G-INDUCED IMPAIRMENT

1.4.44. **Background to G-induced impairment**. The inertial forces resulting from aircraft manoeuvre may produce considerable physiological effects dependent upon the magnitude, duration and direction of any acceleration. The magnitude of acceleration being applied to the human body is usually referred to in units of "G" which is a ratio of acceleration against earth's gravity. From a physiological perspective the direction of acceleration is defined by the human spine with X being the fore/aft axis, Y being the left/right axis and Z being the vertical axis. It is a positive acceleration in the Z axis (+Gz) that is the primary cause for G-induced impairment. The impairment of aircrew cognitive function during +Gz exposure occurs as a result of decreased blood supply to the brain. With a gradual increase in +Gz the reduction of head level blood pressure can cause a reduction of peripheral vision, so called "grey-out", and with increasing Gz the head level blood pressure can fall further resulting in total loss of vision (black-out). If Gz increases further, the amount of blood reaching the brain steadily reduces such that, at about +5 Gz in an unprotected individual, blood pressure in the brain is reduced to approximately zero. Several protective measures can be employed to minimise the effects of +Gz. In order to maintain sufficient cerebral blood supply, aircrew can artificially raise their own blood pressure through the synchronous tensing of body muscle in conjunction with a forced breathing method. These practices are grouped together under the term Anti-G Straining Manoeuvre (AGSM). However, performing an effective AGSM over a prolonged time period can be fatiguing and to assist the pilot anti-G trousers are provided in all RAF fast jets (Hawk specific equipment will be discussed in para 1.4.54). If these protective measures are ineffective, and the Gz exposure is sufficiently high, a lack of oxygen delivery to the brain leads to cognitive impairment and will ultimately lead to G-Induced Loss of Consciousness (G-LOC). The actual manifestations of G-LOC symptoms are variable and are rate/exposure time dependent. For example, brief exposure to even high levels of +Gz may result in no symptoms at all, as both the eyes and the brain contain a sufficient store of oxygen to function for approximately 4 seconds in the absence of a fresh supply of blood. Conversely, if the acceleration has a very rapid onset, and is held for long enough, the aircrew may suffer an episode of G-LOC without any preceding symptoms of grey-out or black-out. Therefore, when considering the possibility of G-induced impairment, the absolute levels of G must be considered with respect to the duration of exposure as shown at Figure 12. The Panel tasked QinetiQ with assessing every +Gz excursion above +3 Gz, for the entire accident sortie, and an abbreviated version of the results showing excursions above 4G is shown at Table 2. It can been observed that during the break to land, the pilot was exposed to 6.327G with the exposure time above 3G equating to 8.75 secs; resulting in the highest combination of absolute Gz versus exposure time for the whole sortie.

Exhibit 15
Annex A
Annex M

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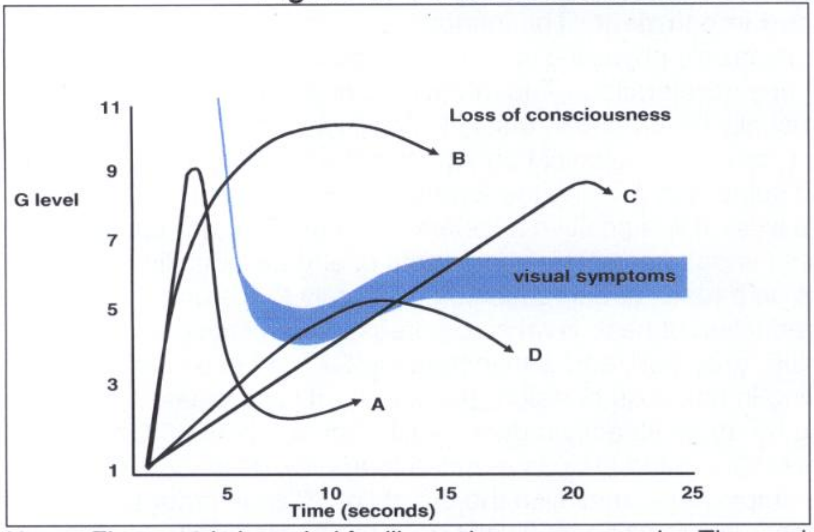
Figure 12 - Effect of Gz onset rate and GZ tolerance



Line A = Rapid onset to High G but for insufficient time for any symptoms to develop

Line B = Rapid onset to High G with a duration that results in G-LOC with no visual symptoms

Line C = Moderate onset to High G with visual symptoms preceding G-LOC

Line D = Moderate onset but corrective action taken at visual symptoms

Note – Figure 12 is intended for illustrative purposes only. The y axis position of visual symptoms will vary from individual to individual.

Table 2 – XX179 accident sortie excursions above +4 Gz

Peak g Attained (a)	Duration of >3 g (secs) (b)	Comment (c)
4.351	0.500	
4.468	11.625	
4.292	5.875	
5.388	4.750	
6.327	3.250	G onset rate peak at 4.771 [g/sec].
4.684	0.625	
4.527	0.625	
6.248	7.250	End of show – Big Vixen Break G onset rate peak at 8.67 [g/sec]
6.327	8.750	Break to Land G onset rate peak at 6.884 [g/sec]
4.292	1.375	

1.4.45. **Symptoms of G-LOC**. During G-LOC there is a loss of muscle tone so that, when seated, the head and body slump. During the recovery inadvertent muscle activity may occur, resulting in aircraft controls possibly being operated or moved. Incapacitation due to classically described G-LOC can be divided into two periods: a period of absolute incapacitation during which the aircrew is unconscious, and a period of relative incapacitation during which the aircrew is conscious, but suffering from confusion and disorientation, such that they are unable to control the aircraft. Studies have shown that initial recovery can take up to 15 seconds, while a further 30 seconds may pass before the subject is capable of appreciating the situation and taking appropriate action to recover the aircraft. However, there is a less well defined syndrome that results in cognitive and functional impairment without the complete loss of muscle tone and body position seen following G-LOC. This is termed 'Almost' Loss of Consciousness (A-LOC). Annex A

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1.4.46. **Symptoms of A-LOC**. A-LOC is caused through a similar mechanism as G-LOC, although it has been less well studied scientifically. It is characterised by a number of physiological, emotional and cognitive signs and symptoms and its features include sensory abnormalities, amnesia, confusion, euphoria, paralysis and reduced auditory acuity. One distinctive feature is the apparent disconnect between the desire and the ability to perform an action. A-LOC symptoms have a potential to cause significant loss of aircrew performance. Unlike G-LOC, with A-LOC muscle tone is not lost and an individual may be able to hold stick forces but, while motor senses remain, cognitive functions may have stopped. If someone experiences A-LOC their initial recovery period may be shortened, in comparison with G-LOC, such that it can start to occur within a few seconds of G levels reducing below their relaxed G tolerance (Centrifuge trials suggest an average unprotected and relaxed G tolerance is approximately 3.5G; although this will vary on an individual basis). In reality, the demarcation between A-LOC and G-LOC may often be somewhat indistinct, and G-induced impairment may be regarded as a spectrum with differing degrees of cognitive function. Annex A Witness 30

1.4.47. **Previous G-LOC Accidents/Incidents**. Notwithstanding the theory, no RAF aircraft accident had ever been attributed to G-LOC. In an attempt to ascertain the actual likelihood of a G-LOC event the Panel studied data from the last RAF G-LOC survey report and previous RAF G-LOC incidents. Exhibit 38

1.4.48. **UK G-LOC Surveys**. The RAF and USAF have each conducted G-LOC surveys. The RAF surveys commenced in the 1980s with the most recent being conducted in 2004. The 2004 survey was sent to approximately 5500 aircrew of which 2259 responded. The following is a summary of pertinent points from the post-survey report: Exhibit 38

a. 454 aircrew reported having a single episode of G-LOC(20.1%); 2 G-LOC episodes were reported by 82 aircrew (3.6%); and 3 or more episodes by 43 aircrew (1.9%).

b. G-LOC was most common when aircrew were under training (70.9%), but was also reported by aircrew in instructional duties (13.7%), front-line duties (12.3%), and display pilots and other miscellaneous groups (3.1%).

c. If G-LOC among current fast jet aircrew only was considered there was a prevalence of 6% (135 aircrew) in this group.

d. G-LOC was most common in aircrew with fewer than 100 flying hours on type and was more prevalent in aircrew with fewer total flying hours, however, beyond 250 hours the prevalence of G-LOC appeared fairly constant.

e. G-LOC occurred in the range of 3 to 9 +Gz, but was most common between 5 to 5.9 +Gz (37% of all reported G-LOC).

f. Acceleration onset rate was described as 'rapid' in 86.1% of G-LOC events. Only 27.3% of respondents were controlling the aircraft at the time.

g. Only 55.3% of aircrew claimed to be performing an AGSM.

h. The propensity for G-LOC at an early stage in training was consistent with data collated from the United States Air Force (USAF).

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i. Analysis of USAF data suggested that while G-LOC incidents were most common in basic training aircraft, the proportion of G-LOC accidents were higher in single seat aircraft than any other category.

j. US data also suggested that prediction of individual characteristics which may predispose to G-LOC accidents proved difficult.

k. A poor AGSM was cited in 72% of all USAF G-LOC events.

l. After centrifuge training was introduced, USAF Safety Centre data indicated a decrease in the number of G-LOC accidents from 4.4 per million flying hours to 1.6 per million flying hours; which broadly equates to the loss of one USAF aircraft every year.

1.4.49. **RAF G-LOC Incidents**. In addition to G-LOC survey data, the Panel investigated the formal recording of G-induced impairment incidents since 1 Jan 00, a summary of which is at Table 3. Exhibit 35

Table 3 – Summary of Reported G related incidents from 1 Jan 00 - Aug 11

Serial (a)	Aircraft Type (b)	Station (c)	Year (d)	Brief Description (e)
1	Tucano	Linton	2001	Student pilot experienced G-LOC at 5 G during dual sortie
2	Hawk	Valley	2005	G-LOC when solo during air evasion training
3	Hawk	Valley	2005	Rear seat student pilot experienced G-LOC at 6.3 G
4	Hawk	Valley	2006	Anti-G equipment malfunction
5	Hawk	Valley	2006	Reduction in my peripheral vision
6	Tucano	Linton	2006	Student pilot Greyout during high G manoeuvres
7	Tornado	Leuchars	2006	Grey-out following rapid onset
8	Typhoon	Coningsby	2006	Greyout
9	Typhoon	Coningsby	2007	Blackout with no pre-symptoms
10	Typhoon	Coningsby	2007	Greyout
11	Typhoon	Coningsby	2007	Greyout
12	Typhoon	Coningsby	2011	Anti-G equipment malfunction

Inspection of Table 3 indicated that there had been a step increase in the number of reported incidents between 2005-2007. Of note, this increase occurred immediately after serial 2 which was a particularly "close call" and resulted in the pilot submitting a separate HF Open Report. A brief resume of the incident and the pilot's post-recovery actions is as follows. Exhibit 36 Witness 32

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a. **RAF Valley 2005**. An A2 Hawk T Mk1 QFI, was conducting evasion training in Southern Scotland. After gaining visual contact with the target aircraft he committed to a 7.3g turn; thereafter he recalled the following:

'As I recovered, although I didn't immediately realise that I was flying an aircraft, my first recollection that something was amiss was when I was able to hear aircraft noise but was unable to see. I regained a degree of poorly focused vision soon after and, despite being extremely disorientated and confused, became aware that my aircraft was in a descent and in close proximity to the ground. Although I cannot recall the aircraft's flight attitude or the moment at which I commenced recovery, I applied sufficient aileron and tail plane control inputs to affect a recovery. During the recovery I falsely perceived that the aircraft had slowed to approximately 120kts and was stalling. In reality the aircraft was flying in excess of 360kts and, in my post G-LOC confusion, I was unable to discern a low speed stall from the wing rock and manoeuvre buffet caused by the 7.75G recovery. It was only at this very late stage of the recovery that I was first able to consider ejection. Although briefly contemplating [this], I felt 'unable' to make a coherent decision and was able only to continue with the recovery.'

Post incident analysis indicated that the pilot narrowly avoided ground impact.

1.4.50. **Unreported incidents**. During the investigation the Panel became aware of 2 other incidents that may not have been formally reported and were able to trace the respective pilots who were willing to help with the inquiry. Their recollections of events are as follows:

a. **A former Hawk T Mk1 Display Pilot**. A former Hawk T Mk1 display pilot recalled: Witness 38

'I was doing a practice at RAF Valley, mid-season to extend my currency in accordance with Support Command regulations at that stage. To get maximum value out of the trip I decided to do two full shows and then one flat show. Everything was fine until the third run through and I went from an outside turn into a hard pitch for a wing-over, so minus 3½ to plus 6½ G and I just went. I was probably about 30 [degrees] nose-up when I lost vision and then went unconscious. After a few seconds, I guess, I recovered enough to realise I was in a jet going up, but I probably wouldn't have been able to do very much about it, if it wasn't going in the right direction, for another couple of seconds. I then rolled out and stopped the display. I mean the only thing I can guess from the fact -- how quickly it all happened was my boss, who was observing from the tower, didn't even notice anything was wrong and assumed I'd just reached minimum fuel, because I'd said to him before I went, "I'll stop the third show when I get down to bingo fuel or need to land or when I'm feeling I've done enough for currency". And so he just thought I reached that point when I terminated the show three or four manoeuvres early, whatever it was. But, I was definitely aware that I'd gone and there was nothing I could do about it.'

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b. **A Former RAFAT Pilot**. A former RAFAT pilot recalled: Witness 35 Witness 36

'When I started the RAFAT training, you didn't wear G-trousers. The thinking behind that was that you didn't want to have your hand locked in the position on the stick and then have G trousers inflating and moving your hand. One day, I think it was at the end of a very long working week, we came back to the airfield for a standard break [to land] which was pull, unload, and pull again. I "came to" downwind, hearing another chap [on the radio], I can't remember whether I heard him first, but I [do] remember hearing an aeroplane noise [and] thinking, "What am I doing here?" And fortunately I was just in a very, very gentle descent and able to sort it out.'

The pilot who had transmitted that radio warning recalled:

'As I rolled out downwind, I looked at the aircraft ahead who was descending through probably 400 feet. So I immediately just called out, "[X], check height". Nothing happened. "[X], check height". I can't remember how many times I called out to check height before I saw his aircraft go back up towards 500 feet. At the time I just thought it was very weird. It was unusual for [X], to fly so much off the correct altitude downwind. He's a very accurate sort of pilot. Anyway, he came in to land afterwards and he said [in the debrief] that he thought [he had experienced] G-LOC.....following the discussions, OC RAFAT said, "Right, that's it, everyone goes into G suits" and we all started flying with G suits.'

1.4.51. Both of the aforementioned incidents were openly discussed at unit level and procedures were amended locally in an attempt to prevent recurrence. However, the incidents were never formally recorded and little, if any, corporate knowledge remains of either event. Indeed it was somewhat fortuitous that the Panel were able to locate these pilots and their candid cooperation provided valuable evidence to the SI. Although this highlighted a broader issue of occurrence reporting, discussed at para 1.4.76, the remainder of this section will remain focussed on G-induced impairment.

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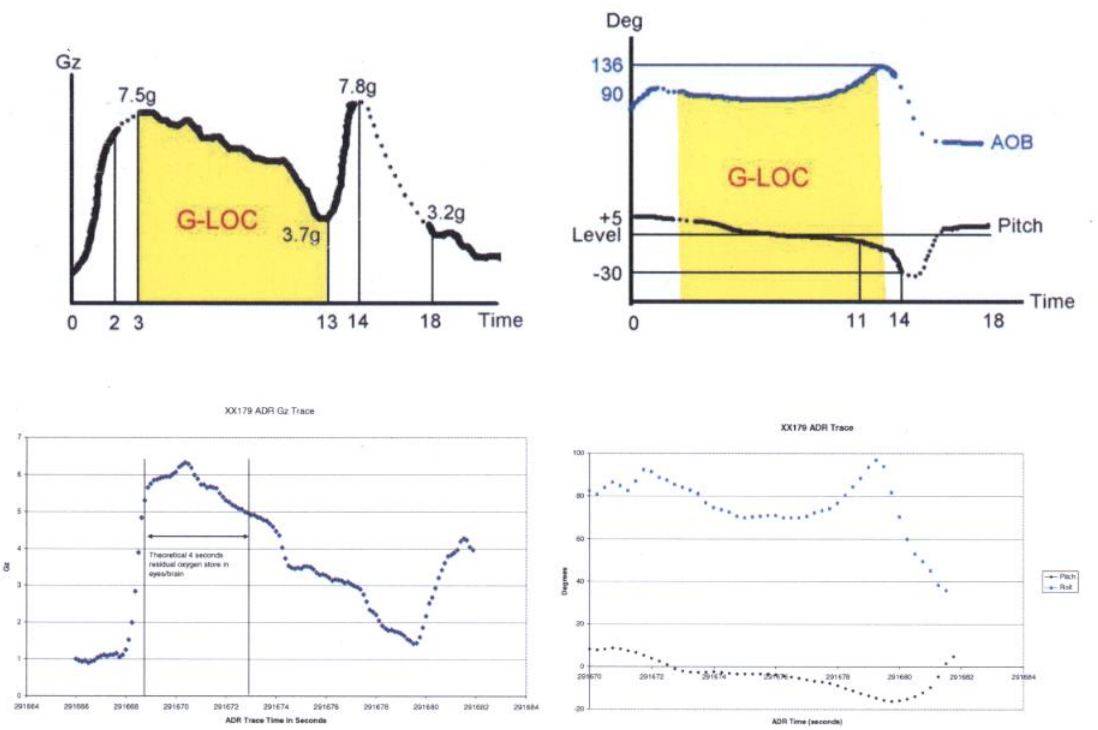
1.4.52. **Discussion of G-LOC Studies and Incidents**. The previous G-LOC studies provided valuable background information for the Panel. XX179's accident sequence Gz trace fitted many of the high-risk trends. For example, the trace demonstrated a high Gz onset rate, with an average Gz over the preceding 5 seconds of between 5 and 5.9 +Gz. The single pilot operation would appear to have placed the pilot in a higher risk group and while the pilot did not fit the most likely profile for G-induced impairment (inexperienced, low hours, in training) he may have been among the 6% of fast jet operators who appear to be more susceptible than their peer group. However, it was noted that US evidence suggested that trying to predict the characteristics that may predispose an individual to G-LOC was difficult. With respect to the 2 unreported incidents, the first occurred after a particularly aggressive manoeuvre and the second occurred to a pilot who was not wearing anti-G trousers. It would be easy to conclude, in isolation, that these explained the respective incidents. However, it should be noted that both these pilots had successfully flown these manoeuvres on many occasions without incident, they were not new, they were not unusual and yet for some reason they succumbed to the effects of G on that particular day. For the previous RAFAT incident, the sortie profile has close correlation with the XX179 accident as the team had completed a full display, then transited for 10-15 minutes and commenced the break. The 2005 RAF Valley incident also provided very tangible comparisons, and the data traces presented in the subsequent HF report are presented at Figure 13 with similar graphs re-created from XX179. Although the absolute values of G, pitch and roll are different, the gradients, and shapes, of the graphs bear a striking resemblance to each other. At the time, the 2005 incident was assessed as classic G-LOC, but no medical advice was sought from RAF CAM who are the RAF SMEs for such medical incidents. Subsequent RAF CAM opinion suggested that the 2005 incident was more likely to be attributed to A-LOC as the pilot had muscle tone throughout, otherwise he would not have been able to maintain the stick force required to maintain G on the aircraft. This apparent omission to seek medical advice appears to be consistent with several other minor G-induced impairment incidents.

Annex C
Exhibit 38
Witness 35
Witness 36
Witness 38
Exhibit 35

Figure 13 – Comparison of 2005 HF Open Report (top) with XX179 Accident (bottom)



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1.4.53. **G-induced impairment Conclusion**. In addition to the close correlation with previous incidents and survey data, this accident also correlated with theoretical medical data. For example, abnormalities commenced within a second of when the brain and eyes would have theoretically depleted their oxygen reserves (para 1.4.44). Additionally, the apparent attempt at recovery did not occur until several seconds after the G exposure dropped below +3.5Gz (average relaxed tolerance levels, see para 1.4.46). When combining trend data, incident comparison and medical theory, the SI Panel concluded that the most likely **causal factor** of the accident involving XX179 was A-LOC, leading to the reduced cognitive ability of the pilot which ultimately resulted in flight into terrain. Having established the most likely cause, the Panel then sought to examine what defensive barriers may have been breached or may have been absent for this accident to occur.

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G PROTECTION MEASURES

1.4.54. **Generic +Gz Protection Measures used on Hawk T Mk1**. Hawk T Mk1 aircrew are equipped with Mk4 anti-G trousers. These comprise inelastic trousers within which 5 air bladders are inflated to a pressure directly proportional to the exposed +Gz, providing, approximately, a personal G tolerance increase of between 1 and 1.5 +Gz. If properly fitting anti-G trousers are combined with a good AGSM (discussed previously in para 1.4.44), aircrew can sustain up to +8 to +9 Gz for periods of up to 15 seconds. The handling pilot will normally have a higher G-LOC threshold than non-handling aircrew as they can anticipate their own demands upon the aircraft. This is especially important during rapid G onset rates when the AGSM must be started at the outset of any manoeuvre and not delayed until any visual symptoms of G-induced impairment have developed.

Exhibit 15
Annex A

1.4.55. **Cultural Attitude to G**. Nearly all RAFAT pilots interviewed reported experiencing 'grey-out' and some loss of peripheral vision, although some stated that they would only formally report G-induced impairment if they lost full vision or if an incident was due to equipment failure. G-LOC was rarely, if ever, discussed and any G discussions were generally limited to aircraft fatigue or overstress considerations. Most pilots had not read about G-LOC since training and most were unaware of where to find up to date RAF G-LOC guidance. With respect to display flying, the supervisory chain were unaware of advice contained from a 1999 Hawk 200 accident report which recommended that all display manoeuvres should be considered for G-LOC potential. Overall, there was a general misperception concerning the high G risk points in the displays. Specifically, some RAFAT pilots thought that the display manoeuvres would expose them to a higher risk of G impairment than the Left/Right break. However, ADR evidence for XX179 indicated that the Left/Right break was the most significant combination of absolute Gz and exposure time on the day. Psychologist SME advice suggested that this incorrect mental model would have had a direct influence on the behaviour of pilots with some choosing to conduct a reactive AGSM for manoeuvres they perceived to be of a lower G level. To test this theory the Panel reviewed the end of show break (6.2g for 7.2 seconds) with the flat Left/Right Break (6.3g for 8.75 seconds) using the evidence from the 2 in-cockpit videos and ADR data; the panel also asked a RAF CAM SME to assess the AGSM techniques. During the end of show break, Red 1 gives a gradual and progressive call of speed as the aircraft accelerate out of a turn, calling "310, 330, 340, 350". This was primarily to assist Red 9 in rejoining the formation, however, the procedure also ensured other pilots were aware of their speed. When the display break was initiated one pilot clearly takes a large breath, whereas the other does not, but both remain quiet for the duration of the manoeuvre. On the lead up to the Flat Left/Right break no speed is called. On initiation of the break, one pilot appears to take a large breath but a few seconds afterwards commences laboured muttering. The second pilot does not appear to take any obvious breath at the start of the manoeuvre, but after 5 seconds commences obvious straining. For both pilots, the muttering/straining was coincident with their peak G during manoeuvre which may have indicated they were, at least in part, conducting a reactive AGSM. The AGSMs were assessed as non-optimal for maintaining a High G tolerance/head level blood flow. The Panel concluded that:

Annex C
Exhibit 1
Exhibit 9
Witness 1-2
Witness 11-2
Exhibit 34

a. A lack of G reporting and management may have masked the requirement for more frequent G awareness training.

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b. The RAFAT pilots did not consider G-LOC to be a high risk event.

c. Manoeuvres were not individually assessed for their G-LOC potential.

d. An incorrect mental model of the Flat Left/Right break may have influenced RAFAT pilots' perception of G-LOC risks.

e. From the 2 in-cockpit videos available as evidence, re-active AGSMs appeared to have been undertaken during the break to land and the techniques observed were assessed as non optimal by a RAF CAM SME.

f. The audio evidence from in-cockpit video was invaluable in assessing when pilots commenced straining during manoeuvre. A cockpit voice recording from XX179 would have significantly assisted this investigation (**Observation**).

g. Overall, the cultural attitude to G was assessed as a **contributory factor** in this accident.

1.4.56. **G Awareness Trg**. All aircrew are mandated, under MRP Regulatory Article (RA) 2135(6), to receive 5 yearly aviation medicine training at RAF CAM which, for fast jet aircrew, includes classroom-based G awareness training. The pilot of XX179 had completed refresher training in Jul 10. RA2135(6) also states that '*Individual Aviation Duty Holders and Commanders **should** issue guidance for continuation training in aviation medicine for aircrew engaged on flying duties'*. There was no formal record of any guidance offered within either 22(Trg) Gp Orders (TGOs) or the RAFAT Display Directive (DD). As stated at para 1.4.55, when aircrew were asked to explain G-induced impairment, interviewee knowledge was varied with a high percentage not knowing where to find advice and guidance on G-LOC in official documentation. Such information is contained within the RAF Manual of Flying Training (AP3456, 6-1-1-3 (Aviation Medicine)) which the Panel considered to be presented in a clear and concise manner, although there the description of the AGSM appeared to slightly contradict current RAF CAM teaching. The Panel concluded that:

Exhibit 88
Exhibit 103
Annex C
Exhibit 15

a. The pilot was current in accordance with RA2135(6).

b. Guidance on aviation medicine continuation requirements was not given in TGOs (**Observation**).

c. Some minor discrepancies, with respect to the AGSM, existed between SME advice given to the Panel during the SI process and the advice within AP3456, 6-1-1-3 (**Observation**).

d. Overall, inadequate G awareness was a **possible contributory factor** in this accident.

1.4.57. **High G Practical Trg**. Centrifuge based high G training not only promotes G awareness, but it also allows aircrew to recognise their own warning symptoms, develop an efficient and effective AGSM and develop the confidence in their ability to sustain high Gz acceleration. However, the history of centrifuge training within the RAF is complex and piecemeal. Following a G-LOC survey in 1987, training had been provided for targeted groups on a stop/start basis but it was not until 2005 that training was provided for all Basic Fast Jet Training students through an agreement between 22(Trg) Gp and RAF

Annex A
Exhibit 88
Exhibit 23
Witness 35

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CAM. Subsequently, High G training was formally mandated for all fast jet aircrew through Change 8 to Joint Services Publication (JSP) 550, in Nov 10, which was implemented to ensure compliance with NATO Standardization Agreement (STANAG) 3827. Subsequently the MRP superseded JSP and RA 2135(7) has been modified to target High Risk groups as opposed to a more narrow focus on fast jet aircrew. Currently, High G training occurs early in flying training, before aircrew fly in aircraft with anti-G systems, and extant regulation does not mandate any currency requirements on centrifuge training. The pilot of XX179 had attended a High G centrifuge trg course in 2002. However, he had been flying the Harrier GR9 since Jan 06 which was a relatively low G aircraft, typically not exposing the pilot to more than +4.5 to +5Gz, and even then not for prolonged periods. There is the potential that skill fade may have resulted in an ineffective AGSM in the intervening years and while there was no definitive evidence to suggest this was the case such speculation would have precedence, as one former RAFAT pilot recalled:

'On the Reds, certainly in backseat trips, I always had to really concentrate on [the AGSM] *and I can remember having to relearn* [it] *because I hadn't done it for so long. In the* [X] *it was enough to have G-trousers and a little bit of straining, I suspect. When I finally got to grips with why I was struggling, sat in the back seat, it was because I was taking one great big breath and kind of holding it; I'd forgotten how to do a G-straining manoeuvre properly'*

It is possible that G awareness was deficient, and that over-reliance on visual symptoms during high G onset rate manoeuvring may have led to a delayed or an ineffective AGSM. Although these factors are speculative, in the final turn of the sortie it remains likely that the pilot succumbed to impairment related to G exposure. The panel also noted that the G-LOC Report, discussed at para 1.4.48, highlighted that an ineffective AGSM had been cited in 55% of all UK G-LOC incidents and 72% of all USAF G-LOC incidents. The Panel concluded that:

a. The pilot was current in all aspects of High G Trg in accordance with RA 2135(7).

b Without continuation training, high risk aircrew groups may develop ineffective AGSM techniques, especially after completing a tour on a relatively low risk platform. The accident pilot may have developed an ineffective AGSM technique and this was a **probable contributory factor** in the accident.

1.4.58. **Centrifuge Trg facility**. The only human rated centrifuge within the UK cannot meet all the requirements of STANAG 3827, owing to an inability to achieve a 3G/sec minimum onset rate (the UK had a formal dispensation for this, with the expectation that this limitation is mitigated by live flying training). The need to improve the UK human centrifuge facility had been identified in 1994 as a consequence of the planned introduction of Typhoon into RAF service. While the requirement to update was accepted, and a contract was placed in 1997 to supply a new centrifuge, the programme was subject to lengthy delays and eventually terminated in Jul 01. RAF CAM opinion is that 75% of their training requirement can be delivered with the extant facility, including recognition of an individual's pre G-LOC symptoms and the teaching of an effective AGSM. However, limitations of the extant facility have resulted in RAF CAM being unable to teach the management of High G onset rates. The Panel concluded that the failure to deliver an updated centrifuge training facility may have resulted in non-optimal training for UK aircrew and this was a **possible contributory factor** in this accident.

Exhibit 39
Annex A
Witness 30

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1.4.59. **Anti-G Trousers**. The pilot's anti-G equipment was discussed at para 1.4.39. Looking at the broader aspects of AEA protection, the basic design of the 5 bladder anti-G suit has remained relatively unaltered since the 1950s. With the advent of highly agile combat aircraft, in the mid 1980s a series of centrifuge trials were undertaken by the Institute of Aviation Medicine (IAM, now RAF CAM) to ascertain the effectiveness of a new design called Full Coverage Anti-G Trousers (FCAGT). The resultant trial used 6 aircrew who were subjected to a series of centrifuge runs, without an AGSM, to determine the Gz level at which they lost 60% peripheral vision. The results concluded that: without any G protection this occurred at 3.5g, with conventional 5 bladder G trousers this occurred at 5.2g, and with the prototype FCAGTs this occurred at 6.5g. FCAGTs are now used on Typhoon in conjunction with pressure breathing to provide a significant improvement to aircrew protection. However, the Panel noted that Typhoon AEA training had been provided on the RAF CAM Hawk T Mk1 at Boscombe Down and traced the original project pilot who had played a large part in integrating the AEA with the aircraft. It appeared that although a modified AGV had been fitted to the RAF CAM Hawk, this was the only modification required, and this was only because the aircraft would be operated at 9G, which was outside the extant Release to Service (RTS). It appeared that if the aircraft was to be flown within the extant RTS there was no requirement for the modified valve. The Panel also noted 2 other reports from the 1980s and 1990s which highlighted that updated G equipment, in conjunction with Pressure Breathing, had also been trialled using Hawk QTIs at RAF Brawdy and RAF Akrotiri with positive results on both occasions. Further afield, evidence from the United States Air Force (USAF) Test Centre suggested that after a series of G-LOC accidents, the USAF were considering retrofitting their high (Gz) risk platforms with FCAGTs. The Panel concluded that:

Annex A
Exhibit 40
Exhibit 41
Exhibit 42
Exhibit 37
Exhibit 43

a. Better G protection equipment may have been available for the Hawk T Mk1.

b. Further work would be required to establish the feasibility of offering FCAGT protection for Hawk T Mk1 aircrew.

c. Conventional 5 bladder anti-G trouser design no longer offer aircrew the best possible protection against G impairment and this was considered a **contributory factor**.

1.4.60. **Physiological Factors which may reduce G Tolerance**. Regardless of the level of +Gz protection offered, certain physiological factors can conspire to reduce G tolerance. These are: increase body temperature; dehydration; minor illness; decrease in blood sugar; alcohol ingestion; hyperventilation and hypoxia; body morphology; time-off-flying (termed 'G layoff') and fatigue. These are discussed individually as follows:

Exhibit 15
Annex A

a. **Increased body temperature**. There was no evidence to suggest that the pilot had been suffering from any infection or fever that may have contributed to an increased body temperature. Additionally the Hawk T Mk1 cabin conditioning system is efficient. The temperature control switch was found to be in the normal operating position and the Panel concluded that it was **unlikely that increased body temperature was a factor** at the time of the accident.

Annex A
Annex L

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b. **Dehydration**. The post mortem examination was unable to provide an indication of the pilot's hydration state. However, it was noted that the pilot completed a morning run of approximately 5 miles and it was possible that the pilot may not have rehydrated sufficiently following this activity. Additionally, the demanding physical requirements of a RAFAT display could have contributed to a state of dehydration. The Panel concluded that the pilot's hydration level was a **possible contributory factor** in this accident. Annex A

c. **Minor Illness**. The pilot's medical records indicated that he had suffered from a painful cervical spine. He presented to the RAF station physiotherapist on 9 Mar 11 and was advised with a programme of neck stretches. There were no further consultations regarding cervical pain documented in his RAF medical notes. However, the Panel **observed** that that he had sought treatment from a local civilian osteopath on 27 Jul 11. Manipulation and mobilisation treatment was performed and hydrotherapy and exercise advice was given. It was indicated that if required a further appointment in 2 weeks could be considered. The osteopath practice indicated that an appointment had been made by the pilot for the 23 Aug 11, a rearrangement of an appointment on 19 Aug 11. However, the circumstances prompting this appointment are not known and it may be unrelated to any previous condition. On the morning of the accident it is apparent that he had experienced some back pain and had self-medicated with ibuprofen. Ibuprofen is a non steroidal anti-inflammatory drug which is useful for pain relief of low grade pain, but the typical side effect profile, such as gastro-intestinal discomfort, is unlikely to have affected his flying task. However, any acute cervical pain during the break manoeuvre could have prevented the pilot from performing an optimal AGSM. Although no acute cervical pain event was identifiable at the post mortem examination, it would be extremely difficult to confirm such an occurrence during such an examination. The Panel concluded that while any cervical pain would not have directly reduced the pilot's G tolerance, a recurrence of such pain may have degraded the pilot's ability to perform an effective AGSM and therefore acute cervical pain was a **possible contributory factor** in this accident. Annex A

d. **Decrease in Blood Sugar**. The pilot had eaten breakfast and lunch prior to the accident sortie, so it is unlikely the pilot would have succumbed to an episode of reduced blood sugar. The Panel concluded that decreased blood sugar supply was **unlikely to have been a factor** in this accident. Annex A Witness 4

e. **Alcohol Ingestion**. The post-mortem examination revealed no evidence of pre-mortem alcohol ingestion. The Panel concluded that alcohol ingestion was **not a factor** in this accident. Annex A

f. **Hyperventilation and Hypoxia**. Examination of the aircraft oxygen system revealed no anomalies. Hypoxia was extremely unlikely as the final high G turn occurred below 500ft and, while it is impossible to prove the pilot was not hyperventilating, this would be abnormal. Additionally, the pilot's radio transmissions over the preceding several minutes seemed normal. Other pilots, whose aircraft were fitted with in-cockpit video, had a normal breathing pattern. The panel **observed** that a cockpit voice recording facility would likely have detected if the pilot had been hyperventilating, but this is not standard fit for Hawk T Mk1. The Panel concluded that it was **unlikely that hyperventilation or hypoxia were a factor** in the accident. Annex A Exhibit 1

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g. **Body Morphology**. The pilot was physically fit and was neither under nor overweight. Anaerobic training may increase the time for which aircrew can sustain high levels of +Gz acceleration, possibly by permitting a more efficient and prolonged straining manoeuvre. However, excessive aerobic conditioning may be self-defeating, as it suppresses the reflex compensations required to counter high G, and such training should not be taken so far as to depress the resting heart below 55 beats/min. The pilot's blood pressure at his recent annual medical was within the normal limits, as was his pulse rate (69 beats/min). The Panel concluded that the pilot's body morphology was unlikely to have had a detrimental factor on his G tolerance and was therefore **not a factor** in the accident. Annex A

h. **Time off Flying (G Lay off)**. RAFAT block leave finished in early August and the pilot had flown 33 times since returning to work. He had flown at least once per day since his last 'down day' on 16 Aug and had flown 5 displays and 3 transit sorties since then. The Panel concluded that G layoff was unlikely to have affected the pilot's G tolerance and was **not a factor** in this accident. Annex A

i. **Fatigue**. The pilot had flown 5 public displays and 3 transit flights since his last, single rest day on 16 Aug 11. He had spent his single rest day at home and reportedly used the time to catch up with some secondary duties; the wider aspects of working on rest days is discussed at para 1.4.85. Prior to this he had flown 27 sorties since returning to work from block leave on 5 Aug 11. Although the team's schedule conformed to TGOs for crew duty, the intense work period around single rest days may have counteracted the benefits of the time off work and some level of fatigue may have been present. However, the pilot had flown the same schedule as other RAFAT pilots who all rated their working pattern, task demands, body clock, fitness and readiness for work as OK or ideal. As previously stated the pilot had completed an approximate 5 mile run on the morning of the accident. Although he was a fit individual who was used to a regular exercise regime, the Panel could not discount the possibility that pre-duty exercise may have resulted in increasing his residual fatigue levels. The Panel concluded that fatigue may have reduced his G tolerance and his ability to perform an effective AGSM and was therefore a **possible contributory factor**. Annex A Exhibit 96 Annex C

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LEFT/RIGHT BREAK PROCEDURES

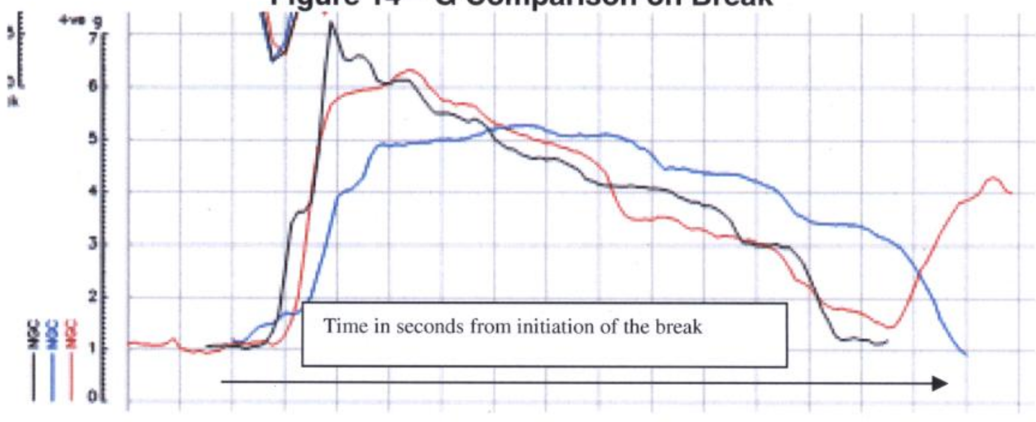
1.4.61. **Left/Right Break**. Several RAFAT pilots were asked to detail the Left/Right break procedure. In general, their explanation of the manoeuvre was broadly consistent in that the manoeuvre was a visually flown, climbing break, from 100ft to 500ft AGL, requiring the aircraft to be rolled, relatively quickly, to approximately 80° angle of bank before initiating a pull to the buffet and then selecting the throttle to idle and the airbrake out. The pilot would then alter the bank angle to capture and maintain 500ft AGL, while holding the buffet level as the aircraft decelerated. Expected entry speed was generally defined as a bracket, depending upon whether the break was flat or looping, between 330KIAS to 360KIAS. Several pilot's stated that if the team were faster than anticipated, then the leader would transmit the codeword "hot" and this would warn them to expect a little more Gz if using the standard technique and, by implication, fly a slightly less aggressive entry to the manoeuvre.

Witness 1
Witness 3
Witness 5
Witness 8

1.4.62. **SOPs**. When the Panel cross-referred pilot opinion with the RAFAT SOPs several anomalies were observed. Although the Left/Right break SOPs were well defined from a domestic perspective (in terms of renumbering, order of the break, de-confliction and smoke procedures) little else was detailed. In the absence of clearly defined parameters, some RAFAT pilots appeared to be using the break minima of 100ft MSD (to be discussed later) as a perceived start point for the manoeuvre. It was also apparent that there was no targeted entry speed, no maximum entry speed, no defined procedure for calling "hot", no prescribed technique for the break itself and, by default, no explanation of how the break technique should be altered if "hot" was called. It was initially suggested that "hot" would only be called if the team were between 390KIAS to 400KIAS, although this was later refined to 15-20 knots fast and then 10-15kts fast. This opinion differed from a previous OC RAFAT who suggested "a little hot" would be called at 370 KIAS with "very hot" called at 380 KIAS. With diverging opinion on what the break procedures actually were, the Panel compared the accident aircraft's Gz trace with the Gz trace from 2 other aircraft on the break, as shown at Figure 14. It was observed from the resultant Gz trace that at least 2, possibly 3, differing techniques were being used. One trace is indicative of a pull to 5g and wait for the buffet. The other 2 appear to pull straight to the buffet albeit the initial Gz level varied by approximately 1.5g and the time to peak G differed by approximately 1.4 secs. On the day, the accident pilot broke at 384 KIAS and from approximately 230 ft AGL. No hot call was made before the break.

Exhibit 10
Exhibit 11
Witness 1-1
Witness 1-2
Witness 1-4
Annex M
Exhibit 1

Figure 14 – G Comparison on Break



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1.4.63. **Discussion On Break Procedure**. The amount of Gz available to a pilot is directly proportional to speed and, when in close formation, a pilot may not be aware of their exact speed at any given time. Therefore, a timely, pre-defined "hot" call would provide heightened situational awareness. To ascertain the likely Gz increase, due to a fast break, the Panel referred to BAE Systems/QinetiQ provided Hawk T Mk1 lift boundary data; previously presented at Figure 1. The accident pilot should have been aware that the team were initially recovering for either a looping or flat break, due to Red 1's transmitted intent, and he should have known that a loop would have required a minimum of 360 KIAS, as detailed in the RAFAT DD. The formation having declared fuel priority at around 3 minutes to run and with the decision in favour of a flat Left/Right break being made at 1 minute 42 seconds to run, which was not accompanied by a power change, it may not be unreasonable to assume that the accident pilot would have expected the aircraft to remain at approximately 360KIAS, or possibly even decreasing. On that basis, the increase in Gz that may have resulted from a 384 KIAS break speed, vice 360 KIAS, was approximately 0.7g. Alternatively, had the accident pilot been anticipating a break entry speed at the 330 KIAS lower end of the 'normal' bracket, the increased Gz would have been approximately 1.4g. The Panel cross referred to recent Left/Right breaks flown by the pilot and noted that 2 were flown on 17 Aug with the speeds broadly equalling the break speed on 20 Aug (one being 2-3 knots faster and the other being 2-3 kts slower). The Panel concluded that:

Annex M
Exhibit 1
Exhibit 12

a. In general, the RAFAT had an over-reliance upon word of mouth, or experiential, SOPs and this was an **other factor**.

b. The pilot would have been aware of the required speed for a looping break and, although the flat break manoeuvre was flown slightly fast and to higher initial Gz without a 'hot' call, he should have been aware of the need for an AGSM. However, a 'hot' call may have acted as a mental prompt to ensure that an appropriate AGSM was applied from the outset of the break, and that the absence of a 'hot' call was therefore a **possible contributory factor**.

c. While the absolute values of Gz and the duration of exposure was inside the spectrum of what could be tolerated by an effective AGSM, and this break had been flown successfully many times in the past, the combination of manoeuvre speed, technique, and lack of detailed SOPs, was a **contributory factor** to this accident.

1.4.64. **Break Entry Height, Approvals and Regulatory Waivers**. The RAFAT break height is stipulated by Commandant (Comdt) CFS within Part 1 of the 2011 RAFAT DD as follows; '*The normal minimum run in height for a break is 250 ft MSD. However, once the formation is established straight and level, on the correct track for the break, and within the airfield boundary, this may be reduced to NB 100 ft MSD.*' The 100ft break for RAFAT operations appeared to have been common practice for many years and the wording within the DD remained unaltered from the 2008 DD signed by the extant Comdt's predecessor. The Panel accepted that, in a display context, there may be a valid reason to undertake such activity but would have expected this to have been formally recorded in the PDA with appropriate dispensation to any relevant Regulation. RA2335 (Flying Displays) clearly stated that the only display flying manoeuvre that could be flown below 300ft MSD was a straight and level flypast (max 20 degrees angle of bank). With respect to the accident the team actually flew the break from a bracketed height of approximately 200-250ft MSD and the run-in was flown in a safe and well controlled manner. The Panel concluded that:

Exhibit 10
Exhibit 13
Exhibit 14
Exhibit 89

a. Although a 100ft MSD break to land had been commonplace for many years, this was not formally approved within the PDA. (**Observation**)

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b. The DDH's authorisation of breaks below 300ft MSD for display flying was in contravention of RA 2335. (**Observation**)

c. The run-in height did not contribute to the onset rate of Gz, the absolute value of Gz or the length of exposure to Gz and therefore the break entry height was **not a factor** in this accident.

1.4.65. The RAFAT had several Regulatory Waivers to RA2335, one of which relaxed the minimum display cloud base requirement from 1000ft to 700ft; specifically to permit a restricted flat display in inclement weather. However, the Panel noted that the RAFAT also conducted display recoveries in a 700ft cloud base post training sorties, flying displays and transit flights, and this activity was not covered by the extant waiver. The Panel does not advocate unpicking every aspect of RAFAT operations to prove they are safe from first principles and accepts that certain mitigation has developed through a process of experiential learning. However, the Regulatory Waivers request should have identified all activity that required a dispensation to the cloud base minima and identified any 2nd order risks associated with a dispensation to Regulations. This would allow the Duty Holder Chain and the Regulator to make a fully informed decision. Lastly, 22(Trg) Gp's Regulatory Waiver request asked for dispensation to remain until 2012 PDA. However, the Regulatory Waiver that was granted did not explicitly state the validity period within the main body of the text and the letter's subject heading suggested the waiver was only valid for the 2011 Display Season. The Panel concluded that: Exhibit 56 Exhibit 57 Witness 1-2

a. The Regulatory Waiver request did not capture all risks associated with display flying in a 700ft cloud base nor did it identify the frequency with which the dispensation was expected to be exercised. (**Observation**)

b. The current practice of conducting display recoveries in a 700ft cloud base was not covered by an extant Regulatory Waiver. (**Observation**)

c. The Regulatory Waiver approved for the RAFAT did not have an explicit validity period in the text. (**Observation**)

1.4.66. **Downwind Height**. The RAFAT used a single circuit height of 500 ft to standardise all recoveries. When queried why 2 different circuit heights could not be practised, it was suggested that the introduction of variable heights into a dynamic manoeuvre could make the visual cues associated with opposition circuits overly complicated. When examining the XX179 ADR trace it is apparent that the aircraft briefly levelled at approx 500ft before entering a gradual descent. It was also assessed that, in the 3.5 seconds prior to impact, the aircraft attitude had altered from 16° nose down to 5° nose up and from 97° of right bank to 18° of right bank. At impact, XX179 was pitching up at 17° per second with an estimated flight path vector of between 1° and 3° nose down. On the assumption that the recovery would have continued, had ground impact not occurred, the 6DOF aerodynamic modelling suggested that the aircraft would have required an additional 70ft to recover from the manoeuvre. The Panel accepted that the aircraft flight path data and control inputs are accident specific and cannot be read across to future incidents. Nevertheless, for this accident the Panel concluded that had this break been flown to a targeted downwind height of 600ft or greater then it was likely that the pilot would have recovered XX179. Therefore, the downwind circuit height of 500ft was a **contributory factor** to this accident. Annex M Exhibit 113

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