Defence
Safety Authority

Service inquiry

Loss of F-35B Lightning ZM152 (BK-18) of 617 Squadron RAF, embarked on HMS QUEEN ELIZABETH

17 November 2021

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PART 1.1

Covering Note & Glossary

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PART 1.1 – COVERING NOTE

DSA DG/SI/06/21

18 Nov 21

DG DSA

SERVICE INQUIRY INVESTIGATION INTO THE LOSS OF F-35B LIGHTNING ZM152 (BK-18) FROM 617 SQUADRON, EMBARKED ON HMS QUEEN ELIZABETH, ON 17 NOV 2021

1. The Service Inquiry panel assembled at MOD Boscombe Down, on 2 Dec 21 by order of the DG DSA for the purpose of investigating the accident involving F-35B ZM152 on 17 Nov 21 and to make recommendations in order to prevent reoccurrence. The panel has concluded its inquiries and submits the provisional report for the Convening Authority's consideration.

2. The following inquiry papers are enclosed:

Part 1 REPORT Part 1.1 Covering Note and Glossary Part 1.2 Convening Orders & TORs Part 1.3 Narrative of Events Part 1.4 Findings Part 1.5 Recommendations	Part 2 RECORD OF PROCEEDINGS Part 2.1 Diary of Events Part 2.2 List of Witnesses Part 2.3 Witness Statements Part 2.4 List of Attendees Part 2.5 List of Exhibits Part 2.6 Exhibits Part 2.7 List of Annexes Part 2.8 Annexes Part 2.9 Schedule of Matters Not Germane to the Inquiry Part 2.10 Master Schedule

{electronically signed}

[redacted]
F-35 SI President

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[redacted]
F-35 SI Engineering Member

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F-35 SI Engineering Member

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GLOSSARY

ADA	Aircraft Dispatch Actions
ADS	Air-System Document Set
ADU	Automatic Deployable Unit
AE	Air Engineering
AEA	Aircrew Equipment Assemblies
AED	Air Engineering Department
AESO	Air Engineering Standing Order
AET	Air Engineering Technician
ALARP	As Low As Reasonably Practicable
ALIS	Autonomic Logistics Information System
APU	Auxiliary Power Unit
AREL	Arm Restraint Extension Line
ASC	Aviation Services Co-ordinator
ATC	Air Traffic Control
ATSB	Australian Transport Safety Bureau
Aux	Auxiliary
BAES	British Aerospace Systems
BK	B variant F-35B built for the UK
BOS	Before Operation Servicing
BRd	Book of Reference digital (Royal Navy)
CAFC	Combat Air Force Commander
CAFHQ	Combat Air Force Headquarters
CAG	Carrier Air Group (Commander)
CAMO	Continuing Airworthiness Management Organisation
Cdr	Commander
Cdr Air	Commander Air
Cdr AE	Commander Air Engineering
CDS	Chief of the Defence Staff
CFD	Captain of the Flight Deck
CLAW	Control Law
CMS	Combat Management System
CO	Commanding Officer
COD	Crash On Deck
CODEX	Crash On Deck Exercise
CPO	Chief Petty Officer
CQ	Carrier Qualification
CSG	Carrier Strike Group
CSMU	Crash Survivable Memory Unit
CT	Computerised Tomography
CTOL	Conventional Take Off and Landing
CVW	Carrier Air Wing
C5ISR	Command, Control, Computers, Communications, Cyber, Intelligence, Surveillance, and Reconnaissance
DAIB	Defence Accident Investigation Branch
DASOR	Defence Air Safety Occurrence Reporting
DAvMed	Diploma in Aviation Medicine
DDH	Delivery Duty Holder

DE	Defence Engagement
DE&S	Defence Equipment and Support
DentO	Dental Officer
DFC	Designated Flying Course
DHAN	Duty Holder Advice Note
DMSpA	Direct Maintainer Spaces per Aircraft
DOO	Deck Operations Officer
DPMO	Deputy Principle Medical Officer
EDM	Exhaust Debris Monitoring
EFSSC	Embarked Forces Sea Survival Course
ERB	Engineering Review Board
ETR	Engine Thrust Request
Ex	Exercise
F	Lt Cdr Flying 1
F2	Lt Cdr Flying 2
FADEC	Full Authority Digital Engine Control
FBW	Fly By Wire
FCS	Flight Control System
FDO	Flight Deck Officer
FDHOC	Flight Deck Hangar Operations Centre
Flt Lt	Flight Lieutenant
FLYCO	Flying Control
FOD	Foreign Object Debris / Damage
FOST	Fleet Operational Sea Training
FSOG	Final Statement of Generation
FSR	Field Service Representative
ft	Feet (distance)
GSSO	Government SAP Security Officer
HMD	Helmet Mounted Display
HMS	His / Her Majesty's Ship (Her Majesty's at the time of the accident)
HQ1	Headquarters 1 for the Ship's damage control and incident management
HUD	Heads Up Display
IAS	Indicated Airspeed
ICC	Issue Centre Custodian
IDMD	Inlet Debris Monitoring Downstream
IDMU	Inlet Debris Monitoring Upstream
IPCC	Intergovernmental Panel on Climate Change
IPP	Integrated Power Pack
JARTS	Joint Aircraft Recovery and Transportation Squadron
JDRB	Joint Deficiency Review Board
JEngO	Junior Engineering Officer
JOAP	Joint Oil Analysis Programme
JNCO	Junior Non-Commissioned Officer
JPO	Joint Programme Office
JSTAG	Joint Strike Training Assurance Group
JTD	Joint Service Technical Data
kts	Knots (speed)
LDT	Lighting Delivery Team see DE&S
LF	Lightning Force

LFHQ	Lightning Force Headquarters
LM / LMA	Lockheed Martin / Aeronautics
LP	Life Preserver
LSO	Landing Signals Officer
Lt	Lieutenant
Lt Cdr	Lieutenant Commander
MAME	Military Aviation Medical Examiner
MAR	Military Airworthiness Review
MARC	Military Airworthiness Review Certificate
MB	Martin Baker Aircraft
MCAS	Marine Corps Air Station
MCSU	Maritime C5ISR Support Unit
MDC	Micro Detonation Cord
Met	Meteorology / Meteorological
METAR	Meteorological Terminal Area Reporting
METOC	Meteorological and Oceanographic (QEC system)
MHQ	Medical Headquarters
Mil	Military Power
Mil CAM	Military Continuing Airworthiness Manager
Mk	Mark
MLG	Main Landing Gear
MOA	Memorandum of Agreement
MRI	Magnetic Resonance Imaging
NAS	Naval Air Squadron
NATOPS	US Naval Air Training and Operations Procedures Standardization
NG	Northrop Grumman
NLG	Nose Landing Gear
OCC	Operational Capability Certificate
OCU	Operational Conversion Unit
OEM	Original Engineering Manufacturer
OF / OR	NATO designation Officer / Other Ranks followed by a number of increasing seniority
Op	Operation
OSI	Occurrence Safety Investigation
P&W	Pratt and Whitney
PARMIS	Performance And Risk Management Information System (Air)
PCM	Post Crash Management
PCMIO	PCM Incident Officer
PE	Principal Engineer
PFE	Pilot Flying Equipment
Pitot	A method of measuring dynamic pressure and thus airspeed on aircraft
PJHQ	Permanent Joint Head Quarters
PLB	Personal Locator Beacon
PMD	Portable Memory Device
PMO	Principal Medical Officer
POS	Post Operation Servicing
PSP	Personal Survival Pack
PTMS	Power Thermal Management System
QA	Quality Assurance

QEC	Queen Elizabeth Class
QOR	Quality Occurrence Report
QNLZ	HMS QUEEN ELIZABETH
RAF	Royal Air Force
RAF CAM	RAF Centre for Aviation Medicine
RFAHX	Return Fuel/Air Heat Exchanger
RN	Royal Navy
RNFSC	Royal Navy Flight Safety Centre
RR	Rolls Royce
SA	Self Audit
SAC	Senior Aircraftsman/woman
SAC(T)	SAC (Technician)
SAP	Special Access Programme
SEngO	Senior Engineering Officer
SERF	Support Equipment Request Form
SNCO	Senior Non-Commissioned Officer
SNO	Senior Nursing Officer.
SQEP	Suitably Qualified and Experienced Personnel
Sqn	Squadron
Sqn Ldr	Squadron Leader
SE	Survival Equipment
STANEVAL	Standards Evaluation
STO	Short Take Off
STOVL	Short Take Off and Vertical Landing
TAA	Type Airworthiness Authority
TC2V	Tactical Command Communications Voice
TES	Test and Evaluation Sqn
TG	Task Group
US	United States
USAF	United States Air Force
USMC	United States Marine Corps
USN	United States Navy
USS	United States Ship
[redacted]	[redacted]
[redacted]	[redacted]
VSBIT	Vehicle Systems Built In Test
VSS	Visual Surveillance System
WCS	Wireless Communications System
WE	Weapon Engineering
Wings	See Cdr Air
WOEng	Warrant Officer Engineering
WTR	Working Time Regulations

PART 1.2

Convening Order & TORs

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Defence Safety Authority

Service Inquiry Convening Order

2 December 2021

SI President
SI Members
Hd DAIB
DSA HQ Legad
DAIB Mentor
DAIB Office Manager

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MA/CGS
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PSO/COMD UKStratCom
PSO/DCOMOPS
MA/CJO
NA/Fleet Comd
PSO/AOC 1Gp
EA/Navy FGen-Dir
DIR HS&EP
DSA Dep-DG
MA/DSA MAA D
Air Inspector RAF
Navy Safety Dir
DDC Dir
DDC Head of News
DDC PR News Air
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DSA DG/SI/06/21 – SERVICE INQUIRY INTO THE LOSS OF F-35 LIGHTNING AIRCRAFT BK18 FROM 617 SQUADRON RAF, EMBARKED IN HMS QUEEN ELIZABETH, ON 17 NOVEMBER 2021 – AL1

1. In accordance with Section 343 of Armed Forces Act 2006 and Joint Service Publication (JSP) 832 – Guide to Service Inquiries (Issue 1.0 Oct 08), the Director General, Defence Safety Authority (DG DSA) has elected to convene a Service Inquiry (SI).

2. The purpose of this SI is to investigate the circumstances surrounding the incident and to make recommendations in order to prevent reoccurrence.

3. The SI Panel will commence administrative briefing at 1200 on Thursday 2 December 2021 at the Defence Accident Investigation Branch (DAIB), B120 at MOD Boscombe Down, and will be formally convened by the DG DSA at 1500.

4. The SI panel comprises:

President: [redacted]
Replacing [redacted]
Members: [redacted]

5. The replacement SI President will commence administrative briefing on 10 January 2022 at the DAIB, B120 at MOD Boscombe Down, and the new panel will be formally convened by the DG DSA at 1000.

6. The Legal Advisor to the SI is [redacted] (DSA-MAA-Legad) and technical investigation/inquiry support is to be provided by the Defence Accident Investigation Branch (DAIB). The nominated mentor for this SI is [redacted] (DSA-DAIB-Air-Ops3).

7. The SI is to investigate and report on the facts relating to the matters specified in its Terms of Reference (TOR) and otherwise to comply with those TOR (at Annex A). It is to record all evidence and express opinions as directed in the TOR. An initial report on the commencement of the investigation is to be submitted on Monday 24 January 2022.

8. Attendance at the SI by advisors/observers, unless extended by the Convening Authority, is limited to the following:

Head DAIB – Unrestricted Attendance.
DAIB SO1 Air – Unrestricted Attendance.
DAIB investigators in their capacity as advisors to the SI Panel – Unrestricted Attendance.
Human Factors specialists in their capacity as advisors to the SI Panel – Unrestricted Attendance.

9. The SI Panel will initially undertake induction training at the DAIB facility at MOD Boscombe Down immediately after convening. Thereafter, permanent working accommodation, equipment and assistance suitable for the nature and duration of the SI will be requested at a location decided by the SI President in due course.

10. Reasonable costs will be borne by DG DSA under UIN D0456A.

Original Signed

S C Gray DBE CB FREng FIET RAF
Air Marshal
DG DSA – Convening Authority

Annex:

A. Terms of Reference for the Service Inquiry into the loss of F-35 Lightning Aircraft BK18 from 617 Squadron RAF, embarked in HMS QUEEN ELIZABETH, on 17 November 2021.

Record of Changes

Date	Change No.	Detail	Made by

16 Dec 21	1.	Para 4 – SI panel change. [redacted] replaced by [redacted]	Service Inquiries SO1
16 Dec 21	2	Para 5 - Additional Convening Brief to be held at the DAIB on 10 January 2022 for incoming SI President.	Service Inquiries SO1

Annex A To
DSA DG/SI/06/21 Convening Order
Dated 2 December 2021

TERMS OF REFERENCE FOR SERVICE INQUIRY INTO THE LOSS OF F-35 LIGHTNING AIRCRAFT BK18 FROM 617 SQUADRON RAF, EMBARKED IN HMS QUEEN ELIZABETH, ON 17 NOVEMBER 2021

1. As the nominated Inquiry Panel for the subject Service Inquiry (SI), you are to:

   a. Investigate and, if possible, determine the cause of the accident, together with any contributory, aggravating and other factors and observations.

   b. Establish the level of training, relevant competencies, qualifications and currency of the individuals involved in the accident.

   c. Identify if the levels of planning and preparation were commensurate with the activities' objectives.

   d. Determine the state of serviceability of the aircraft and other relevant equipment.

   e. Review the levels of authority and supervision covering the task during which the incident occurred.

   f. Examine what policies, orders and instructions were applicable and whether they were appropriate and complied with.

   g. Investigate and comment on relevant fatigue implications of individuals' activities prior to the matter under investigation and on any Human Factors that may have played a part in this accident.

   h. Ascertain if aircrew escape and survival facilities and equipment assemblies were fully utilised and functioned correctly.

   i. Determine whether the Aircraft Post-Crash Management procedures were complied with and were adequate, and review whether the post incident actions, including immediate medical attention and ongoing care, were appropriate, adequate and carried out correctly.

   j. Determine and comment on any broader contributory organisational and/or resource factors.

   k. Ascertain the value of the loss to the Service.

   l. Report and make appropriate recommendations to the DG DSA.

2. The investigation should not seek to attribute blame and you should use JSP 832 Guide to Service Inquiries and DSA 03.10 as guidance for the conduct of your inquiry. You are to report immediately to the DG DSA should you have cause to believe a criminal or Service offence has been committed.

3. If at any stage the panel discovers something that they perceive to be a continuing hazard presenting a risk to the safety of personnel or equipment, the President should alert DG DSA without delay to initiate remedial actions. Consideration should also be given at this time to raising an Urgent Safety[1] notice.

[1] 1 This could be an advice or a recommendation safety note.

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PART 1.3

Narrative of Events

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PART 1.3 – NARRATIVE OF EVENTS

All times Local (UTC + 2 hours).

Synopsis

1.3.1. On Wednesday 17 Nov 21 at 11:45, a RAF F-35B Lightning II, registration number ZM152 (Figure 1.3.1), ditched whilst attempting to launch from HMS QUEEN ELIZABETH (QNLZ). The Ship was operating in the eastern Mediterranean, off the north coast of Egypt. As the aircraft left the end of the flight deck ramp, the pilot ejected and landed back on the deck. The aircraft impacted the sea and subsequently sank. The pilot suffered only minor injuries and has since returned to flying.

1.3.2. 617 Squadron (Sqn) personnel and aircraft documentation referenced in this report referred to the aircraft involved in this accident as BK-18. For simplicity, this report maintains that designation.

Figure 1.3.1 – BK-18 launching from QNLZ on 14 Aug 21.

1.3.3. The Lockheed Martin F-35B was a Short Take-Off / Vertical Landing (STOVL) capable aircraft developed to operate from aircraft carriers without catapults or arrestor gear. After a period of disbandment, 617 Sqn reformed in Apr 18 at Marine Corps Air Station (MCAS) Beaufort and, when it returned to RAF Marham later that year, was the first UK based sqn equipped with the F-35B.

1.3.4. In May 21, QNLZ deployed on Operation (Op) FORTIS, her maiden global operational deployment with embarked aircraft. The Ship had operated in the Far East, in often hot and humid conditions, leading a multi-national Carrier Strike Group (CSG), and at the time of the accident was on the return leg. Embarked on QNLZ were [redacted] F-35Bs from 617 Sqn and [redacted] from [redacted] as well as seven Merlin helicopters from 820 Naval Air Squadron (NAS). The wider task group also included three Merlin aircraft from 845 NAS and four Wildcat helicopters from 815 NAS on the escort ships.

Background

Aircraft design

1.3.5. The F-35 was a United States (US) programme, with production led by Lockheed Martin who allocated workshare to many international suppliers. There were three variants: F-35A was the Conventional Take Off and Landing (CTOL) variant, F-35B was the STOVL variant and F-35C was the catapult-launched carrier variant. The UK purchased the F-35B for use on its aircraft carriers.

1.3.6. The aircraft was powered by a single Pratt and Whitney F135-600 engine capable of delivering more than 40,000 pounds of thrust. Unlike a conventional aircraft with a fixed thrust vector, the F-35B had the ability, when transitioning for STOVL (Figure 1.3.2), to divert the engine thrust downwards via a three-bearing swivel nozzle. An internal lift fan, positioned immediately behind the pilot, was driven via a shaft from the engine to provide further thrust and control. Lateral control was provided by two roll post exhausts mounted in the wings and fed from the engine. These unique features gave the F-35B its STOVL capability. Exhibit 1

1.3.7. The intake and exhaust for the lift fan were covered by the upper and lower lift fan doors which opened when the aircraft was in STOVL mode. During STOVL the main engine provided thrust via the three-bearing swivel nozzle and powered the lift fan via the drive shaft and gearbox. The engine required more airflow in this configuration, which was provided by the opening of auxiliary intake doors on the upper surface of the fuselage. The auxiliary intake accounted for approximately 60% of the engine airflow with the other 40% via the left and right intakes. Exhibit 1

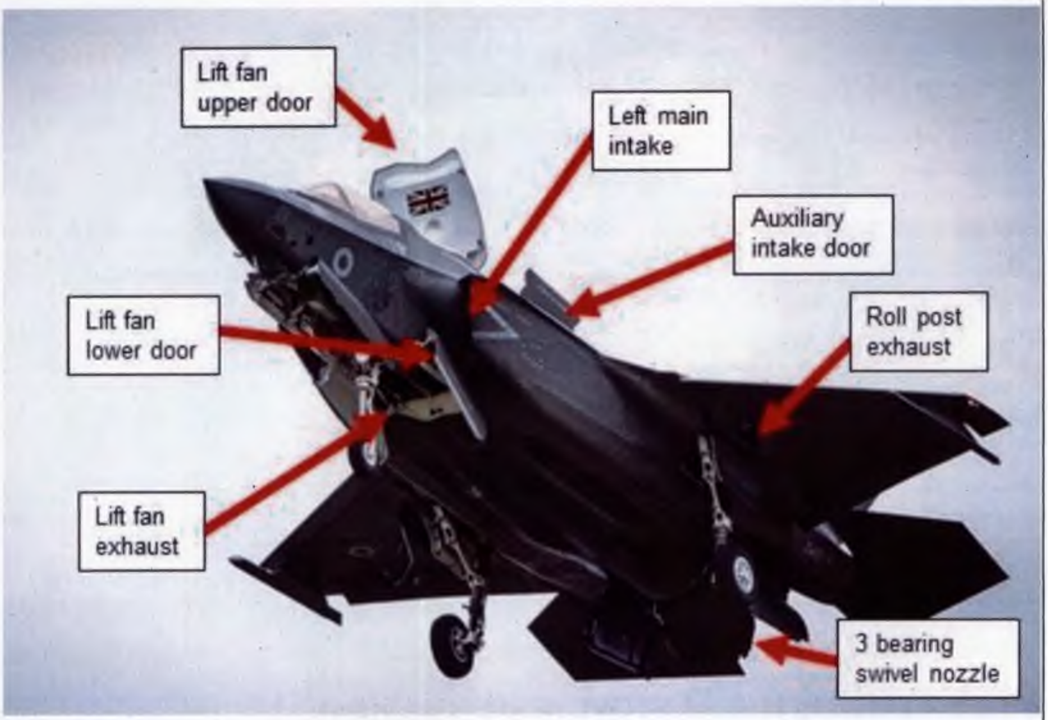

Figure 1.3.2 – F-35B in STOVL mode.

1.3.8. Due to the fly-by-wire design of the F-35B, the pilot did not directly operate the flying control surfaces or the engine of the aircraft. The pilot's control and throttle inputs were measured by flight control system (FCS) computers and a full authority digital engine control (FADEC) system which determined the required outputs to the flying controls and managed the engine. Exhibit 1

1.3.9. The tricycle landing gear had differential, anti-skid braking. An Integrated Power Package (IPP) was used to start the engine, provide environmental control and act as an emergency electrical power generator. It was also used during servicing to provide electrical and hydraulic power. The inlet for the aircraft cooling system, the Power Thermal Management System (PTMS), was on the shoulder of the right intake (Figure 1.3.3). Exhibit 1

1.3.10. The pilot's helmet was fitted with a helmet mounted display (HMD) integrated into the aircraft systems and projected onto the visor. The F-35B was fitted with a Martin Baker Mk16-US16E ejection seat that had a memory unit to record the process of seat activation. The seat had an arm and leg restraint system which was designed to pull the pilot's limbs into position to protect from the effects of wind shear and prevent injury during ejection. Exhibit 1

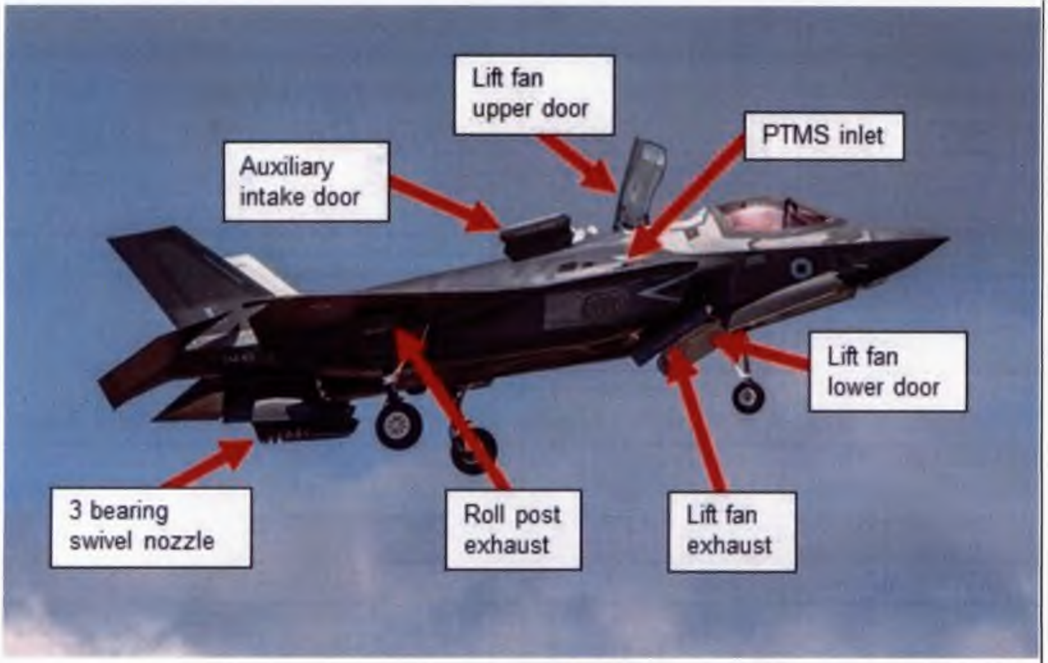

Figure 1.3.3 – F-35B in Mode 4 STOVL mode (side view).

1.3.11. The aircraft was fitted with a crash survivable memory unit (CSMU) that recorded at least 2 hrs of flight data parameters as a continuous loop with older data being overwritten. In BK-18, the CSMU recorded data from start up until after the aircraft impacted the water on 17 Nov 21, it also retained data from its previous flight on 13 Nov 21. Exhibit 2

UK F-35B operations

1.3.12. 17 Test and Evaluation Sqn (TES)[1] received the first three UK F-35B aircraft in 2014 at Edwards AFB, which were flown as part of the multinational effort to develop the F-35. The F-35B first entered operational service with the USMC in Jul 15. Lockheed Martin delivered 617 Sqn's first four aircraft to MCAS Beaufort, in South Carolina in the period from 2016 to 2018, before they were brought back to the UK on 6 Jun 18. Witness 1

1.3.13. Prior to 617 Sqn's reformation in Apr 18, its RAF and RN personnel commenced training in 2016 at MCAS Beaufort. When the Sqn relocated to RAF Marham with the first four aircraft, the facilities were not yet complete. It operated from smaller, temporary accommodation on the north side of the airfield until the Sqn's permanent operating site was ready in Jun 19. Witness 1 Witness 2

1.3.14. In Apr 19 the Sqn deployed to RAF Akrotiri, Cyprus for six weeks on Exercise (Ex) LIGHTNING DAWN[2], which included flying patrols on Op SHADER.[3] This was followed by a series of smaller detachments including

[1] 17 TES was the UK F-35B test and evaluation squadron based at Edwards Air Force Base, USA.
[2] https://www.raf.mod.uk/news/articles/exercise-lightning-dawn/.
[3] Op SHADER was the UK commitment to combat Daesh in Iraq and Eastern Syria.

embarking in QNLZ for Ex WESTLANT 19[4] with 17 TES conducting for First of Class[5] trials off the US Eastern Seaboard. This exercise proved that the Ship and aircraft systems were compatible and integrated the aircraft with the end-to-end weapon delivery process. It proved system interoperability but was not aimed at developing 617 Sqn's operational capability.

BK-18 manufacturer information

1.3.15. BK-18 was the first aircraft delivered directly from the factory to RAF Marham in the UK. The Bureau number[6] of the air vehicle was 169629 and the registration number ZM152. The aircraft had a valid Military Airworthiness Review Certificate (MARC) that was issued on 10 Mar 21 and was due to expire on 9 Mar 22. Exhibit 3

617 Squadron engineering history

1.3.16. The senior engineering officer (SEngO) was a squadron leader (Sqn Ldr) or lieutenant commander (Lt Cdr) in charge of a sqn's engineers, with a management team including a warrant officer and two junior engineering officers (JEngOs), usually a flight lieutenant (Flt Lt) and a lieutenant (Lt). They were responsible to the Delivery Duty Holder (DDH)[7] for all engineering activity and for ensuring the airworthiness of the aircraft. Witness 3 Witness 4 Witness 1

1.3.17. In the two years preceding Op FORTIS, 617 Sqn experienced significant turnover in the SEngO post (Table 1.3.1). From Sep 20 the post was temporarily filled by two successive junior officers while a replacement was recruited. The first nominee declined the role. The SEngO during Op FORTIS was in post from Feb 21, but only awarded their authorisations (auths)[8] in May 21. Exhibit 4 Witness 1 Witness 3 Witness 4

From	To	Rank	Service	Comments
May 19	Sep 20	Lt Cdr	RN	
Sep 20	Oct 20	Lt	RN	617 Sqn JEngO
Oct 20	May 21	Flt Lt	RAF	207 Sqn JEngO
Nov 20	*Dec 20*	*Lt Cdr*	*RN*	*Nominated, but declined post*
May 21	Present	Sqn Ldr	RAF	

Table 1.3.1 – 617 Sqn SEngO timeline.

4 https://www.royalnavy.mod.uk/news-and-latest-activity/operations/north-atlantic/westlant.
5 The RN conducted First of Class trials on each new class of ship built for the Fleet.
6 US produced aircraft were allocated a US Bureau of Aeronautics serial number.
7 A DDH was a qualified individual with formal delegation from the Senior Duty Holder for the delivery of Risk-to-Life activities within defined boundaries. At the time of Op FORTIS the DDH for 617 Sqn was the RAF Marham Station Commander (a group captain.)
8 An auth was an approval to sign for specific tasks in maintenance documentation. A SEngO controlled all auths on their sqn and was empowered to grant further auths to their engineers.

HMS Queen Elizabeth

1.3.18. Displacing 65,000 tonnes, QNLZ was commissioned on 7 Dec 17 and designed from the outset to operate F-35B. The Ship was 284m in length and 69m at its widest point. The runway was 282.7m long and 17.3m wide with a 12.5° ramp on the bow, which was 65m long and 6.6m high. The ramp was to facilitate operations with STOVL aircraft (Figure 1.3.4). Exhibit 5

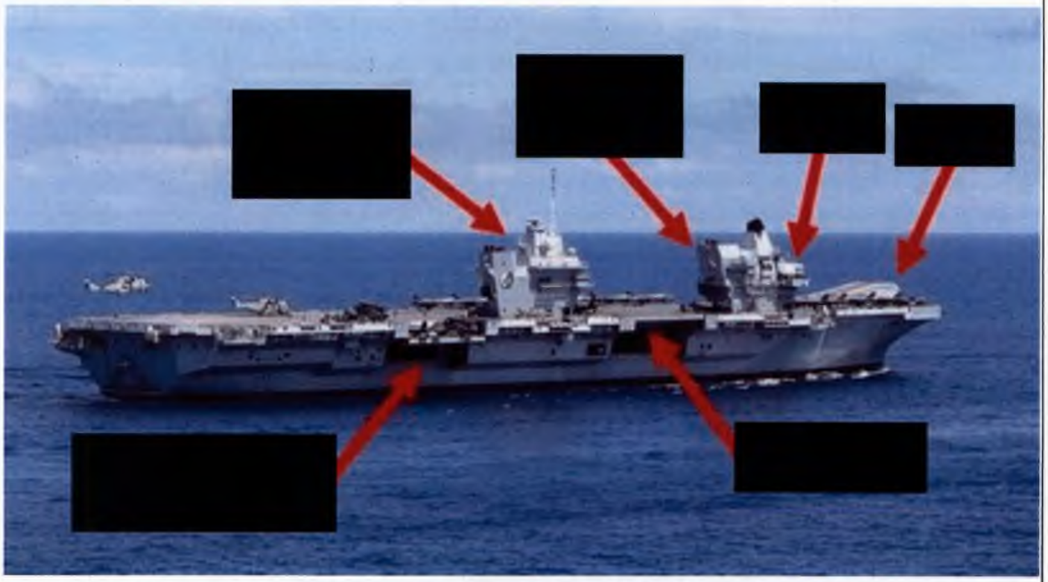

Figure 1.3.4 – QNLZ with the carrier air wing.

1.3.19. The Ship's decks were sequentially numbered with the flight deck as "1 Deck" with numbers increasing downwards through the ship. Aviation related offices were located on 2 Deck. The hangar height spanned 3 and 4 Deck. Accommodation for embarked sqn junior ranks / rates was on 3 Deck, medical and messing facilities were on 5 Deck and officers and senior ranks / rates accommodation on 6 and 7 Deck. Exhibit 5

1.3.20. The Ship had two aircraft lifts on the starboard side that could move two F-35B aircraft at a time between the flight deck and hangar. When not being operated, the lifts could be used for parking aircraft at flight deck level. Safety netting projected horizontally from the lift edge over the sea. When parked on the lifts, the aircraft tail and exhaust nozzle extended beyond the outboard edge of the lift. The deck edge had a 'cat-walk' below deck level which contained aviation services such as [redacted]. Exhibit 5

1.3.21. Aviation engineering on QNLZ was co-ordinated in the Flight deck and Hangar Operations Centre (FDHOC) on 2 Deck. [redacted] Exhibit 5

1.3.22. QNLZ had two islands on the starboard side. [redacted]. The FLYCO compartment was in the aft island and projected out over the deck to provide a better view of the flight deck and of the airspace around the Ship. Exhibit 5

1.3.23. FLYCO contained the workstations for those personnel engaged in the local control of aircraft operating within visual distance of the Ship (Figure 1.3.5). The Landing Signals Officer (LSO) was an F-35B pilot from either of the embarked sqns, responsible for the safety of all F-35B launches and recoveries with direct two-way communication with the aircraft. The Tower Controller managed aircraft in the visual circuit and linked to the Air Traffic Control (ATC) centre located inside the Ship that controlled air activity beyond visual range. There were two Lt Cdr Flying posts, responsible for safe aviation from the deck and in the immediate vicinity of the carrier. One of these would be on shift at any time flying was taking place and they were known as 'F' and 'F2'. At the time of BK-18's accident, F2 was the on-duty supervisor. The Deck Operations Officer (DOO) was responsible for the efficient and timely movement of aircraft on the flight deck. Seated in an elevated position was Cdr Air or 'Wings' who had overall delegated authority for safe conduct of aviation from the Ship. Exhibit 5

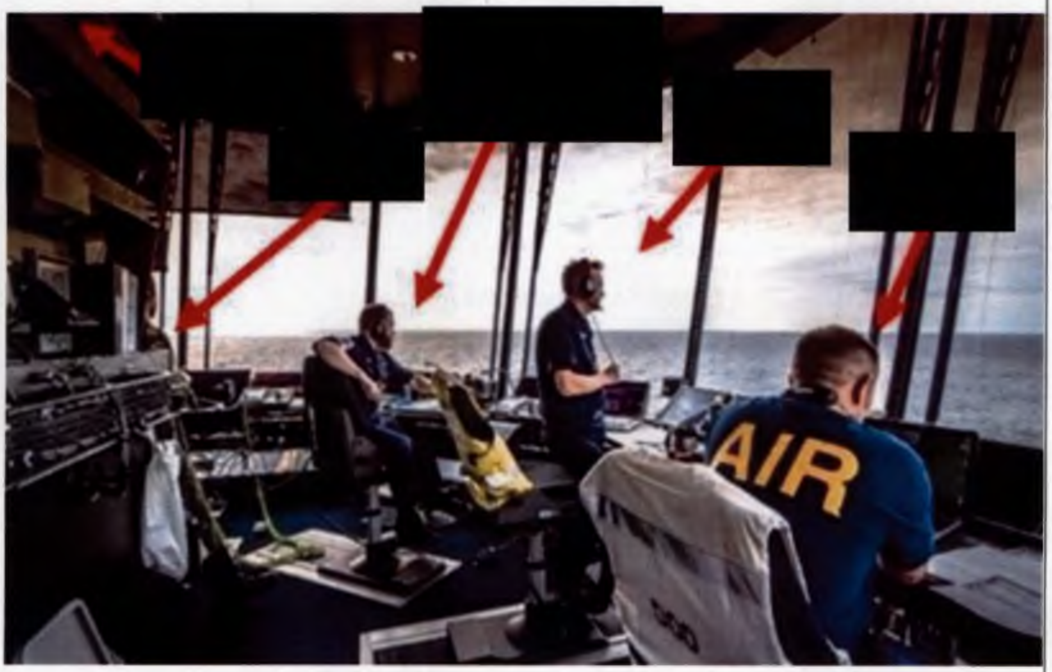

Figure 1.3.5 – View inside FLYCO looking aft.

1.3.24. Located between F/F2 and the DOO was the [redacted] that contained the [redacted] as well as other aviation [redacted] Between F/F2 and the Tower Controller was the [redacted] used to communicate with other parts of the Ship including the bridge, sqns, and aviation services. It was also used to communicate with aircraft. [redacted] If a different channel was required, Exhibit 5 one channel must be deleted and the new channel found in the 'digital phone book,' and added to the active channels. [redacted] This panel could select a broadcast to be targeted to certain sets of speakers such as upper deck, aviation compartments, hangar or, such as in an emergency, the whole Ship.

Red Gear

1.3.25. Each F-35B had a set of covers to provide protection for sensitive and easily damaged components (Figure 1.3.6). These were called 'Red Gear', named due to their colour, which could be fitted as required to aircraft when not flying. A full set of Red Gear comprised: Exhibit 6

Joint-Service Technical Data name	Also known as
Air data pitot probe cover (x2)	
Flush port cover (x2)	
Return Fuel/Air Heat Exchanger (RFAHX)	PTMS blank IPP blank
Static ground wire	Earth bonding lead
Left intake blank	
Right intake blank	
Exhaust Blank	

Table 1.3.2 – Red Gear designations.

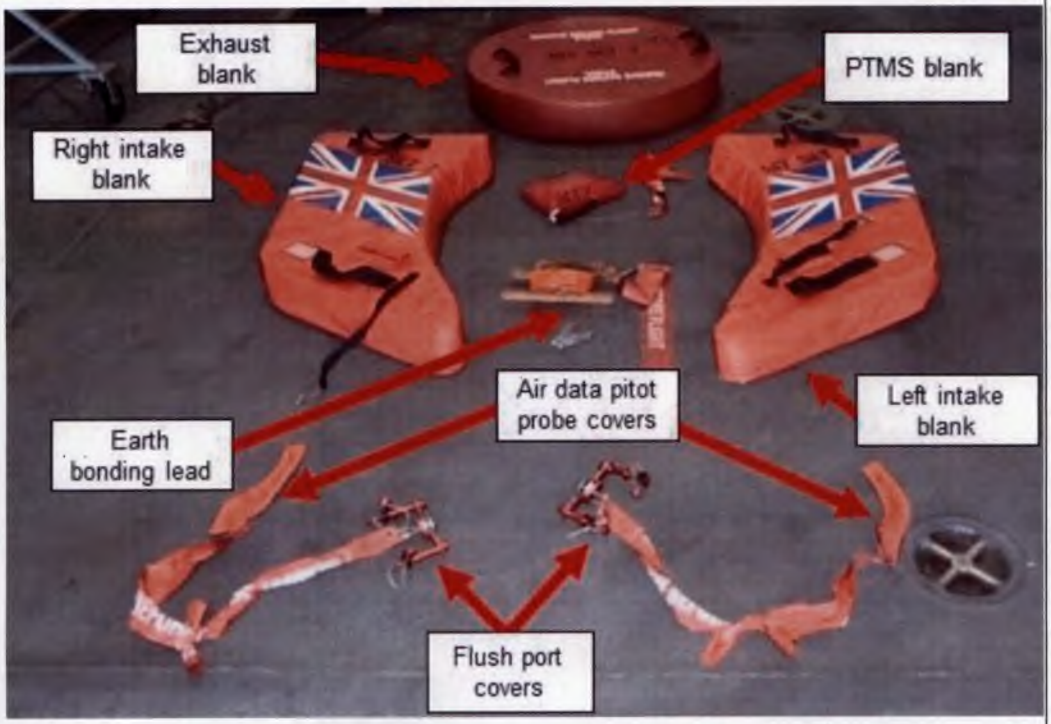

Figure 1.3.6 – Full set of Red Gear.

1.3.26. In the workshare for the F-35 project the central fuselage was designed and manufactured by Northrop Grumman, and the intake blanks were included in this. Their purpose was to prevent Foreign Object Debris (FOD) from entering the intakes and damaging the engine when the aircraft was parked. Exhibit 1 Exhibit 6

1.3.27. At the time of the accident, three different designs of intake blank had been used. The first design was a wrap-around cover (Figure 1.3.7) allocated Lockheed Martin design numbers A00016 (left) and A00017 (right). Lockheed Martin observed that these were difficult to fit and caused damage to the external skin of the aircraft, as well as materially breaking down and presenting a FOD risk. Exhibit 6 Exhibit 7

Figure 1.3.7 – Wrap around intake cover fitted to 617 Sqn aircraft at RAF Marham.

1.3.28. The issues with the first design prompted the acquisition, at MCAS Beaufort, of a second design of locally manufactured intake 'plugs'. In the US, private companies offered customised aircraft blanks which were used on both US and UK F-35Bs at MCAS Beaufort (Figure 1.3.8). This was whilst the UK was operating with [redacted] These locally produced blanks were common until replaced by the Lockheed Martin provided A00020 (left) and A00021 (right) design which were the approved blanks at the time of the accident.

Figure 1.3.8 – Locally acquired intake plugs in a UK F-35B at MCAS Beaufort.

1.3.29. This third design intake blank was also a plug type (Figure 1.3.9). The design change was approved by the Defence Equipment and Support (DE&S) Lightning Delivery Team (LDT). A photo of the locally produced plugs was used as an illustrative example of the design proposal for A00020 and A00021 intake blanks. Exhibit 8 Exhibit 9 Exhibit 10

1.3.30. The text 'REMOVE BEFORE FLIGHT' was printed on the intake blanks by the manufacturer but the characters were found to peel off and present a FOD hazard. Early on Op FORTIS, 617 Sqn engineers removed the lettering from the intake blanks and raised awareness of the FOD issue by raising a Defence Air Safety Occurrence Report (DASOR).[9] Exhibit 11 Exhibit 12 Witness 5 Exhibit 12

[redacted]

Figure 1.3.9 – Plug-type intake blank of the approved design, as used on Op FORTIS.

F-35 security

1.3.31. F-35 was a Special Access Programme (SAP).[10] This was administered on board QNLZ by the Government SAP Security Officer (GSSO) team, appointed by the UK Country Security Manager but under the Ship's executive chain of command. It consisted of an RN Lt with a part-time deputy (also an RN Lt), augmented for Op FORTIS by an RAF sergeant. In comparison, [redacted] — Exhibit 13

1.3.32. The QNLZ GSSO set the requirements for access to the aircraft and SAP compartments on the Ship. They also managed the security precautions for all F-35B aircraft on the flight deck, particularly when the Ship was on a port visit or during the Suez Canal transits. — Exhibit 13

1.3.33. During routine flying operations only those personnel with duties on the flight deck were permitted there. On rare occasions, if flying activity was not being conducted, the deck was opened for recreation to other personnel. Such events added another dimension to the requirement to ensure aircraft were physically protected, and ensure security was maintained. On one of these recreation days a DASOR[11] was raised due to recreational activities infringing aircraft security. — Exhibit 14

[10] A SAP was used to protect the MoD's most sensitive military programmes, including those provided to MoD by international partners.
[11] [redacted]

Preparations for Op FORTIS

1.3.34. The phased introduction of the F-35B to QNLZ was designed to gradually build experience and capability over a series of deployments (Table 1.3.3).

Date	Exercise	Purpose	Comments
14 Oct – 15 Nov 19	WESTLANT 19	Ship / F-35B integration with 17 TES.	First 617 Sqn embarkation.
27 Jan – 14 Feb 20	CQ[12] 20-1	Carrier landing qualifications for 207 Sqn.	Most engineers remained at RAF Marham.
9 Jun – 3 Jul 20	CQ 20-2 and Ex CRIMSON OCEAN 20	Consolidate 617 Sqn embarked experience.	617 Sqn only flying sqn on board. No weapon carriage.
19 Oct – 6 Nov 20	Ex STRIKE WARRIOR 20-2	First opportunity working alongside [redacted]	Deck operations and weapon carriage practice.
1 – 21 May 21	Ex STRIKE WARRIOR 21-1	Pre-cursor to Op FORTIS	Ran immediately into Op FORTIS.

Table 1.3.3 – Deployment schedule.

1.3.35. During Ex STRIKE WARRIOR 20-2, F-35Bs from 617 Sqn and [redacted] with Merlin helicopters from 820 NAS, operated from QNLZ. This provided maritime experience to 617 Sqn and established many of the routines and procedures to be used during Op FORTIS. A lesson identified from the ex was that insufficient engineers were deployed to conduct flight line ops and aircraft rectification concurrently. Witness 3 Witness 4

617 Squadron engineering preparation

1.3.36. All personnel were required to be medically fit to deploy on Op FORTIS. This included having no COVID-19 medical limiting factors and completion of the Embarked Forces Sea Survival Course (EFSSC). To generate enough personnel for the deployment, 617 Sqn were loaned 13 engineers from 207 Sqn, exchanging experienced engineers for less experienced but medically deployable personnel. Witness 3 Witness 4

1.3.37. The flying sqns' engineering teams employed a [redacted] shift pattern. 617 Sqn initially changed over at [redacted], later modifying this to handovers at [redacted], to better accommodate meal times. The shifts tended to change over on port visits, generally remaining either Witness 4 Witness 3

[12] Carrier Qualification.

on [redacted] or [redacted] for [redacted] at a time. Other departments employed different working patterns to suit their tasking requirements.

Red Gear use on-board ship

1.3.38. The Sqn tool 'issue centre' was in the hangar on 4 Deck. When not fitted to an aircraft, the smaller elements of Red Gear (air data pitot probe covers, flush port covers and earth bonding lead) were kept in a small, hardened case in the issue centre. The intake, exhaust and PTMS blanks were too large to be kept inside the issue centre, so were kept outside the compartment in a palletised stacking stowage cage[13] known as a 'Thatcham' (Figure 1.3.10).

Witness 5

Witness 6

Figure 1.3.10 – Red Gear storage in the hangar.

1.3.39. If fitted to aircraft on the flight deck, the intake and exhaust blanks could be blown out by modest wind or aircraft launching nearby; such incidents had been reported by DASORs.[14] Due to the risk of loss, a deviation[15] was approved such that Red Gear was not routinely fitted to aircraft on the flight deck when the Ship was at sea. The only times it would be fitted were during port visits or if otherwise required for security reasons. [redacted]

Exhibit 15
Witness 5
Exhibit 16
Exhibit 17
Exhibit 18

Witness 7

1.3.40. The flight deck was coated in an anti-slip paint. It was found early on during Op FORTIS that the F-35B jet wash eroded the top layer of paint and

Exhibits 19 to 22

[13] NATO Stock Number 3990-99-130-9148 - Pallet Thatcham.
[14] [redacted]
[15] A deviation was an agreed, risk assessed, and time-bound departure from procedures.

created FOD which was found in the intakes of aircraft parked near the runway. A DASOR[16] was raised for this and subsequent FOD events.[17 18 19] Witness 8

Red Gear for security

1.3.41. Exceptionally, when the Ship was in port or in other situations where it may be photographed, there was a requirement to protect aspects of the aircraft from espionage. Items of Red Gear, specifically the exhaust, PTMS and left and right intake blanks, were fitted to fulfil this requirement. Witness 9

1.3.42. The GSSO determined when the Red Gear would be required and promulgated this to the embarked sqns via an email. The GSSO would subsequently ensure that the blanks had been fitted. Witness 9

Pilot history

1.3.43. The pilot was on their first front line tour. After graduating from flying training in 2017, they converted to the F-35B at MCAS Beaufort before returning with 617 Sqn to the UK in 2018. Having deployed twice on QNLZ in 2020 prior to Op FORTIS, they had flown 271:05 hrs on the F-35B and completed 375:35 hrs simulator flying. They achieved four-ship lead status[20] at the start of Op FORTIS and were trained as a day and night LSO. They had completed an Air Combat Lead work up and at the time of the accident were on an Air Combat Instructor work up. Exhibit 23 Witness 10 Witness 7

Medical team history

1.3.44. QNLZ had a primary medical care team, referred to as Role 1[21], headed by an Aviation Medicine[22] trained Surgeon Cdr as Principal Medical Officer (PMO). The deputy PMO (DPMO) was a Surgeon Lt Cdr doctor who, at the time of accident, was ashore. The Surgeon Lt Cdr Dental Officer (DentO) was the deputy head of department who, in an emergency, acted as the medical representative to the Ship's command. Throughout Op FORTIS, the QNLZ medical department was augmented by an enhanced surgical team, referred to as Role 2[23] which changed over during a visit to the port in Guam approximately half way through the deployment. Due to appointment cycles, the medical team had changed a significant number of personnel in the preceding year, including the PMO, DPMO, DentO and Senior Nursing Officer. Witness 11

16 [redacted]
17 [redacted]
18 [redacted]
19 [redacted]
20 The qualification to lead a four-ship of aircraft is only awarded after completion of a recognised training syllabus.
21 A Role 1 medical facility provides primary healthcare.
22 The Diploma in Aviation Medicine demonstrates an appropriate level of competence for working in aviation medicine.
23 Role 2 provides an initial surgical capability.

OFFICIAL - SENSITIVE

Pre-accident events

Duqm Port visit

1.3.45. [redacted] Exhibit 24 Exhibit 25

1.3.46. The working programme in Duqm included Defence Engagement visits from the UK Secretary of State for Defence[24] and the Omani Deputy Prime Minister for Defence Affairs. This was a limited visit which was supported by some 617 Sqn pilots but did not require any engineers. Exhibit 24

1.3.47. The Ship sailed on 7 Nov 21 and conducted routine flying exercises until 13 Nov 21 as it entered the Red Sea heading towards the Suez Canal. BK-18 had flown on 13 Nov 21. The aircraft did not fly again until the morning of 17 Nov 21. Exhibit 26 Exhibit 27 Witnesses 2 & 3

Red Sea transit

1.3.48. The flight deck was closed on 14 Nov 21 for a Remembrance Sunday service. The rest of the day was an afternoon off for the Ship's company and sqns. During the service, around 20 personnel required medical support due to the heat. Exhibit 28 Witness 11

1.3.49. There was no flying on 15 Nov 21 and a series of flight safety events and briefs took place. These briefings were for both the Ship's company and embarked sqns covering human factors and refresher training for deck operations. Exhibit 27 Exhibit 29 Exhibit 30 Exhibit 31

Suez Canal transit

1.3.50. The Ship and Task Group prepared for the northbound transit of the Suez Canal on the night of 15 Nov 21 and exited at the northern end at approximately 16:30 on 16 Nov 21. No flying occurred and the flight deck was out of bounds to all personnel except those engaged in force protection of the Ship. There was a Defence Engagement visit by various Egyptian military and ambassadorial staff during the day of the transit. The proximity of the land, and the location of BK-18 and BK-21 can be seen in Figure 1.3.11. Exhibit 29 Exhibit 32 Exhibit 33

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[24] https://www.gov.uk/government/news/defence-secretary-visits-oman-for-joint-exercises.

Figure 1.3.11 – QNLZ in the Suez Canal 16 Nov 21.

1.3.51. [redacted] were required for the embarked F-35Bs. The GSSO sent an email on 10 Nov 21 directing that the Red Gear should be fitted for the Suez transit. It did not state when Red Gear could be removed or a point at which the defence posture of the Ship would revert to normal again. Exhibit 34 Witness 9

1.3.52. [redacted] and 617 Sqn fitted theirs at the end of the day shift, after being reminded by the GSSO. As the engineers were not permitted access to the flight deck during the transit, they were unable to check the Red Gear. The GSSO was allowed on deck and verified that the blanks were present on all the F-35B aircraft but could not confirm, from an engineering perspective, if they were correctly or securely fitted. BK-18's left intake blank is just visible in Figure 1.3.12. Witness 9

Figure 1.3.12 – BK-18 at 19:54 on 16 Nov 21 with left blank just visible in intake.[25]

Night of flight servicing

1.3.53. During the night of 15 Nov 21 and during the Suez transit on 16 Nov 21 the 617 Sqn engineering shifts were stood down. On the evening of 16 Nov 21 the [redacted] shift commenced work at [redacted] having received a written hand over from the [redacted] shift of the 15 Nov. Three aircraft were tasked to be flight serviced that night: BK-18 and BK-21 were the allocated aircraft for flying on 17 Nov 21, with BK-14 designated as the spare. Witnesses 2, 4 & 5 Exhibits 35 to 39

1.3.54. Two engineers, referred to in this report as Eng 1 and Eng 2, were tasked with conducting combined Post Operation Servicing (POS) and Before Operation Servicing (BOS) schedules on BK-18. This was their only allocated aircraft work for that [redacted] A POS/BOS was divided by the Joint-Service Technical Data (JTD) into discrete maintenance activities. These were routinely shared equitably by engineers (Table 1.3.4), as was the case that night. Eng 1 conducted the engine and ejection seat tasks and Eng 2 conducted the airframe, fluid levels / pressures and lift fan tasks. Witness 12 Exhibit 40 Witnesses 12 & 13

[25] Image courtesy of Uppercut Films.

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Engineer Task Division	JTD Maintenance Activity*
Engine	- Engine inspection.
Ejection seat	- Ejection seat inspection. - Automatic Deployable Unit (ADU) and Personal Locator Beacon (PLB) switch position check. - Inspection of the tell-tale lock on the aircrew land-away toolkit.
Airframe	- Aircraft inspection. - Outer Mould Line inspection.
Levels	- Nose landing gear (NLG) and main landing gear (MLG) pressures and 'x' dimension values to be recorded. - The fluid level checks required as part of the Aircraft inspection (not signed for separately).
Lift fan	- Lift system inspection.

* These maintenance activities are carried out on both POS and BOS, with each being signed for individually. The Outer Mould Line inspection is only required during a POS.

Exhibit 40

Table 1.3.4 – POS/BOS task divisions.

1.3.55. Thunderstorm activity was forecast in the vicinity of the Ship for most of the night. When thunderstorms were close enough to the Ship the Meteorological (Met) Office would declare a thunderstorm warning MEDIUM[26] or HIGH[27] which would trigger limitations on activities such as refuelling, applying power to aircraft and handling of explosive material. A thunderstorm warning of MEDIUM was notified at 22:55, was increased to HIGH at 00:15 and reduced back to MEDIUM at 03:25. Thunderstorm activity finished at 05:10 on 17 Nov 21.

Exhibit 41

Witness 12

Exhibits 42 to 45

1.3.56. Eng 1 chose to start their servicing early in the shift. Eng 2 was nominated to support an additional task requiring personnel to move storage containers around the hangar, so planned to begin their part of the servicing later. Due to the weather conditions, Eng 2 was further delayed until the thunderstorm had passed. At no point were both Eng 1 and Eng 2 at the aircraft at the same time.

Exhibit 46
Witness 12
Witness 13

1.3.57. After signing out the required tools from the Line Controller, Eng 1 started the engine elements of the servicing at 21:13. At the start of their servicing they removed the right intake blank and stowed it by the aircraft while completing the engine inspection. This aspect of a POS/BOS required Eng 1 to enter the right-hand intake to gain access to the front face of the engine. Eng 1 was assisted into the intake by another engineer who was on the flight deck at the time servicing BK-21.

Exhibit 47
Exhibit 40
Witness 13

[26] Thunderstorms were developing or had been reported with 25NM of the Ship but were not expected to affect the Ship in the immediate future.
[27] A thunderstorm was occurring or was expected within 10NM in the immediate future.

1.3.58. On completion of their parts of the servicing, Eng 1 collected the right intake and PTMS blanks and took them down to the Thatcham in the hangar. After this they returned the tools to a makeshift tool tidy in the crew room for Eng 2 to use and mentioned to Eng 2 that their parts of the servicing were complete but did not discuss which blanks had been removed.	Witness 13
1.3.59. While Eng 1 was completing their aspects of the servicing, Eng 2 was employed with other personnel, tasked with moving some containers in the hangar. Afterwards, Eng 2 carried out a check of the tools issued for use on BK-18 then went for their meal break at approximately 23:30.	Witness 12
1.3.60. Eng 2 started their parts of the POS/BOS shortly after midnight. As they arrived at BK-18, they discovered the exhaust blank on the deck a couple of metres behind the aircraft. Eng 2 picked up the blank and secured it to a container on the deck whilst they carried out the airframe elements of the POS/BOS. This was the only blank Eng 2 observed in or around BK-18 that night.	Witness 12 Exhibit 15
1.3.61. Parts of their servicing required the IPP to be run to provide hydraulic power to open and close doors. To run the IPP, Eng 2 required a task supervisor to act as a further safety observer. When Eng 2 went to their supervisor to request the IPP run, they were informed that it was not permitted yet due to the raised thunderstorm warning. Eng 2 went back to the flight deck, collected their tools and returned to the crew room.	Witness 12
1.3.62. At approximately 02:20, Eng 2 requested the assistance of their supervisor to run the IPP so that the required panels could be opened. They went up to the flight deck with the required tools and carried out the IPP run. With the panels opened as required, Eng 2 climbed into the cockpit and from the ejection seat area completed their inspection of the lift fan and upper surface using a torch.	Exhibit 40 Witness 12
1.3.63. On completion of their parts of the POS/BOS, at approximately 02:50, Eng 2 returned all tools to the issue centre and the exhaust blank to the Thatcham. On checking the Red Gear log at the issue centre, Eng 2 discovered that there was no entry for the fitting of blanks to BK-18 following the last removal on 7 Nov 21, upon leaving Duqm Port. They discussed this with the issue centre custodian (ICC) and concluded that the exhaust blank had inadvertently been left fitted when all other Red Gear had been removed.	Exhibit 40 Exhibit 48 Exhibit 49 Witness 12
1.3.64. Eng 2 then returned to the FDHOC and at 03:29 signed for completion of their aspects of the POS/BOS. After confirming with the line controller that there were no further tasks that night, Eng 2 was released from work.	Witness 12 Exhibit 15 Exhibit 40
1.3.65. The three tasked aircraft were also required to be armed with flares for the sorties the following day. The flare loading teams had to wait until the	Witness 14

aircraft had been flight serviced, and then proceeded to conduct the flare load on BK-14 first. Upon arriving at BK-14 at around 22:30 they discovered all the Red Gear was fitted. They needed to remove the PTMS blank to run the IPP to open the flare doors. After this was completed, they replaced the blank, completing the flare load just prior to the midnight meal. They returned at around 03:00 to load BK-18 next, then BK-21 last. They observed no Red Gear on either aircraft, finishing the last load, still in the dark, at around 05:00. Exhibit 40

Flight deck operations (17 Nov 21)

1.3.66. QNLZ left the Suez Canal on the evening of 16 Nov 21. The next morning, due to the posturing of another nation's assets in the Eastern Mediterranean, the air wing held [redacted] Witness 7 Exhibit 39

1.3.67. A FOD walk of the flight deck was conducted at 06:30 prior to flying. No issues were reported, and no debris was found that was significant enough to be reported to the ASC or to FLYCO. FOD walks were conducted in accordance with Air Department Standing Orders. Exhibit 39 Exhibit 15 Exhibit 50

1.3.68. During the first [redacted] launch at 06:45, as the first aircraft took off, an exhaust blank was dislodged from a UK aircraft on 'knuckle alpha'. It rolled aft to the Fly 1 section, entered the catwalk, away from the runway, and was recovered by aircraft handlers (Figure 1.3.13). FLYCO were informed that the blank had been secured and the launch of the second aircraft continued. Exhibit 15 Witnesses 15 to 18

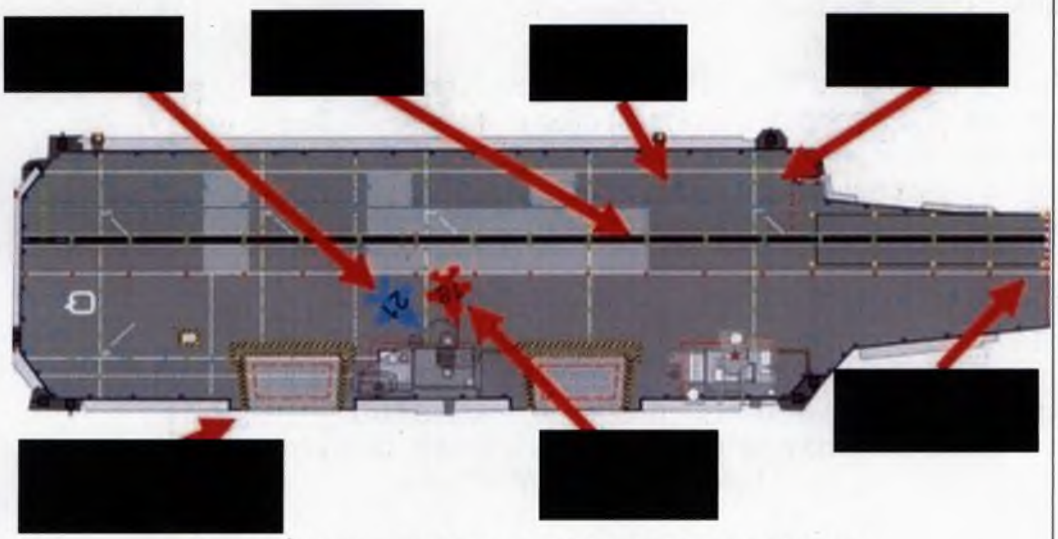

Figure 1.3.13 – Referenced flight deck positions.

28 [redacted]

1.3.69. The dislodged exhaust blank was brought down to the FDHOC by the Ship's aircraft handlers, handed to the 617 Sqn line supervisor and was subsequently sent to the Thatcham in the hangar. The 617 Sqn JEngO in the FDHOC was informed, who initiated a recall of the night shift and sent them to the flight deck to recover the Red Gear. All visible 617 Sqn blanks were recovered at 07:57 and stowed in the Thatcham. No blanks were recorded as being removed from aircraft on the Red Gear log held in the issue centre.

Witness 18
Exhibit 15
Exhibit 48

Loss of BK-20 aircraft blank

1.3.70. At around 07:45 it was reported to FLYCO that another exhaust blank was seen to fall past the aft reception point and was lost into the sea. The aft reception point was located on the starboard side of the ship on 5 Deck, below the flight deck level and was a designated area where personnel could get fresh air during flying operations. The loss of the aircraft blank was reported to 617 Sqn in the FDHOC. The ICC raised a DASOR[29] for the loss.

Witness 16
Exhibit 16
Witness 5
Exhibit 16

Accident events

Aircraft see-off

1.3.71. When land-based, a see-off[30] was normally conducted by one or two engineers. During Op FORTIS, this team was augmented to assist with refuelling and removal of chocks and lashings, to a team of three people and a supervisor. On arriving at BK-18 and BK-21, at approximately 10:50, the see-off supervisors determined that the aircraft canopies required cleaning due to salt deposits. When the pilots arrived at the aircraft at approximately 11:00, the see-off teams were busy cleaning the canopies.

Witness 2
Exhibit 15
Exhibit 51
Witness 7

1.3.72. Each pilot's walkaround[31] included an inspection of both engine intakes, the exhaust, and a general visual inspection of the aircraft. Due to the noise on the flight deck, the pilots wore their helmets throughout the walkaround. BK-18's pilot noticed the undercarriage pins were still installed, removed them and handed them to the see-off team.

Witness 10

1.3.73. Once inside the cockpit, BK-18's pilot conducted a set of tests of the aircraft flight control systems known as a Vehicle Systems Built-In Test (VSBIT). During the VSBIT, fluid was seen coming from the rear of the starboard weapon bay door. The doors were opened, and the fluid examined by the supervisor who determined it to be rainwater, believed to be from the thunderstorm the night before. BK-18's VSBIT was

Witness 2
Exhibit 41
Witness 10

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[29] [redacted]

[30] The see-off describes the process by which engineers supported the pilot walkaround, crew-in and start, and continued until the aircraft was taxied away from its parking space.

[31] The pilot conducted a walkaround check (in accordance with the F-35B Flight Manual) of the aircraft immediately prior to flight to ensure that the aircraft was ready to fly.

subsequently completed successfully. BK-21 had a minor issue with the aircraft navigation systems which took a short time to realign. Witness 7

1.3.74. The see-off team refuelled the aircraft during the start sequence, whilst the engine was running. This was routine during Op FORTIS, but required more workforce than had originally been planned. Witness 2 Witness 3

Aircraft launch and abort

1.3.75. The two-ship of BK-18 and BK-21 were the first UK F-35B flights of the day. At 11:37, as intended, BK-18 taxied first to the runway. The Ship was sailing at a steady speed of 5 kts, which gave 12 kts wind over the deck. Exhibit 39

1.3.76. [redacted] Witness 10

1.3.77. The Ship completed pre-launch checks and was turned on to a Designated Flying Course (DFC) to achieve the necessary wind over deck for launch. The readiness of the Ship to launch was relayed from FLYCO to the flight deck and the Captain of the Flight Deck[32] (CFD) signalled this to BK-18's pilot. The pilot then initiated the aircraft conversion to STOVL configuration in preparation for launch. Witness 10 Exhibit 2 Exhibit 15

1.3.78. [redacted] Exhibit 15 Exhibit 2 Exhibit 52 Witness 10

[32] The Captain of the Flight Deck was responsible for the safe launching of aircraft by ensuring that all personnel and equipment were clear and that authority to launch had been granted by FLYCO.

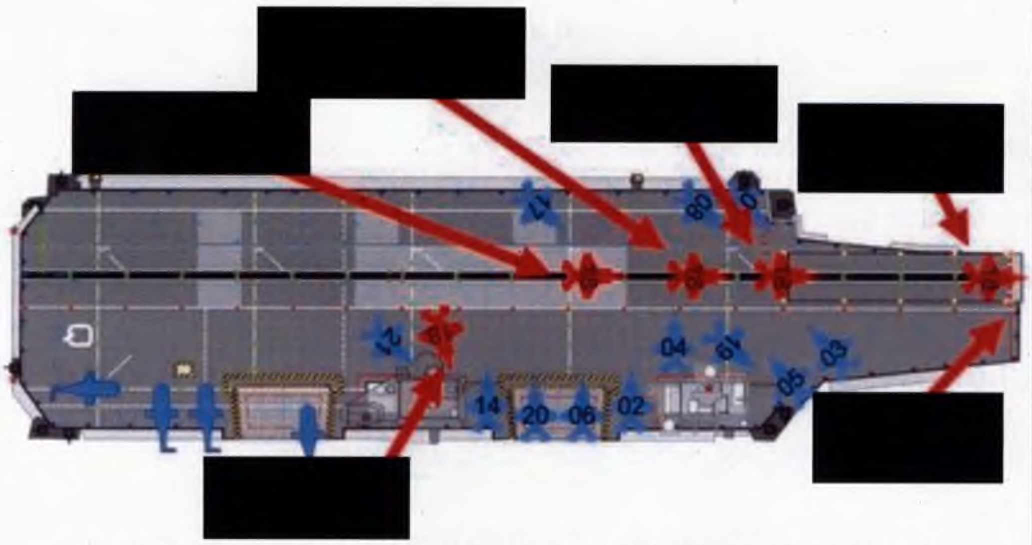

Figure 1.3.14 – Start up, taxi, launch and ejection sequence.

Ejection

Ejection sequence

1.3.79. Upon deciding to eject, the pilot assumed the ejection posture and grasped the ejection lever with both hands. After initiating ejection, the pilot cleared the aircraft, the seat separated and parachute deployed. Once descending in the parachute, and after initially suspecting they would land in the water, the pilot noticed the ship approaching from behind and prepared to land on the deck. A combination of the wind, the forward movement of the ship, and the swing of the parachute meant that the pilot landed on the deck, six feet to the right of the take-off ramp, three feet back from the front edge of the deck. The parachute canopy snagged on the ramp end light shroud and the flight deck nets at the right-hand side of the top of the ramp. The pilot was concerned about their parachute re-inflating, so promptly unstrapped from the harness. The Personal Survival Pack (PSP) was hanging over the front of the ship and, identifying a risk of being dragged overboard, they disconnected from it.

Witness 10
Exhibit 15
Witness 8

1.3.80. **Environmental conditions at time of ejection.** The wind over deck was recorded by F2 as 'G5/12', which is 12kts wind from 5 degrees to the right of the Ship's bow. The Ship's Met Office provided weather forecasts to support flying operations and recorded regular weather observations. The Met Office observation at the time of the accident was:

Witness 15
Exhibit 39
Exhibit 41

a. Visibility: 25km.

b. Clouds: Few at 4000ft.

c. Temperature: 22.7°C.

d. Humidity: 71%.

e. Sea level air pressure: 1016.9 millibars.

f. Sea State: 2, negligible swell.

g. No significant weather change forecast.

Post-accident events

FLYCO and Ship actions

1.3.81. FLYCO emergency actions were contained in the 'FLYCO AVIATION REFERENCE CARDS' and were carried out by F2. On observing the ejection, F2 promptly sounded the COD alarm and turned to the 'CRASH ON DECK' emergency checklist. [redacted] F2 determined that the bridge had broadcast the appropriate pipe, so continued with the remainder of the checklist.

Exhibit 53
Exhibit 15

Pilot recovery on the flight deck

1.3.82. The FDO was first to arrive at the pilot's location. Other than some [redacted] the pilot appeared unharmed, fully conscious and in good spirits. The pilot was keen to stand up, declaring that they were fine. The FDO aided the pilot to their feet and walked with them back to the FDO's office in the aft island.

Witness 8
Witness 10
Exhibit 15
Witness 8

1.3.83. As the pilot walked back along the deck, attempts were made by FLYCO to contact the flight deck team to encourage the pilot to remain immobile on the flight deck until medical attention was administered. [redacted]

Exhibit 15
Witness 16
Witness 17
Witness 8

1.3.84. On arrival at the FDO's office in the aft island, the FDO advised the pilot to sit down and await the Ship's medical team for an initial medical assessment of injuries.

Witness 8

Medical actions

1.3.85. The QNLZ medical staff responded to three different broadcasts. The first was an 'aircraft ditch' from the bridge, the second was the COD alarm sounded from FLYCO and the third was a 'casualty on the flight deck'

Witness 11

[33] A pipe was a broadcast on a ship's loudspeakers.

broadcast by the damage control officer in HQ1.[34] These all referred to the same accident, but the seemingly conflicting messages meant the medical staff were split and sent to three different locations. They were initially unaware of the aircraft type, casualty numbers and type of potential injuries. The medics arriving in the FDO's office were initially unaware that there had been an ejection and that the pilot was the casualty. Witness 7 Witness 8 Exhibit 54

1.3.86. Once the medics understood the circumstances, the pilot was surveyed, and an initial [redacted] assessment conducted. Whilst the casualty insisted they could walk to the medical centre for further assessment, additional authority was requested and given by the medical centre staff. The medics subsequently escorted the pilot via the Ship's ladders from the flight deck to the medical centre on 5 Deck. Witness 11 Witness 10

Role 1 and Role 2 actions

1.3.87. The pilot arrived in the medical centre where the Role 1 medical staff commenced assessment [redacted] Witness 11

1.3.88. The procedures for managing post-ejection patients call for [redacted] imaging by Magnetic Resonance Imaging (MRI) or Computerised Tomography (CT). As the only imaging available on board was an x-ray, the PMO requested imaging of the pilot's [redacted], but the radiologist raised concerns about its efficacy. These were upheld by the consultant orthopaedic surgeon in Role 2 who inspected the pilot and deemed there was no requirement for [redacted]. The ultimate decision was for the patient to remain in the med centre and transfer to an MRI equipped establishment on Crete the following day. Exhibit 55 Witness 19 Witness 11 Witness 10

Transfer to land-based medical facilities

1.3.89. In preparation for the pilot being transferred to a hospital ashore by helicopter, [redacted] Witness 11 Witness 19

1.3.90. On arrival at the airport on Crete, the pilot was met by an RAF Sqn Ldr doctor in the airport and taken by ambulance to hospital. [redacted] Witness 10

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[34] HQ1 – Headquarters 1 was the location from which the damage control and incident management for the Ship was controlled.

[redacted]

1.3.91. [redacted] Witness 10

Post-crash management

Ship's response

1.3.92. Post-crash management (PCM) activity was initiated by Commander Air Engineering (Cdr AE) assuming the role of PCM commander, with the Senior Air Engineer (Snr AE) becoming the PCM Incident Officer (PCMIO). The pre-nominated PCM team mustered in the FDHOC and started the process of impounding evidence associated with BK-18. An initial response to conduct a combat FOD walk to collect any debris was initiated by the CFD but was halted by the FDO until evidence was recorded. The air engineering department collected images of the flight deck and debris using conventional cameras and a 360-degree camera prior to collection. Witness 20 Witness 16 Witness 8

1.3.93. [redacted] One of the cameras showed the aircraft floating on the surface, semi-submerged up to the canopy, but with the wings, tail, lift fan and auxiliary doors above water level. Several witnesses saw a "large red object" pushed up and out of the auxiliary intake on top of the aircraft. The sea boat was sent to recover the debris which was subsequently identified as BK-18's left intake blank (Figure 1.3.15). Exhibit 15 Witness 20 Exhibit 15 Witnesses 3, 4, 7 & 20

Figure 1.3.15 – Left intake blank recovered by QNLZ sea boat.

1.3.94. The pilot's Personal Locator Beacon (PLB) activated automatically during the ejection sequence. It was detected by satellite, and search and rescue co-ordination centres alerted automatically. The communication embargo delayed the Ship's survival equipment section from contacting the rescue co-ordination authorities to inform them that search and rescue activity was not required. Witness 20

Information quarantine

1.3.95. Relevant departments around the Ship, including the bridge, sqns and weapons engineering (WE) department, enacted the appropriate PCM activity. Guidance for this was in PCM Orders issued by Cdr AE which included impounding data and aircraft and Ship documentation for evidence. Witness 20 Witness 17 Exhibits 56 & 57

1.3.96. The WE department was tasked with impounding data items including: Witness 20

a. Autonomic Logistics Information System (ALIS), the information infrastructure and technical log for the F-35B. Witnesses 3 & 4

b. VSS.

c. Combat Management System data (CMS), the Ship's tactical system which records radar and communications information and other data streams.

d. TC2V, used to communicate around the Ship and with aircraft.

1.3.97. The ALIS data for the aircraft was successfully quarantined and impounded by the WE department. Witnesses 3,4,20 & 23

1.3.98. [redacted] Witness 20

1.3.99. The CMS data included [redacted]. This data was impounded at the time of the accident but subsequently lost due to system upgrade.

1.3.100. TC2V audio was saved, downloaded, and preserved for the investigation.

Salvage operations

1.3.101. After falling into the sea, BK-18 floated beside the ship for a short period before subsequently sinking. It was later discovered intact, inverted on the seabed, at a depth of 2,000m (Figure 1.3.16), with a few minor parts such as the ejection seat detached but close to the airframe. A salvage operation recovered the aircraft, and all the detached items, and then transported them back to the UK. [redacted] Exhibit 15 Exhibit 58

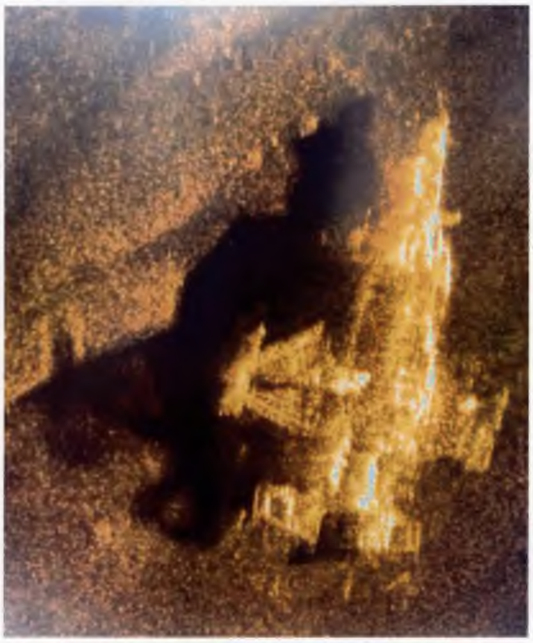

Figure 1.3.16 – BK-18 on the seabed prior to recovery.

[35] DAIB/21/27/Salvage Report - The recovery of UK F-35B BK-18 from the Mediterranean Sea.

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PART 1.4

Analysis and Findings

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PART 1.4 – ANALYSIS AND FINDINGS

All times Local (UTC + 2 hours).

Introduction

1.4.1. On Wednesday 17 Nov 21 at 11:45, an RAF 617 Sqn F-35B Lightning II, BK-18, ditched whilst attempting to launch from QNLZ. The Ship was operating in the Eastern Mediterranean, off the north coast of Egypt. The pilot ejected as the aircraft left the end of the flight deck ramp, landed back on the deck, and has since been returned to flying. The aircraft impacted the sea and subsequently sank.

Figure 1.4.1 – A UK F-35B

Methodology

Accident factors

1.4.2. Once an accident factor had been determined to have been present it was then assigned to one of the following categories:

a. **Causal factor(s).** 'Causal factors' are those factors which, in isolation or in combination with other causal factors and contextual details, led directly to the incident or accident. Therefore, if a causal factor was removed from the accident sequence, the accident would not have occurred.

b. **Contributory factor(s).** 'Contributory factors' are those factors which made the accident more likely to happen. That is, they did not directly cause the accident. Therefore, if a

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contributory factor was removed from the accident sequence, the accident may still have occurred.

c. **Aggravating factor(s).** 'Aggravating factors' are those factors which made the final outcome of the accident worse. However, aggravating factors do not cause or contribute to the accident. That is, in the absence of the aggravating factor, the accident would still have occurred.

d. **Other factor(s).** 'Other factors' are those factors which, whilst shown to have been present, played no part in the accident in question, but are noteworthy in that they could contribute to or cause a future accident. Typically, other factors would provide the basis for additional recommendations or observations.

e. **Observations.** Observations are points or issues identified during the investigation that are worthy of note to improve working practices, but which do not relate to the accident being investigated and which could not contribute to or cause future accidents.

Accident factors modelling

1.4.3. The panel recognised that accidents are usually the result of individual acts or omissions or technical events but that these occur in the context of a complex operational system with established defences against accidents. In investigating the broader factors influencing the accident the panel has exploited the work of Professor James Reason, known colloquially as the 'Swiss Cheese' model[1], adapted by the Australian Transportation Safety Bureau (ATSB), in its initial analysis of the accident assessing evidence across the following categories:

a. **Individual (unsafe) acts or technical events.** Unsafe acts are errors or violations which can be task-related or personal factors but can only be defined in relation to the presence of a particular hazard. Errors comprise slips, lapses and mistakes and are grouped as follows:

(1) **Unintentional acts.**

(a) **Slips.** Error by commission, where a well-practised skill, requiring little cognition, is carried out incorrectly.

(b) **Lapses.** Error by omission, where a well-practised skill, requiring little cognition, is not carried out.

(2) **Intentional acts.**

[1] Reason, J. (1997) Managing the Risks of Organizational Accidents. Ashgate, London.

(a) **Mistakes.** Deficiencies in judgement and / or failing to formulate the right plan based on flawed knowledge and / or incorrect comprehension of rules.

(b) **Violations.** Deliberate and conscious departures from established rules / procedures, although often with no intent to cause harm.

b. **Local conditions.** Local conditions are those events or circumstances which may lie dormant in any organisation or which may contribute to the accident on a particular day. They influence the efficiency and reliability of performance in a particular working context. Examples may include fatigue, perceived or actual pressure on individuals, poor weather, inappropriate crewing, etc.

c. **Organisational influences.** Organisational influences are those factors over which an organisation, at a high level, could reasonably be expected to exercise some measure of control. The 'organisation' in this context is the strategic entity which is responsible for designing, equipping and managing the working environment and for providing defences-in-depth against foreseeable organisational hazards. In the military context, examples of organisational influences may include vehicle design, regulations, orders, hazard identification or safety management systems, etc.

d. **Risk controls.** Risk controls relate to lower level means of creating defences, usually as part of the day-to-day operation of the organisation but are affected by organisational influences. For example, training, local rules or procedures (such as flying order books or military transport orders), authorisation processes and supervision each generate barriers against an accident happening.

Probabilistic language

1.4.4. The probabilistic terminology detailed below clarifies the terms used to communicate levels of uncertainty within the report. It is based on terms published by the Intergovernmental Panel on Climate Change (IPCC) in their Guidance Note for Consistent Treatment of Uncertainties[2] as well as the ATSB in their paper on Analysis, Causality and Proof in Safety Investigations.[3]

[2] https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-uncertaintyguidancenote-1.pdf.
[3] https://www.atsb.gov.au/media/27767/ar2007053.pdf.

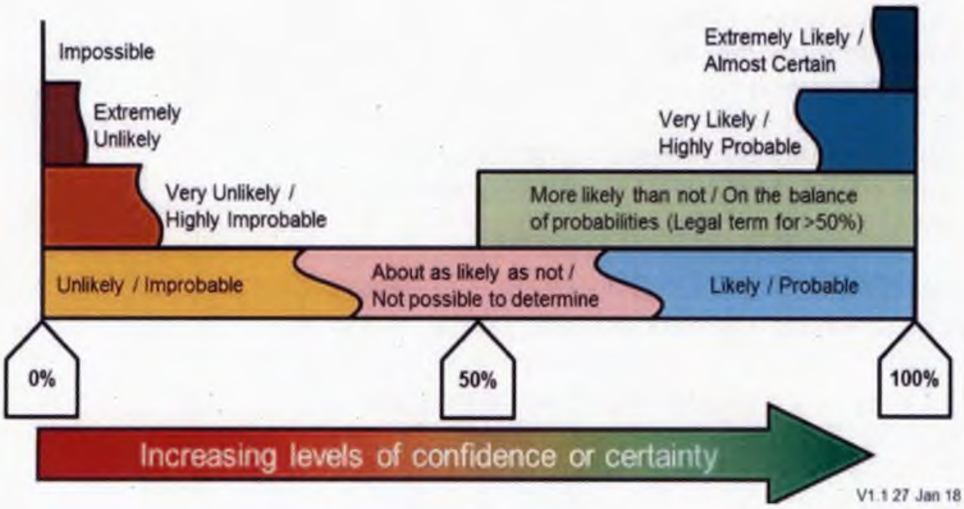

Figure 1.4.2 – Probabilistic terminology.

Available evidence

1.4.5. The panel had access to the following:

a. Aircraft evidence:

(1) Crash Survivable Memory Unit (CSMU).

(2) Pilot Memory Device (PMD).

(3) Autonomic Logistics Information System (ALIS) data.

(4) Aircraft wreckage.

(5) Ejection seat sequencing unit.

b. Interviews including:

(1) BK-18 pilot.

(2) 617 Sqn engineering management.

(3) 617 Sqn engineering personnel.

(4) QNLZ Air Department pers.

(5) QNLZ Air Engineering Department management personnel.

(6) QNLZ Flying Control (FLYCO) personnel.

(7) RAF Marham engineering management.

(8) QNLZ medical personnel and embarked surgical team.

c. Publications including:

(1) Joint-Service Technical Data (JTD).

(2) 617 Sqn Quality Assurance (QA) data.

(3) Lightning Force (LF) Level 0 Plan.

(4) Royal Navy Books of Reference, 760 series, 9600 series.

(5) QNLZ Air and Air Engineering Department Standing and Routine Orders.

(6) 617 Sqn Air Engineering Standing and Routine Orders.

(7) Lightning Force Standing Orders.

(8) Military Aviation Authority - Manual of Air Safety.

(9) Military Aviation Authority - Regulatory Articles.

(10) Military Aviation Authority – Manual of Airworthiness. Maintenance – Processes.

(11) Military Aviation Authority – Aircraft Post Crash Management Aide Memoir.

(12) F-35 Lightning II Program Security Crash and Recovery Field Guide.

(13) Defence Aviation Safety Occurrence Reports (various).

(14) Op FORTIS Phase reports (various).

(15) QNLZ flight deck induction briefs, training design & requirements documents and presentations.

(16) QNLZ Daily Orders.

(17) National Commission on Military Aviation Safety, Dec 1 2020.

(18) US Naval Air Training and Operations Procedures Standardization (NATOPS) - General Flight and Operating Instructions Manual CNAF M-3710.7.

d. Specialist reports:

(1) Defence Accident and Investigation Branch (DAIB) triage report.

(2) DAIB technical report.

(3) RAF Centre of Aviation Medicine (RAFCAM) Human Factors report.

(4) RAF CAM Aircraft Accident Investigation Report.

(5) 17 Test and Evaluation Squadron (TES) Trial FROSTY GLEAM Report.

(6) Lockheed Martin Aeronautics Company "Technical Report of F-35B No.169698 (BK018) Class A Flight Mishap, 17 November 2021".

(7) Martin Baker Aircraft RAF F-35B HMS Queen Elizabeth Post- Ejection Analysis Report. MBA-SYS-MP-202201.

Services

1.4.6. The panel was assisted by the following personnel and agencies:

a. 1710 Naval Air Squadron.

b. 207 Sqn RAF.

c. Combat Air Force Headquarters (CAFHQ).

d. DAIB.

e. Defence Equipment and Support (DE&S).

f. Integrated Training Centre, RAF Marham.

g. Joint Project Office (JPO).

h. Joint Aircraft Recovery and Transportation Squadron (JARTS).

i. UK Carrier Strike Group (CSG) / Carrier Air Wing.

j. Lightning Delivery Team (LDT).

k. Lockheed Martin Aeronautics (LMA).

l. Maritime C5ISR Support Unit (MCSU).

m. Maritime Capability Trials and Assessment (MCTA).

n. Martin-Baker Aircraft.

o. Pratt and Whitney (P&W).

p. QNLZ Air Engineering Department.

q. RAFCAM.

r. RAF Marham Station QA Cell.

s. Rolls-Royce (RR).

t. Royal Navy Flight Safety Centre (RNFSC).

u. Uppercut Films.

Context

1.4.7. Shortly after the pilot ejected, BK-18 was seen to be floating on the surface of the sea beside QNLZ. The aircraft auxiliary intake and lift fan doors were still open and water moved into the intakes and the exhaust of the aircraft. Video cameras on the Ship filmed the aircraft passing along the left side of the hull and recorded a red object floating out of the aircraft through the upper auxiliary intake doors (Figure 1.4.3). Personnel on the Ship replayed this footage after the accident and recognised the object as an item of Red Gear. It was recovered by the Ship's sea boat and impounded for further investigation. It was subsequently identified as an F-35B left intake blank from the set allocated to BK-18. During its investigation the panel examined how the blank may have been ingested or left inside the aircraft right up to the time of launch.

Exhibit 59
Witness 3
Witness 4
Witness 7

Witness 21

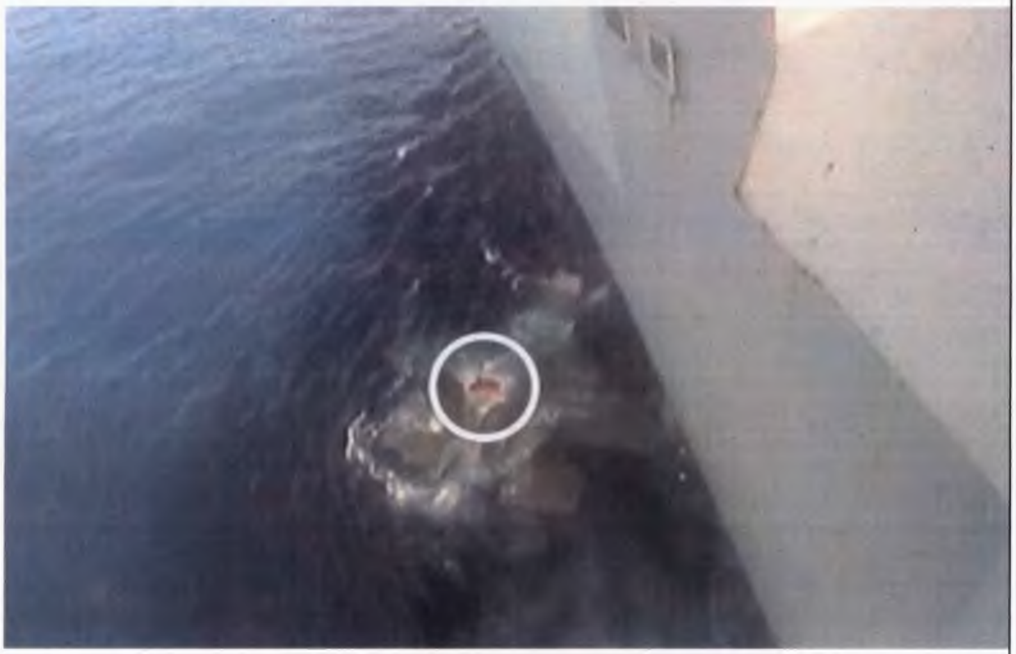

Figure 1.4.3 – Left intake blank floating out of BK-18.

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Op FORTIS

Defence Engagement

1.4.8. Op FORTIS was used by HM Government as a vehicle for delivering its vision of Global Britain around the world. During the deployment the task group engaged with over 40 allies and partners across the world[4]. On the seven month deployment the Ship travelled as far as Japan before returning to the UK, covering over 40,000 nautical miles. HM The Queen and the Prime Minister visited the Ship at the start of the deployment. The panel found that such high-level interest applied acute pressure to achieve significant exercise, operational and Defence Engagement objectives.

Witness 22

Security

1.4.9. The F-35 Special Access Programme (SAP) prevented unauthorised and uncontrolled access to all elements of the F-35 system. The Government SAP Security Officer (GSSO) team's task was to supervise SAP facilities and provide advice to the Ship's command team and to the Carrier Strike Group (CSG) on methods to ensure SAP protocols were complied with. They were responsible for the Ship's SAP compartments as well as F-35B dedicated hardware and software installed on QNLZ.

Exhibit 60
Exhibit 61
Exhibit 13
Witness 9

1.4.10. The Ship's GSSO team of [redacted] officers was augmented for Op FORTIS by an RAF Police sergeant. In comparison, the [redacted] embarked a team of [redacted] GSSOs. They were [redacted] personnel with a thorough knowledge of the security aspects of F-35B, and their area of responsibility was just [redacted] and its aircraft.

Witness 9
Exhibit 61

1.4.11. The Ship's GSSOs were experienced in the Ship aspects of the SAP but had little F-35B experience. With 617 Sqn embarked, their responsibilities were extended to include the security of the UK aircraft, security support to 617 Sqn and liaison with [redacted] GSSOs. [redacted]

Exhibit 61
Exhibit 13
Witness 9
Exhibits 62 to 64

Witness 21

1.4.12. The panel recognised that the RN had a long-standing reputation for delivering excellence in global Defence Engagement[5], but that it had never previously had to do so with a 5th Generation platform such as F-35B on board, with its associated security considerations. [redacted][6], [redacted]

Exhibit 65

Witness 22
Witness 9

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[4] UK Carrier Strike Group's HMS Queen Elizabeth Hosts Senior Visitors from NATO - GOV.UK (www).
[5] Hansard Volume 807: debated on Wednesday 4 November 2020.
[6] Hansard Volume 811: debated on Wednesday 28 April 2021.

[redacted] Exhibit 61

1.4.13. [redacted] Exhibit 61

1.4.14. [redacted]

Engineering

Red Gear fitment

1.4.15. The GSSO emailed both F-35B sqns on 10 Nov 21 to request that Red Gear was fitted to all aircraft on the flight deck during the Suez Canal transit. There was no direction for its subsequent removal in the email, so it was left to sqn managers to identify a suitable moment for this. The GSSO email was addressed to a cross-section of people on the Ship, but on 617 Sqn it was only sent to the JEngOs and Executive Officer. The panel found no evidence that it was shared with the trade desks, line or rectification controllers, and their handover notes contained no reference to planning that included Red Gear fitment. Witness 9 Exhibit 34

1.4.16. The engineering planning and handover notes of 15 Nov 21 contained no prompts to fit Red Gear. After being reminded by the GSSO, the 617 Sqn day-shift engineers fitted Red Gear to their aircraft at the end of their shift that day. On completion of this shift, the 617 Sqn engineers were stood down, next scheduled to work on 16 Nov 21 at 19:30 after the Suez Canal transit. The reminder by the GSSO was in person, to the flight line team that were in the FDHOC, but none of the engineering management team were present or informed. Consequently, no handover notes were updated. It was reported that it was already dark when the task was actioned. The panel considered that by fitting the Red Gear when it was dark it would have been difficult to ascertain how well it had been fitted to the aircraft. Witness 9 Exhibit 66

1.4.17. QNLZ left the north end of the Suez Canal at around 16:30 on 16 Nov 21. [redacted] removed blanks from their aircraft during the early evening of 16 Nov 21 whilst it was still daylight as part of the flight servicing. 820 NAS helicopters were also flight serviced in the early evening. Exhibit 15

1.4.18. In the panel's opinion, if security had been discussed in engineering planning meetings either on 10 Nov 21, in the period leading up to 15 Nov 21, or in the handover notes, it is very likely that more attention would have been paid to the Red Gear being removed correctly. The panel concluded that the omission of security considerations from 617 Sqn's engineering planning cycle was a **contributory factor.**

1.4.19. **Recommendation. The Lightning Delivery Duty Holder should ensure security considerations are included during engineering planning in order to maintain airworthiness whilst necessary security measures are implemented.**

Flight servicing

1.4.20. At the start of their shift, at 19:30 on 16 Nov 21, the Line Controller assigned Eng 1 and Eng 2 to the Post Operations Servicing (POS) / Before Operations Servicing (BOS) on BK-18. During this shift there was an additional task requiring personnel to move storage containers around the hangar. Eng 1 elected to conduct their part of the servicing as soon as possible, but Eng 2 helped in the additional task and, therefore, commenced their part of the servicing later. The panel opined that, if Eng 2 had not been distracted by the storage task, then it is likely that they would have worked on BK-18 at the same time as Eng 1 and, therefore, would have been able to manage the Red Gear more effectively. The panel concluded that the distraction of a peripheral task was a **contributory factor.**

Witness 12

Witness 13

1.4.21. After proceeding to the flight deck at around 21:30, Eng 1 observed the Red Gear fitted to BK-18. A full set of Red Gear was too bulky to be carried by one person, so on completing their servicing they took the right intake and Power Thermal Management System (PTMS) blanks down to the hangar. They left the exhaust and left intake blanks in place and assumed Eng 2 would collect them. Eng 1 returned to the crew room and left the tools there for Eng 2. However, no formal handover was conducted and they did not discuss the partial removal of Red Gear. In the panel's opinion, had there been a more detailed handover it is highly unlikely that any elements would have been missed. The panel concluded that not removing all elements of Red Gear at the same time was a **contributory factor.** The panel further concluded that the omission of a handover which included Red Gear was also a **contributory factor.**

Witness 13

Witness 12

1.4.22. **Recommendation. The Lightning Chief Air Engineer should provide direction and guidance regarding the division of flight servicing tasks between multiple engineers in order to maintain airworthiness.**

1.4.23. When Eng 2 commenced their part of the servicing just after midnight the only piece of Red Gear they observed was the exhaust blank lying on the deck just behind BK-18, which they returned to the issue centre. They discovered the weather on the flight deck was windy and upper surfaces of the aircraft were wet from recent rain. They elected not to climb on top of the aircraft to carry out the upper surfaces inspection, considering that the protective overboots required to walk on top of the aircraft provided

Witness 12

poor traction in the wet. The panel noted that the omission of this part of the flight servicing was neither recorded in any Military Continuing Airworthiness Manager (Mil CAM) deviation registers nor authorised by any orders. The panel concluded that this deviation from flight servicing procedures was an **other factor**.

1.4.24. **Recommendation. The Lightning Military Continuing Airworthiness Manager should identify all deviations required by Lightning engineers and update the Deviation Register in order to ensure they are appropriately mitigated and recorded.**

Flight deck activity

1.4.25. Operations on the flight deck at night were hazardous so a 'two-man rule' was in place so that engineers would not work solo. This was considered by Eng 1 and Eng 2, who ensured other engineers were on the flight deck at the same time as they conducted their servicing. The engineers were unable to identify where this rule was stipulated. The panel reviewed all relevant orders but found no reference to the 'two-man rule'[7]. Whilst prudent, the panel found that it was a QNLZ local order that was only briefed verbally. The panel concluded that the lack of formal stipulation in orders of the 'two-man rule' left it open to interpretation and was an **other factor**.

Witness 12
Witness 13

Exhibits 5, 67 to 77

1.4.26. **Recommendation. Director Force Generation should define the procedures for solo working on Queen Elizabeth Class flight decks in order to ensure the safety of personnel working on deck at night.**

1.4.27. 617 Sqn engineers remarked that torches used for working on the flight deck at night had to be fitted with blue, green or red filters to prevent the bridge team's night vision being affected by white light. The engineers found it hard when using filtered light to conduct flight servicing to the required standard, but understood that white light could not be used anywhere on the upper deck. [redacted] The panel reviewed QNLZ orders, briefings and training but found nothing relating to the use of white light[8]. The panel concluded that the lack of definition of where white light could and could not be used may have unnecessarily limited the potential to identify faults or abnormalities and was an **other factor.**

Witness 13
Exhibit 47

Witness 12
Witness 13

Exhibit 78

Exhibit 79

1.4.28. F-35B internal surfaces were painted white so that bird strikes, leaks or damage could be readily identified. The panel found that 617 Sqn engineers were not trained in flight servicing of aircraft using filtered lights. [redacted] and were proficient, as were 820 NAS from previous embarkations. The panel opined that if the red intake blank were to be dislodged, but still partially visible in the intake, the use of

Exhibit 79

[7] Flight deck induction briefs and associated training requirements, Air Department Standing Orders (ADSOs), Queen Elizabeth Class Embarked Aviation Orders (BRd766), Ship's General Orders (BRd9600(8)).
[8] Nothing detailed in ADSOs, Embarked Aviation Orders (BRd766) nor in the Ship's General Orders (BRd9600(8)).

filtered light in a dark intake would have decreased the likelihood of it being seen (Figure 1.4.4). The panel concluded that not using white light for servicing was a **contributory factor.**

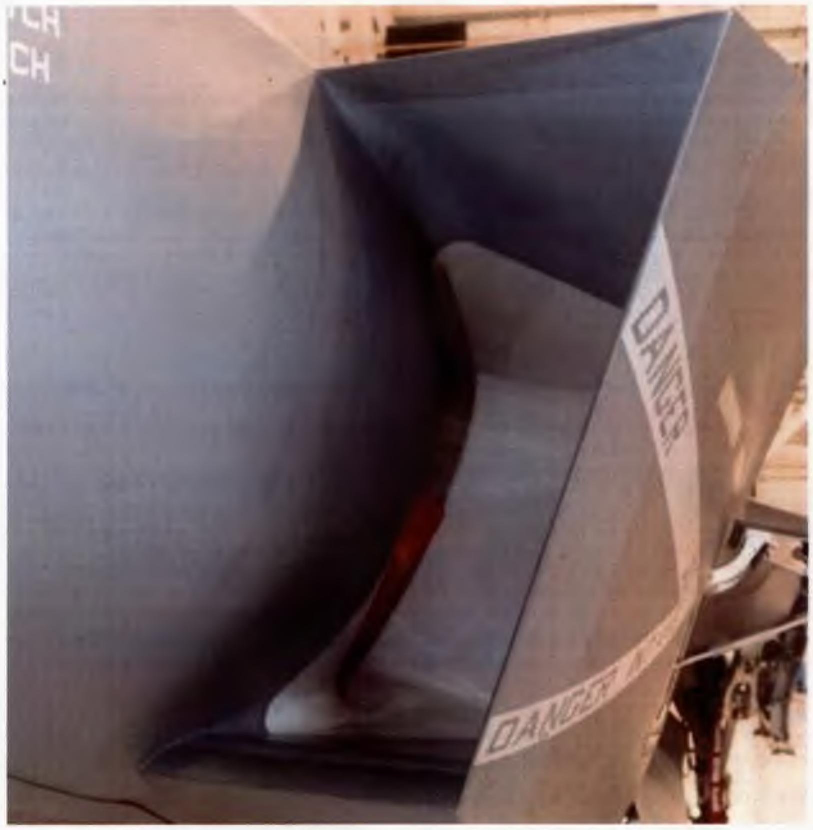

Figure 1.4.4 – Reproduction of F-35B with displaced left intake blank in shadow.

1.4.29. **Recommendation. Director Force Generation should define the procedures for use of white light on the Queen Elizabeth Class flight decks at night in order to ensure engineering standards and practices can be achieved.**

1.4.30. **Recommendation. Lightning Chief Air Engineer should assess engineering environments in which white light is not permitted and enact appropriate measures in order to mitigate the associated risk to engineers and airworthiness.**

Red Gear removal

1.4.31. On the morning of 17 Nov 21, many of the night shift engineers had
finished work and had been released prior to the end of shift, including the Witness 23
issue centre custodian (ICC). During the first [redacted] launch, a blank Witness 5
blew out of a UK jet parked in the 'knuckle' region (Figure 1.4.5). Personnel Witness 25
in flying control (FLYCO) observed that Red Gear was still fitted to 617 Sqn
aircraft, although it had been removed from [redacted] aircraft. The Deck Witness 17
Operations Officer (DOO) informed the 617 Sqn JEngOs, during their Witness 16
handover in the FDHOC, who recalled the duty crew from the night shift, Witness 23
sending them to the flight deck to recover the Red Gear. Subsequently, all

visible and accessible 617 Sqn blanks were recovered at 06:57 (in daylight) and stowed in the Thatcham. The blanks were not stored in set order, so it would have been difficult to identify incomplete sets by the way they were stored.

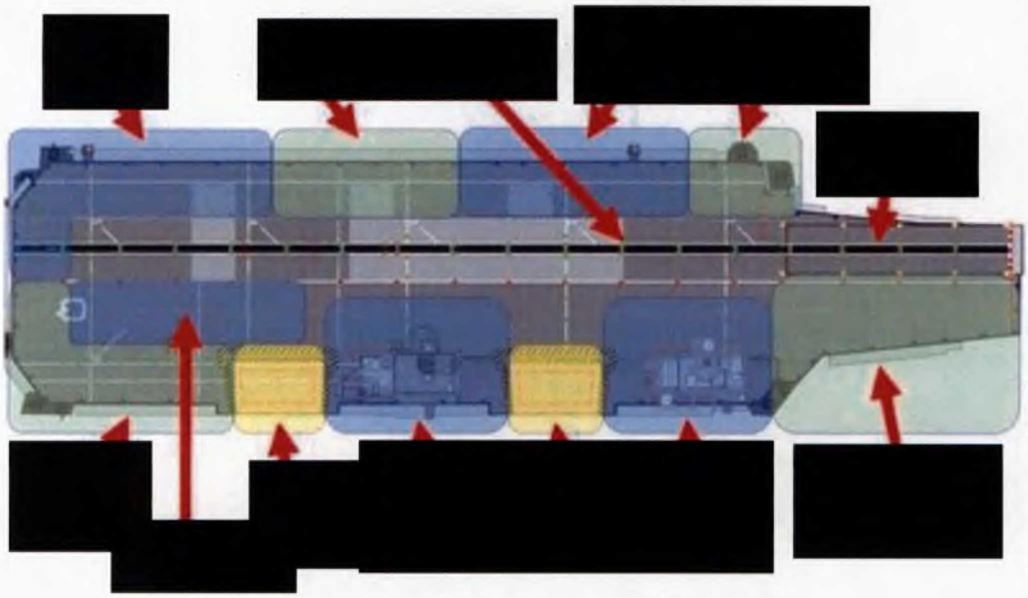

Figure 1.4.5 – Flight deck parking area identification.

1.4.32. The tail of BK-20 overhung the edge of the forward lift, which would have prevented exhaust blank removal, so it had to be left until a tow team could pull the aircraft forward. Subsequently the exhaust blank blew out and was lost in the sea over the starboard side of the ship before the tow team could be mustered. Exhibit 15 Witnesses 3, 4, 5 & 23

1.4.33. As the ICC had been released from shift, the issue centre was closed with the keys held in the FDHOC. Therefore, there was no efficient way to record the removal in the Red Gear log. The panel concluded that reliance on the issue centre being open for Red Gear control was an **other factor**. Exhibit 48

1.4.34. The panel determined that the following series of Red Gear issues occurred on the evening of the 16 Nov 21 until the loss of BK-18 on the 17 Nov 21, none of which were recorded in the Red Gear log: Exhibit 48

a. 16 Nov 22:30: On arrival at BK-14 the flare load team discovered the Red Gear was still fitted after it had been flight serviced. 617 Sqn engineers had endeavoured to remove Red Gear from BK-18 and BK-21 during servicing, but not BK-14. Witness 14

b. 16 Nov 21:30 to 17 Nov 02:00: BK-18 all Red Gear apart from the left intake blank was removed from the aircraft. Exhibit 50

c. 17 Nov 06:47: Blank blown out of UK F-35B by [redacted] F-35B launch. Blank returned to FDHOC during engineering handover. Exhibit 15

d. 17 Nov 06:57: Engineers removed most visible Red Gear from UK F-35Bs on the flight deck. BK-20's exhaust blank was omitted. Witnesses 8, 15 & 23

e. 17 Nov 07:05: Red Gear thrown into the Thatcham in the hangar such that they spill onto the hangar deck. Re-stowed in an uncontrolled fashion, negating the opportunity to identify the missing blank. Exhibit 15

f. 17 Nov 07:45: BK-20 exhaust blank fell out and was lost overboard, with associated DASOR raised by the ICC. Witnesses 8, 15, 16 & 23

1.4.35. In the panel's opinion, if a 100% check of all the Red Gear had been carried out after the mass removal had been completed, the left intake blank in BK-18 would likely have been noticed as missing. In a subsequent search it would likely have been discovered. The panel concluded that the lack of a confirmatory muster after the mass removal of Red Gear was a **contributory factor.**

1.4.36. **Recommendation. The Lightning Chief Air Engineer should ensure a robust and auditable Red Gear control procedure is in place in order to verify the location of Red Gear at all times.**

Engineering management focus

1.4.37. Although the range of Red Gear issues were discussed briefly prior to the first 617 Sqn launch, the JEngO and rectification controller were preoccupied with management of the flare load. This load was not specified in Lightning Force (LF) orders, and so 617 Sqn wrote temporary orders for themselves for Op SHADER. These orders had not been used in the intervening four months and the JEngO and rectification controller were focussed on re-reading and debating the flare load policy and procedures rather than on the Red Gear. It is impossible to ascertain whether more attention to Red Gear issues at this stage would have resulted in the discovery that the left intake blank was missing. The panel concluded that distraction caused by the requirement to operate an unfamiliar load configuration without supporting procedures was an **other factor**. Exhibit 15 Witness 3 Witness 4 Witness 23

1.4.38. **Recommendation. Lightning Operating Duty Holder should ensure that all weapons and countermeasures included in UK F-35B Operational Capability Certificates have supporting orders that detail loading procedures, training, and assurance in order to ensure squadrons are fully prepared to employ them.**

Engineering summary

1.4.39. There were six related blank issues that occurred on the night of 16 Nov 21 and morning of 17 Nov 21. The panel determined that the engineers were working in conditions that increased the likelihood for errors to be made.[9] The aircraft were all left in varying states of Red Gear fitment post-servicing. In the panel's opinion, under the conditions that prevailed that

[9] J. Reason and A. Hobbs, 'Managing Maintenance Error a Practical Guide,' Ashgate Publishing Limited, London, 2003.

evening, the omission of an item of Red Gear could have occurred in any one of the aircraft. The panel concluded that deviation was normalised in:

a. The lack of reaction by the flare loading team upon discovering serviced aircraft with differing states of Red Gear.

b. A general lack of reaction to blanks being blown out or coming loose (vice losses which were reported by Defence Air Safety Occurrence Report (DASOR)).

c. The omission of upper surface inspections during flight servicing in wet conditions.

d. Perceiving Red Gear as a hazard to other aircraft, therefore, not fitting it on the flight deck.

e. Not perceiving Red Gear as a threat to the aircraft to which it was fitted.

1.4.40. In the panel's opinion, at all levels of the Lightning programme, Red Gear was not perceived as a threat. This perception caused it to be treated less rigorously than other tools and instruments. The panel concluded that the perception that Red Gear was only a risk to other aircraft or personnel, not a threat to airworthiness of the aircraft to which it was fitted was a **contributory factor.** This is addressed by the recommendation at Para 1.4.36.

Launch

Pre-sortie events

1.4.41. On the morning of 17 Nov 21, BK-18's pilot was planning to lead two sorties as part of an instructor qualification work-up, supervised by an experienced instructor flying in BK-21 as the number two. Both pilots described their morning routine as being normal. They attended the Ship's Flying Brief[10] at 09:00 and commenced the sortie brief at 09:20. The Instructor attested that the brief was delivered to a high standard and finished on time at 10:30, permitting a short period for refreshment before out briefing[11] at 10:35.

Exhibit 80
Witness 7
Witness 10

1.4.42. After the out brief, the pilots went together to flying clothing to dress in most of their Pilot Flying Equipment (PFE), then proceeded to the FDHOC where they signed for their aircraft at 10:58. After signing they collected their helmets, before heading up to the flight deck. Poor canopy cleanliness due to sea spray had previously been raised by DASOR[12], so the see-off[13] team was cleaning the canopy as the pilot arrived at BK-18. The pilot then conducted a walkaround of the aircraft, electing to remove the undercarriage

Exhibit 81
Witness 7
Witness 10
Exhibit 40

[10] The Ship's Flying Brief includes all information pertinent to flying for the day such as weather, diversions, Ship's equipment, airspace and special procedures for safe conduct of aviation.
[11] The out brief was a last chance check of pilot currencies, aircraft and sqn specific data and procedures.
[12] [redacted]
[13] The 'see-off' describes the process by which engineers support the pilot walkaround, crew-in and start, and continues until the aircraft is taxied away from its parking space.

pins in the process. The walkaround included checking inside the intakes, and the pilot reported not seeing the intake blank. During the start up, a small quantity of liquid was seen to emanate from the vicinity of the weapon bay of BK-18. The see-off supervisor investigated and determined that this was residual rain water from rain fall during the previous night. Other than this the aircraft start up appeared normal, and the engineers completed all their checks and found nothing else untoward. The panel concluded that the way the engineers and pilot conducted the see-off was **not a factor.** Witness 10 Exhibit 15

Take-off roll and abort

1.4.43. The Landing Signals Officer (LSO) had calculated that, [redacted] the aircraft take-off bracket was [redacted]. The pilot signalled to BK-18's see-off team to remove chocks and chains. They did so, and at 11:37 the aircraft was taxied to the [redacted] for departure. [redacted] Witness 10 Witness 7 Exhibit 82 Witness 17 Witness 24

1.4.44. At the moment the pilot decided to attempt to abort, the aircraft was travelling at [redacted] Indicated Air Speed (IAS) and had just started up the ramp with around [redacted] of take-off roll remaining. Upon electing to abort, the pilot selected the throttle to Idle, and simultaneously applied the brakes. The engine momentarily increased to 80% Engine Thrust Request (ETR) before starting to decrease, but it was still delivering a considerable amount of power and deceleration was slow. From commencing the abort to reaching the top of the ramp took 3 seconds, and the aircraft had decelerated from [redacted] to [redacted] IAS. At this point, the pilot ejected. Witness 10 Exhibit 2

Simulator trial

1.4.45. To better understand the aircraft's performance during the accident the panel commissioned 17 Test and Evaluation Sqn (TES) to conduct a simulator trial. The trial reproduced the circumstances of the accident, and then explored the effects of varying the take-off parameters and pilot actions on subsequent aircraft performance. The simulator reproduced the low-power state of the accident aircraft, and so replicated the take-off incident accurately. Exhibit 83

1.4.46. The panel noted that UK F-35B pilots were taught that once brakes were released for take-off that there was no abort option available to them. They were expected to continue a take-off regardless of aircraft failures, and manage any problem when airborne, or eject. The trial investigated what the outcome might have been were the pilot not to have aborted, and to have attempted to continue the take-off. The trial report concluded that with this specific failure case it was extremely unlikely that a continued take-off attempt could have resulted in sustained flight, regardless of the starting Exhibit 84 Exhibit 85 Exhibit 81 Exhibit 83

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[14] Runway positions are measured in feet back from the departure end of the ramp.
[15] In a stream take-off aircraft depart one after another at a given interval.

position on deck. The panel concluded that the pilot's decision to abort was appropriate given the circumstances and was **not a factor.**

1.4.47. The panel noted that it was standard procedure for aircraft to take-off from a position as far forward on the deck as possible, usually 350ft. The accident was reproduced in the simulator with the aircraft starting at the 500ft point. It was determined that in this scenario, had the abort decision been made after the same elapsed time, it was possible to abort successfully. Accordingly, the panel concluded that the selection of the shortest take-off run was an **aggravating factor**. Despite this, in the panel's opinion, BK-18's failure case was so specific that such a result should not be used to modify existing abort training. However, recognising the relative immaturity of the UK F-35B capability the panel considered that take-off distance selection should be reviewed in the light of the experience earned on Op FORTIS. Witness 8 Witness 17 Witness 24 Exhibit 83

1.4.48. **Recommendation. Lightning Operating Duty Holder should direct further work to understand the performance of F-35B on carrier operations in order to assure that the risks to the F-35B associated with take-off distance selection remain As Low As Reasonably Practicable and Tolerable, based on experience from Op FORTIS.**

1.4.49. **Recommendation. Director Force Generation should review the risk to carrier operations of the F-35B take-off distance selection on Queen Elizabeth Class carriers in order to assure that it remains As Low As Reasonably Practicable and Tolerable, based on experience from Op FORTIS.**

Ejection sequence

1.4.50. The ejection sequence was initiated by the pilot whilst the aircraft was still on the ramp but decelerating. The F-35B used an explosive charge to remove the canopy during ejection. This detonated correctly and the canopy separated from the aircraft. [redacted] Exhibit 2 Exhibit 54 Exhibit 41 Witnesses 8, 10 &11 Exhibit 54

1.4.51. The arm and leg restraint system was designed to pull the pilot's limbs into position to protect from the effects of wind shear and prevent injury during ejection. The leg restraint system worked correctly, but the arm restraint extension line (AREL) rings had not pulled to the wrist as designed (Figure 1.4.6). The left AREL did not move on the jacket, the right AREL had broken the red retaining tie but remained above mid-bicep position, so neither restrained the arms correctly. The RAFCAM investigation could not conclusively determine the cause but identified two likely reasons. First, the AREL may have been too long for the pilot. Second, the 'white whistles' through which the AREL are supposed to be routed could have become dislodged, leading to incorrect AREL lug routing (Figure 1.4.7). This incorrect routing could appear normal to the user but would cause the ARELs to be ineffective. Poor fitting of the arm restraint system could have resulted in an increased likelihood of injury during ejection. Since this was a low-speed ejection, the incomplete function of the restraint lines in this instance was an Exhibit 54 Exhibit 54

other factor. RAFCAM determined that all other aircrew equipment worked correctly.

Figure 1.4.6 – BK-18 pilot's flight jacket. AREL red tie on left sleeve remained intact.

Figure 1.4.7 – 'White whistle' into which the lower lug of the AREL was fitted.

1.4.52. **Recommendation. The Lightning Type Airworthiness Authority should provide clear guidance to aircrew and survival equipment technicians on the correct selection, fitment, and use of arm restraint extension lines (AREL), to include length selection and use of 'white whistles', in order to improve the likelihood of correct AREL function.**

1.4.53. This was the first UK ejection using the Mk16E seat. The ejection sequence operated as expected with the seat operating within the operational performance envelope. Analysis of the seat data card by Martin Baker showed all sequenced events required in the ejection functioned correctly. The pilot stated that the acceleration felt smooth, and not violent. Exhibit 54

The panel determined the ejection seat was fit for purpose and concluded that its performance was **not a factor.** Exhibits 86 & 87

Life preserver performance

1.4.54. The F-35 Life Preserver (LP) was not inflated by the pilot during the ejection. The LP was sent to RAFCAM for examination and testing. During the inflation test, one of the stoles[16] failed to inflate. This failure was similar to a recent failure on a Hawk LP stole, so Urgent Safety Advice was published, and the LP was sent to 1710 NAS for forensic examination. Their investigation concluded that the way the stole was packed contributed to a localised increase in pressure that exceeded the structural stability of the material. The panel determined that had the pilot entered the water and inflated the stole, the single working stole would have provided adequate buoyancy, but redundancy would have been decreased. The panel concluded that the failure of the LP was an **other factor**. Exhibit 88

1.4.55. **Recommendation. Lightning Delivery Team Head should engage the Joint Program Office to ensure the performance of twin stole life preserver systems meets the requirement specification in order to minimise the risk of stoles failing on inflation.**

Red Gear

Aircraft design

1.4.56. Red Gear was designed to prevent Foreign Object Debris (FOD) entering the airframe. The use of inlet blanks was common for many civil and military aircraft. The F-35B design had a single engine fed by twin air intakes. The design was unique as its inlet duct formed a large area, known as the common duct, that was unobservable from a position outside the intakes. Exhibit 10 Exhibit 1

1.4.57. Figure 1.4.8 shows an F-35B intake blank deliberately positioned at a point where most of the blank is around the first turn in the duct leaving only a small corner of the blank visible from outside. Figure 1.4.9 shows the blank slightly further down the intake at a position where it is no longer visible to someone looking down the intake. Figure 1.4.10 shows the internal position of the same blank. Items located in the intake duct could only be discovered by someone climbing into the intake to look, not just observing from the ground. No previous UK aircraft had this unobservable area. The panel concluded that lack of familiarity with this design feature and the associated potential for items to be concealed in the intake was a **contributory factor.**

[16] Stole is the inflatable tube that provides buoyancy.

Figure 1.4.8 – Intake blank positioned in the intake.

Figure 1.4.9 – Intake blank positioned in the intake, but not externally visible.

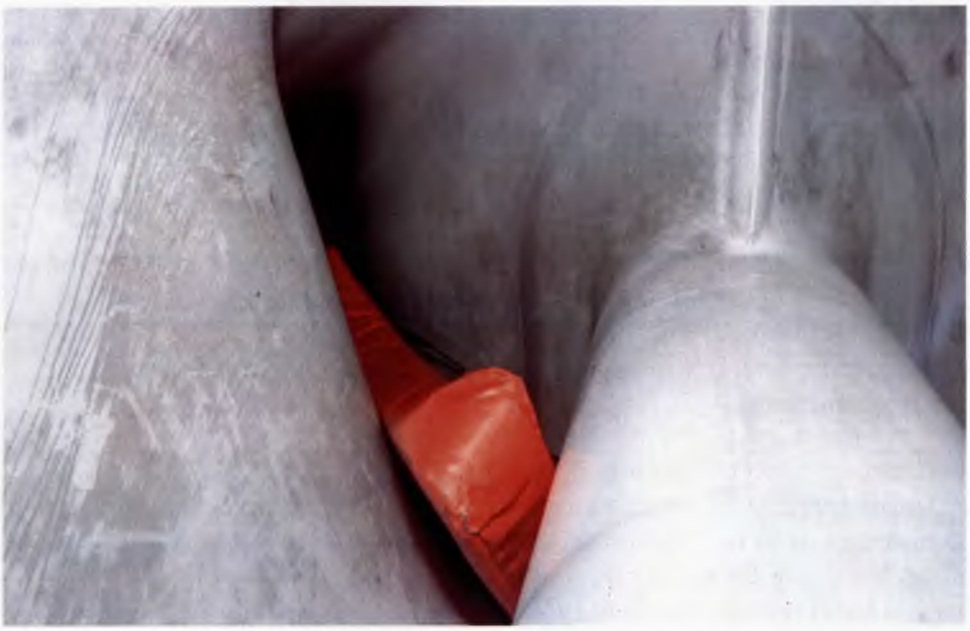

Figure 1.4.10 – Blank located in common duct, but no longer visible to external view.

Red Gear employment policies

1.4.58. To bring conformity to the see-off procedures at RAF Marham a see-off Air Engineering Standing Order (AESO) was created with more detail than the Joint-Service Technical Documentation (JTD) section for 'Aircraft Dispatch Actions (ADA) – Inspections'. The JTD instructions directed that the intake and exhaust should be inspected for FOD but did not explicitly state how to do this. In the [redacted] and the [redacted] who operated the F-35B and F-35C respectively, the see-off team conducted a check

Exhibits 89 to 93

immediately prior to the pilot getting into the aircraft. An engineer climbed into the common duct to check for FOD, a process known as 'diving the duct' which, when completed, was reported to the pilot on their arrival at the aircraft. The JTD did not explicitly instruct the engineer to 'dive the duct,' but the text did include instructions for entering the duct safely and matched those required for the engine intake inspection.

1.4.59. This action of 'diving the duct' was not stipulated in the AESO see-off procedure. In the UK, engineers inspected inside the common duct during a POS/BOS, but this servicing was valid for up to 24 hours. There was no further check in the intervening period before the aircraft went flying. Fitment of Red Gear should have subsequently protected against FOD entering the intake, but as Red Gear was not routinely fitted whilst aircraft were on the flight deck, continuity of protection was lost.

Exhibits 94 & 95
Exhibits 92 & 93

1.4.60. The AESO stated that the see off team should report to the pilot:

Exhibits 94 & 95

> '... this is BK-** (as appropriate) all Red Gear has been removed and accounted for and the 3 groundlock safety pins have been removed, placed in the Pin Bag and stowed within the MIP Panel'.

At RAF Marham the Red Gear stowage was adjacent to the aircraft, so Red Gear could be readily checked to support this statement. On the Ship, the Red Gear was stowed in the Thatcham in the hangar, and thus not readily available to enable compliance with this order. The panel **observed** that the see-off AESO was not easy to apply at sea and was seldom conducted in full whilst on land. The order, whilst seemingly effective, offered negligible assurance.

Exhibit 96

1.4.61. The panel found that the UK had omitted an important safety step when writing the see-off AESO, that if implemented could have led to the discovery of BK-18's intake blank. The panel concluded that the UK omission of an independent check of the common duct immediately prior to flight was a **contributory factor.**

Exhibit 89

1.4.62. Experience from embarked operations was that FOD was often found in jet intakes, most notably those close to the ramp[17]. As the Red Gear was often found to dislodge or to be 'blown out' during the deployment it was not fitted to aircraft on the flight deck. This deviation was recorded in the Mil CAM Deviation Register and agreed on 19 May 21. The panel could not identify that the risk of not fitting the blanks had been reviewed following the previous reports. The panel **observed** that there was no apparent UK mitigation to protect from FOD when not fitting the blanks on the flight deck.

Exhibits 19 to 22

Exhibit 97

1.4.63. **Recommendation. The Lightning Chief Air Engineer should ensure that Instruction 21 of the Joint-Service Technical Data, Aircraft Dispatch Actions, is conducted during all see-offs in order to ensure intakes are clear of Foreign Object Debris immediately prior to engine start.**

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17 [redacted]

1.4.64. The first tranche of 617 Sqn F-35B engineers conducted on-the-job training with the USMC[18] at Marine Corps Air Station (MCAS) Beaufort from 2016 to 2018, operating under US Naval Air Systems Command orders and training. [redacted]

Exhibits 98 & 99

1.4.65. **Recommendation. The Lightning Chief Air Engineer should implement a procedure to ensure UK engineering orders are regularly reviewed in order to ensure they achieve the intent of all Joint-Service Technical Data instructions.**

Red Gear design

1.4.66. The original intake covers[19] used quick release or 'pip' pins[20] to secure the blank around the external contours of the airframe. Use of these pip pins caused damage to the aircraft skin which required time-consuming specialist repair. The F-35B blanks in use on Op FORTIS were designed to fit into the first stage of the intake. [21] The blank had two nylon handles to assist with installation and just one pip pin to secure to the lower edge of the intake in the event it became dislodged. A pocket was provided for the pip pin to be stowed during installation, removal and storage (Figure 1.4.11). The removal/installation procedure in the JTD referred to the original design only, thus there was no specific JTD reference to the new blanks and their pip pins. 617 Sqn engineering management were concerned that the pip pin lanyard would rub on the lower lip of the intake and cause damage to the aircraft skin. They were also concerned that if the blank were to come loose and fall out of the intake, the pull of the blank on the pip pin would damage the pip pin receptacle causing similar airframe damage. The panel noted that upon recovery from the sea, the left intake blank from BK-18 still had its pip pin stowed in the pocket, indicating that it had not been fitted.

Exhibit 6
Witness 4

18 [redacted]

19 A00016 and A00017, described as 'wraparound' blanks.

20 Removable pin device that used a spring-loaded ball bearing to provide a method of temporary attachment to suitable receptacle in the aircraft skin.

21 A00020 and A00021, described as 'intake plug' blanks.

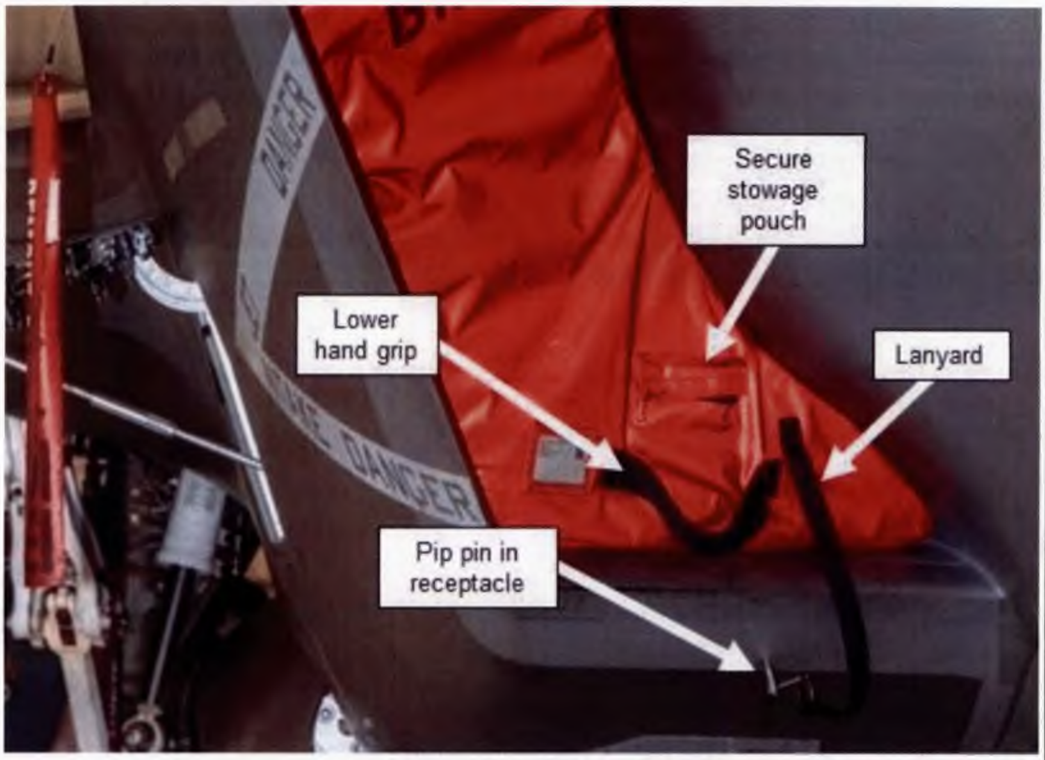

Figure 1.4.11 – Installed intake blank showing lanyard and pip pin.

1.4.67. The earliest test data seen by the panel related to the original intake covers which made use of the pip pins and receptacles in the aircraft skin. The typical user scenario quoted in the test report was '...when the aircraft is parked on a runway or flight deck to prevent possible damage to the aircraft due to intrusion of FOD or weathering elements.' No wind loads were mentioned and the testing was confined to the ergonomics of fitting the blank against a US standard[22]. Exhibit 100

1.4.68. The authorised plug type blanks had a similar report, which was not provided to the Lightning Delivery Team (LDT). This stated: Exhibit 101

> 'The Inlet Plugs are secured within the lip assemblies by incorporating a design that provides a tight fit within the Inlet Lip that allows the Plugs to withstand external forces such as wind. Additionally, each Inlet Plug will interface with the aircraft using one tethered ball lock pin. These pins are inserted through the cover and into a receptacle in the engine inlet lip specifically for this purpose.'

1.4.69. Testing was limited to an assessment of the weight of the blank and the height above the ground that personnel would need to lift it during removal and installation. Annex A of the report contained a section on wind loading. This was restricted to the loading on the pip pin, which modelled the blank as a "Flag" and then calculated the wind force on the blank acting as a "Flag" in the wind. This load was then compared to the maximum load capacity on the pip pin and then the receptacle, both of which exceeded the Exhibit 101

[22] MIL-STD-1472 - US DEPARTMENT OF DEFENSE DESIGN CRITERIA STANDARD: HUMAN ENGINEERING.

requirement. The panel noted that the pip pin was therefore relied upon as the method of resisting the wind and not the 'tight fit' of the blank as no loading calculation was conducted on the fit of the blank. The test report did not state a possible wind speed at which the plug may be either blown into or out of the intake or comment on potential damage by lanyard chafe or impacts from the blank on the engine intake or aircraft skin. Exhibit 102 Exhibit 103

1.4.70. The lack of the JTD reference was not apparent to the LDT as the LM documentation used to authorise the blanks referred to a picture that was not representative of the blanks actually delivered to 617 Sqn for Op FORTIS. The picture used was of a locally manufactured blank which was assumed by the LDT to be the final design. There was no pip pin shown in the picture, and no mention of it in the text. Hence, there was no prompt for the Type Airworthiness Authority (TAA) to assess it and provide guidance to the Lightning Force on its use. The panel found that the use of the pip pin could have prevented the blank from migrating down the intake. The lack of awareness on 617 Sqn of whether the pip pin should be used was a **contributory factor**. Exhibit 10

1.4.71. **Recommendation. The Lightning Type Airworthiness Authority should update the Air System Document Set for the current Red Gear design including the pip pin, in order to ensure the design is fit for purpose and its use supports airworthiness.**

1.4.72. The subsequent Northrop Grumman Engineering Evaluation Test of the insert type blanks assessed several factors, all of which passed: Exhibit 104

a. 'Verify no gaps around the inlet blank to allow FOD ingress.

b. Verify inlet blank fixed to air vehicle inlet.

c. Verify inlet plug achieves consistent/repeatable positioning configuration.

d. Verify that the inlet blank does not damage or wear the air vehicle skin coatings.'

1.4.73. The Northrop Grumman test evaluation of the lanyard noted that the final design should be shorter to prevent it being caught by the wind. However, the test evaluation did not identify the wind limits the blank should be able to withstand. The Support Equipment Request stipulated that the worst-case environmental condition was a 'HANGAR DECK'. The panel determined that the blank was not adequately designed for windy conditions. The panel concluded that the lack of environmental considerations in the blank design was a **contributory factor**. Exhibit 104 Exhibit 8

1.4.74. **Recommendation. The Lightning Delivery Team Head should engage the Joint Program Office to assess the performance of Red Gear during land and embarked operations in order to ensure it is fit for purpose.**

1.4.75. The F-35 support equipment picture book included images of Red Gear, with the original design of wraparound cover listed as support Exhibit 6 equipment in the JTD. However, the Global Pool[23] policy omitted Red Gear from the list of support equipment managed.[24] Consequently, UK Red Gear was not controlled by the LDT, there was just a list of blanks that were delivered with the aircraft. The LDT had no details as to how many intake blanks were in circulation, of which standard, how many had been replaced or whether any of the locally purchased blanks had been brought over from MCAS Beaufort. On a sqn, if a blank was found worn or damaged then the LM Field Service Representative ordered new blanks directly from LM, without requiring LDT involvement. Such inspections were conducted every 28 days and were detailed in the Air System Document Set (ADS). The JTD did not include the intake plug design and only referenced the wraparound cover design. The panel determined that Red Gear was an 'orphan asset' which neither the Lightning Force nor the LDT formally managed. The panel concluded that this resulted in the lack of installation and removal procedures being produced for the new blanks, which was a **contributory factor**.

Exhibit 105
Exhibit 106
Exhibit 107

1.4.76. **Recommendation. The Type Airworthiness Authority should ensure the Air System Document Set includes installation and removal procedures for all in-service Red Gear in order to ensure proper fitment.**

Red Gear losses

1.4.77. Problems with the design of the Red Gear intake, exhaust and PTMS blanks[25] were raised in several DASORs[26], including during Ex WESTLANT 18/19 and during Ex CRIMSON OCEAN 20, for blanks lost overboard. 17 TES raised a DASOR[27] on 26 Feb 18 reporting 'Heat Exchanger' blanks to have been lost, and another referencing an exhaust plug being blown out. At RAF Marham on 3 Dec 18 an intake cover was found trapped around the lower lift fan door of an aircraft. On Op FORTIS several occurrences of blanks falling from aircraft were recorded. Whenever a blank was lost overboard it was reported by DASOR. If a blank was dislodged from an aircraft, but not lost, it would not necessarily be reported. In the panel's opinion there were very likely to have been many more instances of Red Gear being dislodged from aircraft than were recorded.

Exhibits 16
Exhibit 108
Exhibit 109
Exhibit 110
Witness 5
Witness 12

1.4.78. Engineers stated that sometimes they would find a blank on the ground or a blank would fall out of an aircraft during an aircraft tractor tow, but these were not reported by DASOR. The issues reported to the JPO and the previous four identifiable incidents involving support equipment ingestion all showed a trend of intake and exhaust blanks being prone to movement. Weather was attributed as the cause of the loss of blanks in a number of reports and was mentioned in the intake blank engineering evaluation report. The panel determined that these issues occurred across the global F-35 user community but were at a level such that it was considered a 'nuisance,' rather than a documented failing. This resulted in learned behaviour of the

Witnesses 12 & 13
Exhibit 104

[23] The F-35 Global Pool permitted certain equipment to be shared by all F-35 nations.
[24] Business Rule 191 stated that Red Gear was not classed as shareable support equipment.
[25] DASORs commonly referred to the PTMS blank as the 'IPP' blank.
[26] [redacted]
[redacted].

poor performance of the Red Gear being a feature of F-35B operations. The panel concluded that this normalisation to blanks falling out or becoming detached was a **contributory factor.**

Red Gear log

1.4.79. On arrival at BK-18, the only piece of Red Gear that Eng 2 observed was the exhaust blank lying on the deck just behind the aircraft. On returning it to the hangar, Eng 2 discussed this find with the ICC. Although the ICC had oversight of the Red Gear log, the items were not individually controlled as tools. Having examined the Red Gear log, Eng 2 concluded that the exhaust blank had been missed during an unrecorded removal process so gave no more consideration to the configuration of Red Gear on the aircraft. On the rare occasions when Red Gear was fitted on the flight deck, failures such as this were so frequent and routine that they had been normalised by the engineers and did not prompt further action by the supervisors or ICCs. Witness 12

1.4.80. 617 Sqn recorded fitment and removal of Red Gear in accordance with 'Work Instruction – RED GEAR CONTROL and MANAGEMENT', (Figure 1.4.12). The instruction was amended in Sep 21. Prior to this amendment the rectification controller was required to record in a log, located in the FDHOC, when Red Gear was fitted to aircraft. This provided a quick reference that Red Gear would need to be removed before clearing an aircraft for flight. The Sep 21 amendment moved the log to the issue centre, where it was inaccessible if the issue centre was closed. The two ICCs had not signed the Technical Dissemination Log to acknowledge this amendment. The panel opined that had the requirement for Red Gear to be logged by the rectification controller been retained, it would have been a more robust barrier to the loss of Red Gear. The panel concluded that the change to the 617 Sqn Red Gear management order was a **contributory factor.** Exhibits 8, 17 & 48; Exhibit 18; Witnesses 5 & 6; Exhibit 111

1.4.81. The 617 Sqn Quality Assurance (QA) team had not pursued the technical dissemination process compliance, despite the order being extant for two months. The panel concluded that ineffectiveness of the Sqn technical dissemination process, and QA of that process, was an **other factor**. Exhibit 111

1.4.82. It was not unusual for Red Gear sets to be separated and individual items of Red Gear to be used for certain maintenance activities. The Red Gear log was not configured to support this separation of sets (Figure 1.4.12). Entries in the Red Gear log showed that bonding leads were frequently used separately, but other individual items being fitted or removed were not recorded. Difficulties in control were exacerbated when items of Red Gear were lost, so a complete set was not available. In the panel's opinion if Red Gear was controlled as a complete set it would be more obvious when an item was overlooked, but conceded that this may be difficult in reality. The panel concluded that the splitting of Red Gear items from complete sets was an **other factor**.

EMBARKED 617 SQN RED GEAR LOG

Date:	Set UIN:	AV Number:	Fitted or Removed	FD HOC Board Updated:	Serviceability check c/o by:	Rects Control Signature
21/10/21	2	BK13	Fitted		[redacted] Names Redacted	
21/10/21	6	BK 17	FITTED	INTAKE ONLY		
21/10/21	5	BK 14	FITTED	INTAKE ONLY		
21/10/21	6	BK 17	REMOVED			
24/10/21	2	BK13	REMOVED			
2/11/21	2	BK13	FITTED	INTAKE ONLY		
3/11/21	5	BK 14	FITTED	Complete Set		
3/11/21	6	BK 19	Fitted	Complete		
3/11/21	7	BK20	Fitted	Complete		
3/11/21	8	BK 21	Fitted	[illegible]		
3/11/21	4	BK17	Fitted	Complete		
[illegible]		BK13				
9/11/21	5	BK18	REMOVED			
9/11/21	9	BK20	REMOVED			
7/11/21	6	BK 19	Removed			
7/11/21	4	BK 17	REMOVED			
10/11/21	3 - BONDING LEAD SIGN OUT					
10/11/21	3 - BONDING LEAD SIGN IN					
10/11/21	3	BK16	FITTED - BONDING LEAD ONLY			
13/11/21	7	BK13	Bonding lead			
14/11/21	5	BK14	ENGINE BLANKS ONLY [illegible]			
14/11/21	5	BK14	REMOVED			
16/11/21	8	BK 21	REMOVED			
17/11/21	1	BK 14	FITTED BONDING LEAD ONLY			
17/11/21	6	BK18	FITTED BONDING LEAD ONLY			
17/11/21	2	BK21	FITTED BONDING LEAD ONLY			

Figure 1.4.12 – The Red Gear log.

1.4.83. The Red Gear log was an annex from the 617 Sqn Embarked Red Gear Work Instructions. The panel noted the following errors in the Red Gear log at Figure 1.4.12:

a. The Work Instruction allocated Red Gear by set to individual aircraft, and this allocation was reproduced on the outside of the Thatcham as a local reference guide (Figure 1.4.13). The log showed that Red Gear from different sets was fitted to different aircraft in contravention of the instruction. Set 5 was allocated to BK-18 but was fitted to BK-14 on four occasions. BK-18 had Set 5 removed on 9 Nov 21, but there was no entry to show the fitment on 15 Nov 21. BK-18 had the bonding lead from Set 6 used for the flare load on the morning of 17 Nov 21. This mixing undermined the control of Red Gear fitted to aircraft. Exhibit 49 Exhibit 48

b. The log recorded the signing out of Red Gear to an aircraft but was not formatted to leave an open entry; Red Gear was signed back in on a new line. Consequently, there was no easy way to identify which aircraft had blanks fitted. Exhibit 48

c. BK-18 had an entry for 'blanks removed' on 7 Nov 21 but no corresponding entry for the Red Gear being fitted beforehand. The fitment must have occurred after the blanks had been removed from BK-14, which had the same full set fitted on 3 Nov. However, there was no entry stating when they had been removed. The panel considered the log did not give a full picture of which aircraft had Red Gear or elements of the Red Gear sets fitted. The use of the Red Gear log was inconsistent and the absence of corrections suggested that it had not been checked at any time. Exhibit 48

d. Prior to the Sep 21 amendment, the Red Gear log required an FDHOC state board to be updated and signed for in column five, but this requirement was removed in the Sep 21 update. This column was instead used for comments. The annex being used at the time was from an earlier version of the instruction. This made it difficult to understand in the event of it being used as a method of assurance. Exhibit 48

e. The seventh column was for a rectification control signature that was blank on all lines. Based on the Sep 21 amendment of the instruction, this was for the ICC to sign. This again demonstrated that the annex was from an earlier version of the instruction and that the process of implementing the Sep 21 changes had not been completed. This suggested that no independent checks were being conducted on the log, so it could not have aided in identifying the missing blank. Exhibit 48 Exhibit 49

f. The log was not part of any pre-flight assurance, so was not checked before releasing an aircraft for flight. The panel opined that the log may have offered the engineering managers false assurance that Red Gear was being adequately controlled. Exhibit 49

g. By keeping the log in the issue centre, if there were any situations where Red Gear was fitted or removed whilst it was closed, it would not be possible to complete the log. This meant that there were instances, such as the installation for the Suez Canal transit, where Red Gear was fitted to all aircraft but there was no record in the log. This inaccessibility to the log further undermined its effectiveness for Red Gear control. Exhibit 48

h. The loss of exhaust blanks meant that Red Gear sets were incomplete (Figure 1.4.13). The ICCs and sqn engineering management stated that no formal process existed to manage the reallocation of exhaust blanks between sets. It would therefore not be unusual for partial sets of Red Gear intake and exhaust blanks to be in the Thatcham. Witness 5 Witness 3

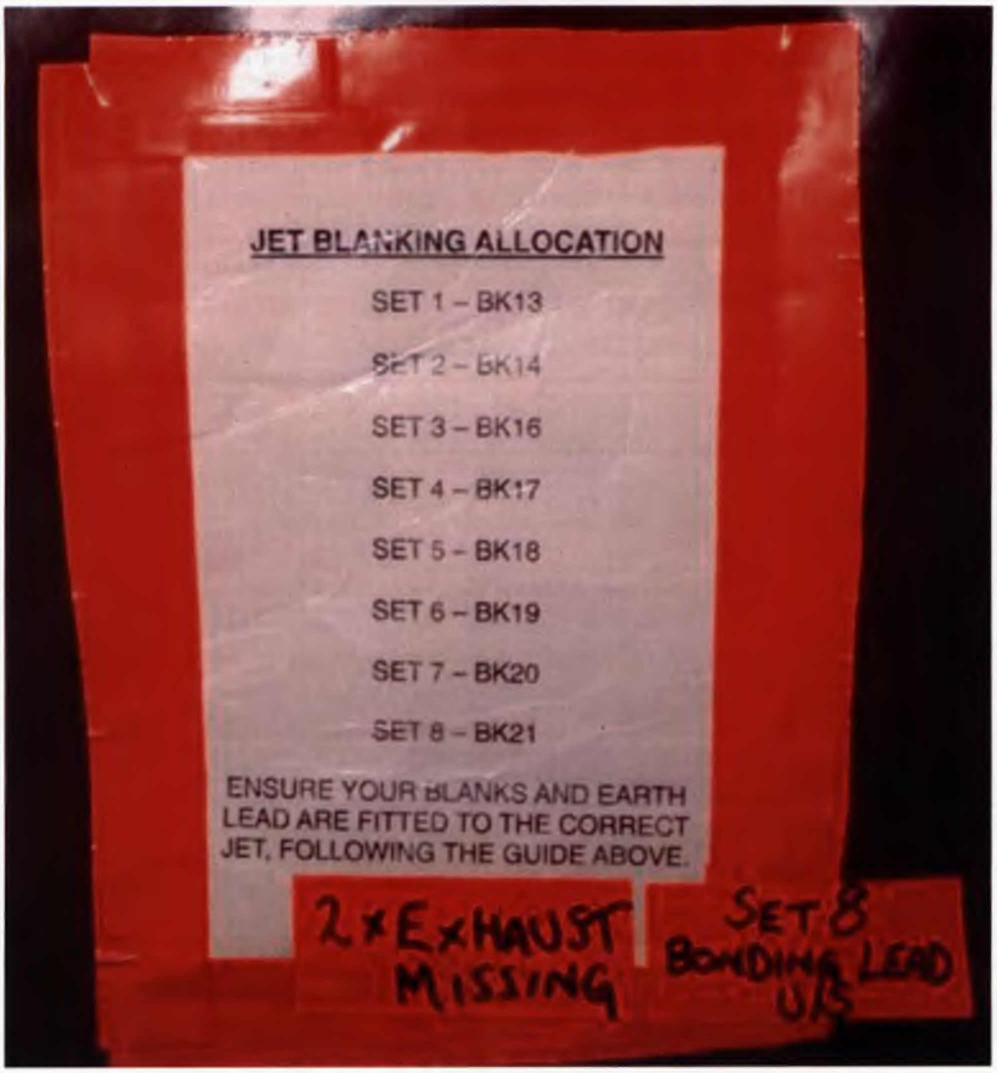

Figure 1.4.13 – Red Gear allocation per aircraft.

1.4.84. The instruction directed the ICC to conduct a daily muster of the Red Gear and record that muster on an Annex A. They generated their own 'Tool Room Duties' form to track this (Figure 1.4.14) which was signed up to the period of entering the Suez Canal on 15 Nov 21 but had nothing after. This was prior to the GSSO ordering blanks to be fitted. The results of the musters were not reported to rectification or line control, so provided no barrier to prevent a piece of Red Gear being unaccounted for. As the log only had to be checked once in any 24hr period, theoretically a piece of Red Gear could remain unaccounted for up to 48hrs. The fitment of blanks on entry to the Suez Canal was never recorded, so it was impossible to use the log to determine which aircraft had blanks fitted on the morning of the 17 Nov 21.

Witness 5
Witness 6

Witness 5

617 Sqn Tool Room Duties

DAILY TASKING	MONDAY (Sign)	TUESDAY (Sign)	WEDNESDAY (Sign)	THURSDAY (Sign)	FRIDAY (Sign)	SATURDAY (Sign)	SUNDAY (Sign)
SYNC PMA's (NIGHTS ONLY)	NIGHTS OFF		NIGHTS OFF	N/A			
CLEAN HANGER TOILETS (MONDAY ONLY)	N/A						
EMPTY BINS	Names Redacted		Names Redacted	N/A	Names Redacted	Names Redacted	
SWEEP TOOL ROOM	Names Redacted		Names Redacted	N/A	Names Redacted	Names Redacted	
CHECK LASHINGS (INSIDE AND OUT)	Names Redacted		Names Redacted	N/A	Names Redacted	Names Redacted	
POL CHECKS (WEEKLY)	Names Redacted						
RED GEAR CHECKS	Names Redacted			N/A			
DAILY POL TEMP CHECKS	Names Redacted		Names Redacted	N/A	Names Redacted	Names Redacted	
MOP TOOL ROOM (SUNDAY ONLY)							

Figure 1.4.14 – 617 Sqn issue centre daily check sheet.

1.4.85. The failings of the log as a management aid were identified earlier in the deployment by one of the ICCs, and both custodians were dissatisfied with the structure of the log. However, the amendment to attempt to improve the process did not resolve the root problems. Witness 5 Witness 6

1.4.86. The failure to record the fitment of blanks before the Suez Canal transit in the log resulted in it being factually incorrect. The daily check sheet was not completed on 16 Nov 21, nor prior to the first UK launch on 17 Nov 21. Use of an older version of the annex, the format of the annex, the confused use of columns for comments and the mixed fitment of blanks resulted in a Red Gear log that could not provide an effective barrier to a blank being unaccounted for or misplaced. The panel concluded that the ineffectiveness of the Red Gear log was a **contributory factor.** Exhibit 48 Witness 18 Exhibit 15

1.4.87. **Recommendation. The Lightning Chief Air Engineer should demonstrate that Lightning Force Air Engineering Orders and Work Instructions relating to safety are robust and effective in order to ensure they achieve their intent.**

Red Gear use for security

1.4.88. Many of the design features of the F-35B were security protected to preserve its technological advantage. One method of protecting the aircraft from espionage was by using aircraft blanks, particularly the intake and exhaust blanks. Thus, the blanks fulfilled dual purposes as FOD prevention and as security devices. The JPO security guide was written for air shows and media events, it did not mention embarked operations. The TAA was responsible for the provision of the aircraft and the ADS to support its safe operation. The JPO security guidance relied upon the use of Red Gear provided by the TAA, but none of the intake blank documentation identified its dual use for aircraft security. The panel found no evidence that the Red

Exhibit 112

Exhibits 8, to 11, 100, 101, 104,

Gear designers were aware of its dual use, therefore could not ensure that it would be fit for the wider range of environments that it might be expected to be used in. to 107, 113 to 115

1.4.89. A DASOR[28] from 29 Jun 22 demonstrated that security and engineering conflict remained an issue after Op FORTIS. Continuing Airworthiness was the responsibility of the Aviation Duty Holder who relied upon the support of the Military Continuing Airworthiness Management Organisation (CAMO) and elements from front line sqns or unit personnel. Therefore, equipment fitted to or removed from aircraft should have been strictly controlled, but on Op FORTIS the GSSOs were ordering the fitment of Red Gear. The dual use of blanks was unique to the F-35B and had not been previously encountered by the UK military. The DASOR demonstrated that GSSOs were still unaware of the potential air safety implications of their actions. The panel concluded that the lack of procedure or policy incorporating the needs of the GSSO whilst maintaining aircraft integrity and good engineering practices was a **contributory factor.** Exhibit 116

1.4.90. **Recommendation. Lightning Operating Duty Holder should produce airworthiness direction and guidance in order to ensure that management of UK F-35B security by Government Special Access Program Security Officers is air safety compliant.**

1.4.91. Consent was given for blanks not to be fitted when at sea, and this was recorded in the Mil CAM Deviation Register. The panel determined the decision to not fit the blanks on the flight deck was prudent and mirrored practice on US Navy aircraft carriers and assault ships. The Mil CAM deviation process did not identify security as a reason for fitting the blanks. The use of blanks for security reasons meant that the blanks were subjected to a much broader range of environmental conditions than expected. The panel concluded that the omission of identifying security as a reason to fit blanks and the lack of an associated management process was a **contributory factor.** Exhibit 97

1.4.92. **Recommendation. The Lightning Military Continuing Airworthiness Manager should update the Deviation Register to include fitment of Red Gear for security purposes.**

Responsibility for UK Red Gear

1.4.93. The LDT was governed by the JPO Global Pool policy, which stated that Red Gear was not to be classified as support equipment. However, Red Gear was described in the support equipment picture book provided by the JPO. One set of Red Gear was delivered per each aircraft purchased, unlike other F-35B support equipment. At RAF Marham a Lockheed Martin Field Service Representative provided logistic support, so the LDT was not required to be routinely involved in the supply and management of Red Gear. Under these circumstances issues of management and ownership were not readily apparent to the LDT or to the engineers at RAF Marham. The LDT support equipment team was involved in the authorisation of the Exhibit 106 Exhibit 6 Exhibit 105 Exhibit 117

28 [redacted]

intake blanks used on Op FORTIS. However, the process also involved comments from the airframe and powerplant teams. Under such circumstances it is understandable that the Red Gear became an 'orphan asset' due to its unique nature. Exhibit 105

1.4.94. The Military Aviation Authority (MAA) required the CAMO to maintain configuration control over air vehicles, support equipment and ancillaries.[29] Due to the F-35 contracted arrangements in place for management of support equipment, this was delegated to the LDT as they were the link to the global pool. The Memorandum of Agreement between the Mil CAM and the LDT also delegated assurance of the support equipment to the LDT. The panel noted that this excluded Red Gear, but also noted that this was not apparent to the Mil CAM. The panel found that Red Gear configuration control was not managed by either the LDT or the Mil CAM due to confusion over the global pool policy. The panel determined that responsibility for Red Gear had inadvertently fallen between organisations. The panel opined that this caused omissions to go unnoticed, the resolution of any one of which may have averted the accident to BK-18. The panel concluded that non-allocation of responsibility for assurance of Red Gear was a **contributory factor.** Exhibit 118

1.4.95. **Recommendation. The Lightning Type Airworthiness Authority should review all Joint Program Office provided Red Gear documentation, to improve the assurance and management processes, in order to support the Lightning Military Continuing Airworthiness Manager's Military Aviation Authority requirements with respect to support equipment, including Red Gear.**

1.4.96. **Recommendation. The Military Continuing Airworthiness Manager should include support equipment in the Memorandum of Agreement with the Lightning Delivery Team in order to formalise the requirement for support with Red Gear assurance.**

Previous intake obstruction events

1.4.97. This was the first loss of a UK F-35B and the third loss of an F-35B globally. The other F-35B accidents[30, 31, 32] resulting in the loss of the aircraft were examined and their causes were found to be unconnected with this accident so were **not a factor.**

1.4.98. The following similar events occurred within the global F-35 community, but did not result in the loss of the aircraft:

a. 23 Sep 14, Eglin AFB, F-35A USAF. The pilot reported an engine stall on take-off, with loud bangs and throttle unresponsive. An intake plug was found ingested into the intake and stuck on the front face of the engine. Exhibit 119

[29] MAA RA 4947.
[30] https://news.usni.org/2020/09/29/marine-f-35b-crashes-after-collision-with-kc-130-over-california-all-aircrew-recovered-safely.
[31] https://www.marines.mil/News/Press-Releases/Press-Release-Display/Article/1648566/f-35b-crash/.
[32] https://news.usni.org/2016/11/08/f-35b-in-training-squadron-experienced-fire-in-weapons-bay-investigation-ongoing.

b. 10 Sep 15, MCAS Yuma, F-35B USMC. A low power ground run was performed with the left intake blank inside the aircraft. The intake plug had gone un-noticed during two previous ground runs.	Exhibit 119
c. 26 Jul 18, Hill AFB, F-35A USAF. The pilot advanced the throttle to 78%, and at 26 kts heard a loud bang and observed black smoke from the exhaust. An intake blank was found in the aircraft.	Exhibit 119
d. 21 Jan 20, VFA-125, F-35C US Navy. A low speed abort on take-off was conducted due to the intake cover still installed. The intake cover was found lodged in the intake of the aircraft. This was reported in 'F-35 safety events' 16-31 Jan 20, newsletter released to all F-35 operators.	Exhibit 119
1.4.99. The panel noted the following incidents involving UK aircraft:	
a. An intake blank fell out during an aircraft tow and was run over by an aircraft tyre. No DASOR raised.	Witness 12
b. An engine intake blank was found dislodged and wrapped around the lower lift fan door[33]. Date 03 Dec 18.	Exhibit 110
c. An aircraft exhaust blank was blown across the runway[34]. Date 7 Feb 19.	Exhibit 120
d. A new F-35B intake blank was found with the painted safety lettering peeling and becoming FOD[35]. Date 25 May 21.	Exhibit 12
e. An engine exhaust blank was lost overboard[36]. Date 29 May 21.	Exhibit 121
f. The PTMS / Heat exchanger / IPP Red Gear was missing from 17 TES aircraft. A FOD plod of the ramp area found a missing blank but later identified that the blank was from a US Navy (USN) aircraft that was no longer at Edwards AFB. All 17 TES aircraft were reported at the time as being deficient PTMS / Heat exchanger / IPP blanks[37]. Date 26 Feb 18.	Exhibit 108
g. An engine exhaust blank was lost overboard[38]. Date: 17 Nov 21.	Exhibit 16
h. The wind blew an exhaust blank off the back of a tractor[39]. Date 7 Nov 17.	Exhibit 122

33 [redacted]
34 [redacted]
35 [redacted]
36 [redacted]
37 [redacted]
38 [redacted]
39 [redacted]

i. An aircraft exhaust blank was found missing in high winds[40]. Date 26 Feb 18. Exhibit 109

1.4.100. The 'iceberg model'[41] describes the likelihood of large numbers of (often unreported) hazardous observations and occurrences (near misses) in relation to the numbers of reported incidents and accidents.[42] The panel opined that hazard perception of Red Gear, and its potential to cause the loss of an aircraft, was low. The MAA Manual of Air Safety identified that a ratio of incidents and near misses to accidents could be established, but this required effective reporting. Given that the F-35 was an international programme, UK reporting was but a small piece of the overall picture. The panel considered it more than likely that other Red Gear issues were going unreported across the F-35 community, so the threat to air safety was under appreciated. The panel concluded that this lack of reporting, assessment and analysis of air safety events relating to Red Gear was a **contributory factor.**

1.4.101. **Recommendation. Lightning Delivery Team Head should engage the Joint Project Office (JPO) to ensure safety reporting from all F-35 users is shared by the JPO in order to identify trends to minimise the risk of repeated incidents.**

Quality Assurance (QA)

1.4.102. The QA process was designed to provide confidence that a sqn was conducting its practices in a safe and compliant manner. In a typical QA programme, a sqn would be expected to conduct self-audit activity on a regular basis as agreed with the Unit Quality System Owner. RAF Standards Evaluation visits would then provide ongoing independent QA, typically around six times a year. A station would then conduct an internal QA audit on each of its sqns roughly once every 12 months. This audit would include a review of a sqn's self-audit activity. A station would then be subject to external QA every one to two years by Air Command.[43] James Reason explains that maintenance procedures are seldom conducted by those who write them[44] and, consequently, QA processes are relied upon to ensure such procedures are fit for purpose.

1.4.103. The QA programme at RAF Marham was significantly impacted by the Covid-19 pandemic, including a complete stop from Mar to Jul 20 and decreased activity during subsequent Covid-19 lockdowns. Prior to Op FORTIS, the only internal QA conducted on 617 Sqn since arriving at RAF Marham was in Sep 19. This identified 14 quality occurrence reports (QOR) and 15 observations for action, which the panel judged to be a significant number. It highlighted low morale amongst junior ranks and a lack of basic standards. One QOR identified four issues with Red Gear, including poor management of blanks, blanks being mixed between aircraft sets and incorrect stowage of blanks. The root cause of these was insufficient

Exhibit 123

Exhibit 124

Exhibit 125

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40 [redacted]
41 AP3028. RAF Manual of Flight Safety.
42 MAA Predicting and Preventing the next Accident. Air Accident Error Prediction.pdf (sharepoint.com).
43 ISO 9001-2008.
44 J. Reason and A. Hobbs, 'Managing Maintenance Error a Practical Guide,' Ashgate Publishing Limited, London, 2003.

provision of sets of Red Gear, which was commented on in the QOR response from the Sqn, requesting additional sets be obtained. Exhibit 126

1.4.104. Once the root cause was addressed, and improvements identified in the other issues, the QOR was closed. When 617 Sqn deployed for Op FORTIS, one set of Red Gear per aircraft was provisioned, and in the markedly different embarked environment similar problems re-emerged.

1.4.105. The only external QA of RAF Marham since F-35B arrived, was in Aug 20. It remarked that the 617 Sqn self-audit programme was ineffective, and the RAF Marham Quality Management System provided only 'limited assurance'[45]. It highlighted that there was insufficient Red Gear, and that it was inadequately managed.

1.4.106. The external QA raised the issue of control of Red Gear, that pitot blank warning flags were tied together, and issues with ejection seat pins. The report quoted Regulatory Article (RA) 4808[46] highlighting the potential for a lost tool or support equipment, such as Red Gear, to cause the loss of an air system: Exhibit 124 Exhibit 125 Exhibit 126

> 'Failure to adequately control all such items, especially when considering the potential hazard of a lost tool, could significantly increase the risk to Air Safety.'

1.4.107. In the panel's opinion, the decrease of internal and external QA of the procedures on 617 Sqn resulted in immaturity of LF and 617 Sqn engineering orders prior to Op FORTIS. If further action had been taken on any of the observations or QOR regarding Red Gear management, the loss of BK-18 may have been avoided. The panel concluded that the lack of QA follow up action was a **other factor.**

1.4.108. **Recommendation. The Lightning Delivery Duty Holder should implement a system that ensures that all quality assurance recommendations are addressed in order to provide confidence that critical actions are not overlooked.**

Technical investigation

Airworthiness review

1.4.109. BK-18 had a valid Military Airworthiness Review Certificate (MARC) and had no outstanding engineering or maintenance issues. Given its limited time in service there was little deviation from the original build standard and platform configuration. As part of the technical investigation DAIB engineers conducted a pseudo, electronic based, Military Airworthiness Review (MAR) on the aircraft in order to identify any change to the aircraft configuration, missed maintenance activity or discrepancies between the aircraft at the time of loss and the extant MAR. No issues were identified. The panel concluded that BK-18's Continuing Airworthiness and Exhibit 3 Exhibit 127

[45] "System of internal control is operating effectively except for some areas where significant weaknesses have been identified."
[46] RA4808(1): Accounting of Equipment, Tools and Materials (MRP 145.A.40(a)).

MARC had not been undermined since that last MAR had taken place and that the airworthiness documentation and modification standard of BK-18 was **not a factor**.

Technical factors

1.4.110. Several technical factors either individually or jointly could have caused the lack of acceleration of BK-18. The DAIB engineering team were tasked with assessing each of these. This section combines their report with evidence and data from other agencies and sources.

Exhibit 127

1.4.111. **Un-commanded braking.** Crash Survivable Memory Unit (CSMU) data traces showed the hydraulic pressures, weight on wheels and wheel speed sensors operated as demanded when the pilot initiated the abort. There were no braking events during the launch prior to the decision to abort. Rubber marks left on the deck confirmed that the brakes were applied just as the aircraft reached the ramp. These marks were consistent with the anti-skid function shown in the CSMU traces. This also matched the helmet mounted display (HMD) data and the pilot's witness account. The panel concluded un-commanded braking was **not a factor.**

Exhibit 127
Exhibit 2
Exhibit 128
Witness 10
Exhibit 2
Exhibit 52

1.4.112. **Control law actions.** The flight control system (FCS) provided the demanded outputs through the CSMU data and showed no abnormalities or issues. It remained in contact with the full authority digital engine controls (FADEC) on the main engine and the lift fan throughout the start-up, taxi and take-off roll. The FCS transitioned through a series of modes of operations, all of which operated correctly. The panel concluded that the control law actions were **not a factor.**

Exhibit 127
Exhibit 2

1.4.113. **Fuel contamination.** The fuel was checked daily by the Ship's marine engineers and sampled at all the aircraft servicing points around the flight deck and hangar. No contamination was found either before flying commenced or after the accident. Samples were also sent to 1710 NAS for analysis, which confirmed the fuel was free from contamination. The panel concluded that fuel contamination was **not a factor.**

Exhibit 129
Exhibit 130
Exhibit 131

1.4.114. **Fuel starvation.** The CSMU indicated that fuel was provided to the engine as commanded by the FADEC. The aircraft had full tanks on launch and significant quantities of fuel were found during the salvage operation. The panel concluded that fuel starvation was **not a factor.**

Exhibit 127

1.4.115. **Hydraulics and oil contamination.** The oil and hydraulics samples recovered from the aircraft were heavily contaminated by salt water and unable to be analysed. The samples taken from the hydraulics rigs provided by the Ship's air engineering department were tested and found to be correct to specification. The panel noted that 617 Sqn had not recorded the batch and serial number of the engine or hydraulic oil used in the servicing of BK-18. The use of historic Joint Oil Analysis Programme data for BK-18 was held by the air engineering department. No concerns with the oil used on BK-18 were raised. The test equipment was calibrated before the deployment and data analysis showed no trends with any of the samples from the aircraft. There were also no engine oil or hydraulic system issues

Exhibit 130
Exhibit 132
Exhibit 52
Exhibits 2, & 133

identified in the CSMU data. The panel concluded that hydraulic or oil contamination were **not a factor.**

1.4.116. **FOD other than Red Gear.** The HMD video and visual surveillance system (VSS) were reviewed and no evidence of FOD ingestion was observed during the start-up and launch sequence. Witnesses saw no FOD on the flight deck or any ingested by BK-18 during the taxy and take-off roll. The FOD log was correctly completed for the period of flying. When the aircraft impacted the water the engine was running and there was substantial damage to the engine associated with the ingestion of debris following the ejection sequence and immersion in the water. Whilst it was impossible to definitively rule out damage caused by earlier FOD ingestion, the lack of any such evidence led the panel to conclude that the damage to the engine occurred post ejection due to water ingress. The panel concluded that FOD (other than the Red Gear) was **not a factor.**

Exhibit 50

Exhibit 127

1.4.117. The F-35B integrated caution, advisories and warnings (ICAW) system displayed indications to the pilot if the aircraft detected an unserviceability. The HMD video showed no engine ICAW indications and the CSMU data recorded no engine cautions or warnings reported to the pilot during the accident sequence.

Exhibit 2

Exhibit 52

Inlet debris monitoring system (IDMS)

1.4.118. The aircraft was fitted with an electrostatic debris monitoring system with two sensors in the common duct before the first stage of the engine, referred to as the 'Inlet Debris Monitoring Upstream' and 'Inlet Debris Monitoring Downstream' (IDMU/IDMD), and an exhaust sensor in the exhaust duct, known as the 'Exhaust Debris Monitor' (EDM). The system measured the electrical charge of particles passing through the duct. The difference between discrete debris or particulate matter (such as sea spray) could be characterised (Figure 1.4.15). Evidence of discrete FOD, such as a bird strike, ingested into the engine would show as a double spike with a phase lag between the IDMU and IDMD, followed by a third on the EDM. Particulate ingestion would appear as a background level increase.[47] All IDMS data was recorded for subsequent aircraft health analysis, but not displayed to the pilot.

Exhibit 127

Exhibit 133

[47] https://www.researchgate.net/publication/224639744.

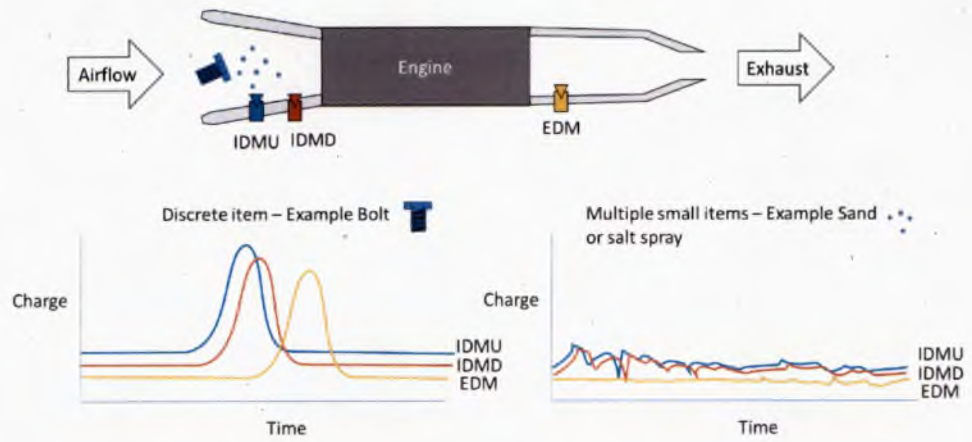

Figure 1.4.15 – Idealised IDMS response to ingestions.

1.4.119. BK-18's IDMS data (Figure 1.4.16) showed readings on the IDMD throughout the period the engine was at idle which increased as air flow through the engine increased. The IDMU and EDM showed no such indications. If the FOD was significant enough to cause engine damage it is likely that an associated engine caution or warning would have been triggered. The data suggested there was FOD in the vicinity of the IDMD, but behind the IDMU.

Exhibit 127
Exhibit 133

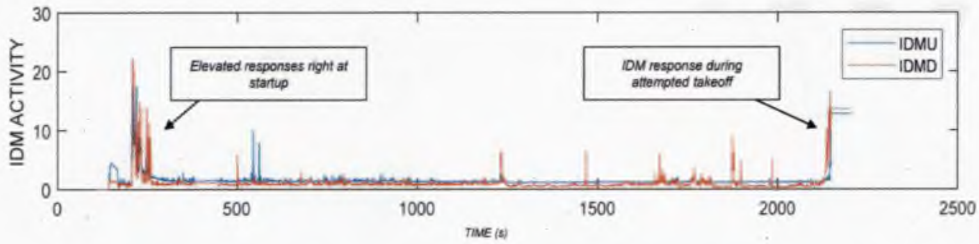

Figure 1.4.16 – BK-18 IDMS trace from start-up to accident.[48]

1.4.120. Analysis of the time period from 2129 to 2135 seconds (just prior to brake release) showed an elevated IDMD response during the period at 34% Engine Thrust Request (ETR) (Figure 1.4.17). An increase at 2135 seconds (97% ETR, brakes release) remained after the selection of idle at 2141 seconds. The ejection at 2145 seconds was likely to have caused the elevated readings at that point. The aircraft impacting the water at 2148 seconds creating the final elevated then flat readings. The panel concluded that the left intake blank was laying against the front face of the engine. The panel went on to investigate the effect of the blank on the engine's performance.

Exhibits 127 &133

48 Courtesy of Pratt and Whitney.

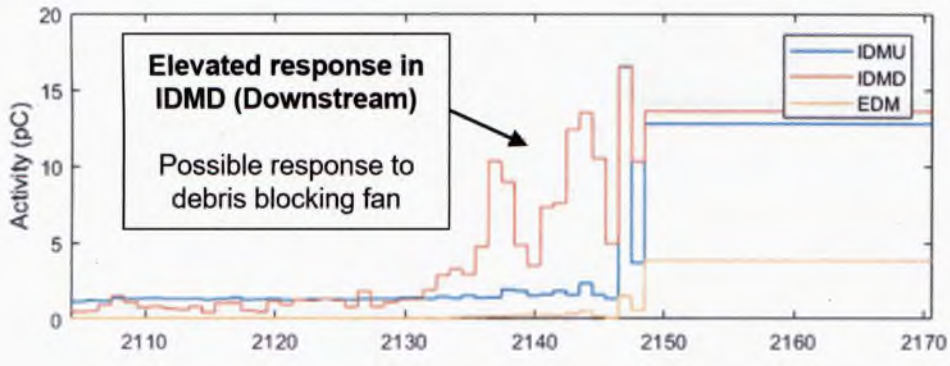

Figure 1.4.17 – IDMD elevated response from BK-18.[49]

Engine performance

1.4.121. The data from the sortie prior to the accident sortie (flown on 13 Nov 21) was also still available on BK-18's CSMU, so 'normal' data could be compared to that recorded during the accident (Figure 1.4.18). During that launch the throttle to power response curves showed that engine output matched ETR within approximately two seconds.

Exhibits 127 &133

Exhibit 2

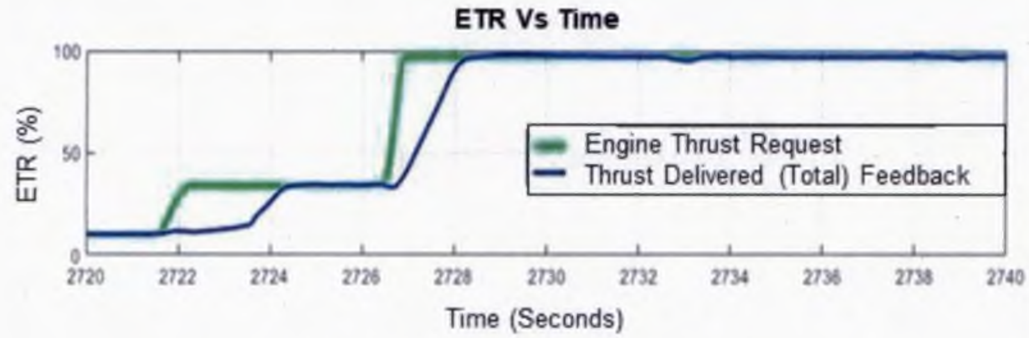

Figure 1.4.18 – Correct ETR and response curves.[50]

1.4.122. On the day of the accident, the initial engine demand to 34% ETR was satisfied, but the engine was unable to respond correctly to any higher throttle setting subsequently demanded by the pilot. The engine initially followed the demand but then never achieved the desired thrust, plateauing no higher than 80% (Figure 1.4.19). Fuel flow was initially set to reach 97% ETR but then modulated by the FADEC to match the decreased airflow experienced by the engine. Air flow was recorded as being 6% less than a normal STOVL take-off, and the engine compressor exit pressure was 30% less than nominal, so the FADEC tolerances were exceeded, and the core fuel flow was reduced by 32% accordingly. The CSMU data showed that the engine performed within the control laws that governed it, and therefore did not raise any cautions or warnings. The lack of air flow through the engine and commensurate reduction in fuel flow resulted in a lack of thrust.

Exhibits 127 &133

[49] Courtesy of Pratt and Whitney.
[50] Courtesy of Lockheed Martin.

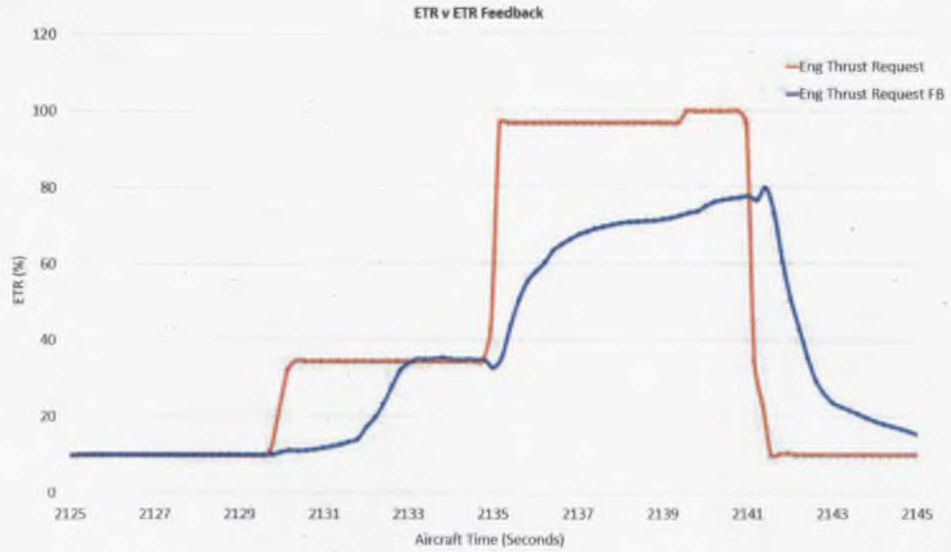

Figure 1.4.19 – BK-18 engine power demand versus delivered.[51]

1.4.123. There was a minimum of 17% deficit between demanded and delivered thrust, which equated to 38,000lb thrust requested, but only 31,500lb of thrust delivered. There was a lag between the time the 97% and 100% ETRs were demanded, and the 80% maximum was delivered (Figure 1.4.19). The time spent at a significantly lower than demanded thrust resulted in the poor acceleration.

Exhibits 127 &133

1.4.124. The pilot reported that the engine indicated it was providing thrust equivalent to 74% ETR at the point of the abort. This low power state was also recorded in the HMD video. This figure was the total thrust of the main engine, roll posts and lift fan combined. The forward momentum of the aircraft during the take-off roll was provided by the main engine thrust. This forward thrust was around 55% of that which would normally be generated. The engine rotational speed and air mass flow rates were lower than nominal for a STO launch so the FADEC matched the fuel flow accordingly. There was no ICAW alerting the pilot that the FADEC was limiting fuel or that the engine had not reached the desired thrust. The panel concluded that the lack of an appropriate warning to the pilot was a **contributory factor**.

Witness 10

Exhibits 127 &133

Exhibit 2

1.4.125. **Recommendation. The Lightning Delivery Team Head should engage with the Joint Program Office to develop a timely and compelling warning to the pilot of mismatch between commanded and delivered thrust.**

Intake blank analysis

1.4.126. The aircraft landed in the water upright and floated with the cockpit, forward and upper fuselage out of the water. The wings were slightly submerged as the aircraft floated down the left side of the Ship. The aircraft auxiliary doors and lift fan door were still open, and water entered the intakes and the exhaust of the aircraft. Several witnesses replayed VSS

Exhibit 15

Witness 7

[51] Courtesy of Lockheed Martin.

footage showing a red object emerging from the auxiliary intake (Figure 1.4.20). This was subsequently recovered by the sea boat (Figure 1.4.21) and identified as the left intake blank from BK-18. The panel then commissioned further work to prove the interaction of the intake blank with the aircraft intake and engine. Witness 20

Figure 1.4.20 – Intake blank (circled) on top of BK-18.

Figure 1.4.21 – BK-18 left intake blank on recovery from the sea.

1.4.127. Examination of the wreckage of BK-18 and the intake blank by 1710 NAS revealed damage to the front face of the engine, to the rubberised Exhibit 134 de-icing boots on the leading edge of the variable inlet vanes. The damaged sections were analysed[52] by 1710 NAS and the sample compared with black marks on the intake blank (Figure 1.4.22). Analysis confirmed there was chemical commonality between the two. Together with other factors, such as damage to the intake blank, the panel opined that it was almost certain that the left intake blank was in contact with the variable inlet vanes. This would have caused the engine to produce insufficient thrust for a successful launch.

Exhibit 127

Figure 1.4.22 – BK-18 left intake blank. Arrows show black marks which were subject to chemical analysis.

Figure 1.4.23 – Cuts to the top edge of BK-18 left intake blank.

1.4.128. Based on all the evidence, the panel concluded that the left intake blank was at the front face of the engine compressor during the aircraft launch and determined this to be the **causal factor**. This factor is addressed by the recommendation at para 1.4.36.

[52] Using Fourier Transform Infra-Red spectroscopy.

Intake blank human factors

1.4.129. The panel explored whether the blank may have been intentionally taken into the aircraft by an engineer to be used as a cushion, to sit or kneel on during inspections of the front face of the engine. The panel attempted to take an intake blank into the common duct area to see what orientation the blank could be sat on. The panel found it difficult to manoeuvre the blank into the intake and found that it was too large when in the common duct to be able to move around the lift fan drive shaft. To get the blank to fit under the drive shaft required significant bending to conform to the curvature of the intake. Such bending was not evident on either of BK-18's intake blanks.

Witness 4
Exhibit 127

1.4.130. Engineers conducting flight servicing (including Eng 1) only accessed the common duct via the right intake to avoid damaging the ice detection probe in the left intake. Eng 1 accessed the aircraft with assistance from the engineer servicing BK-21, who did not report anything extraordinary. In the panel's opinion, if Eng 1 accessed the common duct via the right intake and elected to take a blank to sit on, it would be logical to use the right blank. The blank recovered from the sea was the left blank.

Exhibit 127
Exhibit 93
Witness 13

1.4.131. 1710 NAS analysis of the left intake blank examined the damage and tearing to its top edge (Figure 1.4.24). It attributed the damage as being caused by the ice probe in the left intake, the only sharp-edged component in either intake duct. This damage could not have occurred if the blank was taken down the right intake to be used as a cushion. The panel concluded that it was unlikely that the left intake blank was deliberately taken by an engineer into the aircraft.

Exhibit 127
Witness 13

Figure 1.4.24 – Close up view of damage to BK-18 left intake blank top edge.

1.4.132. In other US F-35B incidents damage was caused to the aircraft and engine by 'cushions' in the intake (Para 1.4.98). US engineers used a yellow maintenance mat when conducting work in the intakes and there were incidents of these being left in the aircraft (Figure 1.4.25). These mats were not in use on the UK Lightning Force. Exhibit 135

Figure 1.4.25 – Yellow maintenance mat used by US forces.

Intake blank engineering investigation

1.4.133. Normal practice was that Red Gear was not used on the flight deck, and if it was fitted for security reasons, the intake, exhaust and PTMS blanks would be fitted as a complete set. The fitment of the blanks during the Suez Canal transit presented several deviations from this normal practice. Witness 4

a. The blanks were fitted but the pip pin and retaining lanyard assembly were not used. Witness 4

b. There was no engineering oversight of the blanks for an extended period due to the flight deck being out of bounds. Witness 3

c. The servicing occurred at night and was split over an extended period. Witnesses 12 &13

d. Eng 1 removed just the PTMS and right intake blanks, leaving the configuration asymmetric. Eng 2 stated that the exhaust blank was found on the deck when their aspect of the flight servicing was commenced. Witness 13 Witness 12

1.4.134. Witnesses observed that the weather the night prior to the accident was very windy, and that they had to lean into the wind when walking on the flight deck. They also observed thunderstorms in the vicinity of the Ship. The panel commissioned a DAIB engineering investigation to Witness 14 Exhibit 15 better understand the forces that may have been exerted on the blank by the wind during the night, and how the blank might have responded to those forces. Exhibit 127

1.4.135. The DAIB investigation considered that the way BK-18's intake blanks were left in an asymmetric configuration, and the subsequent dislodging of the exhaust blank, may have created an unusual wind force on the remaining installed left intake blank. The panel assessed that the wind may have produced a force on the front of the blank pushing it into the intake and a suction force on the inside face of the blank pulling it into the intake. This would have been an unusual load, for which the blanks were unlikely to have been designed or tested. The DAIB investigation only examined the external wind force and was unable to measure the internal suction force caused by the asymmetry of the intake blanks.

1.4.136. The support equipment, which included the intake blanks was designed to operate in up to 35kts[53] of wind. The panel found no mention of this loading in the engineering evaluation test plan for the blanks so there was no prior test plan to follow. The design criteria were used to derive a wind pressure against which the blank should not move or dislodge[54]. Exhibit 136 Exhibit 107

1.4.137. The intake blank was designed to resist external air pressure based on its weight and the frictional forces exerted by its edges against the intake's inner surface. The more surface area of the blank that was in contact with the intake skin, the better it was able to resist the loads. Elastic deformation (squashing) of the blank into the intake assisted in maintaining friction between the blank and the intake skin. This would remain the case until a point that the edge of the blank slipped on the intake skin, at which point the elastic energy stored in the compressed blank could allow it to spring backwards, into the intake. Exhibit 101 Exhibit 127

1.4.138. Six maintainers were tasked with inserting the left and right intake blanks into the aircraft and the resultant relative position of the blanks was measured. Nine aircraft in 207 Sqn's hangar and the RAF Marham maintenance facility on a sample day were also assessed to provide additional data. The installation of the blanks varied considerably with some having minimal contact with the intake's inner surface (Figure 1.4.26). Exhibit 127

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[53] The requirement was set at 40mph, equal to approximately 35kts.

[54] Using Bernoulli's equation and simple force / pressure / area relationship.

 OFFICIAL - SENSITIVE

Figure 1.4.26 – Example of poorly installed intake blank seen at RAF Marham.

1.4.139. The intake blank was fitted using the photographs in the intake blank engineering evaluation test plan as a guide. It was notable that the inboard lower corner was exposed even when the rest of the blank was protected by the airframe (Figure 1.4.27). The curvature of the intake behind where the blank was fitted was complex in this region and the investigation noted that the geometry limited the ability of the blank to be pushed further aft into the intake.

Exhibit 104

Figure 1.4.27 – Blank fitted using Lockheed Martin engineering test plan. Intake blank inboard lower edge remains exposed.

1.4.140. The intake blank was then tested using a newton spring gauge acting through a specially manufactured plate to provide a distributed load. The distributed load was used to replicate the wind load encountered on the flight deck. Where the blank displaced, the displacement load was compared against the design load factor for the blank. Exhibit 127

1.4.141. The adhesion of the intake blank was found to be weak at the inboard lower corner (Figure 1.4.28), with the force required to displace the blank equating to a wind speed in the region of 24kts. In such circumstances the blank failed to maintain its position and rotated across the diagonal between the top inboard and bottom outboard edge (Figure 1.4.29). The application of force in the inboard lower corner caused the blank to become unstable. The blank would rotate, regardless of the degree of contact for the corners of the blank and cause the blank to fall into the intake (Figure 1.4.30). The blank could become unstable and fall into the intake at wind speeds much less than the design requirement of 35kts. Exhibit 127 Exhibit 136

Figure 1.4.28 – Example of observed intake blank fitted to aircraft under maintenance, highlighting the inboard lower corner.

Figure 1.4.29 – Blank in the process of rotating following application of force in the bottom inner corner.

1.4.142. The measured force to push the blank, post displacement, further up the intake was typically between 7N and 16N (Figure 1.4.30). An equivalent wind speed to cause this force was hard to calculate due to the variable cross-section of the blank in the intake but the investigation determined such force could be generated by winds speeds around 30kts. The investigation noted that the smooth surface of the intake would produce much less friction if it was wet. The weather during the night of the 16 Nov 21 included thunderstorms and rain, so the intake was very likely to have been wet.

Witness 12
Witness 13
Exhibits 41 to 45

Figure 1.4.30 – Intake blank orientation after displacement.

1.4.143. The DAIB investigation determined that it was credible that the intake blank could be dislodged by wind at speeds significantly lower than the support equipment design specification. The panel determined that such wind speeds were very likely to have been present on the flight deck on the night of 16 Nov 21. The panel concluded that it was almost certain that wind dislodged the left intake blank in BK-18 from its installed position and moved it to a point at which it could not be seen externally on the night of 16 Nov 21. The panel concluded that the tendency for intake blanks to dislodge in high wind was a **contributory factor**.

Exhibit 136

Exhibit 48

1.4.144. The JTD had a reference for fitment of the original blanks but none for the blanks issued for Op FORTIS. Therefore, there was no method of assuring that blanks were fitted in accordance with the manufacturer's intent. The support equipment picture book and the design/engineering change documentation gave no guidance. For the investigation, fitment of the blank was conducted using the engineering evaluation test plan. This document was not available to front line units. The panel concluded that the lack of a removal and installation procedure for the blank and pip pin, with associated weather limits, was a **contributory factor**.

Exhibit 137
Exhibit 138

Exhibits 6, 10 & 113

1.4.145. **Recommendation. The Lightning Type Airworthiness Authority should issue guidance on the use of the pip pin and lanyard on the A00020 and A00021 blanks which takes into account the potential for aircraft skin damage in order to standardise fitment procedures.**

1.4.146. **Recommendation. The Lightning Delivery Duty Holder should ensure that intake blank fitment is standardised and assured in order to ensure consistency of use across the Lightning Force.**

Aircraft risk to life model

1.4.147. The LDT ran an F-35 risk to life (RtL) model that considered ways that the aircraft could be lost in order to provide quantitative values as to the criticality of systems. Loss of thrust was a key part of the model and examined a failure of the engine or engine support systems. One consideration was loss of airflow to the engine. Exhibit 115

1.4.148. The RtL model did not include Red Gear ingestion as a factor as engineers should remove it prior to flight, nor did it include human error as a factor because this could not be accounted for by the aircraft designer. The panel considered it credible that environmental factors such as wind could cause the blank to displace and become a hazard that would lead to the loss of airflow to the engine. The loss of BK-18 was caused by loss of airflow due to the blank. The panel opined that the blank could be displaced, without human interaction, due to its design. The panel concluded that the design of the blank should be a factor in the aircraft RtL model and its omission was an **other factor**. Exhibit 115

1.4.149. **Recommendation. The Lightning Type Airworthiness Authority should update the Lightning risk to life model in order to include the potential for Red Gear displacement.**

Human factors

Lightning workforce

1.4.150. The UK F-35B workforce was provided by the RN and the RAF. The F-35 programme was predicated on an assumed establishment[55] of 12 'Direct Maintainer Spaces per Aircraft' (DMSpA). This meant that 12 qualified engineers (at sergeant/petty officer rank and below) were required per aircraft to effectively maintain a land-based sqn. A sqn establishment should have been greater than this to accommodate postings and long-term downgrades and provide a sqn strength[56] that accommodated leave and training courses while leaving enough workforce from which to resource DMSpA (Figure 1.4.1Figure 1.4.31 – Generic workforce limiters.). A US Congressional Report of Dec 2020 stated that assumptions that F-35 would

Exhibit 139

Witness 1

Exhibit 140

[55] 'Establishment' describes the number of personnel a unit should have.
[56] 'Strength' describes the number of personnel a unit actually has and can be some way below the establishment.

need fewer engineers than legacy types proved unfounded, and that more personnel than assumed were actually required to maintain F-35.

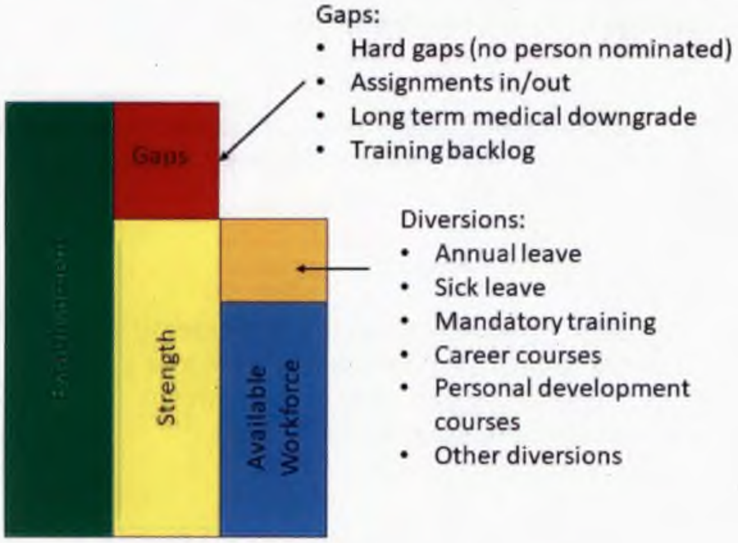

Figure 1.4.31 – Generic workforce limiters.

1.4.151. Since its inception the UK F-35 workforce was under resourced. This resulted in an inability to generate sufficient aircraft to deliver the required operational capability. The establishment was below that required, resulting in insufficient availability of workforce. To put this in perspective, on Op FORTIS 617 Sqn deployed 113 personnel for their [redacted] aircraft, [redacted] deployed 255 personnel to support [redacted] aircraft. Whilst some of these were support staff, they still had around 50-60 more engineers than 617 Sqn for only [redacted] more aircraft. Even to deploy 113 personnel on Op FORTIS, 617 Sqn had to borrow personnel from 207 Sqn.

Exhibit 139
Witness 1
Witness 3
Witness 4
Witness 20

1.4.152. It was not until the commencement of Op FORTIS that it was discovered just how much carrier operations increased demands on see-off teams. Aircraft were required to be moved around the deck more frequently than was the case on an airfield, placing an additional workforce demand on the Sqn. Also, see-offs required additional tasks such as last-minute refuelling and management of chains,[57] which required more engineers. The combined effect of these was that a larger engineering workforce was needed when embarked compared to land-based operations. This resulted in personnel being drawn from maintenance work in the hangar. During Op FORTIS twelve 617 Sqn personnel were repatriated to the UK for personal or medical reasons but were not replaced. The panel determined that carrier operations required even more engineers than the DMSpA figure suggested. The limited workforce available to 617 Sqn worked at a commensurately higher, more fatiguing rate and were therefore potentially more prone to errors. The panel concluded that insufficient workforce availability was a **contributory factor.**

Witness 3
Witness 21
Witness 22
Witness 18
Witness 4
Witness 1

[57] Chains were used on QEC carriers to secure aircraft to the deck. These were not required when aircraft were land-based.

1.4.153. **Recommendation. Deputy Commander Capability should resource the Lightning engineering workforce at an establishment that delivers sufficient Direct Maintainer Spaces per Aircraft, increasing for embarked operations based on the lessons identified from Op FORTIS in order to ensure enough engineers are available to deliver the task safely.**

1.4.154. The Lightning Force raised the risk of 'Insufficient workforce to meet the operational requirement' on the Performance And Risk Management Information System (PARMIS)[58] and assessed it as 'HIGH' risk (frequent/critical).[59] This risk was held by the Combat Air Force Commander (CAFC), but the panel considered that the CAFC was not in a position to make changes to mitigate this risk. The panel concluded that the workforce risk, assessed as 'HIGH', was likely to impact 617 Sqn on operations and should be escalated by the CAFC. The workforce risk was therefore an **other factor**. Exhibit 141

1.4.155. **Recommendation. The Combat Air Force Commander should confirm that the workforce risk is held at the correct level in order to ensure that it can be addressed.**

Fatigue

1.4.156. Different departments around the Ship worked shift patterns to suit their tasking and resource. 617 Sqn engineers were split into two shifts that each worked [redacted] initially handing over at [redacted]. This was later modified to [redacted] to better suit meal times. Many personnel across all departments remarked that the deployment was extremely fatiguing. The Principal Medical Officer (PMO) stated that they had observed everyone on the ship as being very tired by the end of Op FORTIS, and morale in some quarters was very low. Witness 3 Witness 2 Witness 11

1.4.157. The effects of the Covid-19 pandemic were particularly acute on QNLZ. Personnel in eight-berth cabins suffered consecutive isolation periods causing some personnel to remain isolated for periods up to 28 days. Isolating personnel caused those remaining at work to have fewer opportunities for rest. Witness 11

1.4.158. During Op FORTIS a difference between 617 Sqn and [redacted] in attitude towards tasking became apparent. The [redacted] approach was to sustain a high rate of operational flying and the sqn was appropriately resourced to do so. It elected not to participate in Defence Engagement flying. This approach applied pressure to minimise periods when the flight deck was not available for flying operations. This decreased opportunities for fresh air and recreation for those without routine access to outside spaces, thereby contributing to fatigue. Witnesses described QNLZ as 'the largest submarine in the Navy'. Engineers were often unrepresented at planning meetings, so their fatigue issues were sometimes not considered. A combination of factors including Defence Engagement, currency Witness 3 Witness 4 Witness 21 Witness 22 Witness 18

[58] The RAF's risk management system.
[59] According to the RAF Risk Likelihood/Impact Heatmap.

requirements and the [redacted]

1.4.159. The MOD had a legal requirement[60] to comply with European Working Time Regulations (WTR), but its guidelines could be exceeded if operationally required. During periods when the CSG was responding to operational tasking it could be expected that the demands on its workforce might exceed WTR. The deployment was designed and programmed such that the intervening periods between operational phases should have offered opportunities to recuperate. Covid-19 restrictions and the working tempo decreased these opportunities.

Exhibit 142

Witness 2

1.4.160. In Jan 20 the Royal Navy Flight Safety Centre commissioned the Institute of Naval Medicine (INM) to support a study into Human Factors in embarked operations. The INM report, published in Apr 20, found that the most common challenge was fatigue induced by working routines, compounded by time pressure, environmental conditions and insufficient workforce. It recommended the use of fatigue management tools during pre-deployment planning, preservation of maintenance and rest days and provision of adequate workforce. Without such provisions, supervisors commented that they observed an increase in errors and physical signs of fatigue in their teams.

Exhibit 143

Witness 18

1.4.161. An accident on QNLZ in Jun 20 was serious enough to warrant an Occurrence Safety Investigation (OSI). The OSI determined that fatigue was a contributory factor and recommended improvements to the way fatigue was managed. This was echoed by a further RNFSC report, in Dec 20, that suggested adopting the RAF's AP 8000 as a template to introduce fatigue management regulation. In Mar 21, BRd 767 was updated to include Naval Aviation Order 4101 'Air Engineering Personnel Fatigue Management'. This order made Commanding Officers (CO) and Heads of Establishment (HoE) responsible for managing fatigue for Air Engineers for sqns under Navy Command Aircraft Operating Authority (NCAOA), in the same way that AP 8000 placed 'DHs, COs and HoE' responsible for managing fatigue for Air Command sqns. The panel found that the RN was still incorporating this guidance into routine business as Op FORTIS commenced.

Exhibit 144

1.4.162. To comply with WTR and AP 8000, 617 Sqn staffed a Duty Holder Advice Note[61] (DHAN), endorsed by OC 617 Sqn and the DDH, that considered three possible operational tempos:

Exhibit 145
Exhibits 35, 146 to 151

a. ***'Routine.*** [redacted]

b. ***Maintenance Day.*** [redacted]

Witness 23

[60] 2021DIN01-045.

[61] A DHAN made a Duty Holder aware of a risk, and its possible mitigations, for acceptance or transfer.

c. ***Surge Ops***. [redacted]

The panel considered that the way these tempos were written was difficult to interpret and apply to real life operational scenarios. They were not reproduced in either 617 Sqn's Final Statement of Generation (FSOG) or Operational Capability Certificate (OCC)[62]. Exhibit 152 Exhibit 153

1.4.163. Guidance for the CSG planners was in the 617 Sqn OCC, which was classified at Secret. It outlined an increasing maximum number of sorties per week defined as 'Routine', 'Operational' and 'Surge', although even prior to the deployment the DDH was requested to remove what were seen as restrictions. The CSG aspired to a baseline flying rate that equated to the OCC 'Surge' rate, requiring frequent communication with the DDH to try to resolve this tension. The OCC guidance did not account for the environment, weapon loading requirements, sortie durations and alert requirements. In the panel's opinion the DHAN and OCC measures were rudimentary and were open to interpretation. They were difficult to enact whilst responding to the pressures of Op FORTIS. Exhibit 153

1.4.164. 617 Sqn's engineers were frequently required to exceed the DHAN and OCC limitations. The reality of a flying programme with six days flying followed by one no-fly day was that the engineers would invariably still be required to work on that no-fly day. [redacted] Witness 3 Exhibit 148 Exhibits 147 to 150 Exhibit 153 Witness 21

1.4.165. The panel noted that 617 Sqn's fatigue management was governed by AP 8000, but other departments were subject to BRd 767. Although these orders were similar, the panel opined that the differing regulations could create unnecessary friction. The panel noted that the Lightning DDH petitioned the Carrier Air Wing Commander (CAG) to support the management of 617 Sqn's fatigue, but that AP 8000 appointed OC 617 Sqn and CO QNLZ the two deployed people responsible. The panel found that CO QNLZ could help enact mitigations for fatigue, and CAG had the ability to modify the tempo of operations to aid fatigue management. The panel concluded that while orders were sufficient for smaller operations, they had not kept up with the scale and complexity of CSG operations to ensure Witness 4

[62] An Operational Capability Certificate (OCC) outlines the capability and limitations of a sqn in a document that can be used by planners and commanders to understand how to employ the sqn to best effect.

that responsibility for fatigue was actually held by those that could effect change.

1.4.166. In their report, the RAFCAM HF specialists observed that the accident occurred approximately six months into the deployment and it was likely that personnel were experiencing the effects of accumulative fatigue at that stage. They noted that without adequate rest fatigue accumulates and as fatigue accumulates, attention span gets narrower and human anticipation of accuracy and timing degrades leading to lower performance standards being tolerated. They stated that personnel would have been more susceptible to degraded performance, reduced attention and the chances of errors occurring. The panel concluded that accumulative fatigue was a **contributory factor.** Exhibit 154

1.4.167. **Recommendation. The Lightning Delivery Duty Holder should ensure that detachment fatigue management plans are referenced in Final Statements of Generation and Operational Capability Certificates in order to enable operational planners to support fatigue management.**

1.4.168. **Recommendation. The Lightning Operating Duty Holder should implement a procedure to actively manage fatigue of all personnel on all operations / exercises in order to ensure Air Safety can be maintained in fatiguing environments.**

1.4.169. **Recommendation. The Commander Air Group should establish methods to agree planned exceedances of fatigue management processes with Delivery Duty Holders in order to enable them to reduce the risk to air safety to As Low as Reasonably Practicable and Tolerable.**

Heat stress

1.4.170. The temperatures recorded during Op FORTIS reached as high as 40°C. There were no reports of heat illness, but heat stress casualties were treated frequently by medical staff. On 14 Nov 21 a Remembrance Day Service was held on the flight deck and more than 20 personnel received medical support due to the hot weather. Witness 11

1.4.171. JSP 375 stated that a commander must be appointed to supervise any activity where the risk of heat illness existed and conduct a risk assessment. An Executive Temporary Memorandum[63] ordered departments to conduct risk assessments to ascertain their heat illness risk. 617 Sqn staffed a Risk Owner Advice Note to notify its exceedance of tolerable risk levels. The panel found no evidence that this notification was acknowledged by a risk owner. The Commanding Officer (CO) of QNLZ was the Head of Establishment for the Ship, but the CAG had the ability to affect operational tasking which could mitigate heat stress risks. The panel considered that for CSG operations, the CO QNLZ may not be the most appropriate person to hold the risk. Exhibit 155 Witness 21 Exhibit 156

[63] XTM 48/21. An Executive Temporary Memorandum (XTM) was an order that applied to all departments on the Ship.

1.4.172. 617 Sqn tried to rotate personnel working on the flight deck as often as possible to minimise the risk of heat illness in accordance with the guidance in JSP 375 Chapter 41.[64] The length of time required to attend aircraft during see-offs meant personnel often exceeded this guidance. The RAFCAM HF specialists determined that the effect of being in extreme temperatures for prolonged periods was very likely to have heightened the fatigue levels of those personnel. The panel concluded that the increased fatigue, due to the effects of heat stress, on 617 Sqn engineers was a **contributory factor.** | Exhibit 156 | Exhibit 154

1.4.173. **Recommendation. Director Force Generation should identify the appropriate commander for heat illness prevention in accordance with JSP 375 in order to comply with health and safety law, and Defence and Government policy.**

Training and experience

1.4.174. Prior to Op FORTIS, 55% of 617 Sqn had previous embarked experience, and 77% of the Sqn's personnel had completed the minimum sea survival training. The sustained operational tasking throughout Op FORTIS meant that, whilst 617 Sqn had accrued six months of embarked experience prior to the incident occurring, there was little opportunity to identify, implement and assure improvements and lessons as they occurred. | Witness 20 | Exhibit 152

1.4.175. 617 Sqn was supplemented with 15 engineers from 207 Sqn for Op FORTIS. Another 14 engineers joined them directly from Phase 2B training at the end of May 21, four weeks after the Sqn had embarked. | Witness 3 | Witness 13 | Exhibit 157

1.4.176. The POS/BOS on BK-18 was conducted by Eng 1 and Eng 2. Eng 1 deployed on Op FORTIS straight from Phase 2B training, so their first ever flight servicing was conducted whilst embarked. Eng 2 had qualified for flight servicing during on-the-job training on 207 Sqn and was loaned to 617 Sqn for Op FORTIS. | Witness 12 | Witness 13

1.4.177. Lightning RAF engineers did not have a training pathway to qualify in flight line servicing whereas the RN engineers completed their qualification during their Phase 2B training. RAF engineers were unable to work on the flight line unless they could be loaded onto an RN course or undertook on-the-job training. There were two effects of this. First, 617 Sqn had to negotiate to borrow flight servicing qualified personnel from 207 Sqn for Op FORTIS and other deployments, disrupting sqn cohesion and creating inefficiency in the LF as a whole. Second, the limited pool of qualified people had to work proportionately harder with an associated effect on fatigue. The panel concluded that unavailability of flight servicing training for RAF engineers reduced sqn cohesion, created inefficiency and increased individual fatigue and was a **contributory factor.** | Witness 1 | Witness 4 | Witness 3

1.4.178. The Lightning Force raised the risk of 'Training deficiencies creating inability to … meet Op tasking' on PARMIS and assessed it as | Exhibit 158

[64] JSP 375 (www).

'HIGH' risk (frequent/critical)[65]. This risk was held by the CAFC but, based on analysis of the stated risk causes, the panel considered that the CAFC was not able to make changes to mitigate this risk. The panel recognised that workforce training risk being held by CAFC was held at too low a level and should have been escalated as it impacted 617 Sqn on operations. The panel concluded this was an **other factor**.

1.4.179. **Recommendation. The Combat Air Force Commander should confirm that the training deficiencies risk is held at the correct level in order to ensure that it can be addressed.**

1.4.180. **Recommendation. Chief of Staff Support should ensure sufficient Lightning engineers are trained to deliver the requisite qualified personnel for Direct Maintainer Spaces per Aircraft, including any increases for embarked operations based on the lessons identified from Op FORTIS, in order to deliver the task safely.**

617 Sqn engineering management changes

1.4.181. After the departure of the last full time SEngO in Sep 20, there were three changes of 617 Sqn SEngO. In Nov 20 a Lt Cdr was nominated and commenced the related pre-employment training. To ensure they were adequately prepared, the DDH implemented an extended familiarisation period, longer than that in place for other fast jet sqns, and longer than mandated by Regulatory Articles.[66] The nominee subsequently elected to decline the posting due to the impact on their career timeline. Witness 4

1.4.182. RA1003 mandated a maximum 3-month period for handover of an airworthiness post such as SEngO. In the panel's opinion this should provide adequate time for the incumbent to review a sqn's orders and ensure QA observations were addressed effectively. The SEngO for Op FORTIS was previously a JEngO on a helicopter sqn and held Special Level J authorisations[67] and was subsequently a Trials Management Officer on 17 TES. They were posted to 617 Sqn in Feb 21, but only awarded Level J[68] on 1 May 21 and permitted to assume the role after Op FORTIS had already started. In the panel's opinion the unique demands of Op FORTIS reduced their capacity to review their orders. The panel concluded that the compression of the SEngO's time in command to the start of Op FORTIS was an **other factor.** Witness 3; Exhibit 159; Witness 4; Witness 3; Exhibit 3; Exhibit 160

1.4.183. The Sqn warrant officer engineer (WOEng) had assumed post at the end of 2020, having over 4 years experience on Lightning, but none of which was embarked. Only one of the personnel in the four key engineering management positions of SEngO, two JEngOs and WOEng on 617 Sqn had completed more than one of the workup embarkations. Personnel who had gained embarked experience and built relationships during the previous work-up exercises had been posted and the new officers had to re-learn Witness 3; Witness 1; Witness 4

[65] According to the RAF Risk Likelihood / Impact Heatmap.
[66] RA1002 (www).
[67] Someone holding a 'Special' authorisation was entrusted with responsibility normally reserved only for those of higher rank.
[68] Level J: the most senior air engineer on the Squadron, with executive responsibility for airworthiness and also responsible for all Sqn engineering personnel.

while on Op FORTIS, introducing risk to the operation. The panel found no evidence that the inexperience of the deployed engineers had been identified as a risk and concluded this was an **other factor**.

Op FORTIS work-up deployments

1.4.184. The phased introduction of F-35B to the Queen Elizabeth Class (QEC) aircraft carriers was designed to gradually build experience and capability over a series of targeted exercises.

Witness 20

1.4.185. During Ex WESTLANT 19, six aircraft and associated engineering teams were deployed to QNLZ from 17 TES and 617 Sqn whilst operating off the US Eastern seaboard. This Ex was focussed on the basics of ensuring that the aircraft could operate from the Ship and was the first embarkation of 617 Sqn personnel on the Ship as a unit.

Witness 17
Witness 3

1.4.186. Carrier Qualification 20-1 was designed to deliver carrier deck landing training and qualification. The aircraft did not embark on the Ship, which was sailing in the North Sea, but operated daily from RAF Marham. A small engineering team from 207 Sqn embarked to conduct the aircraft turn arounds, so there was no opportunity for 617 Sqn engineers to gain embarked experience.

Witness 17

1.4.187. QNLZ conducted Fleet Operational Sea Training[69] (FOST) in Apr 20. This exercised all the Ship's own war fighting capabilities and practiced emergency reactions and procedures with the embarked helicopters of 820 NAS. 617 Sqn were not embarked. Carrier Qualification 20-2 and Ex CRIMSON OCEAN 20 ran immediately after the Ship had completed FOST. Due to the Covid-19 pandemic, no observers could be embarked, so the Lightning Force relied on the 617 Sqn engineering management team to learn their own lessons from their embarked experience. Due to the changes in engineering management after Sep 20 many of these lessons and experiences were lost.

Witness 1
Witness 4
Witness 3
Exhibit 4

1.4.188. In Ex STRIKE WARRIOR 20-2, embarked UK F-35B aircraft carried live weapons for the first time, with the [redacted] [redacted] joining 617 Sqn on the carrier. [redacted] This was exacerbated by the increased numbers of aircraft on the flight deck requiring more aircraft moves than previous exercises. 617 Sqn borrowed workforce from the Ship's air engineering department and shared see-off teams with [redacted]. The contrast with the more experienced [redacted] was noticeable, as the [redacted] had enough personnel to operate at pace and capacity. Post exercise analysis by 617 Sqn identified that they required at least [redacted] [redacted]

Witness 20
Witness 18
Witness 3
Witness 20
Exhibit 157
Witness 1
Witness 3
Witness 18

1.4.189. The initial intent was for a final workup exercise to be conducted in the first quarter of 2021 as the already planned Ex STRIKE WARRIOR 21-

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69 Fleet Operation Sea Training.
70 [redacted]

1 was a final check of the assumptions, policy and plans prior to Op FORTIS. Due to the pandemic, there was a requirement to quarantine all personnel prior to deploying. Therefore, Ex STRIKE WARRIOR 21-1 ran immediately prior to Op FORTIS which lost the opportunity to implement lessons. Exhibit 159 Witness 13

1.4.190. In principle, the schedule of exercises outlined above, and the smaller training serials in between, should have built embarked experience gradually up to Op FORTIS. In practice many of the people in key posts were not on all the exercises, and there were fewer opportunities to learn lessons than were envisaged. The panel found that 617 Sqn was less well prepared for Op FORTIS than the CSG planners may have been led to believe by the FSOG and OCC. Consequently 617 Sqn faced a higher operating tempo than it was prepared for. The panel concluded that lack of embarked experience within the 617 Sqn engineering team was a **contributory factor.** Witnesses 3, 4 & 21 Exhibits 152 & 153

Aircraft preparation standard

1.4.191. Only three of the aircraft deployed by 617 Sqn were fully mission capable at the time of embarkation. The others required engineering activity after they embarked to achieve this standard. For example, BK-18 had no air-to-air refuelling capability and other aircraft had system deficiencies that would not have permitted participation on Op SHADER[71] until resolved by the 617 Sqn engineers. The FSOG recorded the capabilities and limitations of a formed unit (in this case 617 Sqn) as it was assigned to an operation. 617 Sqn's FSOG stated that all aircraft would be at the required standard for deployment including being able to operate on Op SHADER. The FSOG did not mention their deficiencies, so the CSG was not adequately informed to plan accordingly. The panel determined that deficiencies in aircraft preparation, whilst probably unavoidable, increased the workload on 617 Sqn engineers in the opening weeks of Op FORTIS, thereby contributing to the early onset of fatigue. The panel concluded that not accurately representing aircraft limitations in the FSOG prior to embarkation was an **other factor.** Witness 4 Exhibit 152

1.4.192. **Recommendation. Lightning Delivery Duty Holder should ensure that Final Statements of Generation and Operational Capability Certificates depict a comprehensive and realistic assessment of each Force Element's capabilities in order to permit planning to accommodate its limitations.**

Post-crash management (PCM)

PCM overview

1.4.193. This was the first major air incident on a QEC aircraft carrier. The aircraft related PCM actions for the Ship's air and air engineering Witness 20

[71] Op SHADER was the UK commitment to combat Daesh in Iraq and Eastern Syria.

departments and 617 Sqn activities were conducted from the Ship's PCM plan.

1.4.194. The nature of the incident caused some confusion within the Ship as personnel were unable to decide whether to describe the accident as a 'crash on deck', an 'aircraft ditch' or a 'casualty on the flight deck'. FLYCO sounded the crash on deck alarm, but the bridge broadcast "aircraft ditch" and other internal messages described a casualty on the flight deck. There was confusion in some non-aviation departments as to how best to respond. The panel determined that the Ship self-generated and FOST delivered training had focussed on a crash on deck scenario as this was considered to be the most complex and testing for the Ship to deal with. Air Department Standing Orders had detailed plans for various aircraft emergencies including comprehensive ditch procedures. Some non-aviation departments had standardised responses to incidents, into which this accident did not easily fit. The extant crash on deck and man-overboard training covered all the required PCM actions used to respond to this accident. Despite the confusion, the panel concluded that training was **not a factor** in the PCM response. Exhibits 161 &162

FLYCO actions

1.4.195. FLYCO actions in the event of an air accident were in a checklist in BRd766, a hard copy of which was in a ring binder at the Lt Cdr Flying console. F2 stated that it was difficult to find the correct page because it was in the middle of the binder. They ran through the check list and verified that all actions were being conducted. In the time taken to do this, the personnel on the bridge had sounded the general alarm and had issued a pipe[72] stating that an aircraft had ditched, but with no amplifying information. Having heard the bridge pipe, F2 declared that no further pipe was required from FLYCO. In the BRd766, both the AIRCRAFT EMERGENCY and CRASH ON DECK orders required a pipe that included such information as the type of aircraft, squadron number, persons on board, armament state and status of the ejectee/casualties. The omission of amplifying information in the pipe from the bridge was not noticed by anyone in FLYCO. The bridge pipe was difficult to hear as the speakers in FLYCO had been turned down to prevent routine broadcasts interfering with aircraft communications. FLYCO personnel were often reliant on a speaker in the passageway outside FLYCO for information. The panel determined that the pipe from the bridge was appropriate to start the response process, in lieu of a more detailed pipe from FLYCO. Those responding to the incident reported hearing the general alarm, and the aircraft ditch pipe. Some personnel also heard the crash on deck alarm which was only transmitted in certain locations around the Ship. Consequently, responders did not have complete information about the scenario and the location of the pilot. The medical responders were split between three locations before they found and attended to the pilot. In the panel's opinion, had the bridge pipe been followed up with more detail from FLYCO, the medical response would have been more focussed. The panel concluded that the lack of a comprehensive broadcast slowed the medical

Exhibit 53
Witness 15
Exhibit 15
Witness 20
Witnesses 4 & 15
Witness 18
Witness 22
Witness 11

[72] Pipes are verbal messages announced over the Ship's main broadcast speakers to either the whole Ship or selected parts.

response to the accident and was an **other factor**. The panel also concluded that the location of the FLYCO emergency procedures within the checklists slowed the FLYCO reactions and was an **other factor.**

1.4.196. **Recommendation. Director Force Generation should update and reformat BRd766 Flying Control Emergency Procedures to ensure that users can easily find the relevant procedures in order to respond promptly to aviation emergencies.**

1.4.197. The dedicated console for making a broadcast from FLYCO was [redacted] (Figure 1.4.32). To use this, F2 needed to step away from their position and ascend ladders, up half a deck height. Instead F2 remained at their post and attempted to reconfigure their Tactical Command Communications Voice (TC2V) console to make a pipe. To sound an alarm and transmit a pipe F2 needed to select two channels which were not routinely pre-selected. The panel determined that the distance to the broadcast console, and the time intensive method to set the TC2V delayed F2's response to the crash. The panel concluded that Lt Cdr Flying's position having poor access to timely alarms and pipes was an **other factor.** Witness 15 Exhibit 15

Figure 1.4.32 – FLYCO communications equipment positions.

1.4.198. **Recommendation. Director Force Generation should ensure that key personnel in Queen Elizabeth Class Flying Control are equipped to respond rapidly to emergencies with appropriate communication and alarms in order to allow a timely response to accidents.**

1.4.199. The Wireless Communication System (WCS) radios were used throughout the Ship and by FLYCO and flight deck personnel to communicate and co-ordinate flight deck activity. Critically, they also provided a key safety element in co-ordinating responses to flight deck incidents. [redacted] This occurred immediately after the Witness 8 Witness 16 Witness 17 ejection on the flight deck network. Thus, when Cdr Air tasked the DOO to contact the aircraft handlers to keep the casualty laid down and inform them that medical assistance was enroute, [redacted] Witness 16

1.4.200. [redacted] Witness 8 Witness 17 Witness 8

1.4.201. **Recommendation. Director Force Generation should ensure that a [redacted] is provided in order to support the requirements of safe aviation from Queen Elizabeth Class carriers.**

Medical response

1.4.202. Aviation medicine was not routinely included in the specialty training pathways of all military doctors and was not normally included in the training pathway for medics, nurses, dentists or physiotherapists. For personnel to become qualified in aviation medicine there were two recognised qualifications; the Military Aviation Medicine Examiners Course (MAME), a two-week course held at the RAF Centre of Aviation Medicine and a higher level Diploma in Aviation Medicine (DAvMed), awarded by the Royal College of Physicians. The aviation medicine requirements onboard QEC aircraft carriers were for both the PMO and DPMO to be qualified to DAvMed standard where possible, but replacement of one of these with a MAME qualified doctor was considered acceptable. Witness 19 Witness 11 Exhibit 55 Exhibits 54 & 55 Exhibit 54

1.4.203. The [redacted] deployed a doctor who was only permitted to work with [redacted] The PMO on QNLZ was [redacted]. Role 2 medics were specialists in assessing and treating various types of injury, including those that could have been caused by ejections but had no formal aviation medicine training. Witness 11 Witness 19

1.4.204. Following the crash on deck alarm, the Role 1 medical team began preparations including retrieval of the emergency medical response module, known as a 'grab bag' and the donning of personal protective equipment. During the Role 1 muster, an update was broadcast that an aircraft had 'ditched'. It was not clear to the medical response team whether the initial crash on deck alarm was extant, resulting in the medical response to be split into two teams. One team was sent to the muster point located at a nearby sea boat and the second team was dispatched to the deck. Medical Headquarters (MHQ) subsequently clarified that the incident involved a single ejectee who had landed on deck, with the aircraft ditching in the sea, allowing one of the response teams to be recalled. During the initial Witness 11 response, the PMO remained in the medical facility to facilitate coordination of the medical response.

1.4.205. Immediately after the pilot landed on the deck, two aircraft handlers came to assist. The pilot subsequently walked unaided to the aircraft handlers' crewroom and began to remove their flying equipment. Shortly afterwards, a medic arrived and commenced a medical assessment to report to the MHQ. They observed that the pilot [redacted] and otherwise appeared fully fit and in good spirits. The pilot was not immobilised and was escorted on foot using ladders to descend to 5 Deck. Witness 8 Witness 7 Witness 10 Witness 11 Exhibit 54

1.4.206. On arrival in the medical centre the pilot was assessed by the PMO. [redacted] AP1269A leaflet 6-03[73] stated that following an ejection a CT[74] scan should be completed in the first instance due to the risk of an unstable fracture. An MRI[75] of the spine should ideally be completed within 24 hours. [redacted] Witness 11 Exhibit 54 Witness 19 Exhibit 54 Witness 19

1.4.207. Before being transferred, the pilot left the medical centre on two occasions to meet colleagues, conduct a media interview and prepare for departure from the Ship in his own cabin. Witness 10, 11 &19 Exhibit 163

1.4.208. There was periodic medical response training on board QNLZ. This involved the Ship's Role 1 and included simulated crash on deck scenarios. Post-ejection medical management was not included in these training scenarios. The panel noted that there was a lack of familiarity with procedures and casualty management of ejectees. This was not part of the FOST training for either jet or helicopter crash on deck scenarios, or part of the Ship's internal training plan. The panel concluded that lack of ejection incident management training as part of PCM scenarios was an **other factor**. Exhibit 54 Witness 19 Exhibits 164 to 167

1.4.209. **Recommendation. Director Force Generation should ensure that crash on deck training includes post-ejection protocols in order to**

[73] Medical Management of Aircraft Crashes and Other Accidents.
[74] Computerised Tomography.
[75] Magnetic Resonance Imaging.

support the requirements of safe aviation from Queen Elizabeth Class carriers.

1.4.210. [redacted] The pilot's helmet also sustained some superficial tin splatter to the tinted visor and outer helmet surface with heat damage to the crown area.

Witnesses 7, 8, 10 &11

Exhibit 54

1.4.211. [redacted]

[redacted]

[redacted] The panel concluded that AP1269A was written for application in land-based operations and therefore did not cover deployed or embarked operation and that this was an **other factor.**

Exhibit 54

Exhibit 55

1.4.213. **Recommendation. The Command Flight Medical Officer should update the guidance in AP1269A Leaflet 6-03 Annex D in order to ensure it is applicable outside the UK, in particular on Queen Elizabeth Class deployments.**

1.4.214. [redacted] The panel concluded that failure to self-immobilise unnecessarily risked greater harm and was an **other factor.**

Witness 19
Exhibit 54
Witness 11

[76] A mild injury, sometimes known as a 'bone bruise'.

1.4.215. **Officer Commanding Aviation Medicine Training Wing should remind aircrew of the need to limit physical movement after ejection until cleared by medical personnel in order to reduce the likelihood of further injury.**

Ship data capture

1.4.216. The Combat Management System (CMS) contained information [redacted] but was not impounded as part of the Ship's data capture. The CMS data would have been useful for the Service Inquiry but the evidence had to be pieced together from other sources. The panel **observed** that a loss of CMS data could impact other investigations. Exhibit 168

1.4.217. After the accident there were two factors that influenced the decision making for quarantining VSS data. First, due to the likely complexity of the accident the footage from multiple cameras would be required, but it could not quickly be identified exactly which cameras. Second, the requirement to prevent footage being leaked by personnel on the Ship. [redacted] [redacted]

[redacted] [redacted]

[redacted] The panel subsequently identified that the VSS software had a method of data capture to save and export camera feeds for incidents such as these.

1.4.220. [redacted] Exhibits 164 to 167

1.4.221. [redacted] Exhibit 169

[redacted]

1.4.222. **Recommendation. Director Force Generation should implement a process for quarantining digital data in a timely manner and in an appropriately accessible format in order to preserve evidence for subsequent investigation.**

1.4.223. **Recommendation. Fleet Operational Sea Training (Ships) should include digital data quarantine processes in Post Crash Management training in order to preserve crucial evidence for future inquiries.**

Salvage operations

1.4.224. Shortly after impacting the sea BK-18 sank in approximately 2,000m of water. A UK led salvage operation was conducted using chartered vessels. The aircraft was discovered, by remotely operated vehicle, inverted on the seabed, intact with a few minor parts such as the ejection seat detached but close to the airframe. The salvage operation recovered the aircraft, as well as all of the detached items and then transported them back to the UK. The CSMU had a sonar locator beacon to assist with recovery of the flight data recorder in the event of loss in water. The beacon was not detected during the search and recovery. The panel were informed by the LDT that work is ongoing to understand the reasons why the beacon was not detected. The panel **observed** that this affected the recovery of the BK-18 wreckage and could lead to a failure to locate a submerged aircraft in the future. Exhibit 58 Exhibit 58

Financial implications

1.4.225. The aircraft wreckage was assessed in Dec 21 as beyond economic repair. The LDT provided a cost, at time of loss, for the aircraft at £81.8M. The cost of the recovery, including the hire of specialist recovery ships and transportation was £2.63M. The disposal cost of the wreckage will only be calculated after completion of the investigation. Exhibit 170

1.4.226. No damage to the Ship or other equipment was identified.

Summary of Findings

1.4.227. **Causal factor.** Based on all the evidence, the panel concluded that the left intake blank was at the front face of the engine compressor during the aircraft launch and determined this to be the **causal factor**. 1.4.128

1.4.228. **Contributory factors.** The following were contributory factors to the loss of BK-18.

a. In the panel's opinion, if security had been discussed in engineering planning meetings either on 10 Nov 21, in the period leading up to 15 Nov 21, or in the handover notes, it is very likely that more attention would have been paid to the Red Gear being 1.4.18

removed correctly. The panel concluded that the omission of security considerations from 617 Sqn's engineering planning cycle was a **contributory factor**.

b. The panel opined that, if Eng 2 had not been distracted by the storage task, then it is likely that they would have worked on BK-18 at the same time as Eng 1 and, therefore, would have been able to manage the Red Gear more effectively. The panel concluded that the distraction of a peripheral task was a **contributory factor.** 1.4.20

c. On completing their servicing Eng 1 took the right intake and Power Thermal Management System (PTMS) blanks down to the hangar. They left the exhaust and left intake blanks in place and assumed Eng 2 would collect them. Eng 1 returned to the crew room and left the tools there for Eng 2. However, no formal handover was conducted and they did not discuss the partial removal of Red Gear. In the panel's opinion, had there been a more detailed handover it is highly unlikely that any elements would have been missed. The panel concluded that not removing all elements of Red Gear at the same time was a **contributory factor.** The panel further concluded that the omission of a handover which included Red Gear was also a **contributory factor.** 1.4.21

d. The panel opined that if the red intake blank were to be dislodged, but still partially visible in the intake, the use of filtered light in a dark intake would have decreased the likelihood of it being seen. The panel concluded that not using white light for servicing was a **contributory factor.** 1.4.28

e. In the panel's opinion, if a 100% check of all the Red Gear had been carried out after the mass removal had been completed, the left intake blank in BK-18 would likely have been noticed as missing. In a subsequent search it would likely have been discovered. The panel concluded that the lack of a confirmatory muster after the mass removal of Red Gear was a **contributory factor.** 1.4.35

f. In the panel's opinion, at all levels of the Lightning programme, Red Gear was not perceived as a threat. This perception caused it to be treated less carefully than other tools and instruments. The panel concluded that the perception that Red Gear was only a risk to other aircraft or personnel, not a threat to airworthiness of the aircraft to which it was fitted was a **contributory factor.** 1.4.40

g. Items located in the intake duct could only be discovered by someone climbing into the intake to look, not just observing from the ground. No previous UK aircraft had this unobservable area. The panel concluded that lack of familiarity with this design feature and the associated potential for items to be concealed in the intake was a **contributory factor.** 1.4.57

1.4.61

h. The panel concluded that the UK omission of an independent check of the common duct immediately prior to flight was a **contributory factor.**

1.4.70

i. The panel found that the use of the pip pin could have prevented the blank from migrating down the intake. The lack of awareness on 617 Sqn of whether the pip pin should be used was a **contributory factor**.

1.4.73

j. The panel determined that the blank was not adequately designed for windy conditions. The panel concluded that the lack of environmental considerations in the blank design was a **contributory factor**.

1.4.75

k. The panel determined that Red Gear was an 'orphan asset' which neither the Lightning Force nor the LDT formally managed. The panel concluded that this resulted in the lack of installation and removal procedures being produced for the new blanks, which was a **contributory factor**.

1.4.78

l. Weather was attributed as the cause of the loss of blanks in a number of reports and was mentioned in the intake blank engineering evaluation report. The panel determined that these issues occurred across the global F-35 user community but were at a level such that it was considered a 'nuisance,' rather than a documented failing. This resulted in learned behaviour of the poor performance of the Red Gear being a feature of F-35B operations. The panel concluded that this normalisation to blanks falling out or becoming detached was a **contributory factor.**

1.4.80

m. The panel opined that had the requirement for Red Gear to be logged by the rectification controller been retained, it would have been a more robust barrier to the loss of Red Gear. The panel concluded that the change to the 617 Sqn Red Gear management order was a **contributory factor.**

1.4.86

n. Use of an older version of the annex, the format of the annex, the confused use of columns for comments and the mixed fitment of blanks resulted in a Red Gear log that could not provide an effective barrier to a blank being unaccounted for or misplaced. The panel concluded that the ineffectiveness of the Red Gear log was a **contributory factor.**

1.4.89

o. Equipment fitted to or removed from aircraft should have been strictly controlled, but on Op FORTIS the GSSOs were ordering the fitment of Red Gear. The dual use of blanks was unique to the F-35B and had not been previously encountered by the UK military. The DASOR demonstrated that GSSOs were still unaware of the potential air safety implications of their actions. The panel concluded that the lack of procedure or policy incorporating the needs of the

GSSO whilst maintaining aircraft integrity and good engineering practices was a **contributory factor.** 1.4.91

p. The Mil CAM deviation process did not identify security as a reason for fitting the blanks. The panel concluded that the omission of identifying security as a reason to fit blanks, with an associated management process, was a **contributory factor.** 1.4.94

q. The panel found that Red Gear configuration control was not managed by either the LDT or the Mil CAM due to confusion over the global pool policy. The panel determined that responsibility for Red Gear had inadvertently fallen between organisations. The panel opined that this caused omissions to go unnoticed, the resolution of any one of which may have averted the accident to BK-18. The panel concluded that non-allocation of responsibility for assurance of Red Gear was a **contributory factor.** 1.4.100

r. Given that the F-35 was an international programme, UK reporting was but a small piece of the overall picture. The panel considered it more than likely that other Red Gear issues were going unreported across the F-35 community, so the threat to air safety was under appreciated. The panel concluded that this lack of reporting, assessment and analysis of air safety events relating to Red Gear was a **contributory factor.** 1.4.124

s. There was no ICAW alerting the pilot that the FADEC was limiting fuel or that the engine had not reached the desired thrust. The panel concluded that the lack of an appropriate warning to the pilot was a **contributory factor**. 1.4.143

t. The panel concluded that it was almost certain that wind dislodged the left intake blank in BK-18 from its installed position and moved it to a point at which it could not be seen externally on the night of 16 Nov 21. The panel concluded that the tendency for intake blanks to dislodge in high wind was a **contributory factor**. 1.4.144

u. The panel concluded that the lack of a removal and installation procedure for the blank and pip pin, with associated weather limits, was a **contributory factor**. 1.4.152

v. The panel determined that carrier operations required even more engineers than the DMSpA figure suggested. The limited workforce available to 617 Sqn worked at a commensurately higher, more fatiguing rate and were therefore potentially more prone to errors. The panel concluded that insufficient workforce availability was a **contributory factor.** 1.4.166

w. In their report the RAFCAM HF specialists stated that personnel would have been more susceptible to degraded performance, reduced attention and the chances of errors occurring. 1.4.172

The panel concluded that accumulative fatigue was a **contributory factor.**

x. The RAFCAM HF specialists determined that the effect of being in extreme temperatures for prolonged periods was very likely to have heightened the fatigue levels of those personnel. The panel concluded that the increased fatigue, due to the effects of heat stress, on 617 Sqn engineers was a **contributory factor.** 1.4.177

y. The panel concluded that unavailability of flight servicing training for RAF engineers reduced sqn cohesion, created inefficiency and increased individual fatigue and was a **contributory factor.** 1.4.190

z. The panel found that 617 Sqn was less well prepared for Op FORTIS than the CSG planners may have been led to believe by the FSOG and OCC. Consequently 617 Sqn faced a higher operating tempo than it was prepared for. The panel concluded that lack of embarked experience within the 617 Sqn engineering team was a **contributory factor.**

1.4.229. **Aggravating factors.** The following was an aggravating factor to the loss of BK-18.

a. The panel noted that it was standard procedure for aircraft to take-off from a position as far forward on the deck as possible, usually 350ft. The accident was reproduced in the simulator with the aircraft starting at the 500ft point. It was determined that in this scenario, had the abort decision been made after the same elapsed time, it was possible to abort successfully. Accordingly, the panel concluded that the selection of the shortest take-off run was an **aggravating factor**. 1.4.47

1.4.230. **Other factors.** The following other factors were identified during this investigation:

a. [redacted] 1.4.13

b. Eng 2 discovered the weather on the flight deck was windy and upper surfaces of the aircraft were wet from recent rain. They elected not to climb on top of the aircraft to carry out the upper surfaces inspection, considering that the protective overboots 1.4.23

required to walk on top of the aircraft provided poor traction in the wet. The panel noted that the omission of this part of the flight servicing was neither recorded in any Military Continuing Airworthiness Manager (Mil CAM) deviation registers nor authorised by any orders. The panel concluded that this deviation from flight servicing procedures was an **other factor**.

c. The panel concluded that the lack of formal stipulation in orders of the 'two-man rule' left it open to interpretation and was an **other factor**. 1.4.25

d. The panel reviewed QNLZ orders, briefings and training but found nothing relating to the use of white light. The panel concluded that the lack of definition of where white light could and could not be used may have unnecessarily limited the potential to identify faults or abnormalities and was an **other factor.** 1.4.27

e. As the ICC had been released from shift, the issue centre was closed with the keys held in the FDHOC. Therefore, there was no efficient way to record the removal in the Red Gear log. The panel concluded that reliance on the issue centre being open for Red Gear control was an **other factor**. 1.4.33

f. The panel concluded that distraction caused by the requirement to operate an unfamiliar load configuration without supporting procedures was an **other factor**. 1.4.37

g. Poor fitting of the arm restraint system could have resulted in an increased likelihood of injury during ejection. Since this was a low-speed ejection, the incomplete function of the restraint lines in this instance was an **other factor**. 1.4.51

h. The panel determined that had the pilot entered the water and inflated the stole, the single working stole would have provided adequate buoyancy, but redundancy would have been decreased. The panel concluded that the failure of the LP was an **other factor**. 1.4.54

i. [redacted] The panel did not find any evidence that an assessment as to the scale and impact of such differences had been conducted and concluded that this was an **other factor**. 1.4.64

j. The 617 Sqn Quality Assurance (QA) team had not pursued the technical dissemination process compliance, despite the order being extant for two months. The panel concluded that ineffectiveness of the Sqn technical dissemination process, and QA of that process, was an **other factor**. 1.4.81

1.4.82

k. In the panel's opinion if Red Gear was controlled as a complete set it would be more obvious when an item was overlooked, but conceded that this may be difficult in reality. The panel concluded that the splitting of Red Gear items from complete sets was an **other factor**.

l. In the panel's opinion if further action had been taken on any of the observations or QOR regarding Red Gear management, the loss of BK-18 may have been avoided. The panel concluded that the lack of QA follow up action was a **contributory factor.** 1.4.106

m. The loss of BK-18 was caused by loss of airflow due to the blank. The panel opined that the blank could be displaced, without human interaction, due to its design. The panel concluded that the design of the blank should be a factor in the aircraft RtL model and its omission was an **other factor**. 1.4.148

n. The panel concluded that the workforce risk, assessed as HIGH, was likely to impact 617 Sqn on operations and should be escalated by the CAFC. The workforce risk was therefore an **other factor.** 1.4.154

o. The panel recognised that workforce training risk being held by CAFC was held at too low a level and should have been escalated as it impacted 617 Sqn on operations. The panel concluded this was an **other factor**. 1.4.178

p. The panel concluded that the compression of the SEngO's time in command to the start of Op FORTIS was an **other factor.** 1.4.182

q. The panel found no evidence that the inexperience of the deployed engineers had been identified as a risk and concluded this was an **other factor**. 1.4.183

r. The panel determined that deficiencies in aircraft preparation increased the workload in the opening weeks of Op FORTIS, thereby increasing the early onset of fatigue. The panel concluded that not accurately representing aircraft limitations in the FSOG prior to embarkation was an **other factor.** 1.4.191

s. In the panel's opinion, had the bridge pipe been followed up with more detail from FLYCO, the medical response would have been more focussed. The panel concluded that the lack of a comprehensive broadcast slowed the medical response to the accident and was an **other factor**. The panel also concluded that the location of the FLYCO emergency procedures within the checklists slowed the FLYCO reactions and was an **other factor.** 1.4.195

t. The panel determined that the distance to the broadcast console, and the time intensive method to set the TC2V delayed F2's response to the crash. The panel concluded that Lt Cdr Flying's 1.4.197

position having poor access to timely alarms and pipes was an **other factor.**

u. [redacted] 1.4.200

v. The panel observed that there was a lack of familiarity with procedures and casualty management of ejectees. This was not part of the FOST training for either jet or helicopter crash on deck scenarios, or part of the Ship's internal training plan. The panel concluded that lack of ejection incident management training as part of PCM scenarios was an **other factor**. 1.4.208

w. The panel concluded that AP1269A was written for application in land-based operations and therefore did not cover deployed or embarked operation and that this was an **other factor.** 1.4.212

x. The panel concluded that failure to self-immobilise unnecessarily risked greater harm and was an **other factor.** 1.4.214

y. The panel found that full data capture for investigation purposes had not been attempted prior and there were no processes, procedures or identified resource to support the exploitation of this data. The panel concluded that the lack of VSS post incident procedures was an **other factor.** 1.4.220

1.4.231. **Observations.**

a. The panel **observed** that the see-off AESO was not easy to apply at sea and was seldom conducted in full whilst on land. The order, whilst seemingly effective, offered negligible assurance. 1.4.60

b. The panel could not identify that the risk of not fitting the blanks had been reviewed following the previous reports. The panel **observed** that there was no apparent UK mitigation to protect from FOD when not fitting the blanks on the flight deck. 1.4.62

c. The [redacted] data would have been useful for the Service Inquiry but the evidence was pieced together from other sources. The panel **observed** that a [redacted] data could impact other investigations. 1.4.216

d. The lack of procedures for limiting access to VSS post incident [redacted]. This delayed the data being available for this Inquiry. The panel concluded that the lack of understanding and policy to restrict the VSS replay function was an **observation**. 1.4.221

e. T[redacted] 1.4.224

[redacted]

Intentionally Blank

PART 1.5

Recommendations

Intentionally Blank

PART 1.5 – RECOMMENDATIONS

1.5.1. **Introduction.** The following recommendations are made in order to enhance Defence Safety:

1.5.2. **Deputy Commander Capability should:**

a. resource the Lightning engineering workforce at an establishment that delivers sufficient Direct Maintainer Spaces per Aircraft, increasing for embarked operations based on the lessons identified from Op FORTIS in order to ensure enough engineers are available to deliver the task safely.	1.4.153

1.5.3. **Director Force Generation should:**

a. define the procedures for solo working on Queen Elizabeth Class flight decks in order to ensure the safety of personnel working on deck at night.	1.4.26
b. define the procedures for use of white light on the Queen Elizabeth Class flight decks at night in order to ensure engineering standards and practices can be achieved.	1.4.29
c. review the risk to carrier operations of the F-35B take-off distance selection on Queen Elizabeth Class carriers in order to assure that it remains As Low As Reasonably Practicable and Tolerable, based on experience from Op FORTIS.	1.4.49
d. identify the appropriate commander for heat illness prevention in accordance with JSP375 in order to comply with health and safety law, and Defence and Government policy.	1.4.173
e. update and reformat BRd766 Flying Control Emergency Procedures to ensure that users can easily find the relevant procedures in order to respond promptly to aviation emergencies.	1.4.196
f. ensure that key personnel in Queen Elizabeth Class Flying Control are equipped to respond rapidly to emergencies with appropriate communication and alarms in order to allow a timely response to accidents.	1.4.198
g. ensure that a [redacted] is provided in order to support the requirements of safe aviation from Queen Elizabeth Class carriers.	1.4.201

h. ensure that crash on deck training includes post-ejection protocols in order to support the requirements of safe aviation from Queen Elizabeth Class carriers. 1.4.209

i. implement a process for quarantining digital data in a timely manner and in an appropriately accessible format in order to preserve evidence for subsequent investigation. 1.4.222

1.5.4. **Chief of Staff Support should:**

a. ensure sufficient Lightning engineers are trained to deliver the requisite qualified personnel for Direct Maintainer Spaces per Aircraft, including any increases for embarked operations based on the lessons identified from Op FORTIS, in order to deliver the task safely. 1.4.180

1.5.5. **Lightning Operating Duty Holder should:**

a. ensure that all weapons and countermeasures included in UK F-35B Operational Capability Certificates have supporting orders that detail loading procedures, training, and assurance in order to ensure squadrons are fully prepared to employ them. 1.4.38

b. direct further work to understand the performance of F-35B on carrier operations in order to assure that the risks to the F-35B associated with take-off distance selection remain As Low As Reasonably Practicable and Tolerable, based on experience from Op FORTIS. 1.4.48

c. produce airworthiness direction and guidance in order to ensure that management of UK F-35B security by Government Special Access Program Security Officers is air safety compliant. 1.4.90

d. implement a procedure to actively manage fatigue of all personnel on all operations / exercises in order to ensure Air Safety can be maintained in fatiguing environments. 1.4.168

1.5.6. **The Lightning Delivery Team Head should:**

a. engage the Joint Program Office to ensure the performance of twin stole life preserver systems meets the requirement specification in order to minimise the risk of stoles failing on inflation. 1.4.55

b. engage the Joint Program Office to assess the performance of Red Gear during land and embarked operations in order to ensure it is fit for purpose. 1.4.74

	c. engage the Joint Project Office (JPO) to ensure safety reporting from all F-35 users is shared by the JPO in order to identify trends to minimise the risk of repeated incidents.	1.4.101
	d. engage with the Joint Program Office to develop a timely and compelling warning to the pilot of mismatch between commanded and delivered thrust.	1.4.125
1.5.7.	**The Combat Air Force Commander should:**	
	a. confirm that the workforce risk is held at the correct level in order to ensure that it can be addressed.	1.4.155
	b. confirm that the training deficiencies risk is held at the correct level in order to ensure that it can be addressed.	1.4.179
1.5.8.	**The Lightning Delivery Duty Holder should:**	
	a. ensure security considerations are included during engineering planning in order to maintain airworthiness whilst necessary security measures are implemented.	1.4.19
	b. implement a system that ensures that all quality assurance recommendations are addressed in order to provide confidence that critical actions are not overlooked.	1.4.108
	c. ensure that intake blank fitment is standardised and assured in order to ensure consistency of use across the Lightning Force.	1.4.146
	d. ensure that detachment fatigue management plans are referenced in Final Statements of Generation and Operational Capability Certificates in order to enable operational planners to support fatigue management.	1.4.167
	e. ensure that Final Statements of Generation and Operational Capability Certificates depict a comprehensive and realistic assessment of each Force Element's capabilities in order to permit planning to accommodate its limitations.	1.4.192
1.5.9.	**The Commander Air Group should:**	
	a. establish methods to agree planned exceedances of fatigue management processes with Delivery Duty Holders in order to enable them to reduce the risk to air safety to As Low as Reasonably Practicable and Tolerable.	1.4.169
1.5.10.	**The Lightning Military Continuing Airworthiness Manager should:**	

a. identify all deviations required by Lightning engineers and update the Deviation Register in order to ensure they are appropriately mitigated and recorded.	1.4.24
b. update the Deviation Register to include fitment of Red Gear for security purposes.	1.4.92
c. include support equipment in the Memorandum of Agreement with the Lightning Delivery Team in order to formalise the requirement for support with Red Gear assurance.	1.4.96
1.5.11. **The Lightning Type Airworthiness Authority should:**	
a. provide clear guidance to aircrew and survival equipment technicians on the correct selection, fitment, and use of arm restraint extension lines (AREL), to include length selection and use of 'white whistles', in order to improve the likelihood of correct AREL function.	1.4.52
b. update the Air System Document Set for the current Red Gear design including the pip pin, in order to ensure the design is fit for purpose and its use supports airworthiness.	1.4.71
c. ensure the Air System Document Set includes installation and removal procedures for all in-service Red Gear in order to ensure proper fitment.	1.4.76
d. review all Joint Program Office provided Red Gear documentation, to improve the assurance and management processes, in order to support the Lightning Military Continuing Airworthiness Manager's Military Aviation Authority requirements with respect to support equipment, including Red Gear.	1.4.95
e. issue guidance on the use of the pip pin and lanyard on the A00020 and A00021 blanks which takes into account the potential for aircraft skin damage in order to standardise fitment procedures.	1.4.145
f. update the Lightning risk to life model in order to include the potential for Red Gear displacement.	1.4.149
1.5.12. **Officer Commanding Fleet Operational Sea Training should:**	
a. include digital data quarantine processes in Post Crash Management training in order to preserve evidence for subsequent investigation.	1.4.223
1.5.13. **The Lightning Chief Air Engineer should:**	

a. provide direction and guidance regarding the division of flight servicing tasks between multiple engineers in order to maintain airworthiness.	1.4.22
b. assess engineering environments in which white light is not permitted and enact appropriate measures in order to mitigate the associated risk to engineers and airworthiness.	1.4.30
c. ensure a robust and auditable Red Gear control procedure is in place in order to verify the location of Red Gear at all times.	1.4.36
d. ensure that Instruction 21 of the Joint-Service Technical Data, Aircraft Dispatch Actions, is conducted during all see-offs in order to ensure intakes are clear of Foreign Object Debris immediately prior to engine start.	1.4.63
e. implement a procedure to ensure UK created engineering orders are regularly reviewed in order to ensure they achieve the intent of all Joint-Service Technical Data instructions.	1.4.65
f. demonstrate that Lightning Force Air Engineering Orders and Work Instructions relating to safety are robust and effective in order to ensure they achieve their intent.	1.4.87
1.5.14. **The Command Flight Medical Officer should:**	
a. update the guidance in AP1269A Leaflet 6-03 Annex D in order to ensure it is applicable outside the UK, in particular on Queen Elizabeth Class deployments.	1.4.213
1.5.15. **Officer Commanding Aviation Medicine Training Wing should:**	
a. remind aircrew of the need to limit physical movement after ejection until cleared by medical personnel in order to reduce the likelihood of further injury.	1.4.215
1.5.16. **The Combat Air Force HQ SO1 Security should:**	
a. ensure that the UK deploys sufficient, qualified Government Special Access Program (SAP) Security Officers in order to fully satisfy SAP requirements relevant to the deployed task.	1.4.14

Intentionally Blank

OFFICIAL - SENSITIVE

PART 1.6

Convening Authority Comments

Intentionally Blank

Part 1.6 – CONVENING AUTHORITY COMMENTS

Introduction

1.6.1. This Service Inquiry (SI) was convened on 2 December 2021 to investigate the circumstances surrounding the loss of 617 Squadron F-35B ZM152 (BK-18) from HMS QUEEN ELIZABETH (QNLZ) during Operation FORTIS on 17 November 2021.

1.6.2. During its initial inquiries, the panel learned that an F-35B intake blank had been observed to float from the crashed aircraft shortly after it impacted the sea. The inquiry focussed on determining whether the intake blank had been in a position to cause the accident, and what effect it would have had on the performance of the aircraft. Once this was ascertained, the inquiry explored wider organisational issues to fulfil its terms of reference and understand if these issues may have contributed to the situation in which an intake blank could cause such a crash.

1.6.3. The SI panel has submitted its report to me after 11 months of detailed evidence gathering, interviews and analysis. The panel determined that there was a series of contributory factors in the control of aircraft blanks (Red Gear), and issues in the wider management of such equipment across Defence. There were also issues in the design of the equipment delivered by the Lightning programme. It went on to discover broader factors that, unless resolved, will continue to increase safety risk in forthcoming Carrier Strike Group (CSG) deployments.

Red Gear

1.6.4. The panel determined that basic procedures for the control of equipment were not fully followed prior to the accident. When the panel's recommendations are enacted, these omissions will be readily resolved. However, wider issues surrounding the use of Red Gear on the flight decks of aircraft carriers, and the use of pip pins[1], are not so easily remedied. The Lightning Force and delivery teams will be required to engage with the manufacturer to ensure that equipment is fit for purpose, and that squadrons are resourced to fulfil their tasks safely.

Security versus safety

1.6.5. The complex interaction of safety and security requirements for a fifth-generation platform must be understood and accounted for. In conducting aviation activity, our people continually balance conflicting goals. The requirement to deliver operational capability is in constant tension with satisfying safety and security conditions. The introduction of special access programmes has elevated security thresholds, which places extra strain on safety considerations.

1.6.6. The first global CSG deployment for QNLZ generated a wealth of learning opportunities. The inter-relationship between security and safety was not fully appreciated, as evidenced by the security use of Red Gear and its effects on airworthiness. In an increasingly uncertain global environment, appropriate safety-compliant security procedures must be ingrained in our culture such that they can be employed instinctively, creating capacity to conduct our operations safely.

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[1] Removable pin device that used a spring-loaded ball bearing to provide a method of temporary attachment to a suitable receptacle in the aircraft skin.

Urgent safety advice

1.6.7. During the ejection, the pilot did not inflate their life preserver. Upon examination by the RAF Centre for Aviation Medicine, it became apparent that the F-35 life preserver had failed in a similar manner to that witnessed in the Hawk accident earlier the same year. Having issued urgent safety advice for both failures, the similarities bear scrutiny. Two similar failures in any other piece of equipment would draw our attention, but the critical nature of safety equipment such as this demands resolution of the root cause. I am pleased with the recommendation made by the panel and Defence Equipment and Support's proactive engagement with the Original Equipment Manufacturer.

The Lightning Force

1.6.8. In exploring the wider issues surrounding what contributed to the crash, the panel found that insufficient workforce, training shortfalls and inexperience within the Lightning Force directly influenced the safety of engineering output. Each of these can be addressed individually, but the common linking factor is the 'small force effect'. The Lightning Force has not yet reached the critical mass at which experience can be retained through posting cycles whilst still offering attractive job opportunities. The squadrons appear to be unable to support each other's deployments without infringing on their own operations, and force growth cannot be maintained while front line squadrons are deployed. Until critical mass is reached, Defence must recognise the trade-offs between readiness, growth and safety.

Conclusion

1.6.9. I am content that this accident has been investigated, analysed, and reported accurately and rigorously. The immediate safety engineering issues which gave rise to a scenario in which an intake blank could remain inside an F-35 and subsequently cause it to crash on take-off were comprehensively examined. A broader cross section of engineering and safety focussed security matters across Defence, as well as in Defence Equipment and Support and the F-35 Joint Program Office were identified, and recommendations proposed.

1.6.10. In line with its terms of reference, the SI panel only considered cultural issues that directly affected the incident. I note that, despite pre-briefing the respective ship/air interface duty holders of this inquiry's likely recommendations ahead of the 2022 CSG deployment, there have been 2 subsequent pins related incidents which could have had a serious outcome.

1.6.11. I also note that the Director Military Aviation Authority (DMAA) has observed trends within the Lightning Force regarding failure to follow process (F2FP). F2FP has been cited as a factor in 15 percent of all Defence Aviation Safety Occurrence Reports across the Defence Aviation Environment between 2017–22. This figure has risen annually to 20 percent within the F-35 community. The two recent undercarriage pins related incidents also highlight potential issues with F2FP. Accordingly, and as part of a programmed HQ Air Command (1 Group) audit, I have asked DMAA to conduct a risk-based assurance audit of the elements of the Lightning Force based at RAF Maraham. The Lightning Force will be subject to additional assurance activity as part of a programmed Director Force Generation audit in Autumn 2023.

1.6.12. With the pace of F-35 operations increasing, and the UK aspiring to continue to expand its CSG deployments, this accident delivers a timely reminder to take stock and ensure we are giving the Lightning Force the best chance of success.

S J Shell CB OBE MA
Air Marshal
Director General Defence Safety Authority

