAR) at 1100 hrs, on a northerly track. Although the recovered tape does not cover the entire transit, it is assumed that, had the crew detected a significant abnormality, they would have returned to . The rendezvous was completed successfully and Flt Lt Squires made contact with the tanker's refuelling hose on his third attempt. The Tristar crew noticed nothing unusual during the refuelling process, which commenced at 1103:53 hrs and lasted for approximately 6 minutes, during which time XV230 received some 22 000 lbs of fuel. The Nimrod crew noted 2 occurrences during this period, which were recorded on the mission tape from crew intercom. At 1109:23 hrs, the air engineer commented that the Supplementary Conditioning Pack (SCP) had shut down unexpectedly; the possible significance of this is discussed at paras 27, 38 and 42c. Shortly afterwards, at 1109:33 hrs, as AAR approached its completion, the flight deck crew appear to discuss an unexpectedly low fuel input to one of the fuel tanks; the fact does not appear of great concern to the crew, but the conversation is incomplete and it has proved impossible to determine the complete context (the occurrence is discussed further at Annex N).

Exhibit 7
Exhibit 1
Witnesses 29-31/ Exhibit 83

7. **Incident Events**. At approximately 1110 hrs, XV230 withdrew from the tanker and moved to echelon right, climbing to Flight Level (FL) 220 and preparing to turn right (east), towards the operational area. Shortly after this manoeuvre began, at 1111:33 hrs, the crew experienced almost simultaneous bomb bay fire and elevator bay smoke warnings (relevant Nimrod warning systems are discussed at Annex D). The captain reacted initially to the bomb bay fire warning, requesting the manning of the bomb

Exhibit 1
Annex D

bay periscope (although there is no subsequent evidence of any report from this position). However, the following 50 seconds of mission tape contains a continuous and, at times, overlapping, series of reports, which indicate the ingress of smoke into the cabin from both elevator and aileron bays, culminating in the rapid depressurisation of the cabin. After ensuring that everybody was on oxygen, the crew conducted the Aileron Bay Underfloor Warning Drill, although this was interrupted by the temporary loss of the air engineer's intercom. A report, by the operator at 1113:45 hrs, of flames coming from the rear of the engines on the starboard side was followed at 1114:01 hrs by an initial report of fire in the aileron bay (the fire may well have been alight prior to this, as it would take a finite time for the nominated crew member to don portable oxygen and use the observation scope to examine the aileron bay). The captain initiated a
descent to Kandahar airfield and a MAYDAY was transmitted on the C2 Exhibit 2
frequency. The previous turn towards the aircraft's operational area had
headed the aircraft towards Kandahar and the navigators inserted a steer for Exhibit 1
the airfield; the captain's descent point was correct for an approach to Kandahar's Runway 23. The C2 agency handed XV230 to Kandahar Approach, who passed the airfield's details to the aircraft. At 1115:30 hrs, with flames still visible in the aileron bay, the second of 2 bursts of extinguisher was fired. The mission tape ends at 1115:43 hrs, with a report of more smoke emitting from the aileron bay. The final transmission from
the aircraft to Kandahar Approach was at 1116:34 hrs, when the co-pilot Exhibit 8
acknowledged the airfield QNH (the airfield altimeter pressure setting). Thus, it can be surmised that, at this time, the crew still believed the aircraft to be under control and were intending to land at Kandahar airfield.

CRASH AND POST CRASH EVENTS

8. **Crash Events**. At 1116:54 hrs, the pilot of a Harrier GR7, Witness 27/
engaged on operations at to the west of Kandahar airfield, observed Exhibit 82a-c
XV230 in what appeared to be a controlled descent beneath him (DARU Exhibit 7
analysis shows that XV230 was at FL 120 at this time). Flames were Witness 27/
apparent over the rear half of the starboard wing, close to the fuselage and Exhibit 82a-c
reaching out to the No 4 engine nacelle; the fire did not appear to originate in the engines. These flames ended at the rear crew door and a second source of flame was apparent from the rear starboard fuselage, extending over the starboard tail plane some 10 metres behind the aircraft. No fire was apparent, to the GR7 pilot, on the port side of the aircraft. The GR7 pilot maintained visual contact with XV230, as he ensured that Kandahar airfield was aware of the emergency, before observing what appeared to be
a single, large fuel/airburst explosion at an apparent 3000ft above ground Exhibit 8
level (agl); the time was 1117:39 hrs. Shortly after the GR7 pilot's initial
sighting of XV230, members of A Sqn RCD observed the Nimrod, as it Witnesses
passed to the south of their position, apparently in a controlled descent, 37&38
with the port wing slightly below the horizontal. The RCD witnesses' Exhibits 9&73
testimony agrees to a large extent with that of the GR7 pilot, with 2 exceptions. The RCD witnesses placed the fire on the port wing of the Nimrod, although in other respects the fire they observed was similar to

that seen by the GR7 pilot. One RCD witness also reported a rapid
increase in the fire's strength as the aircraft disappeared from sight on the
horizon (and very shortly before it crashed). suggest that the Exhibit 10
aircraft impacted the ground at 1117:51 hrs. Subsequent analysis of the Exhibit 11/1
crash site suggests that, at a height of approximately 700 ft, the aircraft Exhibit 12a
broke into at least 4 large sections (fuselage, starboard wing, port wing and
tail section) and struck the ground at high speed, with a low angle of
incidence. Several large hay ricks at the crash site were ignited, but these
were the only significant areas of prolonged combustion on the ground.
The crash site, at 3131:54 N and 06534:07 E, was approximately 14 nm
west of Kandahar airfield, some 400 metres north-west of the village of Witness 27 /
Farhellah. Despite being extremely short of fuel, the GR7 pilot transmitted Exhibit 82a-c
an accurate position of the crash to the controlling agency before departing Exhibit 8
the area.

9. **Post-Crash Events**. With the departure of the GR7, the C2 Exhibit 2
agency appointed the leader of a pair of USN F18s as Scene of Action
Commander. A USAF Predator UAV was also used to provide visual Exhibit 13
imagery of the site. Furthermore, US Army helicopters were employed to
actively discourage local nationals from entering the crash area. At 1207 Exhibit 3
hrs a Combat SAR team arrived by helicopter and confirmed that
there were no survivors. The was reinforced by the arrival of
A Sqn RCD at 1257 hrs, who had been tasked to secure the area. The crash Witness 37
site lay in a depression, surrounded by higher land containing housing and, Exhibits 4&14
as such, was not easily defensible. Nonetheless, the RCD prevented the
ingress of any local nationals and recorded video footage of the scene
shortly after their arrival. The Canadians were joined at 1430 hrs by a 22
man patrol from 34 Sqn RAF Regt accompanied by ,
with previous RAF service as an engineering officer, all based at Kandahar.
904 EAW, at Kandahar, had expended considerable effort in
attempting to obtain descriptions of any hazardous materials, weapons Witness 3
carried and the location of the DARU within the Nimrod; although he
experienced difficulty in obtaining this information, the data he garnered
was passed to the on-scene team. The priorities of the combined force were
the recovery of the crew's bodies, personal effects and classified equipment Exhibits 4&14
and data.
the personnel of 34 Sqn RAF Regt,
assisted by those Canadians not actually guarding the site, conducted a
number of searches of the wreckage, under the direction of their respective
commanding officers
. After recovery the crew's bodies were placed in a central
location, surrounded by the Canadians' vehicles, where they would not be
disturbed. As night fell the coalition force assumed a defensive position
which ensured that the site's integrity was maintained. At first light the
following morning the search was resumed and the force was joined by
904 EAW and 34 Sqn, accompanied by a combat camera team, which
was used to provide aerial photography of the crash site prior to departing
for another task. 904 EAW conducted some on-site photography of
elements of the wreckage. In view of the limited nature of evidence

available, the photographic record proved invaluable. The Board noted that the air-to-ground photographs provided by the combat camera team were of a particularly high resolution and thus suitable for detailed analysis. Later that morning the crew's bodies, accompanied by 34 Sqn RAF Regt and 904 EAW, were flown, in a United States Army Chinook helicopter to Kandahar, where they were placed in the mortuary for storage until repatriation could be arranged. Shortly afterwards, A Sqn RCD was retasked to support other coalition units engaging the Taliban, at which point several hundred local nationals, including Taliban elements, began to enter the site. The remaining RAF Regt personnel formed a defensive position in an irrigation ditch crossing the site and, in view of the rapidly deteriorating situation, were withdrawn by air at 0910 hrs, some 21 hours after the initial arrival of ground forces. The security situation, combined with the probability that potential helicopter landing sites had been mined by the Taliban, has prevented any return to the crash site. Subsequent reconnaissance of the site revealed that the majority of the aircraft wreckage was removed within a short period of time, probably by local nationals.

10. The Board concludes that:

a.	The flight was properly authorised.	Exhibit 6
b.	The flight was adequately briefed.	Witness 6
c.	The crew were competent to undertake the flight.	Witness4/ Exhibit 5
d.	The aircraft was declared serviceable for flight.	Witnesses 7-18/ Exhibit 15
e.	The weather was suitable for the flight.	Exhibit 16/ Witness 6

DEGREE OF INJURY

11. The Board finds that:

a. **Service Personnel**. All 14 Service personnel aboard Nimrod XV230 died instantaneously at the time of the crash. — Exhibit 17

b. **Civilian Personnel**. There were no injuries to civilian personnel. — Witness 3

WHETHER SERVICE PERSONNEL WERE ON DUTY

12. All Service personnel were on duty at the time of the incident. — Exhibit 6

AIRCRAFT ESCAPE FACILITIES AND SURVIVAL ASPECTS

13. The accident was not survivable and all personnel would have been killed instantaneously at the time of the crash. The Nimrod has no airborne escape system. Despite exhaustive investigations with MOD and civilian organizations, the Board has been unable to find any evidence of investigations into the utility of parachute escape from the Nimrod. However, no other aircraft in the RAF's multi-engine fleet routinely carries parachutes for crew escape; all rely on the multiple redundancy of systems available in any large aircraft and the ability to divert. Nonetheless, the Board was of the opinion that, even had parachutes been available to Crew 3, all evidence indicates that, until approximately 90 seconds before the crash, the crew believed that they were going to be able to reach Kandahar airfield; thereafter it is unlikely that parachutes could have been employed successfully. Exhibit 17

DAMAGE TO AIRCRAFT, PUBLIC AND CIVILIAN PROPERTY

14. **Aircraft**. Nimrod MR2 XV230 sustained damage assessed as Category 5. Exhibit 18

15. **Public Property**. Public property to the value of £6 585 626.09 was lost as a result of the crash. Exhibit 19

16. **Civilian Property**. The winter animal feed for nearby villages was incinerated during the crash and there was possibly some fuel contamination of the ground. The Civilian Secretariat Lashkar Gah has confirmed that he has been advised of the damage to civilian property caused by the crash and is the party responsible for settling any claims. Witness 3 Exhibit 20

LOSS OF, OR DAMAGE TO, CLASSIFIED MATERIAL

17. The high impact velocity of the crash destroyed most electronic components, although the lack of a widespread and sustained fire led to the partial survival of a number of documents and maps. Personnel at the crash site attempted to recover as much classified material as possible. The material not recovered and action taken following its loss is described at Exhibits 21 and 22. Exhibits 21&22

DIAGNOSIS OF CAUSES

INTRODUCTION

18. The Board was unable to conduct an on-site analysis of the wreckage and crash area, due to the high threat level. A continuing high threat level and the fact that the majority of the aircraft wreckage has been removed by local nationals has precluded any later attempt by the Board to visit the site. Therefore, the Board's determination of the likely causes of the crash has relied for primary evidence principally upon analysis of the DARU, recovered mission tape, ATC recordings, imagery taken at the crash site and the minimal equipment recovered, coupled with witness testimony. As the Board was unable to examine the wreckage to determine a point and mode of failure, available evidence was used initially to determine the most likely point of the fire's initiation; this was an essential prerequisite to considering the factors that might have caused that fire. Thereafter, the Board examined the probable means by which fuel, a means of ignition and oxygen could have been brought together in a viable manner to create the fire which eventually caused the loss of Nimrod XV230 and its crew. While the Board's primary investigation was focused on the cause of the fire which precipitated XV230's crash, it was also conscious of the fact that, until 1117:39 hrs, when the GR7 pilot reported the aircraft exploding, XV230 appeared, to external observers, to be in a controlled, albeit emergency, descent to Kandahar airfield. It can also be assumed that at 1116:34 hrs, when the co-pilot acknowledged the Kandahar airfield pressure setting the crew believed that the aircraft was still in control and that they would reach the airfield. Nonetheless, at a time between the co-pilot's final transmission and the observed explosion, the Board calculated that the aircraft departed from its previous controlled descent into Kandahar: both rate of descent and airspeed increased markedly prior to the aircraft breaking-up. The Board felt that the sequence of events immediately prior to the crash at 1117:51 hrs also merited close examination.

Exhibit 2

Exhibit 65

AVAILABLE EVIDENCE

19. The following evidence was available to the Board:

a. **DARU Data**. The DARU, which is crash-protected, records aircraft pitch, altitude, accelerations, indicated airspeed, heading, control positions and also engine parameters – but not intercom or aircraft position. The DARU was badly damaged in the crash, although the recording unit was recovered intact; with specialist assistance from QinetiQ, it was possible to recover the data. However, recording ceased abruptly at approximately 1116 hrs, shortly before the crash, probably as a result of power failure. Power supplies to the DARU route along the starboard side of the fuselage, inside the pressure hull, and these were probably destroyed by the fire.

Exhibit 7

b. **Mission Tape**. The mission tape records Central Tactical System data, including aircraft position and intercom and its primary purpose is post-flight analysis of a sortie. Although the unit is not crash-protected, a section of mission tape covering the period 1000 hrs to 1115: 43 hrs survived, albeit extensively damaged. The tape was dispatched to QinetiQ for data recovery. Despite extensive specialist restoration, sections of data were irrecoverable. Exhibit 1

c. **ATC Recordings**. The Board was able to obtain transcripts of the ATC radio transmissions on both C2 and Kandahar ATC networks, together with a recording of the ATC transmissions. The C2 agency radar is not video taped and the video from Kandahar ATC was destroyed when staff attempted to remove it from the recorder unit in which it had become stuck. This did not restrict the investigation significantly as aircraft position information was available to the Board from the mission tape. Exhibits 2 and 8; Exhibit 27

d. **Photographs**. A number of photographs were taken by 904 EAW and a UK combat camera team on 3 Sep 06. The photographs consist of general views of the crash site and photographs of specific sections of wreckage. Photographs were limited by the fact that the camera team was subsequently deployed to another task and 904 EAW's camera battery failed. Some of these photographs are compiled within Exhibit 11; the remainder have been archived in the Board's records. A video of the area taken by the Canadian unit shortly after their arrival, while extremely useful as an overall survey of the area gave no additional detail. Similarly, a video provided by the US Predator UAV simply confirmed the fact that the observed fires correlated with the burning ricks of villager's winter feed, but no other information. After analysis , the Canadian and Predator material was archived with the Board's material. Exhibit 11; Exhibit 10

e. **Recovered Equipment**. Although it was impossible to recover large elements of wreckage, the recovery team was briefed to collect all material that might be classified. Thus a large number of relatively small items of principally electrical equipment were returned to Kandahar and subsequently to the UK. This material was identified by the Nimrod Aircraft Engineering Development and Investigation Team and subsequently analysed by the RN Flight Safety and Accident Investigation Centre. Exhibit 28

f. **Witness Statements**. Extensive witness statements were recorded from DOB personnel; the crews of aircraft which had observed XV230 during its flight; Kandahar C2 and ATC radar operators, and personnel who had participated in the recovery. A number of written statements were obtained from those personnel the Board was unable to interview, due to ongoing operations.

g. **Records of Previous Boards of Inquiry**. The Board also examined the records of Boards of Inquiry relating to accidents involving Nimrods XV257 and XW666; the record of the Unit Inquiry into an incident aboard Nimrod XV227 and records of extensive fuel leak rectification on Nimrod XV249 were also examined. Summaries are contained at Annex E. Annex E

EXPERT ADVICE

20. To assist the Board in their deliberations, the following individuals and agencies were consulted:

a. Nimrod specialist advice:

(1) Sqn Ldr (Fg (P)) (Reconstruction of final flight in Nimrod simulator).

(2) Flt Lt (120 Sqn) (Fg (WSO)) (Assistance with interpretation of mission tape).

(3) Chf Tech (A Eng Tech A/P) (Identification of recovered and photographed equipment).

(4) Chf Tech (Eng Tech P). (Specialist advice on fuel system).

b. Department for Transport, Air Accidents Investigation Branch (AAIB): and (Accident Investigation and Report).

c. Centre for Aviation Medicine: (Pathology Report).

d. BAE Systems: (Air Accident Investigation Specialist) and (Support from aircraft designer).

e. QinetiQ: and (Combustion Analysis study); and (Fluid Analysis); (Mission Tape and DARU Analysis).

f. Human Factors Investigations Limited: (Examination of GR7 eye-witness testimony).

g. Defence Science and Technology Laboratory: and (Analysis and modelling of SAM engagement criteria).

h. Maritime Data Analysis Group: Sqn Ldr and team (Mission tape transcription).

i. Air Warfare Centre: Wg Cdr (Analysis of SAM engagement probability).

j.

.

k. RN Flight Safety Accident and Investigation Team: Lt Cdr , Lt and CPO . (Initial analysis of recovered equipment and production of Accident Report).

l. Accident Recovery Officer: WO and Jnr Tech

m. Photographic support was provided by a deployed Combat Camera Team and Ground Photographic Section, RAF Kinloss.

n. Hydraulic Analysis Ltd: (Production of model of No 1 fuel tank).

o. Eaton Aerospace Ltd: and (Analysis of fuel seal condition).

p. Nimrod MR2/R1 Integrated Project Team, DLO RAF Wyton.

q. Air Refuelling and Communications Integrated Project Team, DLO RAF Wyton.

r. Nimrod Aircraft Engineering and Development Investigation Team (Identification of recovered avionic and electrical equipment and temperature trials).

s. Nimrod Software Team: Chf Tech (Analysis of mission tape position data).

t. Fg Off (Assistance in analysis of engineering records of XV230).

LOCATION OF FIRE

21. **Evidence Indicating the Seat of the Fire**. The evidence surrounding the ignition of the primary fire observed in XV230 is, at times, ambiguous and fragmentary. However, the Board used the following data to determine the most probable area in which the fire ignited:

a. Mission tape at 1111:33 hrs: report of a bomb bay fire warning, either coincident with, or closely followed by, an elevator bay warning.	Exhibit 1
b. Mission tape at 1111:33 hrs – 1112:26 hrs: an interlinked and, at times, overlapping series of reports from the crew of smoke entering the cabin from elevator and aileron bays.	Exhibit 1
c. Mission tape at 1112:26 hrs: a report that the aircraft had depressurised.	Exhibit 1
d. Mission tape at 1113:45 hrs: a report from the operator of flames coming from the rear of the engines on the starboard wing.	Exhibit 1
e. Report by Harrier GR7 pilot at 1116:54 hrs of XV230 descending with flames originating from the starboard wing root and starboard fuselage.	Witness 27/ Exhibit 82a-c
f. Testimony from 3 members of A Sqn RCD who observed approximately the final 40 seconds of XV230's flight. The Canadians reported a fire in many respects similar to that of the GR7 pilot, but on the port side of the aircraft.	Witnesses 37&38 Exhibits 9&73
g. Photograph of the AV287 carrier used to hold the Apparatus Sea Rescue (ASR) in the bomb bay, showing no smoke or flame damage. The ASR is a combination of a single inflatable dinghy and 2 survival equipment packs, fitted to Station 4, at the mid-position of the bomb bay.	Exhibit 11/2
h. Photograph of 3 x No 4 Mk1 fusing units, recovered from the crash site, which had been fitted to the ASR's AV287 carrier. None of these items display smoke or fire damage.	Exhibit 11/3a
i. Photograph of the starboard rear bulkhead of the bomb bay showing probable scorching to the top third, but no warping due to heat.	Exhibit 11/3b
j. Photograph of the starboard tail plane with paint discolouration caused by heat and flame.	Exhibit 11/19
k Description of rear hinged fairing with no fire damage, although evidence of molten metal having dropped onto it.	Exhibit 29
l. Mission tape at 1109:23 hrs. A remark from the air engineer as the Supplementary Conditioning Pack (SCP) trips-off, causing a pressure change within the cabin.	Exhibit 1
m. Photographs taken of the interior of the aircraft tail section following the crash and smoke damage to the recovered sonar	Exhibit 11/4 Exhibit 11/5b

location beacon show clear evidence of internal burning in the compartments aft of the pressure hull. However, the fire was of short duration and was probably ignited as a consequence of the principal fire further forward in the aircraft. It was not the initial scene of combustion.

22. **Resolution of Contradictory Evidence**. The principal area of contradictory evidence that the Board had to resolve was the fact that the GR7 pilot reported a fire on the starboard wing and fuselage, with no fire on the port wing, while the RCD reported a fire on the port wing. From correlation of witness positions and XV230's assessed track the Board concluded that the Canadians had observed the Nimrod shortly after the GR7 pilot. The Board thus determined to examine the detailed evidence for the 2 fires.

Witness 27/
Exhibit 82a-c
Witnesses 37&38/
Exhibits 9&73
Annex F

a. **The Starboard Fire**. The GR7 pilot was some ft above XV230 and had a good plan view of the Nimrod as he passed from its port to starboard side. The relative size of the Nimrod to the witness is shown at Exhibit 74a. The evidence for a starboard fire is substantiated by the comment made by the operator and by evidence of scorching on the starboard tail plane. Thus the Board concluded that there was a fire on the starboard side of the aircraft.

Witness 27/
Exhibit 82a-c
Exhibits 74a
Exhibit 1
Exhibit 11/19

b. **The Port Fire**. The GR7 pilot stated that there was no fire on the port side of the aircraft. However, it is possible that the fire started after he placed himself on the starboard side of XV230, or that it was so small as he passed behind the aircraft that he did not see it. Nonetheless, at this point a fire had been burning on the aircraft for approximately 5 minutes and so the port fire must have ignited after the starboard fire and, by implication, have been ignited by it. Evidence from the mission tape suggests that R1 was in the port beam window during refuelling and he would probably have returned there following depressurisation, as his oxygen mask would have been at this position. Although far from conclusive, it might have been expected that, had he returned, he would have commented on any fire on the aircraft's port side. The Canadian witnesses were initially some 2-3 km from XV230, which was approximately 8000 ft above them; it descended from right to left across their position. The initial view reported was of a side elevation. The Board reconstructed the possible view of the aircraft held by the Canadians as it passed their position. Both the aspect of the aircraft and its relative size could have led the Canadians to conclude that the aircraft was banking to the left and that the large, luminous starboard fire was on the port side. Independent analysis by the AAIB confirmed that this could have occurred. Although the aircraft's aspect to the Canadians improved as it travelled from them, its relative size would have decreased and as the fire increased in intensity, it may have continued to appear to originate on the closest wing. Nonetheless, at least one of the Canadians had

Witness 27/
Exhibit 82a-c
Exhibit 1
Annex F
Exhibit 74b
Annex F
Exhibit 12b

seen XV230 for some 40 seconds and the statements they made were considered and cogent. QinetiQ investigated the potential means by which a fire could pass to the port side of the aircraft. Exhibit 30

c. **Transfer of Fire from Starboard to Port**. The only means by which the fire could have reached the port wing at the time noted by the Canadian witnesses was by crossing the fuselage: through the cabin, aileron bay, or bomb bay. Recovered components and the pathology reports indicate that the fire is unlikely to have entered the crew cabin. (Exhibits 28&17) If the fire in the aileron bay had had the strength to breach its port side, it would appear likely that it would have also breached the cabin floor and entered the cabin. The condition of the ASR carrier and bomb bay bulkhead indicate that there was no substantial fire in the bomb bay and that it was thus unlikely that the bomb bay served as the transmission path for the fire. (Exhibit 11/2 & 11/3b) QinetiQ studies were unable to determine a likely means by which the fire could transfer from the starboard to port side of the aircraft. (Exhibit 30)

It is impossible to discount completely the existence of a fire on the port side of XV230. However, if there was one, it was undoubtedly subsidiary to the main fire and caused by it.

23. **Probable Seat of Fire**. From the evidence the Board considered that the fire might have initiated in one of 4 locations.

a. The bomb bay.

b. The No 3 engine.

c. The starboard Rib 1 landing.

d. The dry bay forward of the starboard No 7 fuel tank (known henceforth as No 7 tank dry bay).

24. **Bomb bay**. The undamaged state of the ASR's AV287 carrier and its associated fusing units militates against a fire in the forward bomb bay; in particular it means that the ASR (the only store in the bomb bay) could not have been the fire source. (Exhibits 11/2&11/3b) Although the fire could have originated in the rear of the bomb bay the Board has been unable to find a likely ignition source within this area. Furthermore, the photograph of the bomb bay's rear bulkhead exhibits no evidence that it endured a sustained fire. Thus, the bomb bay was ruled out as the likely seat of the fire.

25. **No 3 Engine**. As the GR7 pilot and the operator reported flames close to the starboard engines, the Board considered the possibility of the fire having ignited in the No 3 engine bay. (Witness 27/ Exhibit 82a-c) However, crew intercom makes no reference to any engine associated fire warnings (Exhibit 1) and the DARU shows no significant fault with the engines up to the time that the DARU stops recording, about 2 minutes before impact. (Exhibit 7) Both Nos 3 and 4 engines (Exhibit 12a)

indicate slightly lower HP RPMs than the other engines; however, No 3 exhibited the same characteristics on a previous flight and a similar, much less pronounced, trait on No 4 was noted, but not considered to be of significance. Moreover, titanium panels separate the No 3 engine bay from the Rib 1 area and from the No 7 fuel tank and wing rear spar attachment point area. Thus, initiation of a fire within the No 3 engine is most unlikely to have produced the observed warnings.

26. **Rib 1 Landing**. As neither the bomb bay nor the No 3 engine appeared to be the likely seat of fire, the Board considered areas at their shared boundaries. Within these criteria a possible location of the fire's origin is the Rib 1 landing, which forms a triangular space between the titanium firewall of No 3 engine bay and the No 1 fuel tank in the centre fuselage, between the main plane front and rear spars. It is immediately forward of the starboard No 7 tank dry bay, but separated from it by a bulkhead at the main plane rear spar. The location of this area is such that a fire burning within it could exit to atmosphere from ventilation holes on the underside of the wing at the rear of the landing. However, an overheat sensor, positioned at the outlet of the Rib 1 landing, should have activated a Centre Section Overheat Light on the air engineer's panel in the event of fire. There is no mention of such a warning on the intercom and, given that the warning light is immediately below the AAR switch panel, its illumination is unlikely to have gone unnoticed. Initiation of the almost simultaneous bomb bay and elevator bay warnings in the early stages of a fire in this location, without having first set off the Centre Section Overheat warning, is improbable. Although this warning could have been recorded on a damaged section of mission tape, if it had occurred, the air engineer would probably have mentioned it when the subsequent alarms initiated. Therefore, the Board consider the Rib 1 landing a possible, but unlikely, location for the origin of the fire. Exhibit 11/6

27. **No 7 Tank Dry Bay**. Immediately in front of the No 7 fuel tank front face, and adjacent to the aileron bay, the No 7 tank dry bay houses the wing rear spar-to-fuselage attachment points, a number of fuel system components, a crossfeed air pipe containing hot engine bleed air and the tail anti-ice duct (see Annex G). The bomb bay's firewire runs in close proximity to an opening between this dry bay and the bomb bay. Furthermore, the electrical feeds to the SCP Pressure Reducing and Shut Off Valve (PRSOV) run close to the bomb bay firewire in this area and the loss of the SCP could have been occasioned by the early stages of a fire melting the electrical insulation and causing a short. Another possibility is that leaking fuel disrupted the airflow through the SCP pre-cooler, instigating a shut down. However, the SCP has been known to stall in the turbulent airflow experienced behind a tanker, such that the loss of the SCP could be a simple coincidence. Nonetheless, a fire igniting in the dry bay could initiate the simultaneous warnings received. A fire in this position would also burn quickly through wing panels to provide the flames noted by both and GR7 reports. The fact that the mission tape intercom recording contains no evidence of the aileron bay warning being activated, despite that bay being on fire, remains an anomaly. Such evidence may Exhibit 11/8 Annex G Exhibit 1/ Witness 27/ Exhibit 82a-c

have been lost in one of the damaged sections of the tape or the aileron bay sensor could have been unserviceable or less sensitive than that in the elevator bay. Equally, the warning could have initiated but simply not been mentioned in view of the plethora of other warnings and smoke entering the rear cabin. The lack of a Centre Section Overheat warning could also be explained in this manner or following heat damage to the wiring.

28. **Conclusion.** From the evidence, the Board considers that the most likely origin for the ignition and initial seat of the fire is an area forward of the No 7 fuel tank on the starboard side – the starboard No 7 tank dry bay. This location has numerous fuel pipes running through it in addition to the crossfeed air pipe. It thus contains all the elements necessary to be the origin and the sustainment point of a fire.

29. **QinetiQ Combustion Study**. In view of the lack of firm evidence and to provide authoritative substantiation of the Board's initial work, a study was commissioned with QinetiQ to investigate the possible causes and subsequent expansion of the fire. While acknowledging the paucity of quantitative data the study was able to confirm that the Board's selection of the seat of fire was viable and that the fire's subsequent spread could be correlated with other evidence as to its size and location. Moreover, the study also eliminated the other potential locations of fire considered by the Board. Exhibit 30

FACTORS CONSIDERED BY THE BOARD

30. The Board considered that the following factors may have had a bearing on the accident:

a. Age of the Nimrod MR2 fleet.

b. Maintenance policy.

(1) Maintenance of fuel system.

(2) Maintenance of engine hot air bleed system.

(3) Nimrod Safety Case.

c. Maintenance.

d. Servicing.

e. Operational pressures.

f. Enemy action:

(1) Improvised explosive device.

(2) Surface-to-air missile.

g. Weather.

h. Hot air leak.

(1) Damage to fuel tanks.

(2) Damage to fuel pipes and couplings.

i. Fuel system.

(1) Fuel pipe leaks.

(2) Fuel coupling and seal leaks.

(3) Fuselage tank leaks.

(4) Wing tank leaks.

j. Air-to-Air Refuelling (AAR):

(1) AAR system incorporation.

(2) Frequency of use.

(3) Over pressure of MR2 fuel system.

(4) Overflow phenomena during AAR.

(5) AAR Procedures.

k. Electrical components as an ignition source.

l. Hot air system as an ignition source.

m. Lack of fire detection/ suppression system in No 7 tank dry bay.

n. The aircraft's final flight path.

DISCUSSION OF FACTORS

31. **Age of the Nimrod MR2 Fleet**

a. Prior to XV230's crash, only 3 Nimrod aircraft had been lost in 36 years of operations: of these, one was caused by multiple bird strikes shortly after take-off; one by the mechanical failure of an engine starter motor, which, by chance, perforated a fuel tank resulting in a fire; and one was occasioned by human factors. Thus, only once has a mechanical failure caused the demise of an aircraft. Indeed, in another incident, an airframe successfully carried its crew to safety after a major bomb bay fire, which damaged the aircraft beyond economical repair. Despite a long period of operational flying, there is no evidence of increasing losses due to mechanical failure as the aircraft has aged. Exhibit 80

b. The increasing age of the Nimrod fleet has been recognised and, in accordance with extant policy, an Ageing Aircraft Audit (AAA) was conducted in 1993 and reviewed in 2003. However, in common with both civilian and military practice, the AAA focussed on the structural integrity of the airframe, although it was expanded in Sep 06 to incorporate aircraft systems as well; formal guidance on implementation has yet to be issued. Nonetheless, the AAA review of 2003 specifically addressed the delay in Nimrod MR2 Out of Service Date (OSD) to 2012 and made a number of recommendations in response to that delay. The Nimrod IPT has enacted all of the recommendations, with the exception of a Mini Life Extension Programme (MLEP); it was decided that this was not necessary as the major driver of platform life is the fatigue index (FI) which has been extended though a structural sampling programme and through an analysis of the tear-down of the fatigue Exhibit 25 Exhibit 32 Exhibit 31 Exhibit 25 test specimen. The Board was presented by the Nimrod IPT with evidence of other processes and documents initiated to oversee aircraft safety; in particular a Safety Working Group, which meets every 6 months and is open to all stakeholders. The Board concluded that, the increasing age of the Nimrod had been recognised and that the measures taken followed existing practice, within both the civilian and military sectors: an age-related audit of the aircraft's structure had been completed and there was evidence of regular oversight of fatigue and safety issues. Although there was no evidence to indicate that all of the aircraft's ageing internal systems had been comprehensively reviewed, this was not mandated by MOD regulations prior to the crash and, indeed, guidance has yet to be issued to describe how the policy initiated in Sep 06 should be implemented. Nonetheless, and despite the MOD's compliance with all extant requirements for the operation of an ageing aircraft, the Board's analysis of both fuel system (para 32a(4)) and hot air system (para 32b) maintenance policies leads it to the conclusion that age was a possible Contributory Factor in the loss of XV230. Exhibit 25 Exhibit 32

32. **Maintenance Policy.**

a. **Maintenance Of Fuel System.**

(1) **Current Maintenance Regime**. The Nimrod fuel system (described in detail at Annex H) is maintained under a process of Corrective Maintenance (as defined in JAP 100A-01) in which components are replaced when they are observed to have failed: such replacement usually occurs following visual detection of a fuel leak in flight or on the ground. The process is supplemented by the zonal survey of areas of the fuel system during periodic maintenance, in which components observed to be in an unacceptable condition due to damage, deterioration or corrosion are replaced. However, these inspections are completed with the fuel system empty and thus are unlikely to provide evidence of leaking pipes or couplings. Moreover, unless they are physically leaking, damaged, or disassembled for access, the couplings used to connect fuel pipes are not dismantled to check the condition of their rubber seals. Annex H Exhibit 33

(2) **Designer's Recommendations**. The Declaration of Design and Performance (DDP) issued in 1968 for the original FRS Series 1 elastomeric fuel seal (used up until approximately 2002) states that, if subject to a 5-yearly inspection regime, they have an unlimited service life. This was based on 15 years experience of use of these seals at that time. A 5 year inspection schedule is also referred to in the seals' design specification. However, no Nimrod seals Exhibit 75 Exhibit 34

have been removed solely for the purpose of the examination scheduled in the DDP. The Board has been unable to determine any formal record explaining the apparent dichotomy between the manufacturer's recommendation and MOD practice, but the Nimrod IPT has stated that such examination would be impractical, as it would effectively require the replacement of the seals every 5 years (standard engineering practice would be to replace the seal if it had been removed from its housing for inspection). At a meeting between MOD staffs and the current seal manufacturer, Eaton Aerospace, the latter stated that, in view of their current experience of elastomeric seal manufacture and use, if seals were subject to the specified inspection regime, they would recommend their replacement after they had been fitted to a coupling for 25 years. However, the seal could now be inspected in situ, without disturbing the coupling. The inspection should be conducted with the fuel system under pressure and should check for leaks and seal extrusion. If a customer decided to retain the seals past 25 years of age, then the inspection regime must continue, but the seals would have a greater tendency to leak. Eaton Aerospace agreed that this advice had not previously been conveyed to MOD or BAE Systems.

Exhibit 76

Exhibit 76

(3) **Effect of Disturbing Seals**. MOD expert advice has stated that the act of replacing fuel seals might actually increase the number of fuel leaks due to disturbance of the system. A BAe document highlights that a 'catalogue of problems causing fuel leakage due to airframe build difficulties when using FRS110 couplings (as used in the Nimrod) relate back to the Lancaster, Vulcan, Lightning, AEW Mk3, and VC 10 CMk1'. It notes that 'each (Nimrod) production aircraft has build differences that exceed the permitted tolerance banding for the couplings' and that 'during production build the correct gap between each production pipe on every aircraft was reached by a careful build up of the system as a whole'. The report notes that when couplings are replaced 'assembly stresses are built into the system' which could provoke further leaking. Thus, any maintenance policy requiring, for example, regular seal replacement would require careful management to ensure that it did not itself degrade the fuel system's integrity. Nonetheless, there has been no scientific study of elastomeric seal behaviour beyond 40 years of age and it is possible that some Nimrod seals have been in place for up to 38 years.

Exhibit 76

Exhibit 35

Exhibit 76

(4) **Analysis of Maintenance Data**. Analysis of

Annexes I&J

Nimrod fleet maintenance data from 1983 to 2006 indicates that there has been a continual increase in fuel leaks over time: the average for the fleet per annum in the 1980s was 10, it had risen to 40 per annum between 2000 and 2005, despite the reduction in Nimrod fleet size. The great majority of fuel leaks are from couplings. In the absence of other factors, the reason for the increase in leaks over time might be that the seals are proving less effective as they age. The 2 aircraft that have been Nimrod R1s since their construction show no increase in fuel leaks over time. While this might be attributable to their operating in a more benign, higher-level, environment than the MR2, the small size of the Nimrod R1 fleet makes it difficult to draw meaningful comparisons.

(5) **Maintenance Regulations**. An interim report into maintenance policies for aircraft system seals suggests that the Nimrod policy for seal replacement is not unusual and is replicated in many other military aerospace organisations. Although life extension documents for the Tornado require the replacement of some O-ring seals and self-sealing couplings, those for the Hercules CMk1 make no reference to a need to replace seals. However, JAP 100A-01 notes that it is important that corrective maintenance trends are analysed and, where appropriate, reflected in changes to preventative maintenance schedules; this is reflected in civilian maintenance procedures defined in CAAIP leaflet 1-7. There is no evidence that the maintenance data for the fuel system at component level was ever analysed in order to inform maintenance policy. It is impossible to prevent completely fuel leaks within any fuel system, but the threat of fire inherent on such occasions, requires a policy that reduces the number of leaks to the minimum reasonably practicable. The current Nimrod fuel policy attempts to meet this requirement by imposing as little disturbance on the system as possible, but appears not to have balanced this risk with a growing risk of fuel leaks from other causes.

Exhibit 77

Exhibit 78

Exhibit 12

(6) **Conclusion**. Although the maintenance policy for the Nimrod's fuel system broadly followed common practice within the aviation industry, the policy did not prevent a gradual increase in fuel leaks within the aircraft over time and was not revisited to take account of the implications of the increasing number of fuel leaks exhibited by the system. The Board was, thus, of the opinion that the fuel system's maintenance policy was a Contributory Factor in the loss of XV230.

b. **Maintenance Of Engine Hot Air Bleed System.** The Nimrod hot air engine bleed system (described at Annex K) is also maintained under corrective maintenance. The construction of the system's insulated pipes consists of an inner steel pipe covered by a 12mm thick glass fibre blanket which is protected by an outer dimpled stainless steel jacket. Observation of the hot air pipes' insulation on various aircraft revealed some areas where the outer jacket was badly compressed and in one case cracked. The damage to the outer jacket is likely to have occurred over time, during maintenance activities. The Aircraft Maintenance Manual (Topic 1) gives clear guidance on the correct assembly of the V-band clamps, which join individual lengths of pipe, and leak checking, but gives no guidance on the condition and acceptable damage limits of the insulated pipes. Any areas of poor insulation of a pipe would reduce its effectiveness and its ability to prevent it becoming a source of ignition. One experiment, conducted by the Board on an area of compressed insulation indicated only a 16 ºC temperature difference between an exposed section of hot air pipe and the exterior of the insulated blanket. Those elements of the hot air system, such as expansion bellows, which cannot be encompassed within the standard insulation blanket, are covered with muffs or individual insulating blankets, secured with laces and abutted to the principal insulation. In some areas on other aircraft it was noted that the laces have loosened and there are visible gaps between the blanket edge and the edge of the main pipe insulation, leaving exposed sections of pipe surface; indeed, an expansion bellows in each of the No 7 tank dry bays possesses no lagging whatsoever (the Board has been unable to determine any risk assessment for the non-insulation of these components). The Board believes that a lack of guidance on the allowable condition for hot air pipe insulation contributed to its gradual deterioration in some areas and that gaps between different types of insulation provided points of weakness in the system, making it possible for leaking fuel to touch bare pipe metal at operating temperatures in excess of 400 °C. Thus, the Board was of the opinion that the hot air system's maintenance policy was a Contributory Factor in the loss of XV230.

Annex K

Exhibit 11/10

Exhibit 36

Exhibit 11/16b

c. **Nimrod Safety Case**.

(1) The Nimrod Safety Case (NSC) is the body of evidence that assures that the aircraft is safe to operate within the Statement of Operating Intent and Usage. It is a suite of documents providing a written demonstration that risks have been reduced to As Low As Reasonably Practicable (ALARP). It is intended to be a living dossier, which underpins every safety-related decision made. The NSC incorporates the Hazard Log, held within the Cassandra Database, which is installed on the BAE Systems

Chadderton computer system and managed, on the Nimrod IPT's behalf, by the company. Data to populate the Hazard Log was obtained by BAE Systems and MOD personnel conducting Fault Tree Analysis, as well as dividing the Nimrod airframe into zones and physically surveying each zone to determine both singular and interacting hazards; a number of non-zonal hazards, such as failure of aircraft structure, were also investigated. From this analysis the hazards were given a 'hazard probability'. Each hazard was then considered, in conjunction with all other hazards, in the context of one of 6 possible accident scenarios, allowing a probability to be assigned to each potential accident. That probability, when considered with the accident severity rating, produced a Hazard Risk Index for each accident sequence.

(2) The NSC analysis of Zone 614 (which contains the No 7 tank dry bay) identifies almost identical hazards to those determined by the Board. However, the NSC assessment of the risk imposed by those hazards is significantly different to that assessed by the Board. The NSC quotes the potential for fuel system leakage as 'Improbable', which is defined as 'Remote likelihood of occurrence to just 1 or 2 aircraft during the operational life of a particular fleet'. The Board's analysis of fault data indicates an average of 40 fuel leaks per annum for the Nimrod MR2 fleet between 2000 and 2005. Even in the absence of such data (which is not easily extracted from the sources) a number of incident reports occasioned by fuel leaks have been raised over the years, including one in which leaking fuel falling on the cross-feed duct began to smoke. The NSC states that the cross-feed duct is only pressurised during engine start, not taking into account the lengthy periods it can be pressurised (at a working temperature of up to 420 °C) when feeding the SCP. Furthermore, the NSC notes, as mitigation for the Zone 614 hazards, the provision of an aircraft fire detection and suppression system: neither exist within Zone 614. These inaccuracies led to an overly optimistic assessment of the hazards related to Zone 614, which in turn affected the assessment of the probability of the loss of an aircraft to an uncontrolled fire/ explosion – given as 'Improbable'. In its examination of the NSC the Board focussed principally on those areas of relevance to XV230's loss, but noticed a number of other inaccuracies, not directly related to the investigation. Had the NSC's inaccuracies been noticed earlier, the Board considers that a more intense review of the hazards concomitant on airframe fuel leaks might have been instigated. Moreover, the higher assessed risk, which

Exhibit 37

Annex I

Exhibit 38

necessarily would have been attributed to such a hazard, would have required sanction at a higher level of management, or active mitigation, such as not using the SCP.

(3) The NSC, released in 2005, reflects a positive desire to identify and reduce the risks of operating the Nimrod. Indeed, the risks highlighted in this discussion have been present since the Nimrod entered service (although the SCP was only introduced when the Nimrod MR2 entered service). Nonetheless, the Board considers that the overly optimistic hazard/ risk categorization of the potential threat to the aircraft caused by the collocation of fuel and hot air system components within the No 7 tank dry bay was a Contributory Factor in the loss of XV230. Exhibit 81

33. **Maintenance.**

a. XV230 underwent a Major maintenance at the end of 2004. The aircraft had a Primary maintenance in 2005 and was the first Nimrod MR2 to undergo Equalised One maintenance in May/July 2006. As a result of the introduction of the new Equalised maintenance schedule XV230 underwent an earlier maintenance intervention than would have occurred under the previous regime. Analysis of the aircraft maintenance records since the Major did not highlight anything out of the ordinary. Nine maintenance work orders were missing from the records, but the Board was able to determine that they were not related to work on fuel or air systems. Indeed, the only significant work to be undertaken on these systems was the reassembly of the fuel tanks and pipe work post Major and the rectification of leaks from the integral wing tanks (see para 39d). Only minor routine rectification work was conducted on the fuel or hot air systems in the intervening period up to the crash (with no work conducted post Equalised maintenance).

b. The Aircraft Maintenance Manual (Topic 1) does not contain guidance for the identification and fitting of elements of the fuel system. No instructions exist for the correct fitting of the locking rings to fuel couplings; it is possible to fit these incorrectly, such that the 2 metal halves of the coupling can partially undo and potentially leak. Two examples of an incorrectly aligned and locked fuel coupling were seen by the Board during a hangar inspection of Nimrod XV236. Local management and the IPT were notified of this fact and ground crew have been advised formally by the IPT of the possibility for error; the IPT is taking action to include assembly and security of fuel couplings within the aircraft Topic 1 publication. Furthermore, the aircraft Illustrated Spares Catalogue (Topic 3) does not comprehensively identify every coupling and its component parts. In many cases it is only possible to identify the Exhibit 11/11 Exhibit 25 Exhibit 39 replacement items by noting the reference numbers of replaced equipment; this practice could lead to the fitting of incorrect parts due to misreading of eroded identification details and even the perpetuation of that misidentification during future maintenance.

c. Despite concern over some individual maintenance procedures, the absence of significant work undertaken on XV230's fuel and hot air systems means that the Board can find no evidence that maintenance was a Cause or Factor in the loss of XV230.

34. **Servicing.** Interviews with ground engineering personnel in and analysis of engineering work records shows that the pre-flight preparation of the aircraft was conducted correctly. No significant engineering rectification had been undertaken on what was reported as a particularly serviceable airframe; in particular, no work had been undertaken on the fuel or hot air systems while the aircraft was on detachment. However, the MOD Form 700 (Aircraft Maintenance Log) for XV230, with all original signatures removed, was carried on the aircraft, as is standard practice within the Nimrod fleet, and was destroyed in the crash. As a result, the Board had to reconstruct the MOD Form 703s (Limitations Log) and 704s (Acceptable Deferred Faults) record sheets from the Maintenance Work Orders. This required extensive research, as a number of specialist Service modifications had been fitted to XV230 for Out of Area operations, and several gaps remain in this reconstruction. Nonetheless, from the data available no entries on Forms 703 or 704 contain information of relevance to the Board's inquiry. The Board considered that there was no evidence to suggest that servicing was a Cause or Factor in the aircraft's loss.

Witnesses 7-18

Exhibit 40

35. **Operational Pressures**. XV230 was lost . However, in the period leading up to the aircraft's final flight, the crew had not been required to work excessively long hours and neither did operational requirements necessitate the completion of an unusual or difficult flight profile on 2 Sep. While there were certainly significant pressures at times to achieve operational tasking, Crew 3 had not faced these pressures on this detachment. Requirements for the Nimrod MR2 force to man a Main Operating Base (RAF Kinloss) and 2 DOBs (and Basra, Iraq) during a period of reorganisation of RAF structures and reductions in manpower had placed pressures on, in particular, the ground crew: it was difficult to maintain Harmony guidelines and it was necessary to deploy personnel with lower than optimum experience levels. In particular the engineering deployment contained 2 individuals with minimal recent experience of Nimrod operations, and one of these was the Engineering Officer. However, in both cases, the individuals had been given appropriate pre-deployment training and support to fulfil their roles in what was admittedly a challenging environment. The continued commitment to long-term operations from disparate locations is undoubtedly placing pressure on the Nimrod force, and diluting experience levels, but there is

Witness 4

Witnesses 23&32

no evidence that either its long or short-term effects were a Cause or Factor in the loss of XV230.

36. **Enemy Action.**

a. Improvised Explosive Device (IED). Security provided by is extremely thorough Witnesses 19&20

. The only occurrence which attracted comment on 2 Sep was the fact that the civilian escort to the van delivering rations to XV230 was reported to have left earlier than usual; however, as the rations driver was seen to remain in his cab and the rations were subsequently loaded successfully, this was not assessed as significant. It was confirmed that there were no reported security incidents on 1 Sep or 2 Sep. Witnesses 8&15 Exhibit 42

. Furthermore, no explosion was reported by the crew and those elements within the bomb bay which survived the crash showed no evidence of explosive damage. Although the physical evidence is limited, the Board determined that there was no evidence of an IED having destroyed Nimrod XV230 and it was not a Cause or Factor in the loss of the aircraft. Exhibit 1

b. **Surface to Air Missile (SAM).** Although, as might be expected, a number of Taliban commanders claimed responsibility for the Nimrod's loss, there is no evidence, from visual observations, of a SAM firing in the area. The Nimrod was observed by the Tristar tanker crew as it departed and that crew reported nothing untoward. The aircraft's underside was scanned by Crew 3's operator and he did not report any damage, other than the fire from the rear of the aircraft's engines . Furthermore, no explosion was reported by the crew. There is no evidence from the DARU of any damage to the aircraft's engines. Examination of the evidence (photographs and available remains) has not shown any indication of missile strike. The Board determined that there was no evidence that a SAM was responsible for the fire which caused XV230 to crash and it was, thus, not a Cause or Factor in the loss of the aircraft. Witnesses 29-31/ Exhibit 83 Exhibit 1 Exhibit 7 Exhibit 43

37. **Weather.** The possibility of weather either initiating the fire through lightning strike or contributing to the aircraft crash through poor visibility was discounted by the Board in view of pilot in-flight reports indicating extremely good weather conditions. Thus, the Board considered that weather not a Cause or Factor in the loss of XV230. Exhibits 44 and 45

38. **Hot Air Leak.** Bleed air from the port and starboard engines is connected by a crossfeed air pipe which runs through the bomb bay, just forward of the aileron bay. The crossfeed air pipe is routed from the engines to the bomb bay via the No 7 tank dry bays. From this crossfeed air pipe, a junction, in the starboard side of the bomb bay, takes air to the SCP system. This junction is immediately below the entrance from the bomb bay to the starboard No 7 fuel tank dry bay. When the SCP is switched on, valves at either end of the crossfeed air pipe and the PRSOV open to allow engine-bleed air into the pipe to supply the SCP. Evidence from the mission tape audio shows that the SCP was in use at the time of AAR and, therefore, probably since take off; thus the crossfeed air pipe was open along its entire length. The Board considered the possibility that a leak from this system could have disrupted part of the fuel system prior to AAR. The potential for extensive damage by engine bleed air was demonstrated following an incident in which a hot air pipe fractured on XV227. However, a repeat of the fault on XV227 is improbable, as the pipe which failed on XV227 was replaced throughout the fleet. Moreover, a leak of similar magnitude, from a different area, is unlikely to have gone unnoticed by the experienced FS Davies; indeed, at the altitude at which XV230 transited, the crew would all have noticed the pressure change concomitant on the loss of conditioning air. It is possible, however, that a smaller hot air leak from the crossfeed pipe could have degraded a part of the fuel system. Due to the large volume of hot air available from the engines such a leak could easily go unnoticed as it would not cause any loss of pressure to the cabin air supply systems. There is no evidence of any maintenance or repair work carried out on the crossfeed air system of XV230, which might have disturbed joints between sections of pipe. Although an adjacent hot air leak should be detected by the centre section overheat sensors, these did not activate during the XV227 incident, despite a proven large air leak. Nonetheless, the Board concluded that, while a large hot air leak was unlikely, a small leak could have caused the necessary disruption, but would have needed a considerable time to do so. Possible disruption to the following parts of the fuel system was considered:

Annex K

Exhibit 1

Annex E

a. **Fuel tanks**. The No 1 and No 6 tanks are close enough to the crossfeed air pipe to be potentially affected by a hot air leak. Both tanks consist of an outer aluminium shell within which a strong rubber bag holds the fuel; No 6 tank also possesses a double skin of aluminium and is within the pressure hull. Even at its highest temperature, hot air from the crossfeed air pipe would take a considerable time to disrupt the aluminium tank structure, particularly as any air leak is likely to have been small and the tank's fuel would delay the effects of heating. Should the fuel tanks remain sound, but heat damage the internal bags, then the leaking fuel would drain either into the bomb bay, away from sources of ignition, or overboard through the interspatial drain, well aft of the seat of the fire. Similar conclusions can be drawn for the No 7 tank, which is an integral tank with no inner bag. The Board considered that, although possible, hot air damage to the fuel tanks was unlikely to be a Cause or Factor in the loss of XV230.

b. **Fuel pipes and couplings**. It is possible that a hot air leak could impinge on one of the fuel pipes or couplings in the No 7 tank dry bay. Each FRS fuel coupling, joining 2 pipes, consists of 2 metal halves with a rubber seal and 2 compression rings between them. Both the coupling shell and fuel pipes are constructed of steel, leaving the rubber seal as the weak point most likely to be compromised by a hot air leak. On XV227, these rubber seals suffered significant damage and were almost destroyed. The fuel feed system pumps for the No 6 and 7 tanks would have been off during XV230's AAR; thus, with little pressure in the feed system, a feed system coupling leak is not considered a potential source of fuel. However, the refuelling gallery and all associated couplings in the dry bay area would have been pressurised during AAR, such that any seals which had suffered degradation due to a hot air leak would probably leak. Whilst the No 7 tank itself is unlikely to suffer structural damage from a small hot air leak, the seals on the front face (in the dry bay) which seal pipes and components entering the tank, would suffer the same fate as a pipe coupling if subjected to a hot air leak. The Board concluded that a leak of engine bleed air could have caused disruption to the fuel system, either to a fuel coupling on the refuel pipe work or to a seal on the front face of No 7 tank, leading to a fuel leak when AAR pressurised the system: thus, such a fault is a possible Cause of XV230's fire and, thus, of the loss of the aircraft.

Exhibits 11/12

39. **Fuel System.**

a. **Fuel-Pipe Leaks**. As would be expected of any
mechanical system, Nimrod fuel pipes have exhibited leaks in the
past; indeed, following XV230's accident, a fuel pipe within the Exhibit 46
Rib 1 area of XV255 was replaced at the DOB in Sep 06, after
spraying fuel through a small fracture. Also, a Serious Fault Report Exhibit 47
on Nimrod MR2 XV236 highlighted a corrosion-induced leak
behind the fairleads in the Rib 1 area. Although analysis of fuel Annex I
pipe leaks since 1983 shows only a slight upwards trend, there has
been an average of 3.2 leaks per annum. Because of the manner in
which the data is recorded some faults attributed to fuel pipes might
actually relate to fuel couplings; nonetheless, the Board believes
that this fact is unlikely to affect the overall trend. However, a
number of fuel pipes lie in the area close to the No7 tank dry bay
and the Board considered that a leaking fuel pipe, within this area,
or the Rib 1 landing, could have provided the fuel for the fire. The
Board concludes that, while a fuel pipe leak is a possible Cause of
the fire in XV230 and, thus, of the aircraft's loss, it is a less likely
Cause than a leak from a fuel coupling (discussed below).

b. **Fuel-Coupling Leaks**. Fuel couplings have been observed
to leak following deterioration of their rubber seal or physical
movement. British Aerospace's records of the difficulties
experienced during the attempted rectification of the persistent fuel
leaks in XV249 illustrate the relative ease with which the integrity Exhibit 35
of the fuel system can be broken. Furthermore, analysis of Annex I
maintenance data indicates a fourfold increase in faults with fuel
couplings between 1983 and 2006. A number of seals were
removed from XV226, undergoing Major maintenance, for analysis Exhibit 48
by Eaton Aerospace, the current designer for FRS couplings and
seals. Other seals from recent fuel leaks were also examined. The
analysis showed various signs of deterioration, hardening,
distortion and damage, indicative of the length of time fitted and
age. However, the seals still retained some flexibility and were not
excessively hardened. In a separate series of tests, BAE Systems Exhibit 49
tested a number of couplings attached to representative pipes,
removed intact from Nimrod aircraft. Although the majority
functioned correctly, within design limits, a few leaked at quite low
pressures; one coupling in particular leaked at high pressure, but
when pressure was released and then reapplied no leak was
apparent. Although there was no evidence of any recent
maintenance work within the fuel system, the past history of fuel
coupling faults across the fleet indicated that a leaking fuel
coupling could have occurred during XV230's last flight. The
Board noted that there are a number of fuel couplings within the No
7 tank dry bay whose failure could have been the source of fuel for
the fire. Indeed, on 15 Feb 07, during a ground refuel, a defuel Exhibit 11/17
valve on the starboard No 7 tank of XV250 suffered a significant

leak. Video of the incident showed considerable amounts of fuel pouring into the No 7 tank dry bay in a manner which, had the cross feed pipe been in operation, would probably have initiated a fire similar to that on XV230. The Board has no evidence that this was what occurred on XV230, but such occurrences indicate that a leaking fuel coupling is a probable Cause of the fire within XV230 and thus of the loss of the aircraft.

c. **Fuselage Fuel Tank Leaks**. A failure of the integrity of any of the fuselage fuel tanks, or the starboard No 7 tank would potentially allow fuel to reach a point of ignition. However, the Nos 5 and 6 tanks are constructed such that leaks will drain away to atmosphere. A leak from No 1 tank would fall into the bomb bay and is unlikely to contact the crossfeed air pipe or migrate into the No 7 tank dry bay. Moreover, the evidence of the unburnt ASR carrier from the bomb bay suggests the fire did not ignite or develop in the bomb bay itself. Fuel leaking from No7 tank might reach the No7 tank dry bay and is a possible source of flammable liquid. However, on balance, the Board considers that a fuel tank leak was not a Cause or Factor in the loss of XV230.

d. **Wing Fuel Tank Leaks**. Although the Nimrod MR2 has suffered from leaks from the integral wing tanks due to wing flexing, particularly in the area of Rib 7, they have been subject to a fleet-wide repair programme, starting in 2006. Nimrod XV230 underwent such work in Feb 06. At the time of the accident, there were 7 recorded leaks, assessed as 'seeps' as defined in the aircraft Topic 2(R)1, from various points in the outer wings. Such leaks disperse directly into the airflow and are unlikely to migrate to the fuselage. The Board could find no evidence that a leak from any wing tank would track to the No 7 tank dry bay and thus believe that such a leak was not a Cause or Factor in the loss of XV230. Exhibit 50

40. **Air-To-Air Refuelling (AAR).**

a. **AAR System Incorporation**. The Nimrod MR2's AAR capability was installed as an Urgent Operational Requirement (UOR) during Operation CORPORATE and subsequently formally incorporated under Mod 715 in 1989. A detailed study (Annex L) of the effects of a number of changes to the AAR system and procedures over time suggests that they were considered in isolation but their cumulative effect was not recognised. A significant consequence of the alterations was that the flow rate to the No 1 tank in particular increased, causing, under certain circumstances, fuel to escape from that tank into the blow-off and vent systems. The Board concludes that the formal incorporation of AAR capability within the Nimrod did not identify the full implications of successive changes to the fuel system and was a possible Contributory Factor in the loss of XV230. Annex L

b. **Frequency of Use**. Extant records for Nimrod AAR sorties commence in 1993 and show that, although the average rate over this period is 9 operational sorties per annum, in the first 8 months of 2006 a total of 18 was flown; XV230 was responsible for half of that total (see table below). Operational sorties usually take on as much fuel as possible during AAR to prolong the Nimrod's on station time and the Board considered that these sorties would have the greatest potential to provoke the blow-off or vent phenomena (a possible source of fuel in XV230's fire, see para 40d). Training sorties involve much lower fuel transfers at lower flow rates and individual tanks are not filled to capacity. Thus, although the data in the table below includes all AAR sorties in the 'Total' rows, the operational sorties alone have been isolated for analysis, as representative of sorties which would exercise the full AAR system.

Summary of AAR Statistics – since 1993

TANKER	NIMROD MR2 SORTIES	NIMROD R1 SORTIES	REMARKS
TRISTAR TOTAL	177	76	
TRISTAR OPERATIONAL	119 total = 9/year average 18 in 2006 (by Sep) (9 by XV230; XV235 next at 4 sorties)	65 total 14 in 2005 24 in 2006	Nimrod R1 - XW665 completed 14 Tristar sorties in 2005 XW664 completed 23 Tristar sorties in 2006
VC 10 TOTAL	468	117	
VC 10 OPERATIONAL	271 – 19 in 2005/6	90 total 23 in 2005/6	Nimrod R1 - XW665 completed 17 VC10 sorties in 2005

Of the 9 operational AAR sorties undertaken by XV230 in 2006, 7 (not including the 2 Sep sortie) were during the Aug 06 deployment. This placed XV230 as the fleet leader for Tristar AAR. Nonetheless, the 7 Tristar AAR sorties prior to 2 Sep 06 provoked no fuel system faults, although the No 1 tank blow-off valve was noted to have operated on 2 occasions (see para 40d(3)). In determining whether or not the frequency of AAR could have contributed to the loss of XV230, the Board noted that Nimrod R1s XW664 and XW665 had individually accumulated a greater number of operational AAR sorties than any MR2 airframe. Neither aircraft experienced any fuel system faults during or following these sorties. The Nimrod R1 fuel system is identical to that of the Nimrod MR2, although because of higher zero fuel weights, the Nimrod R1's No 1 tank is filled to a lower level than

Exhibit 51

that of the MR2. The Board consider that the frequency of operational Tristar AAR sorties was not a Cause or Factor in XV230's loss.

c. **Over-Pressure of MR2 Fuel System**. The air engineer of Witness 22
a previous AAR sortie on XV230 reported refuel pressures, during
Tristar AAR, momentarily in excess of 60 psi. Similar phenomena Exhibit 52
have been observed occasionally in the past, with pressures as high
as 80 psi being noted. It has been determined that the response Exhibit 53
characteristics of the Nimrod probe pressure transducer and gauge
would not show the full extent of any surge pressures; thus the
actual pressures may have been higher. Normal pressure during
AAR in steady flow conditions is 30-40 psi. An early version of Exhibit 54
the Aircrew Manual (ACM) states that the maximum permitted a&b
AAR pressure is 50 psi, although this fact is omitted from later
editions. The maximum working pressure of the Nimrod fuel Exhibit 55
system is 75 psi, although the system has been tested to 112.5 psi
(design proof pressure). During trials to clear the Tristar to refuel Exhibit 56
inter alia the Nimrod MR2, pressure surges of up to 84 psi were
measured. This fact attracted no adverse comment in the trial
report and the Tristar was cleared to refuel the Nimrod; the specific
conditions under which the 84 psi figure was achieved are not
detailed. However, British Aerospace documentation, raised during
the development of the Nimrod AEW3, noted surge pressures of 85
psi and stated that they were 'well below the Def Stan limit of 120 Exhibit 67
psi for a multitank aircraft'. Thus the Nimrod Designer has
accepted the fact of pressure surges and determined that they are
not a safety concern. It is believed that the pressure spikes have 2
causes:

(1) Reducing the number of open refuelling valves on the receiver aircraft causes a rise in pressure that the tanker can counter by reducing the flow rate to restore normal pressure. If the number of valves open on the receiver is few, closing even one valve may have a large effect on pressure and cause a momentary rise.

(2) If the receiver slips back from the tanker, causing the amber light to be illuminated, the tanker fuel valve automatically closes. If the receiver then pulls forward illuminating the green light, without disconnecting and allowing the tanker to prime the hose, the refuel valve will be opened and the now vented refuel hose could allow a rapid flow of fuel under force of gravity and booster pump pressure to cause a pressure spike when it reaches the receiver.

Notwithstanding the British Aerospace statement at Exhibit 67, no Exhibit 67
pressure surges were noted on the day of the accident and XV230 Witness 31

did not drop back into the 'amber'. Therefore the Board concludes that instantaneous pressure surges were not a Cause or Factor in the loss of XV230.

d. **Overflow Phenomena During Refuelling.** During the investigation, 2 separate, but probably related, phenomena concerning overflow of fuel from the No 1 fuel tank came to the attention of the Board. One was from a ground incident at RAF Kinloss, where fuel was observed to overflow from the No 1 tank vent system, while the other concerned fuel coming from the No 1 tank blow-off valve after an AAR sortie. These incidents are discussed below.

(1) **Vent System Overflow**. During a ground refuel of XV252 on 31 Oct 06, fuel began to overflow from the vent system. No fault was found but the cause was attributed to refuelling on a slope, with the aircraft slightly nose down. To understand the mechanism that caused this, the Board investigated the construction and components of the No 1 tank (see Annex M). As is normal practice, XV252 was refuelled using a reduced pressure towards the end of the refuel of No 1 tank, so all cells should have been at a similar level. However, since XV252 was refuelled with a nose down attitude, the high-level float switch in No 1 cell functioned earlier than the one in No 4 Cell. Therefore, although the No 1 Cell was at a level where the refuel should have stopped, the refuel valves stayed open and the extra fuel entering No 1 Cell overflowed into the vent system. Some of the excess fuel entered the main aircraft vent system and flowed out via the wing trailing edge outlets. A smaller proportion leaked out of the vent system into the upper wing root fillet area and the Rib 1 landing. The vent lines from the No 1 tank are of light construction and secured by jubilee clips, which if over tightened, can leak. This incident proved that refuelling of the No 1 tank is sensitive to attitude in pitch and can allow fuel to enter the vent system. Indeed, the same result would happen in reverse if the aircraft was inclined nose up: the No 4 cell would continue to fill while waiting on the No 1 cell high-level float switch to function. This incident also demonstrated that, once in the vent system, where couplings in the centre fuselage are not pressure tested, fuel can leak out into the space underneath the wing fillet panels, from where it can track rearwards to the No 7 tank dry bay. Of note, several vent system fuel couplings are positioned immediately above the No 7 tank dry bay and in close proximity to unlagged cross-bleed pipe expansion bellows.

Exhibit 57

Annex M

Exhibit 11/18

(2) **No 1 Tank Blow-off Valve**. After a sortie that

Witness 22

XV230 flew from DOB in Aug 06, the Aircraft and 28
Ground Engineer noticed that, as the aircraft parked, a small amount of fuel was seen to drip from the bomb bay and there was evidence of fuel exiting from the No 1 tank blow-off valve – the blow-off valve's exit pipe contained fuel and there were witness marks along the side of the fuselage from the pipe, indicating fuel flow. In consultation with the aircraft's air engineer he attributed this to operation of the No 1 tank blow-off valve during AAR. Nonetheless, the aircraft was monitored for fuel leaks during and after its ground refuel. The air engineer subsequently noticed that, during AAR, the No 1 tank appeared to reach full at an indicated 15 000 lbs of fuel. Calculating that attempting to fill the tank beyond this point might have provoked the blow-off valve to open, the air engineer subsequently only refuelled the tank to this level; the solution appeared to work, as he personally experienced no further occurrences of fuel in the bomb bay. Although, on a subsequent sortie, ground crew noticed an extremely small amount of fuel drip from the bomb bay, and fuel was found in the blow-off valve pipe, there were no further occasions on which fuel was discovered. This information had been related to FS Davies when he was briefed on the conduct of operations prior to his first AAR sortie in theatre. After significant investigation, a potential mechanism to explain this
phenomenon was identified and is described in Annex M. Annex M
The in-flight operation of fuel tanks' blow-off valves had
been considered by BAe in 1985, during development of Exhibit 58
the Nimrod AEW3 aircraft. Thought had been given to the possibility of fuel entering ports and intakes; indeed, it had been suggested that, if it was found that fuel entered the SCP, then that system should be turned off during AAR. Although BAe recommended trials, they were not
conducted, probably due to the cancellation of the Nimrod Exhibit 59
AEW project by MOD. There is no evidence that MOD was made aware of the recommendation for trials or the potential for No 1 tank blow-off and subsequent ingestion of fuel, or that any further investigation was conducted.

(3) **Explanation of Blow-Off Valve Operation During AAR**. Given that the refuel rates from a Tristar are significantly higher than standard ground refuelling rates and are not limited by a restrictor at the coupling inlet, pressure in the No 3 cell exceeding the operating pressure of the blow-off valve is a distinct possibility – particularly when the effects of asymmetric filling are considered. The fuel modelling undertaken by HAL/ BAE Systems, the
results of which are described in Annex N, confirms that Annex N
generation of blow-off valve operating pressure is a feature

that can happen towards the end of an AAR uplift, as the No 1 tank approaches full. Furthermore, once blow-off pressure is reached, the fuel in No 3 cell will already be above the top of the blow-off valve. Therefore, if the blow-off valve operates, fuel will exit via the blow-off valve pipe. As shown by the fuel model, it is possible that once fuel has started to exit the tank, it will continue to flow past the blow-off valve for some time, thereby ejecting a substantial quantity. This accords with ground crew experience of occasions when the blow-off valve has operated during ground refuelling: fuel continues to exit until the refuelling flow is stopped. The track of the fuel flow from in-flight blow-off operation has been observed and correlates with air flow calculations along the aircraft fuselage. The routing of the SCP supply pipe places it in a direct line behind the blow-off valve exit; fuel exiting the blow-off valve could enter the SCP fairing through gaps between the fuselage panels. The ACM Book 3 states that the wing vent outlet pipes should be monitored for signs of venting and advises that if venting is excessive, AAR should be terminated. There are no reports of venting on the mission tape but the record is incomplete. However, it would require a large volume of fuel to enter the vent system before it was seen at the wing vent outlets. Moreover, analysis of the fuel model shows that blow off pressure can be reached shortly after that fuel begins to enter the vent system.

Witness 35

Exhibit 60/ Witness 28

Exhibit 11/13

Exhibit 61

(4) **Absence of Reports of Overflow Phenomenon.** AAR on the MR2 had been practiced for 24 years when the accident happened. It would be natural to question why this ejection/overflow of fuel and subsequent fire has not happened before. Firstly, the HAL model shows that small variations in the quantity of fuel taken into the No 1 tank can alter the outcome. Variations in the rate of refuel into No 1 tank also have a significant effect. Aircraft attitude plays a part and this is determined by the airspeed at which AAR is flown, partly dependent on the weight and type of tanker. Statistics show that in relation to overall sortie numbers, operational AAR to full fuel loads is comparatively rare. An even smaller number of sorties have used the Tristar as the tanker. There are no specific instructions regarding use of the SCP (a probable ignition source – see para 42c); on many days in temperate climates, it is not necessary to switch it on. Fuel may have been ejected on a number of occasions but leaked away through the bomb bay doors before the aircraft landed, such that an overspill was undetected. Despite undertaking significantly more Tristar AAR sorties than the Nimrod MR2s, No 51 Sqn's Nimrod R1s have reported no post-AAR fuel system

Exhibit 51

problems. This can be attributed to the fact that, because of the Nimrod R1's higher zero fuel weight and the different conduct of operations, Nimrod R1 air engineers rarely, if ever, fill the No 1 tank to full during AAR.

(5) **Linkage of Fuel Vent and Blow-Off Phenomena**. Annex M describes and explains the means by which the 2 previously noted phenomena can occur within a short time of each other. Moreover, it is probable that fuel in the vent system would contribute to increasing pressure within No 1 fuel tank, increasing the tendency for blow-off to occur. In summary, there are a large number of variables that need to converge to provoke these phenomena. On 2 Sep 06, they may well have done so. The Board considers that the overflow of fuel from No 1 tank was a probable Cause of the loss of XV230. — Annex M

e. **Procedures**

(1) **AAR Procedures**. The AAR procedures extant at the time of XV230's loss were examined to determine whether they were satisfactory and if they were adhered to during the refuelling of XV230. It was noted that Crew 3 conducted the AAR sequence in accordance with SOPs, with one apparent exception. As the receiver's last fuel tank reaches 90% full, the Nimrod ACM Book 3 states that the tanker should be asked to reduce his flow rate to booster pumps only. The ACM Book One states that this is to avoid pressure surges if the receiver closes his last refuel valve while under high fuel flow conditions. None of the Tristar crew recalls this request being made. However, the request could have been blocked by other radio calls. The transmissions can only be heard faintly on the mission tape, as breakthrough, because the radio that Crew 3 were using with the tanker is not recorded. However, on balance, it is likely that no call was made. — Exhibit 1/ Witnesses 29-31/ Exhibit 83; Exhibit 61; Exhibit 54; Exhibit 1

(2) **History of no comms procedure**. For many years, the majority of operational MR2 AAR sorties were carried out on missions for which the communications security policy prevented any radio transmissions. The majority of these sorties were carried out using a VC10 tanker and only occasionally a Tristar. This communication blackout precluded a "90% / booster pump" call to the tanker. In order to achieve the effect induced by the 90% call, the tanker air engineer would control the delivery rate in accordance with the delivery pressure. As delivery pressure began to rise the tanker air engineer would reduce the flow rate, to prevent any pressure surges if the receiver closed the

last valve while fuel was still flowing. Indeed, the receiver would normally withdraw from the tanker with at least one valve still open to prevent pressure surges. This procedure was transferred to other operational scenarios and was adopted on operations even when there were no specific communications restrictions. Witness 36

(3) **Fuel modelling and the 90% Call**. As can be seen from Annex N, the distribution of fuel before and after AAR can be predicted within fairly narrow margins. At the time when XV230 stopped receiving fuel, neither of the last tanks with available space (the No 5 and 6 tanks) would have reached the 90% full point. Therefore, the air engineer would not have been prompted to request a reduction in tanker delivery rates. Even if the tanks had reached 90% full, from that point they would only have required a further 560 lbs of fuel to fill them. Delivery of fuel at Tristar booster pump rate can be as high as 1100 kg/min (2420 lb/min). There would only be 12 seconds between initiation of the call and the tanks reaching full – insufficient time to achieve the reduction in delivery rate aimed at. Therefore, the last tank could reach full and initiate a pressure surge before an effective reduction in flow rate. Annex N

(4) The Board considers that, as no pressure surges were observed, the lack of a 90% call did not affect the outcome of XV230's refuelling operation and was neither a Cause nor Factor in the aircraft's loss.

41. **Aircraft Electrical Components as an Ignition Source.** BAE Systems identified electrical supplies and components in the starboard Rib 1 (zones 611 and 613) and No 7 tank dry bay (zone 614) areas. There are only a limited number of high voltage (200/115V ac) supplies and components: the No 7 tank fuel pump, the No 3 and 4 engine top temperature controllers, starboard BOZ pod power supplies and ESM Yellowgate supplies. Numerous medium voltage (28V dc) supplies route through the areas. No Kapton cable is fitted within the Nimrod, thus eliminating carbon arc tracking as a possible cause. Analysis by QinetiQ and AAIB determined that few of these components would have the requisite current to ignite aviation fuel easily, although arcing electrical wires as the source of ignition cannot be discounted. However, as electrical ignition would require 2 concurrent failure modes, the Board felt it unlikely that electrical ignition was a Cause or Factor in the loss of XV230. Exhibit 62 Exhibits 12&30

42. **Hot Air System As Ignition Source.** The Board considered whether hot air pipes within the airframe could reach sufficient temperature to ignite leaking fuel. Three systems were examined: bomb bay heating, anti-icing and the engine cross-feed/ SCP system.

a. **Bomb Bay Heating**. The bomb bay heating system takes air from the engines and reduces it in temperature and pressure prior to circulating it round the bomb bay. For this system, the supplied air is reduced in temperature and is less than 200 ºC when it enters the bomb bay. It is then further cooled to about 50 ºC before distribution around the bomb bay. Thus, the bomb bay heating air entering the bomb bay is not hot enough to ignite fuel. Furthermore, the hotter parts of the system are forward of the ASR carrier, which was found without heat damage. The bomb bay heating system is, therefore, not considered to be a Cause or Factor in the loss of XV230.

b. **Airframe Anti-Icing**. The airframe anti-icing system would not have been in use in the prevailing weather conditions. Moreover, even if a fault caused hot air to be in the anti-icing pipe, which runs through the wing root area, its temperature would be less than 200 ºC and, therefore, also not hot enough to ignite fuel within the timescales of XV230's accident. Thus, the airframe anti-icing system is not considered to be a Cause or Factor in the loss of XV230.

c. **Engine Cross-feed/ SCP system**. The only pipes to approach a suitable temperature for ignition of fuel are those of the engine cross-feed/ SCP system described at paragraph 37 and Annex K. These pipes are lagged to provide thermal insulation against temperatures up to 550 ºC and the lagging itself is encased in a stainless steel skin to protect it against liquid spillage. However, there are unlagged bellows fittings, within each of the port and starboard No 7 tank dry bays and a ground-based experiment has shown that they can reach operating temperatures of at least 399 ºC. The experiment was conducted on the ground, as use of the SCP is now prohibited in flight and, due to limitations on ground running of the system, full operating temperatures were not reached. Therefore, the temperature of any un-insulated or exposed parts of the SCP pipe work would have been even higher during XV230's last sortie. On 2 Sep XV230's engines were at high power settings, approximately 94% HPRPM, with No 4 engine at 99% HPRPM, due to the aircraft's weight and the need to fly at the correct speed for the Tristar tanker. At these power settings, the temperature of air from the engines inside the crossfeed air pipe is at least 420 ºC; expert opinion suggests that there will be minimal temperature loss across the pipe's skin. Also, some sections of the lagging material have been observed, in some aircraft, to be compressed, possibly as the result of pressure applied during routine maintenance procedures over many years; experiment showed that this significantly decreases the insulation provided by the lagging (see para 32b). Some sections of the system, such as expansion bellows in the No 7 tank dry bays, possess no lagging

Annex K
Exhibit 63
Exhibit 36
Exhibit 7
Exhibit 30
Exhibit 11/10

whatsoever. Moreover, at the point where the SCP pipe exits the fuselage many aircraft exhibit a gap between the lagging at the junction of 2 pipe sections; this area has been observed to reach equivalent temperatures to unlagged pipe work. This area of exposed pipe is raised just clear of a horizontal panel at the base of the No 7 tank dry bay, which experiment has shown will retain dripping fuel; experiment has also shown that dripping fuel could splash onto the pipe area. The Board considers that the SCP/ cross-feed piping provides the most likely source of ignition for the fire that led to the loss of XV230 and it is, thus, a probable Cause of that loss. Exhibit 11/16 Exhibit 11/14&11/16 Exhibit 64

43. **Lack of Fire Detection and Suppression System in No 7 Tank Dry Bay**. The No 7 tank dry bays contain neither fire detection nor suppression systems. Although the crew were warned of a fire by detection systems in adjoining areas, these did not allow immediate identification of the fire's location. Thus, in the limited time available to them, the crew had to determine the fire's source by a process of elimination; there is no evidence that they were able to do so. Moreover, the warnings only activated when the fire began to affect areas outwith the initial site of combustion, thus eroding the time available to the crew to take action. However, the lack of any means of fire suppression in this area, meant that, even had the crew deduced the true seat of ignition, their only course of action, the one they took, would have been to attempt to land as soon as possible, while fighting any secondary fires. Evidence from the incidents involving XV257, XW666 and XV227 illustrates the rapid destructive effect that intense heat and fire can have on the aircraft's structure, particularly the rear spar. Expert advice has noted that modern fire-retardant coatings/ paints can delay the affects of heat and fire on areas such as the rear spar and hydraulics pipes. Moreover, the expert also states that neither explosive suppressive foam nor nitrogen inerting would have prevented the fire developing, or the boiling of the fuel in the No 7 tank, or the subsequent explosion (see para 44a). The Board believes that the lack of a fire detection and suppression system within the No 7 tank dry bay was a Contributory Factor in the loss of XV230. Annex E Exhibit 30

44. **The Aircraft's Final Flight Path.**

a. The last radio transmission from the aircraft was at 1116:34 hrs, when one of the pilots acknowledged the airfield QNH, indicating that at that point the aircraft was still under control and the crew intended to land at Kandahar. However, within a minute of this event, the intensity of the aircraft's fire increased significantly and rapidly. At 1117:43 hrs the GR7 pilot reported that the aircraft had exploded, an event also noted by the RCD witnesses. Analysis suggests that prior to the explosion the fuel in No 7 tank had begun to boil; however, as the pressure inside the tank increased, the bulk of the fuel was trapped in liquid form, at temperatures well above the fuel's boiling point at normal Exhibit 8 Witness 27/ Exhibit 82a-c Witnesses 37&38 Exhibits 9&73 Exhibit 30

atmospheric pressure. The increasing pressure eventually ruptured the fuel tank and the resultant step reduction in pressure initiated a wholesale expansion of the remaining liquid fuel in the tank. This sudden liberation of huge volumes of vapour shredded the remaining tank structure, releasing the entire contents of the tank into the atmosphere. The ignition of this vapour cloud, by the aircraft fire, produced the fireball observed by the witnesses; this type of event is known as a boiling liquid expanding vapour explosion (BLEVE). Analysis of the wreckage pattern, combined Exhibit 10
with aerodynamic modelling, suggests that the aircraft began to Exhibit 12
disintegrate at approximately 700 ft, when the starboard wing (the rear spar weakened by intense heat) broke off, striking and removing the starboard outer tail plane. As the now aerodynamically unstable airframe began to roll to starboard, the left wing broke from the fuselage. The aircraft impacted the ground in 4 main sections. It is impossible to determine whether the Exhibit 30
BLEVE initiated the aircraft's disintegration or whether the aircraft's disintegration ruptured the No 7 tank and produced the BLEVE.

b. In the last few minutes of flight the aircraft's average groundspeed was calculated as approximately 352 kts, with an Exhibit 10
increase in the last few seconds of flight. was
asked to fly the Nimrod simulator using the DARU data to position Exhibit 65
himself at the point where data ceases, some 2 minutes before the crash; he was then asked to fly from this point to the crash point. The principal conclusions drawn from the exercise were that up to the point where DARU data ends the aircraft was being flown as expected for an approach at Kandahar airfield; thereafter both rate of descent and airspeed increased markedly to values beyond those that any Nimrod pilot would fly. Furthermore, the pilots would not have allowed the aircraft to descend to such a low level some 14 nm from Kandahar; and if they had been attempting a crash landing, their final speed should have been considerably lower.

c. The Board believes that at a time roughly coincident with the GR7 pilot's initial observation the fire had spread from its initial seat and was increasing significantly in intensity. From the evidence of previous Nimrod accidents and incidents, the fire was sufficiently hot to melt hydraulic system unions and possibly control cables, which probably resulted in the pilots gradually losing control of the aircraft (this is discussed further at Annex O). Annex O
They would have been unable to halt the aircraft's descent.
Furthermore, from analogy with other Nimrod accidents and Annex E
incidents, the structural integrity of the aircraft would have been weakened significantly by the extensive fire, which allowed disruption of its structure. However, examination of recovered Exhibits 28/
equipment and the pathology report indicates that there is no 17
evidence of the fire extending beyond the underfloor bays into the

crew compartment.

d. The Board concludes that in the aircraft's final moments the pilots were unable to exercise control, following hydraulic system failure. It is impossible to determine whether the aircraft would have reached Kandahar if the hydraulics had not failed. However, the Board believes that the weakened rear spar was unlikely to have survived long enough for a successful landing to be made. It is possible that the excessive speeds noted above (para 44b) may have caused the rear spar to fail sooner than it would have done at normal speeds. Thus, the Board believes that the loss of hydraulics to the flying controls was an Aggravating Factor in the loss of XV230.

RELEVANT DOCUMENTS

45. All relevant documents, orders, instructions and qualifications were examined by the Board and found to be accurate and in date. The MOD Form 700 was lost in the crash and had to be reconstituted in part by the Board from other documentation.

RECONSTRUCTION OF EVENTS IMMEDIATELY PRIOR TO THE CRASH

46. Although, the Board had limited evidence it was able to determine a probable sequence of events, and possible alternatives, that led to the loss of Nimrod XV230 and its crew. Exhibit 30

47. As the AAR serial drew to a close, fuel escaped, from either No 1 tank's blow-off or vent system, or from a leak in the fuel pipe work (probably a fuel coupling, but possibly a fuel pipe). It is possible, but less likely, that the fuel leak was provoked by a hot air leak.

48. The escaped fuel tracked rearwards, either internally or externally. Evidence from previous incidents and investigations suggests that leaking fuel can take a wide variety of routes within the aircraft. If fuel escaped from the No 1 tank blow-off it would track rearwards against the skin of the aircraft penetrating the fuselage along external panel joints.

49. Some fuel accumulated on the lower panel of the No 7 tank dry bay and fuel also entered the SCP pipe fairing immediately aft of that bay.

50. Fuel made contact with one of the areas of exposed ducting (or soaked into pipe insulation). The ducting's high temperature led to auto ignition within seconds and ignited the fuel on the lower panel of the starboard No 7 tank dry bay. Despite a number of drain holes, the lower panel can hold approximately 300 ml of fuel, which is capable of sustaining a large fire for some 100 seconds.

51. Combustion products escaped from the dry bay, exiting outwards, through gaps in the wing structure and internally, into the bomb bay. As hot gases entered the bomb bay the fire wire was triggered. Simultaneous heating of the aileron bay caused hydraulic mist or smoke which activated at least the elevator bay smoke alarm. Within a short period the smoking hydraulic fluid reached ignition temperature and a fire commenced in the aileron bay.

52. The fire, now on both sides of the aileron bay wall, penetrated that wall and the aircraft depressurised. Depressurisation increased the flow of air over the fire and hastened the destruction of nearby wing panels. At the same time the couplings to the fore of No 7 tank began to leak and supply more fuel to the fire. The effect of the depressurisation and venting of the fire to the outside air would have been to draw any remaining combustion gases from the bomb bay and away from the cabin.

53. The crew had no means of attacking the principal fire, but attempted to subdue the secondary fire initiated in the aileron bay.

54. No 7 tank was protected for some 5 minutes by the fuel within it. However, at about this time the tank's fuel began to boil and reached pressures which could not be contained by the tank structure. The fuel escaped as a sonic jet from a breach in the upper surface of the fuel tank. Although initially igniting as it escaped the tank, the velocity of the jet soon exceeded the burning velocity and the start of combustion moved along the jet, downstream of the source. Although dependent on a number of factors, it is likely that the fuel jet arc would travel from the wing over, or intersecting with, the tail plane. This was probably the second fire observed by the Harrier GR7 pilot.

55. At some stage a short-lived fire was initiated in the rear tail compartment. This may have been as a result of fuel leaking into the compartment being ignited either by the fuel-jet or by the fire breaching internal ducting.

56. Comparison with previous Nimrod incidents and the calculations undertaken within the QinetiQ combustion study suggest that the fire would have considerably weakened the aircraft's rear spar. Furthermore, the aircraft's hydraulic systems would have begun to fail as hydraulic liquid boiled and pipe unions melted. The loss of primary and backup hydraulic systems and possible fire damage to flying control cables and pulleys, probably led to a loss of control at some time during the last 60 seconds of flight. During this period the No 7 fuel tank was probably subject to a BLEVE, either as a result of wing deformation or as internal pressure began to rise to a point at which it ruptured; the BLEVE was probably the fireball reported by the GR7 pilot and Canadian witnesses.

57. Very shortly afterwards, and at a height of about 700 ft agl the weakened starboard wing failed, breaking from the aircraft and striking the

tail structure. As the remaining aircraft structure began to roll to the right the port wing also failed and shortly thereafter the tail structure broke from the aircraft. All 4 principal elements of the aircraft structure struck the ground within close proximity and with such velocity that the accident was not survivable. There was no significant ground fire as much of the aircraft's fuel was spilled as it disintegrated.

CONSIDERATION OF HUMAN FACTORS

58. The Board considered human factors with regard to the crew's handling of the emergency and Annex P contains a detailed analysis of the Board's reconstruction of possible crew actions from mission tape evidence. Crew 3 were faced with a series of complex and demanding emergencies. Throughout these events they acted logically and calmly, performing drills initiated by their captain in an attempt to save their aircraft. Although the need to use oxygen masks, following the aircraft's depressurisation, complicated the means by which they could address the multiple emergencies, the crew persevered with every means at their disposal to quell the fire. Despite the seriousness of the situation they also ensured that their 2 army and marine colleagues were provided with oxygen. Nonetheless, this emergency illustrated the difficulty of conducting aircraft drills when crewmembers are restrained in their movements by the need to connect to an oxygen supply. The speed with which the pressure hull was breached highlights the need for all crews to consider seriously the potential problems when conducting emergency drills in such situations. The report from , which provided information about the fire on the wing, emphasises the need to gather data from all sources, to provide information on damage to aircraft external surfaces. Crew 3 needed only to assist 2 non-crew members; the complications imposed by being on oxygen could restrict another crew's actions in dealing with a larger number of passengers. Furthermore, the same restrictions would make it extremely difficult to retrieve the spare oxygen bottle at the rear of the aircraft. The loss of the air engineer's intercom for approximately one minute during the emergency removed a key element from the crew's ability to analyse the emergency and conduct appropriate drills. However, the remainder of the crew clearly began to conduct the correct drills while he cured his intercom problem. The Board considers that Crew 3 acted in a most professional manner throughout and none of their actions contributed to the incident.

Annex P
Exhibit 1

COMPLIANCE WITH ORDERS AND INSTRUCTIONS

59. All relevant orders and instructions were complied with.

SUMMARY OF CAUSES AND FACTORS

60. **Causes.** As the Board was unable to investigate XV230's wreckage at the crash site and it proved impossible to recover more than a few small components from the aircraft, the Board has been unable to determine positively the source or cause of the fire which led to the loss of XV230 and its crew. Nonetheless, through investigation of the limited data available, the Board was able to deduce the most probable location of the fire, a number of probable causes of that event and factors which possibly contributed to it:

a. The escape of fuel during AAR, occasioned by an overflow from No 1 tank, or a leak from the fuel system (fuel coupling or pipe), led to an accumulation of fuel within the No 7 tank dry bay. Although of a lower probability, the fuel leak could have been caused by a hot air leak damaging fuel system seals.

b. The ignition of that fuel following contact with an exposed element of the aircraft's crossfeed/ SCP pipe work.

61. **Contributory Factors.**

a. The age of the Nimrod MR2's non-structural system components.

b. Nimrod MR2 maintenance policy in relation to fuel and hot air systems.

c. The lack of a fire detection and suppression system within the No 7 tank dry bay.

d. The fact that hazard analysis did not correctly categorize the potential threat to the aircraft caused by the collocation of fuel and hot air system components within the No 7 tank dry bay.

e. The formal incorporation of AAR capability within the Nimrod did not identify the full implications of successive changes to the fuel system and associated procedures.

62. **Aggravating Factor.**

a. The loss of flying controls through fire damage to the hydraulic systems or cables and pulleys.

63. **Other Factors.** Nil.

OBSERVATIONS

64. The Board observed that:

a. The recovery operations at XV230's crash site by the Canadian and UK contingents, assisted by US personnel, were conducted with considerable skill and fortitude in an exceptionally demanding and distressing situation.

b. Changes to RAF Kinloss' management structure as a result of Project Trenchard removed the SO1 engineer (OC Engineering Wing) from the station structure. Engineering personnel are now distributed between the station's 2 remaining wings under non-specialist leadership; QR640 responsibility is delegated to a squadron leader. Both operational and engineering witnesses believed that this change had had a negative effect on availability. Witnesses 32-34

c. Service training courses were perceived by a number of witnesses no longer to impart the skill of hand and depth of knowledge necessary to maintain an aircraft built around a design philosophy now some 40 years old. This, combined with a tautly-manned engineering establishment and a recent outflow of skilled personnel, has led to an effective dilution of engineering skills, although there is no evidence that this contributed to the loss of XV230. Witnesses 32-34

d. Some Nimrod aircraft at both DOB and RAF Kinloss had elements of the acoustics mission equipment removed and the resultant voids had been masked with cardboard, held in place with tape. The Nimrod IPT has stated that there are sufficient acoustics systems to make such removal unnecessary, thus there is no need to provide blanking plates. Exhibit 25

e. Following the loss of XW666 the BoI recommended the incorporation of position and voice recording within the Nimrod DARU. This was not enacted.

f. Other aircraft types in the MOD inventory use fuel seals similar to those fitted on the Nimrod.

g. The body bags, which had been provided by the US mortuary at Kandahar and manufactured in the USA (NATO Stock No 9930-01-3316244), were not provided with impermeable membranes.

h. AAR refuel rates in the dynamic simulator are not realistic as they give a fixed refuel rate to each tank, regardless of the number of tanks being filled. This leads to a false impression of real time refuel rates towards the end of an AAR uplift.

i. The Board noted that, while BAe had concluded that individual pressure surges of less than 120 psi were not significant, no studies had been conducted on the cause of pressure surges or on their potential cumulative affect on an aircraft's fuel system.

j. The Board had to travel to theatre without a DASC post-crash pack-up thereby placing great strain on IT and secure communications during the initial investigation. Valuable time was lost resolving the resulting problems.

65. **RECOMMENDATIONS**

a. **Policy.**

(1) The Nimrod Maintenance Policy is reviewed to ensure that maintenance procedures reflect the increasing age of the aircraft.

(2) The Nimrod Ageing Aircraft Audit is reviewed to include aircraft systems. This work should be incorporated within the review of Nimrod maintenance policy.

(3) The Nimrod Safety Case is reviewed, reassessing the factual data used for interpretation and categorization of hazard and risk. The review should include widespread operator (air and ground crew) involvement. This work should be incorporated within the review of Nimrod maintenance policy.

(4) A safety review of the Nimrod fuel and hot air systems is completed. In particular the safety review should consider the suitability of corrective maintenance for these systems. The review should also consider mitigation of the risk of fire and hot air leaks within airframe hidden compartments, such as the No 7 tank dry bay and the Rib 1 landing; mitigation might involve introduction of fire detection and suppression systems, fire retardant coatings, or a change in procedures, which reduces the risk of fire. Nimrod operators (air and ground crews) should be involved closely with the review. This work should be incorporated within the review of Nimrod maintenance policy.

b. **Fuel System.**

(1) A life for the FRS Series 1 fuel seal be determined, based on the designer's recommendation that fitted seals are replaced after 25 years.

(2) A maximum installed life for fuel seals of other material types is determined.

(3) A one-off inspection of the integrity of each Nimrod's fuel system, between Ribs 3 starboard and port, be conducted with access panels removed and the system pressurised. The inspection is to check for leaks, physical damage and is also to include visual confirmation that fuel couplings have been assembled and locked correctly. This inspection will establish a baseline pending action on other recommendations.

(4) An inspection regime for fuel seals be initiated as recommended by Eaton Aerospace (para 32a(2)). The inspection should be a visual check of the fuel coupling, in-situ and under pressure, with panels removed. In view of the potential age of some Nimrod fuel seals this inspection should be annual, until a life is determined for the seals and any seal replacement programme is complete.

(5) A procedure is developed to pressure test the fuel vent system at the fuselage to wing interface.

(6) Detailed instructions for the correct fitting and locking of FRS couplings and seals be incorporated formally within the Nimrod AMM and publicized widely.

c. **Hot Air System.** Existing limitations, prohibiting the use of the SCP and of the cross-feed pipe in the air be continued, unless: the pipe insulation is modified in such a way that the pipe cannot act as an ignition source; the study into corrosion within cross-bleed pipes, undertaken following the hot air leak on XV227, is completed and its recommendations acted upon; a hot air leak detection system capable of detecting any leak within the cross-feed pipe and SCP (to the venturi) is fitted.

d. **AAR.**

(1) Nimrod AAR procedures are reviewed in the light of the Board's report, to establish appropriate levels and rates of refuel, which will prevent overspill of fuel from tanks.

(2) A study be initiated to determine the cause of pressure surges during AAR and their long-term effect on aircraft fuel systems.

(3) A statement specifying that the maximum normal operating pressure of 50 psi during AAR be reintroduced into the Nimrod ACM.

(4) AAR refuel rates in the dynamic simulator are changed to reflect actual refuel rates to provide more realistic training.

e. **Operational.**

(1) Existing limitations, prohibiting the use of the No 7 fuel tanks, introduced following the loss of XV230, be discontinued.

(2) A study be undertaken into the utility of parachute escape on the Nimrod MR2.

(3) Nimrod STANEVAL consider the lessons identified at Annex P and their potential impact on crew emergency procedures.

(4) The port rear emergency oxygen bottle is relocated to a more central position, or another oxygen bottle is provided in this position.

(5) Nimrod STANEVAL consider the lessons identified at Annex P and their potential impact on crew emergency procedures.

f. **Aircraft Modification.**

(1) The design of No 1 fuel tank is reviewed to reduce the effect of asymmetric filling.

(2) The outlet pipes for fuselage fuel tank blow-off valves be modified to ensure that blown-off fuel cannot run down the exterior of the fuselage.

(3) The connections of the No 1 tank vent pipes be modified to reduce the risk of fuel leakage.

(4) The drainage of the lower panel in the No 7 tank dry bay be improved to prevent any accumulation of fuel.

(5) A crash-protected means of recording aircraft position and intercom voice is introduced to the Nimrod.

g. **Post Crash Management.**

(1) The Defence Aviation Safety Centre (DASC) should investigate the provision of details of type specific emergency equipment (ADR, etc) and key internal components (for example the ADR tape unit and housing) on their website to enable Post Crash MOD Incident Officer (PCMIO) to provide guidance to search teams.

(2) Instructions for PCMIO are revised to provide guidance when attending crash sites that are likely to become inaccessible.

(3) Instructions for PCMIO at crash sites which are likely to become inaccessible should include advice to make every effort to ensure the widest possible photographic

coverage of the crash site, at the highest possible resolution. This should take priority over all other tasks for any photographic team.

(4) DASC should increase their current stock of post-crash BOI kits.

(5) Body bag fluid proof liners should be stored within the outer ruggedised bags in crash kits to ensure that they always arrive on scene together.

h. **Engineering.**

(1) The Nimrod Mod Form 700 Sections 2 and 3 (F703/F704) should be copied and retained before the document is carried on the aircraft.

(2) The use of non-approved mission system panel blanks be discontinued.

i. **Personnel.**

(1) Consideration be given to reinstating the SO1 engineering post in Forward at RAF Kinloss to provide senior oversight of station engineering matters.

(2) A review of engineering training is undertaken to identify those areas which, while relevant to Nimrod capability, are not encompassed within existing formal training courses.

ACKNOWLEDGEMENTS

66. The Board wishes to acknowledge the extensive assistance given by all of the organisations and individuals identified at paragraph 20. Their expertise and commitment have been fundamental to the Board in their attempts to explain the tragic loss of XV230 and its crew. The Station Commander and personnel of RAF Kinloss, who, at a time of great strain and considerable workload, were unstinting in the support of the Board's activities, were also central to the compilation of this report.

President ________________________ Wg Cdr

Members ________________________ Sqn Ldr

________________________ Sqn Ldr Date ________________

Annexes:

A. Diary of Action.
B. Details of Aircrew Occupants.
C. Details of Aircraft.
D. Cockpit Warnings.
E. Previous Nimrod Accidents and Incidents.
F. Analysis of Canadian Sighting of Nimrod XV230.
G. No 7 Tank Dry Bay.
H. Fuel System – Technical Description.
I. Fuel System Maintenance History Analysis.
J. Fuel Coupling and Seal Consumption.
K. Air Systems.
L. AAR System Incorporation.
M. Technical Description of No 1 Fuel Tank and Ground Refuelling.
N. Analysis of the AAR Refuel of XV230.
O. Flying Control and Hydraulic Systems.
P. Description of Crew Actions during the Emergency.
Q. List of Exhibits.
R. List of Witnesses.
S. Glossary.

BOARD'S FURTHER INVESTIGATION INTO SPECIFIC ISSUES

PART 2A

CONVENING AUTHORITY DIRECTION TO THE BOARD FOR FURTHER WORK

INTRODUCTION

1. Following a meeting of subject matter experts held at HQ 2 Gp on 24 May 07 to discuss the findings of the Board of Inquiry and ensure all possible avenues of investigation had been explored, AOC 2 Gp determined that there were several areas that would benefit from further examination. Accordingly, the Board was tasked to amplify and clarify the findings presented to the Convening Authority on 20 Apr 07 paying particular attention to:

a. Determining, in the light of new information, whether fault trends associated with fuel system components had been analysed effectively, to validate the suitability of the Nimrod maintenance policy.

b. Clarifying why electricity was discounted as the likely source of ignition that led to the fire suffered by XV230.

c. Providing a more explicit argument regarding the most probable sources of fuel and ignition.

d. Presenting the Nimrod fuel seal failure rate against flying hours rather than as a simple chronological plot.

e. Identifying those components whose age, in the Board's opinion, had been a possible contributory factor to the accident; and clarifying the relationship between the age of the components and their condition.

f. Amending the conclusions as appropriate, if different causes and/or contributory factors were identified as a result of this additional work.

The findings were to be an addendum to the original F412 and be contained within the BOI as Part 2A.

2. **Composition of the Board.** The membership of the Board remained as originally convened.

MATTERS ARISING FROM ADDITIONAL TASKING

3. **JAP 100A-01 Analysis of Fault Trends.** In its main report the BOI noted at para 32a(5) that 'there is no evidence that the maintenance data for the fuel system at component level was ever analysed to inform maintenance policy' in accordance with JAP100A-01. On 7 Jun 07 the Board was provided with fresh evidence that a full Nimrod maintenance schedule review had been carried out in 2001 using Reliability Centred Maintenance (RCM) methodology and had been used to inform maintenance policy. The RCM review searched maintenance records for the Nimrod fleet for the period 1995 to 2000, to identify failure trends, in order to confirm the appropriate level of maintenance required for the Nimrod. The analysis team not only examined formal records, but also interviewed maintenance personnel in an attempt to identify areas of concern. Despite this widespread consultation, the team did not identify any fault trends within the Nimrod fuel system. Although the RCM team used similar data to the BOI, it had a much wider remit and the increase in fuel seal leaks may have been masked by the sheer quantity of other data (in the BOI's analysis fuel system leaks represented only 10% of the total faults recorded with the fuel system over a period of 23 years). The Board acknowledges, however, that this new evidence confirms that maintenance data for the fuel system was analysed as required by JAP100A-01.

Exhibit A1

4. **Fuel System Inspections.** Work undertaken by the Board to investigate the analysis of maintenance data above revealed 2 additional checks of the fuel system undertaken during periodic maintenance. Although not specifically tasked to consider this matter the Board was of the opinion that the fact that a greater range of fuel system inspections are conducted was of relevance in that it illustrated a wider range of such checks than suggested by the main report; the additional inspections are:

a. **Fuel leak mapping**. Before entering periodic maintenance a Nimrod's fuel tanks are filled with fuel and left for 24 hours, to see if fuel leaks become evident. Known as fuel leak mapping this technique is aimed primarily at detecting fuel tank leaks, but the procedure can identify leaks in other areas of the fuel system. This process is followed by the zonal inspections described at para 32a(1) of the main report.

b. **Nitrogen pressure testing**. Following periodic maintenance in which elements of the refuel/defuel system are disturbed pressure tests using nitrogen are performed to confirm correct assembly and detect system leaks.

5. **Combustion Report – Electrical Ignition.** The main BOI report and supporting QinetiQ combustion report do not explain in detail the full rationale behind discounting electricity as a likely source of ignition. QinetiQ was tasked with providing a more detailed explanation for this decision, which is contained in Annex B to Issue 3 of the QinetiQ Combustion Analysis. In summary, electrical ignition requires either a

Exhibit A2

low-energy spark with a very precise mixture of fuel vapour and air, or a very high-energy spark within a less well prepared mixture (the energy required from the spark will increase with altitude). While the former has occurred in sealed containers such as fuel tanks, it is unlikely in an area such as the No 7 tank dry bay, which is vented and open to the much larger bomb bay. The latter scenario is very unlikely at the altitude XV230 was flying as there are no electrical components with sufficient energy within the No 7 tank dry bay.

6. **Sources of Fuel and Ignition.** The BOI F412 Main Report Discussion of Factors is arranged in chronological order and thus the central discussion of the means by which the Board determined the most likely sources of fuel and ignition is dispersed over a number of paragraphs. In view of the complexity of the argument, a short summary of the means by which the Board determined the most likely sources is contained below:

a. **Sources of Fuel**. Only 2 possible sources of fuel were evident: overflow from No 1 tank during AAR or a leak from the fuel system. Circumstantial evidence suggested that the former was a probable fuel source: the fire's proximity in time to XV230's AAR serial, the conjunction of the SCP's failure with the predicted time for blow-off and the fact that No 1 tank overflow had occurred during recent sorties on XV230 (although the first 2 events could also indicate a significant leak from a fuel pipe or coupling). However, none of the evidence suggesting No 1 tank overflow was conclusive and the Board, therefore, also considered the 3 elements of the fuel system (fuel tanks, pipes and couplings) as possible sources of fuel. Fuel tank leaks were eliminated, as such leaks tended to vent to atmosphere, or to the bomb bay, which contains no viable ignition sources; a leak from a pipe was possible, but statistically unlikely; fuel couplings had shown an increase in leakage rates and were present in and close to the No 7 tank dry bay, in locations which would easily supply fuel to the likely ignition point. Although couplings rarely suffered catastrophic failure, significant leaks had been known and such an occurrence during refuelling could have allowed the escape of sufficient fuel to support the fire, particularly from the refuel gallery whilst pressurised during AAR. The disruption of an element of the fuel system by the failure of a hot air pipe was also considered possible, but unlikely. After much consideration the Board decided that the 2 probable sources of fuel were either No 1 tank overflow or leakage from a fuel coupling, but it was unable to determine objectively which of the 2 was the most likely. The proximity in time of the fire's ignition to the AAR serial supports either as being probable sources of fuel.

b. **Ignition Scenarios**. The Board was only able to identify 3 possible ignition scenarios: the cross feed pipe failing, allowing hot air to disrupt a fuel coupling and then the leaking fuel being ignited by the fractured ends of the cross feed pipe; a faulty electrical component causing a spark which ignited fuel vapour concomitant on one of the leaks described above; or escaped fuel touching the SCP/cross feed hot air pipe and spontaneously igniting. The first ignition scenario was discarded on the grounds that the crew would have detected a major hot air leak and that a minor leak would have had to occur in close proximity to a fuel coupling to cause sufficient damage. While considering the second scenario the Board noted that electrical wiring in the No 7 tank dry bay on other Nimrods was in good condition. Moreover, the Board was advised that a high-energy electrical spark would be necessary to ignite a fuel/air mix in the No 7 tank dry bay and there were no such sources within this area. Also, achieving the correct fuel/air mix in the vented No 7 tank dry bay, especially at the altitude at which XV230 was flying, made electrical ignition very unlikely. On balance the Board decided that while an electrical source of ignition was possible, though unlikely, a more likely source lay within the No 7 tank dry bay. The cross feed/ SCP pipe in the No 7 tank dry bay can reach temperatures in the order of 400 °C when operating, which can cause auto ignition of fuel in under a minute. Although the majority of this pipe is insulated there are short sections in some aircraft not covered by insulation and also insulating blankets in which it is possible for fuel to accumulate and be held against the pipe. The SCP had been operating during XV230's refuelling operation and a section of the SCP pipe lies at the lowest point in the No 7 tank dry bay; this section is covered by an insulating blanket, although in most aircraft there is a short section of exposed pipe immediately adjacent to the blanket. The Board believed that fuel leaking in this area would gravitate towards this point and ignite against the pipe, possibly after soaking under the insulation blanket; thus the SCP/cross feed pipe represented the most probable point of ignition.

Note that the Board is not using the term 'most probable' in any specifically defined engineering/ scientific sense. It should be seen as being synonymous with the phrase 'most likely'.

7. **Seal Failure Rates.** The Board was asked to present the fuel seal failure rate in terms of flying hours, in order to inform studies into the failure mechanism, and this information is attached at Annex A to this report. The data supports previous conclusions, showing an increase in fuel coupling leaks. Annex A

8. **Age as a Factor**. The Board was tasked to identify those components for which it considered their age to have been a possible Contributory Factor to the accident. The Board noted that the only 2 components in which it had identified age as a possible contributory factor were the fuel system seals and the SCP/cross-feed pipe insulation; the age

of the airframe was not a factor in the loss of XV230.

9. **Clarification of the relationship between the age of the components and their condition.** The Board was asked to clarify the relationship between the age and the condition of the 2 components identified in the previous paragraph. Analysis has shown that there has been an increase in leaks from the Nimrod's fuel system elastomeric seals over time. This had not been realised prior to the Board's Inquiry. The Board found no evidence of studies indicating that elastomeric seals were susceptible to failure due to age, although the manufacturer of the most commonly used elastomeric seal on Nimrod has recently stated that they should be considered for replacement after having been fitted for 25 years. Exhibits A3 & A4
Both the manufacturer and MOD expert advice noted that there might be a number of reasons for the increase in seal leakage. An investigation into this issue was outside the Board's resources, but, in view of its importance and wider implications, the Nimrod IPT has commenced an investigation into the life of such seals; this investigation is not yet complete. The other component considered by the Board was the cross feed pipe insulation, which was observed in some areas of other Nimrods to be compressed; this may have been caused by manual means (physical contact during maintenance), or possibly because of thermal or pressure cycling. The compression would appear to have occurred over a period of time; however, this condition does not appear to be the result of a natural ageing process, but of the length of time that the component has been fitted. The Board's conclusion is that the condition of the 2 components was linked to their age in terms of 'showing the effects of the passage of time'[1] The Board believes that this could equally be expressed as 'the condition of the components associated with the time fitted'.

10. **Amendment to Conclusions.** The Board considered that it should reconsider 2 Possible Contributory Factors following its additional work:

a. **Fuel System Maintenance Policy.** The additional information presented to the Board illustrated clearly that fault trends had been analysed to inform maintenance policy and that a more comprehensive system of fuel leak checks existed than was previously considered by the Board. Nonetheless, none of the new data altered the fact that the rate of fuel leaks had increased and that the increase had not been detected; thus, in this one area, fuel system maintenance policy remained a possible Contributory Factor. It should be noted that fuel system maintenance policy is only a Contributory Factor if the fuel release was occasioned following a fuel system leak.

b. **Age.** The Board considered that the condition of the fuel seals and crossfeed pipe insulation was linked to the length of time that they had been fitted and through this fact, to their age. The

[1] The Concise Oxford English Dictionary Sixth Edition.

Board had been tasked specifically to consider age and was unable to exclude it as a possible Contributory Factor. Therefore, acknowledging the close linkage with the components' condition as a result of time fitted, the Board believed that the age of the aircraft's fuel seals and crossfeed pipe insulation remained a possible Contributory Factor.

President ______________________ Wg Cdr

Members ______________________ Sqn Ldr

______________________ Sqn Ldr Date _______________

Annex:

A. Fuel System Leaks Per 1000 Flying Hours.

Exhibits:

A1. Nimrod Maintenance Schedule Review 2001.
A2. QinetiQ Combustion Study, Issue 3, Jun 07.
A3. Minutes of a Meeting held at AAIB on 29 Mar 07.
A4. Revised Declaration of Design and Performance FRS110 Pipe Connection (Coupling) Series 1 dated 7 Jun 07.

ANNEX A TO
BOARD OF INQUIRY
NIMROD XV230
DATED APR 07

DIARY OF ACTION

All times local (unless stated otherwise)

Day/Date	**Time**	**Occurrence**
Sun 3 Sep 06	0945	Board of Inquiry (BOI) convenes at HQ 2 Gp, RAF High Wycombe
	0955	BOI joined by DASC BOI Advisor, RAF Aircraft Recovery Unit and RN Flight Safety/Accident Investigation Team personnel
	1000	BOI briefed by AOC 2 Gp
	1800	BOI departs for Heathrow Airport
	2230	BOI departs Heathrow for Bahrain with Gulf Air
Mon 4 Sep 06	0610	BOI and support team lands Bahrain
	1000	BOI and support team departs Bahrain for Al U'died on HS 146
	1230Z	BOI and support team departs Al U'died on C130J
	1530Z	BOI and support team arrives Kandahar Airfield (KAF)
	1600Z	BOI receives initial brief from 904 EAW (PCMIO)
Tue 5 Sep 06	0400Z	BOI reconvenes at KAF HQ
	0500Z	BOI receives Intelligence and Force Protection Brief and view crash site photography
	1520Z	BOI debriefs. Decision taken not to visit crash site due to security situation.
	1800Z	BOI adjourned
Wed 6 Sep 06	0400Z	BOI reconvenes at KAF HQ
		BOI formally interviews , ATC Controller
	0955Z	BOI formally interviews in presence of of 73 Expeditionary Air Control Sqn
	1230Z	BOI view C2 radar control cabin and radar picture
	1900Z	96 hour signal transmitted to AOC 2 Gp on RAFCCIS
	2000Z	BOI adjourned
	2030Z	RAF Accident Recovery Team and RN Accident Investigation Team depart for UK
Thr 7 Sep 06	0400Z	BOI reconvenes in KAF HQ
	0550Z	Formal interview with 904 EAW (PCMIO)
	0640Z	Informal interview with
	1230Z	Informal interview with USAF Predator pilot
	1430Z	BOI departs KAF for Kabul on C130J
	1630Z	BOI departs Kabul for on 146
	1930Z	BOI arrives at and transported to hotel
	2130Z	BOI adjourned
Fri 8 Sep 06	0930Z	BOI reconvenes at RAF Detachment
	1030Z	BOI formally interviews , Nimrod Detachment Exec Officer
	1235Z	BOI formally interviews 120 Sqn
	1630Z	BOI formally interviews , Detachment Briefing Officer
	1615Z	BOI adjourned
Sat 9 Sep 06	0430Z	BOI reconvenes at RAF Det
	0445Z	BOI formally interviews , Nim Det Eng Officer
	0755Z	BOI formally interviews AGE, SNCO IC B Shift
	0845Z	BOI formally interviews Propulsion Technician
	0915Z	BOI formally interviews
	0935Z	BOI formally interviews Avionics Technician

Day/Date	Time	Occurrence
	0950Z	BOI formally interviews Weapons Technician
	1005Z	BOI formally interviews Radar Technician
	1020Z	BOI formally interviews Airframes Technician
	1120Z	BOI formally interviews AGE, SNCO IC Shift
	1210Z	BOI formally interviews Propulsion Technician
	1255Z	BOI formally interviews Airframes Technician
	1320Z	BOI formally interviews Electrical Mechanic
	1430Z	BOI adjourned
Sun 10 Sep 06	0400Z	BOI reconvenes at RAF Det,
	0430Z	BOI formally interviews DOB RAF Det
	0605Z	BOI formally interviews RAF Police, DOB Security Officer
	0710Z	BOI formally interviews SNCO IC DOB Medical Centre
	0920Z	BOI formally interviews Air Engineer, Nim Det, 120 Sqn Crew
	0950Z	BOI formally interviews Pilot 1, Nim Det, 120 Sqn Crew
	1020Z	BOI formally interviews Navigator, 120 Sqn Crew Captain
	1400Z	BOI adjourned
Mon 11 Sep 06	0700Z	BOI reconvenes at RAF Det,
	0725Z	BOI formally re-interviews , AGE, SNCO IC A Shift
	0815Z	BOI formally re-interviews , AGE, SNCO IC B Shift
	1000Z	BOI formally interviews , 216 Sqn Det Eng Officer
	1100Z	BOI formally interviews , Air Engineer, 216 Sqn Det
	1400Z	BOI adjourned
	1600Z	BOI departs International Airport
Tue 12 Sep 06	0640	BOI arrives Heathrow Airport
	1100	President BOI (PBOI) briefs AOC 2 Gp
Wed 13 Sep 06	1000	PBOI and Aviation Psychologist informally interview Harrier GR7 Pilot at RAF Cottesmore
Thr 14 Sep 06		Air and Eng Members (AirM and EngM) open BOI office at RAF Kinloss
	1000	PBOI visits Aircraft Accident Investigation Branch (AAIB) at Farnborough
Fri 15 Sep 06	0900	PBOI briefs AOC 2 Gp
		AirM and EngM in office
Sat 16 Sep 06		EngM reviews Engineering Documentation
Sun 17 Sep 06		PBOI travels to RAF Kinloss
Mon 18 Sep 06	0800	BOI reconvenes at RAF Kinloss
	2000	BOI adjourns
Tue 19 Sep 06	0800	BOI reconvenes
	0900	BOI holds discussions with AAIB and BAES
	1900	BOI adjourns
Wed 20 Sep 06	0800	BOI reconvenes
	0900	BOI holds further discussions with AAIB
	1930	BOI adjourns
Thr 21 Sep 06	0800	BOI reconvenes
	1900	BOI adjourns
Fri 22 Sep 06	0800	BOI reconvenes
	1730	BOI adjourns
Sat 23 Sep 06	0800	BOI reconvenes
	1700	BOI adjourns
Mon 25 Sep 06	0800	BOI reconvenes
	1830	BOI adjourns
Tue 26 Sep 06	0800	BOI reconvenes
	1900	BOI adjourns
Wed 27 Sep 06	0800	BOI reconvenes
	1830	BOI adjourns
Thr 28 Sep 06	0800	BOI reconvenes
	1700	BOI travels to High Wycombe

Day/Date	Time	Occurrence
Fri 29 Sep 06	0900	BOI presents interim report to AOC 2 Gp
	1100	BOI travels to RAF Brampton
	1300	BOI visits
	1430	BOI briefs Nimrod IPTL, IPTL(des) and D Log 2
	1600	BOI formally interviews
	1800	BOI adjourns
Sat 30 Sep 06	0830	AirM and EngM return to RAF Kinloss
Mon 2 Oct 06		PBOI returns to RAF Kinloss
	1300	BOI reconvenes
	1800	BOI adjourns
Tue 3 Oct 06	0800	BOI reconvenes
	1730	BOI adjourns
Wed 4 Oct 06	0800	BOI reconvenes
	1700	BOI adjourns
Thr 5 Sep 06	0800	BOI reconvenes
	1700	BOI adjourns
Fri 6 Sep 06	0800	BOI reconvenes
	1700	BOI adjourns
Mon 9 Sep 06	1100	BOI reconvenes
	1700	BOI adjourns
Tue 10 Oct 06	0800	BOI reconvenes
	0900	BOI discussions with AAIB and BAES at RAF Kinloss
	1830	BOI adjourns
Wed 11 Oct 06	0800	BOI reconvenes
	0900	BOI discussions with AAIB and BAES at RAF Kinloss
	1900	BOI adjourns
Thr 12 Oct 06	0800	BOI reconvenes
	0900	BOI discussions with AAIB and BAES at RAF Kinloss
	1600	BOI adjourns
	1600	PBOI travels to
Fri 13 Oct 06		PBOI visits
Mon 16 Oct 06	1100	PBOI returns to RAF Kinloss
	1100	EngM starts leave
Tue 17 Oct 06		PBOI and AirM in office
		EngM on leave
Wed 18 Oct 06		PBOI and AirM in office
		EngM on leave
Thr 19 Oct 06	0800	BOI reconvenes
	1730	BOI adjourns
Fri 20 Oct 06	0800	BOI reconvenes
	1730	BOI adjourns
Mon 23 Oct 06		PBOI travels to AAIB Farnborough
		AirM and EngM in office
Tue 24 Oct 06		PBOI meets with QinetiQ Combustion Specialist at AAIB
		AirM and EngM in office
Wed 25 Oct 06	0800	BOI reconvenes
	1800	BOI adjourns
Thr 26 Oct 06	0800	BOI reconvenes
	1700	BOI adjourns
Fri 27 Oct 06	0800	BOI reconvenes
	1730	BOI adjourns
Mon 30 Oct 06	0800	BOI reconvenes
		PMA contacted for holding officer. nominated
	1700	BOI adjourns
Tue 31 Oct 06	0800	BOI reconvenes
	1700	BOI adjourns

Day/Date	**Time**	**Occurrence**
Wed 1 Nov 06	0800	BOI reconvenes
	1700	BOI adjourns
Thur 2 Nov 06	0800	BOI reconvenes
	0800	, Holding Officer joins BOI
	1700	BOI adjourns
Fri 3 Nov 06	0800	BOI reconvenes
	1700	BOI adjourns
Mon 6 Nov 06	0800	BOI reconvenes
	1400	BOI formally interviews Ops Wg, RAF Kinloss
	1800	BOI adjourns
Tue 7 Nov 06	0800	BOI reconvenes
	1700	BOI adjourns
Wed 8 Nov 06	0800	BOI reconvenes
	1700	BOI adjourns
Thr 9 Nov 06	0800	BOI reconvenes
	1700	BOI adjourns
Fri 10 Nov 06	0800	BOI reconvenes
	1500	BOI adjourns
	1500	PBOI travels south
Mon 13 Nov 06		AirM and EngM in office. PBOI working at home
	1400	AirM and EngM attend Station Refuelling meeting with IPT
Tue 14 Nov 06		PBOI meets with AAIB and QinetiQ
		AirM and EngM in office
Wed 15 Nov 06		PBOI returns to RAF Kinloss. EngM ill at home
		PBOI and AirM discuss Combustion Study with QinetiQ at RAF Kinloss
Thr 16 Nov 06	0800	BOI reconvenes
	0900	BOI adjourns. EngM sent home sick
		PBOI and AirM discusses Combustion Study with QinetiQ
Fri 17 Nov 06		PBOI and AirM in office. EngM ill at home
Mon 20 Nov 06	0800	BOI reconvenes
	1700	BOI adjourns
Mon 20 Nov 06	0800	BOI reconvenes
	1700	BOI adjourns
Tue 21 Nov 06	0800	BOI reconvenes
	1700	BOI adjourns
Wed 22 Nov 06	0800	BOI reconvenes
	1700	BOI adjourns
Thr 23 Nov 06	0800	BOI reconvenes
	1700	BOI adjourns
Fri 24 Nov 06	0800	BOI reconvenes
	1700	BOI adjourns
Mon 27 Nov 06	0800	BOI reconvenes
	1000	BOI adjourns. AirM attends funeral
Tue 28 Nov 06	0800	BOI reconvenes
		BOI meets with QinetiQ and Hydraulic Analysis Ltd for modelling of fuel system
	1700	BOI adjourns
Wed 29 Nov 06	0800	BOI reconvenes
	1700	BOI adjourns
Thr 30 Nov 06	0600	BOI reconvenes
		BOI travels to AAIB Farnborough
	1100	BOI meets with QinetiQ, AAIB and at AAIB Farnborough
Fri 1 Dec 06	0900	BOI meets with QinetiQ and DSTL ADAC team
	1400	BOI adjourns
	1400	PBOI travels home and AirM and EngM return to RAF Kinloss
Mon 4 Dec 06		PBOI returns to RAF Kinloss. EngM at home ill

Day/Date	Time	Occurrence
Tue 5 Dec 06	0800	BOI reconvenes
		BOI formally interviews NLS, RAF Kinloss
	1700	BOI adjourns
Wed 6 Dec 06	0800	BOI reconvenes
	1700	BOI adjourns
Thr 7 Dec 06	0800	BOI reconvenes
	1700	BOI adjourns
Fri 8 Dec 06	0800	BOI reconvenes
	1700	BOI adjourns
Mon 11 Dec 06	0800	BOI reconvenes
	1700	BOI adjourns
Tue 12 Dec 06	0800	BOI reconvenes
	1700	BOI adjourns
Wed 13 Dec 06	0800	BOI reconvenes
	1700	BOI adjourns
Thr 14 Dec 06	0800	BOI reconvenes
	1700	BOI adjourns
Fri 15 Dec 06	0800	BOI reconvenes
	1700	BOI adjourns
Mon 18 Dec 06	0800	BOI reconvenes
	1700	BOI adjourns
Tue 19 Dec 06	0800	BOI reconvenes
	1700	BOI adjourns
Wed 20 Dec 06	0800	BOI reconvenes
	1700	BOI adjourns
Thr 21 Dec 06 – Wed 3 Jan 07		Christmas and New Year Grant
Thr 4 Jan 07		AirM and EngM in office. PBOI on leave
Fri 5 Jan 07		AirM and EngM in office
		PBOI meets with **at** **.** First indication of Canadian witnesses of crash.
Mon 8 Jan 07		AirM and EngM in office. PBOI returns to RAF Kinloss
Tue 9 Jan 07	0800	BOI reconvenes
	1200	BOI adjourns
	1200	EngM departs on leave
Wed 10 Jan 07		PBOI and AirM in office. EngM on leave
Thr 11 Jan 07		PBOI and AirM in office. EngM on leave
Fri 12 Jan 07		PBOI and AirM in office
		EngM attends meeting with Eaton Aerospace and Nim and ARC IPT at Titchfield, Hampshire
Mon 15 Jan 07		PBOI and AirM in office. EngM returns to RAF Kinloss
Tue 16 Jan 07	0800	BOI reconvenes
	1700	BOI adjourns
Wed 17 Jan 07	0800	BOI reconvenes
	1700	BOI adjourns
Thr 18 Jan 07		PBOI and AirM in office. EngM ill at home
Fri 19 Jan 07		PBOI and AirM in office. EngM ill at home
Mon 22 Jan 07		PBOI and AirM travel to AAIB. EngM ill at home
Tue 23 Jan 07		PBOI and AirM meet with AAIB. EngM ill at home
Wed 24 Jan 07		PBOI and AirM travel to AAIB. EngM ill at home
Thr 25 Jan 07		PBOI and AirM in office. EngM ill at home
Fri 26 Jan 07		PBOI and AirM in office. EngM ill at home
Mon 29 Jan 07	0800	BOI reconvenes
	1330	BOI adjourns
	1400	Memorial Service for Crew 3
Tue 30 Jan 07	0800	BOI reconvenes

Day/Date	Time	Occurrence
	1730	BOI adjourns
Wed 31 Jan 07	0800	BOI reconvenes
	1730	BOI adjourns
Thr 1 Feb 07		PBOI and EngM in office
		AirM meets with BAE SYSTEMS, QinetiQ and HAL regarding Tank 1 Modelling at BAE SYSTEMS Warton
Fri 2 Feb 07	0800	PBOI and EngM in office
	1300	BOI reconvenes
	1730	BOI adjourns
Mon 5 Feb 07	0800	BOI reconvenes
	1700	BOI adjourns
Tue 6 Feb 07	0800	BOI reconvenes
	1400	BOI adjourns
	1400	EngM travels to Manchester
Wed 7 Feb 07		PBOI and AirM in office
		EngM attends test of fuel system pipe couplings at BAE SYSTEMS Samlesbury
		PBOI travels to Manchester
Thr 8 Feb 07		PBOI and EngM meet with IPT Safety Manager and BAE SYSTEM at BAE SYSTEMS Chadderton for brief and discussions on Nimrod Safety Case
		PBOI and EngM return to RAF Kinloss
Fri 9 Feb 07	0800	BOI reconvenes
	1730	BOI adjourns
Mon 12 Feb 07	0800	BOI reconvenes
	1700	BOI adjourns
Tue 13 Feb 07	0800	BOI reconvenes
	1700	BOI adjourns
Wed 14 Feb 07	0800	BOI reconvenes
	1700	BOI adjourns
Thr 15 Feb 07	0800	BOI reconvenes
	1700	BOI adjourns
Fri 16 Feb 07	0800	BOI reconvenes
	1600	BOI adjourns
	1600	PBOI travels south
Mon 19 Feb 07	0800	AirM and EngM in office
	1600	AirM and EngM travel south
Tue 20 Feb 07	0830	BOI reconvenes
	0900	BOI meet with Nimrod IPT
	2000	BOI adjourns
Wed 21 Feb 07		BOI travels to RAF Kinloss
Thr 22 Feb 07	0800	BOI reconvenes
	1700	BOI adjourns
Fri 23 Feb 07	0800	BOI reconvenes
	1700	BOI adjourns
Mon 26 Feb 07	0800	BOI reconvenes
	1700	BOI adjourns
Tue 27 Feb 07	0800	BOI reconvenes
	1700	BOI adjourns
Wed 28 Feb 07	0800	BOI reconvenes
	1700	BOI adjourns
Thr 1 Mar 07	0800	BOI reconvenes
	1700	BOI adjourns
Fri 2 Mar 07	0800	BOI reconvenes
	1600	BOI adjourns
Mon 5 Mar 07	0800	BOI reconvenes
	1700	BOI adjourns

Day/Date	Time	Occurrence
Tue 6 Mar 07	0800	BOI reconvenes
	1700	BOI adjourns
Wed 7 Mar 07	0800	BOI reconvenes
	1500	, BOI Holding Officer returns to unit
	1700	BOI adjourns
Thr 8 Mar 07	0800	BOI reconvenes
	1700	BOI adjourns
Fri 9 Mar 07	0800	BOI reconvenes
	1700	BOI adjourns
Mon 12 Mar 07	0600	BOI reconvenes
	1200	BOI meets with Nimrod IPT Leader
Tue 13 Mar 07	0800	BOI departs for Heathrow
	1430	BOI departs for Canada
	1800L	BOI arrives Ottawa
Wed 14 Mar 07	0800L	BOI departs for Petawawa, Ontario
	1000L	BOI interviews , The Royal Canadian Dragoons (RCD)
	1130L	BOI interviews , RCD
	1430L	BOI departs CFB Petawawa
	1800L	PBOI conducts telephone interview with RCD
Thr 15 Mar 07	0800L	BOI reconvenes
	1230	BOI departs for Ottawa
	1500	BOI returns to UK
Fri 16 Mar 07	0630	BOI lands back in UK
	1200	BOI adjourns
Mon 19 Mar 07	0800	BOI reconvenes
	1700	BOI adjourns
Tue 20 Mar 07	0800	BOI reconvenes
	1700	BOI adjourns
Wed 21 Mar 07	0800	BOI reconvenes
	1700	BOI adjourns
Thr 22 Mar 07	0800	BOI reconvenes
	1700	BOI adjourns
Fri 23 Mar 07	0800	BOI reconvenes
	1700	BOI adjourns
Mon 26 Mar 07	0800	BOI reconvenes
	1700	BOI adjourns
Tue 27 Mar 07	0800	BOI reconvenes
	1500	BOI departs for Farnborough
Wed 28 Mar 07	1000	BOI holds meeting with AAIB and QinetiQ Combustion Team
	1300	BOI departs AAIB
	1630	BOI adjourns
Thr 29 Mar 07	0900	BOI meets with QinetiQ Audio Analyst at AAIB
	1000	BOI attends meeting with DLO, Eaton Aerospace and BAE Systems
	1400	BOI departs for Gatwick
	2230	BOI arrives RAF Kinloss
Fri 30 Mar 07	0800	BOI reconvenes
	1700	BOI adjourns
Sat 31 Mar 07	0800	BOI reconvenes
	1700	BOI adjourns
Sun 1 Apr 07	0800	BOI reconvenes
	1700	BOI adjourns
Mon 2 Apr 07	0800	BOI reconvenes
	1700	BOI adjourns
Tue 3 Apr 07	0800	BOI reconvenes
	1700	BOI adjourns
Wed 4 Apr 07	0800	BOI reconvenes

Day/Date	Time	Occurrence
	1700	BOI adjourns
Wed 11 Apr 07	0800	BOI reconvenes
	1700	BOI adjourns
Thr 12 Apr 07	0800	BOI reconvenes
	1700	BOI adjourns
Fri 13 Apr 07	0800	BOI reconvenes
	1230	BOI adjourns
Tue 17 Apr 07	0800	BOI reconvenes
	1700	BOI adjourns
Wed 18 Apr 07	0800	BOI reconvenes
	1700	BOI adjourns
Thr 19 Apr 07	0800	BOI reconvenes
	1700	BOI travels to High Wycombe
Fri 20 Apr 07	1500	BOI presents final report to AOC

ANNEX B TO
BOARD OF INQUIRY
NIMROD XV230
DATED APR 07

DETAILS OF AIRCREW OCCUPANTS

Section 1:

Flying Experience of Captain/1st Pilot prior to this flight:

Rank, Initials and Surname	Number	Branch
Flt Lt A J Squires	2629600G	Fg(P)

Med Category	Age	Instrument Rating	Flying Category
A 2 G 1 Z 1	39	MG/IRE	CR(A)

Last F5250 Assessment	Squadron/Unit	Date
CR (A) (by 42(R) Sqn on posting)	120 Sqn	31 May 06

Accident Aircraft Type (1)		Capt (2)	1st Pilot (3)	2nd Pilot (4)	Aircrew/ Dual (5)	Total (3-5) (6)	By Instr	
							Act	Sim
* See	A	30	40	-	-	40	1	1
NOTES	B	84	132	-	-	132	2	6
	C	1085	3218	593	21	3832	36	330

Total Flying Hours (7)	1st Pilot (8)	All Duties (9)
Jet	2620	4124
Turbo Prop	801	945
Piston Eng	44	169
Helicopter	-	-
Grand Totals	3465	5238

* NOTES
Flying hours are rounded to the nearest hour.

A = Prev 30 days

B = Prev 6 months

C = Total to date

Section 2:

Flying Experience of Person Flying Aircraft if not Captain/1st Pilot: N/A

Section 3:

Flying Experience of Other Crew Members:

	Crew		Hrs on Type		Hrs all Types	
Rank, Initials, Surname & Number	Duty	Cat	Last 6 months	Total	Last 6 months	Total
Flt Lt S Johnson 8029440A	1st Nav	CR	106	2882	106	4645
Flt Lt L A Mitchelmore 5209063A	2nd Nav	CR	111	998	111	1048
Flt Lt G R Nicholas 8028626Q	AEO	CR	111	4008	111	4008
Flt Lt S Swarbrick 5209046A	Co-pilot	CR	122	363	122	559
FS G W Andrews C8141102	S1	CR	147	8358	147	8358
FS S Beattie H8141472	R1	CR	97	5592	97	5592
FS G Bell A8137073	S2	CR	132	4807	132	4807
FS A Davies R8124709	Air Engineer	CR (A)	213	7817	213	7817
Sgt B J Knight L8261240	R3	CR	111	1151	111	1151
Sgt J J Langton J8427259	R4	CR	93	564	93	564
Sgt G P Quilliam G8260151	R2	CR	119	4976	119	4976

Section 4:

Other Occupants

Rank, Initials, Surname & Number	Unit	Duty	Position
L Cpl O S Dicketts	1st Battalion The Parachute Regiment		N/A
Marine J D Windall	Royal Marines		N/A

ANNEX C TO
BOARD OF INQUIRY
NIMROD XV230
DATED APR 07

DETAILS OF AIRCRAFT

1. **Aircraft**.

Category of Damage	Cat 5	Grades of Fuel	AVTUR

	Permissible Limits		Estimated Values	
All Up Weight	Max Take-off	Max Landing	On Take-off	At Impact
	184,000 lbs	120,000 lbs	180,000 lbs	178,000 lbs
*Centre of Gravity	Forward	Aft	On Take-off	At Impact
	N/A	N/A	N/A	N/A

* Complete only if **relevant** to the accident.

2. **Airframe**.

Type	Nimrod	Mark	MR2	Service Number	XV230

Manufacturer	BAE SYSTEMS	Category of Damage	Cat 5

Total Hours Flown	18691:20	Hours Since Last Maintenance	123:30

3. Serial Nos and classes of relevant modifications embodied and of UTIs and RTIs complied with:

Mod 700 – AAR (UOR modification) – Embodied 5 May 82 - UOR
Mod 715 – AAR (production modification) – Embodied 26 Mar 90 – Class B/2
Mod 957 – Introduction of Flight Refuelling Non-Return Valve – Class C/3
Mod 1026 – Introduction of AAR Probe Cradle Assembly – Class B/2

4. Reason for non-embodiment of relevant modifications or non-compliance with UTIs and RTIs:

Not applicable

5. **Engines**.

Manufacturer, Type and Mark	Rolls-Royce Spey Mk 250

Engine Position	1	Category of Damage	Cat 5
RAF Number	662	Maker's Number	A670659
Date Last Installed	28 Nov 05	Date ~~New~~/Recon	4 Feb 04
Hrs Since ~~New~~/Recon	600:10 T[1] 497:00 P	Hrs Since Last Maint	600

Engine Position	2	Category of Damage	Cat 5
RAF Number	733	Maker's Number	A670683
Date Last Installed	16 Mar 05	Date ~~New~~/Recon	8 Nov 04
Hrs Since ~~New~~/Recon	738:05 T 736:50 P	Hrs Since Last Maint	738

Engine Position	3	Category of Damage	Cat 5
RAF Number	624	Maker's Number	A670635
Date Last Installed	29 Apr 05	Date ~~New~~/Recon	22 Dec 98
Hrs Since ~~New~~/Recon	3433:05 T 2512:35 P	Hrs Since Last Maint	738

Engine Position	4	Category of Damage	Cat 5
RAF Number	735	Maker's Number	A670690
Date Last Installed	7 Nov 01	Date ~~New~~/Recon	30 Apr 00
Hrs Since ~~New~~/Recon	2261:00 T 1736:40 P	Hrs Since Last Maint	2261

6. Serial Numbers and classes of relevant engine modifications embodied and of UTIs and RTIs complied with:

Not applicable

7. Reasons for non-embodiment of relevant modifications or non-compliance with UTIs and RTIs:

Not applicable

[1] T = Total operating hours, P = Powered operating hours.

ANNEX D TO
BOARD OF INQUIRY
NIMROD XV230
DATED APR 07

COCKPIT WARNINGS

1. **Bomb Bay.** Fire in the bomb bay is detected by a continuous loop firewire, which runs along the length of the bomb bay skirt on both sides of the bay (as shown in Figure 1). The firewire operates a warning light on the co-pilot's fire-warning panel and associated audio warnings. The warning light filament and the detector circuit integrity are checked by selecting the Test switch located below the fire-warning lamp. The bomb bay is not fitted with fire extinguishers and is therefore unprotected; in the event of a fire the navigator would jettison the stores overboard.

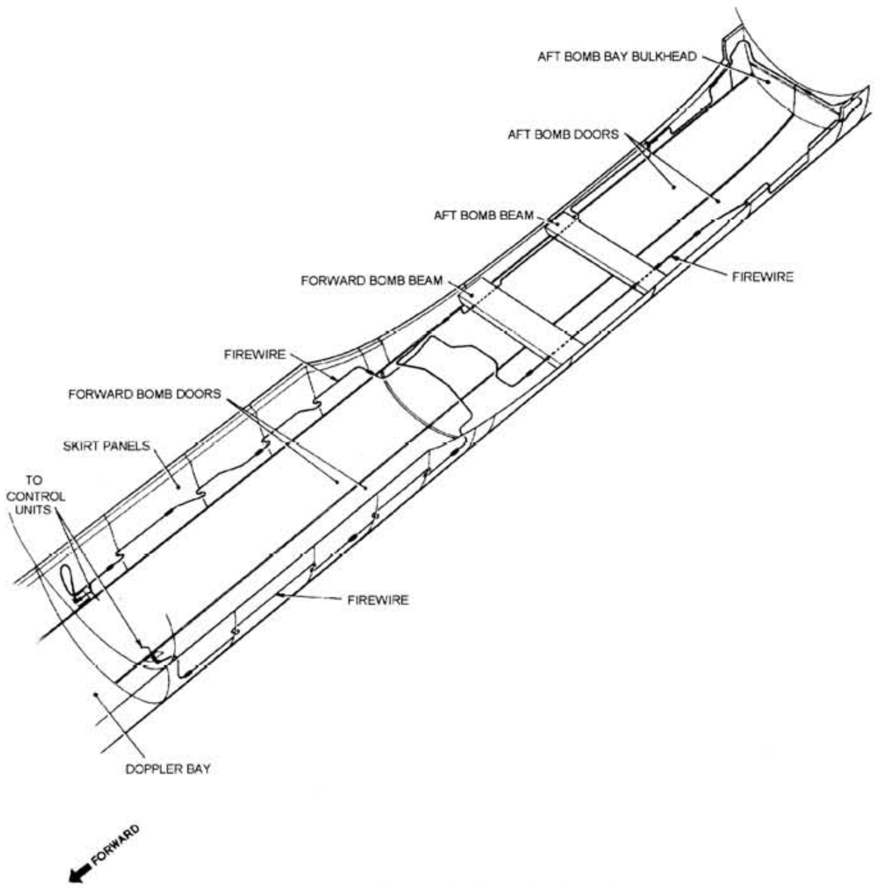

Figure 1 – Bomb Bay Firewire

2. **Underfloor Compartment Detection.** Fire detection in the fuselage is provided by three photoelectric cell smoke detectors (as shown in Figure 2), one fitted in the hydraulic equipment bay, and one in each of the aileron and elevator servodyne bays. These automatically give a warning, when smoke or hydraulic mist disturb the photoelectric cell, by activating the fire warning bell and horn. A warning light on the co-pilot's fire warning test panel is illuminated, identifying the affected bay. The 3 TEST/RESET switches at the engineer's panel allow each detector to be tested. Each bay has independent compartment lighting and an inspection panel, which incorporates a port for the underfloor viewing

periscope. This allows a visual inspection to determine the cause of the warning and thus allow the appropriate action to be taken.

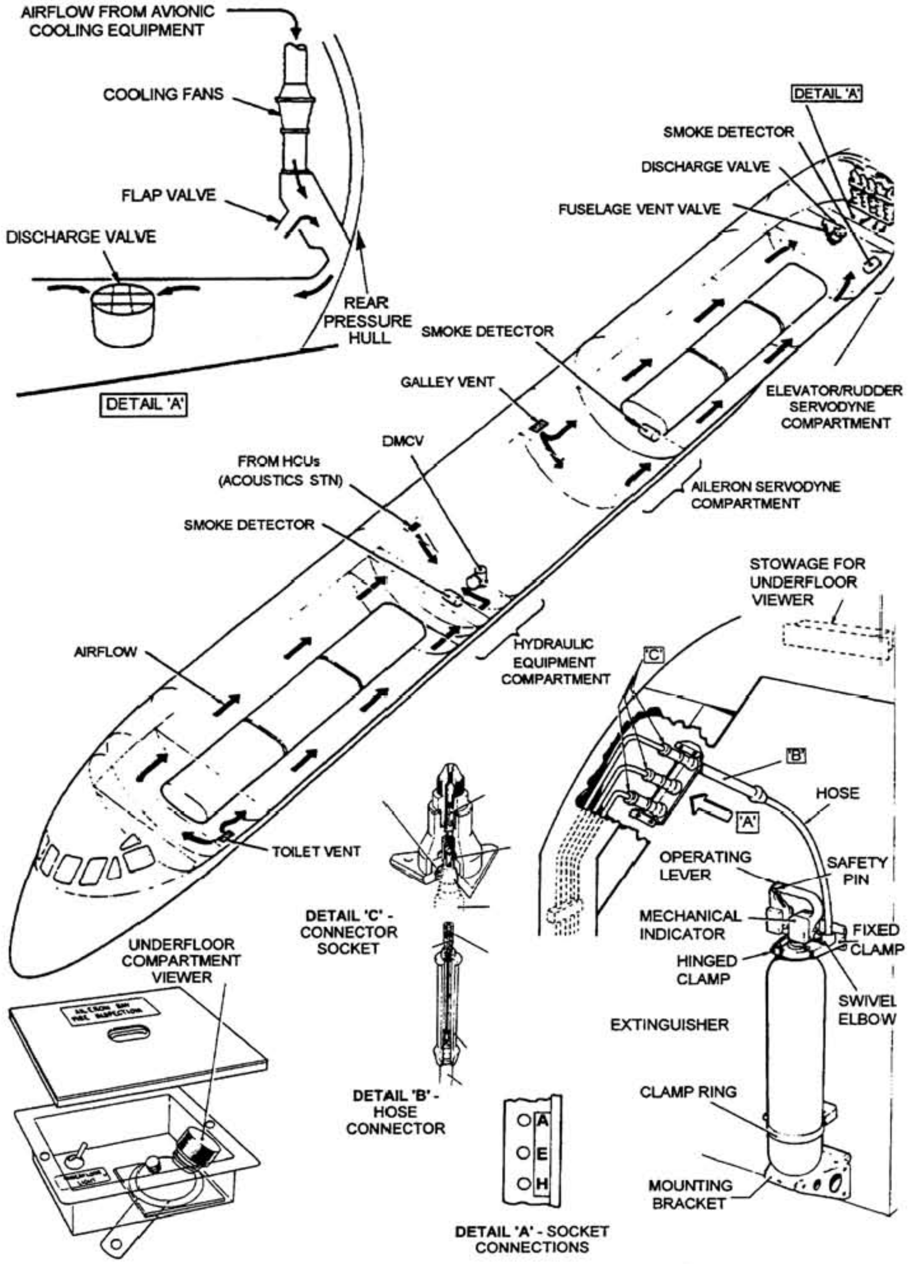

Figure 2 – Underfloor Fire Detection

3. **Underfloor Compartment Fire Extinguisher.** A single Bromotrifluoromethane (BTM) extinguisher of 12 lb charge weight, located at the dinette, discharges through a hose into one of 3 bayonet sockets marked H, A and E. Pipes connect these sockets respectively to the Hydraulic, Aileron and the Elevator underfloor compartments where extinguishant is then discharged through a spray nozzle. Continuous operation will discharge the extinguisher in 20 to 40 seconds; bursts of 10 seconds duration are recommended.

ANNEX E TO
BOARD OF INQUIRY
NIMROD XV230
DATED APR 07

PREVIOUS NIMROD ACCIDENTS AND INCIDENTS

1. The Board reviewed previous Nimrod accidents and incidents to determine whether they contained data of relevance to the loss of XV230. The emergency landing of XV257 at RAF St Mawgan, following an intense bomb bay fire, and the loss of XW666 (a Nimrod R1) following a fire in No 4 engine were considered to contain pertinent information. In addition, the report of a Unit Inquiry into the damage incurred by a Nimrod MR2 XV227 following a hot air leak was considered. The Board also examined the documentation raised following investigations into a series of fuel leaks on Nimrod R1 XV249, which eventually resulted in the replacement of a significant portion of that aircraft's fuselage fuel system.

2. **Nimrod MR2 XV257.** Nimrod MR2 XV257 made an emergency landing at RAF St Mawgan on 3 Jun 84, following an uncontained fire, caused by the ignition of its bomb bay load of flares. The flares, at the rear of the bomb bay, ignited shortly after take-off, initiating the bomb bay fire warning, followed one minute later by the centre section overheat warning and an underfloor alarm in the aileron bay; as the underfloor alarm sounded, smoke began to enter the cabin. The captain completed a dumb-bell turn to return to St Mawgan as quickly as possible. Despite the fact that the aircraft was landed within 4 minutes of the bomb bay fire warning's initiation the aircraft suffered extensive (Cat 5) damage, including a breached pressure hull and the loss of the Green hydraulic system following the melting of alloy pipe unions.

Proceedings of Board of Inquiry

3. **Nimrod R1 XW666.** On 16 May 95, Nimrod R1 XW666 suffered an uncontained fire in the No 4 engine following a mechanical failure. Although the aircraft initially diverted towards RAF Lossiemouth, the captain decided to ditch in the Moray Firth, following reports from a crewman at the starboard escape hatch, that the starboard wing was rapidly disintegrating. XW666 also lost its Green hydraulic system, following the melting of the system's aluminium alloy pipe unions; although not specifically tested, it was assessed that the Red hydraulic system, which follows a similar route, would probably have failed also if used. It was also determined that during the 4 minutes of fire the rear spar's strength had deteriorated by 25%. The Board's recommendation that the aluminium alloy hydraulic pipe unions in the engine bays should be replaced with steel unions was not enacted as it was considered that, in the event of fire, other parts of the hydraulic system would fail first. A further recommendation, that the Nimrod's Data Acquisition and Recording Unit (DARU) should incorporate recording of cockpit voice, GPS position and time code was also not enacted. It is believed that plans to incorporate the changes were halted following a Long Term Costings 99 spending review, although the

Proceedings of Board of Inquiry

Exhibit 23

Nimrod IPT has been unable to provide an audit trail for this decision.

4. **Nimrod MR2 XV227.** Nimrod MR2 XV227 suffered a hot air duct failure on 22 Nov 04, in a section of pipe between the Pressure Regulating and Shut off Valve (PRSOV) and the Flow Limiting Venturi, due to corrosion. The Unit Inquiry determined that the failure had probably occurred some 20 to 40 minutes before the Supplementary Cooling Pack (SCP) was closed down. This leak of air at up to 420 ºC caused, inter alia, damage to aileron and flap control cables and pulleys, the melting or destruction of a multitude of hydraulic pipeline fairleads, damage to the front face of No 7 fuel tank, extensive damage and melting to numerous fuel seals, damage inside the bomb bay and damage to the Rib 1 and rear spar temperature indicator looms. Although this particular pipe was replaced throughout the Nimrod fleet, and is thus unlikely to have contributed to XV230's loss, the incident illustrates the extensive effects of heat damage concomitant on the spread of hot gases within this area. A recommendation was made to incorporate a hot air leak detection system, to ensure that all possible duct failures were covered. The recommendation was not enacted because the IPT believed that such a modification was not practicable in view of the Nimrod's OSD of 2012. Nonetheless, the decision will be reconsidered by the IPT, following publication of this Board's report. The Nimrod IPT also tasked BAE Systems with the survey and testing of a selection of ducts within the hot air system; when the BAE Systems report is complete it will be used to derive a lifing policy for the ducts.

Report of Unit Inquiry

Exhibit 24

Exhibit 25

5. **Nimrod XV249.** Nimrod XV249 was converted from a Nimrod MR2 to a Nimrod R1 to replace XW666 (see para 3). The aircraft subsequently suffered from a continuous series of fuselage fuel leaks, which eventually led to an extensive investigation and rebuild of the fuselage fuel system. Nonetheless, while eventually the aircraft's leaks were cured, it was impossible to isolate a single system as the point of failure. Analysis of the faults highlighted, inter alia: fuel couplings that leaked in flight, but not on the ground; fuel pipes that moved in flight, provoking leaks; and fuel pipes of the same part number, but different construction and lengths. Of note, fuel from leaks originating to the rear of the Rib 1 area was observed to track to the rear of the wing root, the pannier bay (equivalent to the MR2's bomb bay) and the tail cone. Fuel leaks were also noted to be associated with AAR sorties, but not exclusively so. Although XV249's problems were attributed principally to its conversion from an MR2 to an R1, coupled with the fact that it had been stored outside for some time prior to conversion, it does illustrate the potential for complex fault scenarios within the Nimrod's fuel system and the fact that the leaking fuel can potentially find its way to many areas of the airframe.

Exhibit 26

ANNEX F TO
BOARD OF INQUIRY
NIMROD XV230
DATED APR 07

ANALYSIS OF CANADIAN SIGHTING OF NIMROD XV230

1. **Introduction.** Members of a A Sqn, The Royal Canadian Dragoons (RCD) witnessed the final moments of XV230's flight. Their testimony (which only became available some 5 months into the inquiry) indicated that the aircraft was on fire from the port wing; this contradicted previous witness testimony and evidence that the fire was only on the aircraft's starboard side. Nonetheless, the Canadian witnesses provided clear and detailed accounts of what they had seen and the Board determined to conduct an analysis of XV230's final flight path, to ascertain what view of the aircraft was available to the Canadian witnesses.

Witnesses 37-38
Exhibits 9&73

2. **Canadian Position**. A Sqn RCD was in a position at at an elevation of 960 m. The witnesses were looking south and they reported that the aircraft passed from their 2 o'clock to 10 o'clock positions. The aircraft is likely to have become visible as it passed to the south of Mar Ghar mountain (1259m).

Witnesses 37-38/
Exhibits 9&73

3. **Aircraft Track.** The last known CTS position of XV230 is 41RQQ1824993362 (718249E 3493362N) at an altitude of 17 369 ft (5294 m) amsl[1] on a heading of 98° True. The crash site is at 41RQQ4400091500 (744000E 3491500N) at an elevation of 960 m. The direct track between these 2 points is 094°. It is known from the last DARU recording that the aircraft was at approximately 13 000 ft (4000 m) amsl at a point, calculated by the Board, approximately 7.1NM (13 km) from the crash site. Taking a direct line from this position to the crash site gives a descent angle of 13°. Calculating back along the flight path at this descent angle gives a height of 7500 ft (2286 m) agl[2] at a position 10 km from impact. Reports from both the Harrier GR7 pilot and the Canadians suggest that XV230's port wing was slightly below the horizontal. It is likely that this is the cause of the difference of 4° between last known heading and actual track (the left bank causing the aircraft to turn slightly to port); the reported wind was only 256° at 10 knots and would have produced a minimal amount of port drift. The slight turn would have caused the actual track to have been to the south of the direct track and, thus, further away from the Canadian observers. Anything more than a 5-10° left bank would have caused a much smaller radius turn.

Exhibit 1
Exhibit 7
Exhibit 65
Witness 27/
Exhibit 82a-c
Witnesses 37-38
Exhibits 9&73

[1] Height above mean sea level.
[2] Height above ground level.

4. **Method.** The Canadian position and aircraft track for the final 10 km, assuming a direct (nearest) track, were used to calculate (using an Excel spreadsheet) the range, elevation, azimuth angle and slant range to the aircraft. From this information, the aspect angle of the aircraft and the angles subtended by the fuselage and wings were calculated. Finally, the apparent sizes of fuselage and wingspan at arms length (1m) were determined. The results of the calculations are shown at Appendix 1.

5. **Analysis of Results.** The aircraft at 10 km from the crash site would have had a slant range of 5416 m and elevation of 25° on a bearing of 252°. Its apparent size (at arms length) would have been 6 mm (wing tip to wing tip). At its closest approach at 5500 m from impact and due south of the witnesses' position, the slant range and elevation would have been 2211 m and 35 respectively. The apparent size of the fuselage would have been 17 mm, about the width of a man's thumbnail at arms length. Unless XV230 had a greater than 35° left bank, the upper side of the port mainplane would not have been visible. However, the rear underside of the starboard jet pipes would have been visible at this point. The Canadians' view of the aircraft, perpendicular to its flight path with the tailplane and fin merged, would have made it easy for even the most experienced aircraft observer to swap left for right and see the starboard wing as the port. As a result of this optical illusion, the fire under the starboard engine nacelles would appear to be originating from the port upper wing root. It was not until XV230 reached a point 4500 m from the crash site that the rear of the port wing and jet pipes would become visible as the aircraft receded from the Canadians. It would have been 27°above the horizon and 2291 distance on a bearing of 157°, with an apparent size of 14 mm. By the time, the aircraft had reached 1 km from the crash site at a height of 230 m (755 ft), the aircraft would be 2.7° above the horizon at a range of 4806 m on a bearing of 116°. The apparent size would only be about 7 mm. The aircraft was lost from view behind trees immediately prior to impact. The crash site was 5738 m from the Canadians on a bearing of 113°.

6. **Expert Advice.** The Board sought further advice from QinetiQ and AAIB in the light of the Canadian eyewitness statements. Advice from QinetiQ concluded that it would be difficult, based on other available evidence, to place the fire on the port side, although this could not be ruled out at this late stage in XV230's final flight (see main report). Furthermore, AAIB concurred that the Canadian witnesses may have misinterpreted the position of the fire due to relative aircraft size and angle of viewing. Exhibits 12b&30

7. **Conclusions.** From this analysis the Board concluded that:

a. The Canadian witnesses would have seen the aircraft for approximately the final 40 seconds of flight (assuming an aircraft groundspeed of 360kts and using their description of the initial sighting, which suggested an aircraft in side elevation).

b. For at least half of the 40 seconds available viewing time the aircraft would have presented only its port side to the witnesses. During this period the size and aspect could have allowed an observer to misinterpret a fire on the starboard wing as coming from the port wing. Down wash at the rear of the wing would also have caused the flames to be directed underneath the fuselage, reinforcing the impression of a fire on the side nearest to the observer.

c. The aircraft would have to have been at 35° of bank for the witnesses to observe the top of the port wing when the aircraft was initially seen; evidence of the aircraft's track confirms that it was not at 35° of bank.

d. As the rear of the port wing and jet pipes became evident (with 4500m to the crash site) the fire has begun (or was amount to begin) the massive increase in intensity noted by . As the fire expanded into the fireball recorded by both the GR7 pilot and Canadian witnesses its sheer size would have perpetuated the image of a conflagration on the aircraft's port side. Exhibit 10

e. The Canadians' location placed them in a much better position than the GR7 pilot to estimate the aircraft's height when the final explosion occurred. Although they do not volunteer an estimate of that height the descriptions used indicate that it occurred at a much lower altitude than suggested by the GR7 pilot; one which correlated better with the figures suggested by the AAIB .

Appendices:

1. Calculations of Nimrod XV230 flight path.
2. Graphical representation of apparent size and shape Nimrod.

APPENDIX 1 TO
ANNEX F TO
BOARD OF INQUIRY
NIMORD XV230
DATED APR 07

CALCULATIONS OF NIMROD XV230 FLIGHT PATH

Table 1 – Initial position of aircraft and Canadian observers.

	E	N	Grd Ht m	Ac Ht m	Ac Ht ft	Spd m/s	Spd kts	Time
Intial Position[1]	718249	3493362	943	5294	17369	193	376	11:15:29
Last ADR	730000	3492500		3810	12500	181	353	11:16:34
Crash Site	744000	3491500	960	960	3150	182	355	11:17:51
Canadians position			960					

	dE	dN	Track
Track	25751	1862	**94.1**

Table 2 – Calculated position of aircraft in relation to crash site.

Descent angle = **13.3** degrees

Aircraft	Trk[2] DTG	dW[3]	dN[4]	E	N	Ht m[5]	Ht ft[6]
Position	0	0	0	744000	3491500	0	0
and Height	1000	997	72	743003	3491572	230	755
Along Track	2000	1995	144	742005	3491644	460	1510
	3000	2992	216	741008	3491716	690	2264
	4000	3990	288	740010	3491788	920	3019
	4500	4488	325	739512	3491825	1035	3396
	5000	4987	361	739013	3491861	1150	3774
	5500	5486	397	738514	3491897	1265	4151
	6000	5984	433	738016	3491933	1380	4529
	7000	6982	505	737018	3492005	1610	5283
	8000	7979	577	736021	3492077	1840	6038
	9000	8977	649	735023	3492149	2070	6793
	10000	9974	721	734026	3492221	2300	7548

[1] Northings and Eastings are the number of metres (m) from the grid origin.
[2] Track Distance to Go from crash site (m).
[3] Distance west from crash site (m).
[4] Distance north from crash site (m).
[5] Height above the crash site (m).
[6] Height above the crash site (ft).

Table 3 – Calculated range, elevation, azimuth angle and slant range from Canadian Position.

From	Trk DTG	dE[7]	dN[8]	Rng	Elev	Az	Slant
Canadian Position	0	5300	-2200	5738	0.0	113	5738
	1000	4303	-2128	4800	2.7	116	4806
	2000	3305	-2056	3892	6.7	122	3919
	3000	2308	-1984	3043	12.8	131	3120
	4000	1310	-1912	2318	21.7	146	2494
	4500	812	-1875	2044	26.9	157	2291
	5000	313	-1839	1866	31.7	170	2192
	5500	-186	-1803	1813	34.9	186	2211
	6000	-684	-1767	1895	36.1	201	2345
	7000	-1682	-1695	2388	34.0	225	2880
	8000	-2679	-1623	3132	30.4	239	3633
	9000	-3677	-1551	3990	27.4	247	4495
	10000	-4674	-1479	4902	25.1	252	5415

Table 4 – Calculated apparent size of Nimrod to Canadian observers.

Ac Length m	38	Wg Span m	35

					Angle subtended		Size (mm) at arms length	
	Trk DTG	Z[9]	W	V	Ac[10] Size	Wg[11] Size	Ac[12] mm	Wg[13] mm
Calculation of apparent aircraft size	0	18.4	12.0	33.2	0.12	0.33	2.1	5.8
	1000	22.2	14.3	32.4	0.17	0.39	3.0	6.7
	2000	27.7	17.7	31.0	0.26	0.45	4.5	7.9
	3000	36.5	22.6	28.1	0.42	0.52	7.3	9.0
	4000	51.4	29.7	21.8	0.68	0.50	11.9	8.8
	4500	62.5	33.7	16.2	0.84	0.40	14.7	7.1
	5000	76.2	36.9	8.3	0.96	0.22	16.8	3.8
	5500	88.3	38.0	1.1	0.98	0.03	17.2	0.5
	6000	73.0	36.3	10.3	0.89	0.25	15.5	4.4
	7000	49.4	28.8	22.8	0.57	0.45	10.0	7.9
	8000	35.3	22.0	28.5	0.35	0.45	6.1	7.9
	9000	27.0	17.3	31.2	0.22	0.40	3.8	6.9
	10000	21.7	14.0	32.5	0.15	0.34	2.6	6.0

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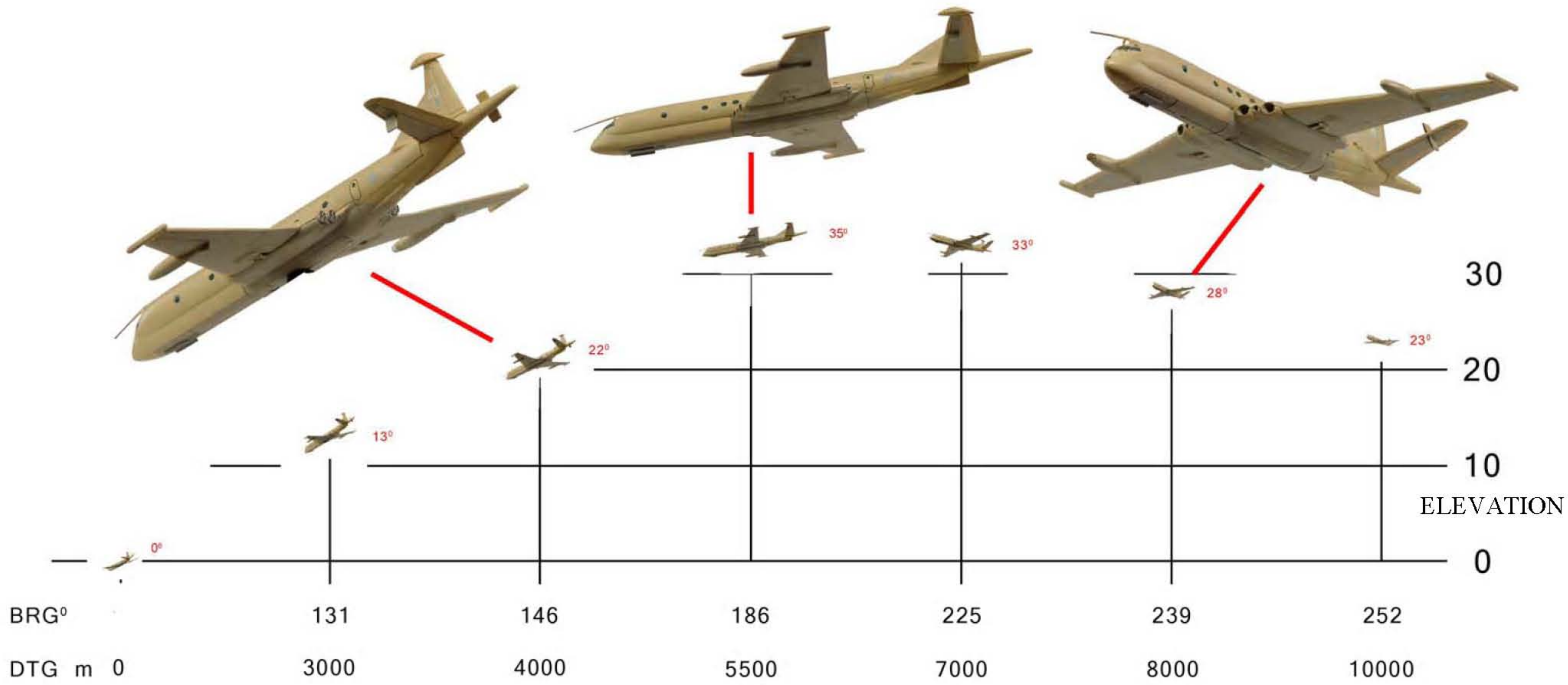
7 Distance east from observers' position to aircraft.
8 Distance north from observers' position to aircraft.
9 Z = aspect angle of aircraft to observer, W = fuselage aspect size (m), V = wing aspect size (m).
10 Angle subtended by the aircraft fuselage.
11 Angle subtended by the aircraft wingspan.
12 Apparent size at arms length of aircraft fuselage in mm.
13 Apparent size at arms length of aircraft wing span in mm.

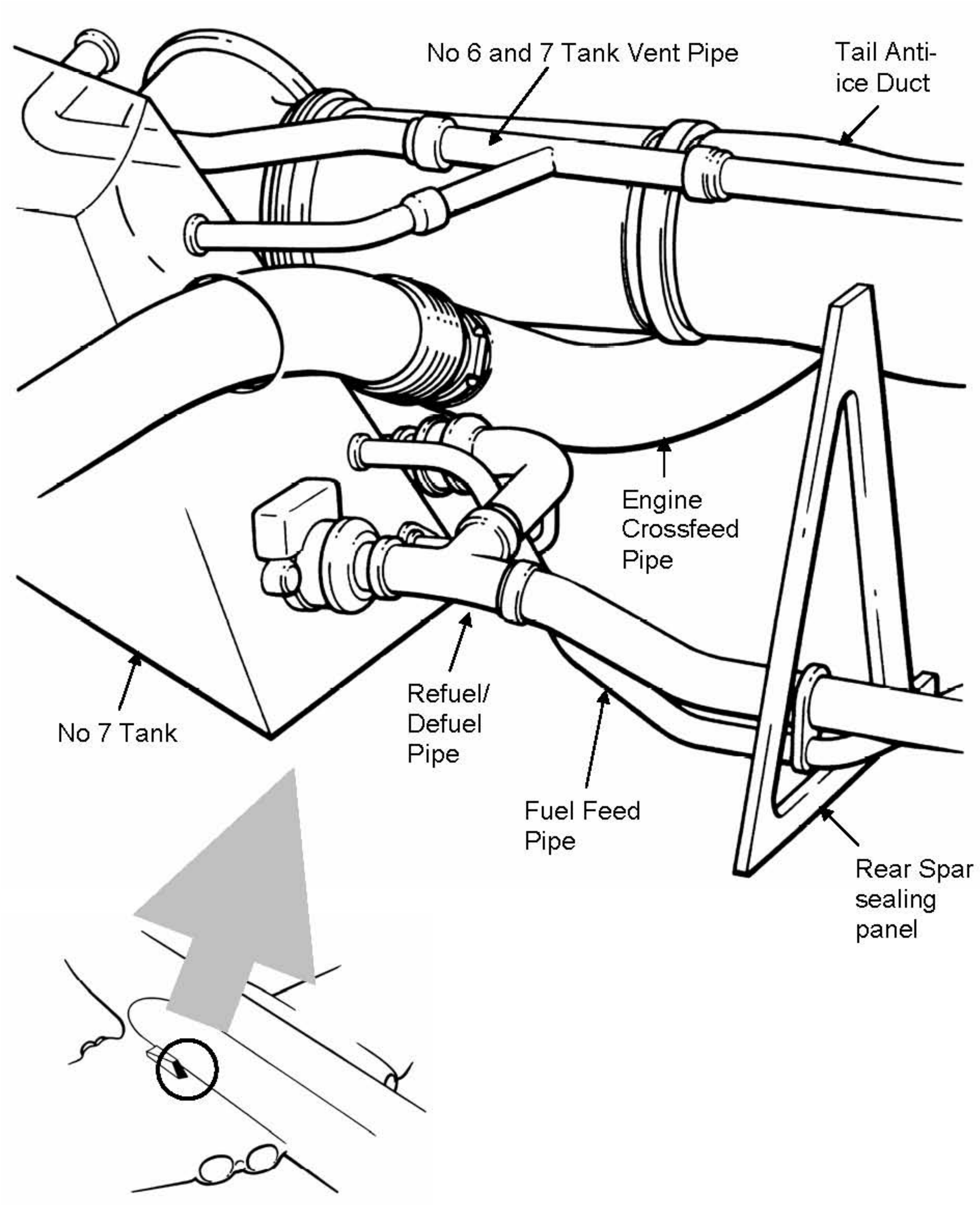
APPENDIX 2 TO
ANNEX F TO
BOARD OF INQUIRY
NIMORD XV230
DATED APR 07

GRAPHICAL REPRESENTATION OF APPARENT SIZE AND SHAPE OF NIMROD



ANNEX G TO
BOARD OF INQUIRY
NIMROD XV230
DATED APR 07

NO 7 TANK DRY BAY



ANNEX H TO
BOARD OF INQUIRY
NIMROD XV230
DATED APR 07

FUEL SYSTEM – TECHNICAL DESCRIPTION

1. **Fuel Tanks.**

a. **Location.** Fuel is stored in 13 tanks. Each wing contains 3 tanks, numbered 2, 3 and 4, and each also houses a pod tank known as 4a. There are 2 tanks (7 tank port and starboard) located in the each trailing edge fillet adjacent to the fuselage. Three tanks are located in the fuselage: 1 tank is positioned centrally between the front and rear wing spars, with 5 tank forward and 6 tank aft, but within the cabin pressure shell.

b. **Structure.** No 2, 3, 4 and 4a tanks are integral with the wing structure. No 1, 5 and 6 tanks consist of interconnected cells each containing a flexible bag. No 1 tank has 4 cells while No 5 and 6 tanks each have 3. Nos 5 and 6 tanks are provided with double skins to obviate the risk of structural collapse caused by the effects of cabin pressure.

c. **Capacity.** The tanks can hold a maximum of 85 840 lbs of fuel. No 1 tank holds 16 048lbs, 5 and 6 tanks 5640 lbs each and 2056 lbs in each 7 tank. Each wing holds 27 116 lbs in its tanks.

2. **Fuel Feed.** Fuel is pressure fed by immersed booster pumps in each tank. Suction feed is available for engine starting, or for emergency use, from 1, 2, 3 and 4 tanks. Fuel from the port or starboard tanks is normally fed to the engines corresponding to that side. However, there is a cross feed system to allow fuel feed to all engines from either side. All engines can be fed from any tank except 5, 6 and 7 tanks, which feed via 1 Tank. See Figure 1.

3. **Refuel.** With the exception of the 4 and 4A tanks, each fuel tank is filled in a similar manner. Each tank's refuelling valves are spring loaded to the closed position and biased by the pressure of fuel in the tank. Selection of the valve dissipates the bias pressure and allows application of refuelling pressure to open the valve and to fill the tank; automatic shut-off occurs as the tank approaches full, when the rising fuel operates a high-level float switch. Fuel enters 4 tank via the 4A tank, where its own float valve stops the process. Blow-off valves, to prevent over-pressure, are fitted in each tank except the 4A and 5 tanks. No 5 tank has a restrictor in the refuel line to limit any pressure build-up. See Figure 2.

4. **Venting.** Tanks are pressurized by ram air taken from inlets at the wing leading edge and are vented to atmosphere. The 4 tank valve covers 4A tank. See Figure 3.

5. **Jettison.** Fuel may be jettisoned from all tanks, with the exception of the 4 tanks.

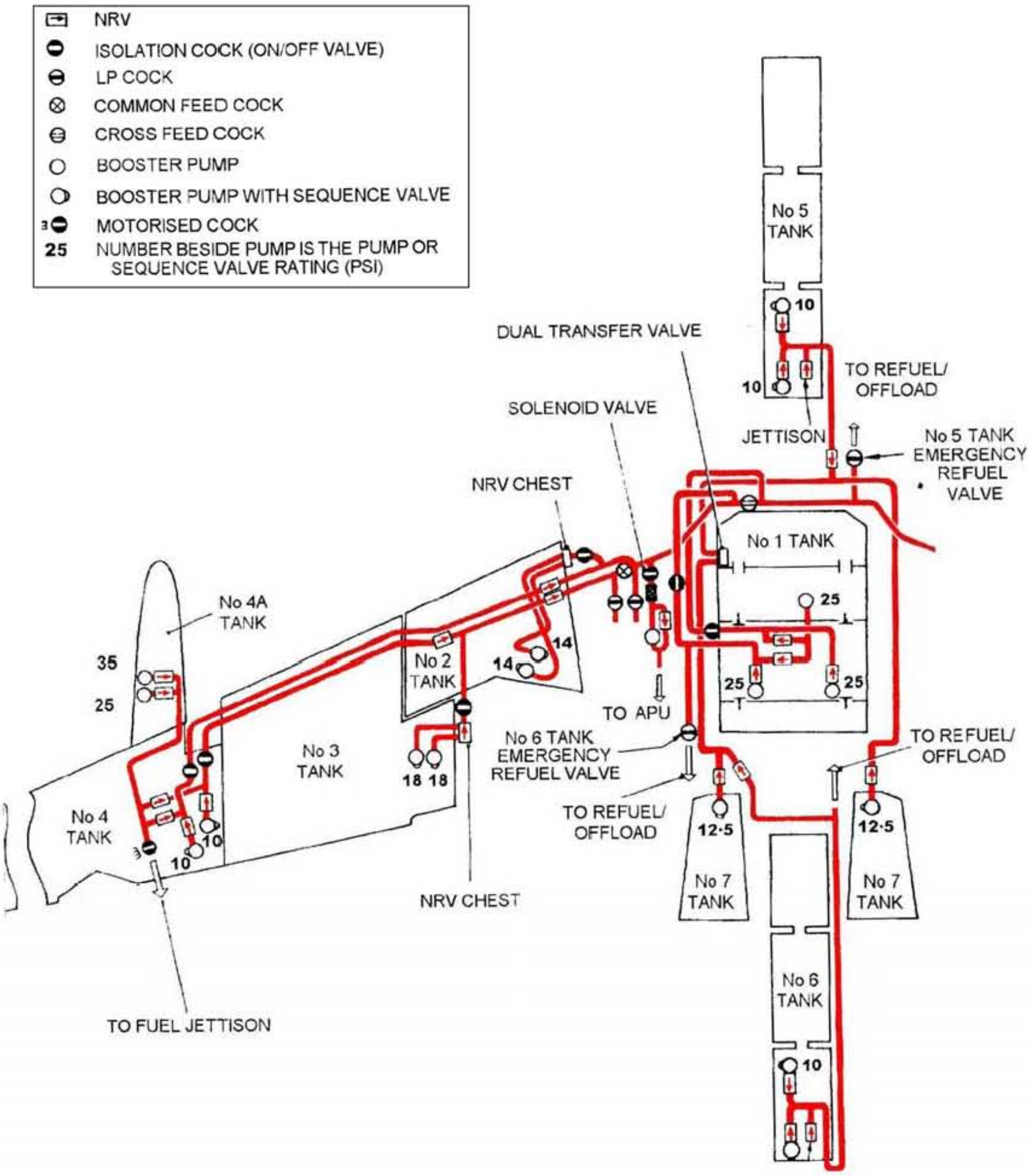


Figure 1 – Fuel Feed

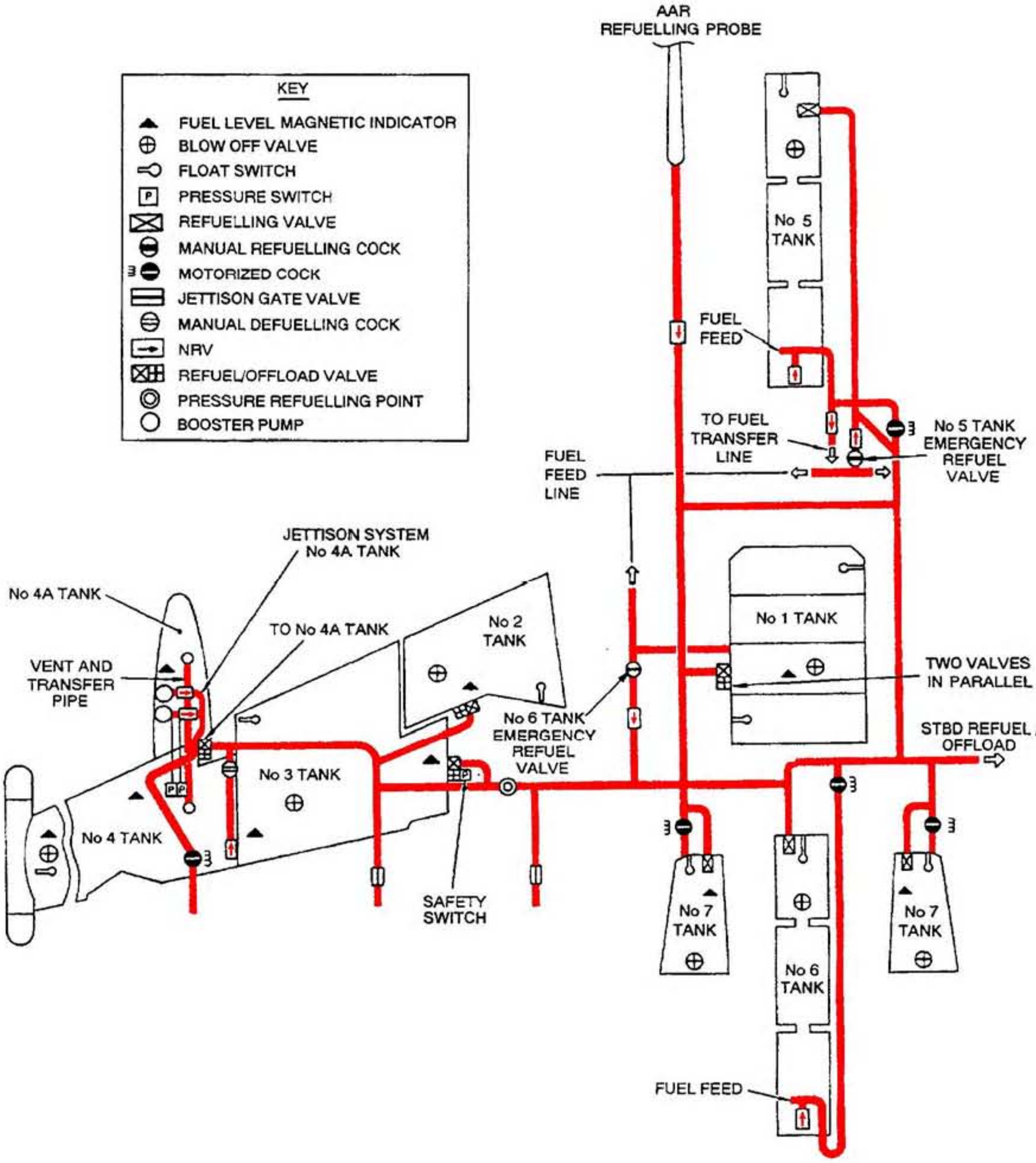


Figure 2 – Refuel System

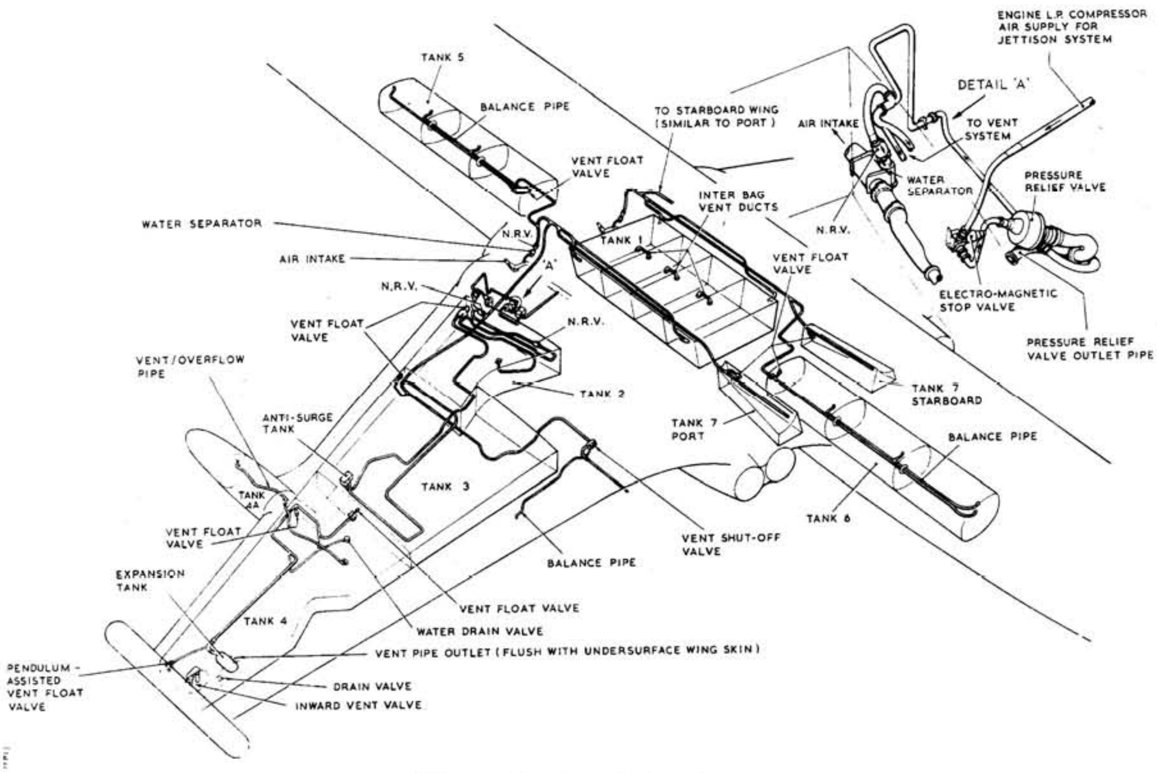


Figure 3 – Fuel Venting

ANNEX I TO
BOARD OF INQUIRY
NIMROD XV230
DATED APR 07

FUEL SYSTEM MAINTENANCE HISTORY ANALYSIS

1. **Introduction.** Data was obtained for the fuel system maintenance history for the Nimrod fleet – all marks (SIN Code 41) for the years 1983 to 2006[1]. The Board analysed this data for trends in faults resulting in fuel leaks.

2. **Method.** The data was provided as an Excel spreadsheet, but imported into an Access database to allow easier analysis. The analysis focused on fuel leaks from pipes, couplings and seals, and from fuselage tanks. The filtering of data was made difficult due to the differing code descriptions applied to particular items (components)[2]. Where possible the data has been filtered to remove reports on wing tanks; however, the encoding of the source data means that it cannot be guaranteed that all such tanks have been excluded from the resultant analysis.

3. **Analysis of Fuel Leak from Pipes, Couplings and Seals.** The data for fuel leaks from pipes, and from couplings and seals, by aircraft tail number and year are given at Appendix 1, Tables 1 and 2 respectively. This shows a low and stable occurrence rate for leaks from fuel pipes, but a distinct increasing trend in leaks from couplings and seals over the same period (see Appendix 1, Figure 1). There is an increase in the average number of connector faults across the fleet for each of the 3 decades covered. There was an average of 10 faults per annum in the 1980s, 26 in the 1990s and 38 per year since 2000. This increase must be seen against a decreasing fleet size. When the fault rate per airframe in the Nimrod fleet is calculated (Appendix 1, Table 3), the increasing trend in fuel leaks from couplings and seals is clearly apparent (Appendix 1, Figure 2). The annual number of leaks per airframe increasing from almost none in 1983 to 1.7 leaks per airframe per annum between 2000 and 2005. The low number of faults recorded in 2006 is attributed to the fact that not all maintenance work orders from that year had been loaded on the maintenance data system at the time of data capture (Oct 06). The high number of faults recorded in 1999 is partly attributed to Nimrod R1 XV249 (36%), which was subject to a major fuel leak investigation in that year. The number of faults recorded for XV230 is below the norm for the fleet.

4. **Analysis of Fuel Leaks from Tanks.** The data for fuel leaks from fuselage[3] tanks are given at Appendix 1, Table 4. The 3-year moving average shows a rising trend in faults over the 3 decades with a significant drop in 2005 (Appendix 1, Figure 3). The low number in 2006 is again as expected. The number of faults recorded for XV230 is low, except for 5 recorded in 2004 prior to its last Major.

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[1] Only data from 1983 to 2006 was supplied from the Maintenance Data System.
[2] From a total of 42 675 Maintenance Work Orders, 4099 (9.6%) had a SYMPTOM or FAULT of 'fuel leak' (filtered using 'fuelleak'). For the pipes, couplings and seals, the ITEM field was filtered to select relevant records (filtered for words containing: 'pipe', 'coupl', 'seal', 'connector', 'ring' and excluding words containing 'compound' or 'compseal' (to remove sealing compound used in tanks)). For tanks, the ITEM field was filtered for words containing 'tank', cell' or 'bag'.
[3] It was not possible to identify positively fuselage tanks; however, by filtering with 'tank', 'cell' or 'bag' most of the integral wing tanks would be excluded.

5. **Conclusion.** The data shows an increasing trend in fuel leaks from couplings and seals and fuselage tanks over the past 2 decades; this increase was paralleled by a continuing reduction in force size. Over the same period, there is only a slight increase in leaks attributed to fuel pipes.

Appendix:

1. Analysis of Fuel System Maintenance Data.

APPENDIX 1 TO
ANNEX I TO
BOARD OF INQUIRY
NIMROD XV230
DATED APR 07

ANALYSIS OF FUEL SYSTEM MAINTENANCE DATA

Table 1 – Fuel Leaks Faults from Pipes by Tail Number and Year

Tail No	Total	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
XV226	3			1									1	1											
XV227	5		1										1			1		1				1			
XV228	4										1			2			1								
XV229	3									1								1						1	
XV230	*4*															*1*	*2*							*1*	
XV231	1									1															
XV232	1						1																		
XV235	2									1		1													
XV236	2											2													
XV237	1						1																		
XV239	2			1					1																
XV240	3								1			1	1												
XV241	3													1	1								1		
XV242	2										1			1											
XV243	1																				1				
XV244	3														1	1							1		
XV245	1											1													
XV246	1									1															
XV248	9			1							1		1			1		2		1				1	1
XV249	5																	5							

Tail No	Total	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
XV252	4			1											1	1	1								
XV254	4				1											1	1			1					
XV255	3															2								1	
XV258	2													1	1										
XV260	3													1				1				1			
XW665	7									2			1			1		1					2		
XW666	1																							1	
XZ284	1														1										
Totals =	81	0	1	4	1	0	2	0	2	6	3	5	5	7	5	9	5	11	0	2	1	2	4	5	1

Table 2 – Fuel Leaks Faults from Couplings and Seals by Tail Number and Year

Tail No	Total	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
XV226	31			1					3			1	1	4		2	2		2	7	2	3	2		1
XV227	20		3		1		1		1	1			1		1			1		1	5	3	1		
XV228	19		2						1	1				2		2	2		1	2	1	4		1	
XV229	17								1	1							1	3	1	5		2		3	
XV230	*12*									*1*	*1*				*1*	*1*	*1*	*2*	*1*	*1*				*2*	*1*
XV231	20								1	1			2	1		2			1	3	2	4	2	1	
XV232	25								1		1						5	4		3	6		4		1
XV233	6		1				1				2	1	1												
XV234	3			3																					
XV235	31							3	1	2		1	1	1			2	1	2	3	7	4	1	2	
XV236	16			1						1	1							1		4	2	1	3	1	1
XV237	8	1	3	4																					
XV238	5		2			1	1			1															
XV239	10				1				1	2		2	3	1											
XV240	20			1	4						4			1	1	1		1			3	3		1	
XV241	14						1			2	1			1		2	1	1				1	3	1	
XV242	1			1																					
XV243	18		1		1					1		1	1	1	1					3	2	4	2		
XV244	29				4	1	1		1	2			1			2		2	1	1	3	3	3	3	1
XV245	23				1	2				1				3	2		1	2	1	2		2	6		
XV246	29				1		1		6	8	1			2	2				1	2		2	2	1	
XV247	1								1																
XV248	23				1	2				1	2	1	5	1	1	3	1			1				4	
XV249	28			1							1					3	4	14	1	1	2	1			
XV250	22					1			1	2							6	2	1		1		3	5	
XV251	5						1			1		2			1										
XV252	15							1			1	1	1		1	2	2			2	1	2	1		
XV253	1				1																				

Tail No	Total	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
XV254	16				1			1		3		4						3	1		1		1	1	
XV255	25									1		1			3	1			1		4	3	2	9	
XV258	5									2	1			1			1								
XV260	7										1							1	1				2	2	
XW664	21			2						1	6	1		2	1	1	1		5					1	
XW665	14			1						2		1				2	1	3		1	2			1	
XW666	6									1	1	2	2												
XZ284	16			1			1	3	3			3		2			2	1							
Totals =	562	1	12	16	16	7	8	8	22	39	24	22	19	23	15	24	33	42	21	42	44	42	38	39	5

Figure 1 – Graph of Fuel Leak Faults from Fuel Pipes and from Couplings and Seals by Year

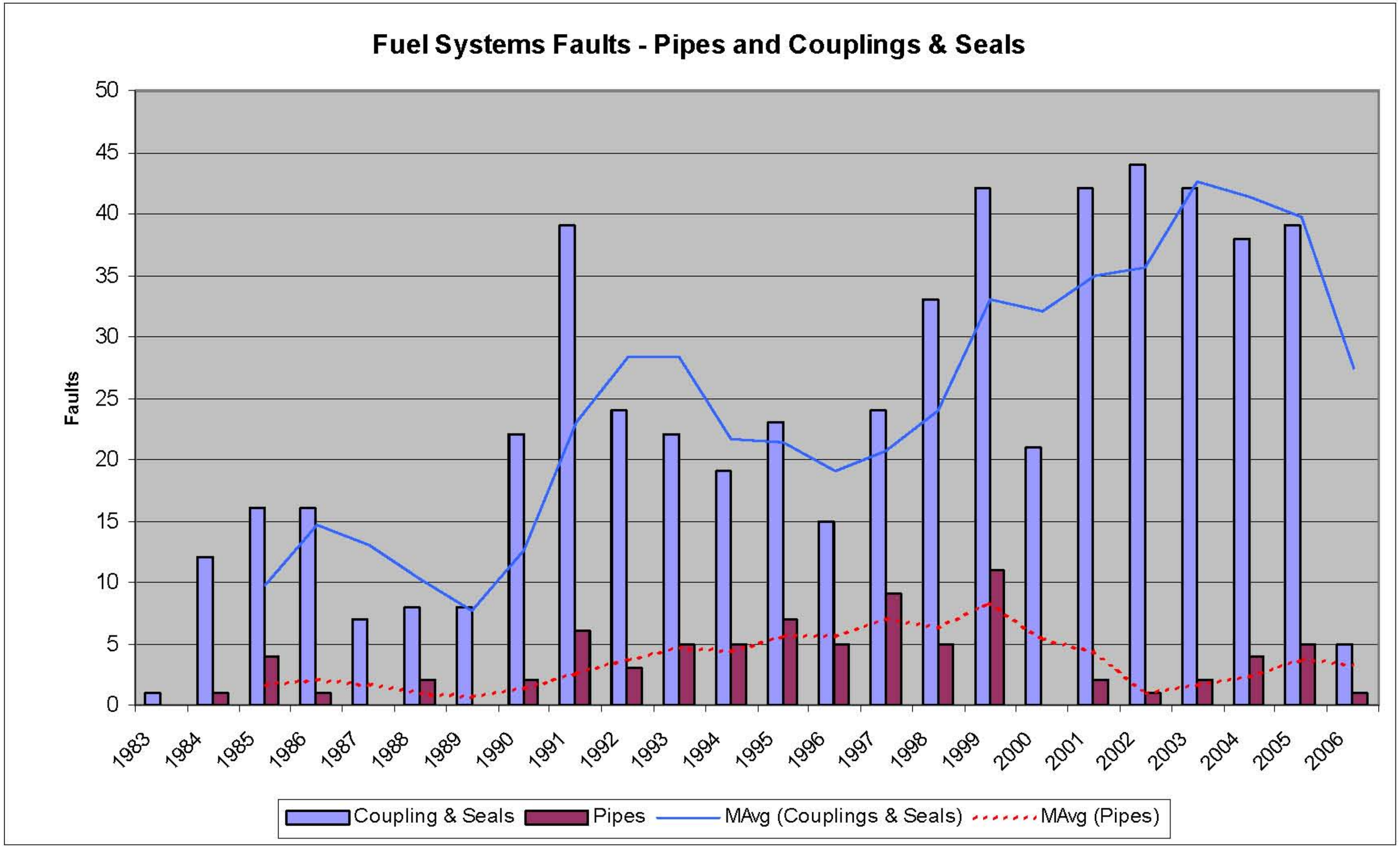


Table 3 – Fuel Leak Faults per Airframe from Pipes and Couplings and Seals

Year	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Nimrod Fleet Size[1]	34	34	34	34	34	34	34	34	34	33	29	29	29	28	28	28	27	26	24	24	24	24	23	21
Coupling & Seal Faults	1	12	16	16	7	8	8	22	39	24	22	19	23	15	24	33	42	21	42	44	42	38	39	5
Pipe Faults	0	1	4	1	0	2	0	2	6	3	5	5	7	5	9	5	11	0	2	1	2	4	5	1
C+S Faults/ac	0.03	0.35	0.47	0.47	0.21	0.24	0.24	0.65	1.15	0.73	0.76	0.66	0.79	0.54	0.86	1.18	1.56	0.81	1.75	1.83	1.75	1.58	1.70	0.24
Pipe Faults/ac	0.00	0.03	0.12	0.03	0.00	0.06	0.00	0.06	0.18	0.09	0.17	0.17	0.24	0.18	0.32	0.18	0.41	0.00	0.08	0.04	0.08	0.17	0.22	0.05

[1] Fleet size includes Nimrod R1 and MR2.

Figure 2 – Graph of Fuel Leak Faults from Pipes and Couplings & Seals per Aircraft

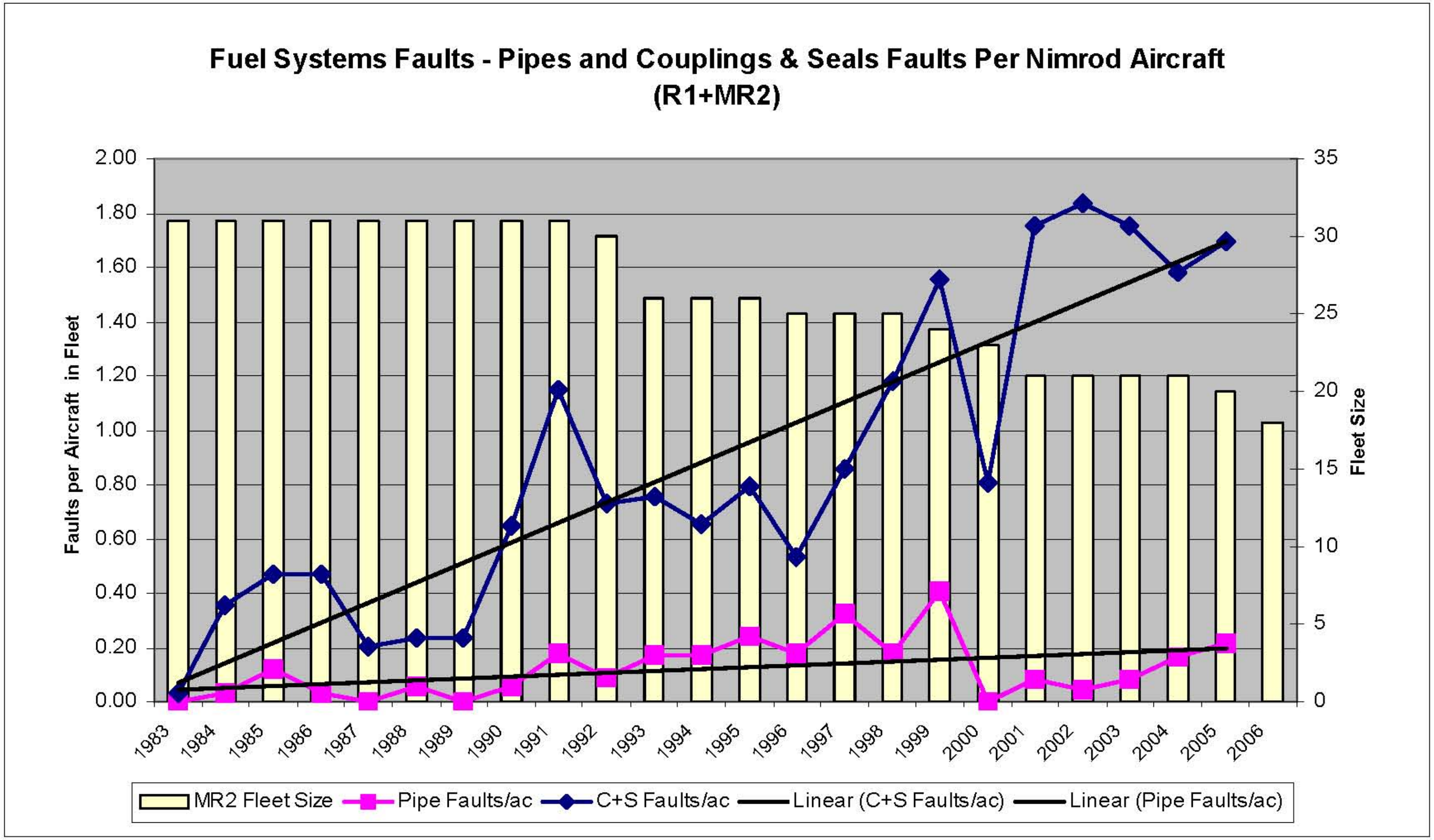
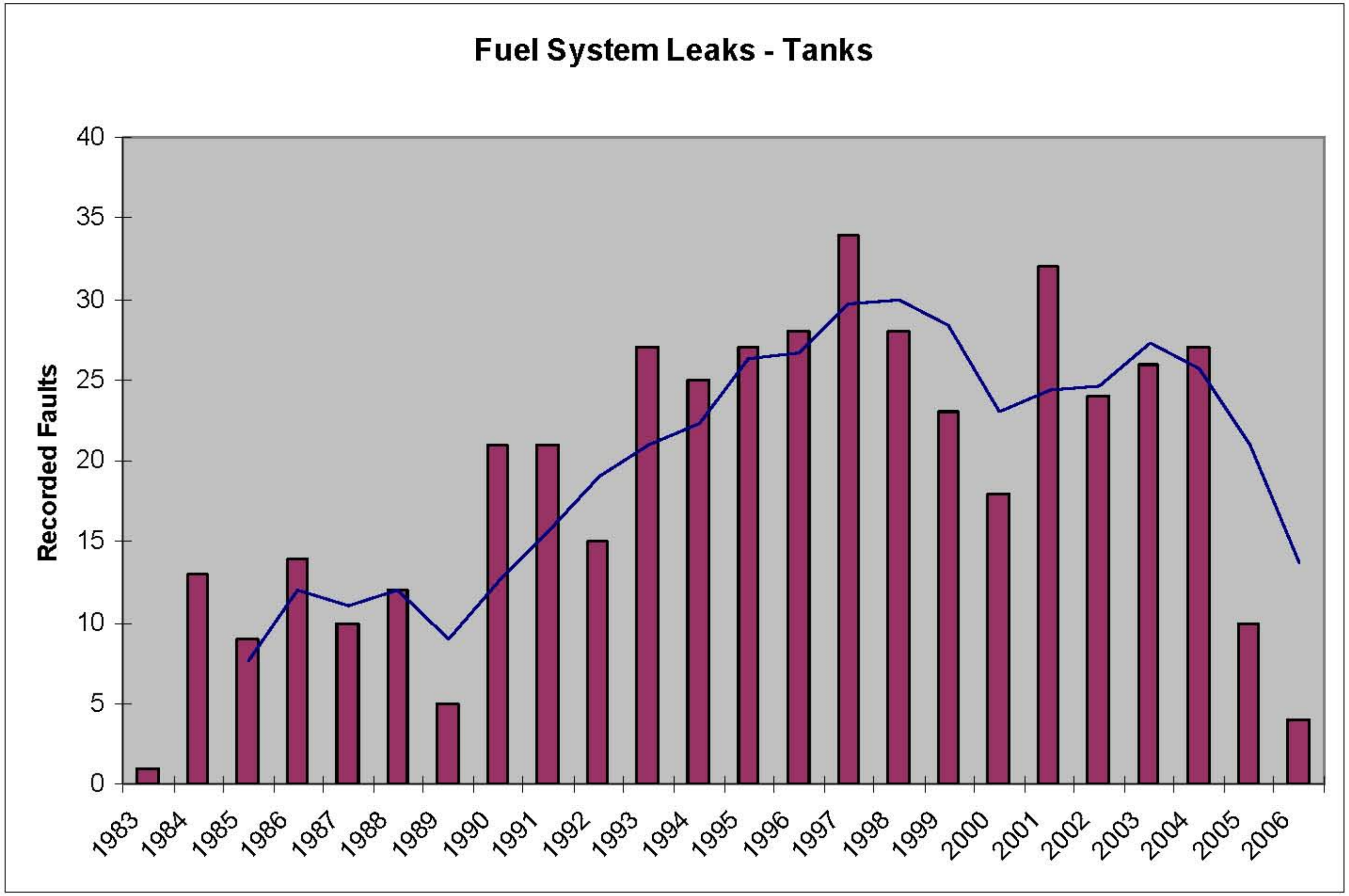


Table 4 - Fuel Leaks Faults from Fuselage Tanks by Tail Number and Year

Tail No	Total	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
XV226	19								2				2	1	3					8			3		
XV227	14		2		1						1	1		2	3		2		1			1			
XV228	13		2											1		1		2			2	5			
XV229	14				1					3	1			3				4						2	
XV230	***16***						***1***						***2***	***2***	***4***		***2***						***5***		
XV231	6												1							1				4	
XV232	21			1					2	1	1				3	5		5					3		
XV233	10								1					5	1		3								
XV235	9			1					3			2						1			1			1	
XV236	22		1	3			1		2		1		4	2	1				2		4	1			
XV237	1						1																		
XV238	7		1			2		1	2	1															
XV239	13	1	1		3	1	1				1		5												
XV240	20			3					2	2	3			2		2	2				1	3			
XV241	13					1	1		1					2		1			3						4
XV242	2		2																						
XV243	26				2			1	1	2		3	4	1	4				1	5	1			1	
XV244	11						1									4					5			1	
XV245	17					1					1	3			4			1		7					
XV246	12				2					4									1	5					
XV247	3		1	1						1															
XV248	14					1				1		1				7						4			
XV249	15													1			3	2	2			7			
XV250	19				3		1		1	2			1		3		3		1	1			3		
XV251	2						1						1												
XV252	21		1				1			1		3				3	3			5	1		3		
XV253	2		1				1																		
XV254	20					1				1	2	6		1		2	2	1	2				2		

Tail No	Total	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
XV255	23		1		1		2	1				3	3		2		3	2				5			
XV258	6									1	1	2	1					1							
XV260	18							1	2		2	1				3							8	1	
XW664	11										1					5			5						
XW665	18							1				2	1			1	4				9				
XW666	3					1			1	1															
XZ284	12					2			1					4			1	4							
XZ285	1				1																				
Totals =	454	1	13	9	14	10	12	5	21	21	15	27	25	27	28	34	28	23	18	32	24	26	27	10	4

Figure 3 – Graph of Fuel Leak Fault from Fuselage Tanks by Year



ANNEX J TO
BOARD OF INQUIRY
NIMROD XV230
DATED APR 07

FUEL COUPLING AND SEAL CONSUMPTION

1. **Introduction.** Data was obtained for the transaction history for Section 27FR items managed by the Air Refuelling and Communications (ARC) IPT. Section 27FR includes fuel couplings and seals known as FRS, after the original manufacturer. Data was available only for the period 2001 to 2007. The Board analysed this data for relevant trends in consumption.

2. **Method.** The data was provided as an Excel spreadsheet, but imported into an Access database to allow easier analysis. The data was filtered to include only Nimrod[1] issues. Only those transactions associated with issues and returns to aircraft or engineering organisations were included[2].

3. **Analysis of Fuel Couplings and Seals Consumption.** The data for fuel coupling and seal consumption by part number and year is given at Appendix 1, Table 1. A selection of 6 high consumption[3] items was subjected to graphical analysis (see Figure 1). There was no discernable pattern or trends in this data. The majority of seal issues is assumed to relate to seals replaced during deeper maintenance when they are replaced as a matter of routine if disturbed.

4. **Conclusion.** The data shows no discernable pattern or trend in the consumption of FRS couplings and seals by the Nimrod fleet. This information correlates with the fairly flat trend in maintenance records for the fuel seals and couplings at Annex I since 2001; a lack of data earlier than 2001 prevents direct correlation of the rise in fuel coupling/ seal maintenance occurrences over that period.

Appendix:

1. Analysis Of Fuel Coupling And Seal Consumption Data.

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[1] The Station was restricted to Kinloss, Waddington, and Basra, although the latter Deployed Operating Bases could also include other aircraft types eg. VC10.

[2] Only the following transaction codes (txn_code) were included: DNR (issues), GDD (auto issues), GEO (external issues off unit). Transaction codes RIN (internal receipt) were deducted from the totals.

[3] Total consumption for period 2001 to 2007 greater than 200.

APPENDIX 1 TO
ANNEX J TO
BOARD OF
INQUIRY
NIMROD XV230
DATED APR 07

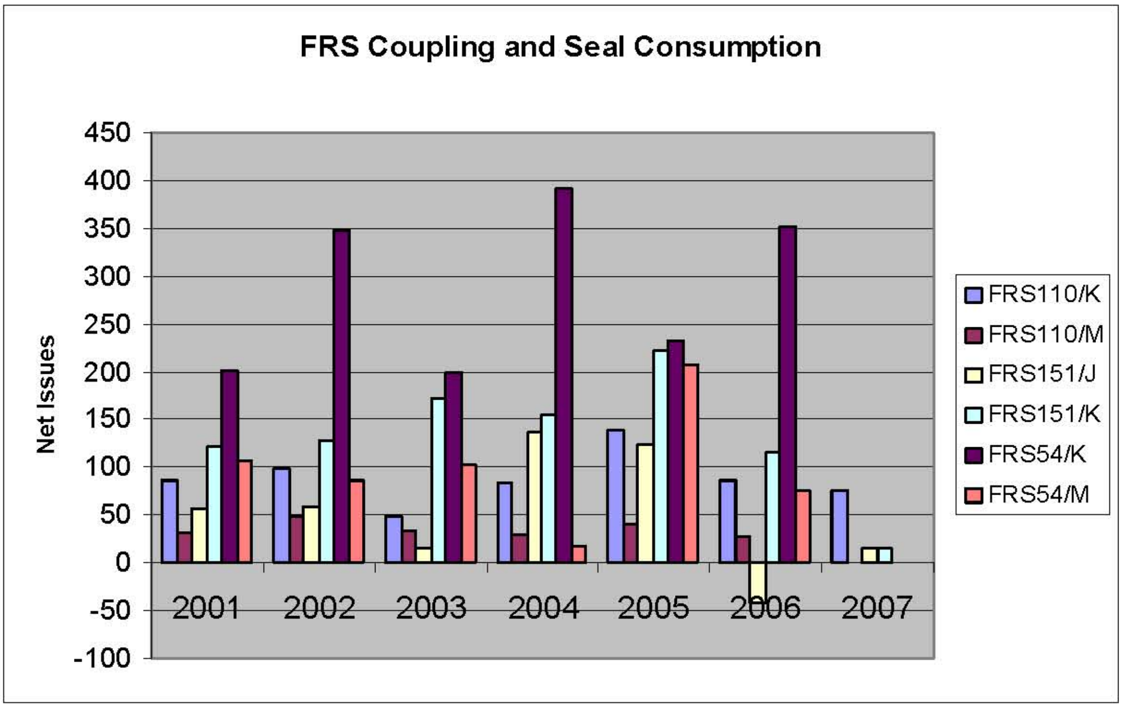
ANALYSIS OF FUEL COUPLING AND SEAL CONSUMPTION DATA

Table 1 –Net Consumption of Couplings and Seals by Tail Number and Year

PtNo	Total	2001	2002	2003	2004	2005	2006	2007
FRS110/H1	109	20	4	10	33	11	30	1
FRS110/J	185	68	57	-10	47	12	11	
FRS110/K	741	117	113	71	104	149	99	88
FRS110/K9	113	12	16	8	29	22	24	2
FRS110/M	246	52	46	34	52	41	20	1
FRS111/K	97	23	9	1	45	3	16	
FRS111/M	14		2	6	5		1	
FRS122/K	28	3	2	11	2	8	2	
FRS151/H	111	35	2	8	30	10	25	1
FRS151/J	368	57	59	18	136	124	-41	15
FRS151/K	1002	141	141	193	166	223	124	14
FRS151/M	140	24	59	-44	37	40	24	
FRS151/P	46	3	9	4	12	10	8	
FRS152/H	47			8	14	16	8	1
FRS152/J	14		1	9	1	2	1	
FRS152/K	125	26	38	-13	16	22	28	8
FRS152/M	50	13	-3	16	13	8	3	
FRS152/P	24	6		2	5	4	7	
FRS229/F	18	5	7	1			5	
FRS231/F	563	45	97	96	137	107	67	14
FRS259	3		1	1	1			
FRS321/P	6				2	3		1
FRS323/P	10	1		-3	9	3	-1	1
FRS325/P	135	35	7	29	25	24	15	
FRS325/R	142	45	3	23	23	19	29	
FRS353/P	7				1	3	2	1
FRS394/P	61	2	14	15	3	14	13	
FRS478/M	8	2	1		1	2	2	
FRS525/K	23	4	3	4	4	5	3	
FRS54/K	2577	314	512	302	446	440	556	7
FRS54/M	664	115	89	124	25	223	88	
FRS66/P	19			2	2	14		1
FRS73/H	13			1		9	2	1
FRS73/J	-65		0	-71	1	2	3	
FRS73/K	174	18	18	28	49	17	41	3
FRS73/M	23	2	2	9	11	-1		
FRS73/P	8	6					2	
TOTALS	**7849**	**1194**	**1309**	**893**	**1487**	**1589**	**1217**	**160**

EMBARGOED UNTIL 1530 4 DECEMBER 2007

Figure 1 – Graph of Fuel Coupling and Seal Net Consumption by Year



The selected FRS couplings and seals are:

FRS110/K	1.5" coupling
FRS110/M	2" coupling
FRS151/J	1.25" seal
FRS151/K	1.5" seal
FRS54/K	1.5" seal
FRS54/M	2" seal

Due to a material change in 2005, the Part Number suffix number changed from 1 to 4. For analysis purposes, both material types were treated as the same.

ANNEX K TO
BOARD OF INQUIRY
NIMROD XV230
DATED APR 07

AIR SYSTEMS

1. **Air Conditioning and Pressurization.** Port and starboard wing supply systems, each using air from the engines in their respective wings, condition and pressurize the cabin. High-pressure (HP) air tapped from the engine compressors is conditioned by being passed through precoolers, heat exchangers and cold air units (CAU) in each wing. The system output air temperature is controlled by varying the amount of HP air passing through the heat exchangers and the CAU. Cabin pressure is determined by controlling the airflow out from the pressure hull. See Figure 1.

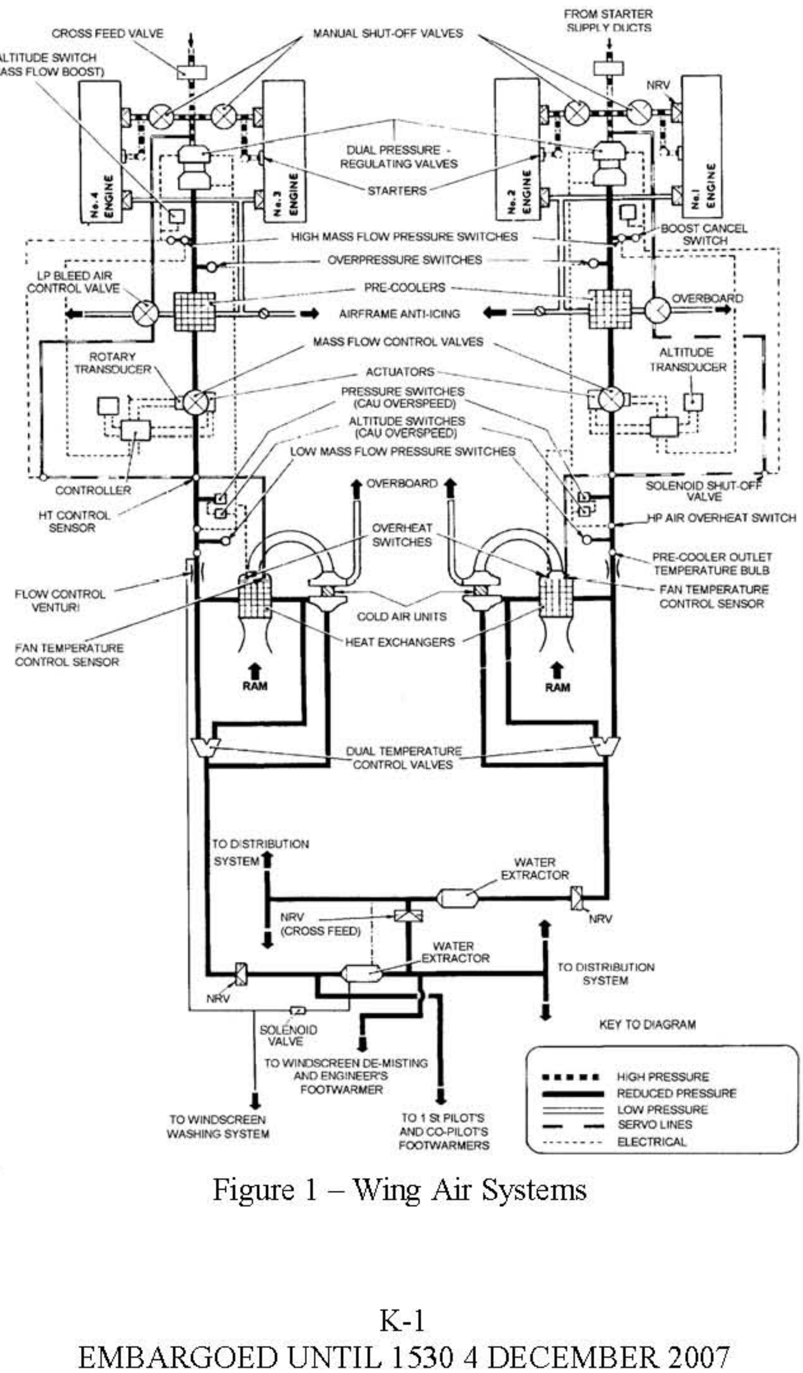


Figure 1 – Wing Air Systems

2. **Supplementary Conditioning Pack.** To cater for the heat generated by the aircraft avionics, a Supplementary Conditioning Pack (SCP) in the tail uses HP air from the engine crossfeed duct. The SCP increases the mass flow of conditioned cabin air by incorporating a precooler in a fairing aft of the bomb bay and a tail pack in the Auxiliary Power Unit (APU) compartment bay, which incorporates a two-stage heat exchanger and a CAU. With the air supply switched on, hot HP air from the crossfeed system feeds through a combined pressure-reducing valve and shut-off valve (PRSOV) and flow limiting venturi to the precooler. A temperature control valve allows some air to bypass the precooler in underheat conditions. Air for the SCP is routed along the outside of the starboard fuselage from the PRSOV to the precooler and along the outside of the port fuselage from the precooler to the tail pack itself. See Figure 2.

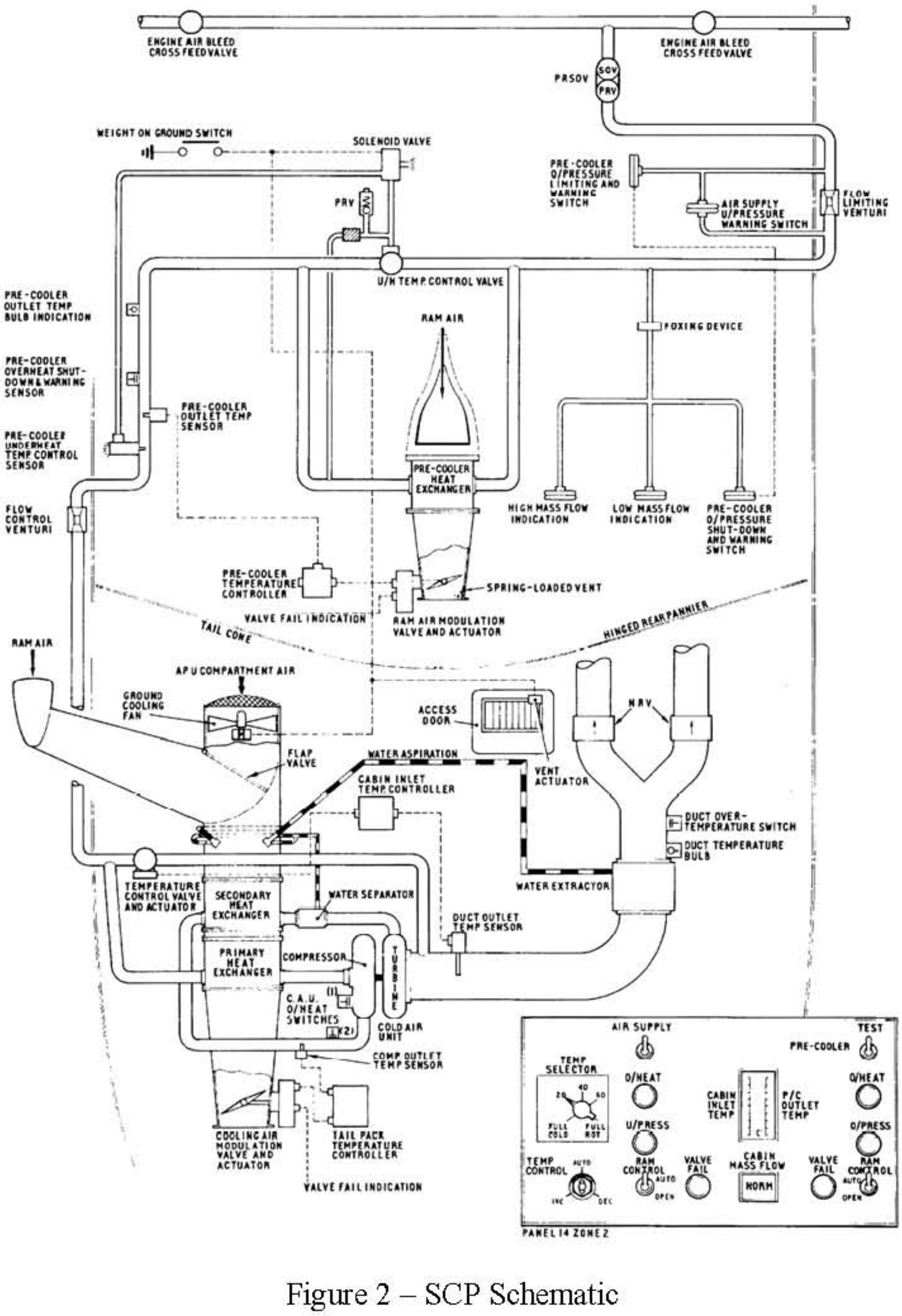


Figure 2 – SCP Schematic

3. **Bomb Bay Heating.** The bomb bay is controlled at 15±10°C for all flight conditions with ambient temperatures below +5°C; at higher ambient temperatures, the bay temperature is maintained at about ambient. Low pressure (LP) hot air is taken from downstream of each wing system precooler to provide adequate heating for the bomb bay.

4. **Airframe Anti-Icing.** LP and HP engine bleed air is conditioned and then ducted to the leading edges of the wings, the tailplane and the fin. The bleed air supply is automatically controlled and regulated by two identical air valve installations in the port and starboard main planes. Temperature sensors, thermal cut-out switches and pressure switches automatically protect against overheat and overpressure conditions in the anti-icing airflow. Engine bleed air is controlled by the air engineer's HP air supply levers. Crossfeeding between the two identical wing systems allows one side to provide total airframe anti-icing.

6. **Engine Starting.** The engine is turned for starting by an air starter motor on the high speed gearbox, geared to the engine HP shaft. Air is supplied to the starter motor from an air starter trolley, or from the APU via the anti-icing tail duct where a feed valve and a non-return valve (NRV) prevent leaks. Engines can also be started by HP air crossfed from an engine running at a minimum of 75% (ground) or 90% (airborne) HP RPM. See Figure 3.

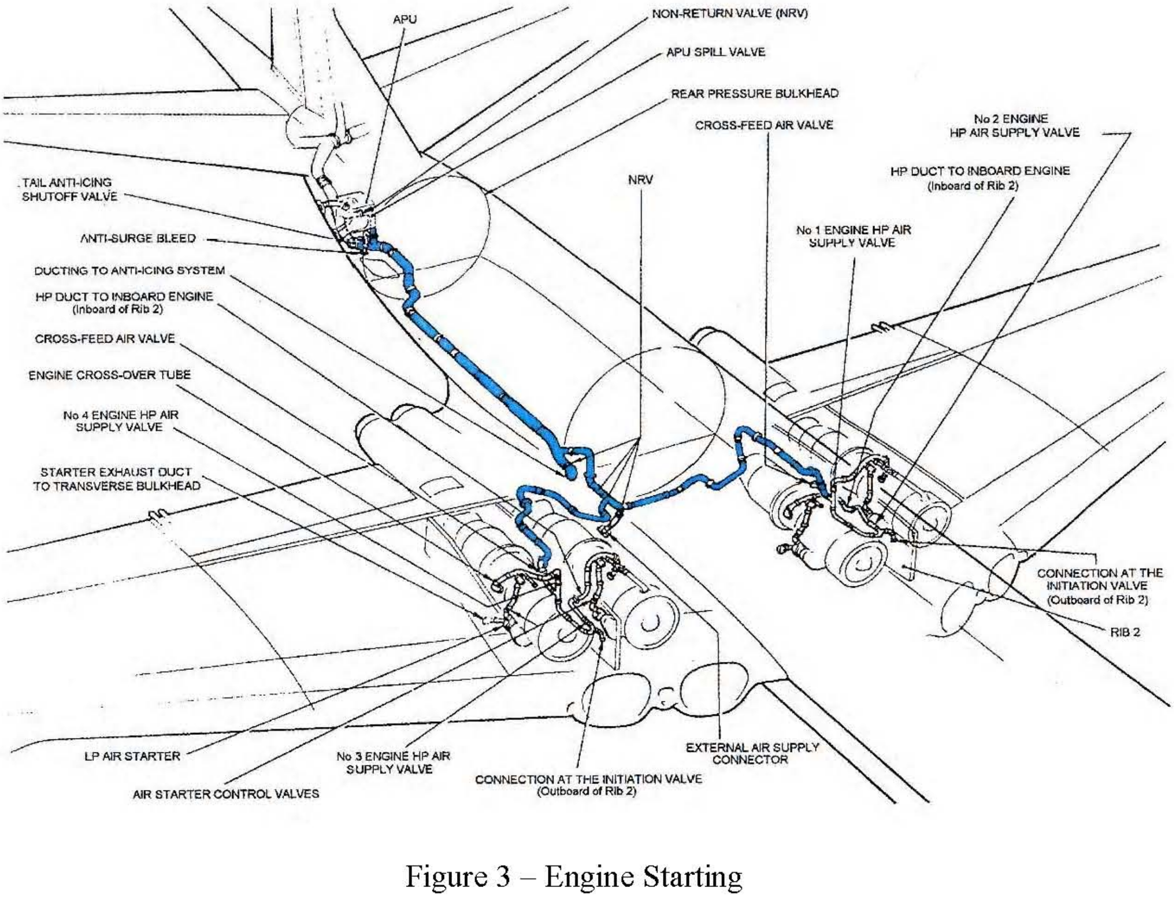


Figure 3 – Engine Starting

ANNEX L TO
BOARD OF INQUIRY
NIMROD XV230
DATED APR 07

AAR SYSTEM INCORPORATION

1. **Summary of Incorporation**. The Nimrod was converted to enable AAR for Operation CORPORATE (The Falklands campaign) during 1982, as an Urgent Operational Requirement (UOR) under Modification (Mod) No 700. In 1985, under PDS Task No 0351, BAe was tasked to incorporate a more permanent AAR capability within the Nimrod AEW3, which was under development. Subsequently, the AEW3 project was cancelled, but the AAR system features developed on that project became the basis for Mod No 715, which was eventually installed on the MR2 and R1, beginning in 1989. Until this point, the Nimrod had refuelled primarily from the Victor and VC10, each with a single Hose Drum Unit (HDU) capable of delivering up to 1800 kg/min. In 1990, the Tristar was converted to be a tanker aircraft and was cleared to refuel a variety of receivers, including the MR2. The Tristar's twin HDUs each delivered fuel at a greater rate (2100 kg/ min) than its predecessors because of the addition of 2 hydraulically driven Carter pumps.

2. **Features of Original MR2 Installation**. One concern on the original installation of Mod 700 during Operation CORPORATE was that the No 5 tank blow-off valve (a safety device to prevent fuel tank over-pressure) could operate during AAR to off-load excess pressure, resulting in fuel entering the intake of No 2 engine (the outlet pipe for the No 5 tank blow-off valve exited the fuselage forward of the port engines). To counter this, a pressure switch was placed in the vent line of No 5 tank to close the refuel valve should fuel enter the vent line. Also, the refuelling procedure for the original installation required the refuel valves of all the tanks requiring fuel to be opened as refuelling commenced and closed individually as each tank filled. This had the effect of distributing the fuel to a number of tanks simultaneously, with a relatively low rate to each one.

3. **AEW3 AAR Development**. As part of the specification for the AEW 3 and in order to protect further the No 2 engine intake from a blow-off from No 5 tank, the blow-off valve from that tank was removed altogether. A restrictor was installed instead, to reduce the flow rate into No 5 tank to 40-gallons/ min. This change, in isolation, had no significant effect, other than to extend the time it took to fill No 5 tank – although the air engineer had to ensure that longitudinal balance limits were maintained between Nos 5 and 6 tanks. While all tanks were being filled simultaneously, No 5 tank would generally fill by the time the last other tank was filled. Much of this work was undertaken as part of the AEW3 development under PDS task 0351. The Board was able to obtain 3 trials reports from this period:

a. **BAe MPP R AEW 0063**. BAe MPP R AEW 0063 reports investigations into the possibility of removing the blow-off valves within Nos 1 and 5 fuel tanks, to prevent the chance of blown-off fuel being ignited by aircraft engines. As a result the blow-off valve from No 5 tank was removed and replaced with a flow restrictor, to prevent tank over-pressure. However, it was decided that a similar arrangement within No 1 tank would prolong AAR unreasonably and that the threat of fuel entering the jet efflux was minimal. The report did recommend further investigation of the potential for fuel to enter ports and intakes after ejection from blow-off valves in Nos 1 and 6 tanks. Furthermore, the report recommended that if, during these trials, fluid was seen to enter the intake of the SCP pre-cooler, then consideration should be given to either switching off the SCP before AAR was undertaken or modifying the outlet of the No 1 and No 6 tank blow-off valve outlets to prevent fuel running down the aircraft skin. Exhibit 66

b. **HAS MPP F AEW 0065**. HAS MPP F AEW 0065 summarises a number of ground and air tests of the Nimrod AEW AAR system. Of note surge pressures of up to 85 psi were recorded as satisfactory as 'they do not greatly exceed the anticipated 75 psi and are well below the Def Standard limit of 120 psi for a multi tank aircraft'. This report also refers erroneously to the report at para 3a discussing blow-off from tank(s) 7. Exhibit 67

c. **HAS MPP F AEW 0068**. Although HAS MPP F AEW 0068 details the operating instructions for Nimrod AEW during AAR, it makes a number of points relevant to subsequent AAR operations. It recommends that AAR is halted if venting is seen and tanks 1 and 7 are full as this may indicate operation of the blow-off valves (this report may perpetuate the error noted in the previous sub-para). It also suggests that the tanker should switch off HDU pumps when the receiver (not the receiver's last tank) is 90% full. Finally the report notes that, if venting has occurred in flight, the APU should not be run until the APU bay has been inspected and declared clear of fuel highlighting continuing concern about fuel entering 'ports and intakes'. Exhibit 58

The most significant facts to arise from these reports are that blow-off was recognised as a potential occurrence and hazard during AAR and that pressure surges of 85 psi were accepted by the aircraft designer as satisfactory. Although the potential hazard of No 5 tank blow-off was obviated, that from No 1 tank (and No 6 and No 7 tanks) was not. The threat of fuel entering fuselage compartments was raised but there is no evidence that it was ever investigated further.

4. **Changes to Refuelling Sequence**. In 1987, BAE Systems advised the RAF that the extant sequence of refuelling could potentially cause structural problems, because of wing bending relief. Following trials, the Exhibit 68

sequence was changed, such that rather than filling all tanks simultaneously, the wing tanks were refuelled first, followed by the fuselage tanks, when the wing tanks were full. This had the side-effect of increasing the instantaneous rate at which individual tanks were refuelled.

5. **Mod 715 Installation Changes**. In 1989, Mod 715 was introduced and the features developed as part of the AEW3 program were incorporated on the MR2 and R1. In particular, the restricted No 5 tank refuel valve was introduced. This complicated the refuelling sequence devised in 1987. To prevent longitudinal balance limits being breached, as No 6 tank now filled faster than No 5 tank, the air engineer had to switch the former's refuel valve on and off. No 7 tanks would reach full before the No 1 tank and, therefore, on most occasions, the only refuel valves open near the end of an AAR serial would be the 2 on the No 1 tank and the restricted No 5 tank. The net effect of this was to increase substantially the instantaneous flow rate into the No 1 tank. Formal trials were conducted to ascertain the functionality of the Mod 715 changes. However, the bowser used to provide fuel for the practical test of the AAR system was unable to deliver fuel at more than 30 psi. The trials team extrapolated figures to calculate fuel flows at 50 psi. A direct result of this was that the opportunity to possibly observe No 1 tank blow-off was lost.

6. **Introduction of the Tristar Tanker**. Trials for the Nimrod to receive fuel from the Tristar were completed in 1989. The Tristar delivery rate of 2100kg/min was higher than that of the VC10 (1800 kg/min). The trials report clears the Tristar to refuel a number of receiver types, and in each case high surge pressures were noted, though rarely commented on. A rate of 2100 kg/min was achieved for the Nimrod and the maximum surge pressure noted was 84 psi. Although no comment on the pressure surge is made in the report it is assumed that it was accepted under the same premise as that quoted above (para 3b). This additional delivery capacity of the Tristar Carter pumps represents another increase in the individual tank refuel rates. Exhibit 56

7. **Summary**. Both BAES and the Nimrod IPT were asked to allow the Board access to all documentation related to the development of an AAR capability on the Nimrod MR2. The passage of time has undoubtedly prevented a full reconstruction of the development process, but the Board has been able to determine that, despite the rapid inception of an AAR capability during the Falklands Campaign, measures were taken to formalise the aircraft's equipment and thought given to making the procedure as safe as possible. However, over a period of 7 years, individual tank refuel rates of the original Mod 700 installation were subtly increased by a number of separate changes. It would appear that each of these changes was considered in isolation, although not the combined effect. Moreover, the potential overspill of fuel due to the increased refuel rates was not considered for the MR2, other than for No 5 tank.

ANNEX M TO
BOARD OF INQUIRY
NIMROD XV230
DATED APR 07

TECHNICAL DESCRIPTION OF NO 1 FUEL TANK AND GROUND REFUELLING

1. **Construction**. No 1 tank (See Figure 1) is in the fuselage, outside of the pressure hull, within the wing centre section. The tank (capacity 16000 lb) is divided into 4 cells, each containing a robust, flexible bag tank. The cells are numbered 1 to 4, from front to rear.

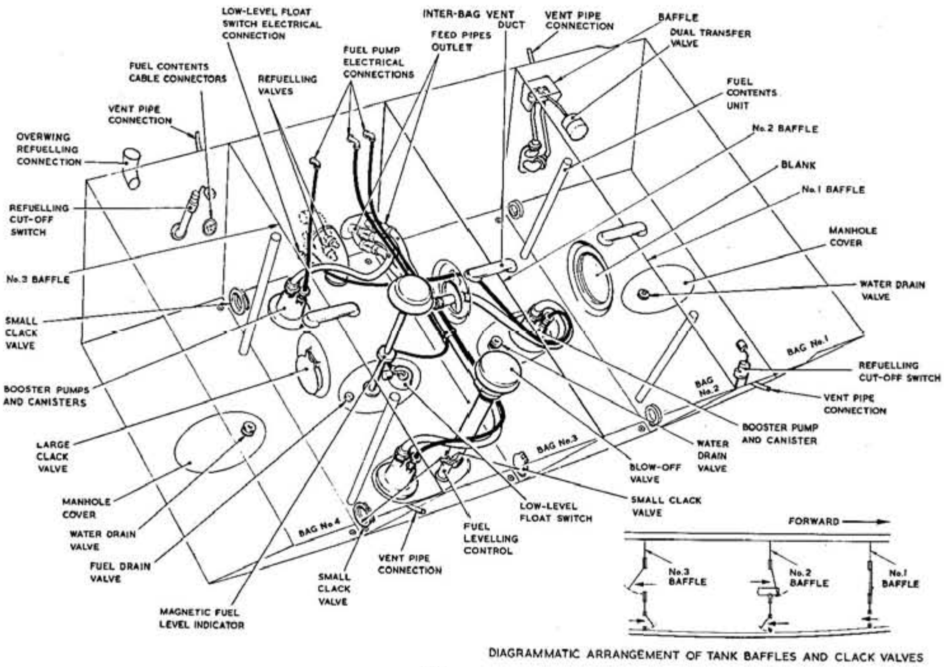


Figure 1

2. **Refuelling**. Fuel enters No 1 tank through 2 refuel valves in cell 3 and, when it reaches the level of 2 large clack valves approximately half way up the cell 3 walls, overflows into cells 2 and 4. The only means for fuel to enter cell 1 is through 2 much smaller holes at the bottom of the cell 1/2 dividing wall. Therefore, at high refuel rates, cell 1 will fill more slowly than cells 2, 3, and 4. Refuelling only stops automatically when high-level float switches in cell 1 and cell 4 are both operated - when those cells reach maximum capacity. At normal ground refuelling rates, all 4 cells fill evenly and the float switches cut-off flow when the tank reaches full capacity. However, with high refuel rates, the rear cells will fill, but the high-level float switch in No 1 cell will not be made and the refuel valves will stay open. Therefore, until the fuel reaches the cut off level in No 1 cell, fuel will continue to enter the already full cells 2, 3, and 4. This fuel will overflow into the vent system through a small diameter pipe in the upper rear corners of the No 4 cell. This can happen at the much higher air-to-air (AAR) rates, but can also happen on the ground if the browser pressure is not reduced towards the end of the refuel (see para 5).

3. **Overflow**. Once cells 2, 3 and 4 have filled, the incoming fuel will have only 3 potential exits: into the vent system, through the small diameter pipe in the upper rear corner of cell 4; into cell 1 via the small vent pipe between cells 1 and 2; or, as previously, through the 2 small holes at the bottom of the cell 1/2 dividing wall. The inability of cell 1 to accept fuel at the rate of the other cells, combined with the small diameter of the vent pipes, is likely eventually to cause an increase in pressure in the other cells. The No 1 tank structure is protected from excess pressure by a blow-off valve within No 3 cell. If the refuel valves are not closed by operation of the high-level float switches, the blow-off valve will release any excess pressure through an overflow pipe, which exits the fuselage under the starboard wing root. It appeared possible to the Board that, during AAR, fuel could enter the vent lines and that, subsequently, additional pressure generated in the No 1 tank would lead to the operation of the blow-off valve, resulting in discharge of fuel from the No 1 tank.

4. **Fuel Vent System**. The vent connections from the No 4 cell consist of moulded pipe extensions of the bag tank. These extensions are pulled through holes in the cell wall and are secured by jubilee clips to the outside of the external metal vent pipe. The fuselage fuel vent system is not subject to any pressure test to ensure that it is sealed. Any fuel leaking from either the small bore No 1 tank vent pipe or the aircraft main vent line to No 7 tank starboard, could escape from the vent pipe and flow down into the Rib 1 and No 7 tank dry bay areas.

5. **Ground Refuelling**. It is an established practice amongst Nimrod ground crew that, during the latter stages of refuelling, the delivery pressure is reduced, to prevent fuel entering and spilling from the vent system or tank blow-off valves. The maintenance procedure for refuelling stipulates that refuelling must be stopped on reaching 70 000 lbs and then recommenced at a reduced pressure of 20 psi. This reduced pressure allows the fuel to level out, such that all cells reach full together and thus, refuelling is stopped before overflow occurs. Also, ground refuelling takes place through 2 under-wing couplings which each have a restrictor fitted to limit flow to a maximum of 200 gall/min (730 kg/min). Therefore, the maximum ground refuelling rate is 400 gall/min (1460 kg/min). This is a significantly lower maximum flow rate than during Tristar AAR. A trial at RAF Kinloss revealed that when the delivery pressure is reduced to 20 psi, Exhibit 69 the delivery rate to No 1 and No 5 tanks together is 154 gall/min (560 kg/min) combined and about 143 gall/min (520 kg/min) to the No 1 tank on its own. A tanker's booster pump rate can be as high as 302 gall/min (1100 kg/ min). Therefore, reducing to tanker booster pumps may not prevent fuel overspill or blow off.

ANNEX N TO
BOARD OF INQUIRY
NIMROD XV230
DATED APR 07

ANALYSIS OF THE AIR-TO-AIR REFUEL OF XV230

1. **Introduction**. Hydraulic Analysis Ltd (HAL) was contracted to produce a computer model of the Nimrod No 1 fuel tank, to investigate the reported blow-off and venting phenomena. The model, which reflects the behaviour of fuel within No 1 tank and its associated vent lines, was independently reviewed by QinetiQ (Exhibit 70) to confirm its validity. BAE Systems completed further independent analysis of the No 1 tank and estimated that the No 1 tank blow-off valve will open at flow rates above 1355 kg/min; furthermore BAE Systems confirmed that, as No 1 tank continues to fill the level of fuel in the aft vent line will rise (Exhibit 71). It was accepted that the model did not reflect the full characteristics of No 1 tank, but that the simplification had a minimal affect on the outcomes it was designed to demonstrate. The model's prime purpose was to determine whether the reported phenomena could have occurred during XV230's final sortie. Using previous experience of such operations and planning data it was possible to estimate the rates of refuel which would have been experienced by XV230 during the air-to-air (AAR) procedure on 2 Sep 06. This in turn allowed the Board to establish the probable individual tank contents at the end of the refuel sequence and the effect that fuel load might have.

2. **Starting Fuel Load On Ramp.** From the MOD Form 700, prior to its final sortie, XV230 had 81 200lb of fuel, loaded as follows:

Table 1

No 4 Tanks	19 000 lb
No 2 Tanks	12 000 lb
No 3 Tanks	20 600 lb
No 1 Tank	15 200 lb
No 5 and 6 Tanks	10 600 lb
No 7 Tanks	3800 lb
Total	81 200 lb

3. **Fuel Used In Transit To AAR Point.** Planning documents predict that, during the flight to the operational area, the aircraft would use approximately 21 000 lb of fuel and, indeed, this was the figure that the air engineer advised would be required during AAR. The Tristar air engineer reported actually transferring 22 000 lbs of fuel, but a 1000 lb difference between planned and actual fuel onload is not unusual.

4. **Distribution Of Fuel Prior To AAR Contact.** During the transit to the area, fuel would have been used from the No 1, 5, 6, and 7 tanks. This would probably have left the fuel in the aircraft tanks distributed as follows:

Table 2

No 4 Tanks	19 000 lb
No 2 Tanks	12 000 lb
No 3 Tanks	20 000 lb (small amount used in take off)
No 1 Tank	4000 lb
No 5 and 6 Tanks	3000 lb / 2000 lb
No 7 Tanks	Empty
Total	60 000 lb

As can be seen from Table 2, it is considered likely that some fuel would have been left in the No 5 and 6 tanks. Although retention of fuel in this way is not a defined procedure, it has become standard practice during operational uplifts. The restrictor in the No 5 tank (implemented as part of Mod 715 – see Annex M) limits its refuel rate to about 320 lb/min (145 kg/min) and can result in a longitudinal imbalance between No 5 and 6 tanks if not managed correctly. Thus, in order to uplift as much fuel as possible and remain in balance, the air engineer usually manipulates his fuel load before an operational AAR serial, such that, during AAR, tanks 5 and 6 will reach full in unison with the other fuel tanks. Not doing so could result in all other tanks being full, while the No 5 tank continues to fill at approximately the same rate as the aircraft is burning fuel; thus the aircraft could never achieve a maximum uplift. The main caveat that would be applied by the air engineer is that the total of the extra fuel carried in the No 5 and 6 tanks, when added to the aircraft Zero Fuel Weight (ZFW), would not exceed the normal maximum ZFW for the Aircraft of 104 000 lb. In this case, with XV230's ZFW of 99 000 lb, up to 5000 lb could be retained in the No 5 and 6 tanks.

5. **Sequence Of Uplift.** With the fuel distribution as in Table 2, the sequence of refuelling would probably have been as follows:

a. No 1, 2 and 3 tank booster pumps would be switched off – to prevent feeding from a tank being refuelled. All engines would be fed from the No 4 tanks, which are refuelled indirectly via the 4A tank and therefore kept 'topped up'.

b. Refuel valves for No 1, 3, 5, 6 and 7 tanks would be opened in addition to the No 4 tank valves. The No 4 tanks valves would then be closed and re-opened as required to maintain their contents between 6000 lb and 6500 lb until the No 1 tank contents reached 8000 lb.

c. When the No 1 tank contents reached 8000 lb, the No 1, 2 and 3 tanks booster pumps would be switched on, thereby transferring fuel feed from No 1 tank to the engines. No 4 tanks' refuel would be continued until their contents reached 6500 lb.

d. Refuel would then continue until each remaining tank indicated full or was selected off by the air engineer.

6. **Final Tank Contents.**

a. **Assumptions**. In order to provide a basis for modelling the refuel of the No 1 tank, the following information was used and assumptions made:

(1) Approximately 2000 lb of fuel would have been consumed by XV230 during the whole of the AAR event, from establishing contact to departing for echelon starboard. Thus, from the 22 000 lb (10 000 kg) total delivered by the tanker, about 20 000 lb (9100 kg) was added to the 60 000 lb carried by XV230 at the start of the refuel.

(2) The tanker did not start at the maximum fuel flow rate; however, pressure was increased quickly, by the initial use of booster pumps, which were then supplemented by first one Carter pump, then the other. The Tristar air engineer reported that fuel was delivered at 2000 kg/min for most of the event, with a relatively rapid reduction in flow rate at the end as first one Carter pump, then the second, was switched off, followed immediately by the booster pumps. An average refuel rate of 200 kg/min was assumed (from Nimrod trials and experience) for each tank refuel valve. Therefore, the total flow rate from the tanker was divided equally amongst all open refuel valves; this gives a progressive increase in flow rate to the No 1 tank as other tanks become full and their valves are closed.

(3) Following the accident to XV230, some further trials were carried out to validate a new refuel procedure that had been put in place (Exhibit 72). Although these trials were completed using only one Carter pump, the refuel rates achieved have been used as a basis for the modelling, with slight increases to the flow rates to account for the second Carter pump used during XV230's AAR event. Also, since use of the No 7 tanks is not currently permitted, they were empty for the above trial and their refuel rate was estimated by reference to previous air engineer experience.

b. Based on the above assumptions, the following refuel rates were estimated for the No 1 fuel tank:

(1) For the first 2.5 min – 400 kg/min (a low rate as a total of 10 refuel valves were open).

(2) From 2.5 min to 4.5 min – 1200 kg/min (the wing tanks were full, and their refuel rates were added to the No 1 tank; No 6 and 7 tanks were still filling but little fuel was going into the No 5 tank).

(3) From 4.5 min to 5.5 min – No 1 tank increased quickly to either 1600, 1800 or 2000 kg/min (No 7 tanks were full by now, No 5 and 6 tanks were still filling with No 6 tank leading and may have reached longitudinal balance limit).

c. **Modelling Results**. The HAL model for the No 1 tank was run with the above input parameters to establish when venting occurs and when the blow-off valve operates. DARU data was used to establish the range of pitch attitude and use this range as an input parameter to the model. The average pitch attitude during this period was 1.4 deg nose up but oscillated between slightly nose down and 3.3 deg nose up. Therefore the modelling process was carried out for each of 1600/1800/2000 kg/min for the final minute and for attitudes of 1, 2 and 3 degrees nose up. Baseline parameters were set at a vent pressure of 0.05 barg, initial contents of 4000 lb in No 1 tank and refuel rates to No 1 tank as noted in sub para 6b.

Table 3

Attitude + final minute flow rate	Contents at vent	Time at vent min.sec	Contents at blow off	Time at blow off min.sec	Amount vented at time of blow off
1 deg nose up 1600kg/min	14 900 lb	5.35	15 400 lb	5.46	19 lb
1 deg nose up 1800kg/min	14 800 lb	5.25	15 400 lb	5.35	18 lb
1 deg nose up 2000kg/min	14 700 lb	5.16	15 300 lb	5.24	15 lb
2 deg nose up 1600kg/min	14 400 lb	5.30	15 400 lb	5.48	30 lb
2 deg nose up 1800kg/min	14 300 lb	5.18	15 300 lb	5.34	26 lb
2 deg nose up 2000kg/min	14 300 lb	5.12	15 300 lb	5.25	22 lb
3 deg nose up 1600kg/min	13 800 lb	5.22	15 200 lb	5.49	46lb
3 deg nose up 1800kg/min	13 800 lb	5.22	15 200 lb	5.32	37lb
3 deg nose up 2000kg/min	13 800 lb	5.03	15 200 lb	5.21	30lb

d. **Interpretation of Results**. The following conclusions were drawn from the tabulated results:

(1) The model clearly establishes the phenomenon of differential filling of the cells in the No 1 tank leading to the attempted continued refuelling of cells which are already full.

(2) As the aircraft pitch attitude increases, fuel enters the No 4 cell vent line earlier and at a level which is always below 15 000 lb.

(3) For the flow rates and pitch attitudes modelled, venting occurs in a timescale which is consistent with the estimated length of XV230's refuel

event from mission tape analysis.

(4) The quantity of fuel entering the vent system is considered sufficient, if it leaked out of the vent system, to cause the No 7 tank dry bay fire once ignited.

(5) Operation of the blow-off valve occurs before the tank is filled to capacity and, dependent on pitch attitude, is close to the 15 000 lb level the air engineer was assumed to be aiming for. The time scale for operation of the blow off valve is also consistent with the mission tape timeline.

(6) Operation of the blow-off valve occurs when the connecting vent pipe from No 2 cell to No 1 cell becomes blocked with fuel; this increases the pressure in the No 3 cell to the level at which the blow off valve operates. While QinetiQ has validated the mathematical accuracy of the model, it is recognised that it does not reflect the dynamic nature of fuel within the No 1 tank. Changes in pitch attitude will cause the fuel to move back and forth and the actual level at which the No 2 to No 1 cell vent becomes blocked will vary considerably. Therefore the point at which the blow off valve operates could be earlier than predicted by the static model. It certainly could have been earlier than the 15 000 lb level to which it is believed the air engineer was aiming to fill the No 1 tank.

e. **Final Tank Contents**. Assumed final wing tank contents based on 22 000 lb delivered; 2000 lb burnt in contact; and 20 000 lb uplifted are shown in table 4.

Table 4

Tank	Final contents	Uplift
No 4 tank	19 500 lb	500 lb
No 2 tank	12 000 lb	0
No 3 tank	22 000 lb	2000 lb
Totals	53 500 lb	2500 lb

(1) Therefore 17 500 lb was shared between No 1, 5, 6, and 7 tanks.

(2) No 7 tanks receive 2000 lb each so No 1, 5, and 6 tanks shared 13 500 lb.

(3) No 1 tank started at 4000 lb and rose to 15 000 lb based on statement of advice to FS Davies from other air engineer that blow off could happen at 15 000 lb. Therefore No 1 tank uplifted 11 000 lb

(4) No 5 and 6 tanks shared remaining 2500 lb. No 5 tank started at 3000 lb and probably uplifted only 200 lb; this is based on the Board's best interpretation of intercom, which is incomplete at this point. Possible reasons for the No 5 tank not appearing to fill are a refuel valve which

failed to open, or a gauge error. It is considered unlikely that this lack of filling is due to a fuel leak, as such a fuel leak would have affected other tank contents as well as No 5 tank and there is no reference to such a fault on the intercom.

(5) No 6 tank started at about 2000 lb and ended at about 4000 lb; it probably stopped before full because longitudinal balance limit with No 5 tank reached.

ANNEX O TO
BOARD OF INQUIRY
NIMROD XV230
DATED APR 07

FLYING CONTROL AND HYDRAULIC SYSTEMS

1. **General Description.** The Nimrod possesses 4 hydraulic systems, specifically designed to provide system redundancy. The 2 principal systems, powered by engine-driven pumps are known as the Blue and Green systems. A DC electrical pump supplies the Yellow system, while an AC electrical pump supplies the Red system. The 4 systems supply hydraulic pressure at 2000 to 2500 psi to activate flying controls, landing gear, nosewheel steering, air brakes, flaps, wheel brakes and bomb doors, as shown in Figure 1.

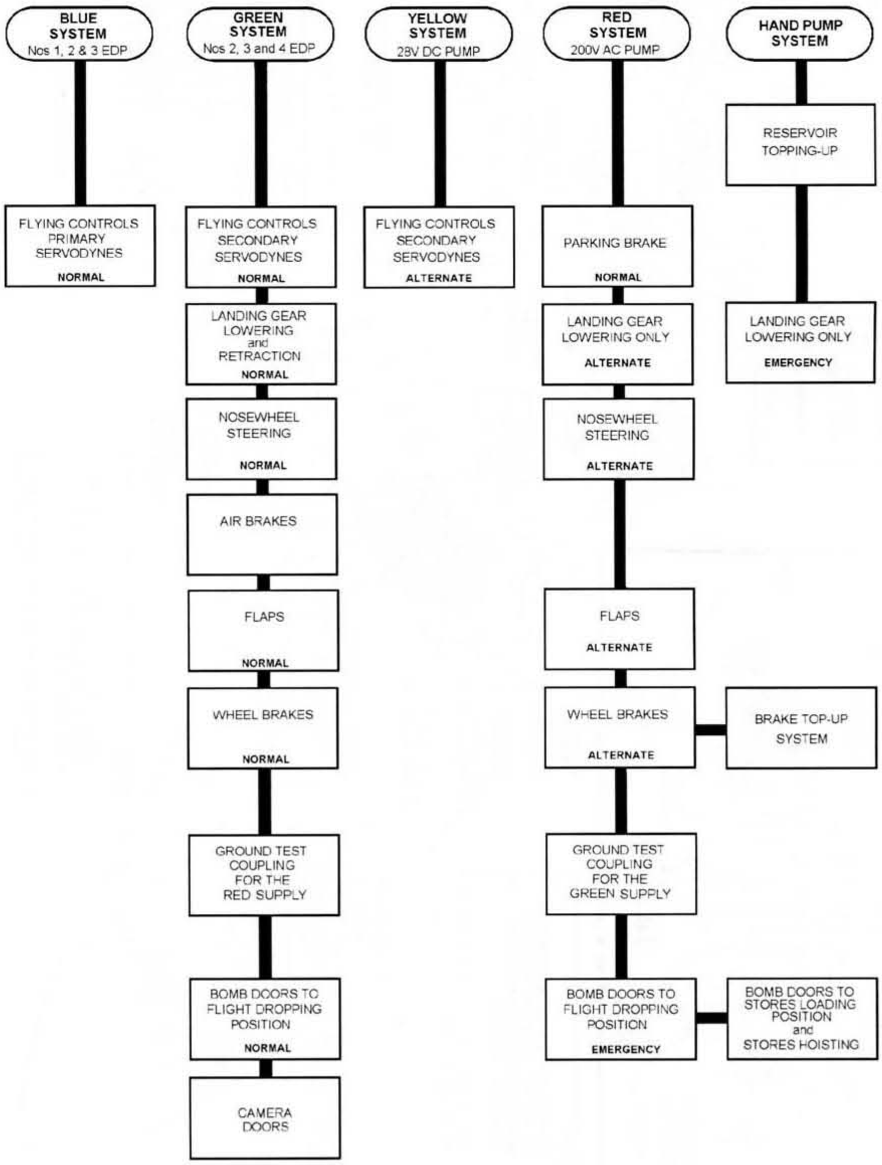


Figure 1 – Hydraulic System Services

2. **Flying Controls.** Each of the flying control surfaces is moved by a hydraulically powered servodyne. Two servodynes are attached to each surface but only one is selected at any one time. The primary servodyne is powered by the Blue hydraulic system and the secondary is powered by the Green system with a back up supply from the Yellow system. Both Blue and Green systems include backing accumulators which provide a reserve of pressure in the event of system failure to allow time for a smooth changeover to the alternate system. The No 7 tank dry bay houses a number of key hydraulic pipes running from the Rib 1 area through the right hand (RH) sealing panel in the rear spar. The pipes originate in the hydraulic equipment compartment and route along the starboard Rib1 area, into the dry bay, from where they take one of 3 routes: into the aileron bay, across the bomb bay towards the port side, or into the starboard wing. They are constructed of steel with aluminium alloy unions. The hydraulic pipes that run through the RH sealing panel include:

a. Blue system pressure.

b. Blue system return.

c. Green system pressure.

d. Green system return.

Therefore, a fire in the No 7 tank dry bay has the potential to cause the failure of both the Blue and Green hydraulic systems. Furthermore, a fire in the aileron bay or close to it could disrupt the Yellow system.

3. **Loss of Flying Controls.** The Board suspects that in the aircraft's final moments, it became uncontrollable as hydraulic power to the flying control servodynes was lost. Once a servodyne loses all hydraulic power it locks in its last selected position so the aircraft would continue to fly in its last trimmed attitude until upset by turbulence or a change in the centre of gravity. A possible explanation of events would be as follows.

a. Due to the co-location of the pressure pipes for the Blue and Green system in the RH sealing panel, it is probable that those 2 systems would fail at approximately the same time. The crew would get a warning that Blue pressure had been lost and attempt to change flying controls to the Green system. A further warning would alert them to the loss of the Green system. This would prompt a change of flying controls to the Yellow system.

b. It is unlikely that the Yellow system was serviceable at this stage; the wiring to the electric motor which drives the pump was probably compromised and the fire had probably caused leaks in the system's pipes.

c. As noted above, the Blue and Green systems have backing accumulators that provide a reserve of pressure to allow time for changing to an alternative system. The inlet from the Blue aileron and rudder backing accumulator to the primary servodyne is on the starboard side of the aileron bay. This is also likely to have been compromised by the fire. Pressure to the elevator from the Blue elevator backing accumulator could still have been available as this section of pipe work is away from the fire area. The Board considers that, in view of the multiple emergencies, the crew would have had insufficient time to restore elevator control using the remaining pressure in the Blue backing accumulator. The non-return valve (NRV) for the green backing accumulator is also located in the aileron bay and a leak downstream of this would allow any reserve of Green backing pressure to leak away.

3. **Summary.** Each of the drills that select a change of flying control system would take a finite time to action. There was no mention of hydraulic failure on the mission tape before data was lost about 2 minutes before impact. Therefore, the crew had only a short time to action the basic drills as their situation rapidly deteriorated.

ANNEX P TO
BOARD OF INQUIRY
NIMROD XV230
DATED APR 07

DESCRIPTION OF CREW ACTIONS DURING THE EMERGENCY

1. **Introduction**. Nimrod crews practise regularly the drills required of the crew of XV230 on 2 Sep. Pilots and air engineers rehearse a wide range of emergencies during sorties in the flight deck dynamic simulator. Additionally, rear crews are involved in the airborne practise of drills to deal with cabin fires and warnings caused by fire or hydraulic mist in the Nimrod's underfloor bays. However, the events of 2 Sep imposed a series of concurrent emergencies on Crew 3, in a manner which would have tested any crew. There are lessons to be identified for all multi-engine aircrew from the difficulties they faced.

2. **Disposition of the Crew Prior to the Emergency**. During AAR, both beam lookout positions would normally be occupied, although the AEO[1] can undertake the starboard lookout duties from his window. Analysis of the mission tape suggests that R1[2] was in the port beam, with S2 either in the starboard beam, or at acoustics. All other crew members would have been at their stations and the 2 would have been close to an oxygen point, as briefed by the captain, but not necessarily seated.

3. **Actions When Warning Received**. Once the bomb bay fire and elevator bay warnings were received, the AEO would have moved to the galley to prepare to operate the fire extinguisher connected to the underfloor bays. The S2 probably made his way rearwards to assist the S1 secure the passengers; the wet team are normally allocated responsibility for conducting underfloor drills. He and the ESM[3] operator would then probably have assisted S1 don the portable oxygen set in view of the smoke entering the cabin from the underfloor bays; as smoke was already entering the aircraft there would have been no need for S1 to physically check the aileron bay before donning the portable oxygen. It is unlikely that anyone would have had time to go to the rear door and collect the second portable oxygen set before the aircraft depressurised. Although the captain ordered the initial actions for the bomb bay fire drill, there is no evidence that these were carried out, probably because the crew focussed on the aileron bay smoke, which may have appeared the greater threat; however, it is possible that the record of these actions could lie on a section of damaged mission tape. The crew would have been aware that the natural airflow under the cabin floor is from the aileron bay rearwards to the elevator bay and deduced that the smoke rising from the latter bay had probably originated in the aileron bay. This was initially reported from ESM as "it's in the rear bay there's smoke coming from it". The captain ordered the co-pilot onto oxygen once the smoke was reported and continued to fly the aircraft while the co-pilot donned his oxygen mask.

4. **Depressurisation**. Within a minute of the initial warnings the air engineer and pilot simultaneously reported the depressurisation of the cabin, probably marking the breach of the aileron bay wall. This complicated matters by restricting the movement of all crewmembers;

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[1] Air Electronics Officer.
[2] The mission crew operators are divided into 2 teams: the radar (dry) team (R1-R4) and the acoustic/sonar (wet) team (S1-S2)
[3] Electronic Support Measures.

each had to remain in a seat using an available oxygen mask, with freedom of movement restricted by the length of their oxygen hose. This is probably another reason why no report is ever offered from the bomb bay periscope. Also, the R1, even if he had left his seat to go rearwards to assist, would now have to return to the port beam to the vacant oxygen mask in that position. Furthermore, the S2 would have had to return to acoustics to use his oxygen mask. A request is heard from the AEO asking the air engineer to deploy the passenger oxygen masks because of the depressurisation. This should have happened automatically as the cabin altitude rose through 12 000 ft but they can also be deployed individually by manually releasing a catch on the mask stowage. However, at this point the air engineer's intercom failed, presumably in the transition from headset to mask and nothing is heard from him for the next one minute. It is unclear whether he had lost just the microphone facility and could hear but not speak or if he was totally out of contact. It is possible that he actioned items from the underfloor and depressurisation drills during this period and deploying the passenger masks would have been one of these actions. It is also possible that the crew may have moved the passengers forward into the tactical area to use vacant crew masks (AEO and S1) as this would have taken them away from the seat of the perceived threat in the aileron bay. At 1113:10 hrs the AEO states 'everyone's on oxygen down the back apart from 2 the passengers are getting theirs on now'. About 40 seconds after the depressurisation, everyone was on oxygen.

5. **Loss of the Air Engineer's Intercom**. The air engineer's role at this stage of an emergency is to take control of the drills by reading from the Flight Reference Cards (FRCs). In particular, he coordinates the underfloor drills with the AEO, to ensure the fire extinguisher is fired at the correct moment into the correct bay. He is also responsible for using his knowledge of the aircraft systems to analyse the situation and provide advice to the captain about the cause of the problem and any potential solutions. That process had begun when he tried to relate the overheated Supplementary Cooling Pack (SCP) with the bomb bay and elevator bay warnings. Given that he was off intercom for one minute, it is considered unlikely that his intercom problem was a simple switch or connection problem as these can be resolved quickly. The air engineer probably used hand signals to make the captain aware that his intercom had failed. Realising the gap in the normal process, the captain nominated the checklist reader to read the drills, but this did not happen. Therefore, loss of the air engineer's intercom was a major disruption to the smooth flow of the drills and any analysis of the problem. However, on this occasion, the nature and location of the fire were such that no action the crew could have taken would have stopped the fire.

6. **The Pilots**. During this time, the pilots had been swapping flying control of the aircraft as they each donned their oxygen masks in turn, finishing with the captain taking control back and confirming that all his crew were on oxygen. The navigators were requested to confirm the destination selected on the navigation system and replied that Kandahar was selected. The captain would then have used this information to refine his descent point; he had continued the turn towards Kandahar which had been initiated after leaving the tanker. A MAYDAY was transmitted as the captain initiated a descent for Kandahar airfield. The pilots would now have focussed on correct positioning of the aircraft to arrive at Kandahar at the correct height and speed to ensure a landing as quickly as possible. As noted in the main report, a simulator reconstruction showed that this had been successful up to one minute before the crash.

7.

No other reports were heard, or requested, of the external situation although the captain does begin to say 'and just look at..' at 1114:56 hrs. Bearing in mind that the rest of the crew were involved in fighting the immediate threat in the aileron bay, or were restricted to their crew stations by the need to remain on oxygen, this is understandable. No mention is made by the pilots of the starboard engines, although the captain asks for the 'nearest suitable'; this is possibly a request for an airfield closer than Kandahar - but there were no other airfields available. The air engineer returned to intercom shortly after this, but makes no reference to the ; this may indicate he could neither hear nor speak when off intercom. The mission tape contains no further reference to the external fire, although it is possible that reference exists in one of the damaged or missing areas of tape; nonetheless, the crew continued to focus on the immediate threat from the fire in the underfloor bay.

8. **Summary**. Crew 3 were faced with an extremely difficult, rapidly developing and complex situation. As noted in the main report, nothing they could have done would have altered the outcome. However, in dealing with those emergencies they were aware of, the crew did all that could be expected. They acted in a coordinated and logical way, adhering to standard procedures and adapting them to overcome the additional difficulties of the depressurisation and the air engineer's intercom failure. The main lessons identified are as follows.

a. It is vital that all available information is gleaned from all sources. It is possible that if the starboard lookout position had been occupied for longer, the crew would have been aware earlier that the source of the fire was external to the pressure hull. In other circumstances, early acquisition of such information might assist fault diagnosis. However, the Board considers that in the case of XV230 this not would have affected the outcome in any way.

b. Continuity of communication is crucial. The reliability of all intercom systems is essential; however, faults will occur and practice for this eventuality should be included in regular training. Nonetheless, the Board considers that the temporary loss of the air engineer's intercom had no affect on the loss of XV230.

c. Dealing with an internal cabin fire, when the crew need to be on oxygen because of fumes, has long been recognised as a difficult situation; the 3 portable oxygen sets are the only means by which a crew member can remain mobile and take an extinguisher to a fire which is not adjacent to a crew station. A similar situation occurred on XV230 but the restriction in movement was caused by the depressurisation. The QinetiQ combustion study stated that the aileron bay wall was breached in a predictably short time scale. It is likely that an internal fire in an underfloor bay will have similar consequences. Therefore, it may be prudent to consider the provision of additional portable oxygen sets. Also, their location should be given careful consideration, as only one set is currently located centrally and in easy reach of crew.

d. The crew of XV230 looked after their passengers and ensured they were on oxygen. However, a larger number of passengers would have imposed a higher supervisory load on the crew as they attempted to deal with the aircraft fire; it is not unusual to ferry larger numbers of ground crew between operational locations in the aircraft. In particular no crew member has a long enough oxygen hose to supervise the correct donning of the passengers' masks in the ordnance area.

ANNEX Q TO
BOARD OF INQUIRY
NIMROD XV230
DATED APR 07

LIST OF EXHIBITS

Exhibit	Description
1	Mission tape transcription Version 12 (23 Feb 06)
2	C2 agency transcript (SECRET US/UK EYES ONLY)
3	Statement of (CSAR Team) (13 Sep 06) provided to SIB Kandahar
4a	Statement of 34 Sqn RAF (15 Feb 07)
4b	Answers by to further questions from BOI
5	No 120 Sqn Crew 3 Combat Ready Status (1 Aug 06)
6	Flight Authorisation Sheet and Flying Times (02 Sep 06)
7	DARU transcription
8	Kandahar ATC Transcript (2 Sep 06)
9a	Statement of , The Royal Canadian Dragoons (2 Feb 07)
9b	Supplementary answers from , The Royal Canadian Dragoons
10	
11	Photographs (held in separate folder)
12a	AAIB Final Report into the Accident to a Nimrod MR2 XV230 (EW/D2006/09/1)
12b	Supplementary letter to AAIB Final Report
13	Notes taken during discussion with (Pilot of Predator) (7 Sep 06)
14	Statements by (Member of initial deployment from Kandahar) (7 Sep 06 and 8 Sep 06)
15	XV230 MOD Form 705 – Flight Servicing Certificate (Sheet 90)
16	Weather Forecast for South West Afghanistan (1 Sep 06 to 3 Sep 06)
17	Aviation Pathology Report - Number 10 of 2006 (2 Feb 07)
18	Confirmation of Aircraft Categorisation Signal (ABA HIL KQY K3H 061200ZDec06)
19	Book value of XV230 and Cost of Role Equipment Lost on XV230
20	Third Party Civilian Claims – Afghanistan (Civil secretariat HQ PRT Lashkargah letter LKG/J8 23 Feb 07)
21	Loss of Protectively Marked material, V&A Equipment and Other Items aboard Nimrod XV230 (11 Dec 06)
22	Missing items of PM material presumed lost in crash of XV230 Nimrod (KIN/310/2/06/06/Sy (2 Oct 06 and 11 Oct 06)
23	Addendum 1 to BAE SYSTEMS Report (MBU-DEF-R-NIM-SC-0976 Issue 2, 2 Sep 04)
24	XV227 Hot Air Duct Failure – Requirement for Leak Detection System (IPT letter DLO(strike)(wyt)/512752/21/227 5 Jul 06)
25	Letter for IPT following meeting on 20 Feb (DLO/STRIKE/WYT/512752/21/230 15 Mar 07)
26	Nimrod R1 XV249 Report Post Fuel Leak Investigations May-Jul 99 (51S/402/1/1/Eng 23 Jul 99)
27	Kandahar ATC Radar Tape Corruption (18 Feb 07)

Exhibit	Description
28	RN Flight Safety and Accident Investigation Centre - Accident Report 3/06
29	Drawing of clam shell doors by (7 Sep 06)
30	QinetiQ Combustion Analysis of Nimrod MR2 XV230 Accident (QINETIQ/05/01833/2 6 Mar 07)
31	Extract of Ageing Aircraft Structural Audit Nimrod MR2/R1 (BAE SYSTEMS Report MBU-DEB-S-NIM-ST-0082 Mar 03, Page 8)
32	JAP 100A-01, Chap 5.13 [Ageing Aircraft Audit]
33	Further clarification of BOI questions – FRS Coupling Maintenance Policy (IPT Letter DLO/STRIKE/WYT/512752/21/230 10 Jan 07)
34	Specification for the Design of Flight Refuelling Ltd. Standard Pipe Connectors (ED/11/100 12 Nov 70)
35	Nimrod XV249 Persistent Fuel Leaks (BAe letter PJP/AF/402 26 Jan 99)
36	NAEDIT Task Report 917/06 Provide Operating Temperatures of Hot Air Pipes and Temp Control Amplifiers (NAEDIT/1505/06/917TASK Dec 06 and 8 Jan 07)
37	Extracts from Nimrod Safety Case (print outs from Cassandra database 8 Feb 07)
38	Ground Incident Report KIN/142/00 XV229 (11 Dec 00)
39	Extracts from AP101B-0503-3A, Chap 41-20, Figures 7 and 8 [Showing unidentified couplings and seals]
40	Reconstruction of MOD Form 703 and 704 for XV230
41	IPT Response to BOI Query – AQS971 Acoustic System (DLO(Strike)(Wyt)/5/8/5/2 Feb 07)
42	Ground Security at – 1/2 Sep 06 (30 Nov 06)
43	DSTL letter from [Miss[illegible] Engagement Report] (7 Nov 06)
44	Post Flight Report (extract)
45	Post Flight Report (extract)
46	Serious Fault Signal XV255 fuel pipe leak in Rib 1 (4 Sep 06)
47	Serious Fault Signal XV236 corroded pipe in Rib 1 (22 Nov 06)
48	Eaton Aerospace Investigation Report [Fuel Seal Analysis] (L1/06/044 12 Jan 07 and 19 Mar 07)
49	Fuel Pipe Pressure Test Report (AWN/NIM/1538, Issue 1 Mar 07)
50	Annex I to AP101B-0500 Topic 2(R)1, Leaflet 013 [Fuel Leaks]
51	Request for Information – Nimrod R1 AAR Fuel Leaks (51S/402/9/Eng 30 Jan 07)
52	Observed Pressure Surges Nimrod R1 (51S/4/2/Air 22 Feb 07)
53	Details of Nitrogen Purge Gauging System [Pressure Transducer and Gauge] (BAE SYSTEMS letter 07/0006/CL dated 31 Jan 07)
54a	AP101B-0503-15A, Book 1, Part 2, Chap 11 [90% call] AL18
54b	AP101B-0503-15A, Book 1, Part 2, Chap 11 [90% call] 3rd Edition, Initial
55	BAE SYSTEMS advice on Definition of Assumed Fuel Pipe Pressures (07/0007/CL 5 Feb 07)
56	Extract from Tristar K Mk1 Release Trials 1986-1989, Nimrod Annex (TM1485 Nov 89)
57	Ground Incident Report KIN 59/06 XV252 (31 Oct 06)
58	Nimrod AEW Mk3 Operating Instructions for AAR (BAe Report HAS-MPP-

Exhibit	Description
	F-AEW-0068 Jul 85)
59	BAES Memo – Advice on Tank 1 and 5 BOV Dye Testing in Flight (07/0010/CL 20 Feb 07)
60	BAES airflow modelling diagrams
61	AP101B-0503-15A, Book 3, Part 2, Chap 11 [AAR Refuelling]
62	Identification of Electrical Supplies in Rib 1 and No 7 Tank Dry Bay
63	Integral Thermal Insulating Scheme for High Temperature Stainless Steel Ducts (Specification DHA/567 13 Sep 67)
64	NiMS/NLS Dry Bay Water Test (KIN/900/30/Eng 16 Feb 07)
65	Decent Profile Study – Nimrod Dynamic Simulator (OC STANEVAL Report W:\STANEVAL\Boss\ CORRESPONDANCE\ SIMULATOR TRIAL run 1 – JR Report.doc 26 Sep 06)
66	Nimrod AEW Mk3 Integrity of Tanks 1 and 5 Blow Off during AAR (BAe Report HAS-MPP-F-AEW-0063 15 Mar 85)
67	Nimrod AEW Mk3 AAR System (BAe Report HAS-MPP-F-AEW-0065 May 85)
68	Nimrod R1 – Airframe Strength [Structural Problems related to AAR] (BAe Letter 15 Jan 87)
69	Nimrod MR2 Refuel System Tests (2 Feb 07)
70	QinetiQ/HAL report on No 1 Tank Modelling
71	Nimrod No 1 Tank Back Pressure Analysis (BAE SYSTEMS letter MBSY/MA/050307/1 1 Mar 07)
72	STANEVAL Tristar Refuel Test (6 Feb 07)
73	Notes on telephone call with , The Royal Canadian Dragoons
74a	Photograph of the relative size of the Nimrod as seen by Harrier GR7 pilot
74b	Photography of the relative size and aspect of the Nimrod as seen by The Royal Canadian Dragoons
75	Declaration of Design and Performance for FRS Couplings
76	Board's record of the meeting with DLO, Eaton Aerospace and BAE Systems (29 Mar 07)
77	Review of Maintenance Procedures for Aircraft System Seals – Interim Report (Task ASG ASI 1/07)(TES(WYT)/366/8/2/ASG 28 Feb 07)
78	JAP 100A-01 Chap 5.4, Para 10 [Corrective Maintenance Data Gathering and Analysis]
79	QinetiQ Report on DARU and Mission Tape analysis (EPT ESR 01446 2 Apr 07)
80	BAE Systems Review of Nimrod Accident History (MBU-DEF-R-NIM-SC-0676 2 Sep 04)
81	Extract from Cassandra database quoting Nimrod IPT's Final approval of baseline Hazard Log (DLO(Strike)(WYT)512725/27/1/Nimrod 1 Feb 05)
82a	Initial Statement by Harrier GR7 Pilot (3 Sep 06)
82b	Human Factors Report by HFI Ltd (9 Oct 06)
82c	Diagram concerning the last minutes of VIGIL 34
83a	Tristar Mission Report (2 Sep 06)
83b	Statement by Tristar Captain (7 Sep 06)
83c	Statement by Tristar Air Engineer (undated)
83d	Statement by Tristar Co-Pilot (undated)

EMBARGOED UNTIL 1530 4 DECEMBER 2007

ANNEX R TO
BOARD OF INQUIRY
NIMROD XV230
DATED APR 07

LIST OF WITNESSES

Witness	Details	Position
1		Air Traffic Controller, Kandahar Air Base
2		73 EACS, Kandahar Air Base
3		904 Expeditionary Air Wing, Kandahar Air Base
4		, Nimrod Detachment, DOB
5		120 Squadron
6		Duty Briefing Officer, DOB
7		Engineering Officer, Nimrod Detachment, DOB
8		Aircraft Ground Engineer, Nimrod Detachment, DOB
9		Propulsion Tradesman, Nimrod Detachment, DOB
10		Electrical Tradesman, Nimrod Detachment, DOB
11		Avionics Tradesman, Nimrod Detachment, DOB
12		Armour Tradesman, Nimrod Detachment, DOB
13		Radar Tradesman, Nimrod Detachment, DOB
14		Airframe Tradesman, Nimrod Detachment, DOB
15		Aircraft Ground Engineer, Nimrod Detachment, DOB
16		Propulsion Tradesman, Nimrod Detachment, DOB
17		Airframe Tradesman, Nimrod Detachment, DOB
18		Electrical Tradesman, Nimrod Detachment, DOB
19		DOB , 902 EAW, DOB
20		RAF Police (Special Investigator), DOB Security Officer, DOB
21		SNCO IC DOB Medical Centre, DOB

Witness	Details	Position
22		Air Engineer, Crew , 120 Squadron, Nimrod Detachment, DOB
23		Captain, Crew , 120 Squadron, Nimrod Detachment, DOB
24		Pilot , Crew , Nimrod Detachment, DOB
25		Engineering Officer, 216 Squadron Detachment, DOB
26		Air Engineer, 216 Squadron Detachment, DOB
27		Pilot, IV(AC) Squadron, RAF Cottesmore
28		Senior Aircraft Ground Engineer, Nimrod Line Squadron, RAF Kinloss
29		Captain, 216 Squadron, RAF Brize Norton
30		Pilot, 216 Squadron, RAF Brize Norton
31		Air Engineer, 216 Squadron, RAF Brize Norton
32		Operations Wing, RAF Kinloss
33		Nimrod Line Squadron, RAF Kinloss
34		Logistics Support Wing and Depth Support Manager, Nimrod IPT, RAF Kinloss
35		Propulsion Trade Specialist, Nimrod Line Squadron, RAF Kinloss
36		STANEVAL Air Engineer, RAF Kinloss
37		Sqn Cdr A Sqn, The Royal Canadian Dragoon, CFB Petawawa
38		Driver, The Royal Canadian Dragoons, CFB Petawawa

ANNEX S TO
BOARD OF INQUIRY
NIMROD XV230
DATED MAR 07

GLOSSARY

Abbreviation	**Meaning**
AAA	Ageing aircraft audit
AAIB	Air Accident Investigation Branch
AAR	Air-to-air refuelling
ac	Alternating current
ACM	Aircrew manual
ADR	Accident data recorder
AEW3	Nimrod airborne early warning aircraft mark 3
agl	Above ground level (height)
ALARP	As low as reasonably possible
AMM	Aircraft maintenance manual
amsl	Above mean sea level (height)
APU	Auxiliary power unit
ARC	Air refuelling and communications
ATC	Air traffic control
BAe	British Aerospace
barg	Bar gravity
BLEVE	Boiling liquid expanding vapour explosion
BTM	Bromotrifluromethane
C2	Command and control
CAU	Cold air unit
CO	Commanding Officer
CR	Combat ready
CR(A)	Combat ready (advanced)
DARU	Data acquisition and recording unit (ADR)
DASC	Defence Aviation Safety Centre
dc	Direct current
Def Stan	Defence standard
deg	Degrees
DLO	Defence Logistics Organisation
DPP	Declaration of Design and Performance
DOB	Deployed operating base
EAW	Expeditionary Air Wing
ESM	Electronic support measures
F700	MOD Form 700 – aircraft maintenance log
F703	MOD Form 703 – limitation log
F704	MOD Form 704 – acceptable deferred defects log
fg hrs	Flying hours
FI	Fatigue index
FL	Flight level (height in thousands of feet in ISA
Flt Lt	Flight Lieutenant

Abbreviation	Meaning
FRC	Flight reference cards
FS	Flight Sergeant
gall	Gallon
GPS	Global positioning system
GR7	Harrier ground attack and reconnaissance aircraft mark 7
HAL	Hydraulic Analysis Ltd
HP	High pressure
IED	Improvised explosive device
IPT	Integrated project team
ISA	International standard atmosphere
JAP	Joint air publication
kg	Kilogramme
lb	Pounds
LCpl	Lance Corporal
LH	Left hand
LP	Low pressure
min	Minute
MLEP	Mini life extension programme
MOD	Ministry of Defence
Mod	Modification
MR2	Nimrod maritime reconnaissance aircraft mark 2
MRA4	Nimrod maritime reconnaissance and attack aircraft mark 4
NM	Nautical mile
NRV	Non return valve
NSC	Nimrod safety case
OC	Officer Commanding
OSD	Out of service date
PRSOV	Pressure reducing and shut-off valve
psi	Pounds per square inch
QNH	Airfield altimeter pressure setting
R1	Nimrod reconnaissance aircraft mark 1
R1	Crew position radar 1
RAF Regt	Royal Air Force Regiment
RCD	The Royal Canadian Dragoons
RH	Right hand
RN	Royal Navy
RPM	Revolutions per minute
SAM	Surface-to-air missile
SAR	Search and rescue
SCP	Secondary cooling pack
sec	Seconds
Sgt	Sergeant
SOP	Standard operating procedure
Sqn	Squadron
Sqn Ldr	Squadron Leader
UAV	Unmanned air vehicle
UOR	Urgent operational requirement

Abbreviation	Meaning
USAF	United States Air Force
USN	United States Navy
ZFW	Zero fuel weight
ZULU	Greenwich mean time/universal time

ANNEX A TO
PART 2A OF
BOARD OF INQUIRY
NIMROD XV230
DATED 25 JUL 07

FUEL SYSTEM LEAKS PER 1000 FLYING HOURS

1. **Introduction.** Annex I of the main BOI report details the analysis of the fuel system maintenance history for the years 1984 to 2005[1]. This Annex illustrates fuel system leaks per 1000 flying hours (FH).

2. **Analysis of Data**. With the decrease in fleet size over the sample period, the number of total fleet flying hours has also reduced. When the fuel leak rate per 1000FH for fuel system couplings and seals (Table 1 and Figure 1) is examined, there is a continual increase from 0.5 leaks/1000FH in the 1980s, increasing to 1.5/1000FH in the 1990s and to 3.5/1000FH in the 2000s. The data for pipe leaks shows a low and stable rate of less than 0.5/1000FH. The leak rate from tanks has also shown an increase (Table 1 and Figure 2), which appears to have stabilised over the past 10 years at 2/1000FH. However, it must be cautioned that although the data was filtered to exclude wing tanks, this cannot be guaranteed and there has been significant work carried out to reduce wing leak on the MR2 fleet over the past couple of years.

3. **Conclusion.** The data shows the same increasing trend (as identified in the main report) in fuel leaks from couplings and seals.

Appendix:

1. Fuel System Fault Rate per 1000FH.

[1] Data from 1983 to 2006 was supplied from the Maintenance Data System, although as the data for 1983 and 2006 appeared incomplete only that for the period 1984 to 2005 was used for analysis.

APPENDIX 1 TO
ANNEX A TO
PART 2A OF
BOARD OF INQUIRY
NIMROD XV230
DATED 25 JUL 07

FUEL SYSTEM LEAK RATE PER 1000FH

Table 1 – Fuel Leak Faults per 1000FH by System Component Level

Year	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Nimrod Fleet Flying Hours[1]	17342	18114	17012	19255	18480	17863	17018	16017	16731	15145	14622	14011
Coupling & Seal Leaks	1	12	16	16	7	8	8	22	39	24	22	19
Pipe Leaks	0	1	4	1	0	2	0	2	6	3	5	5
Fuselage Tank Leaks	1	13	9	14	10	12	5	21	21	15	27	25
C+S Leaks/1000FH	0.058	0.662	0.941	0.831	0.379	0.448	0.470	1.374	2.331	1.585	1.505	1.356
Pipe Faults/1000FH	0.000	0.055	0.235	0.052	0.000	0.112	0.000	0.125	0.359	0.198	0.342	0.357
Tank Leaks/1000FH	0.058	0.718	0.529	0.727	0.541	0.672	0.294	1.311	1.255	0.990	1.847	1.784

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Nimrod Fleet Flying Hours[1]	14094	12869	13456	12931	12546	12270	12482	11982	12072	11978	10196	9106
Coupling & Seal Leaks	23	15	24	33	42	21	42	44	42	38	39	5
Pipe Leaks	7	5	9	5	11	0	2	1	2	4	5	1
Fuselage Tank Leaks	27	28	34	28	23	18	32	24	26	27	10	4
C+S Leaks/1000FH	1.632	1.166	1.784	2.552	3.348	1.711	3.365	3.672	3.479	3.172	3.825	0.549
Pipe Faults/1000FH	0.497	0.389	0.669	0.387	0.877	0.000	0.160	0.083	0.166	0.334	0.490	0.110
Tank Leaks/1000FH	1.916	2.176	2.527	2.165	1.833	1.467	2.564	2.003	2.154	2.254	0.981	0.439

[1] Includes Nimrod R1 and MR2.

Figure 1 – Graph of Fuel Leak Faults from Pipes and Couplings & Seals per 1000 Flying Hours per Year

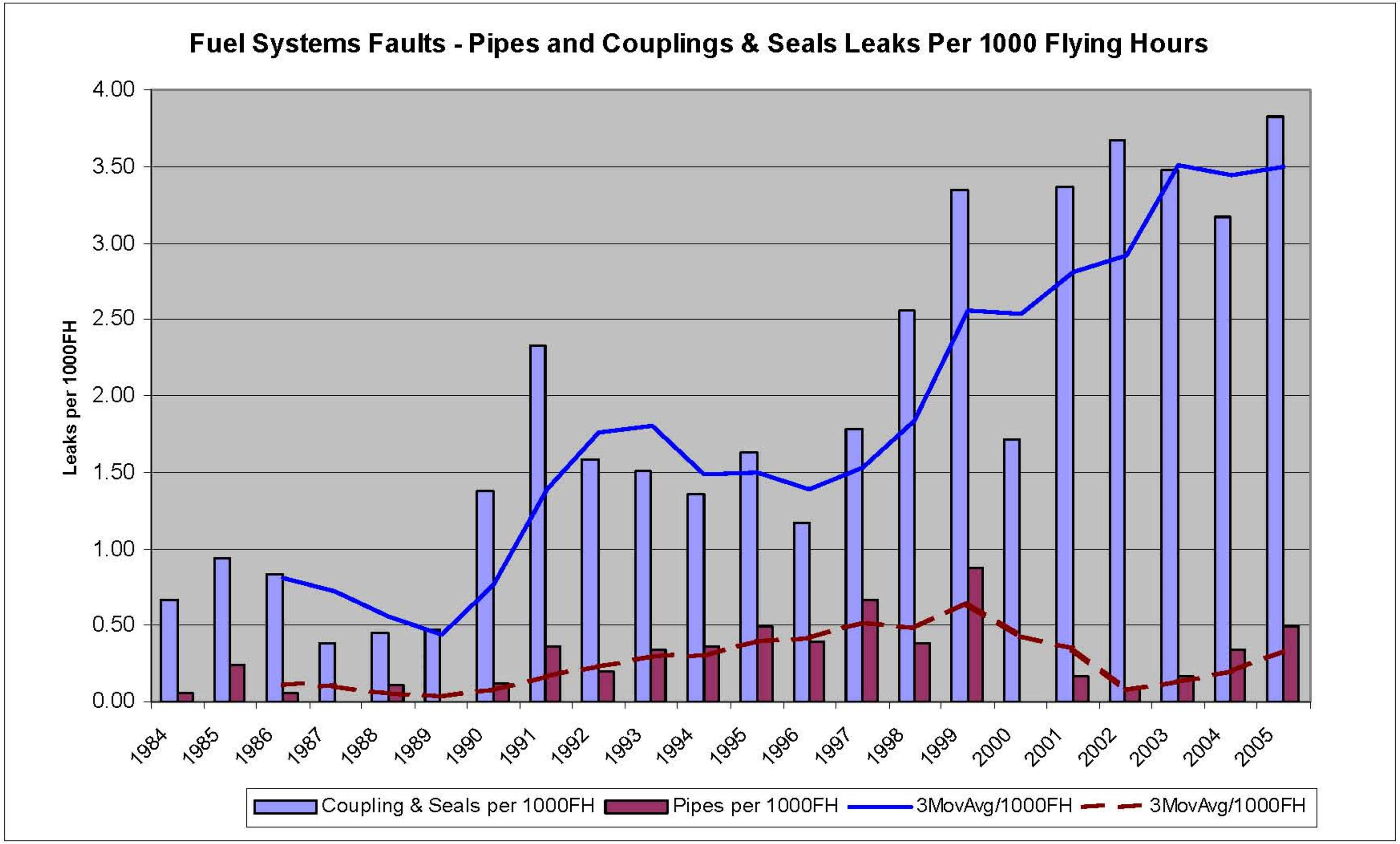
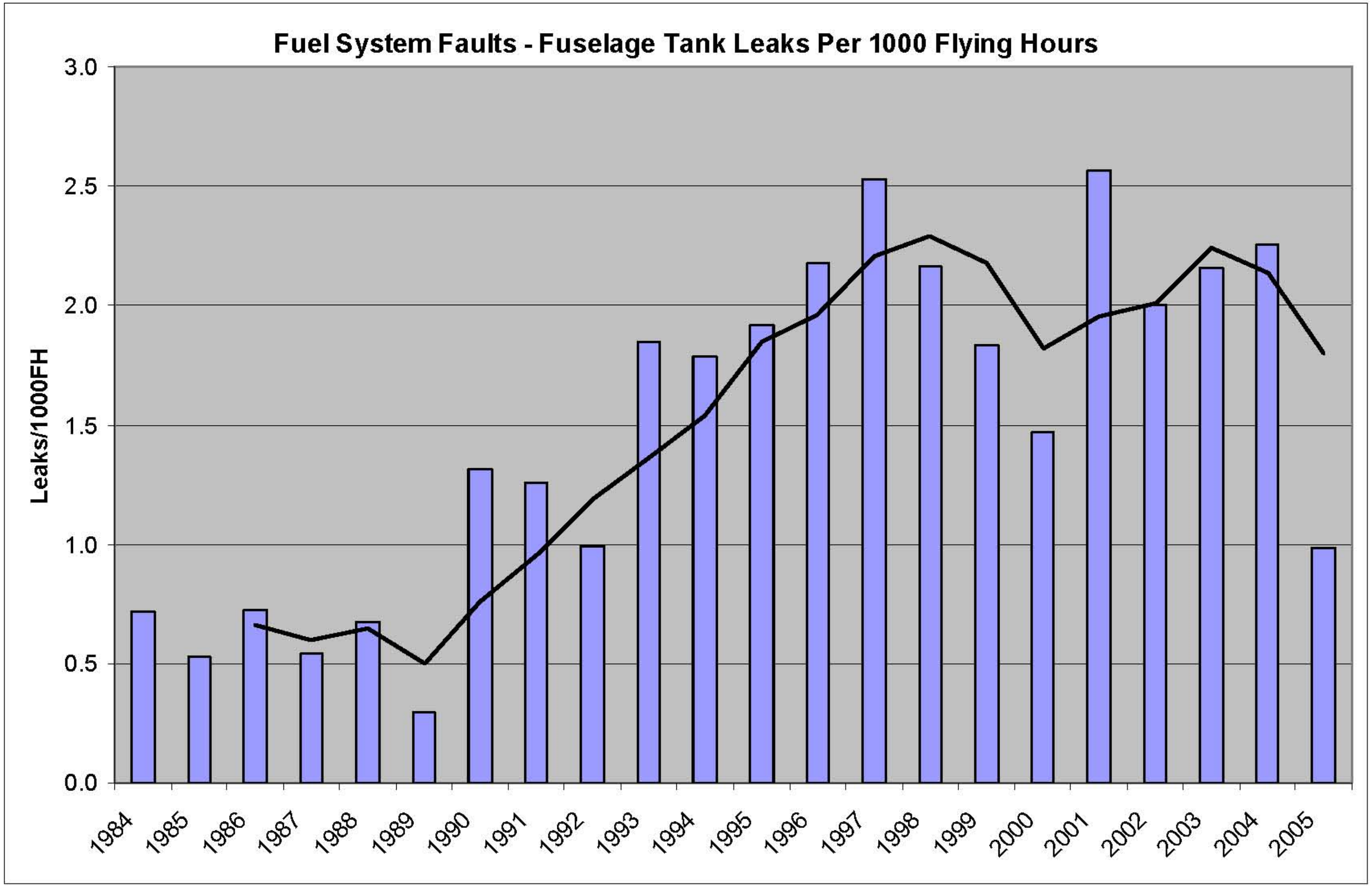


Figure 2 – Graph of Fuel Leak Fault from Fuselage Tanks per 1000FH by Year



BOARD OF INQUIRY (F412) INTO THE LOSS OF NIMROD MR2 AIRCRAFT XV230 ON 2 SEP 06 – STATION COMMANDER'S COMMENTS

INTRODUCTION

1. The Board of Inquiry (BOI) were confronted with a significant challenge in establishing the events that lead up to the crash of XV230. Their inability to examine the crash site, coupled with an almost total lack of mechanical evidence, imposed severe constraints on the lines of enquiry that were open to them. Their achievements are, therefore, notable for their completeness, tenacity and determination to ascertain as best as possible what might have caused the fatal accident on 2 Sep 06. That said, given the limitations under which they were working, I believe establishing with absolute certainty the precise source or cause of the fire, to be impossible.

COMMENT ON FINDINGS

2. Comment on the BOI's findings in terms of causes and factors, is, in this instance, necessarily predicated on acceptance that the seat of the fire has been correctly identified. Having examined the available evidence, I am content the Starboard No 7 Tank Dry Bay is the most likely origin of the fire; furthermore, I believe both the bomb bay and the No 3 engine can be discounted and that the starboard Rib 1 landing is highly unlikely to be the seat of the fire. Hence, I am content that the Board's route of investigation was sensible and I am also happy that their analysis of causes and factors is logical, although I do not fully agree with their findings.

3. Causes. I concur with the BOI's findings in their determination of the probable and possible causes. Now that the mechanics of the No 1 Tank are fully understood, it is evident that overflow of fuel during AAR from the No 1 Tank Blow-Off Valve is a phenomenon that may have occurred since the inception of AAR on the Nimrod MR2. I would also reinforce the BOI's assessment that a fuel leak occasioned by a hot air leak damaging a fuel seal seems the least probable source of fuel for the fire. When placed against the No 7 Tank Dry Bay as the origin of the fire, the QinetiQ combustion analysis at Exhibit 30 is compelling evidence that leaves little room for doubt that the cross feed or SCP pipe assembly was the probable source of ignition.

4. Contributory Factors. I agree with the BOI findings with respect to the lack of a fire detection and suppression system in the No 7 Tank Dry Bay. I would also note, however, that the portion of the bomb bay fire detector wire that runs close to the 7 Tank Dry Bay (which provided the first indication of a problem with the aircraft) can in no way be considered an integral fire detection system for the 7 Tank Dry Bay: this fire detection system is incapable of providing a location of a fire within or around the bomb bay. I also have a number of observations and comments over the other possible contributory factors identified by the Board.

a. Age of Non-Structural Components. While noting in the addendum to their report that the BOI have clarified their conclusions on this question, I disagree that age was a contributory factor. The Board's additional work, which again focuses on fuel seals and the SCP/cross-feed pipe insulation, draws the conclusion that 'condition' is linked to the length of time such seals are in situ. While I agree that age will not improve the condition of these components, condition remains the central piece in this argument and the condition of fuel seals and insulation could be affected at any time during the aircraft or a component's life. I can not, therefore, agree with the BOI; my assessment is that the 'condition' of the Nimrod MR2's non-structural components, specifically fuel seals and the SCP/cross-feed pipe insulation, was a possible contributory factor.

b. Nimrod Safety Case/Hazard Analysis. From the evidence presented by the BOI, I believe the Zone 614 portion of the NSC the most important possible contributory factor in the loss of XV230. The BOI has correctly identified a number of fundamental errors in the hazard analysis and I would add that even when the SCP was not operating, standard procedure was for the engine cross-feed pipe to remain pressurized, whenever engines were shut down for fuel economy, in order to affect an immediate air-assist engine start should an emergency make it necessary. The errors contained within this portion of the NSC, be they over operating practice, aircraft design or the probability of fuel leaks are fundamental, and without doubt lead to an incorrect assessment of risk that perpetuated the likelihood of fuel coming into contact with an ignition source in Zone 614 – that is, the SCP/cross-feed pipe.

c. Nimrod MR2 Fuel System Maintenance Policy. Subsequent to their initial findings, the BOI were asked to determine whether fault trends within the Nimrod MR2's fuel system components had been analysed effectively, in order to validate the suitability of Nimrod maintenance policy. New evidence clearly indicated that fault trends had been analysed and hence, the direction contained within JAP 100A-01 has been followed. That said, the analysis was not effective as it did not identify the increase in fuel leaks that the BOI uncovered. Given that the Nimrod MR2 maintenance policy was, in part, based on an incorrect hazard analysis in the NSC (para 4b), the probability of fuel coming into contact with the SCP/cross-feed pipe was therefore increased. In the instance that the source of the fuel for the fire on XV230 was a fuel system leak, the Nimrod MR2 maintenance policy is a clear contributory factor.

d. Incorporation of the AAR Capability on to the Nimrod MR2. Prior to 2 Sep 06, the AAR capability on the Nimrod evolved through a number of equipment installations and modifications, and procedural changes. In parallel, the Tristar tanker, with an increased refuel rate, arrived in 1989. Annex L to the BOI's report identifies a number of important pieces of information that, while relatively innocent in isolation, when linked together have serious implications. Hence, the Board found that formal incorporation of the AAR capability was a possible contributory factor. Their assessment, however, contains the caveat 'did not identify the full implications of successive changes'. Although I have no doubt that each stage of the development of the Nimrod AAR capability as described in Annex L was appraised, at no point was a holistic view, which looked to the past as well as the present, taken. I believe, therefore, that a more correct caveat would be 'did not identify the compound implications of successive changes'. Although a subtle change, I believe it better reflects the need for comprehensive monitoring of, and responsibility for, through life aircraft development.

5. Aggravating Factor. I agree with the BOI.

COMMENT ON OBSERVATIONS

6. Many of the observations fall out with my remit. However, it is right that I comment on 3, if only to present an up to date picture.

a. RAF Kinloss Management Structure. The Kinloss management structure has now been revised to include an SO1 engineer. This individual now commands the Station's Forward Support Wing and holds QR 640 responsibilities.

b. Non-Standard Blanking Plates. While the IPT is correct in it's assurance that there are sufficient quantities of acoustics systems, the instance in question was wrapped up in the peculiarities of specific role equipment and insufficient acoustics systems being available in theatre. This is only offered as an explanation of the occurrence, and procedures have now been put in place to ensure that this does not happen again.

c. AAR Refuel Rates. All AAR qualified Air Engineers have been re-trained on AAR procedures by STANEVAL Air Engineer and reminded that refuel rates in the dynamic simulator are not fully representative. A software update will be required to provide more accurate simulation.

COMMENT ON RECOMMENDATIONS

7. I have a number of comments and observations on the recommendations made by the BOI. Where I have not commented, it can be assumed that I support the recommendation.

8. Policy. I agree with all of the BOI's recommendations with respect to maintenance policy. In particular, I strongly support the recommendation that the NSC be reviewed with widespread ground and aircrew input. This approach should be adopted for all aircraft fleets in order to avoid misinterpretation or misunderstanding of operating practice and aircraft design leading to incorrect hazard analysis. As to the recommendation for a review of fuel and hot air systems, I would press that the main aim of any such review should be to remove or isolate potential ignition sources. All aircraft will leak fuel at some stage. The only feasible approach is, therefore, to focus on removing potential ignition sources.

9. Fuel System. While supporting the recommendation that a life for the FRS Series 1 fuel seal be determined, such a life should be based on an understanding of the failure mode and factors that promote degradation as these will determine when a seal is not fit for purpose rather than simply installed or shelf life.

10. Hot Air System. Given the limited life remaining for the Nimrod MR2, existing limitations on the use of the cross-feed pipe and the SCP should remain in place until the aircraft goes out of service.

11. AAR. AAR procedures have already been modified to more benign limits in terms of refuel flow rates and pressure, and tank refuel levels. Since these procedures were introduced, more than 35 sorties have conducted AAR without incident. That said, I agree these procedures should be formally reviewed against all AAR scenarios. While a study into the effect of pressure surges and their long term effect will have limited utility for the Nimrod MR2, if widened, such a study would benefit all AAR receiver fleets and should therefore be undertaken.

12. Operational. I do not believe that the fitting of parachutes on the Nimrod MR2 is practical. Available stowage space and, from personal experience of flying a multi-crew aircraft equipped with parachutes, sheer physical space to don a parachute are in my opinion insurmountable limiting factors for the Nimrod MR2.

13. Aircraft Modification. Given that AAR procedures have been modified in order to avoid the potential for No 1 Tank blow off valve operation or fuel to enter No 1 Tank vent pipes, and assuming the review recommended at para 11 provides full assurance over these, I see no reason to pursue the relevant modifications proposed. Likewise, the problems associated with asymmetric filling of the No 1 tank have also been mitigated. Given the source of ignition in the 7 Tank Dry Bay area has also been removed, I see no justification for modifying the 7 Tank Dry Bay lower panels.

ADDITIONAL RECOMMENDATIONS

14. AAR restrictions. Subsequent to 2 Sep 06 Service Deviation (SD) 132, which restricts the occasions under which AAR can be used on the Nimrod MR2, was issued. Given that all potential sources of ignition have been removed from around the refuel gallery and that AAR has been completed successfully on some 35 sorties without any activation of the No 1 Tank Blow Off Valve, consideration should be given to updating SD 132 such that AAR can take place on a routine basis. However, the 50 psi pressure test of the refuel system, articulated within Routine Technical Instruction 170, should remain in place.

HUMAN FACTORS

15. Crew 3 was an unusually experienced crew with 2 of the Nimrod Force's most capable and knowledgeable aviators, Flt Lt Squires and FS Davies, on the flight deck. I knew and had flown on many occasions with both of them, as well as a number of the remainder of the Crew, and am not surprised that the evidence shows they all reacted in a highly professional and determined manner to the complex and demanding set of emergencies they faced.

CONCLUSION

16. Circumstance dictates that the BOI has been unable to positively determine the exact chain of events that lead to the loss of XV230. But for the fire on XV230 to occur, an ignition source and fuel had to be brought together. The genesis of the ignition source – the SCP/cross-feed pipe – can be traced back to the very origins of the aircraft. The Nimrod MR1 design introduced the cross-feed pipe for engine starts on the ground and in the air, while the Nimrod MR2 aircraft update brought the SCP into service. Subsequently, errors in the NSC/hazard analysis lead to an incorrect assessment of risk over the Starboard No 7 Tank

Dry Bay and hence, an unprotected potential ignition source was not mitigated. The exact route of the fuel will never be determined absolutely. However, the incorporation of the AAR capability on the aircraft, combined with the lack of effective analysis within the Nimrod MR2's maintenance policy, increased the likelihood of fuel coming into contact with the SCP/cross-feed pipe and a fire igniting in an area which is both unprotected and impossible to diagnose in the first instance.

17. The BOI are to be congratulated for the completeness they have achieved. Given the constraints that were forced on them, I am entirely content that they have met their Terms of Reference as best as possible. Subject to my comments above, their findings, while not absolute, are on the whole logical and supported by credible and compelling expert evidence which goes a long way towards removing doubt as to the precise cause and factors that lead to the loss of XV230 and its crew.

J B KESSELL
Group Captain
Station Commander   Date____________________

BOARD OF INQUIRY INTO THE LOSS OF NIMROD MR2 AIRCRAFT XV230 ON 2 SEP 06 – AIR MEMBER FOR MATERIEL'S COMMENTS

INTRODUCTION

1. The Board of Inquiry (BOI) has produced a very thorough report and has made significant progress towards identifying the cause of this tragic accident. I can endorse their overall conclusion that the probable cause of the crash was the loss of structural integrity and controlled flight following a severe fire in the starboard wing root that did not arise from hostile action. However, given the very limited access to the crash site, it is clear that we will never know the cause of the fire with any certainty.

2. In my role as the Royal Air Force's Air Member for Materiel and its most senior Engineer, I am therefore keen to ensure that in the absence of such certainty, and given the remaining in-service life of this aircraft, we exercise sound judgement to target those measures most likely to assure the integrity of the current Nimrod fleet, accepting that some measures will be across a broad front to cover a range of perhaps less probable, but still possible causes. Whilst I concur with the general thrust of the BOI findings I am unable to agree with all of their conclusions or all of the Station Commander's remarks, to the extent detailed in the following paragraphs. Where I make no comment either I concur with the findings, or they are outwith my remit.

GENERAL POINTS

3. As with all other aircraft, combustible material (such as fuel) and potential ignition sources are present throughout the Nimrod and the avoidance of fire is dependent upon one being kept from coming into contact with the other. Reducing the occurrence of fuel leaks is clearly desirable and the increased leak rates indicated by the data considered by the BOI are worthy of further examination to substantiate the trend, determine possible causes and effect remedial action. However, as the Station Commander remarks, fuel leaks on aircraft are inevitable and we cannot depend upon eradicating them entirely. We must not, therefore, allow ourselves to be seduced into a belief that reducing fuel leaks, for instance by applying a finite life to installed seals, would necessarily yield improvements in aircraft safety unless there is clear evidence to support this. Indeed, through the necessary associated disturbance to other aircraft systems (for example electrical, hydraulic, flying control) as well as disturbance to the fuel system itself, experience shows that such action may actually introduce more problems than it solves, thereby having a detrimental effect on safety. Instead, primacy should be afforded to taking action to mitigate any consequential hazard to the aircraft arising from a leak.

COMMENTS ON FINDINGS

4. I am satisfied that the BOI has presented sufficient evidence to discount the Port Wing, the Bomb Bay and the Starboard Engine Bay as locations for the origin of the fire and to substantiate their finding that the source of the fire was most probably in the area of the Starboard Number 7 Tank Dry Bay.

Causes

5. The BOI concluded there to be two probable sources of fuel, a leak from a fuel coupling seal failure or Air-to-Air Refuelling (AAR) overflow via the No 1 Tank Blow-off Valve, but were unable to determine which of these is the most likely. Having considered the evidence presented by the BOI, I believe AAR overflow to be the most likely for the following reasons:

a. AAR overflow is a design characteristic which is not predicated on the presence of a fault.

b. The close proximity of the time of the fire with the completion of AAR and the observed Supplementary Conditioning Pack (SCP) shut down.

c. Other cases of apparently similar fuel overflow during AAR in similar circumstances shortly before and after the loss of XV230.

6. I am satisfied that actions now taken to change AAR procedures are sufficient to ensure that the conditions needed for overflow to occur are avoided.

7. Whilst it is in my view the less likely of the two sources of fuel, I agree that a fuel leak from either a coupling or fractured pipe (or indeed as a consequence of a hot air leak) cannot be excluded as a possible source of the fuel. Inspections introduced by Routine Technical Instructions (RTIs) are being undertaken to confirm the integrity of the fuel systems and possible sources of ignition, and further activities are underway to determine whether changes to the maintenance of fuel seals would reduce the likelihood of leaks.

8. As to the ignition source, I agree that the hot air pipe bellows coupling associated with the SCP located in the pannier fairing immediately below the Starboard No 7 Tank Dry Bay is the most likely source of ignition. It must be recognised, however, that for auto-ignition to occur would have required the sustained presence of fuel giving rise to vapour within the No 7 Tank Bay. This would tend to rule out minor fuel system leakage. Prohibiting use of the SCP removes this ignition source but we must not allow ourselves to be convinced that consideration of other potential sources of ignition can thereby be excluded. This is especially important because ignition sources are more readily avoided than fuel leaks and therefore have a more prominent influence on improving aircraft safety. The current enhanced inspection regime is designed to mitigate any hazards arising from these, pending completion of an independent fuel system safety analysis.

Contributory Factors

9. I can find no direct evidence to support the linkage between aircraft integrity and the age of non-structural components (notably fuel seals and hot air duct insulation) ascribed by the BOI, or their condition as ascribed by the Station Commander. Equally, I accept that neither is there evidence that they can be entirely discounted as a contributory factor in the loss of XV230. Further work will therefore be necessary to enable informed

decisions on the long term remedial measures which might be necessary to supplement or relax those measures already put into place to assure the aircraft's safe operation.

10. Although the BOI has shown data that indicates that the rate of fuel leaks has increased, I do not agree that this supports the conclusion that fuel system maintenance policy is a contributory factor. Even if the fire had been occasioned by a fuel leak, as opposed to AAR overflow, concluding that the loss of XV230 would have been avoided by a preventative maintenance regime is flawed without evidential linkage between this, seal deterioration with age and a demonstrable ability to determine, with confidence, a finite seal installed life. Furthermore, even a finite installed life for seals could not guarantee eradication of fuel leaks because many factors contribute to seal failure. Despite ongoing investigations, we have no evidence with which to correlate installed fuel seal degradation with age. The Station Commander suggests that the fault trend analysis conducted as part of the maintenance policy review was not effective as it did not identify the increase in fuel leaks identified by the BOI. I do not agree with this conclusion. During the period reviewed, 1995 to 2000, there was a reported annual average arising rate of between 1 and 2 leaks per 1000 flying hours from fuel seals and couplings; a review of the data provided by the BOI for the previous 5 years would have given a similar overall result. Although this rate is an increase over that reported during the 1980s (between 0.4 and 1 leak per 1000 flying hours), it would not have been considered to be a high leak rate in an absolute sense considering there are over 400 fuel seals fitted to each aircraft. Moreover, in the absence of any air incident or serious fault reports to highlight any cases that were hazardous, the review would have made its recommendations purely on the basis of system reliability. It was therefore unlikely to have recommended a review of the fuel system maintenance policy, even if data had been reviewed over a 10- or 15-year period. As explained in my introduction, it should also be borne in mind that the very act of disturbing aircraft systems to replace fuel seals could, itself, be detrimental to system integrity and therefore on the evidence available to date, I am of the opinion that a corrective maintenance policy bolstered by the current enhanced inspection regime remains appropriate while more evidence is gathered.

11. The BOI has shown that hot air refraisal insulation has been allowed to deteriorate: this was not compliant with extant maintenance instructions in that no acceptable damage limits are defined. The correct procedure on finding damage would therefore be for a concession to be sought; clearly this has not been happening. In this respect this was a maintenance, rather than maintenance policy shortcoming. Although the BOI considered a hot air leak damaging a fuel seal as a possible but less probable cause, it should be noted that the insulation is there to reduce heat transfer rather than prevent hot air leaks. Nevertheless, I do agree that there is insufficient evidence to allow the hot air system maintenance policy to be dismissed as a possible contributory factor.

12. Whilst the proximity of the bomb bay fire detection system to No 7 Tank Dry Bay led to this providing the first indication of a fire to the crew, it is unclear whether the presence of a dedicated fire detection system in the No 7 Tank Dry Bay would have made a material difference to the crew's ability to recover the aircraft. The difference that the presence of a fire suppression system within the Bay might have made is even more difficult to determine. Such a system would only be effective if its capacity exceeded the persistence of a fuel supply and any ignition source; expert evidence stopped short of concluding whether or not, in this case, its presence would have granted the crew the additional time

needed to land the aircraft. Given that the catastrophic failure occurred when only 14 miles or so from Kandahar airfield, I do agree, however, that the lack of fire detection and suppression systems within the No 7 Tank Dry Bay cannot be excluded as a possible contributory factor. Prohibiting use of the SCP and engine cross-feed removes the most likely source of ignition, thereby reducing the likelihood of fire in the No 7 Tank Dry Bay.

13. I do not agree with the BOI's understanding of leak rates being synonymous with hazard likelihood. Fuel leaks vary in nature and not all will hazard the aircraft. Furthermore, whilst the presence of aircraft fire detection and suppression is documented in the safety case as a generic mitigation, BAE SYSTEMS has confirmed[1] that the IMPROBABLE likelihood categorisation in the No 7 Tank Dry Bay did not arise out of any erroneous assumption of fire detection and suppression within the bay. However, I would agree that if, as seems likely, the SCP coupling was the source of ignition, then the failure of the hazard analysis properly to identify the threat represented both by the design of the SCP system and its operation in flight, was a contributory factor.

14. It is particularly disturbing that the undesirable overflow characteristic of the AAR system design appears to have been identified during development trials in the mid 1980s for the Nimrod Airborne Early Warning (AEW) aircraft, yet (although corrective action was taken for No 5 Tank) no corrective action was taken for the No 1 Tank despite recommendations that the phenomenon be investigated further. It is unlikely that the reasons why the development trials recommendations were not acted upon can be established given the passage of time, but I agree that this was probably then further exacerbated by the progressive nature of the introduction of the final AAR installation and the subsequent development of AAR operating procedures. More recently, it appears that the situation has been further exacerbated because the intensity of AAR operations was greater during 2006 than at any time during the life of the aircraft. Whilst the overflow phenomenon had been noticed during some sorties shortly before the accident, it is unfortunate that no aircraft incident reports were raised as a result of these events. As a result, the linkage between overflow and the maximum fill level for No 1 Tank had not been determined prior to the accident. Changes introduced to AAR procedures since the loss of XV230 will ensure the conditions necessary for overflow to occur are avoided.

OBSERVATIONS

15. Whilst I understand that there is concern that the removal of the SO1-level Engineer (Officer Commanding Engineering Wing) has had a negative effect on aircraft availability, there is no evidence to suggest that safety has been compromised. Equally, whilst the Station has had an outflow of skilled personnel, there remains a core of engineering tradesmen who are highly experienced, and engineering standards continue to be maintained through a rigorous system of competency certification and supervision. That said, we clearly need to remain vigilant to ensure that there is no erosion in safety standards.

1 Letter from BAE SYSTEMS to MOD, Reference: IH/003-07-06-07/dpw dated 8 June 2007.

RECOMMENDATIONS

16. **Policy.**

a. I agree that an operational safety review of the fuel system is required. This is under way and is the means by which any changes that are appropriate to the maintenance policy will be determined. I agree that the existing limitation on the use of cross-feed and SCP should remain in place until the aircraft goes out of service. An operational safety review of remaining elements of the hot air system will be considered with this in mind.

b. Action is already in hand to add aircraft systems to ageing aircraft audits.

c. Action is in hand to scope a review of the Nimrod Safety Case. I agree that, should this work be undertaken, then it should include full participation by experienced air and ground crews.

17. **Fuel System**.

a. Evidence presented to the BOI by MOD materials specialists showed that we have insufficient information about seal degradation with age to indicate that regular replacement of seals would ensure with any certainty that leaks would be prevented.

b. The original design certification for the seals did not include a finite installed life. Additionally, no engineering evidence is cited nor benefits quantified to justify a finite installed life, nor is any explanation offered for how this could ensure with certainty that leakages would thereby be eradicated. It is generally accepted that the rate of degradation (and hence installed performance) is dependent on many variables, the combination of which is often unique to each particular application or even location in an aircraft. However, the Nimrod Integrated Project Team has already tasked QinetiQ with undertaking a detailed independent investigation into seal degradation characteristics for Nimrod. A wider review has also been initiated through MOD specialists covering elastomeric seals fitted to all fleets.

c. I agree that, as a precautionary measure, pending the completion of the fuel system safety analysis, inspections of the integrity of fuel systems and ignition sources between port and starboard Rib 3 should be undertaken. Regular visual zonal inspections between port and starboard Rib 3 with the fuel system pressurised are already underway.

d. Given the importance of the installed environment on installed seal life, I do not accept that Eaton Aerospace (the manufacturers of the seals) are the appropriate source of expert advice on this matter. Further investigations have been put in hand with QinetiQ materials experts and the aircraft Design Authority (BAE SYSTEMS) to determine whether further changes to the seal inspection regime are appropriate.

e. The hazard analysis element of the fuel system operational safety review supports the reinstatement of No 7 fuel tanks, provided that the use of the SCP and engine cross-feed remains suspended.

f. Formal action has been taken to introduce instructions for the correct fitting of the fuel couplings.

18. **Hot Air System.** I support the Station Commander's view that the existing limitation on the use of engine cross-feed and SCP should remain in place until the aircraft goes out of service.

(Original Signed)

Sir BARRY THORNTON
Air Marshal
Air Member for Materiel — Date: 8 October 2007

BOARD OF INQUIRY INTO THE LOSS OF NIMROD MR2 AIRCRAFT XV230 ON 2 SEP 06 – AIR OFFICER COMMANDING NO 2 GROUP'S COMMENTS

INTRODUCTION

1. I agree with the comments made by the Station Commander and the Air Member for Materiel (AMM): the Board of Inquiry has made a commendable effort to identify the cause of this tragic accident and has produced a comprehensive and convincing report. However, I acknowledge that given the nature of the accident, the location of the crash site and the inability to recover the wreckage for specialist analysis, the likelihood of the Board identifying a definitive cause of the accident was low. I accept, therefore, that while the Inquiry has been thorough and logical, and has involved a large amount of detailed investigation, the cause of the accident cannot be established with absolute certainty.

2. Although a precise cause of the accident cannot be determined, it is important that the most likely cause or causes, together with all possible alternatives, are correctly identified and considered in full. I am content that the Board has succeeded in meeting this remit and that it has, therefore, met its Terms of Reference.

COMMENT ON FINDINGS

3. I am content that the evidence presented by the Board leads to the conclusion that the starboard No 7 Tank Dry Bay was the most likely location of the fire which led to the loss of the aircraft. I am also content that the Board has identified and considered all the potential sources of fuel and ignition that could have led to the fire. I consider the overall logic and supporting evidence leading to the Board's findings to be persuasive and convincing, and I therefore agree with the majority of its conclusions, Observations and Recommendations. I have made it clear below where I disagree and where I have made no comment, it can be assumed that I concur with the Board.

CAUSES

4. The Board identified the two most likely sources of fuel in the No 7 Tank Dry bay; either a leak from a fuel coupling or pipe, or the overflow of fuel from No 1 Tank during AAR. The Board was unable to determine which of the two was more likely, and the AMM has suggested that the evidence points to overflow during AAR as being the most likely source. While it is tempting to try to determine the priority of these two sources of fuel, I do not believe there is sufficient evidence available to make a considered judgement possible. We can never be certain and must, therefore, take mitigating action that is equally effective against both potential sources of fuel. I am content that this has been done.

5. Having accepted that the starboard No 7 Tank Dry Bay was the most probable seat of the fire, there would appear to be little doubt that the source of ignition was the pipes of the engine cross-feed/SCP system. I am content that the appropriate action has already been taken to prevent these elements of the hot air system providing an ignition source in the future.

CONTRIBUTORY FACTORS

6. Age of Non-Structural System Components. While the Board identified age as a possible contributory factor in the accident, relating this specifically to fuel seals and hot air duct insulation, the Stn Cdr has challenged this, suggesting that it is the 'condition' of these components not their age that is the issue. The AMM has indicated he can find no direct evidence to support the linkage between aircraft integrity and the age or condition of non-structural components but equally, he has been unable to discount either as a possible contributory factor. I believe both age and condition are inter-related as possible contributory factors: the performance of a component is influenced by its 'condition' and one of the ways in which this condition is affected is age. However, because a relatively new component could be in poor condition and an old component could be in a good condition,

I believe that condition rather than age would have been a more accurate term to describe this aspect of the Board's findings.

7. Maintenance Policy – Fuel and Hot Air Systems. While the Board and the Stn Cdr have indicated that they believe the Nimrod MR2 Maintenance Policy to have been a possible contributory factor in the accident, the AMM has indicated that he does not believe this to be the case for the fuel system. It is clear that there were deficiencies in the maintenance of the hot air duct insulation and this is not disputed. The contribution, or otherwise, of the fuel system maintenance policy is more difficult to determine using the evidence available. Importantly, however, regardless of the part played by the maintenance policy in place at the time of the accident, steps have now been taken, in the form of an enhanced inspection regime, with the aim of providing the maximum possible assurance of safety of the Nimrod MR2 fleet's fuel system. I am content that this is the appropriate way forward until more detailed information on the long term maintenance policy of the system is available, following the outcome of the number of studies that are now underway.

8. Nimrod Safety Case/Hazard Analysis, Fire Detection and Suppression System, and Incorporation of AAR Capability. The Board has identified correctly the individual contribution of these three seemingly separate aspects of their Inquiry to the accident, but it is only when addressing the combined effect of the issues that their true impact is recognised. I agree with the Stn Cdr that it was the compound effect of successive modifications and equipment installations to the aircraft, including the AAR modifications, which set the conditions for this accident. In turn, while the Nimrod Safety Case and Hazard Analysis considered the potential fire hazards in Zone 614 (which includes No 7 Tank Dry Bay), the subsequent risk mitigation work assessed the risks as 'improbable'. I agree with the Board that this failure to categorise correctly the potential risk to the aircraft caused by the collocation of fuel and hot air system components in the No 7 Tank Dry bay was a contributory factor in the accident. Furthermore, within this analysis, the aircraft fire detection and suppression system was cited as a Control for the risks in Zone 614.

However, there is no such system in the No 7 Tank Dry Bay, and while I accept that the effect of such a system, had it been fitted, cannot be determined, I am content that on the balance of evidence available, the lack of a fire detection and suppression system in No 7 Tank Dry Bay was a contributory factor in the accident.

OBSERVATIONS

9. RAF Kinloss Engineering Management Structure. The engineering management structure at RAF Kinloss was changed as a result of a Service-wide initiative to modernise Station structures. RAF Kinloss was a pilot station for the new structures and these changes have since been reviewed. While there is no evidence to suggest that a lack of engineering supervision had a bearing on this accident, the SO1 engineer post at RAF Kinloss has since been reinstated.

10. Dilution of Engineering Skills. While there is no evidence to suggest that tradesmen's abilities or practices had any bearing on the accident, it is acknowledged that a greater than normal outflow of experienced engineering personnel has been experienced by RAF Kinloss over the past year. However, this has been managed closely and I am content that engineering standards have been maintained at the levels required to ensure the safe and effective operation of the Nimrod Force.

11. Fuel Seals and Other Aircraft Types. It is acknowledged that similar fuel couplings and seals to those used on Nimrod MR2 are fitted to a number of other RAF aircraft. The lessons identified in the course of the further work being undertaken on fuel seal integrity on the Nimrod MR2 must be shared with other engineering authorities and action taken as appropriate.

RECOMMENDATIONS

12. Policy.

a. I agree that all four recommendations of the Board with regard to Policy should be actioned.

b. I am pleased to note, as a result of discussions held while the Inquiry was in progress, that aircraft systems have been added to ageing aircraft audits and that an operational safety review of the fuel system is underway.

c. I agree that it is important when reviewing the Nimrod Safety Case, to include wide consultation with experienced air and ground crews, and I support the Stn Cdr's view that this should be extended to all aircraft fleets. It is clear that the assumptions used when the Safety Case was constructed have been undermined by changes to the way in which the aircraft is operated and the environment it is operated in.

13. <u>Fuel System.</u>

a. The available expert advice on fuel seals and their installed life is contradictory, and this is clearly an area where authoritative advice should be sought and acted upon as a matter of urgency. I therefore welcome both the independent investigation into seal degradation characteristics for Nimrod, which is being undertaken by QinetiQ, and the investigations by QinetiQ and the Design Authority into whether further changes to the seal inspection regime are required.

b. I agree that until fuel system safety analysis is complete, regular inspections between port and starboard Rib 3 should continue. I note that regular inspections with fuel systems pressurised are already underway.

c. I also note that formal action has already been taken to issue detailed instructions for the correct assembly of fuel couplings and seals.

14. Hot Air System. I agree that existing limitations on the use of SCP and cross feed should remain in place for remainder of the in-service life of the aircraft.

15. AAR Procedures. I support a formal review of AAR procedures. However, I would need to be convinced of the practicality and value of a detailed study into pressure surges during AAR and their effect on aircraft fuel systems before agreeing to such an initiative. Similarly, while I accept that changes to simulator refuel rates are highly desirable, the practicality and cost effectiveness of such changes would need to be understood before such modifications were agreed.

16. Operational.

a. In view of the new procedures adopted to prevent No 1 Tank overflow and the removal of ignition sources in No 7 Tank Dry Bay, I am content to lift the limitations prohibiting the use of No 7 fuel tanks.

b. I agree with the Stn Cdr in that I do not believe the fitting of a parachute escape system to the Nimrod MR2 to be a practical proposition.

c. I am content for Nimrod STANEVAL to consider the lessons identified at Annex P and their potential impact on crew emergency procedures.

17. Aircraft Modification. In view of the planned out of service date for the Nimrod MR2 fleet, and the risk reduction that has taken place through the changes made to operating procedures for AAR and the use of the cross-feed/SCP pipes, together with the planned review of AAR procedures, I cannot support the aircraft modification recommendations made by the Board at sub paras f (1-4). Similarly, I would need to understand the cost benefit analysis and modification timeline before supporting the recommendation to fit

a crash protected means of recording aircraft position and intercom voice to the Nimrod.

ADDITIONAL RECOMMENDATIONS

18. In his comments, the Stn Cdr makes a recommendation regarding an update to Service Deviation (SD) 132. While there are obvious linkages between the findings of this Board and SD 132, the two are independent, and SD 132 is already subject to regular review.

(*Original Signed*)

A D PULFORD
Air-Vice Marshal
Air Officer Commanding No 2 Group Date: 24 October 2007

BOARD OF INQUIRY INTO THE LOSS OF NIMROD MR2 AIRCRAFT XV230 ON 2 SEP 06 – COMMANDER-IN-CHIEF AIR COMMAND'S COMMENTS

1. I commend the members of the Board for their work, which has been conducted with great diligence and determination under the most difficult circumstances, and I accept their Report, along with the amplifications and qualifications provided in sequence[1] by the Station Commander, the Air Member for Materiel (AMM) and the Air Officer Commanding (AOC) No 2 Group. The resulting body of evidence and analysis (including those amplifying remarks) provides a cogent and convincing description of the potential causes of the crash, of the factors that played a part, and of their relative levels of probability. The Report also outlines the appropriate remedial actions required to ensure that the chance of a further loss of a Nimrod, from a similar cause, is reduced to a level which is as low as practicable.

2. I conclude that the loss of XV230 and, far more importantly, of the 14 Service personnel who were aboard, resulted from shortcomings in the application of the processes for assuring airworthiness and safe operation of the Nimrod. Most critically, this accident indicates that the Nimrod Safety Case (NSC) was wrong in its assessment that the overall identified zonal hazard probability for No 7 Tank Dry Bay (which contained Zone 614 – in all likelihood the origin of the fire) was 'improbable'[2]. That assessment was based on incorrect assumptions regarding fuel leaks (also assessed as 'improbable' in the NSC) coupled with a flawed estimate regarding potential ignition sources (notably the Supplementary Conditioning Pack/Cross-Feed ducting). And, although we cannot know whether the presence of a fire detection/suppression system in No 7 Tank Dry Bay would have obviated this accident, here too I accept the assessment of AOC No 2 Gp; the lack of such a system was, on balance, a contributory factor. This flawed NSC assessment was further compounded both by the failure to take action in the 1980s to remedy the predicted No 1 fuel tank overflow phenomenon (identified during development trial work) and also by the failure to recognise and take alerting action when this phenomenon was observed during AAR missions (some shortly before this tragic accident). As regards the Nimrod's broader fuel system and increases in fuel system leaks, I acknowledge the AMM's assertion that it is not possible to eradicate leaks entirely and that removing any potential ignition source is the most effective means of ensuring safety. That said, I accept the compelling evidence[3] that there has been an increase in fuel leaks over the years and I remain determined to reduce such instances to the lowest possible level; I will keep under review the work that has already been initiated in this regard.

3. Whilst I note and am reassured by the fact that the work recommended in this Report provides a path towards restoring the appropriate levels of assurance for full operation of the Nimrod fleet, I am clear that further activity must be undertaken for our other aircraft types to check whether there is any read-across of

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[1] That is, where there is a difference of view, I agree with the later remarks in the sequence.
[2] That is a probability per flight hour of between $1x10^{-6}$ to 1×10^{-7}, which is a remote likelihood of occurrence during the operational life of a particular fleet.
[3] Annex A to Part 2A – Fuel System Leaks per 1000 Flying Hours.

the lessons we have learned from this accident at such enormous (and immensely sad) cost. This should not be taken as implying that flaws exist throughout our entire airworthiness efforts; they clearly do not, or our safety record in relation to airworthiness would not be as good as it is. But, perhaps particularly for those aircraft where (for entirely practical reasons) no aircraft escape mechanism exists, I need to know that we have done (and are doing) all reasonable and practicable to assure ourselves of the safety of our aircraft, of our crews, and of other personnel who fly in those aircraft. That activity, already commenced, will include a high level Safety Case review, in order to determine exactly what is required and where effort should be prioritised. I am also quite clear that, although led by staff, this work must involve appropriate air and ground crews in order to ensure that current practices are fully understood; those personnel, after all, both know most about how our aircraft are operated and flown, and also have the greatest personal interest in having levels of safety with which all involved are comfortable.

4. In concluding my remarks, I wish to thank all those who have been involved in the aftermath of this loss. I commend, in particular, the members of the Canadian, United States and UK armed forces (especially No 34 Squadron RAF Regiment), who took part in the immediate post-crash activity. Also, my thanks go to the many agencies, both MOD and external, who have given assistance and vital evidence to the Board. Finally – and overriding all others – I pay tribute to Crew 3 of No 120 Squadron (as well as the two additional Servicemen on XV230) who lost their lives; they clearly maintained the very highest levels of professionalism right to the end. And so we owe it to them, as well as to their families, friends and colleagues, to work to remedy – to the maximum extent that this is possible and practical in the inherently risky environment of military aviation – any failures within our systems and processes that could result in a future loss of this kind.

Sir Clive Loader
Air Chief Marshal
Commander-in-Chief
Air Command

2 November 2007