the R-ADR data shows the left NH rising to approximately 99%. From T4:42 to T6:16 the NH very gradually increased from 99% to 101%NH. At this point, it rapidly decayed to approximately 83% at T6:19, and settled at 87% by T6:22, where it remained until impact with the sea. At T6:20 the pilot reported a loss of thrust, coincident with the reduction in NH and his speed from around 290KCAS to 238KCAS by the time of the ejection. At T6:01 the pilot had reported that his left NH indications were fluctuating, although the rapidly changing indications did not appear to bear any relation to the engine thrust output. RR transient modelling has suggested that the sudden drop of NH could be caused by either an uncommanded opening of the left nozzle, or the NH emergency over-speed governor operating. This would explain the reported loss of thrust by the pilot. Exhibit 1

e. R-ADR data indicates that the left engine was operating with an NH of 87±1% from T6:22 up until the point of impact. It is the opinion of the Panel that the engine electrical harness cabling failed as a direct result of the left engine bay fire and resulted in the selected engine power output at the time of electrical burn-through being maintained by the engine until impact. Exhibit 1

ANALYSIS AND FINDINGS

37. **Model of Detailing Factors**. The Panel used a modified version of the James Reason accident model to categorise the factors identified. It derived its initial model from the ICAO Safety Management Manual, but also used inputs from the Australian Transportation Safety Bureau's interpretation of this model.

a. **Organisational influences**. The latent factors that were in place at the commencement of the sortie of the crew of ZG792. These include management decisions and organizational processes, as well as preventative risk controls.

b. **Supervision**. Details of the supervision of the crew of ZG792.

c. **Preconditions**. The latent factors in place highlighted by the accident sequence.

d. **Acts**. The physical Acts that took place during the accident sequence, both technical and crew related.

38. **Accident Factors**. The factors identified in this accident are defined in JSP832 and JSP551 as follows;

a. **Causal Factor**. A factor which led directly to the accident.

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

c. **Aggravating Factors**. Those factors which did not cause the accident but aggravated the final outcome – i.e. made it worse.

d. **Other Factors.** Noteworthy features including deficiencies discovered by the Panel that were not causes, aggravating or contributory factors of this accident, but which if actioned may prevent future accidents.

e. **Observations.** Other points that are not considered a factor in the accident but are worthy of comment and may have recommendations.

ORGANISATIONAL INFLUENCES

Emergency handling training

39. The Panel considered the standard of emergency handling by the accident crew, and how this may have compared to other TGRF aircrew. In order to assess this, a trial was devised by the Panel to be conducted in the Tornado GR4 simulator. In addition, and as directed by DG MAA, the Panel also conducted a broader investigation into emergency training over the entire TGRF. The trials aspect would examine the handling of similar emergencies amongst a variety of current TGRF crews, to provide a comparison with the crew of ZG792. The trial was split into 2 different phases:

a. **Trial phase 1 - mechanical failure diagnosis and shut-down time.** It was agreed with the GR4 Simulator Training Manager (STM) that, without direct supervision by the Panel, the simulator staff would give a variety of different crews engine mechanical failures and record how long they took to diagnose the fault and shut down the affected engine. The simulator instructors were briefed not to discuss the reasons for the trial or to give the crews any advanced warning. Furthermore, they were asked to try to initiate the emergency at a point in the simulator exercise where the crew would not necessarily expect to have to deal with an engine failure. Records were made of crew experience levels, the times to diagnosis and shut-down as well as any other comments on crew performance. The trial was conducted on 13 crews in total. Exhibit 18

b. **Trial phase 2 - full reproduction of ZG792 accident symptoms.** The Panel also subjected 2 crews, with pilots at different ends of the experience spectrum, to as close a reproduction as possible of the emergency faced by the crew of ZG792. This was observed and supervised directly a Panel member. Exhibit 18

40. **Simulator limitations.** There are 2 main limitations in using the simulator to assess typical crew performance:

a. The GR4 simulator is not able to completely recreate the exact symptoms experienced by the crew of ZG792. It is not possible, for example, to give crews a nozzle failure to ENC and a REHEAT caption Exhibit 18

1 The Panel was made aware of 12 Ti fire events since 1990, but these figures require further verification.

at the same time as an engine mechanical failure. Indeed, the only way to cause a REHEAT caption (without having a THROT caption as well) is to pre-arm a reheat failure which the crew will only experience if the pilot attempts to use reheat. Furthermore, with high power settings, it is difficult to generate mechanical failure-related surges in the simulator that do not cause an associated TBT warning – a caption not initially experienced by the crew of ZG792 (possibly due to the pilot retarding the throttles quickly on hearing the machine-gun noise). Bearing these limitations in mind, the Panel asked the simulator staff to present the Trial 1 crews with surges outside of normal surge parameters with at least one additional engine-related caption. Exhibit 18

b. It is inevitable that crews operating in the simulator environment, despite attempts to occupy them with other tasks, will be more alert to the possibility of emergencies occurring. Furthermore, when presented with emergencies, crews are likely to take actions (such as shutting down an engine or ejecting) with less regard for their consequences than would normally be the case. The Panel judged that this would probably shorten the typical response times seen in the simulator when compared with those seen in real emergency situations. Exhibit 18

41. **Trial phase 1 timing results.** The results table at Exhibit 18 show the experience level of each crew along with the time to diagnosis, time to selecting HP SHUT and any comments on the crew's performance. Unless specifically commented on, the crews shut the LP cock immediately after the HP cock was shut. There was a large spread of reaction times seen across the 13 different crews, with the quickest initiating the correct IA drill after just 3 seconds. The slowest of the crews that correctly dealt with the emergency initiated the IA drill after 30 seconds. There did not appear to be an obvious correlation between experience level and response time. Allowing for the fact that the crew of ZG792 were dealing with a real emergency situation and that shutting down the engine was a serious decision with major consequences, the Panel judged that the crew's response time (of 38 seconds) was not outside the bounds of normality. This view was supported by STANEVAL (F), RAF Marham, who commented that the crew's handling of the emergency in the initial stages was calm and methodical. Exhibit 18

42. **Trial phase 1 errors.** 2 of the 13 crews, both of which had pilots with considerable Tornado experience, made critical mistakes in handling the emergency:

a. One crew reacted to the TBT caption but ignored the other symptoms and therefore carried out the TBT drill initially. They only started to deal with the engine mechanical failure after 1 minute.

b. The other crew incorrectly diagnosed the mechanical failure as a locked-in surge. The pilot selected HP SHUT after 9 seconds but, as he was not carrying out the correct drill, never closed the LP cock or used the fire extinguisher. Exhibit 18

43. **Trial phase 2, crew 1.** This crew undertaking this full emergency recreation were of similar experience level to that of the crew of ZG792.

The pilot was very experienced on both GR4 and other types and the WSO was in the early stages of his first tour. The timeline of significant events is shown at Annex A. The Panel made the following observations: Exhibit 18

a. The crew diagnosed the fault reasonably quickly, taking only 9 seconds to commence the IA.

b. The L FIRE caption was brought on immediately after the right HP cock was closed. As with the crew of ZG792, this delayed the carrying out of the rest of the drill. The GR4 ACM states that Ti fires may cause 'a confusing contradictory fire indication on the good engine'. The pilot in this case, unlike that of ZG792, decided to press only the left fire button as he believed that only the left engine had a fire. Exhibit 14

c. Notwithstanding the confusion caused by the L FIRE caption, the LP cock was closed after just 21 seconds. However, just as the pilot of ZG792 had done, the pilot in this case decided to attempt a relight of the right engine. In so doing, he opened the right LP cock again, causing an additional period of possible fuel leakage of some 14 seconds. Exhibit 18

d. The GR4 FCC emergency drills clearly state that if signs of fire remain after the fire extinguisher has been used then the crew should eject. As with ZG792, the trial crew opted to try to recover the ac to a nearby diversion airfield, despite worsening symptoms of a rear fuselage fire. The trial crew only initiated ejection when the simulator staff failed the taileron controls. Exhibit 14

44. **Trial phase 2, crew 2.** The pilot of this crew was somewhat less experienced than that of ZG792, being 2 years into his first tour. The WSO was also a first tourist of similar experience to the pilot. The Panel made the following observations in this trial run: Exhibit 18

a. As with crew 1, this crew were reasonably quick to initiate the required IA drill, taking 10 seconds from the initial symptoms to close both the HP and LP cocks.

b. Again, the appearance of the contradictory opposite engine fire warning caused considerable confusion. The crew took a further 30 seconds to decide on an appropriate course of action, opting to fire the extinguisher into the left engine (the engine with a fire warning) only, contrary to the IA drill. Exhibit 18

c. This crew also opted to remain with ac right up to the point of loss of control, rather than ejecting earlier due to the confirmatory signs of fire.

45. Given the wide variety of actions carried out by different GR4 aircrew in the sim trial, and the actions of other crews who had faced this actual emergency, the Panel consider that greater training in dealing with this situation is necessary. Specifically, more focussed training was required to equip crews to deal with complex, multiple emergencies with potentially

conflicting information.

46. **TGRF Emergency handling and training within the TGRF.** The Panel reviewed over 700 Sim reports chosen at random from current members of the TGRF (all Sqns and OCU staff). However, OCU student reports were not reviewed. Sortie content, allowing for RAF Lossiemouth's OCU training, was broadly similar across the two bases (RAF Marham and RAF Lossiemouth). However, this sortie content is "customer driven" and misgivings concerning the balance between operational training and emergency handling/pure flying were expressed at both Sims. The Panel noted that sim instructor experience and background was considered to be good, with the majority having Tornado experience and a considerable number of instructors had recent GR4 experience. Of the sorties reviewed, a small but significant number contained errors in emergency handling resulting from poor system knowledge and a lack of airmanship in line with the results of the trials at Para's 42 and 43. In addition, informal and anecdotal evidence suggested that crews lacked system knowledge and airmanship in fundamental aircraft handling and specifically in emergency procedures and ac emergency handling. Major errors, including misidentification of specific emergencies and carrying out subsequent actions, appear concentrated in the multiple failures or the series of failure emergencies that can occur on the Tornado GR4 ac. These types of emergencies tend to require deeper system knowledge and invariably higher levels of airmanship. Examples of this type of emergency are: engine mechanical failure leading to a Ti fire, engine failure with additional speed switch failures, TBT captions (a dual CWP caption requiring diagnosis of what has failed), massive fuel leaks and gearbox failures. All of these emergencies have and do occur on the Tornado GR4 ac. Further emergency training is given across the TGRF at daily emergency briefings at Sqn Met briefs and in structured ground training in association with the TTS (Tornado Training Syllabus) 8, as well as in preparation for the TGRF standardization visits. These visits now include pre and post Op deployment visits by wing Stds personnel as well as the formal TGRF standardization visit from the OCU Stds flight. A review of these Stds visits reports confirms the evidence from the Sim sortie review that emergency handling and fundamental flying skills appear to be declining across the TGRF. It would appear that, coupled with low flying hours, the decline has come about as the TGRF has focused on operational knowledge and procedures to the detriment of pure flying skills. **As such, the Panel concluded that TGRF emergency handling training was a CONTRIBUTORY factor in the accident.**

Annex L

Annex L

Engine Mod State and FCC advice

47. **HPC modification.** RR Modifications 41237 and 41278 introduced a 0.35-0.55mm thick layer of zirconium dioxide within the engine HPC inner casing to reduce the probability of a Ti fire breakout. This is due to the low thermal conductivity of zirconium dioxide. Mod 41278 encompassed this within a re-design of the front stages of the HPC stator vanes to avoid critical resonance and hence improve their tolerance to aerodynamic disturbance. Both engines had Mod 41278 embodied. At the RB199 Risk Assessment Meeting dated Nov 10, Turbo-Union stated that Mod 41278 has successfully addressed the blade/vane fatigue failures, but the fire protection aspects

Exhibit 19

Exhibit 19

Military Aviation Authority MAA

have not made a significant change to the likelihood of Ti fire breakout. Turbo-Union are currently focussing on a new modification to reduce the risks of Ti fire breakout in the RB199 and the Tor PT are aware of this. **The Panel concluded that the HP Compressor modification state was a CONTRIBUTORY factor in the accident.**

48. **GR4 mechanical failure/Ti fire drill.** The Panel observed some variation in the understanding of the reason for the 15-second pause in the IA drill amongst TGRF aircrew and simulator instructors. The Panel reviewed 2 BAE Systems reports that state that the delay is to allow, in the event of a breakout causing a fuel leak, the majority of any fuel pooled in the engine bay to drain away. The extinguisher would then be capable of suppressing any residual fires in the bay. Mathematical modelling in the reports suggests a 200kg fuel leak would have almost completely drained from the ac after 15 seconds. However, the fire observed in the left nozzle area of ZG792 did not appear to extinguish until approximately 5 minutes into the accident sequence. This could indicate incorrect assumptions about the drainage rate, thereby explaining the presence of the glow until T5:00. However, if the LP cock was not closed until later in the emergency, then clearly this would provide a constant flow of fuel. Notwithstanding, the Panel determined that, having diagnosed a Mech fail/Ti fire, it was important to ensure that fuel was isolated asap. **As such, the Panel concluded that the content of the mechanical failure/Ti fire drill remained valid and the FCC advice was NOT a factor in the accident.**

Exhibit 26
Exhibit 30
Exhibit 6

Survival Equipment (SE)

49. **Initial use of SE.** Both the pilot and WSO of ZG792 reported a number of difficulties they had encountered accessing their SE. The Fastfind Personnel Locator Beacons (PLB) were housed in a Combat Survival Waistcoat (CSW). On initially boarding their life rafts, both crewmembers had difficulty opening the zips on the CSW to gain access to the beacons. The Panel concluded that had the crew sustained injuries that affected their arms or hands, this process would have been even harder. Likewise, had cold affected the dexterity in their hands, the Panel concluded there was a very real risk they may not have been able to access their beacons. Once in the liferaft, the pilot commented that the length of the lanyard attaching the beacons to the CSW was not sufficiently long enough to allow it to be placed level on his lap. In the case of the WSO, this led to the beacon resting on its side against the side of the liferaft.

Witness 1, Part 1, Pg 3
Witness 1, Part 1, Pg 4
Witness 2, Part 1, Pg 4
Witness 1, Part 3, Pg 16
Witness 2, Part 1, Pg 4

50. **Fastfind Performance.** One week after the accident, the Panel was contacted by the UK Maritime Coordination Centre (UKMCC) at RAF Kinloss over concerns about the performance of the Fastfind Personnel Locator Beacons. Following the decision not to monitor the 243 MHz PLBs traditionally carried by fast jet aircrew, Air Command purchased Fastfind PLBs to give crews an up to date COTS solution to bridge the gap prior to the introduction of PELS. The system is manually operated by the survivor and crews should have been briefed at a local level by squadron survival instructors on its use. Once activated, the Fastfind should transmit its position 2 mins after activation, giving an alert (containing position) and beacon ID every 50s. The position is updated every 20 mins. UKMCC reported that they only received one coarse position data burst from the

Annex G

pilot's beacon, and only one data burst from the WSO's beacon which did not contain any position.

51. **Air Platform Systems (APS) Project Team Functional Trials.** Following on from the concerns about Fastfind performance, the APS PT were requested by the SI President to conduct trials into the Beacons' performance. They had access to both beacons used by the crew of ZG792, but also the un-used beacons carried by the crew of ZD741. This ac was involved in an accident 2 weeks later in which the crew ejected at RAF Lossiemouth. As such the beacons had been subject to ejection conditions, but had not been activated. All 4 beacons were functionally tested at the RAF Centre of Aviation Medicine (RAFCAM) where 3 passed the functional checks. Since these checks were carried out in an adhoc test facility, they were passed back to McMurdo and factory tested whereupon all 4 passed functional checks. Annex G

52. **APS PT Field Trials.** Given that the functional testing had failed to highlight any failings of the beacons, the 4 beacons were sent to Horsea Island, where a practical test of their functionality was made at sea in a single man life raft in order to replicate, as closely as possible, the conditions experienced by the crew of ZG792. The pilot's beacon operated as expected when activated and its transmissions were detected. The WSO's beacon was placed on its side in the liferaft, as the WSO in ZG792 had done, but its signal was not detected. When the beacon was re-positioned, according to the manufacturer's recommendations, its signal was detected. Following the sea trial the beacons from the crew of ZD741 were activated simultaneously, 1m apart, on dry ground. Whilst the beacons' signals were detected, the received signals were not as expected as per the manufacturer's specification. Further testing by the manufacturer revealed that if the beacons were operated simultaneously, then only one beacon's signal would be detected. The beacons were then re-activated, this time with a 25s split, and both signals were received. This did not, however, completely explain the failings of the beacons as a randomisation circuit built into the beacons should have offset the signals after several minutes of continuous operation. Annex G

53. **Defence SERE Training Organisation (DSTO) Trial.** DSTO conducted trials to ascertain if operation of the Fastfind, G2R and PLB simultaneously could interfere with each other and reduce signal strength. The trials were conducted in single and multi-man liferafts at sea on the Moray Firth. Both Fastfind and G2R operated as expected, with the signals being received, both with the life rafts cover up and down. However, the PLB signal was not detected. The trial concluded that Fastfind and G2R would not interfere with each other. Annex G

54. **Conclusions.** The McMurdo Fastfind beacon performed successfully, as per its specification, in all of the trials conducted, when operated in accordance with the manufacturer's advice. The Horsea Island trial proved that, in the case of the WSO's beacon, if the beacon was placed on its side, thereby obstructing a clear view of the GPS zone at the front of the beacon, its signal would not be detected. The pilot's Fastfind passed all the tests placed on it. Whilst the Panel accepted that the WSO's beacon performance could be attributed to the way it was placed, this could not Annex G

explain the pilot's beacon performance at the time of the accident. As such, the Panel considered that further investigation was required. **The Panel could not positively determine why the Fastfind beacons did not perform correctly immediately post the ejection from ZG792. The Panel concluded that had recovery been required in different circumstances, the consequences could have been severe; therefore the Panel concluded that SE was an OTHER factor in the accident.**

Safety Case Management

55. **Introduction.** The Panel reviewed the current GR4 hazard log and interviewed the current hazard log manager. In order to gain an appreciation of the level of risk being held, an identified hazard (or accident as defined in the GR4 hazard log) is awarded a risk rating. This risk rating is defined by a number of variables, but specifically the likelihood of the accident happening over the life of the ac. An 'A' risk defines an unacceptable risk. A 'C' risk would be described as broadly acceptable. A number is associated with the risk to define its priority amongst the other risks in its category. Within the hazard log, there is the opportunity to enter controls into the log. A control is a mitigation of the risk, typically an amendment or modification. Having entered a control to mitigate the risk, the Engineering Authority (EA) can assess the effectiveness of the control and report back to the hazard log manager, so that a new appreciation of the risk can be seen within the Post Control Status box.

56. **Tornado hazard log.** Having determined the likely sequence of actions that led to the loss of ZG792, the Panel were interested to see if the Tornado hazard log accurately identified and mitigated the various hazards highlighted in this accident. The Panel focused its investigation into the following specific areas of the hazard log; uncontrollable engine fire, critical or uncontrollable oil fire, critical or uncontrollable hydraulic fire, uncontrollable fuel fire and uncontrollable engine Ti fire. The Panel noted that in all these emergencies/accidents listed, there were no Post Control Status indications, implying that there was no control analysis in the areas the Panel focussed. In order to enable the Panel to provide a more focused analysis, the Panel elected to pick 2 of the emergencies that it considered were the most severe within the ZG792 accident sequence and focus on them.

57. **Uncontrollable Engine Fire (A143).** The Panel noted that in the case of A143, this hazard had no risk rating associated with it. By examining the Tornado Hazard Working Group (HWG) minutes, the Panel ascertained that the accidents that made up this emergency had been split between uncontrollable Ti Fire and uncontained engine breakout. Despite this, A143 still existed on the hazard log. Exhibit 20

58. **Uncontrollable Ti Engine Fire (A146).** Having ascertained that some of the hazards from A143 had been moved to A146, the Panel focused on this accident. The risk rating, C10, had been derived from 3 previous accidents caused by Ti fires that took place between 1990 and 1999. Since 1990, the Panel is aware of a number of Ti fires in addition to those listed within A146[1]. Three Ti fires in Tornado GR4 ac stood out from these post Exhibit 20

1999; ZD714 25 Feb 08, ZA446 23 Sep 09 and ZG792 – the accident ac. The Panel were interested to find out if these accidents had been taken into account in determining the risk rating for the Ti fire. To be classed as an accident there must be a fatality, serious injury or Cat4/5 damage sustained to the ac. In the case of the three Ti events listed above, they either had not sustained the damage to be considered in the hazard log or the accidents/incidents were subject to ongoing inquiries and as such had not been incorporated. The Panel noted that one of these accidents had happened on the ground and so the severity of the potential airborne consequences could not be determined. Another ac had successfully landed after the event, although the Panel noted that the crew were fortunate that this incident had not been an accident, as was the case with ZG792. The hazard log manager stated that it was standard practice to wait for UIs/SIs to report before considering the accident within the risk rating. Given the additional number of actual Ti fires affecting that GR4 ac, the hazard log manager conceded that had these accidents/incidents been included within the hazard log, then the risk rating might have changed. During interview he stated that he could only work with the information that was given to him by the Engineering Authority (EA).

59. **Post Control Measures.** Having looked into the processes of determining the risk rating, the Panel then sought to find out how the Tor PT managed the Post Control Status in the hazard log. The Panel ascertained that a number of improvements to the GR4 engine had been made in an attempt to reduce the number of Ti fires under Tor/C9: Mods 41206, 41168 and 41278. These controls had been entered into the controls section of the hazard log, and yet there was still no Post Control Status. In interviews with the hazard log manager the Panel discovered that the manager had correctly entered these controls into the log, but had not received any feedback from the EA as to their effectiveness. These controls had been entered on 8 Feb 2005. The hazard log manager stated that until he received feedback from the EA, he was unable to update the Post Control Status. The Panel therefore sought to determine why it had been 6 years since the controls were entered, and yet the hazard log manager had received no feedback. The hazard log manager stated that because the risk associated with the accident, C10 was low, the importance placed on reviewing the controls was similarly low and he used this to explain the lack of feedback. The Panel were concerned that until additional Tornado accidents/incidents were included in the hazard log, it was unlikely that the overall risk rating would change, and the review of controls would continue to remain a low priority. The Panel established that the hazard log was not a 'live document', because not all of the significant Ti fire events had been included. The Panel noted that because the majority of these incidents had not resulted in the loss of the aircraft or crew, then there was a degree of justification in this. However, the Panel considered that in some of these incidents, there was an extremely thin line in the difference between incident and accident. This directly affected the Tor PT's ability to be aware of the extant risks facing the ac, and crucially to be able to manage the controls put in place. The Panel concluded that there was no single point of failure, but rather a wider organisational issue that resulted from the hazard identification process, analysis of controls and the time taken to incorporate additional accidents/incidents into the hazard log.

Witness 22

Witness 22

60. **Manpower.** The Panel noted that a number of posts within the Safety Management Group were gapped, and the hazard log manager rated the amount of support given to him as poor. Witness 22

61. **Review of control measures.** The Panel determined that there was evidence to suggest that some of the Mods incorporated to reduce Ti fire risks had not been as effective as originally devised. Despite this, the Panel noted that there was no record of this within the hazard log. Mod 41278 was still entered as a control in the hazard log, yet the panel were aware that it had not been as effective in reducing Ti fires as had been envisaged. The Panel determined that the EA were aware of this, and were actively attempting to mitigate it, but this was not reflected in the hazard log. Exhibit 19

62. **Risk awareness.** Given the concerns raised from its initial investigation into the hazard log, the Panel were interested to ascertain the level of risk awareness ultimately held by the Operational Duty Holder (ODH) and the Delivery Duty Holder (DDH). The Panel inspected both the HQ 1 Gp risk register and their new draft risk register. In both cases there was no mention of Ti fires. These risk registers are mainly focused at Risk to Life (RtL) risks. However the Panel opined that there was a potential RtL associated with Ti fires that is presently not accounted for.

63. **Conclusion.** The Panel concluded that the current GR4 hazard log had the potential to not accurately reflect the level of risk being held by the ODH, and the post control status did not accurately reflect the effectiveness of the controls. The Panel determined that the exclusion of some significant Ti fire events could have an impact on the overall risk rating. It also noted that the process for reviewing the controls was not effective enough to enable to hazard log to reflect a current, up to date appreciation of the risk. Whilst the Panel noted that, within the EA, there was an awareness of the risk posed by Ti fires, and controls were being actively sought, it determined that the process for reflecting this within the hazard log was undefined, and as such there was potential for the risks not being fully appreciated by higher authority. Because the ODH was not aware of the risk, he was unable to understand or mitigate it. **The Panel concluded that the current state of the GR4 hazard log was a CONTRIBUTORY factor.**

SUPERVISION

64. **Ac State.** The ac was fitted in an acceptable role fit in accordance with the release to service (RTS). The Panel found no evidence suggesting that ZG792 was operated outside of the parameters set within the RTS. **The Panel concluded that the ac state was NOT a factor in the accident.**

Exhibit 9

65. **Engineering Practices.** Throughout the interview process, engineering paperwork audit and interviews with Sqn engineering personnel, the Panel found no evidence to suggest that engineering practices were a factor in the accident. **The Panel concluded that engineering standards and practices on XV(R) Sqn was NOT a factor in the accident.**

66. **Supervision, Authorisation and Planning.** The levels of supervision and authorisation are clearly defined in 1 Gp GASOs and the RAF Lossiemouth Flying Order Book. During an audit of the Sqn's documentation post the accident, the Panel found these documents to be at the correct amendment state and well kept. A couple of minor errors were noted in the recording of amendment states, about which the Sqn was informed. The Sqn employed a supervisory chain including a Sqn Duty Auth and Duty Executive, as well as a Duty Controller Flying (DCF). The sortie was correctly authorised by the senior auth in the formation. Due to a previous programmed PCON phase brief, the pilot was not present at the beginning of the sortie planning process, because the previous commitment overran, however he joined the plan as soon as he could and he was present for the brief. The Panel considered whether the pilot felt rushed and whether this had any effect on his state of mind, or his ability to react to unforeseen circumstances. Given his experience, the Panel concluded that he would be able to transit from the PCON phase brief straight into the plan, and his attendance at the brief was sufficient to enable him to carry out his tasks adequately. Likewise, the Panel considered whether the student WSO was adequately prepared for the task. The plan was supervised by the formation auth, and the proposed sortie profile was realistically achievable. Although the student WSO commented that he felt rushed and had forgotten most of the plan by take off, the Panel concluded that this was more likely down to his lack of experience rather then any failings in the planning cycle. **The Panel concluded that supervision, authorisation and planning were NOT factors in the accident.**

Witness 15, 16, 21

Exhibit 23

Witness 1, Part 3, Pg 4

Annex A. Pg 11

67. **Operational tempo.** XV(R) Sqn is a busy Operational Conversion Unit. The Panel considered whether the task placed on it was achievable, and whether the current operational demands to produce qualified TGRF aircrew had any impact on the Sqn's daily routine. In his formal interview with the Panel, OC XV(R) commented that he considered the Sqn to have been working hard, as was everyone in the RAF. He also considered that the OCU was not resourced to the correct levels, specifically in terms of manpower, and that this increased the pressure on his Sqn to achieve the task. The Panel considered whether these factors had a detrimental effect on the personnel working on XV(R), and whether there were any associated flight safety trends emerging from it. The Sqn had recently implemented a Continuous Improvement (CI) programme to increase the availability of ac for the flying programme. However, OC XV(R) was keen to point out that despite an increase in ac availability, the Sqn manpower, from an

Witness 20, Pg 2

Witness 20, Pg 2

Witness 20, Pg 4

engineering perspective, was being closely monitored to ensure that people were not being worked to a level where their actions became unsafe. Management of that risk was one of OC XV(R)'s greatest priorities. The Panel then focused its attention on the engineers to ascertain whether they felt the task was achievable, and any pressure, perceived or not, that they were subjected to. Throughout the interview process, the general impression given to the Panel was that the Sqn was working hard, but that it was being well managed.

Witness 20, Pg 3

Witness 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

> *"it's well balanced and well managed, there is pressure but its never undue".*

At the JNCO and airman level the Panel found that, whilst the engineering team was working hard, the perceived successes at generating ac were just rewards for their hard work, and morale was high:

> *"Yeah it's good it's busy... I think it's spot on to be honest the right amount."*

From the aircrew perspective the Sqn was operating at 3 WSO's and 7 pilots below its LUE. The Panel concluded that, whilst there was a considerable task being placed on XV(R) Sqn, it was achieving this task helped by its implementation of CI and morale was high. **The Panel concluded that op tempo was NOT a factor in the accident.**

Witness 20, Pg 4

68. **Competency, qualifications and fitness to complete the task.** The Panel considered whether the crew were adequately qualified to fly the sortie, whether they were competent to do so and whether they were fit to fly. A review of the pilot's F5020, other supervisory documentation held on the Sqn and interviews with the crew's supervisory chain confirmed that he was competent both to fly the sortie and to supervise the student WSO. He was also in date for all periodic and supervisory checks and as such was qualified to fly the sortie and act as ac captain. Although a student, the Panel concluded that the WSO, whilst not yet qualified on the GR4, was sufficiently competent to complete his task, and was in-date for all his periodic and supervisory checks. Interviews confirmed that the pilot had been ill the day before the accident, and the WSO reported being under pressure to perform. The Panel considered whether either of these factors affected the crew's ability to carry out the task. The pilot had been ill the day before the accident, but had not sought medical advice electing to declare himself un-fit to fly and went home. In the morning the pilot felt better and so reported for duty. The pilot was under no obligation to seek medical advice, although the fact that he was physically sick by the side of the ac could have warranted it. The pilot confirmed that he was fit to fly the sortie both to the Panel, but also to the Duty Authoriser (Auth) at the out brief, who agreed. The WSO commented that he felt under pressure, but that this was normal for this stage in the course and was not unusual. The Panel also determined that he had adequate rest prior to reporting for work. **The Panel concluded that the crew were competent, qualified and fit to fly the sortie and these considerations were NOT factors in the accident.**

Exhibit 24

Witness 1, Part 3, Pg 3

Witness 2, Part 1, Pg1

Witness 1, Part 3, Pg 5

Witness 21, Pg 1

Witness 2 Part 1, Pg 1

69. **Engineering documentation.** The ac's in-use and archived paper and electronic documentation set was impounded and quarantined as part of

the PCMP and subsequently sent to RAF Marham EP&R, for formal review. The full report can be found at Annex H. However, in summary, the documentation set was generally found to be in good order, with all maintenance and servicing requirements correctly annotated and in date. A significant number of administrative discrepancies were identified, but did not affect the serviceability of ZG792. Of particular note, the Panel observed a significant number of forms that were out of date. The results of the audit were passed to SEngO XV(R) for review. **The Panel concluded that the standard of engineering documentation was NOT a factor in the accident.**

Annex H

PRECONDITIONS

70. **FOD/Fatigue.** The Panel concluded that the initial failure that led to the Ti fire was caused by either FOD or fatigue leading to failure of a compressor blade or stator vane within the right engine. Investigation to date has not provided the Panel with the substantive evidence to support either theory at this point. **The Panel could not positively determine the cause of the initial blade or vane failure. However, FOD or fatigue would have been the initiator that led to the Ti fire and therefore was a CAUSAL factor.**

Para 9

71. **Ti fire.** The Panel concluded that debris, potentially from a failed stage 2 vane/blade, became lodged in a HPC stage 2 stator vane. This was frictionally heated by each HPC stage 3 blade in turn striking the debris. The heat generated eventually led to a localised Ti fire. **The Panel concluded that the Ti fire in the HP2 stator/HP3 blade area was a CAUSAL factor in the accident.**

Para 10

72. **Breakout.** Evidence concluded that the Ti fire broke through the HPC casing, the CCOC and the engine outer casing. As the engine casing could not contain the Ti fire breakout, the fire broke through the reheat fuel line. **The Panel concluded that the breakout of the Ti fire was a CAUSAL factor in the accident.**

Para 11

73. **Fuel line failure.** Given all the available evidence and supporting analysis, the Panel was unable to positively determine the exact cause of the fuel line rupture. However, it is highly probable that the Ti engine fire penetrated the reheat fuel line causing it to rupture at a hot-spot, or violently ejected heated material impacted the line causing failure at a hot-spot. The Panel noted that the current level of protection for the reheat and main supply lines was insufficient for this failure mode. **The Panel concluded that the failure of the reheat fuel line was a CAUSAL factor in the accident.**

Para 11

74. **Right engine bay fire.** The damage to the reheat fuel line led to a fuel leak. Fuel vapour contained in the engine bay ignited on the hot surface of the NCU. This initiated a fuel fire in the right engine bay which reached a temperature between 635 and 1667°C. **The Panel concluded that the right engine bay fire was a CAUSAL factor in the accident**.

Para 22

75. **Fuel transfer.** A BAE Systems test carried out in 1980 assessed the engine bay venting and draining systems. It highlights that small amounts of fuel drained from the right engine bay can transfer and enter through the left thrust reverse air motor exhaust, confirming that positive pressure gradients do exist in parts of the flight envelope. The RR RB199 Engine Nacelle Fire Hazard Review in 2001 also states that purged fuel exiting the ac upon re-heat de-selection may re-enter the engine bay during flight through either the NCU exhaust, TRCU exhaust, or the combined drain/overboard purge outlet. The Panel concluded that, given the lack of physical evidence to suggest an alternative fuel transfer route, re-ingestion was the most likely scenario. **The Panel concluded that the fuel transfer from right to left engine bay was a CONTRIBUTORY factor in the accident.**

Annex F

Para 33

76. **Left engine control.** Evidence highlighted that the wiring looms to the left engine were significantly damaged in the left engine bay fire. The Panel concluded that this damage resulted in the pilot's loss of throttle control in the left engine. Along with his loss of taileron control, the pilot's decision to eject was based upon his loss of left engine control. **The Panel concluded that the loss of throttle control of the left engine was a CONTRIBUTORY factor in the accident.** Para 31

77. **Hot Spots**. The NCU is fed by 4th stage HPC air which is approximately 400°C. Testing by Turbo-Union has shown that the NCU supply pipe and air motor can reach surface temperatures from 300-375°C. This provides the environment for spontaneous ignition, for which the probability is increased when there is an air/fuel/gas mixture. Recognition of the NCU as an ignition source dates back to 1978 in a report by Turbo-Union heat transfer department. **The Panel concluded that hot spots were a CONTRIBUTORY factor in the accident.** Para 34

78. **Fire detection.** The Pilot did not receive a R FIRE indication until T1:33. This indication followed the L FIRE indication. Had the fire detection system alerted the pilot to the right fire that he was experiencing, the Panel concluded that there was a higher likelihood that the pilot would have shut down the right engine sooner. This act in itself may have prevented the fire in the left engine bay. The Panel is of the opinion that the fire wire was submerged under the fuel pool, preventing a fire indication, and then subsequently damaged by the fire. A BAE Systems led study into the fire detection and suppression system of the Tornado in June 2010 states that the current fire detection system can fail to provide a fire warning if the flame from a fire burns through the fire wire and causes a short-circuit. It also states that the current system is prone to spurious warnings and suffers from contamination. It suggests that a new pneumatic fire/overheat detection system, as used in the Typhoon, would provide redundancy as the system can be installed as a dual loop system and also provides feedback to the pilot through the integrity monitoring unit, should the wire become damaged. This could then be used by the pilot as evidence for a Ti fire and hence aid a clearer diagnosis of the fault. The Panel noted that the recommendation from the Board of Inquiry for ZE830, in Nov 99, for the Tornado engine bay fire detection system to be modified remains outstanding. **The Panel concluded that the limitations of the fire detection system was a CONTRIBUTORY factor in the accident.**

Exhibit 1

Witness 1, Part 3, Pg 8

Exhibit 26

Exhibit 16

79. **GR4 Fire Suppression.** Following the shut down of the right engine, the pilot was then faced with the contradictory left engine fire caption. Although confused initially, he elected to press both fire buttons iaw the FCC advice for Mech fail. He could not remember how long he waited from shutting down the right engine to pressing the fire buttons. The fire suppression system in this event was not sufficient, as the fire continued following his selection. The Tornado GR4 currently uses Halon 1121: one dual headed fire bottle capable of delivering bromochlorodifluoromethane (BCF) to either of the engine bays, or both simultaneously via fire extinguisher buttons in the cockpit. A BAE Systems report states that Halon 1211 (BCF) is one of the best agents available to extinguish fires. Clearly, the timing of the closure of the LP cock would have been critical. If it was left

Exhibit 14

Witness 1, Part 4, Pg 2

open, thereby providing a steady supply of fuel to the fire, the Panel reasoned that any fire suppression system would have been ineffective. However, if the LP cock was closed during the initial right engine shut down drill, as the pilot reported, the Panel reasoned that the current fire suppression system was ineffective in this case. The Panel observed that the ability to have been able to fire more then one shot of extinguishant into the affected engine bays may have provided a greater level of fire suppression. **The Panel concluded that the Tornado Fire Suppression System was a CONTRIBUTORY factor in the accident.** Exhibit 26

80. **FS FIRE caption.** Although a FS FIRE caption was reported by the WSO, there was no physical evidence of fire discovered in the vicinity of the FS FIRE RFODS fire wire Nor was there any evidence of a 4th stage HP air leak. The FS FIRE caption illuminates when the RFODS detection system senses a temperature in excess of 200°C. Therefore, the Panel concluded that the FS FIRE caption was most likely illuminated as a result of heat transfer from the engine bay through the heat shield into the rear fuselage bay containing the RFODS fire wire. The average temperature within the FS FIRE fire wire bay during flight is approximately 100°C, and with a temperature in excess of 635°C on the other side of the heat shield, it is highly probable that the ambient temperature was raised above the trigger of 200°C. **The Panel concluded that the FS FIRE caption was NOT a factor in the accident.** Witness 2, Part 1, Pg 2; Annex D Para 1.6

81. **ECS.** All of the fire damage discovered was aft of the engine forward bulkhead, frame X 12737. All of the ECS pipes recovered indicated no fire or heat damage. The Panel did not find any evidence linking the ECST captions and the accident. Anecdotal evidence suggests that ECS captions are common in the GR4 and are generally cured by recycling the system. **The Panel concluded that the ECS system was NOT a factor in the accident.** Annex D Para 2.2.1

82. **Pitch feel accumulator.** During the initial ac walk-around, the pilot highlighted a pitch-feel accumulator gauge at the level of 100 bar as opposed to 60 bar, which is usually expected. The high reading on the pitch feel accumulator was attributable to the residual pressure from the previous sortie. The pitch feel accumulator gauge is only checked by engineering personnel on a before-flight servicing and not on a turn-around or after-flight servicing due to this fact. **The Panel concluded that the pitch feel accumulator gauge reading was NOT a factor in the accident.** Witness 1, Part 1, Pg 3; Witness 11, Pg 1

83. **Weather conditions at the time of the accident.** The Panel had access to both the RAF Lossiemouth daily met brief slides and the TAFs for the North coast on the day of the accident. Weather conditions were benign and fit for VFR recoveries at both the home base and diversions. The crews did not report experiencing any difficulties associated with the weather. **The Panel concluded that weather conditions were NOT a factor in the accident.** Exhibit 22

ACTS

84. **Right hydraulic bay fire.** The Panel confirmed that the fire within the right engine bay reached temperatures of over 635°C, and may have reached temperatures as high as 1667°C. The Panel concluded that the path of the fire focussed the heat intensity on the outer firewall, adjacent to the hydraulic bay. Heat transfer through the titanium firewall led to a hydraulic leak from a aluminium/steel union or flexible pipeline, which took place approximately 49 - 77 secs after the initial failure. Ignition of the hydraulic leak either took place by hot-plate ignition on the titanium firewall, or the degradation of the CSAS wiring within the bay leading to a short circuit, providing the required spark. **The Panel concluded that the right hydraulic bay fire was a CAUSAL factor in the accident.** Para 25

85. **Flying control failure.** The fire in the right hydraulic equipment bay burnt through the CSAS wiring looms, leading to the reversion into Mech mode at T2:50. The fire then continued to heat the right taileron mechanical control rod, leading to the gradual deformation of the rod and eventual loss of control. **The Panel concluded that the loss of right taileron flying controls was a CAUSAL factor in the accident.** Para 29

86. **Pilot emergency handling**. The pilot of ZG792 was faced with a complicated emergency. On recognising the surge, he brought both throttles back to idle and maintained less than 10 units AOA. T0:14 is the first indication that he has diagnosed a Mech fail. He informs his WSO, flies the ac away from the ground and transmits to his wingman. At T0:31 he concludes that he is going to shut down the right engine and at T0:39 he shuts the HP cock. At this stage the Panel concluded that there were sufficient symptoms available to allow the pilot to diagnose the nature of the emergency and action the full Mech fail/Ti fire drill. The Panel noted that, having made the decision to shut the engine down, there was doubt in the pilot's mind whilst he re-considered, but then having shut the HP cock nothing more is heard for a further 8s until the L FIRE caption illuminates. The Panel were able, from witness testimony, to determine that the LP cock was not closed until sometime after the L FIRE caption. The pilot stated that it was the emergence of the L FIRE caption that delayed his actioning of the full Mech fail/Ti fire drill and that this was coincident with shutting the HP cock. As such the Panel were unable to account for this 8s gap in the pilot's immediate action drills. The Panel could not identify any factors that would have prevented the LP cock being closed in the 8s period after the HP cock was closed. The Panel also noted that at this point the pilot stopped verbalising any of his Mech fail/Ti fire immediate actions. The pilot was an experienced GR4 operator and the Mech fail/Ti fire symptoms presented to him were exactly as described in the GR4 FCC drills. As such, the Panel concluded that although his diagnosis was ultimately correct, his actioning of the Mech fail/Ti fire drill, and specifically the initial doubt in the pilot's mind prior to closing of the HP cock, the 8s pause and lack of verbalisation of the drills, was not consistent with his experience. Given that the reheat fuel pipe was found to be perforated, then an open LP cock would provide a steady supply of fuel into the engine bay, feeding a fire. The Panel were able to ascertain an approximation of the time taken for the heat transfer to lead to a hydraulic leak was between 49-77s from the initial failure. As such, isolating

Exhibit 6

Exhibit 6

Exhibit 6

Annex A Part 2, Pg 6

Witness 1, Part 3, Pg 8

Annex D, Para 1.5.1

the fuel supply to the engine was critical. Had the LP cock been closed before this point, it is the Panel's opinion that it is unlikely that the fire would have been able to reach the temperatures necessary for the Hydraulic lines to fail, and then ignite. The Panel noted that the technical evidence suggested that this action had probably not occurred until approx T4:37. It also noted that better CRM would have made the probability of closing the LP cock sooner more likely. The Panel conducted a full review of the pilot's Training Folder to see if any obvious trends existed. Whilst the Panel found that the total number of specific HIEST (High Intensity Emergency Simulator Training) serials carried out by the pilot since his arrival on XV(R) was comparatively low (6 full HIESTs), it did not note any obvious concerns raised over the pilot's standard of emergency handling. The Panel also considered whether the pilot's illness the day before had any effect on his performance. Aircrew can declare themselves un-fit to fly without seeking medical opinion, and the decision as to when they are fit again rests with the pilot, as long as he has not been specifically grounded by a MO. The Panel were unable to determine if the pilot's illness the day before had any detrimental effect on his performance. Ultimately, the Panel determined that the supply of fuel to the fire was a critical factor. However, as the Panel were unable to determine a specific point at which isolating the fuel would have allowed the ac to be recoverable, **the Panel concluded that the pilot's emergency handling was a CONTRIBUTORY factor.**

Annex K

Para 21

Para 88

Exhibit 33

87. **WSO emergency handling**. The TGRF SOP is for the WSO to monitor the pilot's immediate actions and confirm each action from the FCCs, then to read out any 'subsequent actions' and advice. The WSO did not do this. At no stage did he question the lack of "LP Cock" in the pilot's verbalization of the Mech fail immediate action drill and he remained passive for most of the emergency. **The Panel concluded that the WSO's emergency handling was a CONTRIBUTORY factor.**

Exhibit 6

88. **CRM.** The Panel noted that it was the pilot of ZG792 who played the most active role in the emergency, while the WSO was comparatively quiet. Throughout the preceding portion of the sortie, both pilot and WSO conduct themselves in a calm, relaxed manner in a professional cockpit environment. At the onset of the emergency, the pilot communicates his diagnosis to the WSO, talking through the captions he can see and what his action is going to be i.e. "*I am going to shut down the right hand engine*". As the pilot completes his shut down, SOPs dictate that the WSO should have confirmed each action from the FCC and be ready to read out any 'subsequent actions' that the pilot would not necessarily know from memory. Whilst the pilot does verbalize his initial drills, at no stage does he mention the LP cock, nor does his WSO question him over this. Likewise, contrary to what might have been expected, the pilot did not direct the WSO to back his actions up by confirming the FCC advice during his initial actions. The HF report comments that this would increase the possibility of an action being missed. In the context of LP cock closure times, this may have been a vital action. Ultimately, if the LP cock was not closed until approx T4:30, then this breakdown in CRM would have been a major factor in this omission. However, if the pilot did close the LP cock at T1:00, as he claims, it is possible that he felt he did not need the WSO to read out the FCC advice as, by then, he would have been occupied with the potential rear fuselage fire and left engine fire. Of note, the pilot uses the WSO in CACTUS 1

Annex A

Exhibit 6

Exhibit 6

Annex A Part 2, Pg 7

significantly (a fellow staff instructor) and the Panel reasoned that this may have caused his own WSO to play a less active role in the emergency. The Panel also noted that, given the WSO's inexperience, he may not have been best placed to appreciate or deal with the contradictory captions presented to him. The Panel also noted that had the crew received a R FIRE caption from the onset of the emergency then this may have provided the crew with the additional information they needed to gain a clearer picture of what was happening to the ac. At T2:57 and T3:35 the pilot asked both the WSO in CACTUS 1, and his own WSO, to back him up with the cards. As with emergency handling, the CRM aspects were linked to the closure of the LP cock, however the Panel determined that the action of closing the LP cock could have been achieved faster if the CRM between the crew had been more effective. **The Panel concluded that CRM was a CONTRIBUTORY factor in the accident.**

Annex A, Part 1, Pg 12

Exhibit 6

Exhibit 1

89. **Malicious Intent.** The Panel found no evidence to suggest that malicious intent, from either aircrew or engineering, played any role in the accident. **The Panel concluded that malicious intent was NOT a factor in the accident.**

90. **Birdstrike.** Neither crew member of ZG792 was aware of any birds prior to the accident, and no initial birdstrike impact was felt by the crew. Extensive investigations by the MilAAIB and RR have found no evidence of birdstrike. Given the lack of any evidence pointing towards a birdstrike**, the Panel concluded that birdstrike was NOT a factor in the accident.**

Witness 1, 2, 3, 4

91. **Post Crash Management Plan (PCMP).** The Panel reviewed the XV(R) Sqn PCMP and reviewed the actual actions of those implementing it during the day of the crash. The Panel ascertained that the PCMP had been correctly activated and had worked effectively. The Panel noted that XV(R) Sqn had recently practised their PCMP and were able to implement the recommendations that had arisen from that exercise. The only area for comment came from OC XV(R) Sqn, who felt that greater training was required of supervisors in the kinforming process. OC XV(R) noted that when undertaking kinforming, where family circumstances were complex, potential for confusion existed. **The Panel OBSERVED that the PCMP had been correctly activated and managed.**

Witness 20, Pg 3, 5

92. **Post Incident Drug and Alcohol Testing (PIDAT).** Following transfer to Raigmore Hospital, both pilot and WSO were interviewed by the RAF Lossiemouth Senior Medical Officer (SMO). He had no reason to believe that either crew member was under the influence of drugs or alcohol and as such PIDAT was not initiated. In their formal interviews, both crew members confirmed that they had not consumed any alcohol in the 24hrs leading up to the accident. **The Panel concluded that drugs and/or alcohol were NOT a factor in the accident.**

Annex C

Witness 1, Part 3, Pg 2

Witness 2, Part 3, Pg 2

SUMMARY OF FINDINGS

93. **Cause(s).** The Panel concluded that the cause of the accident was the failure of a blade or stator vane caused by FOD or fatigue. This led to an uncontrollable rear fuselage fire, which ultimately resulted in the loss of ac control, and ejection.

a. Following an undetermined failure within the right engine HPC, a Ti fire broke out through the HPC casing, the engine outer casing, and the reheat fuel line. It is likely that the breakout did not have sufficient energy to penetrate the engine bay firewall. Para 71/72

b. Following the rupture of the reheat fuel line, fuel leaked into the right engine bay, pooling at the base of the bay. Ignition of the fuel vapour occurred via the NCU hot surface, leading to a right engine bay fuel fire, which was continually fed by the pool of fuel. The fire was also fed by the leaked fuel from the perforated fuel line, the time period for this is dependent on the 2 theories of the LP cock closure time. Paras 73-75

c. As the fire in the right engine bay increased in temperature, thermal heat transfer occurred through the engine bay firewall into the adjacent right hydraulic component bay. This caused different rates of heat expansion in hydraulic unions and pipelines, leading to hydraulic leaks. Hydraulic oil ignition is believed to have been caused by the degradation of electrical looms, caused by heat intensity in the area, leading to an electrical short, and/or hot-plate ignition caused by the hydraulic oil spray hitting the hot firewall and igniting, leading to a hydraulic fire in the right upper rear fuselage bay. Paras 76-77

d. The hydraulic fire burned through the CSAS wiring looms and caused the heat deformation of the right taileron control rod, leading to eventual loss of control. Para 85

94. **Contributory Factors.** The Panel identified the following contributory factors that did not directly cause the crash, but made the outcome more likely:

a. Concurrently, pooled fuel drained through the exhaust outlets, and leaked through panel latches, hinge seals and fasteners in the right engine bay doors. Due to a pressure gradient, fuel was re-ingested into the left engine bay, through the same apertures and ignited on the nozzle air motor. This led to a subsequent left engine bay fire, which remained relatively contained in the rear of the left engine bay. This fire continued until the exhaustion of aviation fuel from the right engine bay and damaged the wiring looms, leading to the loss of throttle control to the left engine. Para 75

b. Within the cockpit, the crew did not receive a R FIRE caption. As such, neither crew member were aware of the severity of the right engine fire, and the fire suppression system was unable to extinguish Para 78 the fire.

c. The Panel were unable to determine the exact time that the LP cock was closed. Based on the weight of technical evidence it opined that this was, most likely, not to have been until sometime around T4:30 (after the aborted re-light attempt). As such, it concluded that it was likely that incomplete initial drills, and a breakdown in CRM, allowed a continual source of fuel to both the right engine fire, and subsequent left engine fire. Paras 86/88

d. Although safeguards had been put in place to reduce the risk associated with Ti fires, these modifications were not effective enough to contain the failure and fire. Para 61

e. The Panel found a wide variation of emergency handling drills across the TGRF. It also discovered a number of errors by Force aircrew in the handling of the Mech fail/Ti fire drill, and as such more detailed emergency training was required to equip crews with the knowledge to deal with Mech fail/Ti fires. Para 46

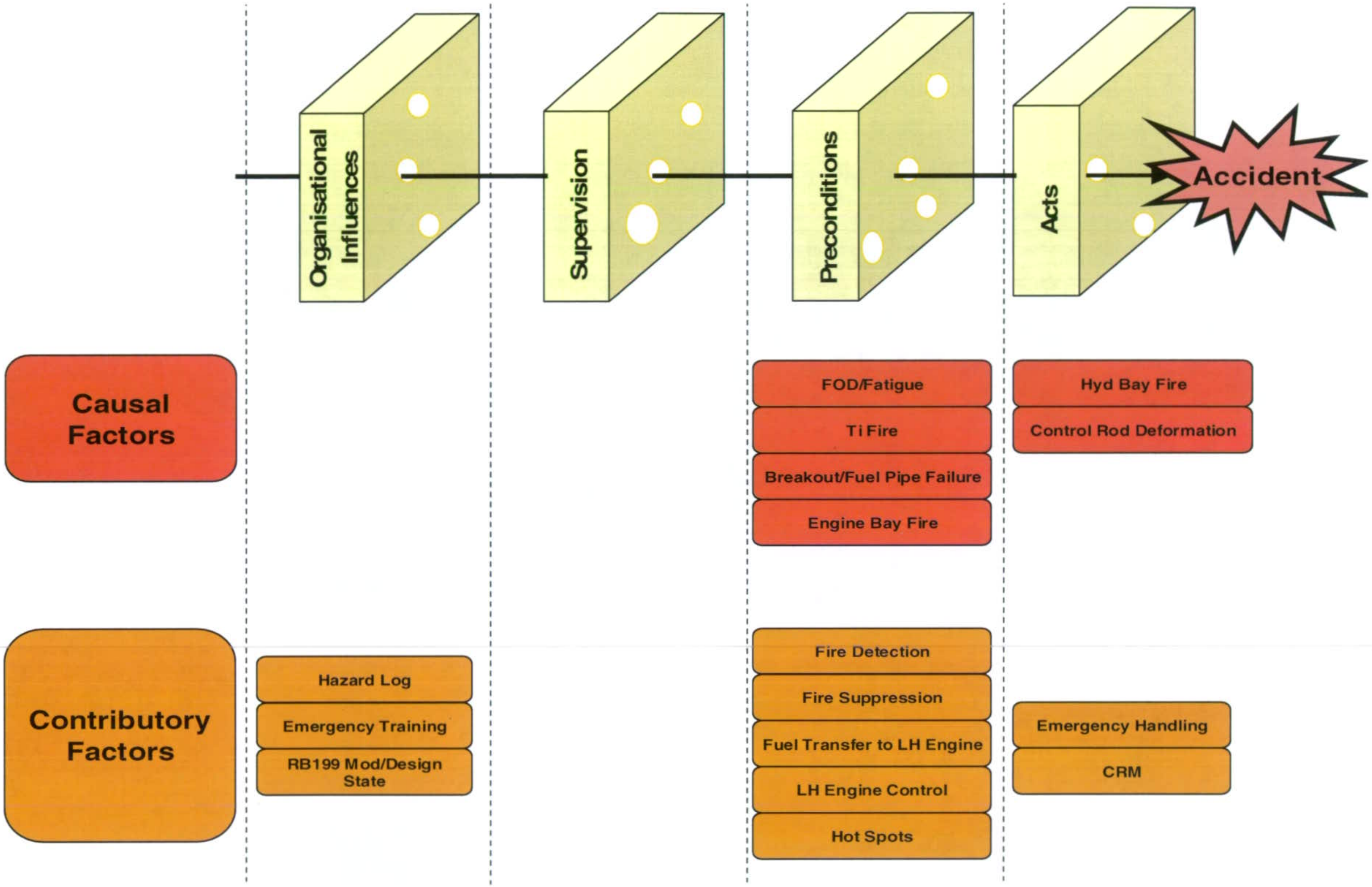
f. The Tornado Hazard Log does not reflect a current, up to date appreciation of the risk being carried. As such, it should be updated to account for recent Ti fire events, and the Post Control Status should reflect more plausibly the effectiveness of the controls placed within it. Para 56/63

95. **Other Factors.** The Panel concluded that if the following factors are actioned, future accidents may be prevented:

a. The failure of the Fastfind location beacons to provide an accurate position to aid the recovery of the crew could have severely impacted the crew's chances of survival once in the water. The ODH should seek measures to mitigate this risk. Ultimately, all fast Jet aircrew should be fitted with automatic PLBs. Para 49

96. **Observations.** The Panel observed the following factors which did not impact on the accident, but are worthy of comment:

a. There did not appear to be an effective process for transporting ejectees back to their home units following hospital admission, and where this responsibility lies appears to be undefined, or misunderstood. Part 1.3 Para 24



Organisational Influences
Supervision
Preconditions
Acts
Accident
Causal Factors
FOD/Fatigue
Ti Fire
Breakout/Fuel Pipe Failure
Engine Bay Fire
Hyd Bay Fire
Control Rod Deformation
Contributory Factors
Hazard Log
Emergency Training
RB199 Mod/Design State
Fire Detection
Fire Suppression
Fuel Transfer to LH Engine
LH Engine Control
Hot Spots
Emergency Handling
CRM

GLOSSARY

AAIB	Air Accidents Investigation Branch
ac	Aircraft
ACM	Aircrew Manual
APS PT	Air Platform Systems Project Team
CBLS	Carrier Bomb Light Store
CCOC	Combustion Chamber Outer Casing
CI	Continuous Improvement
CRM	Crew Resource Management
CSAS	Command and Stability Augmentation System
CSW	Combat Survival Waistcoat
CVR	Cockpit Voice Recorder
DCF	Duty Controller Flying
DDH	Delivery Duty Holder
DSTO	Defence SERE Training Organisation
EA	Engineering Authority
EHUMS	Engine Health and Usage Monitoring System
ENC	Emergency Nozzle Close
EP&R	Engineering Publications and Records
ERA	Emergency Ram Air
FCC	Flight Crew Checklist
FCU	Fuel Control Unit
fg hrs	Flying Hours
FOB	Flying Order Book
FOD	Foreign Object Debris
GASOs	Group Air Staff Orders
HIEST	High Intensity Emergency Simulator Training
HF	Human Factors
HP	High Pressure
HPC	High Pressure Compressor
HWG	Hazard Working Group
IA	Immediate Action
ICAO	International Civil Aviation Organisation
IP	Intermediate Pressure
IPC	Intermediate Pressure Compressor
JARTS	Joint Aircraft Recovery and Transportation Squadron
kg	kilogram
KCAS	Knots Calibrated Air Speed
LP	Low Pressure
LPC	Low Pressure Compressor
LRU	Line Replaceable Unit
MAAIB	Military Air Accident Investigation Branch
Mech fail	Mechanical failure
Mech mode	Mechanical mode
MECU	Main Engine Control Unit
MIG	Materials Integrity Group
MO	Medical Officer
mm	millimetres
NCU	Nozzle Control Unit
NH	High Pressure Compressor Speed
ODH	Operational Duty Holder
ODM	Operating Data Manual

PCMP	Post Crash Management Plan
PCON	Pilot Conversion
PELS	Personal Equipment Location System
PFCU	Primary Flying Control Unit
PIDAT	Post Incident Drug and Alcohol Testing
PLB	Personal Locator Beacon
POL	Petroleum, Oils and Lubricants
PT	Project Team
QFI	Qualified Flying Instructor
QQ	QinetiQ
R-ADR	Replacement-Accident Data Recorder
RAF	Royal Air Force
RAFCAM	Royal Air Force Centre of Aviation Medicine
RFODS	Rear Fuselage Overheat Detection System
RR	Rolls-Royce
RtL	Risk to Life
RTS	Release to Service
s	seconds
SI	Service Inquiry
SMO	Senior Medical Officer
SPS	Secondary Power System
STM	Simulator Training Manager
TAF	Terminal Area Forecast
TBT	Turbine Blade/Bearing Temperature
Ti	Titanium
TGRF	Tornado GR Force
TIALD	Thermal Imaging Airborne Laser Designator
Tor PT	Tornado Project Team
TRCU	Thrust Reverse Control Unit
UK MCC	United Kingdom Maritime Co-ordination Centre
UI	Unit Inquiry
VFR	Visual Flight Rules
VRS	Video Recording System
WSO	Weapon Systems Operator

RESTRICTED – SERVICE INQUIRY