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 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 on Nimrod MR2 XV236 highlighted a corrosion-induced leak behind the fairleads in the Rib 1 area. Although analysis of fuel 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 No 7 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 of the fuel system can be broken. Furthermore, analysis of 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 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 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 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 No 7 tank might reach the No 7 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.

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.
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

<table>
<thead>
<tr>
<th>TANKER</th>
<th>NIMROD MR2 SORTIES</th>
<th>NIMROD R1 SORTIES</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRISTAR TOTAL</td>
<td>177</td>
<td>76</td>
<td></td>
</tr>
<tr>
<td>VC 10 TOTAL</td>
<td>468</td>
<td>117</td>
<td></td>
</tr>
<tr>
<td>VC 10 OPERATIONAL</td>
<td>271 – 19 in 2005/6</td>
<td>90 total 23 in 2005/6</td>
<td>Nimrod R1 - XW665 completed 17 VC10 sorties in 2005</td>
</tr>
</tbody>
</table>

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

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**Exhibit 51**

2-31

EMBARGOED UNTIL 1530 4 DECEMBER 2007
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 a previous AAR sortie on XV230 reported refuel pressures, during Tristar AAR, momentarily in excess of 60 psi. Similar phenomena have been observed occasionally in the past, with pressures as high as 80 psi being noted. It has been determined that the response 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 the Aircrrew Manual (ACM) states that the maximum permitted AAR pressure is 50 psi, although this fact is omitted from later editions. The maximum working pressure of the Nimrod fuel 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 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 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 pressure surges were noted on the day of the accident and XV230

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Witness 22

Exhibit 52

Exhibit 53

Exhibit 54

Exhibit 55

Exhibit 56

Exhibit 67

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.

(2) **No 1 Tank Blow-off Valve.** After a sortie that Witness 22

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EMBARGOED UNTIL 1530 4 DECEMBER 2007
XV230 flew from DOB in Aug 06, the Aircraft 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. The in-flight operation of fuel tanks’ blow-off valves had been considered by BAE in 1985, during development of 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 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 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 airflow 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

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.

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.

(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.

(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 two 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.

(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.

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 °C when it enters the bomb bay. It is then further cooled to about 50 °C 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 °C 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 °C 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 °C. 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 °C; 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.
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.

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 out with 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.

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
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
with aerodynamic modelling, suggests that the aircraft began to
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
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
increase in the last few seconds of flight. was asked to fly the Nimrod simulator using the DARU data to position
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).
They would have unable to halt the aircraft’s descent.
Furthermore, from analogy with other Nimrod accidents and
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
equipment and the pathology report indicates that there is no
evidence of the fire extending beyond the underfloor bays into the

Annex O
Annex E
Exhibits 28/17
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 Ninrod XV230 and its crew.

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.