a. **Self Medication.** Toxicological analysis suggests that the Pilot had taken over the counter cold medication[7] the evening before the accident. The Pilot did not have any cold or flu symptoms and his reason for taking it is unclear. Additionally, a prescription only medicine for the treatment of [redacted], was also present in his system. Neither of these treatments were annotated in the Pilot's RAF medical records, indicating self-medication or prescription from a non-military medical source; activity which is prohibited by Regulatory Article (RA) 2135. The sedative properties of the active ingredients within the cold medication can last up to 12 hours post-consumption. The Panel concluded that self medication may have produced a degree of cognitive impairment that made detection of the SFH in an unsafe condition less likely and that it is possible that this was **a contributory factor**. Witness 3 Witness 8 Exhibit 11 Exhibit 12 Exhibit 23

b. **Re-Programming of VHF Radio.** Due to the plan to operate from RAF Valley it was necessary to change the pre-set frequencies on the VHF radio. The direction as to when to carry this out was not specifically briefed and no additional time was allocated during start-up. While none of the other pilots carried out this action on the ground, intending instead to carry it out when airborne, the Panel found that the frequencies had been inputted to XX177's VHF radio at some point prior to the accident. Although the re-programming of a VHF radio is not a complex activity, it is not within the normal start up procedure and would have increased the workload for the Pilot. Witness 6 Exhibit 22

c. **Mobile Phone Call.** Whilst walking from the line office to XX177, the Pilot received and answered a mobile phone call. Although not prohibited by regulation, all military flight safety organizations recognise the danger of aircrew distraction following the sortie brief. The call itself was short (49:05 seconds), relatively mundane in nature and not animated. It is the Panel's view that the timing of the call, which terminated as the Pilot reached XX177, may well have led to a period of distraction of the Pilot at the point where he commenced aircraft checks, including the ejection seat. Witness 4 Exhibit 10 Annex C Annex E

1.4.2.29. The Panel concluded that the acceptance of a mobile telephone call just prior to conducting aircraft checks, and re-programming the VHF at the same time as starting the aircraft, is likely to have distracted the Pilot during this period and therefore distraction may have been **a contributory factor**.

[7] Night Nurse.

SECTION 1.4.3 – EJECTION SEAT FAILURE

1.4.3.1. **Background.** XX177 was fitted with a MB Type 10B1 Mk 1 ejection seat in the front cockpit and a MB Type 10B2 Mk 1 ejection seat in the rear cockpit (see Figure 30). The ejection seats are fully-automated, cartridge operated, rocket-assisted escape systems which are designed to provide safe escape from most altitude and speed combinations, including a ground level ejection at zero speed and zero altitude for aircrew boarding weights up to 108.9Kg. Both ejection seats were fitted to XX177 in Mar 2011 following bay maintenance at RAF Valley. The last maintenance work carried out on the ejection seats was the conduct of RTI59D (Top Block Cracking NDT Inspection) on 24 Oct 2011, 9:40 flying hours prior to the accident. This Section will describe the normal operation of a Mk10B ejection seat before analysing the evidence regarding the accident on 8 Nov 11.

Exhibit 7
Exhibit 27
Exhibit 32
Annex B

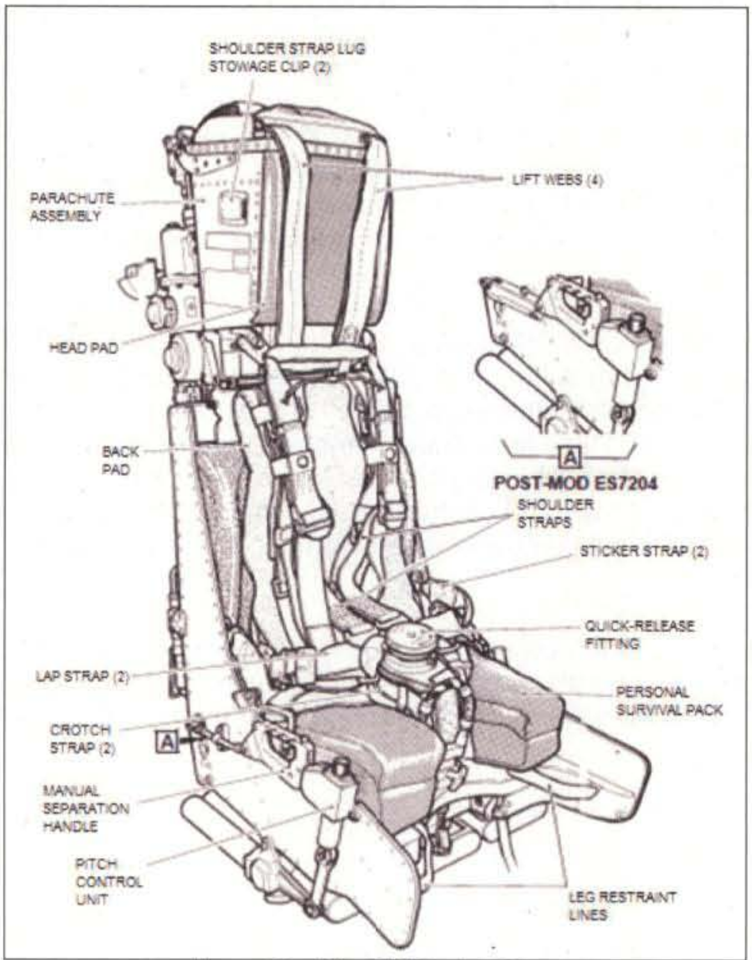

Figure 30 – Mk 10B Ejection Seat.

EJECTION SEAT NORMAL OPERATION

1.4.3.2. The following describes a normal independent ejection sequence, with command eject selected 'OFF'[8]:

Exhibit 27
Annex B
Annex C

a. The SFH is pulled, releasing the seat firing unit sear which in turn initiates

[8] Command Eject: A system that allows initiation of ejection of the front seat by the rear seat occupant - When the command eject is selected 'ON' this will automatically initiate ejection of the front seat should the rear seat occupant eject. Selection of 'OFF' ensures that operation of either seat requires independent initiation.

the firing unit cartridge producing hot gasses which are distributed to (see Figure 31):

1. The harness power retraction unit cartridge which fires to pull the occupant's shoulders back into the seat and lock the retraction straps.

2. The ejection gun sear withdrawal unit to rotate the cross shaft to remove the sear and fire the ejection gun primary cartridge.

Movement of the SFH also unlocks the manual separation handle enabling pilot operation should it be required post main chute deployment.

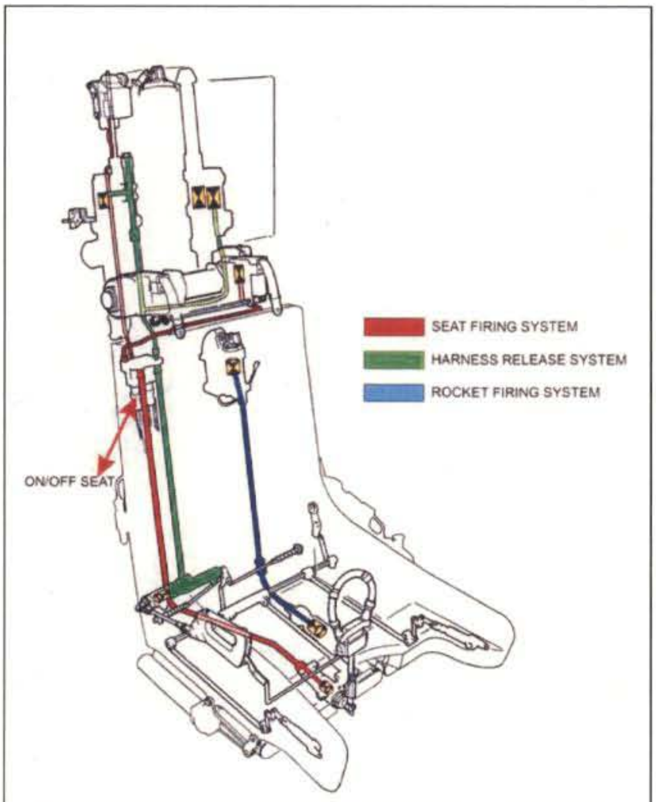

Figure 31 – Showing the Mk 10B ejection seat gas flow.

b. The pressure caused by the expanding gases from the ejection gun primary cartridge causes upward movement of the seat along in-cockpit guide rails; releasing the locking plunger from the top latch and hence the seat from the ejection gun.

c. As the seat accelerates upwards along the guide rails, the following events occur automatically (see Figure 32):

1. Ejection gun secondary cartridges fire in turn as the firing ports are exposed to the gasses from the primary cartridge.

2. The MDC firing unit is engaged by the striker (attached to the seat), detonating the MDC which shatters the canopy before engagement with the top of the seat.

3. Static trip rods withdraw the sears from the drogue gun and the Barometric Time Release Unit (BTRU). Static cables disconnect the

command ejection system, the aircraft portion of the PEC and the main oxygen supply. A plocket (plug and socket assembly) disconnects the seat height adjustment motor from the aircraft electrical cable.

4. Emergency oxygen supply is selected on and the regulator set to 100%.

5. The leg restraint lines are pulled downwards through the snubbing units to restrain the occupant's legs.

d. As the telescopic tubes of the ejection gun separate (about 0.25 seconds after ejection initiation), the Rocket Remote Initiator (RRI) sear is removed. This sear removal initiates the RRI cartridge which produces the hot gasses that fire the rocket initiator cartridge and ignite the rocket pack.

e. As the rocket pack completes its burn the drogue gun fires (0.5 seconds after the drogue gun sear has been withdrawn) and ejects the drogue piston. This piston removes the 22" controller drogue which in turn withdraws the 5' drogue which fully develops approximately one second after ejection initiation. The purpose of the drogues is to decelerate and stabilise the seat prior to main parachute deployment.

f. The remainder of the sequence is controlled by the BTRU which will not fire until the ejectee is below g-stop barostat altitude (normally 10,000'). At this point a 1.5 second time delay occurs and the BTRU cartridge fires generating further hot gasses.

g. The BTRU gasses cause the following to happen:

1. The scissor shackle is released allowing the drogue shackle and the harness top locks to be released.

2. A cartridge is initiated within the manual separation breech which operates a piston to release the harness bottom locks and the leg restraint taper pins.

3. The back up drogue gun second cartridge is fired.

h. Release of the harness top locks frees the occupant from the seat, although at this stage the occupant remains attached to the seat by the seat pan sticker straps and the combined seat and parachute harness until the parachute is released by the operation of the scissor shackle.

i. Scissor shackle release enables the drogue shackle and duplex drogue assembly to be disconnected from the seat. The force from the drogue parachutes is therefore transferred through the duplex drogue assembly to pull open the inner closure flaps of the parachute container and withdraw the main parachute.

j. As the parachute develops, the seat falls away pulling the seat pan stickers and PSP lowering line connector from their clips and the leg restraint lines run out freely through the leg garters. A normal descent should then follow with the occupant separated from the seat.

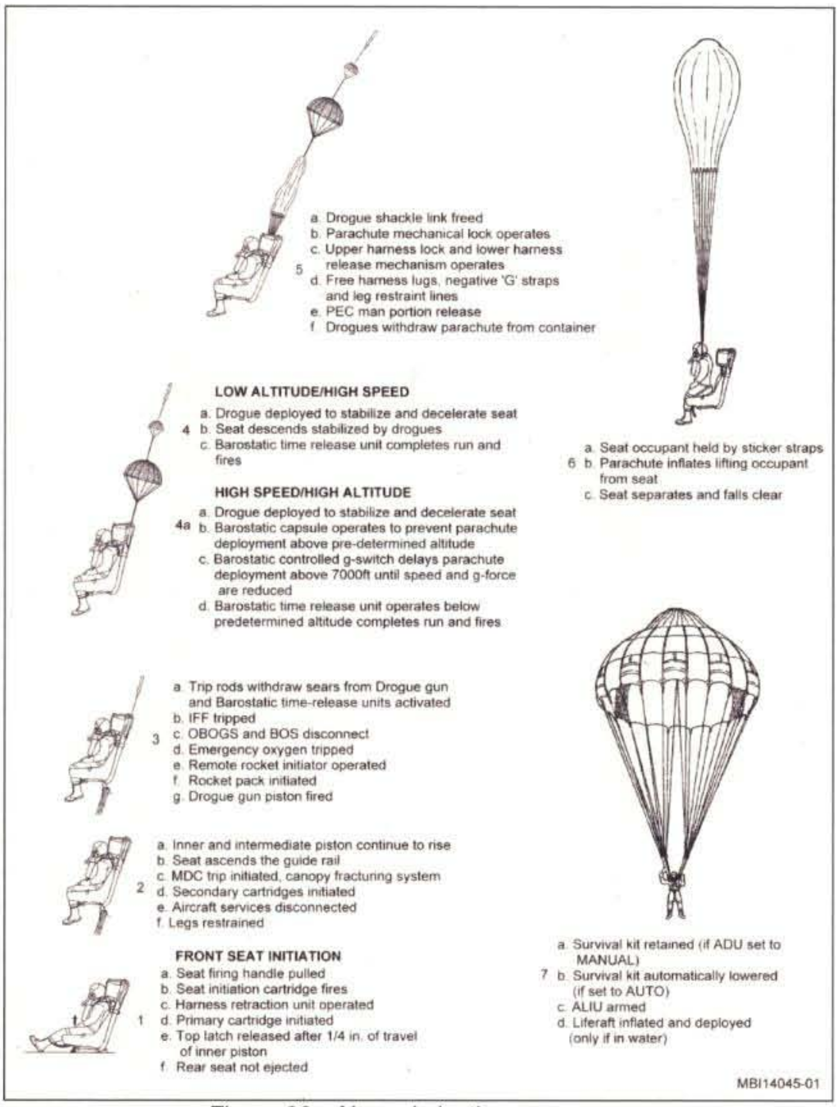

Figure 32 – Normal ejection sequence.

XX177 EJECTION SEAT SERVICEABILITY

1.4.3.3. Examination and testing of the seat and its components was undertaken at MB, 1710 NAS, MilAAIB and RAFCAM, monitored by HSE personnel, to ascertain the serviceability and operation of components. The Panel concluded the following: Annex B Annex C

a. The Command Ejection system was found selected to 'OFF' and ejection had not been initiated from the rear seat; it was found to be fully serviceable and this was **not a factor**.

b. All ejection seat cartridges had fired in the correct sequence and this was **not a factor**.

c. The seat weight was set at 80Kg, which was within the operating range of the seat and appropriate for the Pilot. The subsequent angle of the rocket motors was consistent with this weight setting. The seat weight setting and rocket motor angle were **not factors** in the accident.

d. The front cockpit canopy MDC firing unit sears had withdrawn from the MDC firing units and the MDC had fired. Damage to the MDC firing unit lever protective cover indicated that the firing unit lever had operated by contact with the ejection seat striker (see Figure 33) as expected and this was **not a factor** in the accident.

Figure 33 – XX177 Front Cockpit MDC firing unit and lever.

e. The drogue gun timer mechanism operated within expected limits and was **not a factor**.

f. The rocket motors fired as expected and propelled the seat to a height in excess of the minimum required for safe deployment of the main parachute and was **not a factor**.

g. The 22 inch drogue, 5ft drogue and main parachute were all in date for servicing with no damage to the rigging, other than that sustained post landing through cutting by emergency responders, and were **not factors**.

h. The BTRU timer mechanism operated within expected limits and had released the scissor shackle release plunger (see Figure 34) and the scissor shackle jaws were found unlocked and free to open. The Panel concluded that the BTRU was **not a factor** in the accident.

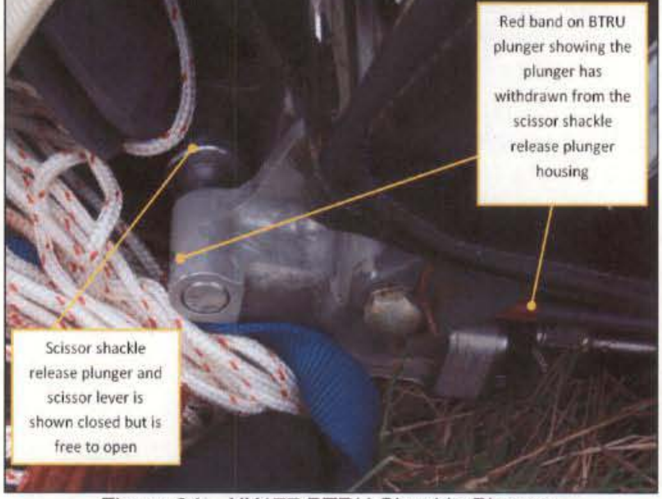

Figure 34 – XX177 BTRU Shackle Plunger.

i. The upper and lower harness locks were released and the strap lugs unrestrained consistent with normal operation of the BTRU and was **not a factor** in the accident.

j. The sticker straps remained in place and intact and were **not a factor** in the accident.

k. The parachute remained stowed in the parachute pack container and had not deployed; the parachute pack container was found distorted but intact (see Figure 35). The parachute retaining flaps were closed; one of the flap securing ties was intact and three flap ties had broken. Further examination of the parachute pack at RAFCAM determined that the parachute had been correctly packed. Functional testing demonstrated correct parachute pull-out sequence and operation; indicating that the parachute packing had not restricted the deployment of the main parachute and that it was **not a factor** in the accident.

Figure 35 – XX177 Duplex Drogue and Parachute Container.

l. The drogue shackle was intact with the nut and bolt fitted and the parachute withdrawal line and drogue extender strap attached. The parachute withdrawal line was tested as part of the 'pull-out' test and the Panel concluded that it was **not a factor**.

1.4.3.4. **Analysis of Seat Serviceability.** Video evidence and additional testing indicated that following the initiation of ejection, the seat operated as expected in all respects up until the failure of the main parachute to deploy. Subsequent testing of the main parachute demonstrated that it would have deployed had the drogue shackle separated from the scissor assembly. The drogue and scissor shackle assemblies were further examined: Exhibit 2 Annex B Annex C

DROGUE AND SCISSOR SHACKLE 'NORMAL' OPERATION

1.4.3.5. **Drogue and Scissor Shackle Fitment.** The drogue shackle is retained within the scissor shackle assembly at the top of the Mk10B ejection seat (see Figure 36) using the drogue shackle nut and bolt. Annex B

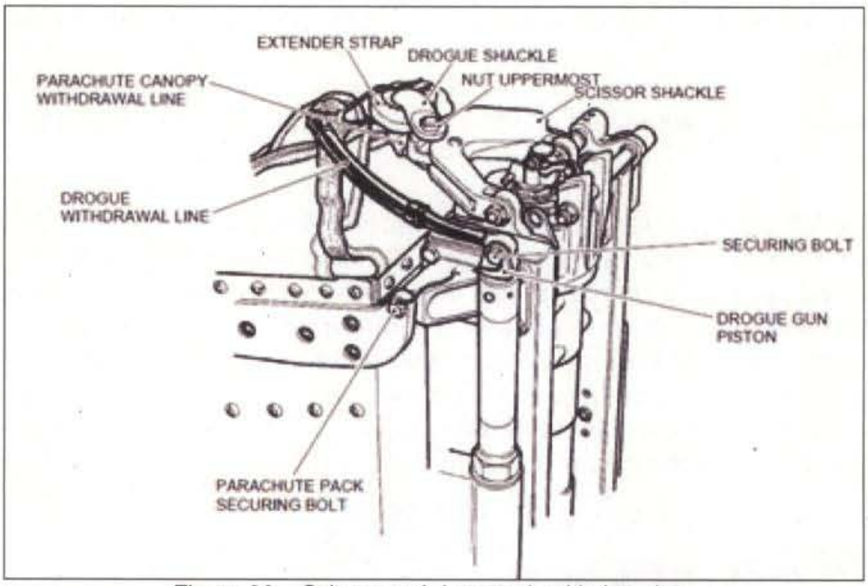

Figure 36 – Scissor and drogue shackle location.

1.4.3.6. **Role and Operation of Components**:

a. **Scissor Shackle.** This comprises a fixed shackle frame and a pivoting shackle lever which move fore and aft around the main beam attachment in response to changes in directional forces from the drogue parachutes during ejection. Under normal conditions the drogue shackle bolt is held by the closed 'jaws' of the scissor shackle (see Figure 37 view A) which secures the drogue assembly to the ejection seat, preventing main parachute deployment until release conditions are obtained. The scissor shackle is held in this locked position by the shackle release plunger, which in turn is restrained by the BTRU. Post ejection, once the seat velocity is within the operating envelope and in a stable attitude the BTRU releases the plunger which removes the lock on the scissor lever. This allows the drogue assembly to be withdrawn (see Figure 38 view A) under the forces from the drogue parachutes, leading to main parachute deployment. Exhibit 27 Annex B

b. **Drogue Shackle Assembly.** Drogue parachute deployment occurs for two reasons; firstly to stabilise and decelerate the ejection seat[9] and secondly to deploy the main parachute. During ejection the drogue gun fires which deploys the 22 inch and then 5ft drogue parachutes. The sequence is then halted; the drogue shackle is held within the jaws of the scissor assembly (see Figure 37). Once released, the force of the drogue parachutes is transferred through the parachute withdrawal line resulting in deployment of the main parachute from its housing (see Figure 38). Exhibit 27 Annex B Annex C

[9] Often required in high speed ejections.

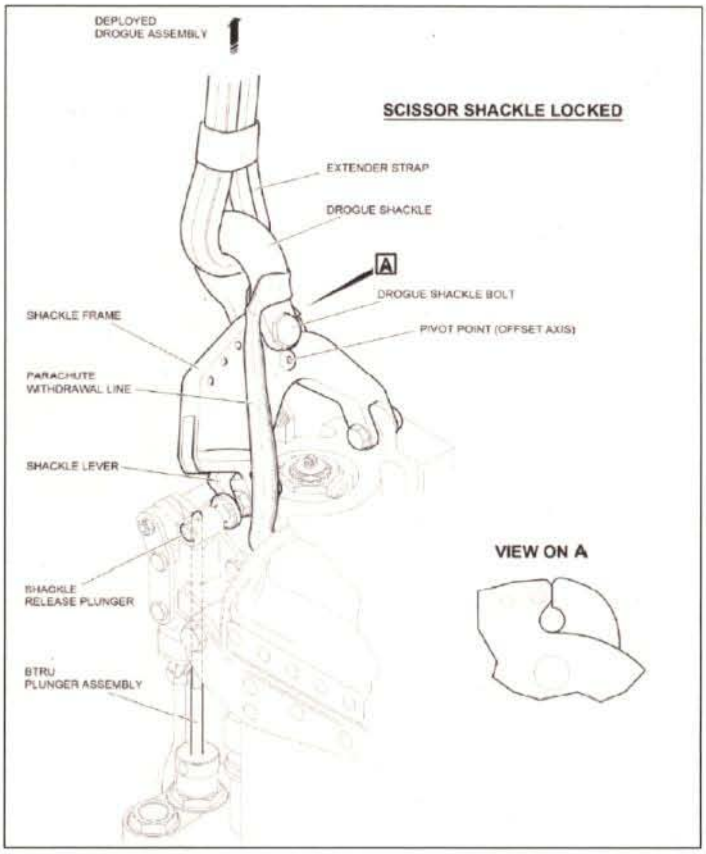

Figure 37 – Scissor assembly in locked condition.

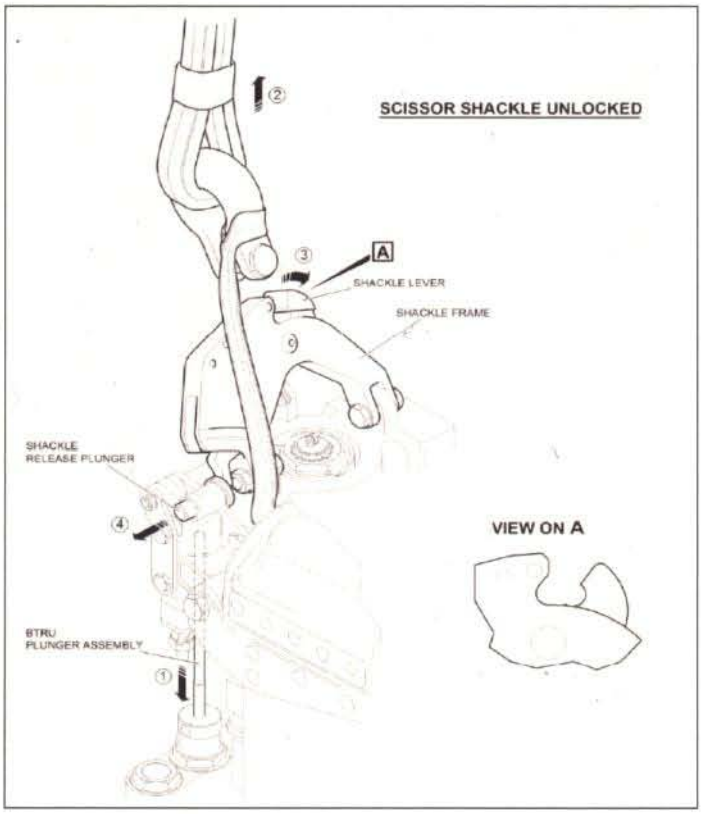

Figure 38 – Scissor assembly in un-locked condition.

DROGUE AND SCISSOR SHACKLE ANALYSIS

1.4.3.7. **Component Specification.** Drogue and scissor shackle components from XX177 were measured and compared to MB engineering drawings to ascertain if they met specification. Additionally, samples from the supply system were gathered and measured for comparison. All of the critical dimensions were satisfied with the exception of the following: Annex B

a. **Drogue Shackle Lug to Lug Gap.** The gap between the internal faces of the two lugs on the XX177 drogue shackle components was 0.098 inches too small (see Figure 39). When the nut was undone and the components separated, the lug to lug gap returned to within drawing specification; demonstrating that the compression out of tolerance was caused by fitment of the drogue shackle nut. It is most likely that the drogue shackle was manufactured within drawing specification. The effect of this compression is significant and is discussed below. The Panel concluded that drogue shackle manufacture was **not a factor**.

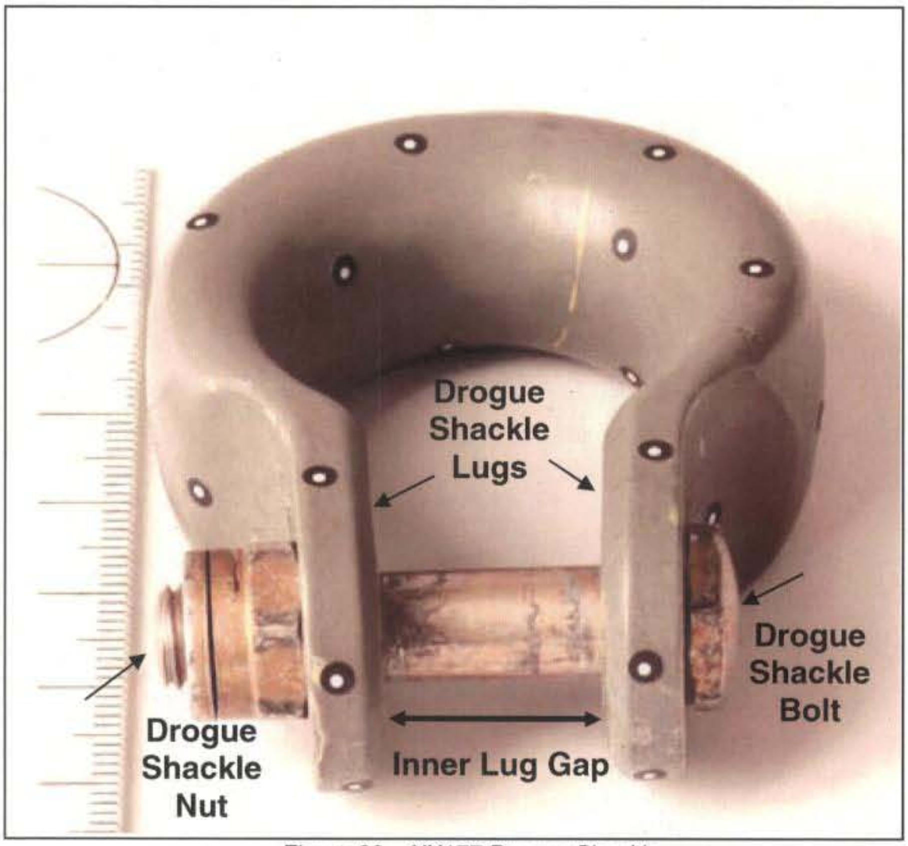

Figure 39 – XX177 Drogue Shackle.

b. **Drogue Shackle Nut.** The nut fitted to XX177 drogue shackle was 0.007 inches higher than the drawing specification (see Figure 40). By design, all locknuts plastically deform to create the required locking mechanism, increasing their height during fitment. Locknuts of the same specification as that fitted to XX177 were tested to ascertain the extent to which they deform. Following comparison, the Panel concluded that the drogue shackle nut fitted to XX177 was most likely manufactured within drawing specification and was **not a factor** in the accident.

Figure 40 – XX177 Drogue shackle nut.

c. **Drogue Shackle Bolt.** The dimensions of the XX177 bolt were within tolerance. Evidence existed of thread having been 'cut' during fitment of the drogue shackle nut. Testing revealed that other in-service bolts, including those that were un-used, although having the correct overall bolt length had a shank length marginally shorter than that required by design specification (See Figure 41). The Panel concluded that the specific finding of bolts with a short shank length was not a factor; however, that there were aircraft components in circulation that were outside of design specification might be indicative of a shortfall in quality control and was **an other factor**.

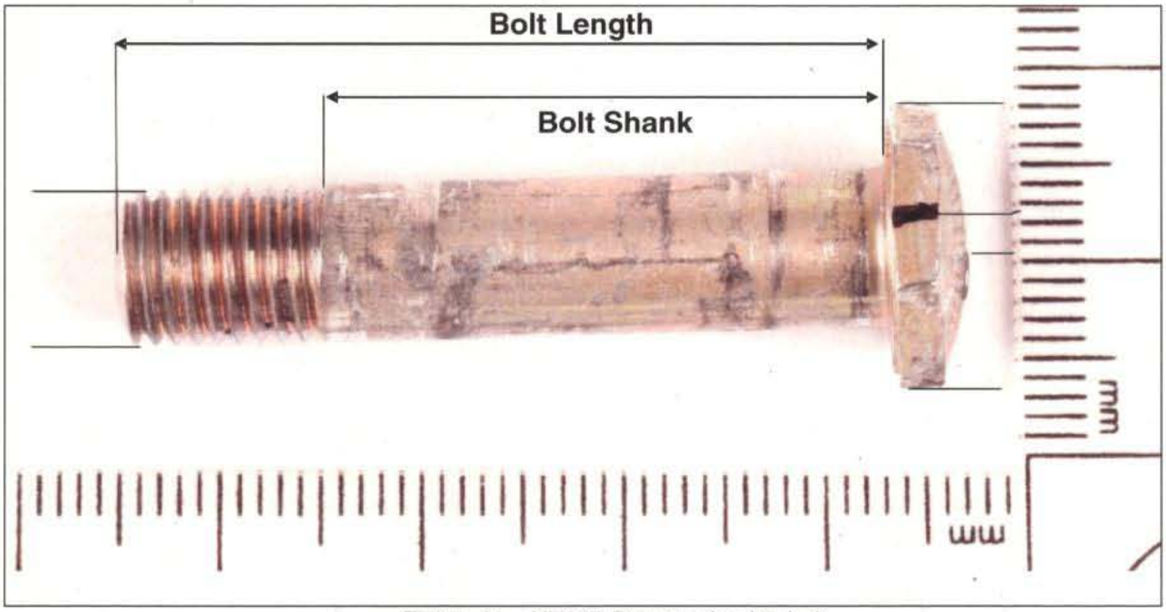

Figure 41 – XX177 Drogue shackle bolt.

1.4.3.8. **XX177 Component Examination.** In order to ascertain what caused the failure of the drogue shackle to release from the scissor assembly during the ejection sequence extensive forensic examination of the components was conducted at 1710 NAS, as follows: Annex B

a. **Drogue Shackle.** A number of areas of damage were found adjacent to the shoulder (see Figure 42). Abrupt lifting of the paint, consistent with heavy localised loading, was identified along with angled, vertical and circumferential scoring. The drogue shackle lugs had been compressed by the drogue nut and bolt to such an extent that an interference fit of 0.009 inches existed between the drogue and scissor shackle (see Figure 43).

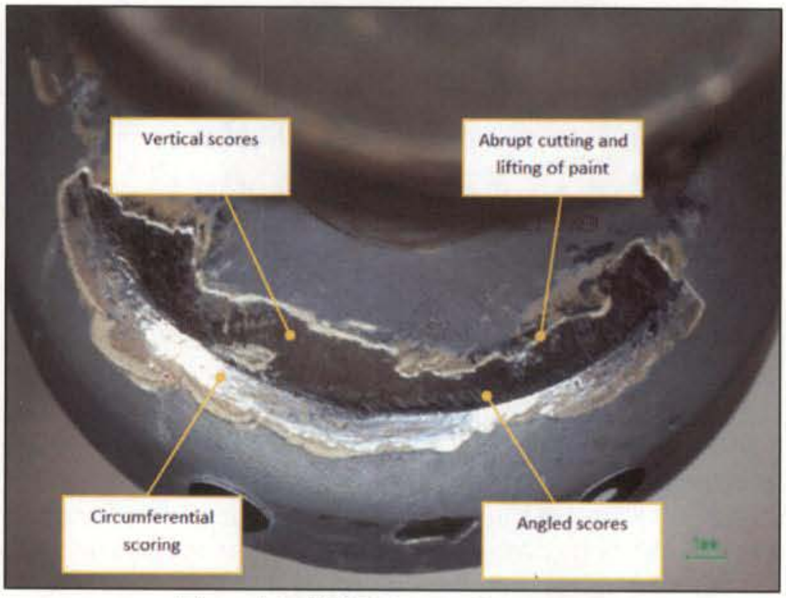

Figure 42 – XX177 Drogue Shackle Damage.

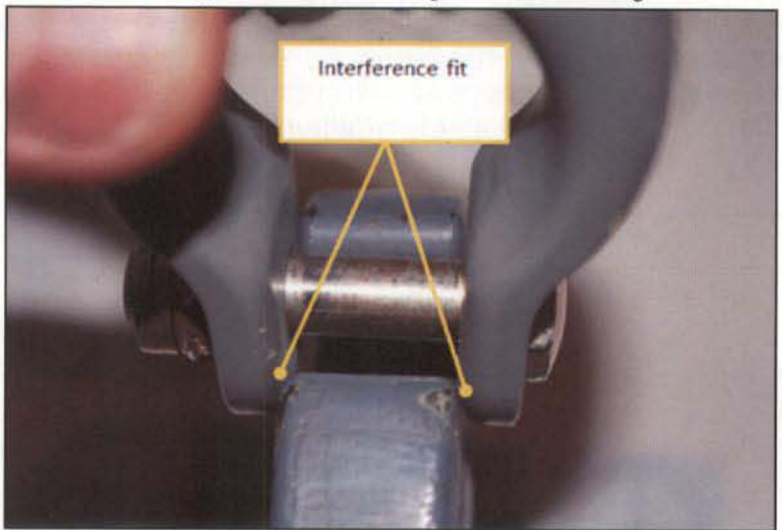

Figure 43–Drogue & Scissor Shackle Assembly (not XX177) showing interference fit.

b. **Scissor Assembly.** Visual examination of the scissor lever revealed scoring in an arc running from the bottom horizontal edge of the upper jaw face (see Figure 44) point A towards the vertical jaw edge (see Figure 44 point B).

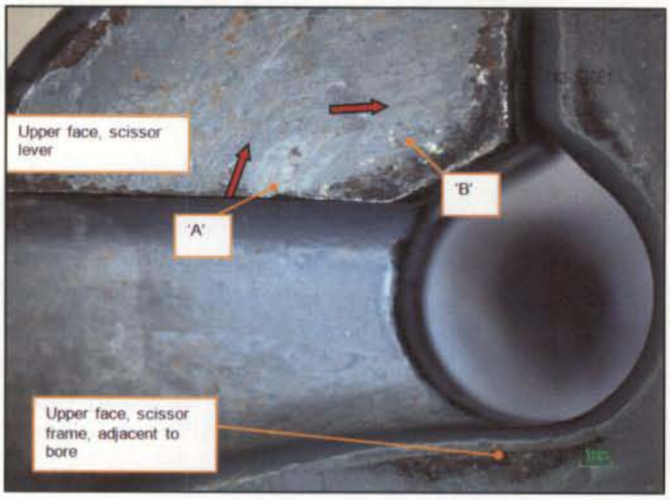

Figure 44 – XX177 Drogue Scissor Lever Damage.

c. **Drogue Shackle Nut and Bolt.** The drogue shackle nut was tightened to 1.5 threads bolt protrusion above the nut (see Figure 45). There was no significant internal damage to the threads. However, evidence of swarf[10] was found on removal of the nut, and the bolt had two separate score marks close to the unthreaded portion of the shank; the threads of the bolt exhibited adhesive wear in the region of contact with the nut threads. This suggested that the nut had bottomed out on the unthreaded shank of the bolt and cut new thread.

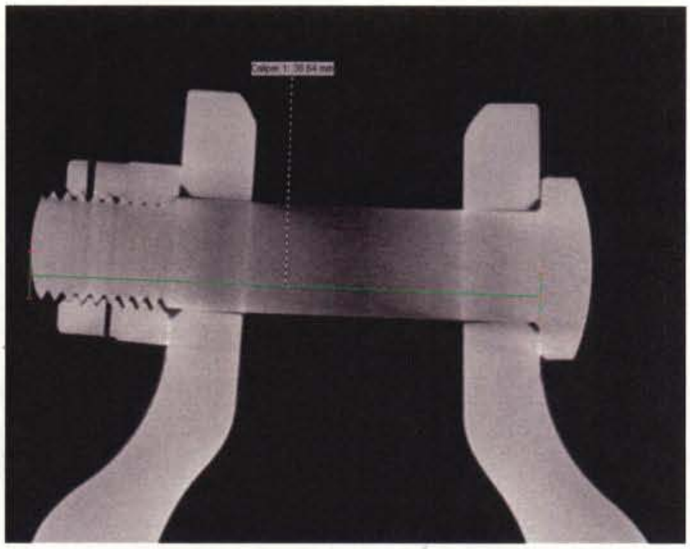

Figure 45 – XX177 Drogue Shackle Bolt showing bottoming out of the threads of the nut.

1.4.3.9. **Testing of Drogue and Scissor Shackle Components.** A test rig was designed and built at 1710 NAS to simulate the sequence of events and loading for a deployed drogue parachute on a drogue and scissor shackle (see Figure 46). This enabled consistent and replicable testing to be carried out to provide supporting evidence for the investigation into the failure of the XX177 drogue shackle to release. This was initially carried out on representative in-service components and subsequently on those from XX177. Different drogue shackle assembly configurations were trialled to measure the interference or clearance between drogue shackle lugs and the scissor shackle and to ascertain the effect on drogue shackle release: Exhibit 33 Annex B

Figure 46 – Drogue and scissor shackle test rig

[10] Swarf – Material, as metallic particles or abrasive fragments, which are removed by a cutting or grinding action.

a. **Nut Fitted to 'Flush'.**[11] This configuration resulted in drogue shackle lug compression of 0.040 inches producing a clearance of 0.063 inches when compared to the scissor shackle. The drogue shackle successfully released from the scissor assembly.

b. **Nut Fitted to 1.5 Threads (Representative Components).** Component parts taken from the stores system were measured for manufacturing tolerance. While many different combinations of components were used during testing, this particular test was carried out using the 'worst case' combination of components[12]. This configuration resulted in drogue shackle lug compression which created a 0.023 inch interference fit with the scissor shackle. The drogue shackle failed to release from the scissor assembly despite the test rig applying a force of 756 N. Repeated testing found that as the bolt attempted to pass through the gap in the scissor lever, the drogue shackle lugs jammed on the scissor lever jaw (see Figure 47). Additionally, visual examination of the inner surfaces of the drogue shackle jaw concluded that the abrupt severance of paint, consistent with heavy localised loading, was similar to that found on XX177.

Figure 47- The drogue shackle jammed on the scissor shackle jaws.

c. **Drogue and Scissor Shackle from XX177.** The XX177 components were assembled to the accident configuration, resulting in a 0.009 inch interference fit with the scissor shackle. Of note, when fitted but not deployed, lateral movement of the drogue shackle was possible, giving no indication of an interference fit until loading was applied. As the force was applied to the drogue shackle it became jammed on the scissor lever jaw and did not release until a force of 1187N was applied. This force was in excess of that expected from a zero/zero ejection once the BTRU had operated, where testing showed that a non-jammed drogue shackle would be expected to release at 200N. In the case of XX177, the maximum force experienced by the drogue shackle post BTRU operation would have been just short of 800N and hence insufficient to affect release (see Figure 48). Analysis suggested that XX177 would have required speed in excess of 50 knots[13] to overcome the jammed components in order to achieve successful main parachute deployment.

[11] The nut is fitted so the domed end of the bolt is proud with no threads visible.

[12] Worst Case - Shortest bolt, longest nut, smallest lug to lug measurement.

[13] This is in addition to 20 knots being experienced due to the ejection.

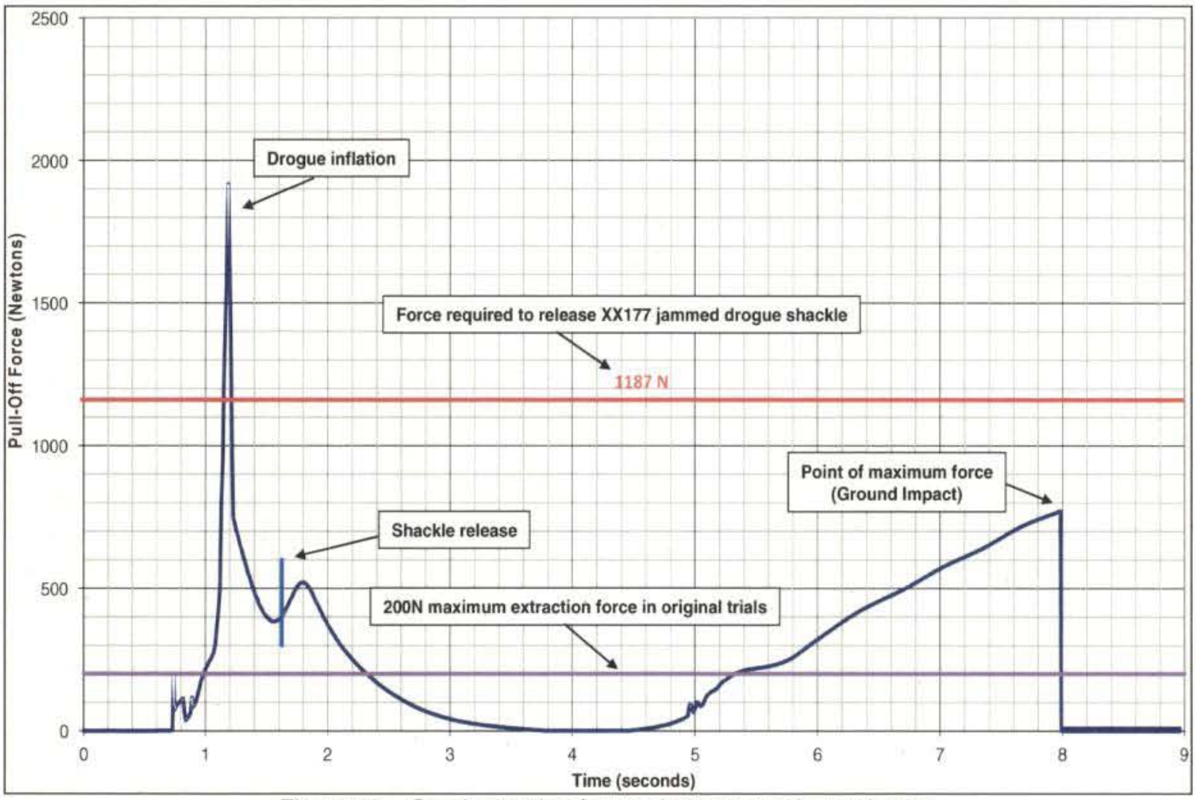

Figure 48 – Graph showing forces during a zero/zero ejection.

1.4.3.10. **Analysis of Component Testing.** Examination of XX177 components revealed that the scoring and paint damage found on the drogue shackle and scissor shackle assembly was consistent with the two components having contacted during the ejection. The vertical scoring on the scissor assembly suggested that the drogue shackle had moved vertically to the point of paint accumulation where it became jammed. The fitment of the drogue shackle nut to 1.5 threads, and in the process cutting new thread to the bolt shank, caused compression of the drogue shackle lugs. This resulted in an interference fit of 0.009 inches which prevented the release of the drogue shackle from the scissor shackle. This in turn stopped the deployment of the main parachute and subsequent separation of the Pilot from the seat. The lack of retardation caused by the failure of the main parachute to deploy, exacerbated by the increased weight of the seat remaining attached, resulted in a high impact velocity with the ground, causing fatal injury to the Pilot. Annex B

Of note, the findings from this testing and analysis were passed to Duty Holders, DE&S and MB, which informed subsequent changes to the guidance on fitment of the drogue shackle in order to prevent future reoccurrences.

XX177 EJECTION SEAT MAINTENANCE HISTORY

1.4.3.11. **Background.** The XX177 front ejection seat entered service on 19 Jul 76. It was in date for bay maintenance and was last fitted to XX177 on 03 Mar 11, some 133:25 flying hours prior to the accident. The last activity requiring fitment of the drogue shackle nut and bolt was RTI/Hawk/59D; a procedure that was required every 50 flying hours and was last carried out on XX177 on 24 Oct 11, 9:40 flying hours prior to the accident. Exhibit 7 Exhibit 32 Exhibit 34 Exhibit 35

1.4.3.12. **RTI/Hawk/59D.** RTI/Hawk/59D involves NDT of the ejection seat top block for cracking, necessitating the removal of the drogue shackle from the scissor shackle. In order to do this the drogue shackle nut must be undone and the bolt removed to allow the drogue Exhibit 35 Exhibit 36 Exhibit 37 shackle to slide over the closed jaws of the scissor shackle[14]. The reverse procedure is carried out on subsequent fitment. The direction to the tradesman on how to re-attach the drogue shackle to the scissor shackle following the NDT was contained within AP 101B-4401-1G Maintenance Procedure 29-10/7 which covers ejection seat safety equipment installation and stated:

a. Remove nut and bolt.

b. Position drogue shackle over scissor shackle jaws.

c. Pass bolt through drogue shackle and scissor shackle, secure with locknut.

The procedure provides no direction as to the degree to which the locknut should be tightened, regarding either thread protrusion or torque setting. Additionally, there is no specific guidance to fit new components during each assembly. In situations where specific guidance was not given, tradesman are trained to use accepted engineering practices; in the case of locknuts, DEF STAN 00-970 states that "in all cases where the method of locking…does not demand more, the end of the bolt or stud shall protrude beyond the nut by a dimension equal to at least 1.5 thread pitches". Examination of the components following the accident showed that the lock nut had been fitted to 1.5 bolt threads protuberance. It is the Panel's view that the physical fitment of the drogue shackle locknut was carried out in accordance with the extant MOD maintenance publications.

1.4.3.13. **Ejection Failure Summary**:

a. The ejection seat was in date for servicing and operated as expected post initiation in all respects up until the failure of the drogue shackle to release from the scissor shackle. Had the drogue shackle not jammed, the parachute would have deployed and it is most likely that the Pilot would have survived.

b. The drogue and scissor shackle components were manufactured within design tolerance. Although the shank length of the bolt was found to be too short (possibly due to new thread being cut) the overall length was within tolerance.

c. The drogue shackle was fitted in accordance with the extant publications of the day.

d. Had the aircraft forward speed been in excess of circa 50 Knots, it is likely that the load applied to the shackle would have been sufficient to separate the drogue shackle from the scissor shackle.

[14] It is normal practice to refit the nut hand tight to the bolt whilst the NDT inspection is being carried out to ensure components do not get lost and become loose articles.

SECTION 1.4.4 – DESIGN AND COMMUNICATION

1.4.4.1. **Background.** Effective communication amongst stakeholders is essential within any construct or organization, particularly when it involves safety and mitigating RtL. This Section will discuss the wider communication relevant to this accident and in particular the aggravating factor of the failure of the drogue shackle to release from the scissor shackle. The key stakeholders in this case are MB, BAE Systems, DE&S and the users (MOD and other nations).

1.4.4.2. **Drogue Shackle Warning.** Evidence suggests that neither DE&S nor the MOD were aware of the potential failure mechanism associated with tightening of the drogue shackle bolt. As a result, no specific guidance on the degree to which the nut was to be tightened was issued, nor were the dangers of over tightening included in the relevant MOD maintenance publications. Therefore, the general engineering principles learnt during initial training requiring a minimum of 1.5 thread protrusion were applied by engineers during drogue shackle lock nut fitment. Witness 38 Exhibit 36

Inspection of the maintenance publications from a number of other nations that operate the Hawk aircraft and utilize MB Mk10B seats or derivatives revealed that a warning[15] relating to pinching of the drogue shackle did exist in some cases. The Finnish Air Force maintenance publications relating to the assembly of the drogue shackle were found to include the following warning: **"To prevent possible pinching of the scissor shackle, which may cause hang up of the drogue shackle during ejection, do not over tighten or torque load the drogue shackle nut and bolt".** The Finnish publication went on to direct that engineers "Secure the bolt with a self locking nut ensuring that 1-1.5 bolt threads protrude through the nut and that the drogue shackle does not pinch the scissor shackle". Similar warnings and guidance were found to exist in the publications of at least 5 other nations and had done so since circa 1991. MB were unable to determine why the warning had been distributed to some Hawk and Mk10B seat users but not to others. There did not appear to be a robust closed-loop system whereby all interested parties could be assured that the transmission, reception and implementation of safety critical information had occurred. Additionally, there is no record of the MOD receiving this warning and it was not incorporated into the Hawk document set. It is the view of the Panel that knowledge that pinching of the drogue shackle could have potentially caused a "hang up of the drogue shackle during ejection" might have resulted in a revision of maintenance training and practices relating to the fitment of the drogue shackle nut. The Panel concluded that poor communication between stakeholders and the lack of a robust system of tracking amendments, including warnings, is likely to have restricted the flow of safety critical information; and that in the case of drogue shackle fitment, made compression of the drogue shackle lugs more likely and was **an aggravating factor.** Witness 38 Exhibit 73 Exhibit 74 Annex B

1.4.4.3. **Component Dimensions.** In a fax, dated 14 Jun 91, British Aerospace PLC (forerunner of BAE Systems) raised a concern to MB in relation to the Tornado MB Mk10A ejection seat highlighting the inability to achieve "the normal 1.5 thread protrusion through the drogue shackle self locking nut, even when pinching the shackle on". MB agreed with British Aerospace's concerns and stated that in-service applications could continue as long as two criteria were met: Exhibit 75 Annex B

[15] The S1000D European standard for technical publications states that: "Warnings used in data modules and technical publications are included to warn users that possible hazards are associated with the materials/processes/procedures or limits. These may cause death or injury in any form, if the instructions in the operational or procedural task are not followed precisely. Warnings describe the hazards and possible impact."

Military Aviation Authority MAA

a. When tightening the nut and bolt, the drogue shackle must not 'pinch' the scissor shackle when assembled to the seat.

b. The bolt shank must actually protrude clear of the stiff nut locking section.

By way of a longer term solution MB amended 2 technical drawings on 6 Aug 91:

c. **Drogue Shackle Bolt.** The length was slightly extended from 1.50" (+/- 0.005) to 1.50"-1.51".

d. **Drogue Shackle.** The left lug width dimension was reduced from 0.218" to 0.212"-0.217", the right lug dimension of 0.218" was deleted and a lug to lug outside dimension was added of 1.169"-1.174". The removal of the right lug dimension was not critical to the design as long as the other dimensions were satisfied and this was **not a factor**.

Communication between MB and British Aerospace demonstrated that some in MB and British Aerospace were aware of the potential for ejection failure if the drogue shackle nut was done up to a point where it caused compression of the drogue shackle and subsequent pinching on to the scissor lever. The extent to which this was known more widely within MB or promulgated externally is not clear; however, the issue of the warning to some users demonstrates that at some level, MB were aware of 'pinching' and the severity of the consequences. It is the view of the Panel that MB amended the technical drawings for the drogue shackle components based on British Aerospace's findings highlighted in the 14 Jun 91 fax, and that the XX177 components were manufactured within these tolerances. The XX177 components were fitted in accordance with the extant guidance of 1-1.5 threads protrusion. Testing showed that although this would cause an interference fit of 0.009 inches during operation, 'pinching' would not have been apparent during fitment. The Panel concluded that the dimensions of the drogue shackle components, when combined with the extant guidance on fitment, resulted in an interference fit of 0.009 inches during operation and was therefore **an aggravating factor**. Exhibit 75 Exhibit 76

RTI/HAWK/059D

1.4.4.4. **RTI/Hawk/059D.** UTI/Hawk/026 was an Urgent Technical Instruction (UTI) issued by the Hawk Support Authority (HSA) on 28 Jul 10. This instruction, which ultimately led to RTI/HAWK/59D, was in response to the discovery of cracking on the ejection seat top beam of Hawk XX263. The UTI required a visual check of all Hawk seats before next flight which resulted in a further 2 instances of cracking being found. Subsequent work conducted in consultation with MB, 1710NAS and the Aircraft Escape Systems Project Team (AES PT) centred on two areas: Witness 37 Witness 38 Exhibit 74 Exhibit 77

a. **The Impact of Cracking on Seat Safety.** Testing was completed by MB to ascertain if cracking of the top cross beam had an adverse effect on seat operation during an ejection. On 30 Jul 10, a Mk10 seat with a cracked top cross beam was fitted with a 120kg dummy (the max operating weight) and fired into a net. The test identified that even with a fully cracked beam, the performance of the ejection seat was not affected; 1710 NAS confirmed that loads in normal flight and during ejection were transferred to secondary load paths, allowing complete failure of the beam. MB advice to all its customers was to conduct a visual inspection every 14 days. Witness 37 Witness 38 Exhibit 78 Exhibit 79 Exhibit 80 Exhibit 107

b. **The Future Inspection Regime.** On 02 Aug 10 the Hawk Support Authority (SA) in consultation with the AES PT produced RTI 59 which introduced a regular inspection of the top block area. The scope of the inspection was Witness 38 Witness 41 Exhibit 35 increased, and to ensure that both visual and non-visual cracking was identified, a number of different Non-Destructive Testing (NDT) techniques were utilized. These necessitated the disconnection of the drogue shackle from the scissor shackle to facilitate access. On 20 Aug 10 the AES PT issued an ALARP statement, stating that the risk identified due to a cracked beam was 'Critical' but that with mitigation "even with a cracked Top Beam Block the seat will function correctly." AOC 22 (Trg) Gp, as AOA, chaired a meeting to review the SA actions and agree future inspection regimes; however, despite carrying out an extensive search, the Panel could find no formal record, minutes, RoDs or Actions for this meeting. Witness testimony refers to the AOA being content with MB's and 1710 NAS' findings but not content to operate aircraft with a cracked cross beam as the visual affect may undermine aircrew confidence in the system. Additionally, as the propagation rate was unknown, even if the ejection seat remained serviceable, cracked beams could potentially produce loose article hazards in the aircraft. Therefore, an NDT inspection was introduced for completion every 28 days, with a view to understanding the crack propagation rate and characteristics and replacing affected components. Witness testimony suggests that whilst maintenance issues were considered, these concerned the maintenance hours burden, rather than the extant maintenance procedure to prepare the top beam for NDT inspection, which was assumed to be adequate. RTI/59 was amended 4 times between Aug 10 and Oct 10, including the change in periodicity of the NDT inspection from 28 days to every 50 flying hrs. This regime was continued after 1710 NAS had provided assurance to the PT that the crack growth rate was slow and that a non-dismantling visual inspection would be adequate. Exhibit 80 Exhibit 91 Exhibit 92 Exhibit 93

1.4.4.5. **Safety Case.** RA 1220(2) states that "the Project Team shall produce and update a Safety Case". Def Stan 00-56 describes the approach that may be adopted for the auditable production of safety cases, and which can be used as an acceptable means of compliance: that "the contractor shall produce a Safety Case for the system on behalf of the DE&S Duty Holder[16]. The Safety Case shall consist of a structured argument, supported by a body of evidence that provides a compelling, comprehensible and valid case that a system is safe for a given application in a given environment." The AES PT is known as a 'commodity' PT and as such provides expertise, advice and equipment to other PTs. The MAP states that the AES PT is "responsible for…all elements of AAES, including raising Safety Cases and passing [these] to Platform PT's for integration into the Platform Safety Case." The UK Military Flying Training System Project Team (UK MFTS PT) Safety Management Plan (SMP) also stated that "these organizations [commodity PTs] will maintain safety cases and hazard logs for their equipment." Neither the UK MFTS PT nor the AES PT was able to produce a Mk10 ejection seat safety case report, the latter believing that it was held by the HSA. Witness 41 Exhibit 87 Exhibit 90 Exhibit 94 Exhibit 95 Exhibit 110 Exhibit 111

1.4.4.6. **Audit Trail.** The UK MFTS PT SMP states that "Individuals holding LoAAs[17] are to ensure that where they exercise engineering judgements in the execution of their duties, that an auditable record of the rationale is maintained" and that "a core element of the SMS is the documentation of all the safety related activities, including meetings". There is evidence that extensive work was carried out within the Hawk SA, AES PT and 22 (Trg) Gp to support the implementation of UTI/HAWK/026 and the subsequent rationale for the RTI/HAWK/059 series. However, despite significant investigation by the Panel to understand this process, a lack of formal records relating to this high profile safety critical issue hindered a thorough understanding of the decision making that had taken place to such an extent that even the dates of formal meetings are unknown. Witness 38 Witness 41 Exhibit 87

[16] The DE&S Duty Holder is responsible for the 'equipment' safety case, and these responsibilities should not be confused with those of an Aviation Duty Holder who is responsible for managing RtL for all platforms within their AOR.

[17] LoAA – Letter of Airworthiness Authority.

Def Stan 00-56 states that a Hazard Log is the primary mechanism for providing traceability of the safety risk management process and assurance of the effective management of hazards and accidents. The Hazard Log shall…accurately reflect risk management activity." The system used by DE&S is 'eCassandra'; hazards, mitigation and control measures are entered and tracked using this database where the probability (pre and post mitigation) of hazards are ascertained and managed to provide a recorded history. Exhibit 90

The initial cracking of a Mk10 ejection seat top beam block was raised to the HSA on 27 Jul 10 and UTI/HAWK/026 was issued 28 Jul 10 to conduct a visual inspection for cracks in order to gather further evidence, and RTI/HAWK/059 was issued on 02 Aug 10 to conduct NDT techniques to determine if non-visible cracking was present. During this period, MB conducted testing while 1710 NAS developed further NDT techniques and tests to determine crack propagation rates. HSA raised Hazard 194 (Ejection Seat Top Beam Block Assembly Cracking) on 05 Aug 10, mitigated by control measure C252 (RTI/HAWK/059). The Panel found no reference to the UTI, the MB testing, 1710 NAS analysis or any meetings regarding Hazard 194 recorded in eCassandra during this period. Exhibit 89 Exhibit 93

RTI /HAWK/059 was uplifted to RTI/HAWK/059A on 05 Aug 10, increasing the scope of the NDT inspection, followed by RTI/HAWK/059B, issued 20 Aug 10, introducing a 28 day inspection regime. Between the recording of RTI/HAWK/059B on 20 Aug 10 and a trial installation of a new Top Beam Block in Jul 11 (exact date unknown due to no record in eCassandra), there are no recorded changes to the eCassandra Hazard Control Measures. However, during this period RTI/HAWK/059B was up issued to 059C on the 17 Sep 10 (introducing a revised inspection period of 50 flying hours) and 059D on 27 Oct 10 (introducing revised off –aircraft procedures for ejection seat bays). Aside from the RTI's themselves, there is no log of these events within eCassandra and therefore no reference or audit trail of the airworthiness decision making process to support these changes.

1.4.4.7. **RTI/HAWK/059D Summary.** It is the Panel's view that the initial actions following the discovery of a cracked top beam block were appropriate and based on sound engineering, technical and operating advice. The absence of a clear audit trail, poor Hazard Log tracking and paucity of decisional meeting records meant that it was only possible to conclude this following extensive investigative interviewing of multiple stakeholders. Furthermore, the audit trail after issue of RTI/HAWK/59B (20 Aug 10) appears to be almost non existent; there is no visibility of the airworthiness decision making process which led to significant changes to the inspection periodicity. Additionally, the apparent lack of awareness over ownership of the ejection seat safety case report directly contravenes Def Stan 00-56 and the UK MFTS SMP and it is difficult to understand how the management of this hazard could have been appropriately achieved without reference to it. It is the Panel's view that the HSA did not maintain sufficient records of the decision making process behind the introduction of RTI/HAWK/059, which appears to be indicative of wider airworthiness recording shortfalls that were highlighted in a recent MAA audit of the PT that identified "weak audit trails to justify decisions…(which) raises questions over the demonstrable rigour being applied to airworthiness decision making". Whilst the forums to receive SME advice and make appropriate decisions appeared to have taken place following the cracked top beam block, the lack of records surrounding airworthiness decision making is concerning. It is the Panel's view that this general shortfall in auditable recording of airworthiness decisions fundamentally undermines safety cases and therefore the Panel concluded that it was **an other factor.** Exhibit 88

SECTION 1.4.5 – CULTURE, ORGANIZATION AND SUPERVISION

BACKGROUND

1.4.5.1. **Background.** Formed in 1965, the Royal Air Force Aerobatic Team, The Red Arrows, is a full time display Sqn and is acknowledged as one of the world's premier aerobatic display teams. Since their formation they have displayed to large audiences in the UK and around the world, and have played a central part in many of the Nation's most significant public events. The RAFAT is busy throughout the year: autumn and winter are spent training and incorporating new pilots into the Team, the spring is the final work-up, leading to Public Display Authority (PDA)[18], and the summer is dominated by a challenging programme of public displays and fly pasts. Witness 8 Witness 22 Exhibit 18 Exhibit 38

1.4.5.2. **RAFAT Identity.** The RAFAT promotes the professional excellence of the Royal Air Force. The skill, timing and courage demonstrated during their displays, often on the international stage, has resulted in an almost unrivalled affection and pride felt by the British public. A global brand in itself, the RAFAT attracts sponsorship from major corporations, its personnel attend numerous high profile PR events and it is not uncommon for them to be afforded VIP status by sponsors. Their unique uniforms and merchandise ensure that as a military unit their profile is second to none, regularly attracting significant media attention and praise from the very highest levels. Exhibit 38

PILOT SELECTION

1.4.5.3. **Organizational Culture.** Organizational culture is the shared beliefs, values and behaviours that are collectively expressed as an organization. Individuals will often identify with and incorporate the 'norms' of the group to which they belong and, as such, an organization's culture can influence the behavior and performance of those within it. Exhibit 83

1.4.5.4. **OC Selection.** It is a pre-requisite for OC RAFAT to have served on the unit at some point in the past; normally the OC returned after at least one tour away from the unit. However, the previous OC RAFAT, in post until autumn 11, was promoted to OC from within the RAFAT without a break, thus staying on the unit for 5 consecutive seasons. He therefore transitioned from being one of the most junior pilots on the Team in his first year, through to being the OC some three years later; this gave the individual little opportunity to step away from the 'norms', refresh his knowledge of the wider aviation community and broaden as an officer. It is the view of the Panel that had he had an opportunity to serve away from the unit prior to assuming command, he may have been more likely to critically re-evaluate some of the 'norms' and potentially effect change. The selection of an OC from 'within the ranks' did not afford the individual an opportunity to gain a remote, and perhaps more objective, view of RAFAT operations, making the continuation of 'norms' more likely. Witness 8 Witness 28

Aside from attending the Flying Supervisors' Course, neither the current or previous OC RAFAT had received any formal pre-employment training to prepare them for command of a Sqn comprising some 15 officers and 85 engineers. The Panel made **an observation** that the criteria for Sqn command selection and the emphasis placed on pre-command training varied significantly between the three Services, all of which exercise aviation command from OF3 to OF6 level. Witness 8 Witness 28 Exhibit 84 Exhibit 85

1.4.5.5. **RAFAT Selection Process.** At the time of the accident, the incumbent OC RAFAT had not conducted a pilot selection process. The previous OC RAFAT provided the Witness 28 Witness 56

[18] Public Display Authority (PDA) – PDA for RAFAT was granted by AOC 22 (Trg) Gp on completion of their work up phase and was clearance to perform their display in public.

following description of RAFAT pilot selection. In the order of 25-35 pilots applied each year to join the RAFAT, their flying reports were viewed by OC RAFAT who would write a short précis on each. These were then presented to the RAFAT Team pilots, with names removed, who collectively graded the individuals, the lowest being discarded. Names were then introduced and all RAFAT pilots were given the opportunity to veto applicants that "you are not going to be able to work with" and that "no questions [would be] asked" by the rest of the pilots, although it should be noted that the veto was rarely employed. Of those pilots remaining, fitting in with the Team was deemed the principal factor as it was perceived as "not just a flying job, it is living in each others' pockets". The applicants were down-selected to a maximum of nine who would join the Team in Cyprus during their annual work-up training for further assessment. This consisted of a flying test[19] for each individual and a 25 minute formal interview; the applicants' characters were assessed by the Team's pilots and an impression of suitability was also sometimes sought from JNCO ground-crew and holding officers[20]. The RAFAT pilots would then convene and vote on who should join for the following season. Witness 57 Exhibit 18

The Panel observed that the RAFAT was an extremely cohesive unit. The pilots spent a considerable amount of time detached from RAF Scampton and formed lifelong bonds carrying out an elite role that many aspire to and few experience. There were undoubtedly some positives to the RAFAT pilot selection process; severe character clashes could occur on any unit leading to an individual being moved on. Should the need to do so arise mid-season for the RAFAT it would significantly affect the display and, due to their high profile, could attract adverse publicity that would detract from their ability to conduct their primary role. Such reasoning underpinning the RAFAT pilot selection process appeared to be widely accepted within 22 (Trg) Gp, but there appeared to have been little examination of any potential adverse outcomes. Tight knit units deployed for extended periods of time together and operating in high stress environments are not unique to display flying and, whilst they may have a little more flexibility to manage personnel, it is not necessarily easy to do so. A closed and highly subjective selection process is neither practised, nor deemed necessary, outside of the RAFAT.

1.4.5.6. **Groupthink.** Groupthink is a term coined by social psychologist Irving Janis in 1972. It occurs when a group which is highly cohesive and under considerable pressure to make quality decisions, makes flawed decisions because of group pressures which lead to a deterioration of "mental efficiency, reality testing, and moral judgment". When pressures for unanimity seem overwhelming, members are less motivated to realistically appraise the alternative courses of action available to them. These group pressures lead to carelessness and irrational thinking since groups experiencing groupthink fail to consider all alternatives and seek to maintain unanimity. Janis documented eight symptoms of groupthink: Exhibit 83 Exhibit 86

a. Illusion of invulnerability – creates excessive optimism that encourages taking extreme risks.

b. Collective rationalization – members discount warnings and do not reconsider their assumptions.

c. Belief in inherent morality – members believe in the rightness of their cause and therefore ignore the ethical or moral consequences of their decisions.

d. Stereotyped views of out-groups – negative views of "enemy" make effective responses to conflict seem unnecessary.

[19] RAFAT selection flying test - The flying test consisted of 4 loops and 4 rolls in formation and lasted circa 15 minutes.

[20] Holding Officers – These are junior officers who are between training courses and are not yet on RAF trained strength.

e. Direct pressure on dissenters – members are under pressure not to express arguments against any of the group's views.

f. Self-censorship – doubts and deviations from the perceived group consensus are not expressed.

g. Illusion of unanimity – the majority view and judgments are assumed to be unanimous.

h. Self-appointed 'mindguards' – members protect the group and the leader from information that is problematic or contradictory to the group's cohesiveness, view, and/or decisions.

1.4.5.7. **RAFAT Pilot Selection Summary.** The RAFAT selection process lent towards the selection of like-minded individuals who conformed to the Team's 'norms'. As an example, when questioned on their SOPs, however divergent from the wider military aviation community, the general response was that they were "tried and tested over time", "represent best practice", or that it was "just the way we have always done it". It is the Panel's view that the RAFAT demonstrated many of the symptoms of 'groupthink', and that this had evolved, unchecked, over many years. The unique nature of the role, and potential impact to the display season should there be a personality clash, led to a selection process unusually and significantly biased towards the perceived need to fit in. The result was a cohesive unit where departure from conventional procedures and the aircraft document set became the norm and there was a reluctance to question deviant activity, facilitated by the paucity of robust external assurance and reinforced by success. The Panel concluded that the pilot selection process produced like-minded individuals who were susceptible to groupthink, which created an environment where safety critical activity was reduced or removed and procedures were changed without the requisite risk assessment and authorization. The conditions this created (eg divergence from procedures and responsibilities and compressed timelines) made the dislodgement of the SFH to an unsafe condition more likely and reduced the probability of its subsequent detection, therefore the RAFAT pilot selection process and assurance of it was **a contributory factor**.

Witness 6
Witness 24
Witness 28
Witness 46

PILOT TRAINING

1.4.5.8. **RAFAT Training Documentation.** There were 11 pilots within the RAFAT; display pilots Reds 1 through to 9 (which included OC RAFAT), Red 10 – Unit Flight Safety Officer (UFSO) and Red 11 – Wg Cdr RAFAT. Each year 3 new pilots would join the Team, replacing those leaving, and all the remaining display pilots would change position. The normal tour length on the RAFAT incorporated 3 'seasons'. The supervision of RAFAT pilot training was laid down in the RAFAT DD and carried out by Comdt CFS, Wg Cdr RAFAT, OC RAFAT and Red 10. The Panel found no mandated requirement to record training sortie content or decisional criteria with which to judge progress. There appeared to be no record of any decision making process in the training folders, or any Measures of Effectiveness (MoE) stipulated. Similar observations and relevant recommendations were made in the XX233/XX253 SI[21] report dated Jul 10; the Panel found no evidence that these recommendations had been implemented. The Panel noted the following:

Witness 28
Exhibit 13
Exhibit 18
Exhibit 39
Exhibit 51
Exhibit 114

a. The RAFAT DD provided work-up requirements for a new Leader, new pilots, the Synchro Pair, Reds 8,9,10 and Wg Cdr RAFAT. The Panel noted that there was no articulated training requirement for positions Red 4 or Red 5[22].

[21] SI XX233 & XX253 – The SI report related to a RAFAT Hawk accident that occurred at Kastelli, Crete in Mar 10.

[22] Red 5 was the position flown by the accident Pilot.

Red 4's training was incorporated within the individual's training requirement as a 'new pilot'. Although Red 5 had flown in a similar position the year previously, the Panel noted that the display manoeuvres changed year on year and the omission of any formal record made assessment of his progress during the work up difficult.

b. None of the pilots' training folders contained sortie reports for the arrival checks conducted by OC RAFAT or his predecessor.

c. More than half of the sortie reports for the RAFAT specific refresher course, conducted by the CFS Examination Wing, were found to be missing from training folders.

d. The RAFAT DD required OC RAFAT to seek approval for Red 7 to step down his display altitude during the 'Synchro Pair' work-up. The training folder entries for the previous season did not contain a request for the change from 500 ft to 250 ft.

e. There were no records detailing the training requirements for the Synchro Pair, who were working-up at the time of the accident, contained within Red 6 and Red 7's training folders.

It is the view of the Panel that by not keeping accurate and relevant records of training against valid MoEs, a clear understanding of the progress of individuals was not readily available to external scrutiny. Moreover, without them, it is difficult to see how Comdt CFS and Wg Cdr RAFAT would have had available the auditable information necessary for them to discharge their duties as senior supervisors effectively, and the Panel therefore concluded, as the XX233/XX253 SI Panel had before them, that the recording of training of RAFAT pilots was **an other factor**.

1.4.5.9. **Simulator Training.** Simulator training for the Hawk TMk1 is delivered under contract by BAE Systems at RAF Valley, utilizing civilian instructors and 3 simulators, only 2 of which have the capability to practise 'visual' emergencies handling. Training is delivered in 1 hour 'slots' to student pilots and other UK military Hawk operators. The RAFAT DD stated a requirement to complete a minimum of six simulator sorties in a year[23]. Having reviewed the achievement of this requirement, the Panel found that a number of RAFAT pilots had not achieved the minimum number of simulator practices and there was no evidence of any recorded extension requests in the training folders. The Panel noted that there was not any feedback of simulator sortie content or progress recorded in any training folders.

Witness 43
Exhibit 18
Exhibit 51
Exhibit 52
Exhibit 114

1.4.5.10. **Periodicity, Sortie Content and Logging.** The Panel looked at the utilization of the simulators and noted that RAFAT pilots, including supervisors, had routinely used a single, hour long simulator slot to train 2 pilots. The pilots would swap halfway through the hour, flying half an hour each; both pilots would claim the full hour and annotate it accordingly in their log books. The pilots would routinely claim 30 minutes of actual IF and several instrument approaches, although evidence suggests that the total length of the sorties rarely exceeded 30 minutes and the composition was almost exclusively visual emergencies[24]. It is the view of the Panel that this practice of 'sharing' simulator slots resulted in RAFAT pilots not undertaking the expected minimum safe training to operate the Hawk T Mk1 and concluded that this was **an other factor.**

Witness 43
Exhibit 18
Exhibit 51
Exhibit 52
Exhibit 114

[23] Simulator currency - 1 every 60 days, with an extension to 3 calendar months on request to Comdt CFS. Although the length of sortie is not stipulated, the sorties are purchased for the hour and it is expected that a single pilot will use a single 1 hour slot.

[24] Currency claimed - The IF hours and instrument approaches claimed were regularly needed to achieve the minimum requirements for their Instrument Ratings.