PART 1.4 – ANALYSIS AND FINDINGS

Methodology

1.4.1 **Accident Factors.** Once an accident factor had been determined it was assigned to one of the following categories[1]:

a. **Cause.** The event that led directly to the accident.

b. **Contributory.** Factors that directly or indirectly made the accident more likely.

c. **Aggravating.** Factors that made the outcome of the accident worse.

d. **Other.** Factors that were none of the above, but could cause, contribute to or aggravate a future accident.

e. **Observations.** Factors that were not relevant to the accident but worthy of consideration to promote better working practices.

1.4.2 **Available Evidence.** In conducting the Service Inquiry the Panel had access to the following evidence:

a. **Physical Evidence.** Intact XX177 airframe, front ejection seat, the Pilot's clothing and Aircrew Equipment Assemblies (AEA).

b. **Witness Statements.** 58 witness statements taken from a variety of sources.

c. **Electronic Data.** The following electronic data was available: Air Data Recorder (ADR) files, external eye witness video, Air Traffic Control (ATC) audio transmissions, digital video footage and pictures from: Lincolnshire police, Military Air Accident Investigation Branch (MilAAIB), RAF Police and 1710 Naval Air Squadron (NAS) Materials Integrity Group (MIG).

d. **Documentary Evidence and Formal Reports.** The Panel reviewed and considered aircraft engineering documentation, maintenance manuals, policy and regulatory documents, log books, authorization sheets, training documentation, external audits and formal reports during the course of the Inquiry.

e. **In-cockpit Man In The Loop (MITL) Testing.** MITL testing in the XX177 airframe fitted with an inert Mk10B1 ejection seat was carried out. This was to enable qualitative testing in a representative environment of potential theories regarding ejection initiation, guided by forensic results and was used to inform subsequent laboratory testing.

1.4.3 **Unavailable Evidence.** None to effect.

1.4.4 **Services.** The Panel members were assisted by the following personnel and agencies:

a. 1710 NAS.

b. BAe Systems (BAe).

c. Brazilian Air Force.

[1] Aviation Safety Information Management System (ASIMS) User Guide, V4.2.

d. Defence Science and Technology Laboratory (DSTL).

e. Empire Test Pilot School (ETPS).

f. Finnish Air Force.

g. Health and Safety Executive (HSE).

h. Joint Air Reconnaissance Intelligence Centre (JARIC).

i. Lincolnshire Police.

j. Martin Baker (MB).

k. MilAAIB.

l. Military Aviation Authority (MAA).

m. QinetiQ

n. RAF Centre of Aviation Medicine (RAFCAM).

o. Rolls Royce.

STRUCTURE OF THE ANALYSIS AND FINDINGS

1.4.5 The accident involving Hawk aircraft XX177 was a complex event. Whilst a failure in the ejection sequence led to the Pilot sustaining fatal injuries, the Panel has determined that **the accident event was the initiation of ejection**. The analysis and findings are grouped under the following headings:

a. **Section 1.4.1 - Pre-Accident Events.**

b. **Section 1.4.2 - Ejection Seat Initiation.**

c. **Section 1.4.3 - Ejection Seat Failure.**

d. **Section 1.4.4 - Design and Communication.**

e. **Section 1.4.5 – Culture, Organization and Supervision.**

f. **Section 1.4.6 - Post Crash Management.**

SECTION 1.4.1 – PRE-ACCIDENT EVENTS

1.4.1.1. **Pilot Background.** The Pilot was coming to the end of a year of extreme highs and lows. He had recently completed his first season with the Red Arrows, fulfilling a long term ambition, but had lost a close friend and Royal Air Force Aerobatic Team (RAFAT) colleague who had been killed in an aircraft accident a few months earlier. At the end of the season he had taken a three week break during which he had completed a charity cycle ride with other members of the RAFAT and taken a period of leave. The Pilot had returned to flying at the beginning of the previous week and had completed a total of seven sorties prior to the accident: one dedicated Continuation Training (CT) sortie, two transits and four formation aerobatic sorties. During that week he had also completed a simulator sortie, passed his annual aircrew medical and attended the memorial service for his RAFAT colleague.

Witness 3
Witness 8
Witness 21
Exhibit 5
Exhibit 8

1.4.1.2. **Pilot Currency.** Initially it appeared that the Pilot was current to complete the planned flying events on the day of the accident. However, following closer investigation into the conduct and recording of CT and Instrument Flying (IF) on the RAFAT, the Panel found that the Pilot had not completed enough IF for his instrument rating to be valid and had probably not undergone the minimum prescribed emergencies training in the simulator or conducted sufficient CT. A detailed explanation of the Panel's findings and their conclusions regarding flying currency and emergencies training is at Section 1.4.5.

Exhibit 8
Exhibit 114

1.4.1.3. **Sortie Planning, Preparation, Brief and Authorization.** The sortie briefing and authorization was conducted by OC RAFAT. Although this was the first formation land away[2] of the season, all aspects of the sortie preparation were considered normal by the other formation members. It is one of the duties of an authorizing officer (RA 2306) to ensure that the formation members are qualified and current. OC RAFAT relied on a reactive system whereby he would only be informed in the event of a pilot's currency having lapsed. In practice this responsibility was devolved to a single individual to monitor (a duty generally attached to the position of Red 4). The Panel's analysis revealed discrepancies in the conduct and recording of currency flying. Specifically, a number of RAFAT pilots were not current to fly, did not hold a valid instrument rating and had not completed the requisite emergencies training. A detailed explanation of the Panel's findings and conclusions regarding the planning, briefing and authorization of RAFAT sorties, including the accident sortie, is at Section 1.4.5.

Witness 2
Witness 3
Witness 6
Witness 8
Exhibit 18
Exhibit 19
Exhibit 20
Exhibit 114

1.4.1.4. **Pilot Readiness.** Personal readiness concerns any physical or psychological readiness issue relating to the operator's personal characteristics and condition, such as their fitness, attitude, confidence levels, trust, motivation, morale and wellbeing, which may influence their ability to perform in their role. This also includes the operator's psychological readiness for escape and survival actions if required. The Panel considered the recent bereavement of a close colleague, the Pilot's decision to self-medicate, medical records, post mortem report and first hand witness testimony of the Pilot's state of mind leading up to, and including, the day of the accident. On balance of evidence, the Panel concluded that pilot readiness was **not a factor** in the accident; however, the potential impact of impairment through self medication is discussed at Para 1.4.2.28.

Witness 24
Witness 8
Exhibit 10
Annex D

1.4.1.5. **Weather/Environmental.** The weather/environmental conditions were **not factors** in the accident.

[2] Land-away - colloquial term for a short term detachment to a non-parent Station.

SECTION 1.4.2 - EJECTION SEAT INITIATION

1.4.2.1. **Introduction.** Cases where an ejection has been initiated without apparent explanation are very rare, but not unknown. The Panel studied three such occurrences to aid their analysis: the ejection of a passenger from an RAF Hawk in 1983 during Air Combat Manoeuvring, assessed to have been caused by an optimising violation[3]; the ejection of the pilot from a Swedish Grippen in 2007 during a high g-force manoeuvre, assessed to have been caused by a technical failure involving the interaction between the pilot's AEA (g-suit) and the Seat Firing Handle (SFH); the ejection of a student pilot from a Brazilian Tucano in 2012 during the take-off, which was assessed to have been caused by inadvertent initiation of ejection by the pilot due to incorrect strap routing. Exhibit 24 Exhibit 25 Exhibit 26

1.4.2.2. **Possible Causes.** Five main theories were considered when determining the cause of the accident:

a. **Deliberate Act (Aircraft Emergency).** The ejection seat fitted to XX177 was designed to operate within a wide envelope which included zero altitude and zero forward speed, enabling aircraft escape via ejection when the aircraft is stationary and on the ground. It is standard procedure for operators of aircraft fitted with 'zero/zero' seats to have the option to eject during aircraft start as there are scenarios where it might be the most appropriate method of egress. The Panel found no witness, video, radio or technical evidence to suggest that there was any emergency that would have caused the Pilot to initiate ejection deliberately. At the time of the accident, the Pilot's mask was not secured to his face, and the visor was up and Post Mortem analysis of MDC burns revealed that the Pilot's eyes and mouth were open at the point of initiation, further supporting the hypothesis that the ejection was not anticipated. Additionally, the only method taught (or believed possible at the time) for deliberately initiating ejection was via a sharp pull of the SFH upwards of between 20lb and 70lb. As discussed later in this Section, it is extremely unlikely that a vertical pull of the SFH in this way initiated the ejection. The Panel therefore concluded that a deliberate act as a result of an aircraft emergency was **not a factor** in this accident. Witness 1 Witness 5 Exhibit 10 Exhibit 16 Exhibit 27 Exhibit 28 Exhibit 29 Annex B Annex C Annex E

b. **Deliberate Act (Suicide).** The Panel investigated the wellbeing of the Pilot at the time of the accident. The Pilot had long term plans, was in good spirits and there were no psychological problems recorded in his medical documentation or discovered post mortem. Additionally, as discussed above, the ejection seat is designed to save life in a zero/zero situation, therefore the Pilot would have expected that an ejection from a Hawk aircraft on the ground to have been survivable. The Pilot could have had no knowledge that the ejection seat would not operate correctly, resulting in the failure of the parachute to deploy. The Panel concluded that a deliberate act by the Pilot to commit suicide was **not a factor** in this accident. Witness 4 Witness 8 Exhibit 10 Exhibit 27 Annex C Annex E

c. **Deliberate Act (Optimising violation).** The Panel examined whether there was evidence that the Pilot may have initiated ejection to satisfy a personal need to experience an aircraft ejection, of which the expected outcome would be survival. Optimising violations occur having weighed up the perceived risks against the perceived benefits. As discussed above, the only method taught for deliberately initiating ejection was via a sharp vertical pull of the SFH. The physical evidence from XX177 indicated that ejection was not initiated in this way. The Panel concluded that the XX177 ejection was not as a result of an optimising violation Exhibit 27 Annex B

[3] Optimising violations involve breaking the rules "for kicks".

and was therefore **not a factor** in this accident.

d. **Sabotage.** Access to RAFAT aircraft was controlled: the aircraft were on a guarded RAF Station within a hangar that was locked out of hours and the keys were available on a signature basis only. No motive for sabotage has been identified and knowledge of the SFH positions described later in this Section is unlikely. The Panel concluded that an act of sabotage was **not a factor** in this accident. Witness 4 Witness 7 Witness 10 Witness 51 Witness 54

e. **Inadvertent Ejection (technical).** Examination of the XX177 airframe, including loose articles, the Pilot's AEA and its potential to interact with the SFH and both ejection seats (including the command eject system) identified no faults, failures or damage consistent with anything other than an ejection initiated via the SFH. The Panel concluded that technical failure was **not a factor** in the accident. Annex B Annex C

f. **Inadvertent Ejection (pilot).** Through a process of elimination, inadvertent initiation of the ejection by the Pilot was found to warrant more analysis. This hypothesis is supported by a significant amount of evidence the analysis of which is discussed in this Section.

DESCRIPTION OF COMPONENTS AND NORMAL OPERATION

1.4.2.3. **Mk 10B1 Seat Pan Firing Handle (SFH).** The Mk10B1 SFH is a black and yellow semicircular handle joined at both ends to a red coloured firing handle assembly (see Figure 4). The assembly is composed of an upper and lower assembly. A slotted connecting link is riveted to the red coloured lower sub assembly. The slotted connecting link is passed through the centre of a metallic housing on the ejection seat. The slotted connecting link is connected to a sear swivel link via a clevis pin and split pin. A sear is fitted to the sear swivel link slot with a self locking nut and bolt (see Figure 5). Exhibit 27 Annex B

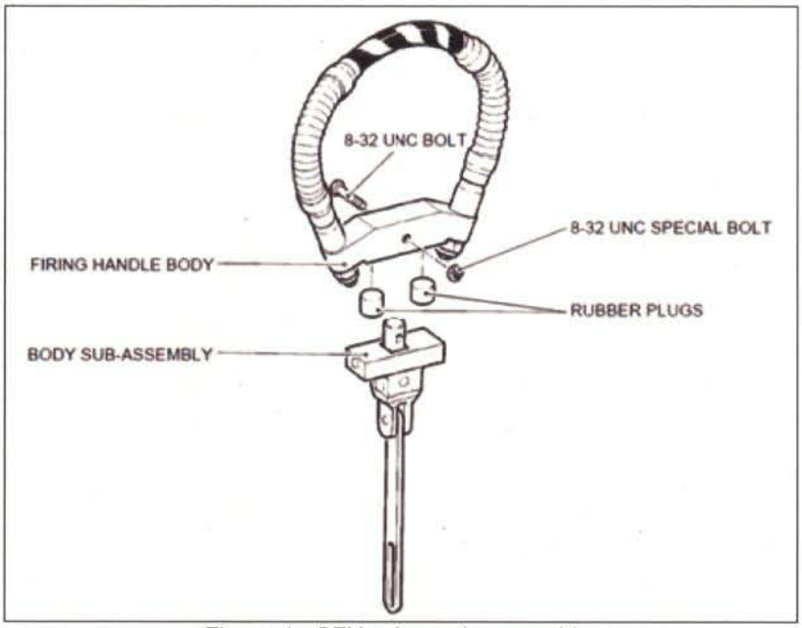

Figure 4 - SFH schematic assembly.

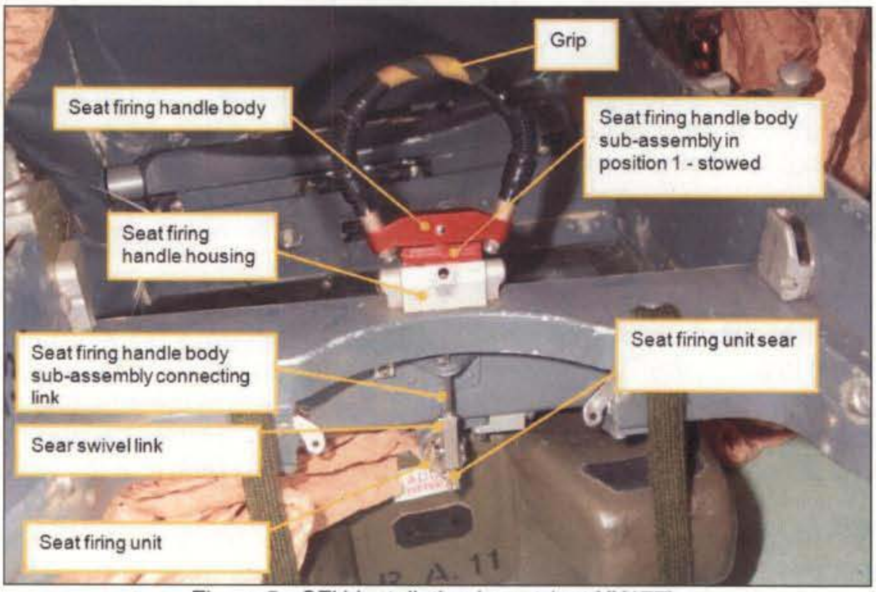

Figure 5 - SFH Installation layout (not XX177).

1.4.2.4. **Normal Operation.** The SFH lower assembly sits within a housing and is made 'safe' with the insertion of a SFH safety pin, shown at Figure 6. The SFH is retained in the stowed position by spring pressure; this pressure is applied by plungers located in the housing that sit in the recesses on the SFH lower assembly. The normal series of events to initiate ejection post SFH safety pin removal is described below: Exhibit 27 Annex B Annex C

a. The SFH is pulled vertically upwards from the stowed position.

b. The retaining springs of the plungers are compressed. The plungers remain in contact with the SFH lower assembly as it moves upwards due to spring pressure, see Figure 7.

c. The front face of the sear acts against a roller forcing the roller to rise up the cam face of the sear, withdrawing the firing unit under spring pressure. As the roller reaches the end of the cam face it is released under spring pressure to fire the percussion cap on the seat firing unit cartridge. See Figure 8.

d. Once the firing cartridge has been fired a chain of events requiring no further input is initiated and is described in detail at Section 1.4.3.2.

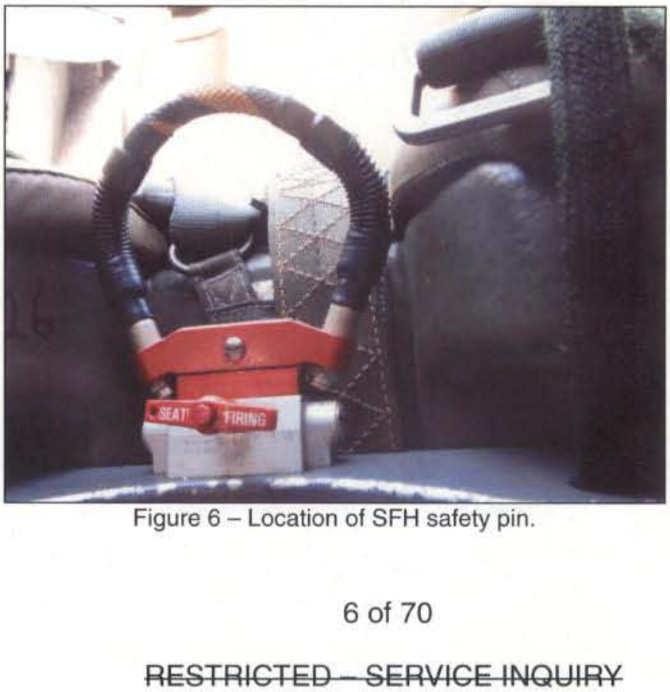

Figure 6 – Location of SFH safety pin.

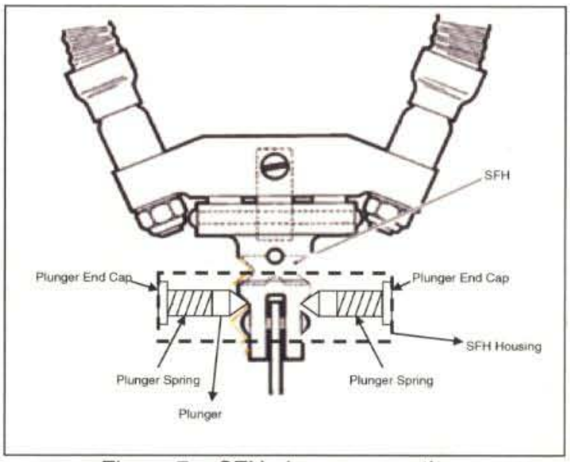

Figure 7 – SFH plunger operation.

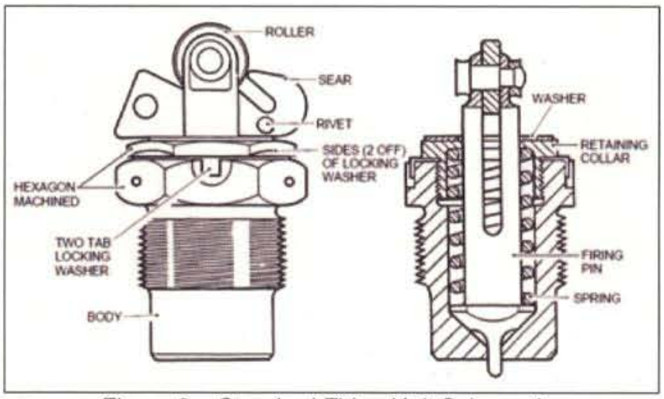

Figure 8 – Standard Firing Unit Schematic.

HOW WAS THE XX177 EJECTION INITIATED?

1.4.2.5. **Initial Examination.** Following the accident an initial examination of the ejection seat was conducted and the XX177 SFH was found un-stowed from the housing and the sear was not engaged within the firing unit (Figure 9). Examination of the seat firing unit cartridge showed that it had fired and there was a firing pin indentation on the percussion cap. There was damage to the sear and the SFH which were consistent with a single impact following ejection. All of this evidence was consistent with an ejection initiated via the SFH and the Panel found no evidence to the contrary.

Witness 4
Annex B
Annex C

Figure 9 – XX177 SFH out of housing and sear not engaged.

[4] A pull-off check is a test to ensure the SFH will operate within prescribed load tolerances. The test is conducted in accordance with instructions detailed in maintenance publication DAP 109B-0140-1 Chap 3 Para 6.

1.4.2.6. **SFH Markings.** Forensic examination of the SFH undertaken by 1710 NAS Materials Integrity Group (MIG) found marks that were not evident on other in-service SFHs that had undergone bay maintenance or SFHs that had been subjected to an ejection. Also, the markings were not consistent with impact damage as a result of the ejection sequence. Annex B Annex F

Markings on the sides of the SFH appeared unique in two ways: a substantial 'scuffing' mark on the right hand side of the SFH body sub-assembly and an 'angled' score (score 1) passing over the scuffing area (see Figure 10). A similar 'angled' score mark was found on the opposite (left hand) face of the body sub-assembly (see Figure 11). There was no scuffing evident on the left hand side of the body sub-assembly.

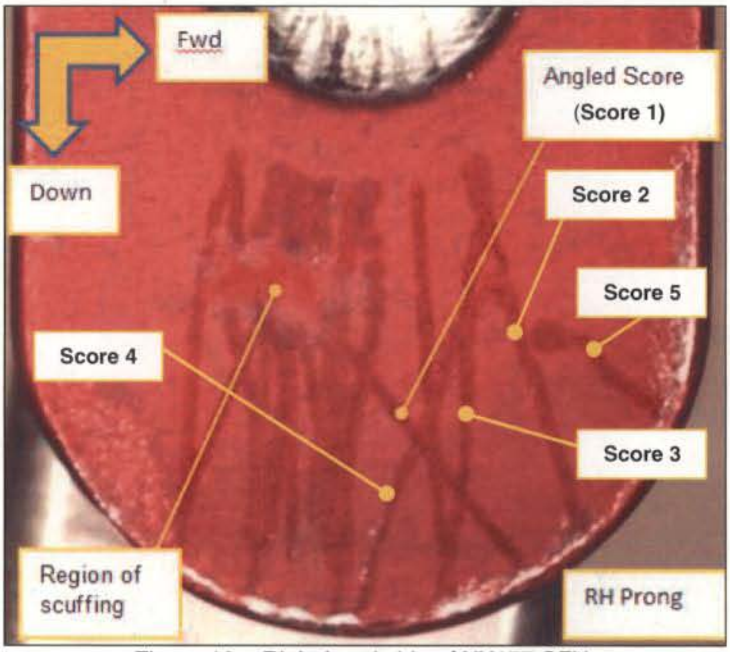

Figure 10 – Right hand side of XX177 SFH.

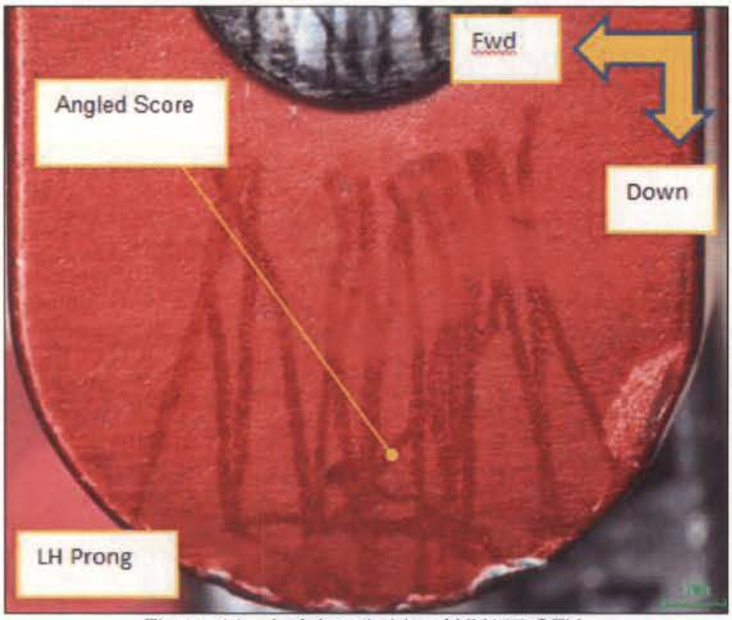

Figure 11 – Left hand side of XX177 SFH.

The scuffing and angular score mark 1 had over-laid all of the vertical scores with the exception of two: one where the angular score did not intersect (score 2); and the other where it was not clear whether the angular score had passed over or under the vertical score at the intersection of score 1 and score 3. It could be established that score 2 and score 3 had been created after the accident when a 'pull-off'[4] test had been conducted at MB. Score 2 was most likely to have been created when inserting the SFH prior to the pull-off check and score 3 (which overlaid score 2) was caused by the pull-off check itself. Furthermore score 4 was found to be under score 1 and score 3. The angular scoring was therefore likely to have been the penultimate event that had occurred in this region of the SFH. There was one other angular score evident on the SFH (score 5): the score was not straight and was shorter than all of the other scores; it originated at a lower location compared to the majority that could be traced below the body sub-assembly connecting link rivet. A similar score mark was evident on the left hand side. The location and length of the scoring on both sides suggested that this was as a result of fitment rather than operation.

The SFH body sub-assembly also exhibited three unique transverse angular markings on the front face (see Figure 12), and a compression mark on the lower rear face of each prong (see Figure 13). These marks were not considered to be as a result of ground impact damage.

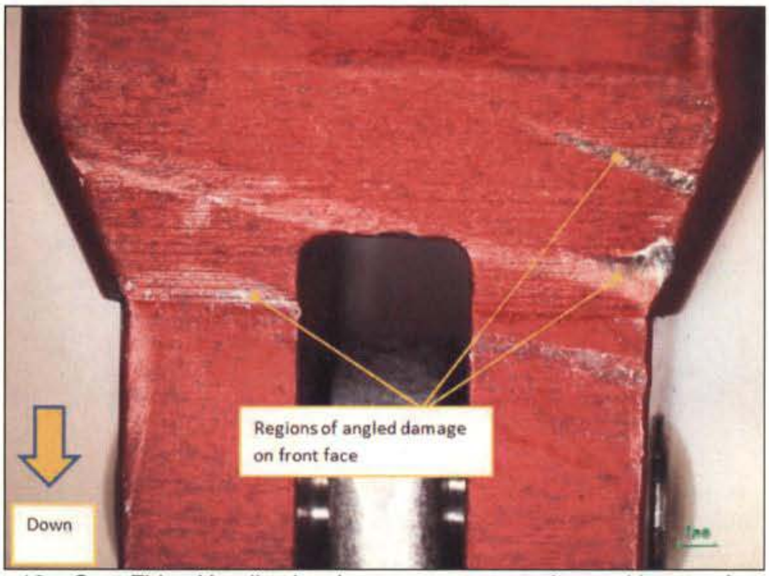

Figure 12 – Seat Firing Handle showing transverse angular markings on front face

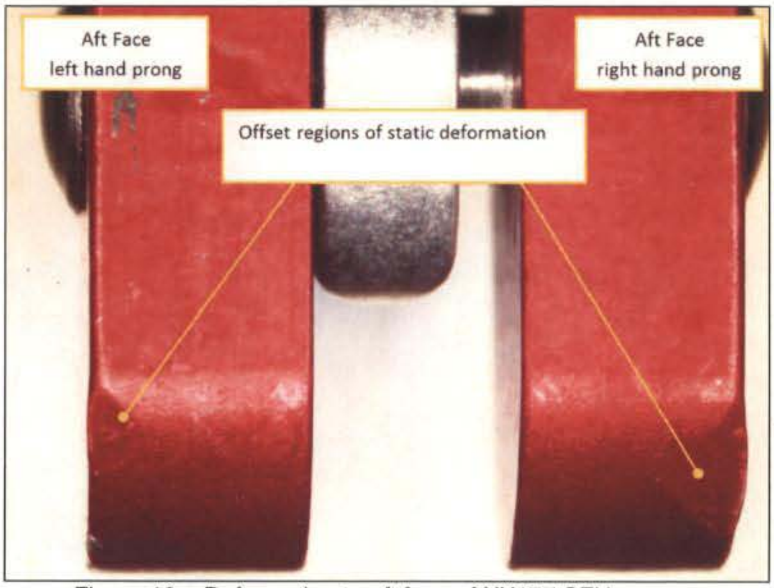

Figure 13 – Deformation to aft face of XX177 SFH prongs.

1.4.2.7. **SFH Movement and Positions.** The scuffing marks found on the right side of the SFH body sub-assembly suggested that the SFH had been held out of the normal stowed condition (see Figure 14). Testing established that the SFH could be positioned in a number of Annex B Annex C locations within the housing assembly in addition to the normal stowed position, whereby it was not sufficiently raised to release the sear from the firing unit and therefore initiate ejection. The positions found were as follows:

a. **Position 1.** SFH stowed in the housing (see Figure 14).

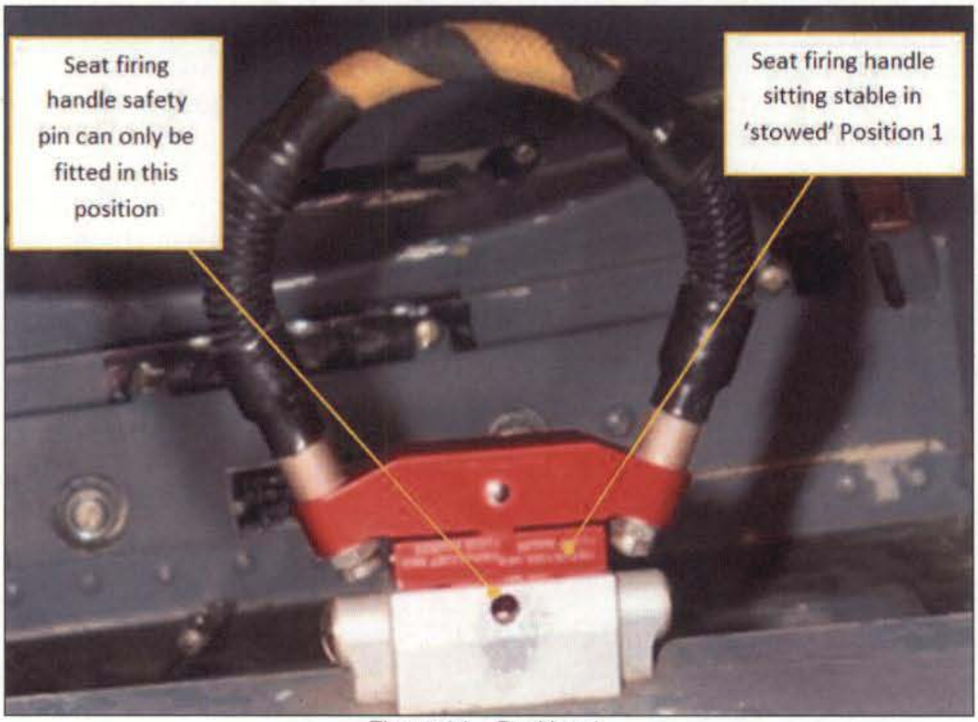

Figure 14 – Position 1.

b. **Position 2.** Out of the stowed position with the housing plungers resting above the connecting link attachment rivet (see Figure 15).

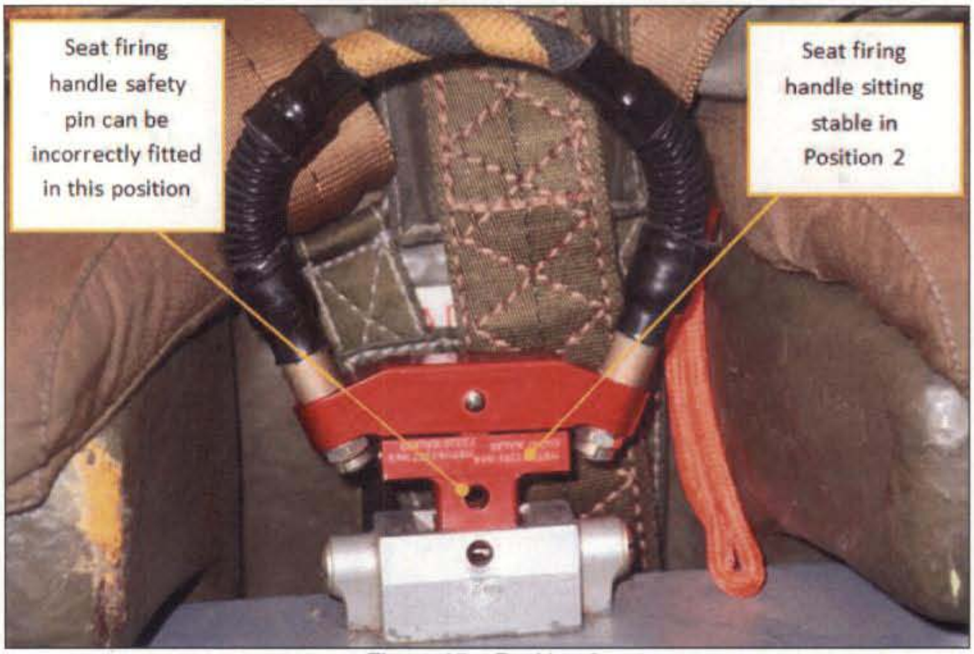

Figure 15 – Position 2.

c. **Position 3.** Out of stowed position with the housing plungers resting below the connecting link attachment rivet (see Figure 16).

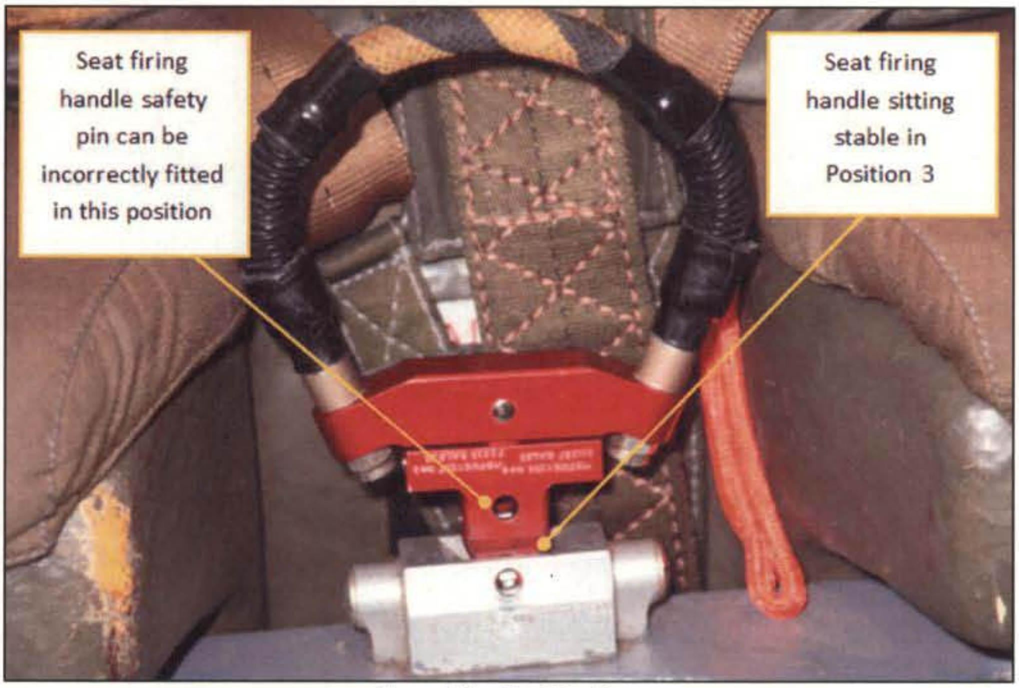

Figure 16 – Position 3.

Position 2 was found to be a relatively stable condition, whereby the SFH could be moved in a variety of ways and would remain in that position unless pulled vertically upwards to initiate ejection or pushed downwards to re-stow the handle. Position 3 was found to be less stable, whereby movements could displace it in one of two ways: by returning the SFH to Position 2 or overcoming seat firing unit spring pressure to withdraw the sear and initiate ejection. It was also found that in Position 3, movement of the SFH in a forward direction, away from the pilot, could initiate ejection; this was not possible from Position 2. The majority of operators and engineers would have had no reason to recognise the specific unsafe positions referenced in this report (Positions 2 and 3). However, they were aware that the only position they should expect to find the SFH in was with the handle fully housed (safety pin inserted in to the handle and housing, or removed for flight). Any other condition, if discovered, would be assessed as being unsafe. Moreover, the ability to initiate ejection by anything other than a vertical pull, was unknown. The Panel concluded that had the information regarding Position 2 and 3 been more widely known, including the possibility of initiating ejection through a forward movement, different procedures and training could have been introduced which may have made the discovery of the SFH in an unsafe condition more likely and was therefore **a contributory factor**.

Witness 7
Witness 10
Witness 51
Witness 54
Annex B
Annex C

1.4.2.8. **Replication of SFH Markings.** In order to ascertain how the SFH scoring and compression marks might have occurred, tests were conducted using representative components. The direction of the scoring on the SFH sub-assembly sides, transverse markings on the front face and compression on the rear prongs suggest the handle had moved in a forward direction. It has already been established that with the SFH in Position 3 it was possible to move the seat firing handle in a forward direction and to initiate ejection and that this was not possible from Position 2. Testing was able to demonstrate that the application of a force vector (60 Newtons) to the SFH in a forward direction at an angle of 20 degrees down from the horizontal plane and 30 degrees right from SFH housing centre line (see Figure 17) replicated the scoring and damage found on the XX177 SFH sub-assembly.

Annex B
Annex C

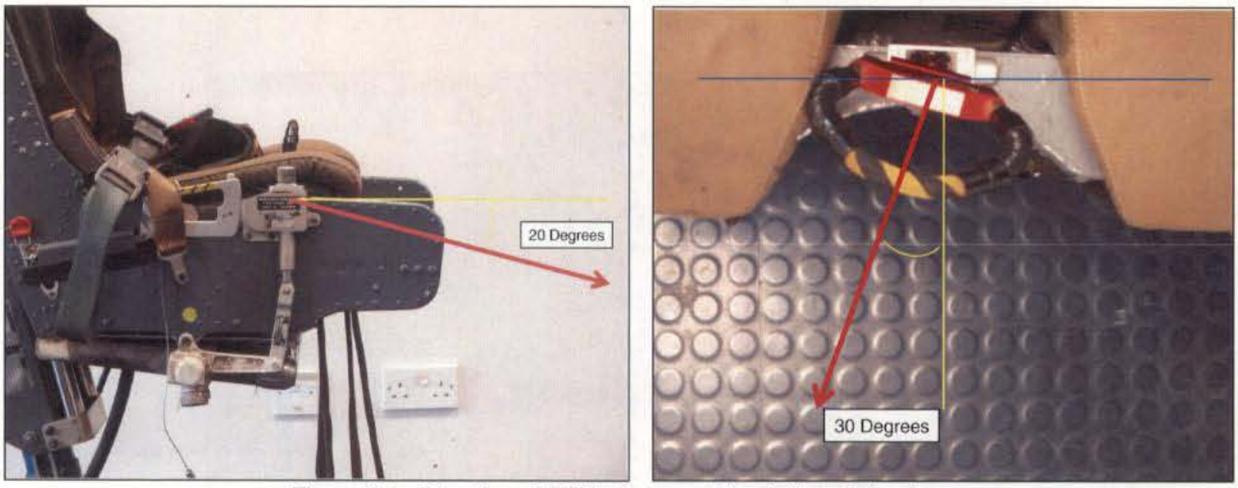

Figure 17 – Direction of SFH movement that initiated ejection.

1.4.2.9. **Ejection Initiation Cause.** The Panel concluded that **the cause** of the accident was an inadvertent ejection following the application of a force to the SFH in Position 3; 20 degrees down from the horizontal plane and 30 degrees right from SFH housing centre line.

HOW DID THE SFH GET TO AN UNSAFE CONDITION (POSITION 2 OR 3)?

1.4.2.10. **Methods of Movement.** MITL trials were conducted using the XX177 aircraft, an inert ejection seat and a pilot with similar anthropometric measurements to the accident Pilot. One of the primary aims of the trials was to try and identify possible methods by which the SFH could be moved from Position 1 to either Position 2 or Position 3, with particular emphasis on pilot interaction with the ejection seat in a representative environment. Multiple tests were carried out to asses the viability of moving the SFH to an unsafe condition by interaction of the SFH with the following: clothing, pilot's watch, flying controls, leg restraints, helmet, oxygen mask, Life Saving Jacket (LSJ) and various combinations of strap routing. A number of methods caused the SFH to move; some were found to dislodge the SFH slightly and others were able to initiate ejection. However, misrouting of the crotch strap was found to be the only repeatable method of moving the SFH into Position 2 or 3 and only this method was consistent with the forensic evidence described later in this section. Annex C Exhibit 115

1.4.2.11. **Fitment of SFH Safety Pin.** It is impossible to move the SFH from Position 1 with the safety pin inserted correctly through the housing and SFH, see Figure 18. There are two scenarios where the SFH safety pin should be moved: Exhibit 7 Exhibit 27 Exhibit 28

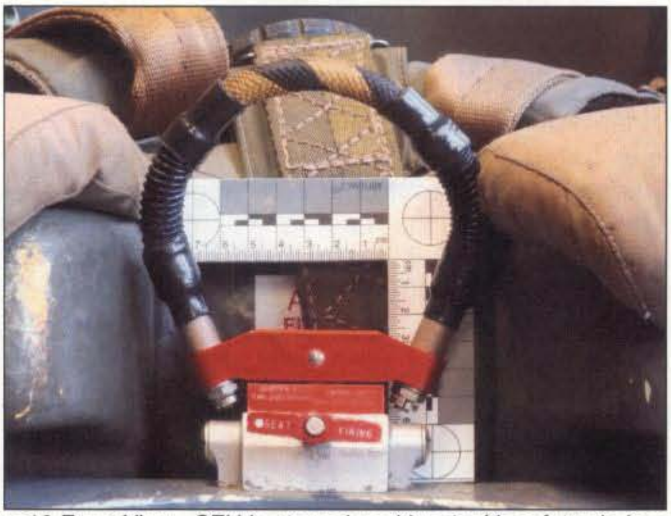

Figure 18 Front View– SFH in stowed position 1 with safety pin inserted.

a. **Ejection Seat Bay Maintenance.** Ejection seats are removed from the aircraft every 3 years for routine maintenance. Only once the seat has been taken from the aircraft and the explosives removed, is the SFH safety pin removed. This is to allow 'pull-off' checks to be performed in order to ensure the force required to initiate ejection is within limits. The SFH safety pin is re-inserted through the handle and housing prior to the explosives being reconnected. The accident ejection seat was last fitted to XX177 on 3 Mar 11, after which it had flown 133.25 hrs. The Panel concluded that this maintenance was **not a factor** in this accident.

b. **During 'Flight'.** The SFH safety pin should be removed and stowed alongside the MDC pin in the cockpit stowage during every flight, see Figure 19. The Flight Reference Cards (FRCs)[5] state that this should be done after strapping-in is complete, the canopy is closed and before engine start. The pin is usually re-inserted into the SFH through the housing as part of the after landing checks.

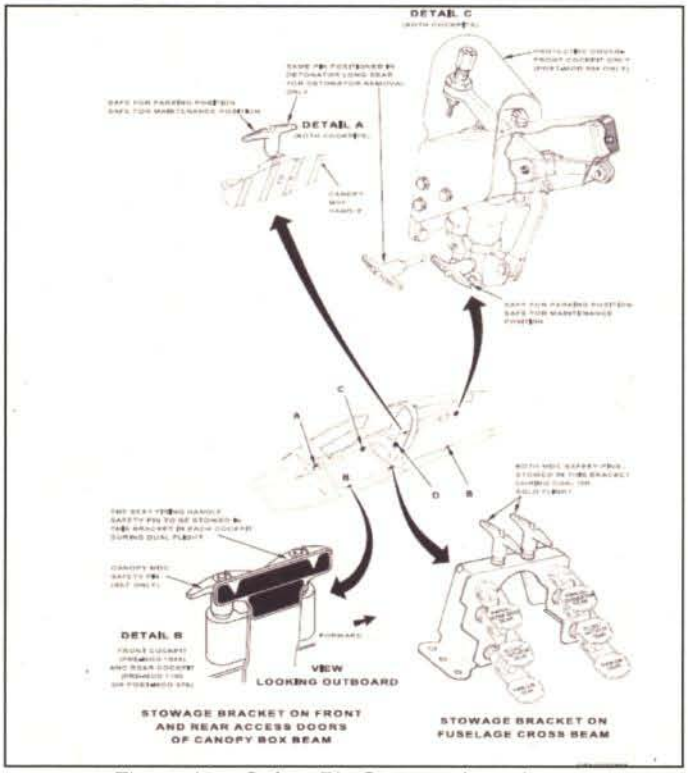

Figure 19 – Safety Pin Stowage Locations.

1.4.2.12. **Incorrect Routing of Crotch Straps.** It is normal for ground-crew to leave the ejection seat straps folded on the seat to tidy the cockpit in preparation for the next flight. Prior to entering the cockpit pilots often move the straps away from this position to ease their entry into the cockpit prior to strapping in. Figure 20 shows how a harness crotch strap could fall through the SFH and potentially go unmissed. It was established that during strapping-in misrouting either one of the seat harness crotch straps through the SFH could cause it to be moved from the Position 1 to Positions 2 and 3 (see Figure 21), but this was only possible once the SFH safety pin was removed. The movement of the SFH was found to be relatively easy to achieve through routine cockpit activity by the pilot, such as the leg movement required to apply full rudder during a 'full and free' control check. Moreover, testing demonstrated that detection of this SFH movement through feel was extremely difficult and therefore unlikely if not anticipated. Although it was found to be possible to initiate ejection while strapped to the SFH in this manner it was difficult to achieve and required abnormal and significant movement

Witness 7
Witness 54
Exhibit 115
Annex C

[5] Hawk FRCs list normal and emergency drills for aircrew, are issued by RAF Handling Squadron and form part of the Hawk Document Set.

by the pilot. Additionally, the initiation of ejection with the crotch strap misrouted through the SFH was only achievable via a vertical movement upwards of the SFH. It was not possible to initiate ejection in a manner consistent with the XX177 forensic evidence while the crotch strap remained incorrectly routed through the SFH.

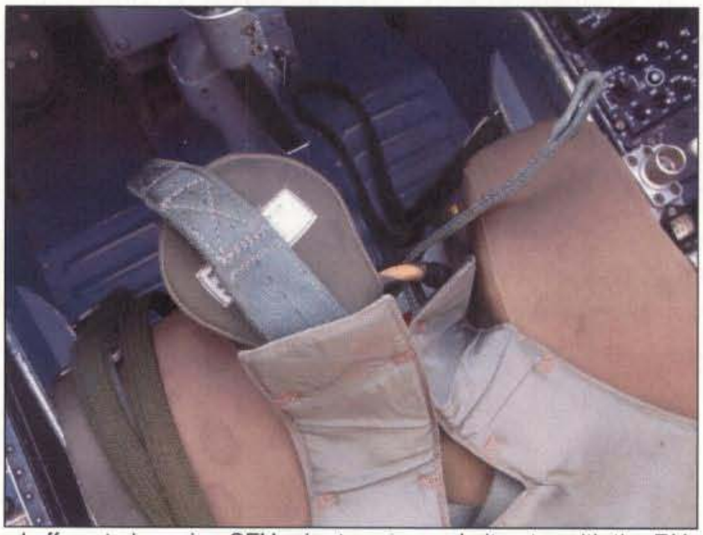

Figure 20 – Straps moved off seat obscuring SFH prior to crew cockpit entry with the RH crotch strap miss-routed through the SFH.

Figure 21 – Incorrect routing of RH crotch strap through SFH.

1.4.2.13. **Replication of 'Scuffing'.** The patch of 'scuffing' was only found on the right hand side of the SFH, at a location beyond Position 3 (see Figure 22). This position was not found to be naturally stable and indicated that it must have been held for a period of time by some other means other than the SFH assembly. It was observed that by misrouting the right hand crotch strap (Figure 21) and performing leg and buttock movement, which the Panel considered to be consistent with normal pilot activity, it was possible to raise and hold the SFH at a location beyond Position 3, but without releasing the sear. In this configuration it was possible to cause scuffing on the right hand side of the SFH in the same region as that found on XX177. No other configuration was found to cause scuffing in this manner.

Annex B
Annex C

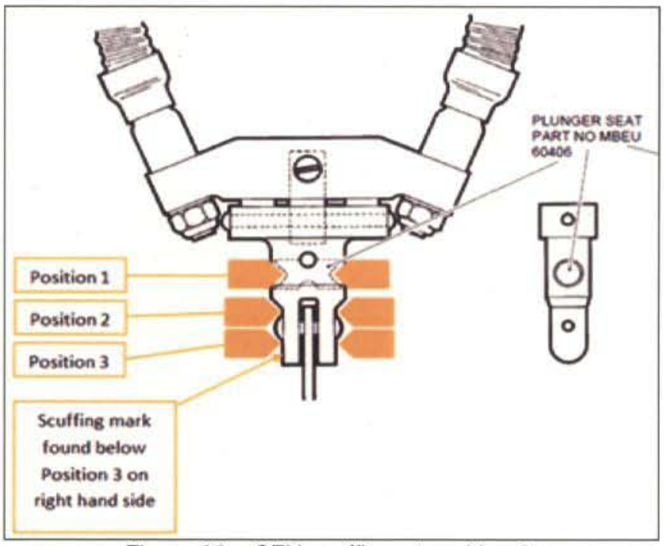

Figure 22 – SFH scuffing at position 3.

1.4.2.14. **Methods of Movement Summary.** The MITL testing, led and supported by the forensic evidence, established that the only plausible method of inadvertently moving the SFH into Position 2 or 3 was via incorrect routing of a crotch strap through the SFH. However, the initiation of ejection in a manner consistent with the forensic evidence was impossible whilst the right hand crotch strap was incorrectly routed through the SFH. Therefore, it was concluded that incorrect routing of the right hand crotch strap during strap-in moved the SFH into an unsafe condition and was **a contributory factor**, but the straps were not mis-routed at the time of the accident. The Panels analysis regarding the timing of the SFH movement is included later in this section.

Exhibit 115
Annex B

1.4.2.15. **Incorrect Fitment of the SFH Safety Pin.** During the testing at 1710 NAS and during MITL testing the Panel observed that with the SFH in the raised Position 2 or 3 it was possible to fit the SFH safety pin through the handle only (see Figure 23). In this configuration the ejection seat was not safe and the SFH could be operated. However, particularly when viewed from above, the SFH could appear to be in a safe condition, giving a false sense of safety. That it was possible to insert the pin into the handle in this way was not widely known and this was compounded by maintenance and operator publications which referred to checking that "the pin was inserted into the SFH" as a confirmation of safety. The Panel concluded that the ability to incorrectly insert the safety pin through the SFH alone, leaving the seat in an unsafe condition, was a **contributory factor** in this accident

Exhibit 27
Exhibit 28
Exhibit 30
Exhibit 115
Annex B
Annex C

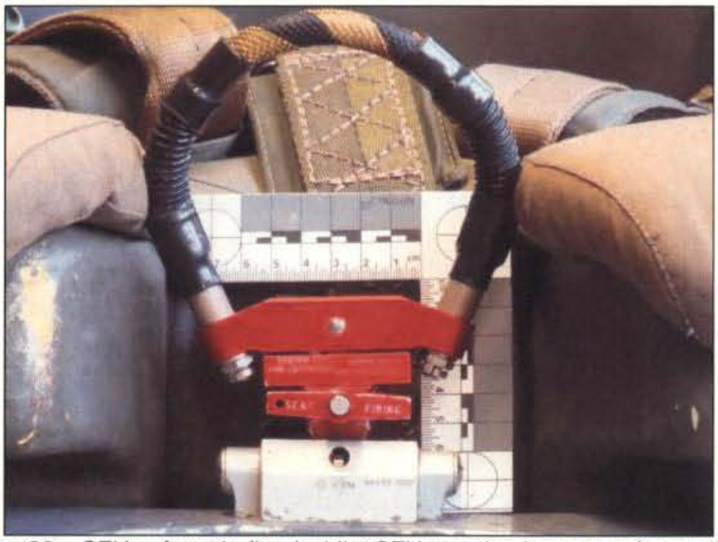

Figure 23 – SFH safety pin fitted whilst SFH remains in an unsafe condition.

1.4.2.16. **Warning of Unsafe Condition.** The Panel **observed** that the ejection seat fitted to XX177 had no method of warning the pilot or engineers of a potentially unsafe condition, or the positioning of the pins, other than a visual inspection. Of note, there are ejection seats in service on other fast jet platforms which have electronic or mechanical warning systems to alert aircrew as to the status of the ejection seat.

WHEN DID THE SFH GET INTO AN UNSAFE CONDITION?

1.4.2.17. **XX177 Strap Routing (8 Nov 11).** Examination of the ejection seat straps and witness evidence strongly suggests that the Pilot was strapped-in correctly on the day of the accident. This is further supported by the fact that the forward and downward movement of the SFH to initiate ejection was not possible with a crotch strap incorrectly routed. The Panel concluded that on the day of the accident the Pilot was correctly strapped in and therefore the SFH was moved to an unsafe condition during a previous sortie.

Witness 1
Witness 4
Witness 12
Witness 13
Exhibit 115
Annex C

1.4.2.18. **Detection of Unsafe Condition.** In addition to ascertaining the likelihood of detecting the movement of the SFH to an unsafe condition, the MITL testing looked at the probability of detecting the SFH being in an unsafe condition once it had moved. To ensure that tests were representative, an anthropometrically similar 'test' pilot and the XX177 airframe with an inert ejection seat set to the accident height were used. RAFAT pilots carry out a 'full and free' control check in the following manner: rapidly moving the control column fully forward then anti clockwise through 360° around the extremities of available movement. Simultaneously, full right and left rudder inputs are applied in opposition to full left and right control column inputs, finishing with the control column in a central position. This took RAFAT pilots approximately 5 seconds to complete. The 'full and free' checks carried out by RAFAT pilots did not differ significantly from other Hawk users who use it as a last check of all of the flying controls. However, the Panel noted that it was not preceded by a check of the individual controls for 'correct' movement in a manner consistent with the wider Hawk community, where full deflection inputs are methodically applied to the aileron, tail-plane and rudder in turn which are monitored by ground-crew for correct operation and acknowledged by the pilot. For the tests outlined below, the SFH was in an unsafe condition and were carried out before the 'test' pilot had been made aware of the existence of Position 2 or Position 3. These tests were also carefully sequenced to ensure that the subject 'test' pilot had no knowledge of the existence of Position 2 or Position 3 prior to the start of testing. During both sets of testing he was tasked with strapping in and carrying out checks (including 'full and free') using timings and techniques consistent with RAFAT operations. The following describes the significant findings from the MITL testing:

Witness 3
Witness 6
Witness 7
Witness 8
Exhibit 18
Exhibit 115
Annex C

a. **Control Restriction - Correctly Strapped.** The unsafe condition of the SFH went unnoticed until he carried out 'full and free' checks, at which point he felt what he termed a "control restriction" push against his thigh as the control column (in the fully aft position) was moved from left to right. This "control restriction" was due to interaction of the control column with the SFH in the 'raised' Position 3[6].

b. **Control Restriction - Right Hand Crotch Strap Incorrectly Routed.** When 'full and free' checks were carried out in this condition, with the SFH in Position 2 or Position 3, at no time was the "control restriction" apparent to the 'test' pilot. This was because the right hand crotch strap held the SFH closer to the 'test' pilot's body and clear of the control column during 'full and free' checks.

Analysis of the 10 previous XX177 sorties was carried out using Air Data Recorder (ADR) traces and witness interviews to ascertain if any similar 'control restrictions' had been

Witness 4
Witness 7

[6] Similar tests were carried out with the SFH in Position 2; as with the previous test a "control restriction" was felt.

experienced during 'full and free' checks. As the accident Pilot was the last pilot to fly XX177 on 4 Nov 11 only the three other pilots could be interviewed; none recalled experiencing a 'control restriction'. All of the traces, including the four from 4 Nov 11, showed similar control inputs and timings during the 'full and free' control check. These were compared to the accident sortie and showed similar control inputs to all of the other sorties with one exception: during the accident sortie, on completion of the 'full and free' checks, a rapid aft movement of the control column followed by a reset to the central position was carried out by the Pilot. On no other ADR trace examined was this apparent, see Figure 24. It is common practice that if a 'control restriction' is felt during a 'full and free' control check, a pilot will revisit the area of restriction as confirmation and to aid diagnosis. It is therefore the Panel's view that on the day of the accident the Pilot experienced a 'control restriction' during his 'full and free' checks, which caused him to carry out the additional control input. Examination of the ADR traces and witness statements indicate that no similar 'control restriction' (indicative in this case of an SFH in an unsafe condition and correct strap routing) had been experienced on any of the previous four sorties. Following dislodgement of the SFH into an unsafe condition through incorrect strap routing, it is the Panel's view that had it not been detected by some other means, the next pilot to fly the aircraft would have felt a similar 'control restriction' during 'full and free' checks. Evidence suggests that no such control restriction was detected on any of the previous four sorties; therefore the Panel concluded that **the XX177 SFH was most likely moved into an unsafe condition on the final sortie on 4 Nov 11**.

Witness 54
Exhibit 31

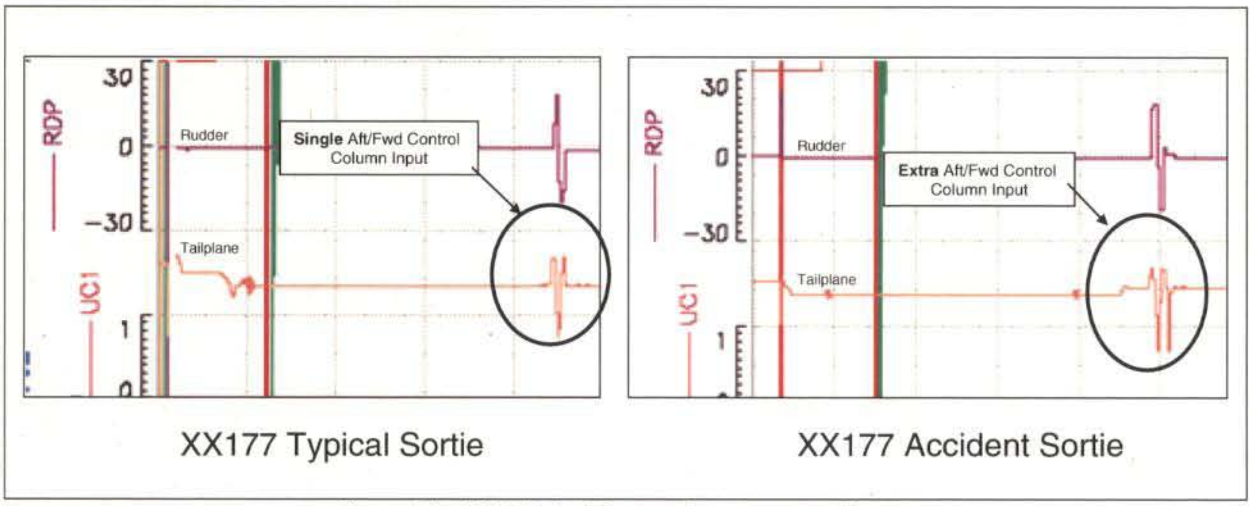

Figure 24 – XX177 Accident sortie extra control input.

Detecting a SFH in an Unsafe Condition

1.4.2.19. **Difficulties in Detecting an Unsafe Condition.** Evidence suggests that the XX177 SFH was in an unsafe condition from 4 Nov 11 until the accident on 8 Nov 11. During this time, there were at least ten different detection opportunities where checking the status of the ejection seat was mandated: these included AF and BF servicing, safe for parking and maintenance tasks involving at least six different personnel in addition to the Pilot's post-flight checks on 4 Nov 11 and pre-flight checks on the day of the accident. MITL testing, review of the Hawk document set and witness testimony indicated 4 primary factors that may have affected the detection of the SFH in an unsafe condition:

Witness 1
Witness 2
Witness 7
Witness 54
Exhibit 5
Exhibit 30
Exhibit 28
Exhibit 115
Annex B
Annex C

a. **Document Set.** The Hawk document set refers to inserting safety pins into 'ejection seat firing handles' or 'the seat', making no reference to the housing. While the document set could appear slightly misleading, it is the Panel's view that the lack of knowledge that it was possible to insert the SFH safety pin into the handle alone was of greater importance.

b. **Visibility.** MITL testing highlighted significant challenges involved in identifying a SFH in an unsafe condition. The Panel noted that when viewed from a front aspect (see Figure 23) visibility of the SFH, and subsequent identification of an unsafe condition, was relatively straight forward. However, gaining access to view the front face of the SFH was difficult and required the observer to lean into the cockpit. When viewed from above (see Figure 25), the aspect is narrowed and the front face is not visible; however, the end of the pin can be seen pushed through the other side of the handle. Evidence suggests that it was not uncommon for RAFAT ground-crew and aircrew to use protrusion of the pin through the back of the SFH as confirmation that it was fitted correctly, rather than viewing the SFH from a front aspect.

Figure 25 – SFH viewed from above.

c. **Seat Height.** The ejection seat is able to be motored up and down, allowing the pilot to select the optimum height for flight. The Panel noted that it was harder to gain a front aspect view of the SFH when the seat was motored down (see Figure 26 and 27). Of note, at the point of initiation the XX177 ejection seat was towards the lower limit of travel. Although it is part of the Hawk AF servicing schedule to operate the ejection seat to the upper limit, it is likely that the XX177 ejection seat had not been moved since the previous sortie on 04 Nov 11. The probable reason for this omission is discussed at Section 1.4.5.23a.

Figure 26 – SFH viewed from above; seat motored to the lower limit.

Figure 27 – SFH viewed from above; seat motored to the upper limit.

d. **Time Compression.** MITL testing demonstrated that time compression made the discovery of a SFH in an unsafe condition less likely. The Pilot was working to a standard RAFAT timeline, which is analysed in detail at Section 1.4.5.17, and therefore may have not felt rushed. However, MITL testing, using a pilot who was unaware of the existence of Position 2 or 3, demonstrated that when he carried out his cockpit checks (including the ejection seat) in a time comparable to the accident, he failed to detect the seat in an unsafe condition. Subsequent tests carried out using the 'test' pilot's normal timeline (less time compressed than that used by RAFAT pilots), but still unaware of Position 2 or 3, resulted in his discovery of the SFH in an unsafe condition.

1.4.2.20. **Detection of Unsafe Condition Summary.** The Factors outlined above highlight some of the challenges involved in detecting the SFH in an unsafe condition, reinforced by some ambiguity in the aircraft document set and the lack of specific knowledge regarding Position 3. Additionally, the difficulties in identifying the condition were exacerbated by low seat height and time compression. Furthermore, the ability to see the pin protruding out the back of the handle in a similar manner, whether safe or unsafe, and normal practice of accepting this as a positive check of safety, added to the likelihood that individuals could have 'seen what they expected to see'. The XX177 ejection seat was most likely in an unsafe condition for 4 days, during which time a significant number of personnel interacted with an unsafe seat. The Panel concluded that the difficulty in identifying an unsafe condition, exacerbated by the lack of corporate knowledge that it could occur, was **a contributory factor.**

Safety Pin Handling

1.4.2.21. **FRC/Aircrew Manual:**

a. **Emergency Ground Egress.** In the event of an emergency on the ground requiring rapid cockpit egress, such as a fire, the Hawk FRCs direct that the aircraft should be vacated using the 'emergency ground egress' drill, which does not involve ejection. However, the Hawk Aircrew Manual (AM) states that "In emergency ground escape circumstances retain the ejection option (occupant must not un-strap) until it is evident that no danger is present which might inhibit a manual escape [emergency ground egress] from the aircraft or the use of the ejection facility is not feasible". Furthermore, the Panel **observed** that the drills for the emergency ground egress in the Hawk AM differ from the FRCs in a number of ways; most notably in that the FRCs require fitment of the SFH safety pin prior to egress, whereas the Hawk AM does not state that the seat pins should be fitted Exhibit 27 Exhibit 28 prior to egress and states that "if it appears safe to do so, return to the aircraft [post egress] and fit firing handle safety pin to each seat".

b. **Retention of Ejection 'Option'.** The FRCs direct the pilot to "remove and stow" the MDC and seat pin prior to engine start, which is consistent with the Hawk AM advice to "retain the ejection option". However, the third after landing check in the FRCs direct the pilot to "fit [pins] to seat and MDC firing handles". This leads to a situation whereby the ejection seat is 'live' for the entire engine start and taxi prior to take-off, yet is made 'safe' for the taxi-back and shut-down. The reason given for this contradiction by RAF Handling Squadron was that although emergency ground egress was the "preferred option" on the ground, aircrew/groundcrew interaction to positively confirm movement was required to mitigate the risk "that the seat could be left safe [during] a flight" when conducting single pilot student operations. The Panel noted that Tornado crews are directed to leave the seat safe until the pre take-off checks, relying on challenge and response checks to ensure correct procedures are carried out, while Typhoon pilots are protected by seat warnings. The Panel **observed** that Tucano procedures mirror those employed by the Hawk TMk1 despite not being fitted with a 'zero/zero' seat which could be safely used on the ground below 70 knots airspeed. Exhibit 28 Exhibit 29 Annex C

1.4.2.22. **Safety Pin Insertion into SFH.** Witness evidence from other RAFAT pilots indicated that some pilots regularly inserted the SFH safety pin by feel without visual reference. Witness evidence indicates that once the final aircraft in the formation "knows that he is not going to be flying through or over shooting" he calls "clear cross"; this is an indication to the Formation that that they can start to taxi clear of the runway in close formation and that they can make their ejection seats safe. The last sortie prior to the accident was a five aircraft formation practice. The final landing was in number sequence with the accident Pilot, Red 5, piloting XX177 (see Figure 28). In order to make the ejection seat 'safe' following the final landing, the safety pin is usually inserted into the SFH and housing as part of the after landing checks. During MITL testing the 'test' pilot was tasked with inserting the SFH safety pin by feel alone whilst maintaining 'eyes out' of the cockpit to simulate a requirement for visual activity outside of the cockpit. This test was executed with the SFH in Position 2 and 3 and was carried out before the 'test' pilot was aware of the existence of Position 2 or 3. On each occasion the safety pin was inserted into the SFH only, leaving the 'test' pilot unaware that the ejection seat remained 'live'. It is normal to move the control column forward to gain access to the SFH for safety pin insertion. The ADR trace from XX177 (4 Nov 11 final sortie) was analysed and showed a forward control column input, consistent with this movement, at 50 knots airspeed (see Figure 29). Although the time of safety pin insertion into the SFH cannot be definitively established, it is the view of the Panel that the safety pin was most likely inserted into the 'unsafe' SFH on roll-out from landing. Due to the speed of XX177 and subsequent rate of closure to the aircraft ahead, it is likely that the Pilot inserted the SFH safety pin by feel whilst maintaining eyes out of the cockpit. The Panel concluded that the practice of inserting the SFH safety pin without visual reference is likely to have decreased the probability of discovering the SFH in an unsafe condition or incorrect strap routing and was **a contributory factor** in the accident. Witness 4 Witness 7 Witness 54 Exhibit 31 Exhibit 106 Exhibit 115

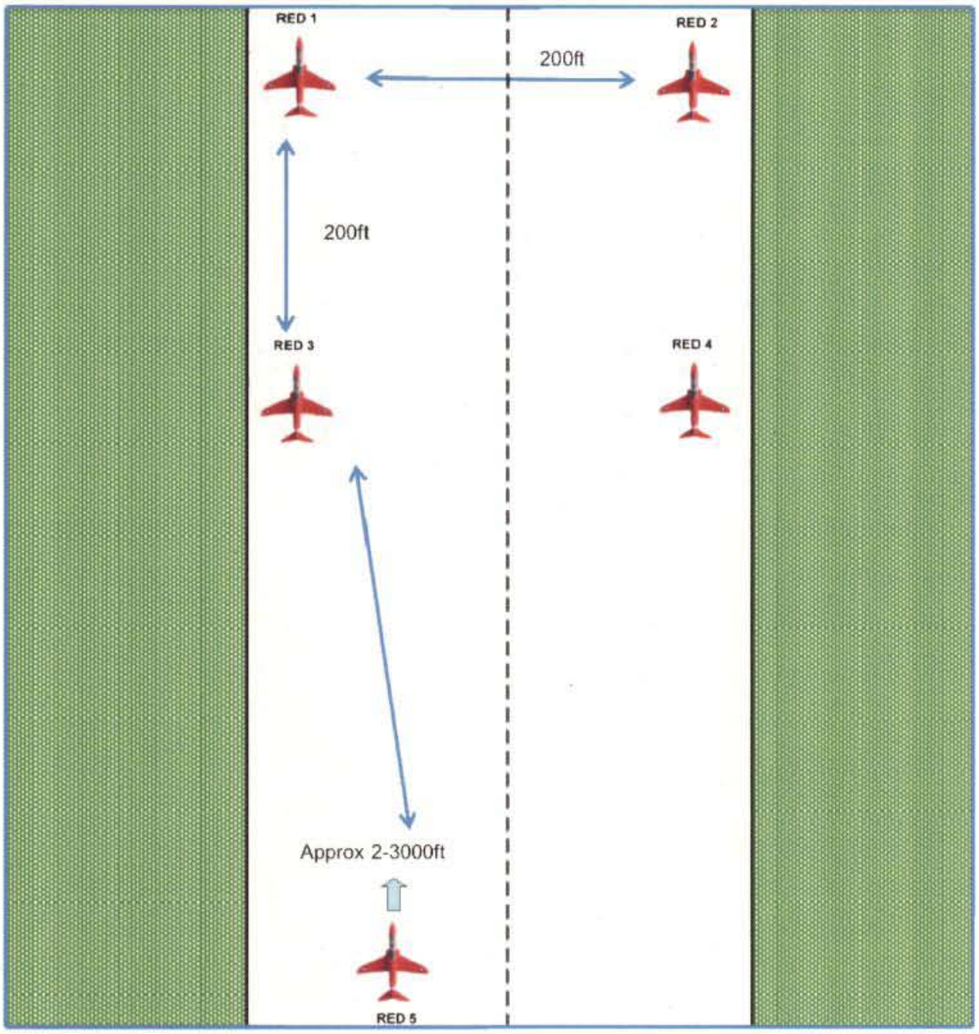

Figure 28 – RAFAT Landing Sequence.

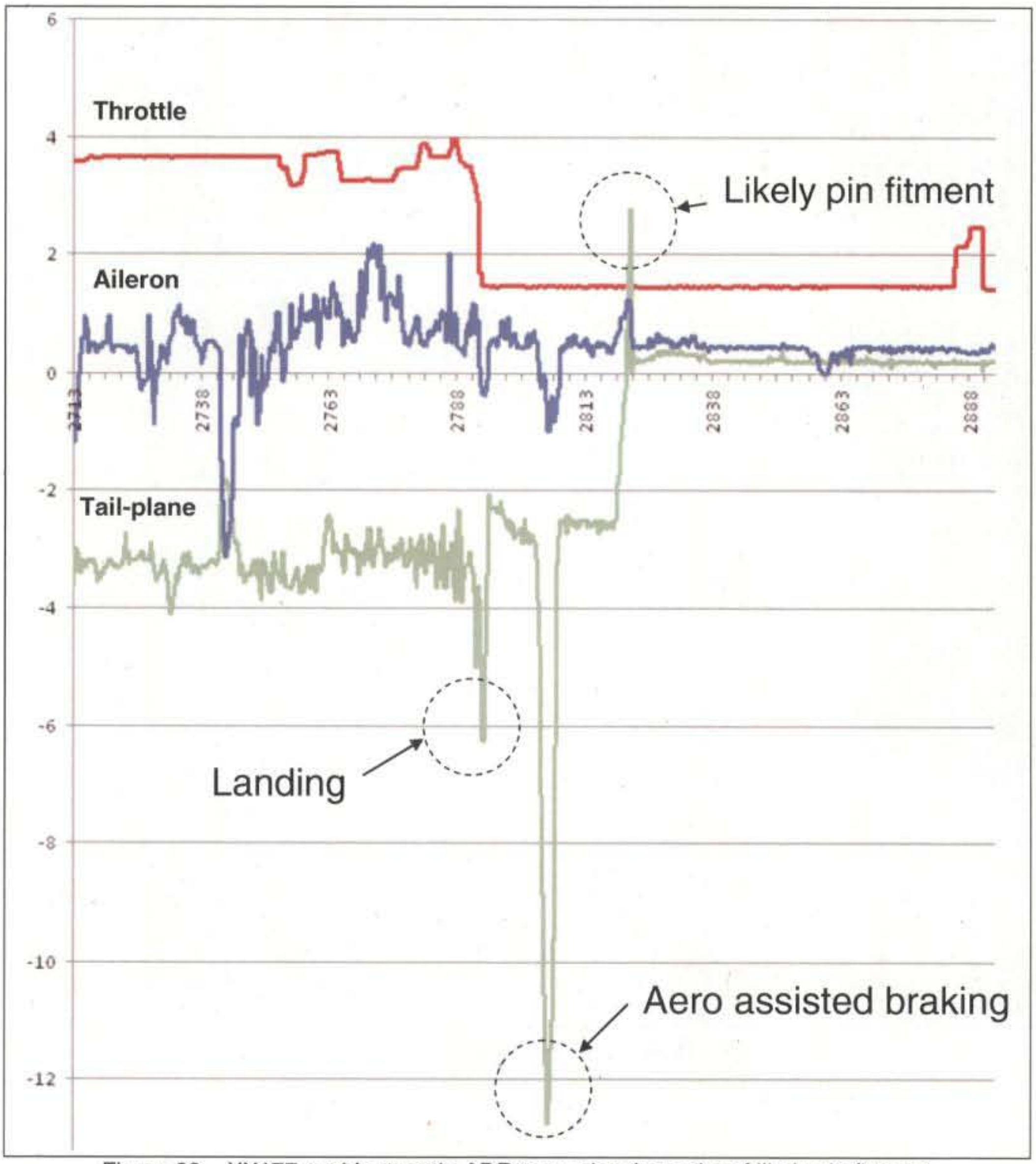

Figure 29 – XX177 accident sortie ADR trace showing point of likely pin fitment.

1.4.2.23. **Movement to Position 3.** The only possible method found to move the SFH into position 2 or 3 and reproduce the 'scuffing' was via incorrect routing of the right hand crotch strap through the SFH. This 'scuffing' only occurs when the SFH is held above Position 3 and to one side by the crotch strap (in this case the right). It is not possible to initiate ejection in a manner consistent with the forensic evidence described at section 4.2.6 while the SFH is held against the leg through incorrect crotch strap routing. The incorrect strap routing, and therefore removal of the SFH from Position 1 through Position 2 and 3 to cause the 'scuffing', must have occurred on a previous sortie. The ejection (in a manner consistent with the forensic evidence) was only possible from Position 3, therefore either the SFH remained in Position 3 following its dislodgement through incorrect strapping on a previous sortie or it reverted to Position 2 and was subsequently returned to Position 3 at some point prior to the accident. Position 3 was found to be relatively unstable; slight movement tended to move it back to Position 2 which was found to be far more stable. While it is possible that the SFH remained in Position 3 from the 4 Nov 11 until the accident on the 8 Nov 11, it is the Panel's view that this was less likely. Therefore, MITL testing was carried out to identify possible ways in which the SFH could have been returned to Position 3 just prior to the accident when the Pilot was correctly strapped in.

Witness 1
Witness 5
Exhibit 28
Exhibit 31
Exhibit 115
Annex B
Annex C

During MITL testing a significant number of different methods were trialled including, but not limited to, ejection seat strapping, leg restraints, helmet and mask, pilot's watch and general AEA. However, the only consistently reproducible method to achieve movement of the SFH to Position 3 from Position 2 when correctly strapped-in, was by applying a slight upwards vector during removal of the safety pin from the SFH. Of note, whilst this movement was not 'easy' to achieve in this manner, the method of pin removal appeared consistent with normal operations and techniques employed by other Hawk operators. The Hawk FRCs state that the pilot should move the SFH safety pin immediately prior to engine start. Examination of the ADR trace and witness statements show that the Pilot did not move his safety pin at the expected time and did so after being prompted by ground-crew intervention some 22 seconds prior to the accident and just 15 seconds before commencing 'full and free' control checks. Additionally, the Pilot had his mask down whilst removing the safety pin which is likely to have obscured his view of the SFH. The Panel concluded that reversion of the SFH to Position 2 at some point between 4 and 8 Nov 11 was likely and that therefore the late and expeditious removal of the safety pin with an upwards vector and without visual reference was sufficient to inadvertently dislodge the SFH to position 3, was the only repeatable method discovered in testing, and may therefore have been **a contributory factor**.

SFH Movement Summary

1.4.2.24 The Panel concluded that:

a. The SFH on XX177 front ejection seat was moved from Position 1 to an unsafe condition (Position 2/3) through incorrect strap routing on the last sortie flown prior to the accident on the 4 Nov 11.

b. The SFH safety pin was inadvertently inserted into the SFH when in Position 2 or 3, during rollout from the last landing.

c. The SFH most likely reverted to Position 2 following the last sortie on the 4 Nov 11 and that it was returned to Position 3 immediately prior to the accident when the safety pin was removed from the SFH.

d. The front cockpit seat of XX177 was in an unsafe condition for four days.

HOW WAS THE FORCE APPLIED THAT INITIATED EJECTION?

1.4.2.25 **Background.** Forensic examination, supported by lab testing, demonstrated that the ejection was initiated through an inadvertent movement of the SFH from Position 3, in a forward direction at an angle of 20 degrees down from the horizontal plane and 30 degrees right from SFH housing centre line. Annex B

1.4.2.26 **Application of Force to SFH.** The Panel investigated four possible actions that could have applied the requisite force to the SFH causing its movement in a manner consistent with the forensic evidence: Exhibit 115 Annex B Annex C

a. **Strap Routing.** Incorrect routing of the crotch strap could not have caused the SFH to move forwards, right and down. Other incorrect routing combinations were also investigated (including leg restraints) to assess their viability. Forensic examination of the SFH and straps revealed no evidence of recent interaction between them; MITL and lab testing produced no viable combinations that could replicate the force applied to the SFH. Additionally, there was no evidence to suggest that the Pilot was not correctly strapped in on the day of the accident. The Panel concluded that on the day of the accident incorrect strap routing did not apply the requisite force to the SFH to cause initiation and was **not a factor** in the accident.

b. **Routine Pilot Movement.** With the SFH in Position 3, multiple combinations of leg and body movement were carried out by the 'test' pilot in an attempt to initiate ejection. These were carried out in multiple configurations of strap routing and it was not found to be possible to initiate ejection in a manor consistent with the forensic evidence and was **not a factor**.

c. **Control Interference.** Forensic analysis revealed no physical evidence of cockpit control interference having occurred with the SFH in XX177. Additionally, considerable MITL testing was carried out to assess potential causes of initiation; whilst some interaction between the control column and the SFH was noted, at no time during MITL testing was it found to be possible to initiate ejection in this manner. The Panel concluded that this was **not a factor** in the accident.

d. **Unintentional Application of Force by Hand.** In acknowledgement of the forensic evidence and the absence of any other viable method of applying the necessary force vector to the SFH reported at para 1.4.2.9. above, the Panel concluded that, on the balance of probabilities, the inadvertent ejection was initiated following a 'push' of the SFH by the Pilot away from his body. During MITL testing it was found to be possible to initiate ejection from Position 3 in this manner by the application of relatively minor 'push' of the SFH away from the body with either hand. It is the Panel's view that in responding to the perceived 'control restriction', the Pilot may have pushed the SFH with his hand away from his body immediately after completion of his 'full and free' control checks, possibly to afford him better visibility of the area where the apparent control restriction had emanated. Such a 'push' of the SFH in this manner would not necessarily have been considered an unsafe action, as the only known method of ejection initiation at the time was via a vertical pull of the SFH. The Panel concluded that the ability to initiate ejection in a manner different to the design intent was **a contributory factor** in the accident.

1.4.2.27. **Pilot Distraction and Impairment.** The Panel noted the following lapses in the period immediately prior to the accident:

a. **Check-in Call out of Sequence.** It is a RAFAT Standard Operating Procedure (SOP) for Red 2 to acknowledge information calls from Red 1 on behalf of the formation. One such call was also acknowledged by Red 5, an action that was deemed unusual by other members of the formation. Witness 8 Witness 2

b. **Forgetting to move ejection seat safety pins**. It is a RAFAT SOP to start the Gas Turbine Starter (GTS), close the canopy and then immediately move the Miniature Detonating Cord (MDC) and Seat Firing Handle (SFH) safety pins prior to continuing with the main engine start. On the accident sortie the Pilot did not move his pins at the appropriate time, which was unusual, and he had to be reminded to do so by ground-crew, just prior to the accident. Witness 1 Witness 5 Exhibit 21

1.4.2.28. **Potential Causes of Pilot Distraction or Impairment.** Lapses such as those described above can be caused by an interruption by an external event, time compression or the unexpected workload derived from an unplanned event. There were a number of findings which may have affected the Pilot's performance, leading to impairment or distraction in the period immediately prior to the accident: