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

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

PART 1

DETAILS OF THE BOARD

Assembled on 25 Aug 00 at Defence Evaluation Research Agency (DERA) Aircraft Test & Evaluation (AT&E) BOSCOMBE DOWN.

By order of the DCOS Ops, STC.

To inquire into an accident involving HARRIER T10 ZH654 on 24 Aug 00.

1. Composition of the Board.

Duty	Rank, Name, Service No & Decoration	Branch	Unit
President	Redacted Sect 40- Gp Capt A	GD/P	RAF Innsworth
Members	Redacted Sect 40- Sqn Ldr B Flt Lt C	GD/P Eng	RAF Waddington RAF Wyton
In Attendance (QR 1261)	Redacted Sect 40- Civ D	TP	DERA AT&E BOSCOMBE DOWN

2. Full Terms of Reference.

a. Investigate the circumstances of the accident to Harrier T10, ZH654, at DERA AT&E Boscombe Down on 24 Aug 00.

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

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

d. Ascertain if Service personnel involved were on duty.

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

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

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

h. Assess any human factors involved in the accident.

i. Report the loss or quantify the damage to such classified material that was carried on or in the aircraft at the time of the accident iaw JSP440 paras 0246 and 0247.

j. Make appropriate recommendations and observations.

k. Assess the supervision and authorisation of the sortie.

CONCLUSIONS OF THE BOARD

PART 2

NARRATIVE OF EVENTS (All times LOCAL)

1. Introduction. On 24 Aug 00, the pilot of Harrier T10 ZH654, [redacted] of the Fast Jet Test Squadron (FJTS), conducted a Continuation Training (CT) sortie from DERA AT&E Boscombe Down. [redacted] was the rear seat, non type-qualified test pilot (TP). ZH654 took off at 1547 hrs and conducted low and medium level general handling and Thermal Imaging and Laser Designator (TIALD) training. The ac was recovered to Boscombe Down for circuit flying. The crew flew 7 circuits to runway 05, sharing the flying. On the last circuit [redacted] flew a tight circuit for a Rolling Vertical Landing (RVL). Just prior to the final descent to land, at 200 ft agl, [redacted] reduced and re-applied power to establish the ac on a 5 to 6 degree approach to final touchdown. At this point the crew heard a marked change in engine note and [redacted] assessed that the engine had started to wind down. [redacted] was then aware of the ac pitching rapidly nose down and, as the pitch attitude passed 10 degrees nose down he called "eject" and initiated a successful command ejection. The ac crashed onto runway 05 at 1701 hrs and both pilots landed close to the wreckage. As the board focussed much of its attention on the engine fuel supply, it is appropriate to include a description of the Harrier Fuel system.

Witness 1
Witness 3
Witness 1
Witness 1
Exhibit 4 Annex G
Annex E

2. Harrier T10 Fuel System.

a. Description. The Harrier T10 fuel system is similar to that of the GR7 with a left and right group consisting of five fuselage and two integral wing tanks. Additional fuel can be carried in external, pylon mounted, jettisonable tanks. See Diagram 1.

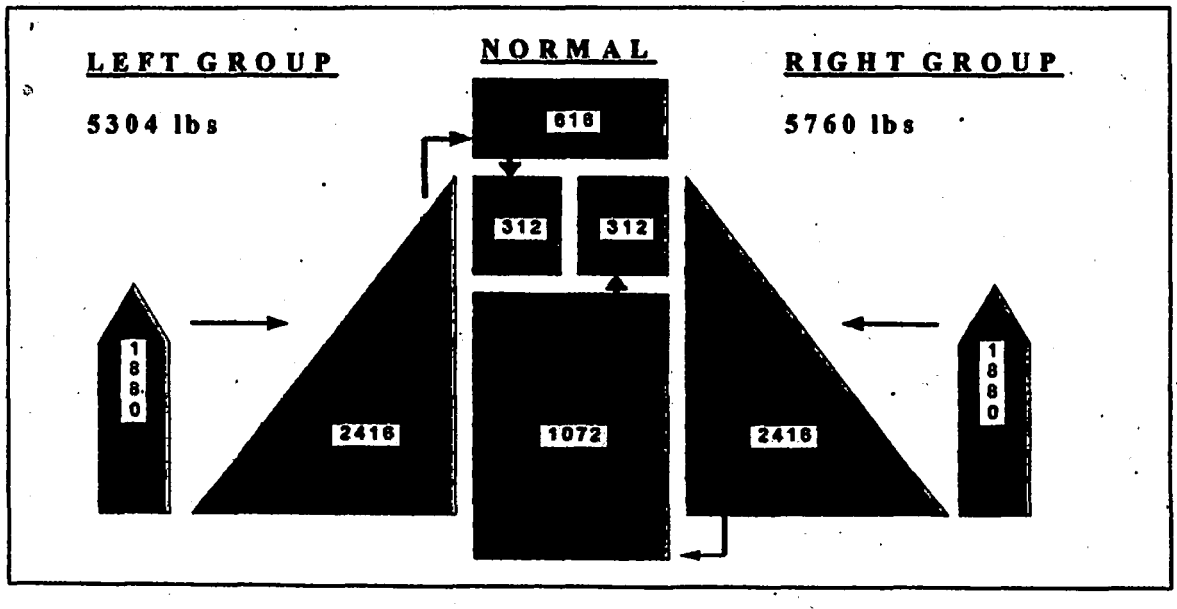


Diagram 1 - Total Fuel Harrier T10 with 2 Drop Tanks

As in the GR7 all the fuel tanks are pressurized by engine bleed air. In order to maintain a suitable longitudinal centre of gravity, the left group fuselage front tank capacity is reduced by 450lbs. With 2 drop tanks fitted and full, the fuel quantities are 5304lbs LHS, 5760lbs RHS giving 11064lbs total.

b. Automatic Operation. An automatic crossfeed system, selected to AUTO in Diagram 2, ensures that all fuel is fed from the left and right groups.

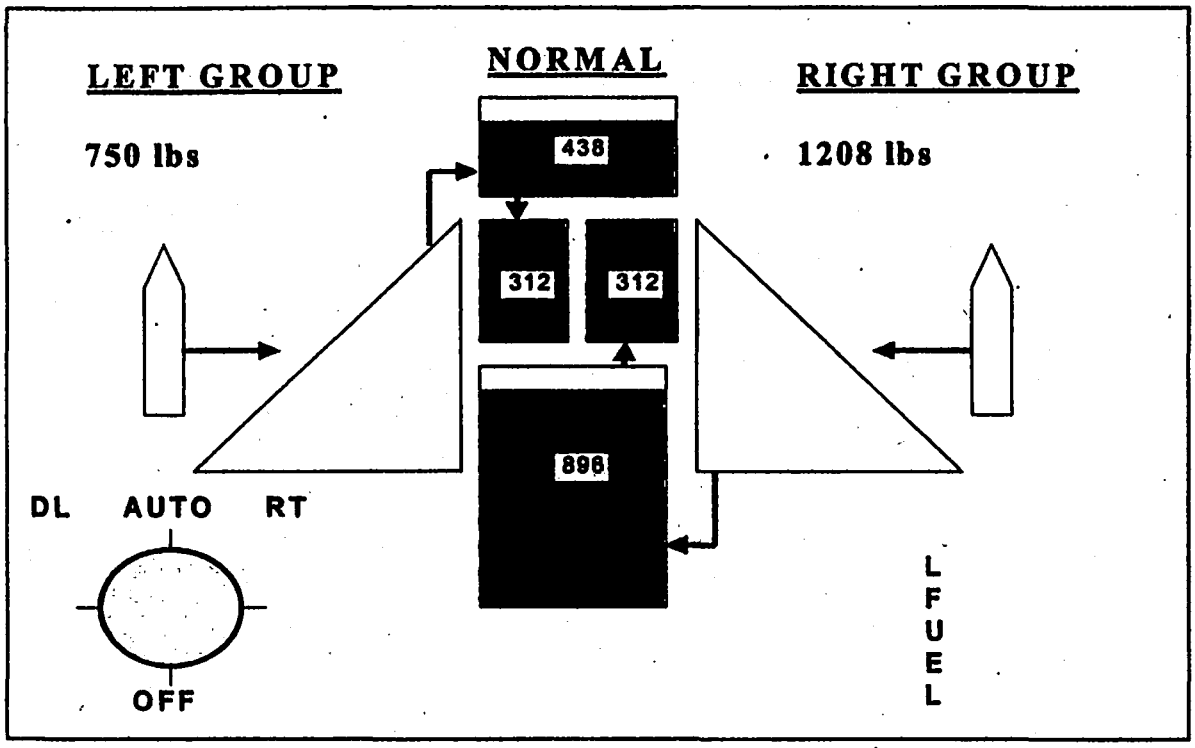


Diagram 2 - Illumination of LFUEL Caution

When the front tank, which is part of the left group, has 438lbs of fuel remaining there is only 750lbs total fuel remaining in the left hand side (LHS). At this stage the silent and steady LFUEL caution illuminates as shown above.

The fuel continues to feed equally from both sides until the front tank is empty as seen below in Diagram 3. At this point there is still an imbalance between the sides of 450lbs. The fuel stops feeding from the left group and the RFEED advisory light illuminates as confirmation of this event.

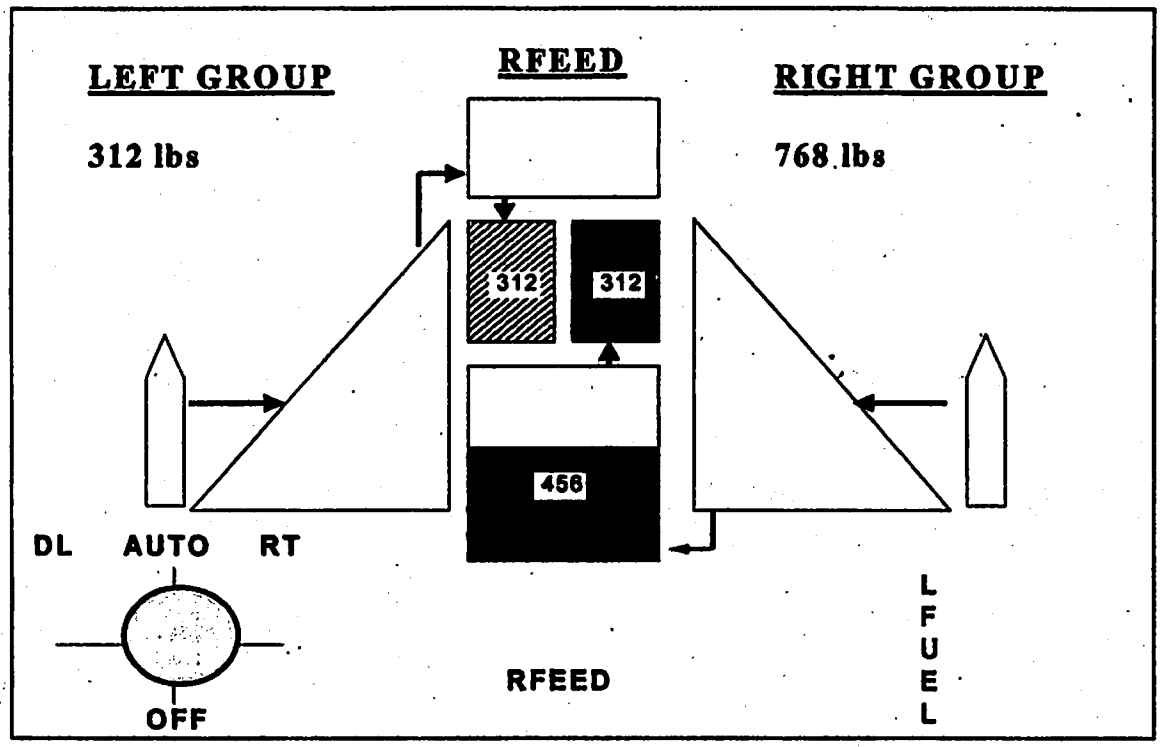


Diagram 3 - Illumination of the RFEED Advisory Caution.

When 750lbs of fuel is remaining in the right hand side (RHS) the silent and steady RFUEL caution illuminates as in Diagram 4.

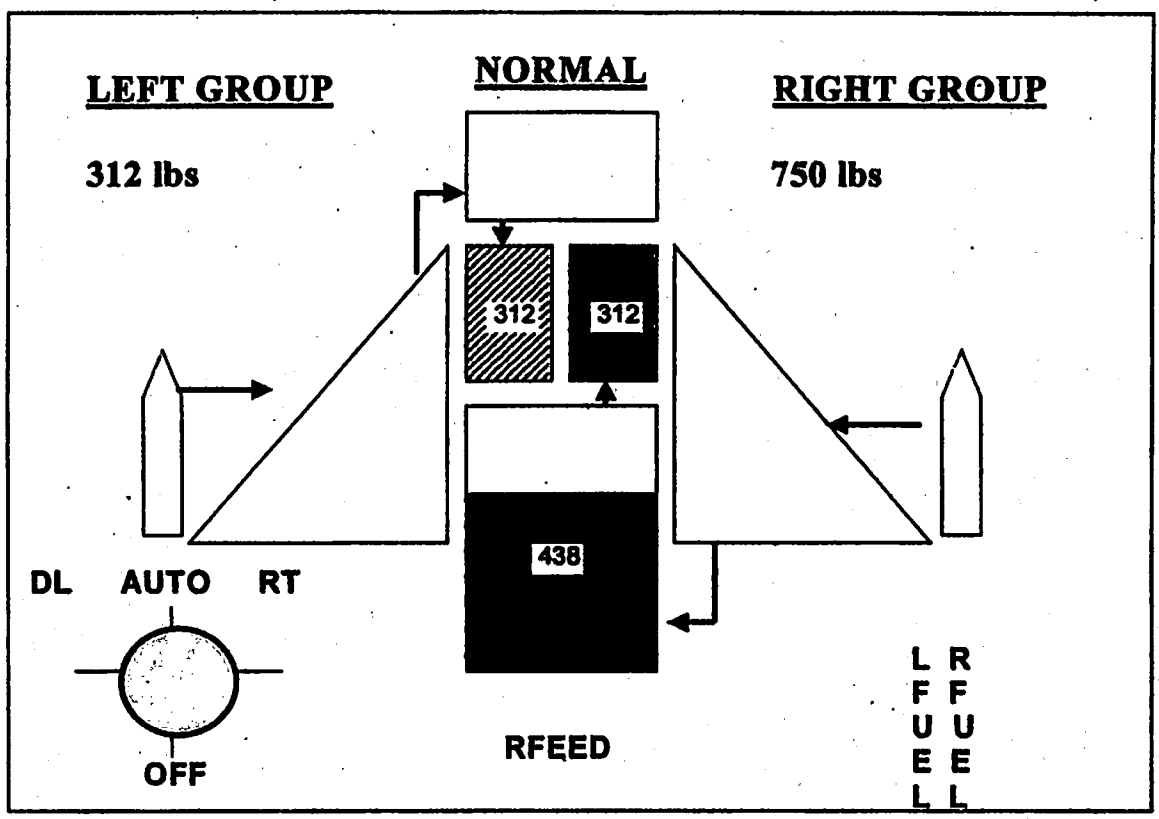


Diagram 4 - Illumination of RFUEL Caution

The fuel starts feeding from both groups again when the rear tank is empty, the rear tank being a part of the right group. When both groups are feeding again the RFEED advisory caution extinguishes. The only fuel now remaining is in the centre tanks and when each side reaches 250lbs of fuel remaining the respective L/RFUEL caution light will start flashing as in diagram 5. An associated audio will also sound with the flashing L/RFUEL but it only lasts for 900 m/secs.

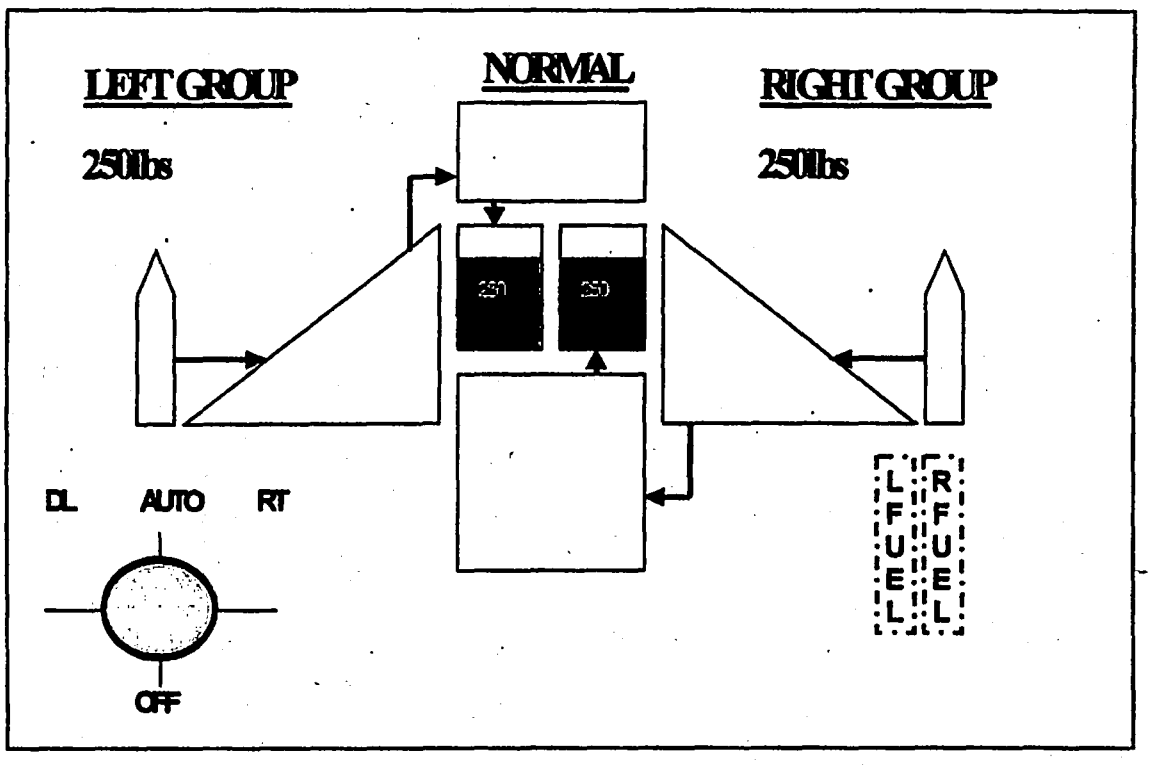


Diagram 5 - L/RFUEL Flashing Caution with Audio.

The warning, caution and advisory system has been modified for T10 to provide indications of the operation or malfunction of the crossfeed system. The crossfeed valve allows automatic or manual selection of fuel feed from either the left and right groups or the right group only. A RFEED warning, which is completely separate to the RFEED advisory caution, comes on in each cockpit to give an independent indication of incorrect operation of the crossfeed system. To avoid oversensitivity of the warning, its control relay incorporates a delay of 18 to 25 seconds.

c. Fuel Proportioner Switch Selections. The front cockpit fuel proportioner switch allows the selection of automatic crossfeed, manual crossfeed or override of automatic crossfeed. The switch is a four toggle switch lever locked to a central AUTO position. The functions of the switch are:

(i) OFF. The proportioner is off.

(ii) AUTO. The crossfeed functionality is automatic.

(iii) DL. If the crossfeed is in operation (feeding from the right group only), the selection of DL overrides the crossfeed and demands feed from both left and right groups via the proportioner.

(iv) RT (right feed). If the crossfeed is not in operation (feed from both groups via the proportioner), the selection demands crossfeed from the right group only.

d. Fuel Balance. Until the external, wing and front fuselage tanks are empty, a 450lb discrepancy heavy in the right group indicates that the fuel is correctly balanced. If a further check is required the fuel indicator selector rotary switch can be used to monitor the fuel in the drop tanks, internal wing tanks and total internal right and left groups. If an incorrect imbalance exists, the low side booster pump and the fuel proportioner should be switched off until the balance is corrected.

3. Crew Background. [redacted] Witness 1

Exhibit 6

Redacted Sect 40- Flt Lt E and Sqn Ldr F

P Witness 3

4. FJTS. FJTS is a discrete Unit within the AT&E facility at DERA Boscombe Down. Overall responsibility for the running of the facility and its core Units rests with the Director AT&E (D/AT&E). However, the flying activity is regulated by the Director of Flying (DPA) (D/Flying (DPA)), and associated control is exercised through Director Air Operations (D/Air Ops) and the Chief TP (CTP), a RAF Air Cdre and Gp Capt respectively. D/Air Ops liases with D/AT&E to ensure that Air Operations are conducted in an efficient and safe manner. Ac Engineering Department (AED), another discrete Unit, provides the Engineering support for the FJTS task. Annex M

5. Ac Background. Harrier T10 ZH654, manufacturers airframe number TX2 had been allotted to DERA on 27 Jun 00. Prior to then, it had been part of a Productionisation Programme at BAE SYSTEMS Dunsfold where it had been since Apr 97. During the Productionisation Programme the ac had not flown. ZH654 started flying again on 13 Jun 00 and flew a total of 4.45 hrs at BAE SYSTEMS Dunsfold prior to being delivered to FJTS. A total of 16.05 hrs had been flown by ZH654 since leaving BAE SYSTEMS Dunsfold and no unserviceabilities relating to the accident had been reported. On the take-off for its last sortie ZH654 had logged a total of 140.40 airframe hrs. Exhibit 15

6. Previous 24 Hrs. On 23 Aug 00 both pilots were at work carrying out their normal daily routines. [redacted] flew 2 sorties in the Vectored-Thrust Witness 1

Advanced Ac Control (VAAC) Harrier whilst [redacted] flew once in the Jaguar GR3. Both pilots had left work by 1830 hrs and retired to their separate homes for the evening. [redacted] consumed an evening meal but no alcohol before retiring to bed at his usual time of midnight. His young child awoke him during the night, for about 20 mins, but this was not unusual. [redacted] spent a normal evening at home he did not consume any alcohol and retired to bed at approximately 2300 hrs. Both pilots had breakfast before attending the met brief on the Sqn at 0830 hrs. During the morning of the accident [redacted] attended a pre-arranged meeting between 0845 and 1030 hrs and then spent until 1200 hrs reviewing paperwork. He went home for lunch, [redacted] before returning to work at 1400 hrs. [redacted] attended to some more paperwork in his office and checked the NOTAMS for the afternoon sortie. Before lunch [redacted] had been made aware that the rear seat occupant had been changed from the Sqn Navigator to [redacted]. After met brief [redacted] planned and flew in a Jaguar GR3. Upon his return to the Ops Room at 1240 hrs he noted that there had been a change to the flying programme and that he was now flying in the rear seat of the Harrier T10. [redacted] attempted to find [redacted] but was unable to. He therefore, had an informal discussion with another Sqn Harrier pilot about the ac escape systems before carrying on with his paperwork. At around 1445 hrs both pilots met in the Ops Room and went to the Harrier Project Office to carry out the sortie brief.

Redacted Sect 40- Flt Lt E and Sect 32.

Witness 3
Witness 1
Witness 3
Witness 1
Witness 3
Witness 3
Witness 1

7. Pre-Flight Briefings. During the Sqn met brief at 0830 hrs it was briefed that hover performance checks had not been carried out on ZH654. A hover performance limitation had been put in the F700 that advised pilots that this Harrier T10 could not hover because of the engine performance figures in the F700 and because of the lack of hover performance figures. The pre-sortie brief started at 1445 hrs, lasted 15 to 20 mins and consisted of the sortie content, who would fly what and some peculiarities of flying the Harrier. The sortie content was briefed to include a take-off and climb, ML and LL TIALD attacks, Thrust Vectoring in Forward Flight (VIFF), recovery and circuits. Emergencies were discussed during the brief and it was decided that [redacted] would carry appropriate Flight Reference Cards (FRCs). The TIALD profiles were covered in detail, as [redacted] was TIALD experienced and would, therefore, fly the profiles. [redacted] would fly the Auto Flap take-off and departure; thereafter, [redacted] was to fly an event and then [redacted] would repeat it. During the brief [redacted] produced a TIALD HOTAS guide and low level map. No other visual aids were used. At the end of the brief [redacted] asked some questions including how a take-off is flown in a Harrier T10. The sortie was out briefed and authorised by [redacted] between 1505 to 1515 hrs. The authoriser was aware that [redacted] would fly a large proportion of the sortie including the take-off and landings and cautioned [redacted] on the need for sound briefing and monitoring. [redacted] briefed [redacted] that he planned to land with 1000lbs fuel for CofG reasons.

Witness 1
Witness 2
Exhibit 15
Witness 1
Witness 3
Witness 1
Witness 3
Witness 2

8. Pre Take-Off. The pilots walked to the engineering line control together. [redacted] noted the limitation on hovering in the F700 but was unable to query the limitation, as there were no suitably qualified engineers available. During the crew-in and see-off, an adjacent Harrier was starting up, so [redacted] carried out the external checks before briefing [redacted] on the rear cockpit. [redacted] taxied the ac whilst [redacted] carried out taxy and pre-take-off checks. The delay in the departure was reflected in an amended Flight Notification. Witness 1 Witness 3 Exhibit 19

9. Pre-Accident Airborne Events. Taxy out and take-off were normal, however [redacted] helped [redacted] to "nozzle out" during the take-off. On departure the TIALD pod was not working and so [redacted] opted to carry out the first part of the sortie at low level. Exeter airport was contacted and flown over at about 300' agl before the crew departed to the north of the airfield and carried out ML and LL TIALD profiles. The ac was then climbed to above 7000' agl where VIFF manoeuvring was demonstrated by [redacted] and practised by [redacted]. During the VIFF manoeuvring, and whilst [redacted] was flying the ac, an overstress of 6.1g occurred. Before the overstress [redacted] states "Don't forget this trainer's only limited to 4.5G" and after the overstress he states "We've probably got about 5.5G at the moment, light weight". The actual G limit at this ac weight was 5.5G. [redacted] did not see the overstress. Both pilots flew the ac in excess of 30 α on a number of occasions. After the VIFF manoeuvring the ac was recovered to Boscombe Down to carry out circuits. Witness 1 Witness 3 Witness 1 Witness 3 Exhibit 3/4 Exhibit 4 Exhibit 4

10. Accident Events. The events leading to the loss of ZH654 are recorded using a timeline in secs. Time 0 is the time of the first ejection. At **T-19:12** ZH654 joined the circuit at DERA AT&E Boscombe Down. Throughout the circuit phase checks were verbalised. The verbalised checks were incomplete and carried out at different parts of the circuit pattern. The first 2 circuits were Auto Flap Slow Landings (AFSL), which were flown by [redacted] and [redacted] respectively. **T-13:52** was the first mention of fuel and this was by [redacted] whilst flying the ac on the upwind turn at the start of the third circuit. At **T-12:28** with [redacted] flying the ac, the silent LFUEL Caution illuminated indicating 750lbs useable fuel in the LHS fuel system. At **T-11:20** [redacted] had taken control after the third circuit landing and noted "Two point four on the fuel". [redacted] flew the fourth circuit, a STO Flap Slow Landing (SFSL), which was uneventful. At **T-8:20** [redacted] was flying the ac upwind on the fifth circuit and stated "I'm gonna manually select the right feed 'cos it should've fed by now, I don't know why it hasn't. OK, and I'm waiting for a right feed caution." At **T-8:00** the RFEED Warning illuminated and [redacted] said "That comes on." When [redacted] selected the Fuel Proportioner to RFEED manually, he did so with indicated fuel contents of 400lbs LHS. At **T-7:36**, during the fifth circuit, [redacted] had been given control for a SFSL and he questioned whether the fuel in the RHS was feeding. [redacted] confirmed that the RHS fuel was feeding and commented at **T-7:20** "and, anyway, one side can run dry, it doesn't matter." At **T-7:12** [redacted] commented that there was not much fuel left as the indication was in pounds. Exhibit 3/4 Witness 1 Exhibit 4 Exhibit 4 Witness 1 Exhibit 4 Witness 1 Exhibit 4 Witness 3 Exhibit 4 Exhibit 4 Witness 1 Exhibit 4

[redacted] then carried out some very abbreviated downwind checks. Witness 3
After the landing from the fifth circuit [redacted] once again took
control for the roller. During the roller at **T-5:24** the silent RFUEL Caution
illuminated indicating that there was 750lbs of fuel remaining in the RHS. [redacted] Exhibit 4
[redacted] did not notice this caption come on, although he stated that he
saw both the LFUEL and RFUEL Cautions illuminated at a later stage of the Witness 1
flight. Sixteen seconds later, at **T-5:08,** [redacted] was flying the ac
upwind for the sixth circuit and noted the fuel indications of 400lbs LHS, 1000lbs Exhibit 4.
RHS and total 1500lbs. During this circuit, the first RVL, [redacted]
decided to let [redacted] fly the approach to land because he wanted
[redacted] to have the chance of landing from an RVL. From **T-5:08**
to **T-4:08** [redacted] briefed [redacted] on how to fly an
RVL, made the downwind radio call, and mentioned the STO Flap, water and the
gear as he turned finals. During this circuit [redacted] did not verbally
mention the downwind checks. At **T-4:00** [redacted] was given
control as the ac started the finals turn. At **T-3:20** [redacted] stated
"we can just let the height come down to about two-fifty...and we'll land about Exhibit3/4
three quarters of the way down the runway. And this should be our last landing".
[redacted] continued to talk [redacted] through the finals
turn and the jet-borne plateau associated with an RVL. Between **T-3:08** and **T-**
2:12 [redacted] attempted to talk [redacted] through the Witness 1
approach. Finally at **T-2:00** [redacted] took control to overshoot Exhibit 3/4
confirming with [redacted] that there was not enough runway
remaining to land the ac. On the overshoot [redacted] noted the fuel Exhibit 3/4
indications as 400lbs LHS and 700lbs RHS. On the overshoot there were 2
cautions that illuminated with associated audio cautions, the first at **T-1:56** when
the Master Caution illuminated with an associated Caution. The Air Data Exhibit 3/4
Recorder (ADR) did not indicate which Caution was illuminated. At **T-1:48** the
second Caution illuminated during the overshoot and this time there was no Master
Caution. The final circuit only took 2 minutes to complete compared to the
previous 2 circuits that had taken between 3 and 3 $^{1}/_{2}$ minutes. The ac was
positioned downwind for 5 seconds before the finals turn was started. Once again
there was no verbal confirmation that the downwind checks had been carried out. Exhibit 3/4
During the finals turn at **T-00:52** [redacted] stated "My toes are clear,
four wheels Auto Flap...STO Flap rather, we got water....gear down two-four to Exhibit 3/4
land RVL." The finals turn was tight with the AOB remaining more than 45°
throughout the turn until the ac was rolled out on the final approach at 300'agl. Exhibit 3/4
From **T-0:28** to **T-0:08** [redacted] continued to talk to [redacted] Witness 1
[redacted] about how the final stages of the RVL are flown. At **T-0:08** [redacted]
[redacted] had established the ac on the RVL plateau and was well within Exhibit 3/4
the ac performance margins. He noted an RPM of 100% with water flowing.
During the plateau [redacted] recalled fuel indications of 400lbs LHS Exhibit 3/4
and 500lbs RHS. At **T-0:06** a Master Caution illumination and audio activated.
The ADR does not record the Caution and [redacted] did not recall it.
At **T-0:05** [redacted] said, "fine, that's flashing". When the Master
Caution sounded the engine RPM was 101% with a fuel flow of about 210lbs/min.
The ac was at a height of 200' radalt and a speed of 79kts. It was configured gear Exhibit 3/4
down with 74° of nozzle and 62° of flap. At **T-0:05** the fuel flow started to drop
and was decreasing through 150lbs/min, but all other parameters remained
unchanged. The engine RPM started to drop at **T-0:03** and this was coincident

with the throttle being advanced to a full-power position. At this point the fuel flow was decreasing through 80lbs/min. The ac height had begun to reduce slowly. At **T-0:02** the RPM reduced to 68% and fuel flow was 63 lbs/min. The ac attitude started to pitch nose down rapidly and the height reduced by 32'. The nozzles rapidly advanced from 75° to 9° and the flaps scheduled from 62° to 25° during the same period in accordance with the normal STOL Flap logic. With the ac pitching nose down and with the sound of the engine winding down, [redacted] Sect 40- Flt Lt E initiated ejection at **T+0:00**. The fuel flow reduced further to approximately 31 lbs/min. At **T+0:01** the RPM picked-up to 79% with a fuel flow of 60 lbs/min. The ac had, by this time, pitched to an attitude 19° below that for the approach and had started to roll left. At **T+0:02** the ac impacted the runway with a pitch attitude 44° below that for landing and 10° of left bank. The ejection sequence was successful for both pilots. Exhibit 3/4 Witness 1 Annex G Exhibit 3/4 Annex G

11. The Board concluded that:

a. The flight was not properly authorised. Exhibit 1

b. The flight was not adequately briefed. Witness 1 & 3

c. [redacted] Redacted Sect 40- Flt LT E and Sqn Ldr F were competent to undertake the flight. Witness 2

d. ZH654 was serviceable to undertake the flight. Exhibit 15

e. The weather was suitable for the flight. Annex L

DEGREE OF INJURY

12. The Board finds that:

a. Service Personnel. [redacted] Redacted Sect 40- Flt Lt E and Sqn Ldr F and Sect 44 Witness 14

b. Civilian Personnel. There were no injuries to any civilian personnel.

WHETHER SERVICE PERSONNEL WERE ON DUTY

13. [redacted] Redacted Sect 40- Flt Lt E and Sqn Ldr F were both on duty at the time of the accident. Witness 1 & 3

AC ESCAPE FACILITIES

14. This was the first Harrier T10 command ejection. The ejection sequence was initiated by the front seat pilot within seat parameters and both seats performed satisfactorily. After seat separation and automatic PSP lowering had occurred, both pilots attempted to steer clear of the burning wreckage. In the event, the light wind that prevailed at the time of the accident drifted both pilots clear of the ac. Both pilots [redacted] Redacted Sect 40- Sqn Ldr F and Sect 44 Annex G

DAMAGE TO AC, PUBLIC AND CIVILIAN PROPERTY

15. Ac. ZH654 suffered Category 5 damage. Annex D

16. Public Property. There was no damage to public property other than to the role equipment of the ac. Annex D

17. Civilian Property. There was no damage to civilian property. Annex D

LOSS OF, DAMAGE TO, CLASSIFIED MATERIAL

18. Although damage was incurred to classified material as a result of the accident to ZH654, there was no loss and the Aircraft Recovery and Transport Flight (ARTF) recovered it all. Annex D

DIAGNOSIS OF CAUSES

19. Full and informative statements from [redacted] were available to the board, in addition to statements from [redacted] and eyewitness evidence. The Harrier T10 ac has an excellent ADR system which records cockpit voice communications and most cockpit instruments and warning lights over a 2 hr period. The ADR, once processed, can be loaded onto a computer or lap top, for replaying a sortie in real time with a graphical display of flight and engine instruments. Although the ac caught fire after impact with the ground, the engine was sufficiently intact to allow an effective technical investigation to take place. Witness 1 & 3 Exhibit 3/4

AVAILABLE EVIDENCE

20. To assist the Board in their deliberations, they had available the following:

a. [redacted] Statement. Witness 1

b. [redacted] Statement. Witness 3

c. [redacted] Statement. Witness 2

d. Eye Witness Statements. Witness 5 & 9

e. The wreckage of the ac. Annex D

f. The ADR. Exhibit 3/4

g. Ac Accident Investigation Branch (AAIB) Report. Annex H

h. Rolls Royce Report. Annex F

i. Accident Investigation Centre of Aviation Medicine Report. Annex G

j.	DERA Ac Release (DAR).	Exhibit 12
k.	Extracts from AT & E Boscombe Down Flying Order Book (FOB).	Exhibit 10
l.	Extracts from Director of Flying Instructions (DFIs).	Exhibit 11
m.	Medical Report.	Witness 14
n.	PARKER-HANNIFIN Engineering Report on Capacitors.	Annex K
o.	A Human Factors Report from [redacted]	Annex I
p.	[redacted] Ground School Essential Knowledge Quiz Results.	Exhibit 14
q.	ARTF Report on Crash site, Wreckage Removal and Hazards.	Annex D
r.	Extracts from Ac F700.	Exhibit 15
s.	Performance & Flying Qualities (P & FQ) Section, Boscombe Down Report on the Effect of Nozzle Movement.	Annex J
t.	RAF Wittering Avionics Flight Report.	Annex C
u.	Information Reports and Documentation Maintenance Data System Report for Task 9073HARFUEL.	Annex P

FACTORS CONSIDERED BY THE BOARD

21. The Board considered that the following factors might have had a bearing on the accident:

a. TP Training.

b. Pilot Currency.

c. Ac Serviceability

d. Weather, including wind and visibility.

e. Pressure on Sortie.

f. Engine Failure at a Critical Stage of Flight.

g. [redacted] Fuel System Management.

h. Fuel Gauge Errors

i. [redacted] Airmanship Decisions.

j. L/RFUEL Cautions.

k. Reasons for Nozzle Movement.

l. Implications of Nozzle Movement

DISCUSSION OF FACTORS

22. TP Training. The Board considered whether the TP Course had prepared [redacted] sufficiently for the sortie that he flew on 24 Aug 00 [redacted] Witness 1 Witness 3 The Board believe that both Schools have similar courses although different ac types are flown. TP School starts with 5 weeks of ground school followed by a mix of ground school and flying before concluding with an extensive flying phase. Included in the ground school phase is an in-depth look at general aviation safety, trials risk assessment and trials discipline. Early in the training students are introduced to many ac types over a short period of time. This makes them aware Witness 19 of the demands of a TP and assesses their potential. Generic essential knowledge on ac systems is briefed before applying that knowledge to specific ac types. Students are trained to be cautious as they fly many different ac types and they are encouraged to use FRCs and knee-board aides to help remember ac checks and Witness 19 limits. The students are briefed to be extra vigilant when flying ac types that they are more familiar with as they are unlikely to be as current as they may previously have been on these types. During the course students will often fly with other students on dedicated CT sorties and are in the habit of demonstrating and practising flying events that they have seen and briefed. During some assessments students are given tasks that are impossible to complete in the allotted time or fuel that is available and they are assessed on their safety management of the sortie. Finally, a main lesson from the TP schools is to land if there are any doubts as to Witness 20 the serviceability of the ac. The Board concluded that [redacted] had been sufficiently trained to carry out the CT sortie whilst flying the ac in a safe manner and his TP training was not a factor.

23. Pilot Currency. DFIs have the requirement for pilots to achieve an overall-flying rate of 144 hrs per year. This equates to 3 hrs in the last 7 days or 12 hrs in Exhibit 11 the last 30 days. [redacted] had flown 629 hrs total in Harrier ac. He had flown 24 hrs on the Harrier GR7 and T10 ac in the last 30 days of which 10 Witness 1 hrs were in the T10. On 23 Aug, [redacted] had flown 2 sorties as front seat captain in the VAAC Harrier. The VAAC Harrier has a conventional T4 front cockpit and a non-standard rear cockpit, configured for trials and Witness 2 development work. [redacted] had a current Instrument Rating Test. He had completed 6 simulator sorties as a part of his OCU Refresher Course [redacted] Exhibit 5 and a further 2 simulator sorties in Jul and Aug 00. The Board was able to Exhibit 6 discount Pilot Currency as a factor in the accident.

24. Ac Serviceability. During the 24hrs prior to the crash sortie, ZH654 flew 3 sorties with no unserviceabilities raised in the F707A. All flight servicings were Exhibit 15 correctly recorded, there were no significant Limitations or Acceptable Deferred Faults and the F700 had been completed and signed up correctly. However, the

Board identified a clerical error in the F705 entry for the refuel undertaken before the last sortie. Normally, the "Total Put In " entry is calculated from the "Fuel Remaining" and "Total in Ac" entries in the F705, which are taken from the Fuel Quantity Indicator Panel (FQIP) in the ac cockpit. Prior to the last sortie, the "Total in ac" was 11200lbs and the "Fuel remaining" from the previous sortie read 600lbs in the left and 1200lbs in the right. The "Total Put in" entry was incorrectly calculated and read 10400 lbs instead of 9400lbs (11200 subtract (600+1200)). The Board believe that [redacted] the Line Technician responsible for completing the F705, correctly transferred the "Total in Ac" and "After Refuel" entries from the FQIP to the F705. [redacted] had a thorough technique for recording ac fuel states and transferring the figures to the F700. The Board assumed that the FQIP readings for total, left and right fuel were as per the F705 and the figure in the "Total Put in" entry can be dismissed as incorrect. The Board therefore concluded that ZH654 was serviceable and the F700 had been signed for the ac having been refuelled and correctly flight serviced. Witness 6 Witness 6 Exhibit 15

25. Weather, Wind and Visibility. At the time of the accident, the airfield colour state was blue. The surface wind was 050/08 knots, the sky was clear and the visibility was 18 Kms. The outside air temperature was +26 degrees C. The weather was more than adequate for all events in the sortie to be completed satisfactorily and there were no meteorological factors that could have affected the accident. The Board concluded that weather was not a factor. Annex L

26. Pressure on Sortie. The Board considered whether there was pressure on either the content or the timing of the sortie that might have contributed to the accident. The sortie was planned as a CT sortie for [redacted] with a take-off at 1530 hrs. Originally, the Sqn Navigator was due to fill the back seat but the programme was changed to put [redacted] in the back seat as a good opportunity to expose him to Harrier handling characteristics that he had not previously witnessed. [redacted] spent the morning at a meeting with trials officers from 0845 hrs until 1030 hrs; following that he spent the rest of the morning "doing paperwork". [redacted] went home at 1200 hrs for lunch, attended to a minor domestic matter and returned to the Sqn after 1400 hrs. On return, he dealt with more paperwork, checked the NOTAMS for the low-level section of his sortie and met up with [redacted] at 1430 hrs. As a CT sortie for his benefit, the sortie content was up to [redacted] discretion. ZH654 was only scheduled to fly the one trip that afternoon and there were no aircrew or engineering reasons for landing at a fixed time. The airfield was remaining open until 2000 hrs. Strapping [redacted] into the rear cockpit was delayed by another Harrier engine running next to ZH654. [redacted] recollects delaying his low-level booking to reflect his delayed take-off that occurred at 1547 hrs. The Board concluded that there was no pressure on either the content or the timing of the sortie that could have contributed to the accident. Witness 2 Witness 3 Witness 1 Witness 1 Exhibit 19 Witness 1

27. Engine Failure at Critical Stage of Flight. From the ADR, it was discovered that a decay in the Fuel Flow led the engine rundown by around 2 – 4 secs and that prior to the fuel flow reduction, the engine performance was consistent with normal engine operation. From these 2 facts, a LOPEC, surge, mechanical failure and birdstrike were all dismissed as possible causes of the Annex F Exhibit 3/4 Annex F

engine run down. Further, following the satisfactory results from some fuel samples, and given that the ac flew for 1 hour and 13 minutes prior to the accident without any fuel-related problems, fuel contamination was also discounted. The Board concluded that the run down was caused by an interruption in the engine fuel supply from the aircraft, upstream of the fuel flow meter. The following scenarios were considered: Exhibit 13

a. Mechanical Failure of the Fuel Metering Unit. A mechanical failure of the Fuel Metering Unit would result in a simultaneous reduction in the fuel flow and engine speed. The Board discounted this option. Annex H

b. Trapped Fuel. The board considered whether trapped or blocked fuel might have caused the engine to wind down prematurely. Trapped fuel within a Harrier ac would normally involve a transfer fault, which would, in turn, result in an R/LTRANS Caution, accompanied by the Master Caution and a Caution Audio Tone. There is no evidence that a Transfer Caution occurred during the sortie. Furthermore, historically, there is little evidence of fuel transfer faults on the Harrier ac and the few that have occurred were connected with the external tanks. In this case, the external tanks were known to be indicating empty. Finally, the ADR fuel consumption figures for ZH654 show that all the fuel during the accident sortie can be accounted for. The Board therefore discounted blocked or trapped fuel as a contributory factor. Annex H / Exhibit 3/4 / Witness 1 / Annex H

c. Fuel Starvation. Through the integration of the Fuel Flow figures, recorded on the ADR, the board was able to obtain fuel consumption figures for the entire the sortie. These figures were then subject to detailed analysis both by the Board and the AAIB, and all fuel could be accounted for. Calculations showed that 10460lbs of fuel were consumed during the sortie and we know that approximately 400lbs were shut off in the left hand side at the time of impact. From these facts, it can be seen that 10860lbs of fuel can be accounted for as either consumed or unavailable. Given that the book capacity of the T10 (using the AP101B-0610-1A, recommended as the most accurate by BAES) is 10926lbs (assuming 7.9lbs/gal) the board concluded that the engine ran down due to fuel starvation brought on by the consumption of all available fuel. Annex H / Annex H / Witness 1 / Exhibit 16

28. [redacted] Fuel System Management. The Board examined all of [redacted] actions in the circuit and all cockpit indications in relation to the fuel system. Although it was not a requirement to state the checks verbally, the few checks that were recorded on the ADR voice were irregular and incomplete. They did not always include fuel checks and they occurred at different points in the circuit pattern. Exhibit 4

a. Illumination of the Silent LFUEL Caution. After the 2nd circuit, [redacted] noted fuel indications of 750lbs LHS, 1800lbs RHS. Although this imbalance of 1050lbs was 600lbs higher than the normal of 450lbs, it was not discussed. The LFUEL Caution illuminated, indicating 750lbs useable fuel in the LHS fuel system, this was 84 secs after [redacted] had noted the fuel. During this time, fuel Exhibit 4 / Exhibit 3/4

usage was a total of 145lbs; 73lbs per side from the LHS and RHS fuel tanks. As the LHS and RHS fuel quantity indications were only accurate to within 50lbs, it was assessed that the LHS fuel quantity indication was probably correct for this, and subsequent, circuits. When the silent LFUEL Caution illuminated, [redacted] did not see it. — Annex H, Witness 1

b. Decision to Select RFEED Manually. Upwind for the 5th circuit [redacted] was flying the ac. He decided to manually select the Fuel Proportioner switch from AUTO to RFEED and stated "I'm gonna manually select the right feed 'cos it should've, erm, it should've fed by now, I don't know why it hasn't. OK, and I'm waiting for a right feed caution." In fact, the automatic RFEED should not have operated as there was still 400lbs of fuel remaining in the left-hand fuel group. The 400lbs in the LHS remained isolated until the accident. Twenty seconds later, the RFEED Warning illuminated with the associated audio warning, which advised him of the incorrect operation of the RFEED system. [redacted] noted the RFEED Warning, but took no action. In his statement [redacted] later mentioned that he selected RFEED because of the higher than usual fuel imbalance. However, although this action would correct an unusual imbalance it is not the recommended action as per the FRCs or the Aircrew Manual. Later when [redacted] questioned [redacted] as to whether the fuel in the RHS was feeding [redacted] confirmed it was and commented "and, anyway, one side can run dry, it doesn't matter". If one side were to run dry the fuel proportioner would be aerated and the engine would flame out. However if the fuel proportioner were selected OFF it would be possible to run one side dry without the engine flaming out. — Witness 1, Exhibit 4, Exhibit 3/4, Witness 1, Exhibit 16, Exhibit 4

c. Illumination of the Silent RFUEL Caution. T-5:24 was at the start of the 6th circuit. The silent RFUEL Caution illuminated which indicated that there was a total of 750lbs of fuel remaining in the RHS, [redacted] did not see the caution. The Board believe that he did not see this caution illuminate because he was flying the ac carrying out a roller landing. Sixteen seconds after the illumination of the silent RFUEL Caution [redacted] stated "four hundred, a thousand, fifteen hundred...". If this fuel check had been cross-referred with the RFUEL Caution it would have indicated that there was either trapped fuel in the right hand fuel group or that there was an indication problem with the FQIP. However, the RFUEL Caution was not noticed until the last circuit. Between the RFUEL illuminating and the accident, the fuel usage was 750lbs. — Exhibit 3/4, Exhibit 3/4, Exhibit 4, Annex H

d. Decision to Land from First RVL. During the 6th circuit [redacted] decided to land and to let [redacted] fly the final circuit. The Board believed that the low fuel state was a factor in the decision to land off that circuit. [redacted] briefed [redacted] on how to fly an RVL, whilst flying downwind, and did not verbally mention the fuel. Even though the aim was to land, [redacted] allowed [redacted] to continue with the approach until they reached a point where it was not possible to achieve a — Witness 1, Witness 1, Exhibit 3/4

safe landing. [redacted] took control for the overshoot into the last circuit and noted the fuel as "four hundred, seven hundred, that's fine". Disregarding a fuel indication problem, a total of 1100lbs fuel remaining on the overshoot committed [redacted] to land below his planned minimum fuel regardless of the type of last circuit. Although aware of his indicated fuel state, [redacted] still decided to perform another RVL, which is a high fuel consumption circuit. Witness 1 Exhibit 4 Witness 1

e. Flashing RFUEL. During the overshoot into the last circuit, there were 2 cautions with associated audio warnings, both of which were not commented on by [redacted] The first was at **T-1:56** when the Master Caution illuminated with an associated caution and audio. The ADR did not indicate which caution illuminated. However, at that time the Jet Pipe Temperature (JPT) was reading more than 710 ± 3°C and this temperature would have illuminated the steady 15 Sec Caution with Master Caution and associated audio. At **T-1:48** the second caution, during the overshoot, illuminated with an associated audio of under one second duration and there was no Master Caution light. This caution was either the Bingo light or flashing RFUEL Caution. However, the BINGO audio would have continued to sound until the BINGO total was altered and the flashing RFUEL Caution audio would have automatically stopped after less than one second. The caution audio on the ADR stopped after just under one second. If [redacted] had decided to set his BINGO total to just above his desired minimum landing fuel of 1000lbs the BINGO audio would have sounded at the correct time. However, it is unlikely that, while overshooting, [redacted] would have been able to react to the audio and twist the BINGO total knob quick enough to stop the audio from repeating. [redacted] does not remember altering the BINGO total knob during the overshoot. After the accident, the BINGO total on the front cockpit FQIP was set to between 400-500lbs. This setting would have been appropriate if [redacted] had decided not to use the BINGO total for this stage of the sortie and had instead decided to set it to a total that he was not planning to reach, this would also prevent the audio caution from sounding. From the second caution during the overshoot until the accident it was calculated that 248lbs of fuel were used. From the steady RFUEL Caution illuminating at 750lbs to the point where the second caution illuminated, 500lbs of fuel was used and from the steady RFUEL to the accident, 750lbs of fuel was used fuel. The Board concluded that the second caution was a flashing RFUEL and that it was flashing for the remainder of the sortie. Exhibit 4 Exhibit 3/4 Exhibit 3/4 Witness 1 Annex D Annex H

f. Fuel Observations During the Last Circuit. On the last circuit there was no verbal mention of fuel. However, when describing the final approach, [redacted] later stated "Also at this point I checked the fuel and noted 400lbs LHS and 500lbs RHS and with RFEED still selected and noted that I would land slightly less than my desired 1000lbs. Both BINGO lights were illuminated steady". The BINGO lights were a reference to L/RFUEL Caution lights and [redacted] would have expected them to be steady with a fuel state of 400lbs LHS and 500lbs RHS. The Board believes that the RFUEL was flashing at this Witness 1

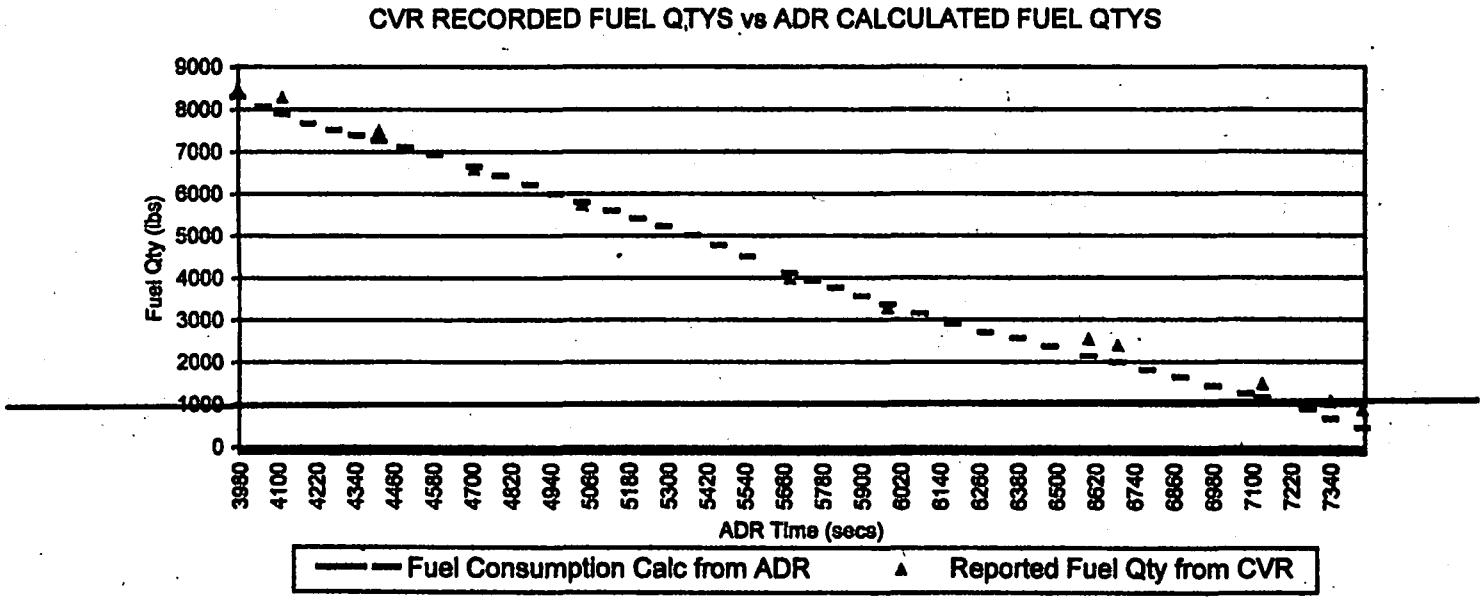
stage. On the overshoot into the last circuit 2 cautions illuminated, one of which could only have been a BINGO light or the flashing RFUEL. The probability was that the caution was a flashing RFUEL because of the associated audio that sounded with the caution. The right hand group 250lb thermistor, that senses when there is 250lbs of fuel remaining in the right hand centre tank, was serviceable post crash and the Board have no reason to doubt the serviceability of the fuel caution lights. Exhibit 4 Annex C

g. Cautions in Final Moments of Sortie. At **T-0:06** a Master Caution illuminated and an audio was activated. The ADR did not record the caution and [redacted] did not recall it. The caution could have been either an H_2O Priority Caution or an RPUMP. An H_2O Priority Caution would illuminate when there is approximately 15 secs (8.3 gallons) or less of water remaining. However, there was approximately 13 gallons of water remaining when the caution illuminated. The Board believes that the caution was associated with an RPUMP Caution. The RPUMP Caution would illuminate if the right hand fuel booster pump pressure fell below 8 PSI. At the point when the Master Caution illuminated, at **T-0:06**, the fuel flow was above 210lbs/min which would suggest that the fuel pressure would have been above 8 PSI. However, the ADR feed for the booster pump was up stream of the fuel proportioner in the centre tank whereas the ADR feed for the fuel flow was downstream of the fuel proportioner in the fuel transmitter. Therefore, the booster pump PSI would fall before the ADR indicated a drop in fuel flow. The Board believe that when [redacted] attention was drawn to the Master Caution, he probably then noticed the flashing RFUEL, which the Board believe had been flashing for that entire circuit. At **T-0:05** [redacted] said, "fine, that's flashing", which would have been a reasonable comment if he had thought that the RFUEL had just started to flash as he would now have had 250lbs of fuel remaining in the RHS with which to land. It would have been a strange comment to make about the Master Caution light, which was the only other light that could have been flashing at that point. Exhibit 4 Exhibit 3/4 Exhibit 4

The Board believes that throughout the circuit phase the fuel checks were sporadic. The Harrier T10 automatic crossfeed system had been overridden either because of a higher than expected imbalance or because [redacted] felt that the automatics should have started feeding from the RHS only. In either situation and with 400lbs of fuel remaining in the LHS the FRCs and Aircrew Manual recommends different actions to those that were carried out during this sortie. Comments between the 2 pilots led the Board to conclude that [redacted] understanding of the Harrier T10 crossfeed system was limited. [redacted] did not notice the illumination of the L and RFUEL steady Cautions. The illumination of the RFUEL steady Caution was the first indication of trapped fuel or an over-reading indication problem. The Board believes that the flashing RFUEL Caution worked as designed and was flashing from the overshoot into the last circuit but, as with the other fuel warnings, was not noticed by [redacted] The Board concluded that [redacted] premature selection of RFEED and his inattention to the fuel warning lights exacerbated by poor checks in the circuit were all contributory factors in this accident. Exhibit 4 Witness 1 Exhibit 16 Exhibit 3/4 Witness 1 Exhibit 3/4 Witness 1

29. Fuel Gauge Errors. At T-5:24 the silent 750lb RFUEL caption illuminated. Sixteen seconds later, [redacted] was recorded as noting a FQIP reading of 1000lbs on the right hand side. This apparent discrepancy in fuel quantities led the board to investigate the possibility of a fuel system over-read fault. The final position of the FQIP dials suggested that there were 400lbs remaining in the left system and 400lbs remaining in the right. Investigation by the AAIB revealed some bruising and indentations on the dials, which supported this prognosis. This was contrary to the evidence of the ADR fuel consumption calculations, which proved that all fuel in the right hand system had been consumed. More evidence of a gauging error was found by comparing the FQIP readings that were spoken out loud by the aircrew and recorded on the CVR, with the fuel remaining as calculated from the ADR. During the 10mins 20secs of the period T-24:18 to T-13:58 (5980secs - 6600secs ADR time), the indicated fuel values on the FQIP reduced by 750lbs, whilst the fuel consumption calculated from the ADR fuel flow figures was 1231lbs. At all other times of the sortie, there is a close correlation between the FQIP fuel figures and the ADR fuel consumption figures. This period of flight incorporated the end of the VIFF and an over-stress, the recovery and some circuits and as a result, the reduction in the FQIP reading is considered insufficient to provide an accurate calculation of consumption. From the graph below, the difference in fuel quantities is clearly the result of a step increase in the fuel indicated, which remains consistent until the end of the sortie.

Witness 1
Exhibit 4
Annex E
Annex H
Exhibit 3/4



Also, from the above graph, it can be seen that there is another over-read between the times 3980 secs and 4430 secs. This may be an earlier occurrence of the fault, although an alternative theory can be derived by examining the BAES accuracy figures for the Harrier fuel system:

Total Fuel Quantity	System Accuracy
5000lbs	+300lbs, -100lbs

3000lbs	+200lbs, -200lbs
500lbs	+0lbs, -200lbs

From the table above, with greater fuel loads on board, the Harrier fuel system is biased towards over-reading, and as the fuel quantity reduces this bias decreases before becoming a bias towards under-reading with smaller amounts of fuel on board. This trend mirrors what can be seen in the "Reported Fuel Qty from CVR" line in the above graph, between 3980 secs and 6060 secs, and may account for (some of) the earlier over-read. Regardless of the cause of the early over-read, it is the conclusion of the Board that between the period T-24:18 to T-13:58 a fault occurred in the fuel indication system causing it to over-read on the RHS by around 400lbs until the end of the sortie. The Board concluded that fuel guage error was a contributory factor in the accident.

INVESTIGATION INTO OVER-READ FAULT

30. The board investigated the fault modes that would cause the fuel indication system to indicate a consistent over-read. In discussion with BAES, the 2 most likely fault scenarios were examined.

a. Pre Mod KT 486 Fuel Quantity Processor (FQP). The FQPs were prone to an internal fault, which then led to a 400lbs over-read. During discussion with BAES, it was learnt that mod KT 486 was brought in to eliminate the problem. The FQP was removed from ZH654 and found to be pre-mod KT486. It was then sent for testing at 2nd Line, RAF Wittering and found serviceable, barring a transient fault in the Bingo wiring. The board concluded that a fault within the FQP was not a factor in the crash. Annex C

b. Fuel Quantity Transmitters (FQT). The FQTs comprise of 2 capacitors, in a capacitor/diode bridge circuit. One capacitor consists of 2 concentric tubes, one within the other, between which fuel can rise and fall, according to the level of fuel in the tank. The other capacitor is a reference capacitor which equals the capacitance of the tank-based capacitor when empty (full of air). An alternating current is applied across the bridge circuit which, because of the orientation of the diodes, applies the negative half of the alternating current to the tank unit and the positive half to the reference capacitor. The fuel level is detected through the change in capacitance of the tank unit as the fuel level rises and falls. These changes are transformed into a meaningful output through the comparison of the negative and positive voltages at the output. It can be shown that an open circuit of the reference capacitor will produce a step input in the FQIP display. Annex H

(1) When empty, the tank capacitance (C_{Tank}) equals the reference capacitance (C_{Ref}) and so the difference between the positive and negative voltages equals zero.

(2) When full, C_{Tank} is twice that of C_{Ref}. Therefore the negative voltage (across the tank unit) is greater than the reference voltage by an amount equal to the reference output.

(3) Should the reference capacitor be open circuited, then the reference capacitance is zero. Therefore, the difference between C_{Tank} and C_{Ref} is increased by C_{Ref}. This will have the effect of increasing the reading for the tank in question by an amount equivalent to the tanks capacity.

All right hand side Fuel Quantity Transmitters were also sent to 2nd Line for testing, although only the feeder (308lbs), front external (361lbs) and rear external (454lbs) tanks had capacities approximating 400lbs. Only 2 FQTs could be tested and both were found out of limits. Only one was of interest, having a capacity of 308lbs, and that was the feeder tank FQT. Neither had an open circuit within the reference line. The remaining FQTs were too badly damaged to be tested at 2nd line. Of the thermistors attached to the FQTs, the centre tank and right wing tank thermistors were serviceable whilst the rear tank thermistor was too badly burnt. All FQTs and the FQP were sent to Parker-Hannifin, the manufacturer, for further testing. Further investigation into the fuel system and its fault history was carried out. ES(Air) Information, Reports and Documentation were requested to assist, as were the RAF Wittering Tank Bay. The Maintenance Data System report from ES(Air) consisted of a data base containing all Harrier Fuel System Faults recorded since 95. Of the 6352 entries, 124 were system over-reads and a further 241 entries related to incorrect readings and fluctuations. Of these entries, 104 were traced to the External Fuel Tank and 76 to the airframe Fuel Transmitters. During discussion with the bay, it was learnt that the most likely source of faults came from the front and rear Fuel Transmitters. Annex C Annex C Annex H

31. [redacted] Airmanship Decisions. After the 5th circuit and approximately 15 secs after the silent RFUEL caption came on steady, indicating 750lbs remaining on the RHS, [redacted] noted the fuel indications as 400lbs LHS, 1000lbs RHS and 1400lbs total. Although this was the first opportunity for [redacted] to establish that he had an over-reading fuel indication on the RHS, he did not notice the RFUEL caution and continued to rely on the gauged indications. Contrary to his authorisation, [redacted] then elected to allow [redacted] to fly an RVL without a demonstration. [redacted] has stated, correctly, that an RVL circuit and landing took approximately 400lbs of fuel (whereas an AFSL and SFSL take at least 200lbs and 300lbs respectively), and planned this circuit to culminate in the final landing. He was concerned that he had had to select RFEED to 'redress the fuel imbalance' and landing off the first RVL would have satisfied his minimum fuel on landing of 1000lbs. Having flown the ac downwind, he gave control to [redacted] at the end of the downwind leg and attempted to "talk him through" an RVL to land. The cockpit workload was high for both [redacted] and [redacted] and the approach that resulted was 'poorly flown'. Normal practice for an RVL landing on a main runway from a 50kt plateau is to aim to touch down ⅓ to ½ the way down the runway. During the finals turn, [redacted] advised [redacted] to aim to land about ¾ of the way down the runway. This further reduced the margin for error available to [redacted] However, [redacted] allowed the approach to continue to a point where he considered that a landing was not possible and took control for the overshoot. [redacted] was Exhibit 3 Witness 1 Witness 2 Exhibit 4 Exhibit 4

convinced that in spite of going below his stated minimum landing fuel, he still had sufficient fuel to demonstrate an RVL circuit to [redacted]. Although [redacted] statement was understandably confused on fuel indications, ADR voice recorded [redacted] as noting his fuel indications as 400lbs LHS and 700lbs RHS on overshoot. Surprisingly, given his concerns about the fuel system, he elected to carry out the least fuel-efficient circuit in the Harrier. When he was subsequently established on the jet borne plateau, prior to the 2nd RVL landing attempt, he recalled seeing 400lbs LHS and 500lbs RHS, which was the last fuel indications [redacted] noted. In failing to take control in sufficient time to land the ac above his planned minimum fuel for landing and, in electing to make his final circuit an RVL, the Board concluded that [redacted] poor airmanship decisions were a contributory factor in the accident. Witness 1 Exhibit 3 Witness 1

32. L/RFUEL Cautions. The L/RFUEL Caution lights are positioned just below the Master Caution light on the Master Caution and Priority Caution Lights Panel to the LHS of the Up Front Controller. When the fuel remaining in the L/RHS reaches 750lbs the respective L/RFUEL Caution light comes on steady with no audio. When the fuel remaining in the L/RHS centre tank reaches 250lbs the respective L/RFUEL Caution light starts to flash continuously. This is accompanied by an audio that lasts just under a second. As with the majority of other cautions in the Harrier the L/RFUEL Cautions are coloured green to make them NVG compatible. Neither the 750lb nor 250lb L/RFUEL Cautions cause the Master Caution light to flash. The silent and steady L/RFUEL Cautions are the first chance that the pilot has to confirm that the FQIP agrees with the warning lights. The flashing L/RFUEL Cautions tell the pilot that there are only 250lbs of fuel remaining in the L/RHS. If the other side were isolated then this fuel could equate to about one minute of flying time remaining during high fuel consumption manoeuvres, such as RVLs. When the L/RFUEL flashes the pilot needs to take action. The pilot's action should be to land immediately, turn off the Fuel Proportioner or to carry out an emergency procedure. Although the L/RFUEL starts flashing continuously at 250lbs, the audio is over in just under a second. Both the, steady and the flashing L/RFUEL are important cautions that require a pilot reaction. The Board concluded the L/RFUEL steady and flashing cautions were too inconspicuous to attract the pilot's attention during a high workload phase of the sortie and were, therefore, a contributory factor to the accident. Exhibit 16

33. Reason for Nozzle Movement. Five seconds before [redacted] initiated command ejection, the ac was at 200 feet radalt and at a speed of 79 knots. It was configured gear down with 74 degrees of nozzle and 62 degrees of flap. At this point, the fuel flow started to decrease rapidly, 2 secs later the engine RPM started to drop and the throttle was advanced to the full power position. At some point in the next 2 seconds, the nozzles moved from 74 degrees to 9 degrees. The Board and the AAIB examined the sequence of events just prior to and post ejection initiation, with particular emphasis on the nozzle movement. The ADR does not record the point of ejection and ADR sampling rates together with the associated limitations on synchronising the CVR with the ADR make precise timings impossible. Commensurate with the nozzle movement the flaps automatically scheduled up to 25 degrees and the nose of the ac naturally pitched down. [redacted] had no recollection of moving the nozzles, but he Exhibit 3 Witness 1

clearly recalled the aircraft pitching nose down to his ejection. The board considered the implications of inadvertent nozzle movement prior to ejection and asked the P&FQ section of the CAD at Boscombe Down to investigate. The Board believes that the correct interaction of nozzles and flaps discounts any mechanical failure of the nozzle system. Therefore, the nozzles could only move if a selection occurred from either cockpit. Prior to the nozzles moving the throttle was advanced from 100 % to full power of 108%. This throttle movement was comparatively small relative to the large movement of the adjacent nozzle lever, which would have been required to change the nozzle angle from 74 degrees to 9 degrees. This would discount the possibility of the nozzle lever accidentally catching on flying clothing. The nose down pitch, caused by the flaps scheduling up, would account for [redacted] perception of pitch prior to ejection. However, AAIB analysis identifies the ejection from ADR data on stick movement and suggests that nozzle movement occurred after ejection as a result of disturbances in the cockpit. Although there is no historical evidence that this has occurred before, it would explain why [redacted] had no recollection of moving the nozzles. The nose down pitch he experienced could have been a combination of the increase in negative vertical acceleration (sink rate), recorded on the ADR, and the lack of response from the front puffer. The rearward stick movement, believed by the AAIB to be the last stick input from the captain before releasing the controls prior to ejection, would demand more bleed air from the engine to the front puffers in an attempt to raise the nose. However, by now the engine was rapidly winding down, and the reducing output from the front puffer would have resulted in a nose down pitch. Therefore, the Board and the AAIB cannot determine the exact sequence of events surrounding the ejection or the cause of the nozzle movement. However, the Board believes that the flaps scheduling up following the nozzle movement aft contributed to the nose down pitch angle of 44 degrees at impact.

Annex J
Exhibit 3
Witness 1
Witness 1
Annex H
Annex H

34. Implications of Nozzle Movement. At the latter stages of an RVL approach coming off the plateau, approximately two thirds of the required lift is produced from jet thrust and one third from the limited lift produced by the wings at 79 kts. P&FQ calculated that the rapid reduction in engine thrust that resulted from the reduction in rpm was sufficient to cause the aircraft to descend rapidly, regardless of the position of the nozzles. Furthermore, the scheduling up of the flaps would have reduced the amount of lift produced by the wing. However, if the flaps had remained down, the slightly reduced vertical velocity at impact that would have resulted would not have been sufficient to prevent the destruction of the aircraft through impact with the runway and subsequent fire damage. Therefore, the Board concluded that the movement of the nozzles aft, for whatever reason, was not a factor in the accident.

Witness 1
Annex J
Witness 18
Annex J

CONSIDERATION OF HUMAN FACTORS

35. Planning and Briefing. [redacted] arrived back on the Sqn after lunch at 1400 hrs and he was aware that [redacted] was to be the rear seat passenger. [redacted] decided to continue with his paperwork and did not carry out any preparation for the sortie until he met up with [redacted]. However, [redacted] had flown an identical sortie profile 13 days earlier with [redacted]. Between 1430 and 1440 hrs

Witness 1

the NOTAMs were checked, using the same map and targets that were used on 11 Aug, and the low level was booked. The brief was approximately 20 minutes long. Witness 3
Prior to the brief [redacted] had been unable to find out any in depth information about the Harrier T10 and [redacted] was aware that this Witness 1
was [redacted]'s first sortie in a Harrier. No illustrations were used to brief [redacted] on what the rear cockpit of the Harrier T10 looked Witness 3
like and no illustrations or explanation was given on how to fly the circuits. A HOTAS illustration was used to brief [redacted] on the TIALD Witness 1
profiles and this formed the predominant part of the briefing. The Harrier Force has been issued with Mission Operating Procedures (MOPs) in the form of FRCs which contain a comprehensive 5 page briefing aide memoire that could have been used to help brief this sortie. Similarly a T10 video exists to help brief pilots unfamiliar with the rear cockpit. MOPs were not used for this sortie and FJTS did Witness 2
not possess a copy of the T10 video. As a result, a number of important items were missed from the briefing. However, the brief did cover some emergencies, peculiarities of the Harrier and the responsibilities of each pilot with reference to low level TIALD Toss manoeuvres, although [redacted] was unsure how much of this was covered. At the end of the brief, [redacted] Witness 3
was aware that he was going to fly the take-off and asked how the take-off was performed. Finally, once in the Ops Room, [redacted] calculated his VSTOL figures on the VSTOL computer by altering the performance figures for the other Harrier T10 ZH653, as there were no performance figures available for Witness 2
ZH654. The Board concluded that the preparation and briefing for the sortie was inadequate because [redacted]'s lack of experience in the Harrier was not taken into consideration. The lack of preparation and the poor briefing Witness 1
meant that [redacted] cockpit workload was going to be greatly increased if, as he intended, he wanted [redacted] to carry out Harrier VSTOL circuits and landings.

36. Distraction. With the knowledge that the briefing on Harrier handling had been very limited, the Board considered the extent to which [redacted] Witness 1
became distracted from flying the ac and managing the systems during the latter Witness 3
stages of the sortie. Although [redacted] was an experienced Harrier pilot and shortly to qualify as a VAAC safety pilot, he had had no training as an instructor, either as a QFI or QWI. [redacted] was described as an enthusiastic pilot who was keen to fly the Harrier, a new experience for him. [redacted] Exhibit 4
[redacted] understood at the outbrief that [redacted] would be flying the take-off, circuits and landings including an RVL. [redacted] Witness1
assured [redacted] that each type of circuit would be demonstrated by [redacted] Exhibit 3
[redacted] before [redacted] was to attempt them. Once in the air the ADR voice recorded a fairly constant dialogue between the 2 pilots discussing Harrier handling and TIALD attacks at medium and low level. When ZH654 joined the circuit, the dialogue exchange increased dramatically. By the 5th circuit, [redacted] elected to allow [redacted] to attempt an RVL, arguably the most difficult Harrier approach, without a demonstration. He was concerned about his RFEED fuel selection and the imbalance and decided that this RVL would be to land. [redacted] had so far flown the ac satisfactorily in the circuit but was now obviously working hard to fly the final circuit. In the descent from the plateau in the final stages of the approach, [redacted] was slow to reduce power to establish the ac onto the required 6

degree approach path to land. [redacted] allowed [redacted] to continue beyond the point at which a safe landing was achievable on the runway remaining and elected to overshoot. Through this high workload phase of the sortie, [redacted] cockpit checks were perfunctory and his airmanship decisions were swayed by his desire to teach [redacted] how to land the Harrier from an RVL. There was no requirement for [redacted] to acquire this skill; indeed, it was an added bonus for [redacted] to get any flying in the Harrier on a CT sortie tasked for [redacted] benefit. The Board believe that the flashing RFUEL warning came on whilst [redacted] was overshooting from the penultimate RVL circuit. At this stage of flight the workload in the cockpit would have been high as he reconfigured the ac for the final circuit. [redacted] noted the fuel from the FQIP, and continued to talk to [redacted] whilst flying the final circuit. The Board concluded that [redacted] allowed himself to become distracted teaching [redacted] Harrier VSTOL circuit and landing techniques to the detriment of the safety of the sortie. Exhibit 4 Exhibit 16 Exhibit 4 Exhibit 3/4

37. Fuel System Knowledge. When [redacted] returned from his TP course [redacted], he carried out a Harrier refresher course at RAF Wittering before proceeding to Boscombe Down. The ground school phase of this course included an Essential Knowledge quiz and [redacted] answers showed lapses in his knowledge of the Harrier Fuel System, particularly the section covering the differences between the GR7 and the T10. During his handling of the perceived fuel imbalance during the sortie on 24 Aug he made a premature selection of RFEED. Furthermore, his comment to [redacted] that with RFEED selected he could safely 'run one side dry' was incorrect with the fuel selections he had made at the time. Finally, if [redacted] had reselected Auto or DL on the proportioner switch at any stage, the remaining 400lbs, isolated in the LH Fuel Group, would have been sufficient to have landed the ac safely, albeit at a low fuel state. Exhibit 16 Exhibit 3 Exhibit 4 Exhibit 16

38. VIFF. The ADR voice and flight instrument recordings have provided a unique insight into events during the sortie prior to the accident and the Board was particularly concerned with the way the ac was flown during the VIFFing phase. In turns and aerobatics, [redacted] demonstrated how the use of the nozzles could enhance turning capability with vectored thrust. Ac Handling notes advise T10 pilots that the α limit for any weight and configuration should be the onset of the Manoeuvre Tone (MT) plus 3 degrees. The MT for ZH654, at that ac weight, came on at 19 degrees giving a maximum α of 22 degrees. During the VIFFing demonstration, [redacted] flew the ac beyond 30 degrees (the limit of the ADR recording range) and claimed that during a loop "it is impossible to avoid the manoeuvre tone, even with the stick fully forward...". [redacted] copied the demonstration not only with a similar high α, but also with sufficient yaw at the slowest point (50kts) over the top of the loop to activate the pedal shaker. The pedal shaker warned the pilot that unless the out of balance yaw force or sideslip was addressed, there was a serious risk of the ac departing out of control. At no time during the VIFFing phase did [redacted] acknowledge that he was deliberately flying the ac beyond the stated limits of the ac. Also, during this phase of the sortie, the ADR recorded an overstress of 6.1g. Although [redacted] was not aware of this, the information was Exhibit 3 Witness 3

available to him in the HUD as he had NAV selected. If 4.5g is exceeded then the maximum acceleration attained is displayed prefixed by MAX G. In this case MAX G 6.1 would have appeared in the HUD with NAV selected. However, as the Video Recording System (VRS) was not selected on, the exact indication registered in the HUD is not known. Witness 3 Exhibit 4

39. Redacted Sect 40- Sqn Ldr F The Board considered the role played by Redacted Sect 40- Sqn Ldr F Redacted Sect 40- Sqn Ldr F was an enthusiastic and able pilot who had, like Redacted Sect 40- Flt Lt E, been a TP for 6 months. Redacted Sect 40- Sqn Ldr F was naturally keen to fly the Harrier on this, his first trip, and was not surprised to be flying the take-off and some of the circuits including landings. In his statement, Redacted Sect 40- Sqn Ldr F was unsure on a number of issues and was not surprisingly confused. He was certainly working hard during the circuits to fly the ac whilst the fuel problems were beginning to unfold. He did ask Redacted Sect 40- Flt Lt E about fuel transfer after Redacted Sect 40- Flt Lt E had selected RFEED manually and had received assurance from the captain that all was well and that the fuel was transferring from the right hand fuel group. Redacted Sect 40- Sqn Ldr F cancelled an audio warning at some stage in the sortie. As he could not recall when or which warning it was or whether he had mentioned it to Redacted Sect 40- Flt Lt E, the Board reasonably concluded that it was one of the oxygen warnings which occur frequently in the Harrier T10. Redacted Sect 40- Sqn Ldr F would not have prejudiced the safety of the sortie by cancelling an oxygen warning. Redacted Sect 40- Sqn Ldr F had no knowledge of the Harrier fuel system and had no reason to question the captain's authority or airmanship decisions. However, as the fuel gauges are replicated in the rear cockpit, he should have been aware that, by not landing off his first attempt at an RVL, they would be going beneath their agreed minimum fuel for landing. However, the Board believe that Redacted Sect 40- Sqn Ldr F could not have been expected to have affected the outcome of the sortie. However, TPs are expected to act as a crewmember, exercising airmanship skills including bringing unusual events to the captain's attention. Witness 3 Witness 19 Witness 2 Witness 19

40. Redacted Sect 40- Wg Cdr G The Board considered the role played by Redacted Sect 40- Wg Cdr G Redacted Sect 40- Wg Cdr G he is permitted to authorise sorties on all aircraft types flown by FJTS. At his own request, he carried out a short Harrier course in Redacted Sect 40 on the OCU at RAF Wittering. From his F5000, he approached this course with a very professional attitude and was cleared to fly the GR7. However, in spite of his strong performance on the course, he was not permitted to carry out vertical take-offs and landings, simply through lack of experience on type. Although he achieved approximately 12 hrs on the course, he has hardly flown the Harrier since and has approximately 15 hrs total on the aircraft. In authorising Redacted Sect 40- Flt Lt E, Redacted Sect 40- Wg Cdr G had considered Redacted Sect 40- Flt Lt E experience as a VAAC safety pilot that gave him "exceptional handling skills". Redacted Sect 40- Wg Cdr G also discussed CofG limits, the restriction on ZH654's hovering ability and wet and dry VSTOL performance figures. Redacted Sect 40- Wg Cdr G perception of the sortie brief was based on the responses from Redacted Sect 40- Flt Lt E during the outbrief and sortie authorisation process. Although he admitted to doubting whether Redacted Sect 40- Sqn Ldr F should fly the take-off, considering the comparatively high AUW of the 2 seat ac, Redacted Sect 40- Sqn Ldr F s lack of Harrier experience and the OAT of +25 degrees. Witness 2 Witness 2

However, he was again persuaded by the answers he received at the outbrief, coupled with [redacted] experience in the VAAC Harrier. His final decision to allow [redacted] to fly circuits and landings was based on the good weather, his belief in [redacted] ability to maintain safety at all times and reassurance from [redacted] that all circuit types would be preceded by a demo. Specialist knowledge from within FJTS and from outside varies as to the wisdom of the decision to allow [redacted] to take-off and land the Harrier T10 on his first trip. The board believe that insufficient guidance was given to [redacted] from his superiors to assist this decision making process for an aircraft with unusual handling characteristics and that much rested, rightly or wrongly, on the implicit trust placed in [redacted] by [redacted] In the event, [redacted] elected to allow [redacted] to fly an RVL without a demo contrary to his instructions at the outbrief. [redacted] filled in the auth sheets incorrectly by omitting the specific reference to [redacted] carrying out landings, as required by the Flying Order Book (FOB). Finally, [redacted] authorised the sortie knowing that the ML work included VIFFing. He was unaware that VIFFing was prohibited in the section of the DAR on TIALD handling limitations. The DAR was the responsibility of the Harrier Project Pilot. However, all pilots who flew the aircraft were expected to have read and be aware of its contents. There was no method of confirming that this had been done other than by word of mouth.

Witness 12, 15, 16, 19 & 20
Exhibit 18
Witness 1 & 3
Witness 2

SUMMARY OF CAUSES AND FACTORS

41. Cause. The Board concluded that the accident which resulted in the loss of Harrier T10 ZH654 was caused by the aircraft engine being allowed to become starved of fuel causing it to wind down at a critical stage of flight.

42. Contributory Factors. The Board concluded that the following factors contributed to the accident:

a. An erroneous fuel gauge indication.

b. The Captain's management of the ac fuel system.

c. The Captain's airmanship decisions during the circuit flying phase of the sortie.

d. The inconspicuousness of the R/LFUEL steady and flashing cautions.

43. Aggravating Factors. There are no aggravating factors.

44. Other Factors. There are no other factors.

RELEVANT ORDERS AND INSTRUCTIONS

45. FOB. In Section G Order No 5 Para 10, the FOB states that landings by non type-qualified pilots should be specifically entered in the Flight Authorisation Sheet. (RAF Form 1575B). Although [redacted] the authoriser, was well aware at

Exhibit 10
Exhibit 1

the outbrief that the sortie was planned for [redacted] to carry out landings, this specific entry was omitted.

46. DAR. In the TIALD section of the DAR, published for ZH654, TVC is prohibited other than for take-offs, transitions and landings. Although the DAR was kept in the Harrier Project Pilot's Office, where the sortie was briefed, neither pilot nor the authoriser was aware of this restriction. However, the DAR describes the use of nozzles in forward flight in the basic ac configuration (Section B-4-9) as VIFF, and the TVC abbreviation is used in the TIALD Limitations (Section B-8-28). In his statement, the Technical Leader from the P&FQ department of CAD at Boscombe Down, author of the DAR, confirmed that VIFF and TVC were the same. Exhibit 12 Witness 4

47. FRCs. [redacted] did not carry out the correct drill for Fuel Imbalance as listed in FRCs. Similarly, [redacted] did not switch on the VRS, prior to take-off, in accordance with the FRC Before Take-off checks. [redacted] did not see the warning lights (pertinent to the fuel system) as listed in the landing checks in the FRCs. Exhibit 16 Exhibit 16

OBSERVATIONS

48. DERA Flying and Supervision is regulated by D Flying who is Chief of Defence Procurement's aviation Regulatory Authority at the working level. D Flying has regulatory authority over UK Military ac operated by DERA and publishes DFIs to regulate the operation of UK military registered ac, either allotted to DERA or on the permanent ac fleet. Overall responsibility for the control of flying at Boscombe Down rests with the CTP who in turn can delegate this to a Duty Flying Executive. Sqns, in turn, appoint either a Duty Sqn Supervisor or a Sqn Duty Ops Officer to address Sqn specific matters. A Type Advisor should also be available on the ground to provide support with FRCs etc, when single pilot operations are taking place. However, the Board, with the assistance of the DERA Observer, spent time during the inquiry to understand the routine nature of TP flying and how daily supervision is exercised given the wide range of ac types operated by FJTS. The Board believes that the normal supervisory lessons adopted by the RAF at large should work in parallel with the inherent trust that is required of TPs. On supervisory aspects, the Board observed that: Annex M

a. Although the Harrier ac was not new to FJTS, the availability of 2 T10s from Jun 00 with flying hrs allocated for CT was unusual.

b. The late change to the flying program to add [redacted] to the accident sortie gave the impression that there was no proper plan as to who would be flying in the rear cockpit of the T10 CT sorties. Witness 2

c. All 5 Harrier pilots, including CTP, that were interviewed had different views on exactly how much flying they would have allowed a non type qualified pilot to carry out in similar circumstances.

d. There was no guidance given to [redacted] as to what

events would be appropriate for [redacted] to fly on that sortie.

e. There was no forum for the supervisory chain to discuss how the T10 hrs could be best utilised or even if there were any supervisory issues associated with operating an unfamiliar type of ao with unusual handling qualities.

f. No system existed for [redacted] 's progress to be monitored following their arrival on FJTS in Jan 00, other than casual observation of their early trials work.

g. [redacted] had 15 hrs on the Harrier in the last 18 months; [redacted] had 629 hrs total Harrier and had recently qualified as an authoriser. Notwithstanding the extant rule on self-authorisation, the Board questioned who was the best person to authorise the sortie.

h. The DAR was in the Pilots briefing room with specific instructions that TVC was not permitted in this ac, due to the TIALD pod, yet neither the captain nor the authoriser were aware of this. Exhibit 12

i. There was no formal process in place to confirm that TPs had read documents such as the DAR.

j. [redacted] did not enter the correct information on non-type qualified pilots carrying out landings in the authorisation sheet, as required by the FOB. Exhibit 1 Exhibit 10

k. The RAF Harrier Operating Authority (No. 3 Group) have issued an order stating that the minimum Harrier landing fuel state is to be 800lbs on arrival at the destination airfield. For any subsequent VSTOL practice on the airfield, pilots must plan their final vertical descent such that at least 500lbs remains on landing. There is no equivalent order in the Boscombe Down FOB or the DAR. Exhibit 20

49. Other observations of the Board are as follows:

a. It is gratifying to note that this first command ejection in a Harrier T10 worked exactly as designed. Annex G

b. The Board observed that on a sample of approximately 20 T10 sorties on 20(R) Sqn at RAF Wittering, the average fuel imbalance on shut down showed the RH group to exceed the LH Group by 650lbs. This is 200lbs more than is technically correct.

c. The Harrier ADR and the ICARUS system for replaying the ADR data proved to be an excellent system for reconstructing the events of the sortie. ADR Services at Boscombe Down were notably prompt with their work in processing ZH654's ADR. Exhibit 3/4

RECOMMENDATIONS

50. The Board recommends that:

a. Harrier GR7 and T10 Fuel Warnings are reviewed with consideration given to an audio warning with R/LFUEL steady at 750lbs remaining; and a master warning with R/LFUEL flashing.

b. The integrity of Harrier FQTs is the subject of further technical investigation as identified in Annex H.

c. The Fuel system section of the Harrier T10 Aircrew Manual is amended to include clearer text and supporting diagrams.

d. 'FUEL' in the Landing Checks should include fuel warnings on the warning panels.

e. The ADR is modified to record flashing R/LFUEL warnings in addition to the steady warnings.

f. VIFFing and high α handling to be a specific part of OCU TP refresher course.

g. The Harrier Simulator is modified to have the capability to replicate the T10 fuel system and associated crossfeed emergencies.

President [redacted]

Members [redacted]

Date 5 Feb 2001

COMMENTS BY CHIEF TEST PILOT, BOSCOMBE DOWN

PART 3

TECHNICAL ANALYSIS

1. The Board conducted a rigorous technical analysis of the accident. I agree with the Board's analysis of the technical causes of the accident including: the actual and indicated fuel quantities throughout the flight; the warning and caution lights and audio that were triggered and their timings; the fact that a fuel gauging error occurred and the potential sources of that fuel gauging error.

DIAGNOSIS OF CAUSES

[redacted] APPRECIATION OF THE AIRCRAFT'S FUEL STATE AND CONTROL OF THE FUEL SUPPLY TO THE ENGINE

2. The critical issue in the accident is to understand how [redacted] an experienced Harrier pilot, mishandled the management of the fuel system to such an extent that the only source of fuel to the engine was exhausted. It is axiomatic that [redacted] did not want this outcome so in some way he was confused into believing that sufficient fuel was available to the engine despite the correct functioning of warning systems that should have made his situation clear to him. The factors that contributed to [redacted] confusion are mostly identified by the Board but the consideration of those factors is to a degree unbalanced or incomplete. The main factors were: the fuel gauge error; [redacted] fuel system knowledge; the nature of the fuel system warnings and cautions; the weather conditions (including brightness and sun angle); distraction.

3. Fuel Gauge Error. It is clear from the Report that a fuel gauge error of approximately 400lbs occurred in the RH Fuel Group probably due to a failure in one of the right external fuel tank probes. It was [redacted] failure to identify that fuel gauging error that led directly to the accident. Contrary to the implication of various statements and assertions by the Board, notably at page 2-18 *"The Board believes that throughout the circuit phase the fuel checks were sporadic."*, it is clear that [redacted] had a good appreciation of the fuel quantity indicated on the Fuel Quantity Indication Panel (FQIP); fuel checks are explicitly stated on 5 occasions in the final 13mins 52 secs of the sortie and it is implicit in the ADR transcript and in [redacted] evidence that he had silently checked the fuel indications at other times. Furthermore, his actions, including the manual selection of RFEED and sequence of circuits flown, were guided (albeit erroneously) by his appreciation of the FQIP indications. I agree that, based on the ADR transcript alone, [redacted] checks in the circuit appeared incomplete. However, given his single-seat background it is likely that he was in the habit of conducting his checks silently and hence it is possible that such verbalisation as occurred on this sortie was conducted mostly for [redacted] benefit and peace of mind. I conclude that the Board's conclusion that poor checks contributed to the accident is at best speculative. It is certainly true that [redacted] was unaware of his actual fuel state and that he failed to note the fuel warning lights; this is discussed further below. However, given his appreciation of the FQIP indications one can conclude that had those indications been accurate [redacted] would have landed the aircraft with sufficient fuel remaining for

continued safe flight. Hence, the fuel gauge error was a Cause of the accident, not a Contributory Factor, since had the fuel gauge error not occurred the accident would not have occurred.

4. The AAIB Report makes it clear that failures of the Harrier Fuel Quantity Transmitters are not uncommon. Two previous accidents are attributed to such failures and the importance of accurate fuel quantity indications in an aircraft that is routinely operated to very low fuel levels is emphasised. I support the Board's recommendation that the integrity of the Harrier's FQTs be subject to further technical investigation. Indeed, I would strengthen the recommendation to state that the failure rate of Harrier FQTs must be reduced. I would further recommend that until improvements are made aircrew should alerted in the Aircrew Manual to the unreliability of the Harrier's FQTs.

5. The AAIB Report refers to a USMC Harrier TAV-8B accident at NAS Cherry Point on 13 Apr 99. It is understood from the DERA Observer to the Board, Redacted Sect 40- Civ D that the Board had access to some details of that accident. The accident had striking parallels with the subject of this Report: a right fuel tank probe had failed giving an erroneously high fuel indication in the RH Fuel Group, manual RFEED was selected and the system was left in manual RFEED until the RH Fuel Group fuel was exhausted and the engine wound-down. However, the aircraft was at a very low height on the approach (10 – 20 ft) and the resulting crash thus fortuitously resulted in less than catastrophic damage. It is extraordinary that the existence of this accident goes completely unremarked by the Board given that it may well provide further evidence of a systemic problem with the Harrier fuel and warning system. It is recommended that information be sought on the USMC Harrier TAV-8B accident in order properly to learn the lessons from both accidents.

6. Redacted Sect 40- FR II E Fuel System Knowledge. Redacted Sect 40- FR II E failure to identify the RH Fuel Group fuel gauging error was critical. His knowledge of the fuel system should have been a key defence against such a failure. Before examining any failure to control the fuel system correctly it is important to understand if any deficiencies in Redacted Sect 40- FR II E knowledge led him to fail to identify the RH Fuel Group fuel gauging error. Redacted Sect 40- Civ H of CHS states in his report at (Annex I, para 3 & 5) that in interview Redacted Sect 40- FR II E recalled no instances of fuel gauging error during his tour on Harriers and also that he was unaware that the fuel gauges and the fuel warnings were driven by different sensors.

a. Experience of Gauging Errors. Redacted Sect 40- FR II E reported recalling no instances of fuel gauging error during his tour on Harriers, but the Board reported (para 49b) that an average imbalance between fuel groups on shut-down in the Harrier T Mk 10 was 650lbs, or 200lbs more than designed. It is possible, therefore, that such errors are regarded as normal and this may account for Redacted Sect 40- FR II E not recalling any instances of fuel gauging error; alternatively the fuel gauging systems may be deteriorating. Furthermore, if a 650lb imbalance is the average imbalance on shutdown a greater range of imbalance is implied. Again this may have become regarded as normal and may have desensitized Redacted Sect 40- FR II E to abnormal fuel imbalance. This in turn may account for Redacted Sect 40- FR II E failure to comment on or to question earlier the abnormal apparent imbalance that existed in the latter part of the sortie. It is recommended that further work be done to diagnose and correct the incorrect average fuel imbalance experienced on the Harrier T Mk 10; in particular, it is vital to understand whether

such imbalances are real or indication errors.

b. Fuel Gauging and Fuel Warnings. As argued at para 3, Redacted Sect 40- FR LL E had a good appreciation of the fuel quantity indications on the FQIP. His critical error was that he never considered that the indicated imbalance might be due to a gauging error; he stated in his evidence that he had no reason to doubt the accuracy of the FQIP. The information that he needed to diagnose the failure was provided by the RFUEL caption which illuminated steady and silently at 750lbs while the FQIP was indicating a RH Fuel Group quantity of approximately 1050lbs Redacted Sect 40- FR LL E had a second opportunity to diagnose the problem when the RFUEL caption started to flash at 250lbs on overshoot from the penultimate RVL and while the FQIP was indicating a RH Fuel Group quantity of approximately 700lbs. Redacted Sect 40 FR LL E failed to note the steady or the flashing RFUEL captions and hence missed his only 2 opportunities accurately to diagnose the gauging error. However, if he was, as he seems to have been, unaware that the fuel gauges and the fuel warnings were driven by different sensors he would have been unaware that the LFUEL and RFUEL captions offered him vital independent information. He was thus not pre-disposed, as he should have been, to take particular cognisance of the fuel warnings as a tool to aid him in his analysis. The characteristics of the warning system that further diminished its efficacy are discussed later.

c. Training on Harrier I and Sea Harrier historically emphasised the independence and accuracy of the fuel warnings. Indeed, the validity of the 'bingo lights' was held almost as an article of faith by Harrier I and Sea Harrier pilots and such pilots are typically highly attuned to those warnings. It was thus initially extremely surprising to note that Redacted Sect 40 FR LL E did not have this understanding. However, the Harrier Aircrew Manual does not explain the independence of sensing or the relative accuracy of the LFUEL and RFUEL priority cautions so he could not have gained this knowledge from the Aircrew Manual. The only remaining source of information for him was the instruction he received on the OCU; it is not possible to prove now whether such instruction was delivered but it seems unlikely. It is recommended that the Harrier Aircrew Manual be amended to emphasise the independence of sensing and the relative accuracy of the LFUEL and RFUEL priority cautions when compared to the FQIP. It is further recommended that the teaching on the OCU ensures that the independence of sensing and the relative accuracy of the LFUEL and RFUEL priority cautions when compared to the FQIP is emphasised.

7. Redacted Sect 40- FR LL E had a critical gap in his knowledge and previous experience that together militated against him correctly diagnosing the fuel gauging error in ZH654. When the fuel indications were slightly less than the "*two point one*" reported at T-08:36 and with the LH Fuel Group indicating 400lbs (so the RH Fuel Group must have been indicating approximately 1600lbs) Redacted Sect 40 FR LL E made his decision that there was a fuel imbalance and he took action to correct it by selecting RFEED. Having taken that action, and without due cognisance being taken of the RFUEL priority caution, Redacted Sect 40 FR LL E had no reason to revisit or question his decision. Indeed, from that moment to the end of the sortie the FQIP indications accorded exactly with his analysis of the situation. The Board, notably in para 31 of the Report, express surprise at Redacted Sect 40- FR LL E airmanship decisions "*given his concerns about the fuel system*". Redacted Sect 40 FR LL E "*concerns*" were further alluded to as being key to his decision-

making in para 36, "*He was concerned about his RFEED fuel selection and the imbalance and decided that this RVL would be to land.*". In contrast, I conclude that [redacted] was not overly concerned about the fuel system. He had (albeit erroneously) diagnosed an imbalance in the fuel feed and was taking action to correct it, that action was apparently having the intended effect and he was apparently in control of the situation. I contend that his decision to land from the next circuit (the first RVL) was conditioned more by his total indicated fuel state and his desire to land at or above his stated minimum fuel of 1000lbs than by any doubt about the security of fuel flow to the engine. His willingness to overshoot from the penultimate circuit underpins this view. In this context, the Board's subtle implication that [redacted] actions in the circuit were in some way reckless is rejected. Some of [redacted] airmanship decisions were flawed and the degree to which he persisted with allowing [redacted] to fly the aircraft was ill-judged, these factors will be discussed later, but there is no sense that [redacted] was in any way wilfully pushing his luck or knowingly bending the rules.

8. Crossfeed System and Proportioner Selections. [redacted] knowledge of the Harrier T Mk 10 crossfeed system in his evidence was accurate, but this may have been the result of some post-accident revision. By his statement at T-08:20, "*I'm gonna manually select the right feed because it should have...fed by now, I don't know why it hasn't.*", and with fuel quantity indications of L400 R1000, [redacted] betrayed a lack knowledge as the RFEED should not have engaged automatically until the LH Fuel Group contents were 312lbs, or 350lbs indicated. However, [redacted] is explicit in his evidence that he manually selected RFEED to correct the perceived imbalance and not to overcome a perceived failure of the RFEED system. The action he took, in selecting RFEED, was not in accordance with the Aircrew Manual advice to correct an imbalance: Aircrew Manual, Part 1, Chap 3, para 19 states "*If an imbalance exists, switch off the low side booster pump and the fuel proportioner until the balance is corrected,....*". However, his action would have the same effect in that it stopped fuel flow from the LH Fuel Group and allowed fuel to be drawn solely from the RH Fuel Group. Irrespective of the action taken indicated balance was never achieved. So whether the corrective action had been RFEED, or left booster pump and proportioner OFF, [redacted] never achieved the condition that would have caused him to cancel his corrective action and in both cases the engine would still have flamed-out. I disagree with the Board's statement (para 28, bottom of page 2-18) that [redacted] *premature selection of RFEED .....[was] a contributory factor in this accident.*". Whilst disappointing, [redacted] apparent lack of knowledge and inappropriate use of the RFEED system was not a Contributory Factor.

9. [redacted] statement at T-07:20, "*and anyway if one side runs dry it doesn't matter*", was inaccurate in the context of the fuel system configuration at the time. With RFEED selected the engine would, and did, flame-out when the RH Fuel Group was exhausted. However, it is a Harrier SOP at very low fuel states to select the booster pumps ON and the proportioner OFF in order to ensure fuel flow to the engine even in the situation where one Fuel Group runs dry. [redacted] made it clear that he understood this in his answer A23 on page 6-10 of his evidence and I conclude that the remark at T-07:20 is a fragment of a description that [redacted] did not have time to qualify and that it was not intended to pertain to the fuel system with RFEED selected.

10. Fuel System Warnings and Cautions. The fuel system warnings and cautions should have been [redacted] salvation and yet he failed to recognise the priority cautions that told him that his aircraft was shortly to run out of fuel. The possible role of distraction in [redacted] failure to note the priority cautions is discussed below but an effective warnings and caution system should reliably alert the pilot to failures or critical system states under conditions of the greatest distraction, and potentially while in combat. I agree with the Board's conclusion that the inconspicuous nature of the L/RFUEL priority cautions was a Contributory Factor in the accident but the reasons for [redacted] failing to notice the warnings is given insufficient weight in the Report and bears further scrutiny. The factors which influenced [redacted] failure to notice, critically, the RFUEL priority caution were: the visual presentation of the warning; the location of the warning; the ambient brightness and sun angle; the associated audio tones; desensitization.

a. Visual Presentation. The warnings and cautions in the Harrier GR7 and T Mk 10 are all displayed in the same NVG-compatible green. Gradation of warnings is achieved by zoning into a warnings block, a priority caution block and a cautions block. However, this does not present an immediately compelling sense of the priority of the different warnings and cautions in the same way that red and amber captions do. Furthermore, the captions are relatively dim. The illumination of the steady or flashing L/RFUEL captions is not accompanied by illumination of the Master Caution or Master Warning lights. It is notable that [redacted] reports in his evidence that on the plateau during the final RVL, "*Both BINGO lights were illuminated steady.*". So despite having scanned the captions, [redacted] failed to appreciate that the RFUEL was flashing probably because it was insufficiently bright and compelling. Overall the visual presentation of the warnings and cautions has poor attention-getting qualities and is more appropriate to the presentation of information for discretionary scrutiny by the pilot.

b. Location. The location of the L/RFUEL priority cautions to the left of the Up Front Controller (UFC) places them high in the cockpit where they are subject to wash-out in bright conditions. The captions are poorly shielded.

c. Ambient Brightness and Sun Angle. I disagree with the Board's conclusion at para 25 of the Report that "....*there were no meteorological factors that could have affected the accident*". On the day of the accident the sky was clear and there was bright sunshine. The sun was at 28° elevation on a bearing of approximately 250°M, or 160° off the runway heading. When on the runway or flying on the runway heading bright sunlight would have been falling over the pilot's left shoulder and directly on the priority caution panel reducing the apparent brightness of any captions that were displayed there. When flying downwind the sun would have been prominent in the pilot's forward field-of-view and potentially dazzling. On both headings, and therefore for the majority of the time in the circuit, the conspicuity of the fuel system priority cautions would have been degraded therefore reducing still further the attention commanding properties of the priority cautions. The high ambient brightness and the sun angle were factors in [redacted] failure to notice the RFUEL priority caution

d. Audio Tones. The design of the warnings and caution system does not provide for a warning tone in association with the steady illumination of the L/RFUEL priority cautions. So the poor visual attention-getting qualities of those priority cautions are not mitigated by audio and this reduced the likelihood that [redacted] would have noticed the illumination of those priority cautions. The illumination of the flashing L/RFUEL priority cautions is supported by the sounding, for only 900ms, of the Master Caution tone or "tweedle dee". The fact that the sound is short, and particularly since it is cancelled without intervention, and therefore acknowledgement, by the pilot reduces its efficacy as a support to the priority caution.

e. Desensitization. As noted by [redacted] at Annex I to the Report, the frequent sounding of the "tweedle dee" Master Caution tone during the normal operation of the aircraft reduces its efficacy as an attention-getter through over exposure. This, together with the 'normal' sounding of the "tweedle dee" due to the 15s light on the overshoot from the penultimate RVL will have contributed to [redacted] failure to note the RFUEL starting to flash. It is recommended that the Harrier GR7 and T Mk 10 warning and caution system be modified to reduce the frequency with which warnings and cautions are triggered during the normal operation of the aircraft.

11. The deficiencies of the Harrier T Mk 10 warning and cautions system, while not a Cause of the accident, in that they did not lead directly to the accident, were a major Contributory Factor. I assert with a high degree of confidence that if the RFUEL priority caution had been more compelling the accident would not have happened. I agree with the Board's recommendation for the modification of the Harrier GR7 and T Mk 10 fuel priority cautions.

12. Distraction. Distraction had a potential impact on 3 aspects of [redacted] management of the sortie: his analysis of the fuel gauging error; his monitoring of the fuel system priority cautions; and his assessment of priorities and selection of an appropriate course of action at the end of the sortie, this third point will be discussed later. The fuel gauging error was present and apparent for a large portion of the sortie including periods, such as the recovery, of low workload. [redacted] was thus slow to identify the disparity between the indicated Fuel Group quantities and slow to recognise this as a problem. However, as argued at para 6 above [redacted] may well have been pre-disposed to accept such imbalances as normal and it was only the persistence and size of the imbalance (1050lbs indicated at T-13:52) that stirred him to action. Having identified the problem, and based on his background and experience, he assessed the disparity in the fuel indications to be due to a real fuel imbalance. He did not consider a gauging error but there is little evidence to suggest that distraction had any bearing on his analysis. [redacted] monitoring of the L/RFUEL captions was poor. But, both the design of the system and his lack of knowledge, apparently through no fault of his own, of the independence and relative accuracy of the L/RFUEL captions militated against him making the best use of the information provided by those captions. Finally, and as argued para 7, having decided that the disparity in the fuel indications was due to a real fuel imbalance and having taken action to correct it by selecting RFEED [redacted] had no reason to revisit his decision. His corrective action was apparently being effective and FQIP indications for the remainder of the sortie fitted his mental model. There is little evidence that distraction affected [redacted] management of the

fuel system.

13. Comment on the Conclusions of the Board. The Board concluded at para 28 on page 2-18 that "[redacted] *premature selection of RFEED and his inattention to the fuel warning lights exacerbated by poor checks in the circuit were all contributory factors in this accident.*". In contrast to the conclusions of the Board, I conclude that the selection of RFEED was not a factor since the application of the correct procedure of left booster pump and proportioner OFF would have produced the same, catastrophic result. [redacted] did fail to give appropriate attention to the fuel priority cautions but there is significant mitigation for that failure most of which is not considered by the Board. Finally, the assertion that poor checks in the circuit contributed to the accident is not substantiated.

14. The critical issue was not [redacted] failure to manage the fuel system but his failure correctly to analyse the fuel gauging error but that failure is barely discussed by the Board. Again, there is considerable mitigation for [redacted] failure. I would reword the Contributory Factor at para 42b of the Report to read "*The Captain's failure correctly to identify the erroneous fuel gauge indication.*".

AIRMANSHIP DECISIONS IN THE CIRCUIT

15. Allowing [redacted] to Fly the Aircraft in the Circuit. It is a vital element of becoming and being an effective test pilot regularly to experience the characteristics of different aircraft. This practice ensures that test pilot skills remain honed, objectivity is maintained and a broad-based knowledge of solutions to aircraft design problems is acquired. It was thus appropriate that [redacted] be allowed to fly the Harrier. [redacted] was an experienced Harrier pilot and had demonstrated the intervention skills required in his training as a VAAC Safety Pilot. Indeed, I note from [redacted] evidence, that as a Harrier qfi [redacted] considered that VAAC Harrier Safety Pilot training had probably made [redacted] better able to intervene than a qfi. As a previous OC FJTS and VAAC Harrier pilot, I would support that view. [redacted] had the skills to demonstrate circuits to [redacted] to monitor [redacted] s flying and to intervene if necessary.

16. The brief was too short to have properly briefed how to conduct an RVL. A brief would certainly have been required in order to give [redacted] a realistic chance of understanding what was going on in the RVL and of completing one successfully. A proper brief would also have mitigated [redacted] workload in briefing and monitoring [redacted] through the approach. The short brief would not have precluded [redacted] flying AUTO and STOL flap slow landings as, apart from the novelty of moving the nozzles, the control strategies on the approach are very similar to other fast-jets. Demystifying aircraft in this way is a major facet of becoming an effective test pilot. However, the control strategies for an RVL are markedly different to those for a slow landing and are not immediately intuitive. I agree with the conclusion of the Board that the flight was not adequately briefed given the intended scope. The content of the brief that the Board would have found satisfactory is not stated explicitly but it is implicit in their questions to witnesses. I disagree with the Board's implicit expectation that only a full OCU-style brief would have been adequate for the sortie. Thus, while the brief was certainly inadequate, the margin between the actual brief and a satisfactory brief was not as grave as the Board has portrayed.

17. Personally I would not have authorised either the take-off or RVLs on this, [redacted] first, Harrier sortie. However, the sortie was properly authorised, albeit with some errors that will be discussed with respect to [redacted] involvement, and it was appropriate that [redacted] be allowed to fly the Harrier under [redacted] monitoring and guidance. There was no failure of [redacted] airmanship in him allowing [redacted] to fly the aircraft in the circuit. There may have been a failure of supervision and this is discussed later.

18. RVL Without a Demonstration. In allowing [redacted] to attempt an RVL without the benefit of a demonstration [redacted] certainly exceeded the spirit of his authorisation. It is not clear from the evidence whether the sequence of demonstration followed by practice was a condition of the authorisation or whether the captain and the authoriser only understood that that would be the flow of the sortie. I conclude that, albeit possibly implicit, the orders given at the authorisation were clear and that [redacted] should have given a demonstration before allowing [redacted] to attempt each type of circuit. In not declining to fly the penultimate RVL [redacted] too, was a party to the conditions of the authorisation being broken. As argued above, it was unreasonable to expect [redacted] successfully to fly an RVL without the benefit of a proper brief or a demonstration. In allowing [redacted] to attempt an RVL [redacted] exceeded his authorisation and showed a lack of airmanship. It is highly likely that [redacted] enthusiasm to allow [redacted] to fly an RVL and the workload that that entailed overwhelmed his ability to prioritise and to select a safe and sensible course of action. There was, however, no suggestion that [redacted] was incapable of effectively monitoring [redacted] flying throughout the period in the circuit. In fact, [redacted] did intervene successfully on 2 occasions: once to assist with the nozzle handling on take-off and once, close to touchdown, on [redacted] STOL flap slow landing when the aircraft was disturbed in ground effect.

19. Failure to Assure a Landing from the First RVL. [redacted] exhibited two failures of airmanship in failing to assure a landing from the first RVL. He directed [redacted] to land ¾ of the way up the runway thereby eliminating any tolerance for error and he failed to set himself a cut-off point at which he would take control to assure the landing.

20. Decision to Fly a Further RVL. [redacted] exhibited several failures of airmanship in electing to fly an RVL as his final landing. Again, it is highly likely that [redacted] enthusiasm to show [redacted] an RVL overwhelmed his ability to prioritise and to select a safe and sensible course of action. In selecting an RVL as his final landing [redacted] committed himself to a high fuel consumption circuit and the certainty of landing at below his planned minimum fuel, although he was convinced that he had the fuel to complete the circuit. [redacted] had set himself a 1000lb fuel minimum as a blanket protection against any CG problems that might occur at lower fuel weights; this was based on an OCU rule of thumb. He had not checked the exact fuel-CG characteristics of ZH654 so could not be certain that at fuel weights below 1000lbs he would not encounter handling difficulties. He was also acting in contravention of the Flying Order Book which, at that time, allowed Harrier captains to burn down below diversion fuel when in the circuit to a minimum of 800lbs provided they had vertical landing performance. The rule has since been changed to fall into line with HQ 3 Gp ASOs.

21. Comment on the Conclusions of the Board. I agree with the conclusion of the Board that the Captain's airmanship decisions during the circuit flying phase of the sortie were a Contributory Factor in that: he allowed [redacted] to attempt an RVL without proper briefing or a demonstration; he failed to assure a landing from the first RVL; and he elected to fly an RVL as his final landing.

OTHER ISSUES

22. General Airborne Airmanship. Although not commented on by the Board it is worthy of note that in many aspects of the sortie [redacted] demonstrated good airmanship. The pre-take-off brief was comprehensive and the take-off was flown in a satisfactory manner, was well-monitored and was in accordance with the authorisation. [redacted] situational awareness and checks at low level were good; in particular his liaison with Exeter airport, his planning of an alternative route should Exeter have refused overflight and his radio altimeter setting procedures were all highly satisfactory. His briefings and demonstrations of the TIALD system and his monitoring of [redacted] were very good. Also, during the TIALD phase, his consideration of the weather and tailoring of the sortie to extract the best value for himself and for [redacted] in a safe and expeditious manner were all well up to standard.

VIFF PHASE

23. Exceedance of AOA Limits in VIFF Looping Manoeuvres. In their Report the Board clearly imply that in conducting VIFF looping manoeuvres at AOAs significantly above the AOA limit [redacted] was gratuitously and deliberately exceeding the aircraft limits. The facts are that the limits were grossly exceeded on 3 occasions and little effort was made to prevent the exceedances. However, [redacted] actions do not tally with his clear understanding of the AOA limit and his prompt and accurate observance of the limit in VIFF manoeuvres other than the VIFF loops. [redacted] clearly knew that the AOA limit for the aircraft was the Manoeuvre Tone Line; he stated to [redacted] in flight "*When you get that manoeuvre tone that means you have got to unload 'cos you have got to the limit AOA.*". He also clearly understood that he would be unable to prevent the AOA exceeding the limit in VIFF loops; he stated to [redacted] "*...and even with full forward stick you can't avoid the manoeuvre tone.*". Given his otherwise strict observance of the AOA limit, why would [redacted] enter into and repeat a manoeuvre that he clearly knew, and proved, would involve exceeding the AOA limits? It may have been a flagrant disregard for the limits but I judge that to be unlikely given that he was flying with a fellow test pilot who now also clearly understood the limits. I judge it to be more likely that [redacted] indulgence in conducting VIFF loops in the Harrier T Mk 10 was based on his previous experience. All marks of Harrier I, including the Sea Harrier, Harrier T4 and Harrier T8, and the Harrier GR7 are capable and cleared to conduct VIFF loops with no AOA limit; such 'back-flips' are a favourite party trick and one of the unique features of the Harrier. Given that the Harrier GR7 is cleared for the manoeuvre it would clearly be desirable to teach OCU students how to conduct the manoeuvre in the Harrier T Mk 10; however, this is not possible because of the T Mk 10's more restrictive AOA limits. I surmise that [redacted] indulgence in VIFF loops in the T Mk 10 may be indicative of a wider acceptance that the conduct of such manoeuvres is acceptable. I recommend that HQ STC take steps to determine whether my conjecture has substance.

24. Overstress. The aircraft was overstressed to 6.1g during a VIFF-enhanced break turn at 408KCAS and at a fuel weight of approximately 3600lbs. The NE limit at that weight was 5.5g at less than 420KCAS; at more than 420KCAS the limit reduced to 4.5g in VIFF manoeuvres. It is not explicit in the evidence whether [redacted] had selected the NAV HUD format for the break turn. He had certainly selected the VSTOL HUD format for the looping manoeuvres in order to have the HUD slip ball available to monitor sideslip. Two clues suggest that he did select NAV for the break turn and would thus have had a display of g. On recovery immediately after the break turn [redacted] states "*...and we put VSTOL up in the HUD so that we get our ball.*" Suggesting that he made the switch back to VSTOL from NAV at that time. Also at the moment of overstress [redacted] makes a slight grunt that suggests that he had seen a high g figure; immediately after the overstress the g backs off to a very accurate 4.5g at which time [redacted] states "*That's four and half, we've probably got about five and half at this light weight.*". The first statement combined with the accuracy of the g being held indicates that [redacted] was monitoring g on the NAV format. The second part of the statement is a reference to the g limit, and is also a tacit acknowledgement, and perhaps a reassurance to [redacted] that he knows that he had at least got very close to the limit. However, given the update rate of the HUD g display it is not certain what g figure [redacted] saw; in conditions of high g onset rate it is not unusual for the HUD to under-read by up to 0.6g. [redacted] exhibited poor airmanship in conducting a break turn and VIFFing at very close to the g limit; the rapid g response to the VIFF input should have been anticipated by [redacted] and he should have taken more care to respect the g limit. However, it is not proven that he knowingly exceeded the g limit.

USE BY THE BOARD OF THE VERB TO TEACH

25. Throughout the Report the Board describe [redacted] as teaching [redacted], they also make the point that [redacted] is not a qfi. The Board refused to accept the point that was made to them by several witnesses that [redacted] was not teaching; he was demonstrating and then allowing [redacted] to fly the aircraft in order for [redacted] to experience the characteristics of a type that was new to him. [redacted] was appropriately qualified and skilled to enable him to conduct the required demonstrations and subsequently to monitor [redacted] s flying. Had the purpose of the sortie been to work towards qualifying [redacted] on type or imparting to him a new skill that he was expected to retain and use in his own right then teaching, and an appropriately qualified instructor, would have been required. This was not the case. In this respect I agree with the comment of the Board at para 36 of the Report that "*There was no requirement for [redacted] to acquire this skill [to land from an RVL],...*". Since the accident a new order has been raised that now clearly defines trials flying; air experience flying; instructional flying; demonstration flying; clinical flying; qualitative evaluation (qualeval) flying; and test flying continuation training.

COMMENTS ON [redacted] STATEMENT UNDER QR12169(7)

26. I agree with [redacted] statement with the following comments and exceptions:

a. The points made at Section 1, para iv are valid but they are not Aggravating Factors as defined in AP3207.

b. I cannot substantiate the points made at Section 1, para v, on [redacted] decision to overshoot on the penultimate circuit, but neither do I have reason to doubt his statement.

c. In contrast to the statement at Section 1, para v (last para on page 3), [redacted] was operating in contravention of the Flying Order Book as it was written at that time in that he was operating below diversion fuel but without vertical landing performance. That rule has since been changed to fall in-line with HQ 3 Gp ASOs and judged against the current rules [redacted] statement is accurate.

d. I disagree with [redacted] statement at para 3, page 4 on his decision to allow [redacted] to fly the penultimate circuit. My comments are at para 18 above.

e. In para 5, page 5 the statements on the extant flying order are again flawed (see the comment at sub-para c above).

f. Section 2, para 5. I can find no reference to the evidence that [redacted] refers to; moreover, the statement in the cockpit "*...and we'll land about three quarters of the way down the runway.*" is quite explicit.

g. I cannot agree with [redacted] statement at Section 2, para 11 that in all cases he initiated corrective action within 2s of the Manoeuvre Tone sounding. On one loop there is no reaction to the tone for 4s and the tone is on for a total of 7s. On one of the loops flown by [redacted] the tone is on for a total of 9s and [redacted] prompts [redacted] to "*ease forward*" after 8s of the tone sounding.

h. I cannot agree with [redacted] statement at Section 2, para 12 that the comment "*fine, that's flashing*" might have referred to the Master Caution. It cannot be proven but the very nature of the comment implies that it was in response to an expected event and one which did not cause alarm. I agree with the Board's analysis that, on balance, the comment probably referred to the RFUEL caption flashing.

[redacted]

27. I disagree with the Board's conclusion at para 11a of the Report that the sortie was not properly authorised by [redacted] The sortie was authorised properly in accordance with all the extant regulations by an authorising officer who had been duly promulgated as having authorising powers for the Harrier T Mk 10. In addition an appropriate and comprehensive out-brief checklist was employed and all the questions prompted by that checklist were satisfactorily answered by [redacted] From the point-of-view of [redacted] the authorisation process was complete and satisfactory. It is true that there were errors of omission (recording of the intent for a non-type qualified pilot to land the aircraft) and of ignorance (prohibition of VIFF with TIALD) in the authorisation process but those errors are not sufficient basis to argue that the authorisation was improper.

28. Contrary to the use of an apparent quotation in para 40 of the Report, [redacted] did not say in his evidence that "[redacted] *experience as a VAAC safety pilot [..]gave him*

"exceptional handling skills.". This apparent attribution to [redacted] of a statement that he did not make is both provocative and misleading.

29. Decision to Authorise the Initial Take-off and Landings by [redacted] In authorising [redacted] to allow [redacted] to fly the initial take-off and a variety of landings, including RVLs, [redacted] was operating entirely within his delegation, terms of reference and authorisation powers as [redacted] It is also important to remember in the consideration of this Board of Inquiry that the aircraft did not crash because [redacted] had been allowed to fly it. Indeed, [redacted] achieved a safe take-off (with appropriate intervention by [redacted]) and smooth touchdowns from AUTO flap and a STOL flap slow landings.

30. Guidance to [redacted] The Board contend that there was insufficient guidance given to [redacted] to assist his authorisation decision making process for an aircraft with unusual handling characteristics. The Board also state that *"much rested, rightly or wrongly, on the implicit trust placed in* [redacted] *by* [redacted]'. In the latter statement, the Board are quite correct, in test flying we demand and expect high standards and a high degree of personal integrity and responsibility. The character of the system, which is totally unlike that on a normal station or squadron, demands that a high degree of responsibility is devolved to the individual aircrew. This is part of the reason that the typical test pilot recruit is a well-respected second tourist with at least an Above Average assessment in his Flying Log Book. In the former contention the Board betray a lack of appreciation of the nature of test flying and a test flying establishment.

31. On a normal station there is enormous strength in depth with respect to the main type operated. Experience on the type will often be directly proportional to rank and seniority and it is highly appropriate that guidance on the operation of the station's aircraft be cascaded down through the hierarchy. At Boscombe Down, the most knowledgeable pilot on a type will usually be the Project Pilot, a working test pilot typically in his first test pilot tour. He will be the type expert and is treated as such. The hierarchy have greater experience in identifying and managing trials risks and typically develop a canny ability to 'ask the right question'; however, they will not be the type expert. There is thus a difficulty in the hierarchy providing guidance to the test sqn cdrs. Moreover, it would be inappropriate to set hard and fast rules as to who can do what and in what aeroplanes under what conditions. In the case in point [redacted] based on a knowledge of [redacted] and his experience, [redacted] and his experience, the aircraft, the aircraft configuration, the weather and a host of other considerations reached a judgement on the appropriate content and conduct of the subject sortie. On another day and with another crew his judgement may well have been justifiably different. Had it been [redacted] second sortie, and based on his success, or otherwise, in the first sortie, again the scope and ground rules for the sortie may have been different. It would be inappropriately limiting to proscribe rigid limits and it is also, in my view, unnecessary. Again, the aircraft did not crash because [redacted] had been allowed to fly it. Since the accident a major review of the rules and regulations and authorisation procedures pertaining to the flying of aircraft by personnel not qualified on type has been conducted. Guidance is now provided as to the factors to be considered in deciding the scope of sorties in which a non-type qualified person is to be allowed to handle the controls of an aircraft.

32. Confirmation of Knowledge of the DERA Aircraft Release. I accept the observation by the Board that there was no method of confirming that pilots had read and were aware of the contents of the DAR. A signature sheet system is being introduced that will ensure that aircrew that are due to fly aircraft are made aware of the amendment state of the DAR. Of course, a signature sheet can still not guarantee that the aircrew will be fully aware of the contents of the DAR any more than the current system of challenge in the authorisation process. However, the system should bring an additional degree of assurance.

COMMENTS ON [redacted] STATEMENT UNDER QR 1269(7)

33. I agree with [redacted] s statement with the following comments and exceptions:

a. I am concerned that there was no feedback from the OCU on [redacted] Harrier refresher. I recommend that OC 20(R) ensures that end-of-course reports are rendered on all students that pass through the OCU. Had [redacted] been pre-warned that [redacted] may have had a weakness in his fuel system knowledge a more inquisitorial approach could have been taken to authorising him on the Harrier T Mk 10.

b. I agree with [redacted] s comments, at his para 12, on the selection of an appropriate authoriser. The review of the rules and regulations and authorisation procedures pertaining to the flying of aircraft by personnel not qualified on type also re-examined the principle of barring self-authorisation for trials sorties (except when away from base) and discouraging its use for other sorties. The review found that, on balance, and for the unique circumstances at Boscombe Down, the policy was still the best one to minimise risks. It should be noted that had [redacted] self-authorised for this sortie the outcome would almost certainly have been the same and, based on [redacted] willingness to allow [redacted] to fly an RVL without a demonstration, the conduct of the sortie may have been more lax.

c. I disagree with [redacted] s comment at his para 20 that the sortie was adequately briefed. My comments on the briefing are at para 16.

COMMENTS ON THE OBSERVATIONS OF THE BOARD

34. I agree with the Board's statement that "the normal supervisory lessons adopted by the RAF at large should work in parallel with the inherent trust that is required of test pilots." with the only proviso that the statement be caveatted with "where appropriate". As discussed at paras 30 & 31 above Boscombe Down is in many respects completely unlike a normal station or squadron environment and it presents unique challenges. Of course, we are keen to, and do, adopt the best practice from the Services where we can but it is not always possible.

35. Para 48a and b. I agree with [redacted] s comments at his para 8.

36. Para 48c. My comments are at para 30 & 31 above.

37. Para 48d. On the contrary, the authorisation process provided [redacted] with all the guidance he required. I also support [redacted] 's comments at his para 9.

38. Para 48e. I support [redacted] comments at his para 10.

39. Para 48f. I support [redacted] comments at his para 11 and I would add that I keep a very close watching brief on new test pilots through their sqn cdrs. [redacted] and I had specifically maintained very close contact with respect to [redacted] to monitor some initial demotivation occasioned by [redacted] realising that there was no prospect of him immediately becoming the EF2000 project pilot. That was a mere blip and [redacted] had settled quickly to become an effective Harrier test pilot. [redacted] and I had decided in Jun that [redacted] no longer required specific monitoring.

40. Para 48g. My comments on this subject are at para 33b above.

41. Para 48h. I agree with this statement of fact.

42. Para 48i. My comments on this subject are at para 32 above.

43. Para 48j. I agree with this statement of fact.

44. Para 48k. The wording of the 3 Gp ASO has been adopted in Boscombe Down orders (ATECOs).

GENERAL COMMENT

45. The Board have fixated on the content and crewing of the sortie, and even the nature of test flying, to a degree that has unbalanced their consideration of the factors affecting this accident. This is perhaps unsurprising given that no-one on the Board had any experience of the test flying environment. It is recommended that future Boards of Inquiry for accidents involving ATEC aircraft or crews should include, in whole or in part, personnel with experience of test flying. While [redacted] performance on this sortie was gravely disappointing in some respects there is significant mitigation for some of his failures; the Board has, in many instances, failed to present those mitigations; these comprehensive comments are intended to provide that balance.

COMMENTS ON THE CONCLUSIONS AND RECOMMENDATIONS OF THE BOARD

46. Conclusions (Para 11). I disagree that the flight was not properly authorised. There were errors in the authorisation but the authorisation of the flight was entirely proper. I agree with all the other conclusions of the Board with the proviso on the nature of the brief which is discussed at para 16.

47. Summary of Causes and Factors (Para 41 – 44). I agree with the Cause identified by the Board but I also believe that the fuel gauge error was a Cause of the accident; my reasoning is at para 3.

48. I disagree that "The Captain's management of the aircraft fuel system." was a Contributory Factor. I believe that the Factor would be more accurately stated as "The Captain's failure correctly to identify the erroneous fuel gauge indication.".

49. I agree with the other two Contributory Factors and with the Board's conclusion that there were no Aggravating or Other Factors.

50. Recommendations. I agree with the Recommendations of the Board provided they are supplemented by the Further Recommendations below.

51. Of note, and with respect to the recommendation that VIFFing and high α be a specific part of the OCU tp refresher course, I am not aware that those aspects of the handling of the Harrier have ever not been covered during an OCU tp refresher course.

FURTHER RECOMMENDATIONS

52. It is further recommended that:

a. The failure rate of Harrier FQTs must be reduced.

b. Until improvements are made in the reliability of the Harrier FQTs aircrew should alerted to their unreliability in the Aircrew Manual.

c. Information be sought on the USMC Harrier TAV-8B accident in order also properly to learn the lessons from that accident.

d. Further work be done to diagnose and correct the incorrect average fuel imbalance experienced on the Harrier T Mk 10; in particular, it is vital to understand whether such imbalances are real or indication errors.

e. The Harrier Aircrew manual is amended to emphasise the independence of sensing and the relative accuracy of the LFUEL and RFUEL priority cautions when compared to the FQIP.

f. The teaching on the OCU ensures that the independence of sensing and the relative accuracy of the LFUEL and RFUEL priority cautions when compared to the FQIP is emphasised.

g. The Harrier GR7 and T Mk 10 warning and caution system be modified to reduce the frequency with which warnings and cautions are triggered during the normal operation of the aircraft.

h. HQ STC take steps to determine whether there is a broad Harrier force acceptance that exceedance of AOA limits while conducting VIFF loops in the Harrier T Mk 10 is acceptable.

i. OC 20(R) ensures that end-of-course reports are rendered on all students that pass through the OCU.

j. Future Boards of Inquiry for accidents involving ATEC aircraft or crews should include, in whole or in part, personnel with experience of test flying.

REMEDIAL ACTION TAKEN

53. The 3 Gp ASO on minimum fuels for landing for Harrier aircraft has been adopted.

54. A new system of signature sheets to track whether aircrew are aware of the latest amendment state of DARs (now QinetiQ Aircraft Releases) is in place.

55. A major review of the rules and regulations and authorisation procedures pertaining to the flying of aircraft by personnel not qualified on type has been conducted. Guidance is now provided as to the factors to be considered in deciding the scope of sorties in which a non-type qualified person is to be allowed to handle the controls of an aircraft. The new order clearly defines trials flying; air experience flying; instructional flying; demonstration flying; clinical flying; qualitative evaluation (qualeval) flying; and test flying continuation training.

56. The same review has examined and re-endorsed the principle that self-authorisation must not be used for trials flights (except when operating away from base, and subject to specific approval) and that self-authorisation for all other flights should be discouraged.

57. FJTS have adopted a standard briefing guide.

58. A copy of the Harrier T Mk 10 rear seat briefing video is now available on FJTS.

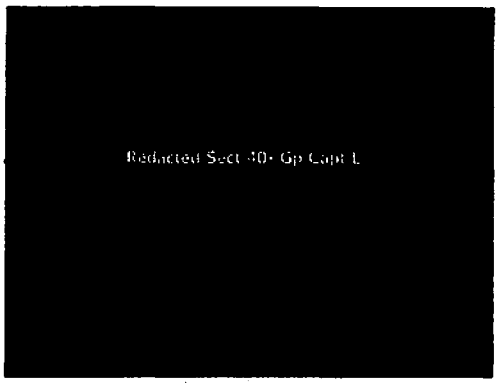
POINTS OF ACCURACY

59. Paragraph 16 of the Report indicates that there was no damage to public property other than to the role equipment of the aircraft. In fact, damage was caused to the Boscombe Down runway surface which was repaired at a cost of £3500.

60. Contrary to the statement at the first sentence of paragraph 31 of the Report that states a total fuel quantity indication of 1400lbs, [redacted] stated the fuel contents at T-05:08 as "*four hundred, a thousand, fifteen hundred...*".

61. The final sentence of paragraph 37 of the report, "*...if* [redacted] *had reselected AUTO or DL on the proportioner switch at any stage, the remaining 400lbs, isolated in the LH Fuel Group, would have been sufficient to have landed the ac safely, albeit at a low fuel state.*", is inaccurate. If AUTO or DL had been selected 'at any stage' fuel would then have been drawn equally from the LH and RH Fuel Groups and may have been sufficient to land the aircraft. However, if that selection had been made late on the final approach, for instance when [redacted] noted the FQIP Indications of L400 R500, only the selection of both booster pumps ON and the proportioner OFF would have guaranteed that all the remaining fuel would be available without the risk of the engine flaming-out if the RH Fuel Group had run dry. It is notable, and indicative of the complexity of the fuel system,

that the Board, under no pressure and with all the reference material available, made this inaccurate statement.



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REMARKS BY AIR COMMODORE TEST & EVALUATION

1. I agree with the principal technical findings of the Board. The sequence of events which led to the accident started with a fault in a fuel quantity transmitter which caused the fuel gauge to over-read in the right-hand group. The pilot took action to balance the fuel by feeding from the apparently high side and, while he was still attempting to balance the fuel, the engine flamed out as the right-hand group ran dry on the approach to land.

2. The Board's report demands a good deal of comment and I am grateful for the Chief Test Pilot's comprehensive remarks. I agree with his comments and will therefore keep these remarks brief.

3. I agree with the recommendations of the Board as modified by the Chief Test Pilot.

4. While agreeing with the Board's analysis of what happened, I believe that the Board did not give sufficient consideration as to why it happened. Specifically, the Board did not give sufficient attention to the following aspects:

a. The 2 previous similar accidents in RN and USMC experience were not discussed – see AAIB report page 48. Surprisingly, the Board made no reference at all to the Harrier's history of similar accidents. Neither did the Board comment on the apparent lack of dissemination to RAF Harrier pilots of lessons learned from these accidents.

b. The Board did not seek to understand the captain's interpretation of the information presented to him, his diagnosis of the fuel problem and the extent to which familiarity with the Harrier T Mk 10 predisposed him to presume a fuel imbalance. When one strips away the fog, the captain made 2 errors that led to engine fuel starvation with indicated fuel contents above minimum fuel on the ground for the type. First, he did not identify the gauge error in the presence of a "normal" and a real abnormal fuel imbalance (see next sub-paragraph). Second, he did not subsequently cross-check the fuel gauge and the fuel caution / warning lights. The Board did not consider sufficienly the captain's background and training, the cockpit environment and his thought process in order to understand these 2 errors.

c. The Board did not consider the effect on the captain's interpretation of the fuel problem of the actual fuel imbalance, in excess of the erroneous imbalance, revealed by the crew's fuel checks. Fuel checks at T-13:52 and T-8:36 revealed an indicated imbalance of 1050 to 1200 lb. Hence in addition to the "normal" imbalance of 450 lb and the gauge error of c400 lb, there was an abnormal imbalance of some 200 to 350 lb. This is consistent with the Board's observations at Wittering during the Inquiry. The captain thus faced the situation of a real fuel imbalance together with a gauge error in an aircraft which by design displays an imbalance continuously to the pilot. Two thirds of the imbalance was real; the captain's error was not to diagnose that one third of the apparent imbalance was a gauge error.

d. The effect on the legibility of the NVG-compatible caution and warning system of bright sunlight shining over the captain's shoulder when on runway heading or directly into his eyes when downwind was not considered. Again surprisingly, the Board discounted meteorological conditions as a factor even though the fact that the captain was not alerted by the fuel caution / warning was central to the accident.

e. The Board did not comment on the lack of guidance in the Harrier Aircrew Manual, and possibly in the training system, on the independence of the fuel caution / warning lights from the gauging system and the need to give precedence to the fuel lights at low fuel states. This was second nature to Harrier 1 pilots but the same cannot be assumed for those trained on Harrier 2.

f. Lack of information to Harrier aircrew of the Harrier's susceptibility to fuel gauging faults.

g. Pilot desensitisation to audio warnings.

5. In addition, while noting that the captain did not follow the procedure in the Aircrew Manual for dealing with a fuel imbalance, the Board did not consider the likely outcome of events had the captain followed the recommended procedure. The Board therefore did not observe that the accident would probably still have occurred in the same way.

6. The Board referred a number of times to the captain's "concern" about the fuel state. However, the evidence indicates that the captain was not particularly concerned. On the contrary, he appears to have been satisfied throughout that he was dealing successfully with a fuel imbalance. Overall, while criticising the captain's airmanship, often for good reason, the Board did not seek to understand the captain's thought process and why an able pilot of considerable experience misinterpreted the fuel system indications.

7. The attached Figure is an analysis of factors contributing to the accident. The factors depicted in blue / italics were not considered by the Board.

8. Turning to the events earlier in the sortie, in relation to the over-stress in normal acceleration (g) revealed on the ADR, the Board gave insufficient consideration to the known Harrier display characteristics of lag and under-reading of both the instantaneous and MAX G displays. This is a well documented problem. The Board was then not in a position to weigh up the deficiencies of the system against the captain's duty nevertheless to respect the limits. In relation to the (apparently deliberate) flying beyond the AOA limit, the Board did not consider whether the pilot was conditioned by his training and previous Harrier experience to treat AOA limits in VIFF loops with less than full respect.

9. I have the following remarks on the Board's observations:

a. Paragraph 48b. I am not sure what "proper plan" the Board expected in relation to who would fly in the rear cockpit. Although a change occurred during the day, this is hardly unusual and both crew compositions were sensible.

b. Paragraph 48c. I agree with the remarks of the Chief Test Pilot.

c. Paragraph 48e. There was a clear structure for the supervisory chain to discuss any topic and such discussions were / are regularly undertaken. It is absurd to refer to Harrier T Mk 10 as an "unfamiliar type of aircraft" with respect to Fast Jet Test Sqn.

d. Paragraph 48f. This observation is substantially misleading. Both pilots were monitored within the squadron and [redacted] progress was monitored personally by the Chief Test Pilot, i.e. at gp capt level.

e. Paragraph 48g. The Board's comment implies a preference for self-authorisation in the case of this flight but the Board does not argue the point through. As a result of this accident, the authorisation process has been reviewed in depth and

the review confirmed that the benefits of cross-authorisation outweigh the disadvantages in this role.

f. Paragraph 48h. I would not expect the authoriser to be aware of the limitations of the aircraft in a specific configuration, in this case with a TIALD pod. The number of combinations of aircraft and potential configurations on Fast Jet Test Sqn is large and constantly changing. It was the duty of the captain to ascertain the limitations from the DERA Aircraft Release and the authorising officer to verify that he had done so using the out-brief check list.

g. Paragraph 48k. The equivalent order required captains to plan their final landing with fuel to reach the nominated diversions(s) and land with minimum fuel for the type (800 lb for Harrier). Harrier aircraft carrying out VTOL operations at the airfield were permitted to operate to minimum fuel for the type.

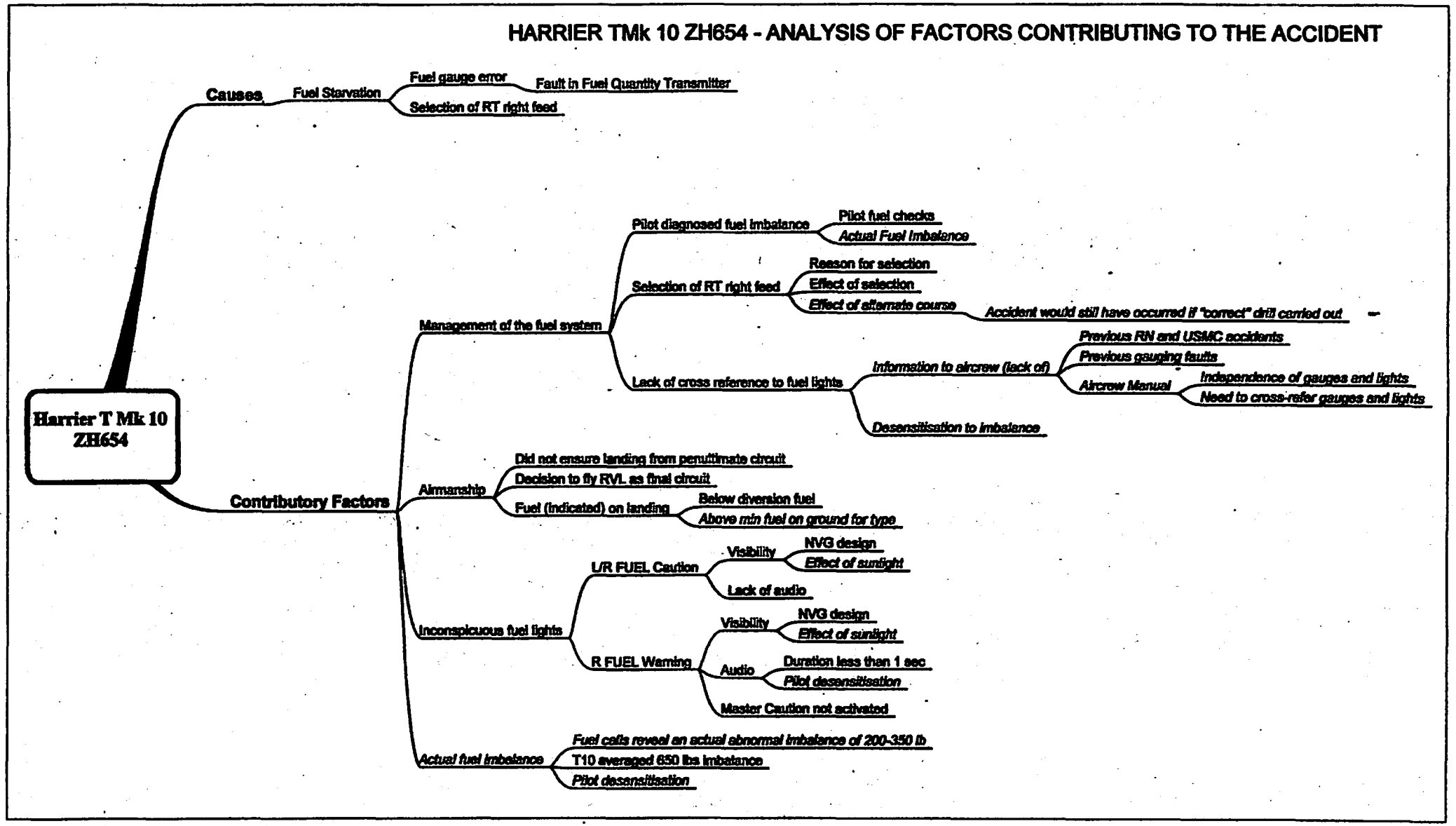
h. Paragraph 49b. The Board noted the tendency for the Harrier T Mk 10 to have an excess fuel imbalance, right-hand side heavy but did not consider the implications for the captain's analysis of the situation and for the safety of Harrier operations in general.

10. Overall, while there is little doubt as to the technical causes of the accident and the action needed to prevent a recurrence, I am disappointed by the imbalance of the Board's report. The Board has presented a litany of criticism of the captain and the squadron supervision, often justified but in other areas straying too far, while ignoring other highly relevant issues brought to their attention. In ignoring the previous similar accidents, the Board has not explored the implications of the fact that [redacted] was not the first Harrier pilot to experience an engine run-down in these circumstances. There are substantial grounds for requiring the Board to reconsider the evidence but I do not recommend such action because it would prolong the already considerable pain for all concerned. We must, however, ensure that we fully learn the lessons here about the Harrier fuel system integrity, fuel management and the caution / warning system along with Harrier training and aircrew information.

11. Finally, I would not wish these remarks to be misconstrued as protection of the flight test community. That is emphatically not my purpose. The Board's report makes uncomfortable reading and there are many lessons to be learned. In particular, for an organisation that is highly professional in the management of flight trials risks, Boscombe Down cannot afford – in human, financial or reputation terms – to lose aircraft on training flights!

N R WOOD
Air Commodore

HARRIER TMk 10 ZH654 - ANALYSIS OF FACTORS CONTRIBUTING TO THE ACCIDENT



PART 3

REMARKS BY THE DIRECTOR FLYING(DPA)

1. Cause. I believe the Board has carried out a thorough technical investigation and correctly identified the fundamental cause of the accident, in that the engine wound down because it was starved of fuel.

2. Contributory Factors. I am largely in agreement with the Board's list of contributory factors, and make the following comments:

a. Fuel Gauge Error. Although CTP sees this as a cause of the accident, had the captain cross-checked the cautions/warnings then the fuel gauge error may have been identified, and therefore I am content for it to be categorised as a contributory factor.

b. Captain's management of the Fuel System. I agree with CTP that the contributory factor in question here would be more correctly termed as misdiagnosis of a fuel problem, albeit the captain carried out some non-standard actions in his attempt to redress the fuel imbalance.

c. Captain's airmanship in the circuit. I believe the decision to overshoot from the first RVL and the fact that the final landing was set up as an RVL, both contributed to the accident.

d. Inconspicuousness of Fuel Cautions. The apparent inability of the fuel caution and warning system to give clear, prompt and unambiguous information to a pilot in a high workload situation is worrying, and I support strongly the relevant recommendations to address this.

I do not believe the Board has highlighted sufficiently the shortcomings in the aircraft's fuel system and associated cautions and warnings. In particular the exclusion of reference to the AAIB's comments on the very similar USMC accident is a major omission. Neither do I feel that the Board has given sufficient weight to the many mitigating factors in relation to the captain's decisions and actions, which were comprehensively detailed by CTP and concisely summarised by Air Cdre T&E. This has unbalanced the Board's judgement in their comparison between the contributions to the cause of the accident by the captain and the aircraft. In my judgement the Board has concentrated too much on the captain and too little on the aircraft.

3. Supervision. The additional difficulty of regulating and supervising test flying compared to typical front-line activities is illustrated by the variety of aircraft for which an individual holds responsibility. As the regulator for UK military test flying our rules cover the operation of 45 different types of aircraft. Air Cdre T&E's responsibilities cover approximately 36 types, CTP some 23 types and OC FJTS at least 10 types. The test flying Sqn Cdr cannot therefore be expected to be an expert on all the aircraft types for which he has supervisory responsibilities. He has to rely on his Project Pilots for that expertise, which is the exact reverse of the front line situation where squadron executives inevitably have more type experience than do

their junior pilots. The Board's observations indicate that they have failed to grasp this fundamental difference. CTP and Air Cdre T&E have addressed the criticisms thoroughly, and I continue to have every confidence in the supervisory chain at Boscombe Down. My one comment on flying supervision is that I strongly support the need for any flying course reports to be issued promptly, and then retained in training folders that are easily accessible to the flying supervisors.

4. Authorisation.

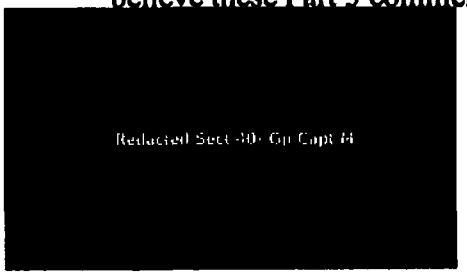
a. Authorisation of VIFF. The inclusion of VIFF in the authorisation, which was not permitted by the DAR, had no bearing on the accident. Each airframe has its own individual DAR, so although the captain is expected to have intimate knowledge of it, the authoriser does not necessarily share that same level of detail. However, the captain's assertion that he did not recognise the VIFF restriction listed in the DAR as TVC, leaves an unanswered question. As TVC was described as "prohibited except for take-off transition and landing" why did the captain not check to find out exactly what TVC was? I am pleased to see the introduction of a signature sheet system to make aircrew aware of the DAR amendment state. I recommend this acknowledgement takes the form of signing as having "read and understood".

b. Independent Authorisation. The Board's questioning of the need for independent authorisation, based on their observation that the authoriser had less type experience than the captain, is at odds with their view that the authoriser should have done more to check and modify the captain's intentions. I am glad to see that the review of authorisation practices has led to a decision to retain independent authorisation wherever possible. I believe that, even in cases where the captain is more experienced on type, it offers a valuable check on what the captain has, in isolation, planned for the sortie.

5. Conduct of the Sortie. The captain's understandable enthusiasm to expose a fellow test pilot to as much of the Harrier's unique characteristics as possible, led him to plan an ambitious sortie. His workload in the circuit would have been reduced had the sortie been briefed more thoroughly and the agreed sortie sequence of demonstration followed by practice been adhered to. This in turn might have left more capacity for fault diagnosis. Although the captain had been trained as a VAAC Harrier safety pilot, he was not used to planning and carrying out a demonstration sortie of such ambitious scope. His decision to talk through rather than demonstrate an RVL, the most demanding landing technique, went against his agreement with his authoriser and meant it was more likely that an overshoot would be required. The chosen aiming point of about three quarters of the way down the runway again made an overshoot more likely. His decision then not to take control before that overshoot became necessary, meant he would have landed below his planned landing fuel.

6. Recommendations. I agree with the Board's recommendations and believe that CTP's additional recommendations ensure the correct emphasis is now given to identifying and correcting aircraft faults.

7. Summary. As is usually the case, many factors played a part in the accident. The Board's concentration on Human Factors is understandable, but their lack of emphasis on the aircraft's shortcomings risks the possibility of future Harrier pilots being caught out in the same way. I do not believe there is anything to be gained by reconvening the Board, particularly in light of the long delay caused by the Police Inquiry. The reviewing chain has the opportunity to provide the right balance, and I believe these Part 3 comments have done so.



D Flying(DPA)

HARRIER T10 ZH654

PART 5

REMARKS BY COMMANDER-IN-CHIEF STRIKE COMMAND

1. I concur with the comprehensive remarks at Part 4 regarding the causal and contributory factors involved in this accident. The accident was wholly avoidable. I believe that the aircraft captain became fixated on guiding and monitoring his colleague's circuit flying, a demanding exercise that saturated his mental capacity to such an extent that he was unable to recognise the fuel gauge error. His self-induced workload prevented him from re-evaluating his airmanship priorities. However, his handling of the situation can be ascribed in part to the ineffectiveness of the Harrier warning system. I am disappointed that the Harrier warning system has once again proved ineffective in drawing the pilot's attention to a critical situation at a crucial stage of flight: in this instance, an extremely low fuel state in the circuit. Pilot desensitisation to the number of transitory audio warnings on the Harrier has been noted in the past. I am aware that an earlier recommendation to review the entire Harrier warning and caution system was made by a Board of Inquiry following the loss of a Harrier GR7 in 1997. For lamentable reasons, that recommendation does not appear to have received due attention. There is ample evidence to suggest that this is the third 2-seat Harrier to have been lost because of fuel starvation attributable in part to over-reading fuel contents displays in the cockpit. Many factors have played a part in this accident but, if we allow the aircraft's shortcomings to continue unchecked, we risk the possibility of future Harrier pilots being caught out in the same way. Modification of the warning system would need to be justified by a cost/benefit analysis and, bearing in mind the potential costs of modifying the warning system, it is important to consider the requirement against the other contributory factors in this accident. I will therefore task AOC 3 Gp, in concert with the Harrier IPTL, to arrange for a comprehensive review of the Harrier aircraft warning systems, in particular the Harrier T10 fuel indication and associated warnings, and to ensure that any recommended action is progressed through to conclusion. In the interim, I endorse the recommendation of the Chief Test Pilot to increase aircrew awareness and the requirement for cross-reference of fuel gauging systems. The ADR modification to record flashing L/R FUEL captions also appears feasible, and the Harrier IPT should investigate this further to allow a cost/benefit judgement to be reached. In sum, I add my weight to the recommendations to improve the reliability of the fuel gauging system. However, before we embark upon any modifications, we need to be satisfied that the course of action is appropriate and justified.

2. I am pleased to note the major review of rules, regulations and authorisation procedures that has occurred at Boscombe Down as a consequence of this accident. I am reassured that lessons from this accident have been learned and that best practice is now in place.

3. Finally, I am concerned about the length of time that it has taken to complete this Inquiry, and I shall be writing to the Inspector of Flight Safety and DLS (RAF) and inviting them to review our procedures.

Sir John Day
Air Chief Marshal
Commander-in-Chief Strike Command
14 December 2001