Defence
Safety
Authority

Service Inquiry

Loss of Watchkeeper (WK043) Unmanned Air Vehicle over Cardigan Bay in West Wales

24 Mar 17

Defence Safety
Authority

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PART 1.1

Covering Note

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PART 1.1 – COVERING NOTE

DG DSA

SERVICE INQUIRY INVESTIGATION INTO ACCIDENT INVOLVING A WATCHKEEPER AT CARDIGAN BAY ON 24 MAR 17

1. The Service Inquiry Panel assembled at Main Building, London, on 07 Apr 17 by order of the DG DSA for the purpose of investigating the accident involving Watchkeeper WK043 on 24 Mar 17 and to make recommendations in order to prevent recurrence. 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 Part 1.2 Convening Orders, TORs, Glossary & WK Overview Part 1.3 Narrative of Events Part 1.4 Findings Part 1.5 Recommendations Part 1.6 Convening Authority Comments	Part 2 RECORD OF PROCEEDINGS Part 2.1 Diary of Events Part 2.2 List of Witnesses Part 2.3 Witnesses 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

[Signature]

[redacted]
Sqn Ldr
President
WK043 SI

MEMBERS

[Signature]

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Maj
Ops Member
WK043 SI

[Signature]

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CPO
Engineering Member
WK043 SI

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PART 1.2

Defence Safety Authority

Service Inquiry Convening Order

7 Apr 17

SI President
SI Members

Hd Defence AIB
DSA Legad

Copy to:

PS/SofS
MA/Min(AF)
PS/Min(DP)
PS/Min(DVRP)
PS/Perm Sec

DPSO/CDS
MA/VCDS
NA/CNS
MA/CGS
PSO/CAS

PSO/Comd JFC
MA/CFA
MA/JHC Comd
Dir DDC
WKF HQ Comd

PS/SofS
MA/Min(AF)
PS/Min(DP)
PS/Min(DVRP)
PS/PUS
DPSO/CDS

MA/VCDS
NA/CNS
MA/CGS
PSO/CAS
MA/Comd JFC
MA/CFA

MA/Dir MAA
MA/GOC 1 (UK) Div
Dir DDC
CO 3 SCOTS

DSA DG/SI/04/17 – CONVENING ORDER FOR THE SERVICE INQUIRY INTO THE LOSS OF WATCHKEEPER UNMANNED AIR VEHICLE (UAV) (WK 043) THAT OCCURRED OVER CARDIGAN BAY ON 24 MAR 17

1. In accordance with Section 343 of Armed Forces Act 2006 and in accordance with 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 recurrence.

3. The SI Panel will formally convene at 1100L on Friday 7 April 2017 at Ministry of Defence Main Building, Whitehall, London.

4. The SI Panel comprises:

President: **Squadron Leader [redacted] RAF**

Members: **Major [redacted] AAC**
Chief Petty Officer [redacted] RN

5. The legal advisor to the SI is **Major** [redacted] (DSA LEGAD) and technical investigation/inquiry support is to be provided by the Defence Accident Investigation Branch (Defence AIB).

6. 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.

7. Attendance at the SI by advisors/observers is limited to the following:

Head Defence AIB – Unrestricted Attendance.

Defence AIB investigators in their capacity as advisors to the SI Panel – Unrestricted Attendance.

8. The SI Panel will work initially from the Defence AIB facilities at Farnborough. Permanent working accommodation, equipment and assistance suitable for the nature and duration of the SI will be requested by the SI President in due course.

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

Original Signed

Sir R F Garwood
Air Mshl
DG DSA – Convening Authority

Annex:

A. Terms of Reference for the SI into the loss of Watchkeeper UAV (WK043) that occurred over Cardigan Bay on 24 Mar 17.

Annex A To
DSA DG/SI/04/17 Convening Order
Dated 7 Apr 17

TERMS OF REFERENCE FOR THE SI INTO THE LOSS OF WATCHKEEPER UNMANNED AIR VEHICLE (UAV) (WK043) THAT OCCURRED OVER CARDIGAN BAY ON 24 MAR 17

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

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

b. Establish whether there are any significant similarities to the causes identified in the loss of WK031 and/or WK006, but not to further investigate known issues.

c. Examine the policies, orders and instructions applicable to this activity and whether they were appropriate and complied with, specifically:

i. Those associated with the conduct of conversion to type training at West Wales Airport.

d. Determine the state of serviceability of relevant equipment.

e. Establish the level of training, relevant competencies, qualifications, currency and supervision of the individuals involved in the activity.

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

g. Report and make appropriate recommendations to DG DSA.

2. If at any stage the Panel discover something they perceive to be a <u>continuing hazard</u> presenting a risk to the safety of personnel or equipment, the President should alert DG DSA without delay; in order to initiate remedial actions immediately. Consideration should also be given to raising an Urgent Safety Advice note.

3. You are to ensure that any material provided to the Inquiry by any foreign state, is properly identified as such, and is marked and handled in accordance with MOD security guidance. This material continues to belong to those nations throughout the SI process. Before the SI report is released to a third party, authorization should be sought from the relevant authorities in those nations to release, whether in full or redacted form, any of their material included in the SI report, or amongst the documents supporting it. The relevant NATO European Policy or International Policy and Plans team should be informed early when dealing with any other foreign state material.

4. During the course of your investigations, should you identify a potential conflict of interest between the Convening Authority and the Service Inquiry, you are to pause work and take advice from your DSA Legal Advisor and DG DSA.

GLOSSARY

Acronym / Abbreviation

NOs	
47 RA	47 Regiment Royal Artillery
A	
AAvn Stds	Army Aviation Standards
ABU	Airborne Beacon Unit
ADF	Acceptable Deferred Fault
ADH	Aviation Duty Holder
ADS	Air-System Document Set
ADT	Air Data Terminal
ADU	Air Data Unit
AFS	After Flight Service
AM(CAw)	Accountable Manager Continuing Airworthiness
AM(MF)	Accountable Manager Military Flying
AMSL	Above Mean Sea Level
AI	Aircrew Instructor
AIB	Ascension Island Base
AO	Authorising Officer
APC	Application Computer
APCM	Aircraft Post Crash Management
Army HQ CAP CS	Army Headquarters Capability Combat Support
ALARP	As Low As Reasonable Practicable
ASC	Air Safety Culture
ASMP	Air Safety Management Plan
ASMS	Air Safety Management System
ASRA	Air Safety Risk Assessment
ASSC	Air System Safety Case
ASSWG	Air System Safety Working Group
ATOL	Automatic Take-off and Landing
ATOLS	Automatic Take-off and Landing System
ATZ	Air Traffic Zone
Auth Sheet	Authorisation Sheet
AV	Air Vehicle
AVGAS	Aviation Gasoline
B	
BDN	Boscombe Down
BF	Before Flight
BFS	Before Flight Service
BIT	Built In Test (refers to codes)
C	
CAA	Civil Aviation Authority
CAB	Competency Assessment Board
CAE	Chief Air Engineer
CAME	Continuing Airworthiness Management Exposition

CAMO	Continuing Airworthiness Management Organisation
CAPH	Continuing Airworthiness Post Holder
C to I	Competent to Instruct
CAR	Corrective Action Report
CAS	Calculated Airspeed
Cdrs	Commanders
Cdr JHC	Commander Joint Helicopter Command
CFAOS	Contractor Flying Approved Organisation Scheme
CFOE	Contractor Flying Organisation Exposition
CPS	Crank Position Sensor
CPU	Central Processing Unit
C of C	Certificates of Competence
Comd WKF	Commander Watchkeeper Force
CQT	Certificate of Qualification on Type
CRM	Crew Resource Management
CSALMO	Chief Salvage and Mooring Officer
CS	Client Server
CTM	Conversion to Mark
CTPH	Crew Training Post Holder
CTT	Conversion to Type (Training)
CVR	Cockpit Voice Recording

D

DA	Design Authority
DADS	Defence Aircrew Documentation Specifications
DAIB	Defence Accident Investigation Branch
DAOS	Design Approved Organisation Scheme
DASOR	Defence Aviation Safety Occurrence Report
DCFO	Defence Contractor Flying Organisation
DDH	Delivery Duty Holder
DE&S	Defence Equipment and Support
DH	Duty Holder
DM	Data Module
DO	Design Organisation
DMIS	Development, Manufacture and Initial Support
DQAFF	Defence Quality Assurance Field Force

E

EAT	External Air Temperature
ECU	Engine Control Unit
EFI	Electronic Fuel Injection
EGRC	Engine Ground Running Certificate
EMC	Electromagnetic Compatibility Configuration
EMI	Electromagnetic interference
EMS	Error Management System
EOP	Electro-Optic Payload
EOP/IR	Electro-Optic Payload/Infrared
ERL	Emergency Recovery Locations
ERP	Emergency Recovery Point
ES2	Equipment Standard 2
ESL	Elbit Systems Limited

F	
FAC	Flight Authorisation Certificate
FCS	Flight Control Software
FELA	Flight Execution Log Author
FLAC	Flight Authorisers Course
FLM	Flight Line Manger
FLIR	Forward Looking Infrared
FLRC	Flight Line Reference Cards
FLSCU	Flight Line Section Command Unit
FM	Frequency Modulated
FMV	Full Motion Video
FOB	Flying Order Book
FOO	Flight Operations Organisation
FOPH	Flight Operations Post Holder
FRC	Flight Reference Cards
FRF	Flying Record Folder
FRS	Functional Requirements Specification
FRT	Flight Real Time
FSC	Flying Supervisors Course
FTT	Full Task Trainer
G	
GBU	Ground Beacon Unit
GCMS	Gas Chromatography Mass Spectrometry
GCS	Ground Control Station
GCU	Generator Control Unit
GDT	Ground Data Terminal
GE	Ground Elements
GFCC	Ground Flight Control Computer
GMCC	Ground Mission Control Computer
GMTI	Ground Moving Target Indication
GPS	Global Positioning System
GPS/INS	Global Positioning System /Inertial Navigation System
GRU	Ground Radar Unit
GSE	Ground System Elements
GTOL	GPS Take-off and landing
H	
HCI	Human Computer Interface
Hd UAS	Head of Unmanned Air Systems
HF	Human Factors
HS	Handling Squadron
I	
IETP	Interactive Electronic Technical Publication
IFF	Identify Friend or Foe
IMC	Instrument Meteorological Conditions
INS	Inertial Navigation System
INS/GPS	Inertial Navigation System/Global Positioning System
iRtS	initial Release to Service

ISA	Independent Safety Advisor
ISTAR	Intelligence, Surveillance, Target Acquisition and Reconnaissance
J	
JHC	Joint Helicopter Command
L	
LLP	Lost Link Procedure
LMAR	Lightweight Multimode Air Radio
LRDC	Launch and Recovery Detachment Commander
L&R	Launch and Recovery
LRU	Line Replaceable Unit
LSS	Land Site Survey
LS-S	Laser Sub-System
LWI	Local Work Instruction
M	
MAA	Military Aviation Authority
MAA-RA	Military Aviation Authority – Regulatory Article
MAOS	Military Approved Organisation Scheme
MAP	Military Airworthiness Publication
MARC	Military Airworthiness Review Certificate
Met	Meteorology
MFTP	Military Flight Test Permit
MFL	Maintainer Fault List
MOD	Ministry of Defence
MOE	Maintenance Organisation Exposition
MINS	Minutes
Mil CAMO	Military Continuing Airworthiness Management Organisation
Mil CAM	Military Continuing Airworthiness Manager
MRCOA	Military Registered Contractor Operated Aircraft
MRP	Military Regulation Publications
N	
NAS	Naval Air Squadron
NBDL	Narrow Band Data Link
O	
OCU	Operational Conversion Unit
ODH	Operating Duty Holder
OEM	Original Equipment Manufacturer
OFT	Operational Field Training
OJT	On Job Training
OSI	Occurrence Safety Investigation
P	
P1	The Handling Pilot of the Unmanned Aircraft
Panel	The Service Inquiry Panel convened to investigate the loss of WK043
PATE	Portable Aircraft Test Equipment

PCDU	Power Control Distribution Unit
PCM	Post-Crash Management
PCMO	Prime Contractor Management Organisation
PCMIO	Post-Crash Management Incident Officer
PDS	Power Distribution System
P2	Payload Operator
PR	Problem Report
R	
RA	Royal Artillery
RAF	Royal Air Force
RAFCAM	Royal Air Force Centre of Aviation Medicine
REME	Royal Electrical and Mechanical Engineers
RFC	Reversionary Flight Control
RPM	Revolutions Per Minute
RSA	Royal School of Artillery
RtL	Risk to Life
RtS	Release to Service
RVTIU	Remote Viewing Terminal Interface Unit
RWY	Runway
S	
SA	Safety Advice
SAR	Synthetic Aperture Radar
SATCO	Senior Air Traffic Control Officer
SME	Subject Matter Expert
SI	Service Inquiry
SIL	Safety Integrity Level
SOP	Standard Operating Procedure
SQEP	Suitably Qualified and Experienced Personnel
SRO	Senior Responsible Owner
STBY	Standby
Sys Eng	System Engineering
T	
TAA	Type Airworthiness Authority
TAF	Terminal Aerodrome Forecast
T&E	Test & Evaluation
TEPH	Test and Evaluation Post Holder
TOR	Terms of Reference
TNA	Training Needs Analysis
TPS	Throttle Position Sensor
TQ	Technical Query
TRF	Training Record Folder
TUAS	Tactical Unmanned Air System
U	
UA	Unmanned Aircraft (formerly referred to as UAV)
UAS	Unmanned Air System
UAST	Unmanned Air Systems Team
UAV	Unmanned Air Vehicle

UAV Cdr	Unmanned Air Vehicle Commander
UFR	Unsatisfactory Feature Report
UTacS	UAV Tactical System Ltd

V

VHF	Very High Frequency
VMS	Vehicle Management System
VMSC	Vehicle Management System Computer
V/UHF	Very/Ultra High Frequency

W

WAP	Whereabouts Plan
WBDL	Wide Band Data Link
WCA	Warnings Cautions Advisories
WK Fce Cdr	Watchkeeper Force Commander
WK Fce	Watchkeeper Force
WK	Watchkeeper
WoW	Weight on Wheels
WOT	Wide Open Throttle
WTF	Watchkeeper Training Facility
WWA	West Wales Airport

DEFINITION OF TERMS

Term	Explanation
Air Safety	Is the state of freedom from unacceptable risk of injury to persons, or damage, throughout the life cycle of military air systems. Its purview extends across all Defence Lines of Development and includes Airworthiness, Flight Safety, Policy, Regulation and the apportionment of Resources. It does not address survivability in a hostile environment.
Air Safety Management System	An SMS specific to aviation, including activities such as the operation, control and maintenance of aircraft.
Aircraft Document Set	The documents that have a prime airworthiness function for each aircraft type. They include the Release To Service (RTS), Aircraft Maintenance Manual (AMM), Operating Data Manual(ODM), Flight Reference Cards (FRCs), Support Policy Statement, Engineering Air Publications (including the Flight Test Schedule (FTS)) and the Statement of Operating Intent and Usage(SOIU). The documents comprising the ADS may be held electronically.
Aircraft Post Crash Management	Those activities carried out at an aircraft accident site which encompass the preservation of evidence, Health and Safety precautions, Corporate Communication and those activities undertaken to restore the accident site to a satisfactory condition
Airworthiness	Is the ability of an aircraft or other airborne equipment or system to be operated in flight and on the ground without significant hazard to aircrew, ground crew, passengers or to third parties; it is a technical attribute of materiel throughout its lifecycle.
Approved Maintenance Organization	A contractor-run organization that maintains aircraft and/or aircraft components that is approved by the MAA under the MAOS.
Audit	Systematic, independent and documented process for obtaining and evaluating evidence objectively to determine the extent to which audit criteria are fulfilled.

Term	Explanation
Authorisation	Approval given to an individual and recorded in an appropriate record. Authorisation may be given to specified individuals, or may be implicit with the responsibilities of a specific rank or appointment. Authorisation is granted by individuals empowered to do so.
Built-In Test	A Built-In Test (BIT) is used to assess the serviceability of individual system components; each type of failure is assigned a code to assist maintainers in isolating the fault and assessing serviceability.
Competency	The ability to undertake responsibilities and to perform activities with regard to specific standards to meet the authorized mission or task.
Configuration Management	A key discipline in the through-life management of defence materiel. It is the cornerstone of aircraft and equipment management safety, ensuring that the various parts of a complete product or system remain compatible, including spares, test equipment, tools, ancillaries, software and support documentation.
Defence Equipment and Support	Parent organisation for the management of procurement and support for equipment in the MOD. Individual or groups of equipment are managed by Project Teams within this organisation.
Design Organization	The organization appointed by the PTL to be responsible for the design or design change of an airborne system or its associated equipment, and for certifying the airworthiness of the design by issue of a Certificate of Design. The authority for acceptance of a design or any design change remains with the PTL.
Defence Systems Approach to Training	Defence Systems Approach to Training (DSAT) Quality Standard (QS) sets out the strategic principles to be applied to all individual training provided by, or on behalf of, the Ministry of Defence.
Flight Reference Cards	Cards, or electronic presentations, designed to be used by aircrew in flight, which contain checks and drills for normal and emergency operation of the aircraft and its systems.

Term	Explanation
Human Factor	The organization established to advise the RN, Army and the RAF on the normal and emergency handling of in-service aircraft. Where authorised by the TAA, OC HS is responsible for Flight Test Schedules (FTSs), Flight Reference Cards (FRCs), Flight Crew Checklists (FCCs), Mission Operating Procedures Cards (MOPCs) and Aircrew Manuals (AMs) including Pilot's Notes (PNs) and Minimum Equipment Lists (MELs) where required.
Incident	An Air Safety related occurrence which has not resulted in an accident but has resulted in any or all of the following conditions; an aircraft sustaining category 1, 2 or 3 damage; a person receiving a reportable over three day injury; an event which compromises Air Safety.
Interactive Electronic Technical Publication	Technical information (TI) comprising/containing data modules and associated illustrations extracted from a common source database, optimally arranged and formatted for interactive screen presentation to the end user on an electronic display system.
Line Replacement Unit	Any readily accessible air vehicle unit normally consisting of sub-assemblies or modules mounted together and designed for ease of replacement normally at the Service operating unit
Medical Certificate	An official written or printed statement detailing the medical standard achieved by aircrew or RPAS operator during their annual medical. This may take the form of a signature in the Flying Logbook or in the individual's medical records.
Military Aviation Authority	The Military Aviation Authority (MAA), established on 1 April 2010, provides the regulatory framework, certification and approvals for the acquisition, operation and continued airworthiness of air systems within the Defence aviation environment. It has full oversight of all Defence aviation activity and, through independent audit, provides assurance to the Secretary of State for Defence that the highest standards of aviation safety and airworthiness are maintained in the conduct of military aviation. It brings together the regulatory functions previously carried out by the Directorate of Aviation Regulation and Safety (DARS), Defence Airspace and Air Traffic Management (DAATM), the Air Systems Group and the Military Flight Test Regulator (MFTR).

Term	Explanation
On-the-Job-Training	That training which bridges the gap between training received to meet the training objectives and the operational requirement.
Operating Data Manual	A manual giving definitive performance data on the aircraft concerned, for aspects such as take-off, climb, manoeuvre, descent and landing. This information is normally presented in the form of performance graphs, which are used by aircrew in planning the flight concerned. The ODM is a part of the Aircraft Document Set for the aircraft.
QinetiQ	Privatized aspects of the military aviation evaluation and research establishment formerly known as the Defence Evaluation and Research Agency (DERA).
Qualified Aircrew Instructor	A qualified aircrew instructor (Qualified AI) who is authorized to instruct and certify aircrew to operate aircraft within the MAE.
Release to Service	The release document that authorizes Service flying on behalf of the Service Chief of Staff. The RTS refers to the Safety Assessment documentation for the aircraft or equipment, including the limitations and aircraft description, and defines the as-flown standard of the aircraft. For legacy aircraft that have yet to move to the Generic Aircraft Release Process (GARP), it also contains Service Deviations (SD) for the aircraft. The limitations of the RTS are the definitive limits for the aircraft in Service-regulated flying. Release to Service Authority (RTSA) is the authority that issues the RTS.
Risk to Life	RtL addresses fatality and injury, but excludes damage to assets or the environment where no harm results. People should only be exposed to risk of harm where some defined benefit is expected and where the risks are adequately controlled.
Safety Integrity Level	Safety integrity level (SIL) a relative level of risk-reduction provided by a safety function, or to specify a target level of risk reduction.
Scheduled Maintenance	That preventive maintenance undertaken at regular predetermined intervals to keep an aircraft or other item of equipment in a sound overall condition and to minimize the amount of corrective maintenance and other day-to-day attention required.
Subject Matter Expert	The individual or organization most directly concerned with a specific subject. Whilst the sponsor of the subject remains

Term	Explanation
	ultimately accountable for the subject, an SME is responsible for the completeness and technical accuracy of the information they provide and for notifying the sponsor when the information changes or requires amendment. The SME may appoint additional SMEs to assist in providing information.
System Integrity	The ability of an aircraft system, designed, certified and maintained to defined standards, to retain, at an appropriate level of safety, its function, within defined limits and without undue frequency of failure or adverse effect on other systems, throughout the aircraft's service life while operating to the Aircraft Document Set.
Type Airworthiness Authority	The Type Airworthiness Authority is the individual, often an aircraft TL, who on behalf of the Secretary of State for Defence, oversees the airworthiness of specified air system types. As the TAA the TL responsibilities are as laid down and agreed in their Letter of Airworthiness Authority from their respective Director.
Watchkeeper Flight Modes	Fly to Coordinate: The AV will fly directly to the requested location (position and altitude), climbing or descending if required. Route: AV will fly from waypoint to waypoint on the active route, climbing and descending as required by route waypoint properties. Service: AV is under PATE control while on the ground. The responsibility for the aircraft lies with the launch and recovery crew. Standby: AV is under GCS Control while on the ground. The responsibility for the aircraft lies with the GCS operators and all GCS command and control functionality is available. The mode can be changed from Standby to Take-off when the VMSC receives a 'Take-off' command from the GCS, or changed to service on connection of the PATE umbilical/switching of the switched umbilical. Take off: The AV will accelerate under full throttle, rotate, and climb towards the go-around point on the active take-off

Term	Explanation
	route. Take-off is also commanded to initiate a throttle check while the aircraft is still in its chocks at the take-off start position.

WATCHKEEPER OVERVIEW

1.2.1. Introduction. This section gives an overview of the Watchkeeper (WK) programme and system, and a more detailed description of specific systems relevant to the incident. The information provided represents the SI Panel's understanding of the system and is based on available documentation as well as through discussions and interviews with personnel from DE&S Unmanned Air Systems Team (UAST), Thales UK (Thales), WK Training Facility (WTF) and the WK Force.

1.2.2. WK Capability Overview. WK is a system comprised of an unmanned Air Vehicle (AV) fitted with sensors, connected via data-links to a Ground Control Station (GCS). WK is designed to deliver a flexible, 24-hour, low visibility (including poor weather) Intelligence, Surveillance, Target Acquisition and Reconnaissance (ISTAR) capability. WK is employed primarily within the Land environment and contributes to Information Superiority.

1.2.3. WK Procurement Overview. In 2005, Thales was awarded the contract for the development, manufacture and initial support phases of the WK programme. Thales was able to undertake the development flying of WK aircraft as they had been approved by the Military Aviation Authority (MAA) under the Contractor Flying Approved Organisation Scheme (CFAOS) and its predecessor scheme(s). The system was originally intended to reach Initial Operating Capability by Jun 2010 and Full Operating Capability in 2013. In Sep 2013, the MAA provided a Statement of Type Design Assurance for WK, confirming its airworthiness.

1.2.4. WK Programme Organisation. Thales is the Prime Contractor Management Organisation (PCMO) and Design Authority (DA) for the WK system. As PCMO, Thales leads an industry team consisting of Cubic Corporation (data-links), Elbit Systems Limited (ESL) (UA air vehicles), Marshall SV (ground station shelters and ground vehicles), Altran (programme safety), and UAV Engines Ltd (AV engines). UAV Tactical Systems Ltd (UTacS) is a joint venture company that was created by Thales and ESL to enable technology transfer, manufacture and UK support. UTacS also provide crews and maintenance personnel for WK air operations at West Wales Airport (WWA). Figure 1 depicts the relationships between the organisations.

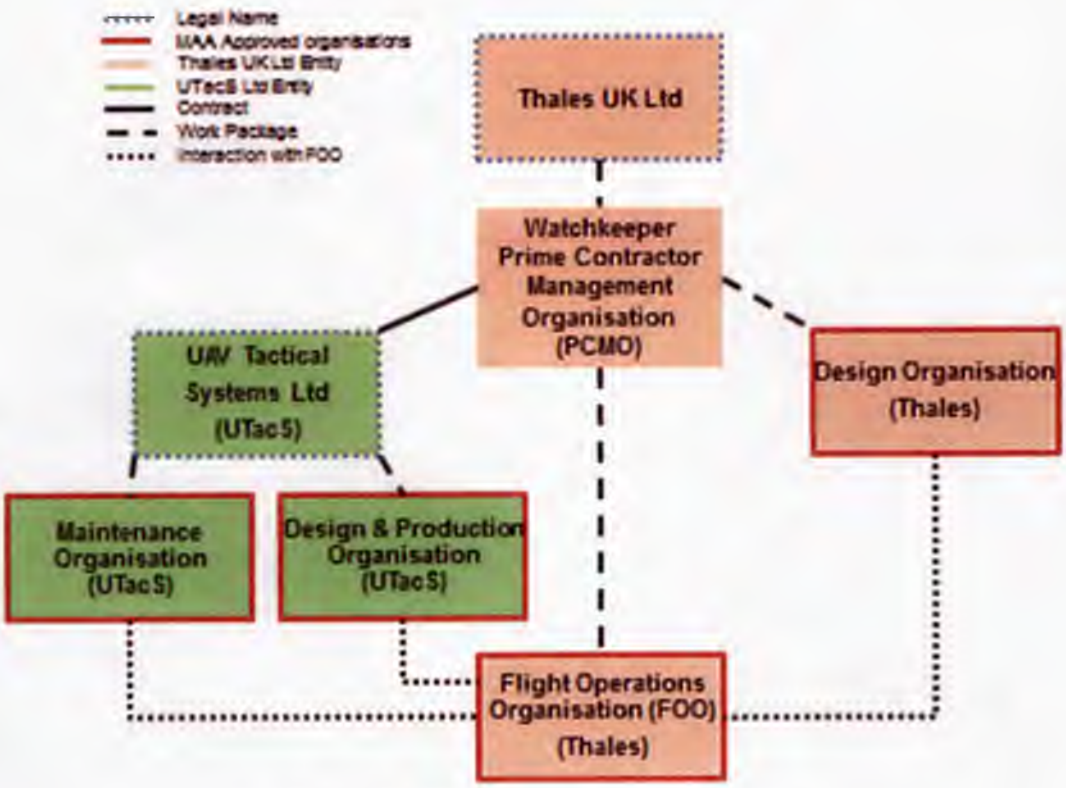

Figure 1 – WK Programme Organisation.

1.2.5. WK air operations have been conducted at WWA since Apr 2010 under the Thales Flight Operations Organisation (FOO). Primarily a Test and Evaluation (T&E) organisation, Thales created the FOO which would provide the overarching organisation and an equivalent Duty Holder (DH) chain along with the operations personnel supported by UTacS Ltd. UTacS provide both the Maintenance Organisation and a Design and Production Organisation, ergo providing both the engineering support and the design production support. Thales also provide an equivalent to the military Delivery Duty Holder (DDH) construct through the Accountable Manager/ Military Flying (AM(MF). All flying at WWA is conducted under a Military Flight Test Permit (MFTP) that outlines what flying is permissible at WWA, and if there are any special conditions imposed on the flying activity.

1.2.6. The FOO is set up to undertake flight operations of the WK AV on behalf of the Defence Equipment and Support (DE&S) Unmanned Air System Team (UAST) for the British Army. The FOO has a number of post holders who are legally responsible and are named individuals within the management structure of the MAA approved CFAOS. Figure 2 outlines those key posts and who is either accountable, responsible or a specialist – all these posts are named individuals within the organisation.

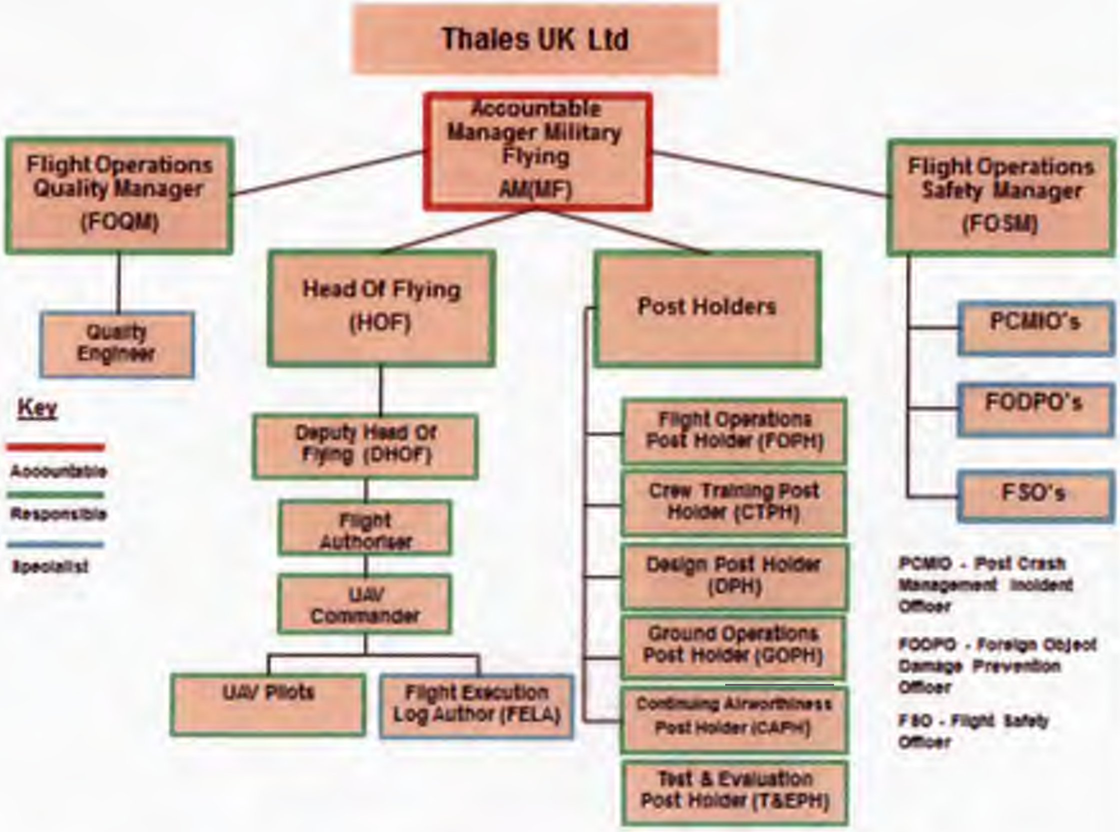

Figure 2 – Roles of the FOO personnel showing responsibility to the AM(MF).

1.2.7. WK Military Flying. On 28 Feb 2014 the WK platform was issued with its initial Release to Service (iRtS) and the Royal Artillery (RA) commenced flying operations at Boscombe Down (BDN). In Aug 2014, WK was deployed to Afghanistan in support of Operation HERRICK, whilst Thales continued to conduct T&E flying at WWA. In Mar 2015, on return from Afghanistan the Army re-commenced WK flying operations from BDN and flying continued until 2 Nov 2015. A programme was then put in place for the RA to fly WK at Ascension Island Base (AIB), to allow military personnel to convert onto the Operational Conversion Unit (OCU) build standard WK allocated to the Army. T&E flying continued with the development of Equipment Standard 2 (ES2) aircraft under the FOO at WWA.

1.2.8. The AIB training took place using a mix of military, Thales and UTacS instructors and allowed the Army to build a cohort of qualified and experienced WK Aircrew Instructors, Pilots and Launch & Recovery (L&R) crews that were trained on the OCU standard WK aircraft. This training concluded at AIB on 30 Mar 2017.

1.2.9. The DDH for Military WK Flying is Commander Watchkeeper Force (Comd WKF) and the Operational Duty Holder (ODH) is Commander Joint Helicopter Command (Cdr JHC). The set-up of Industry WK flying closely mirrors that of the Military WK flying – both have a clearly defined structure for operational responsibilities and for maintenance responsibilities.

WATCHKEEPER SYSTEM DESCRIPTION

1.2.10. Introduction. This section provides an overview of the WK system as described in paragraph 1.2.2 relevant sub-systems will be examined in more detail.

1.2.11. System Overview. WK is an Unmanned Air System (UAS), which provides a network enabled ISTAR capability. The WK consists of a number of separate system components and support equipment that enable pre-flight preparation, launch, operation and recovery of the AV, controlled from a Ground Control Station (GCS). There are also associated ground elements to enable transportation, storage and maintenance. The major UAS components can be broken down as follows:

a. Air Vehicle (AV)

b. Ground Control Station (GCS).

c. Ground Data Terminal (GDT).

d. Automatic Take-Off and Landing System (ATOLS) comprising of:

i. Ground Beacon Unit (GBU).

ii. Ground Radar Unit (GRU).

iii. Airborne Beacon Unit (ABU).

e. Arrestor System.

f. Portable Aircraft Test Equipment (PATE).

Air Vehicle

1.2.12. The AV is the airborne element of the WK ISTAR capability. Externally it comprises a cylindrical fuselage, main wing, V-Tails, rear-mounted engine and propeller, a tricycle undercarriage and an Electro-Optic Payload (EOP) and a Radar Payload, as shown in Figure 3.

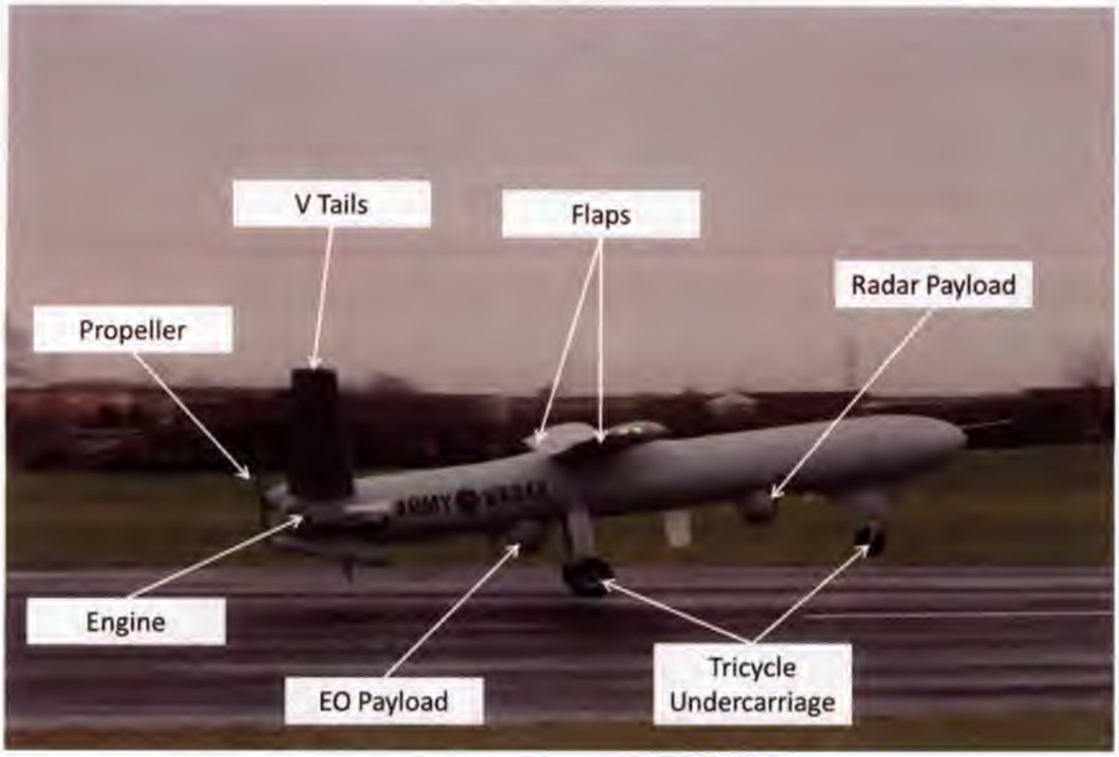

Figure 3 – Watchkeeper AV

1.2.13. The AV has a length of 6.50m, a wingspan of 10.95m and an overall height of 2.18m. It has a maximum all up mass of 500kg. Further details of the AV are as follows:

a. Fuselage. The fuselage is a carbon composite monocoque design. The majority of the avionic components are packaged inside the fuselage, with the payloads, undercarriage and antennae protruding outside.

b. Undercarriage. The AV has a non-retractable tricycle undercarriage and is able to take-off and land on paved and semi-prepared airstrips. It has a steerable nose landing gear assembly. There are no wheel brakes; on landing, the AV is halted by a fixed arrestor hook system.

c. Propulsion, Fuel, Lubrication and Cooling System. The AV is powered by a Wankel rotary engine, produced by UAV Engines Ltd in the UK, which runs on aviation gasoline (AVGAS) and drives a pusher type propeller. The fuel system comprises an integral fuel tank and collector tank designed to ensure that the engine will not run dry at low fuel levels or whilst manoeuvring. The engine is water cooled and has a total loss oil system, using Mobil Pegasus 1 oil, which is indirectly heated by the coolant system.

d. Payloads. The AV can be fitted with two payloads as optional role equipment. An Electro-Optical Payload (EOP) and Synthetic Aperture RADAR Ground Moving Target Indicating (SAR GMTI)/ (RADAR payload).

e. Vehicle Management System (VMS). The VMS is an all-encompassing term used to describe the essential electronic installations within the AV and the associated top level tasks it carries out. It is an amalgamation of Line Replacement Units (LRUs) designed to fully prioritise and task the automated AV in providing monitoring and control, automated flight, instrument sensor feedback and navigation throughout all phases of flight. The VMS has full authoritative control of the AV flying controls, utilising information derived from the AV navigation instrumentation and sensors. The operators in the GCS, therefore, only have indirect control of the flight controls via commands sent to the AV. The VMS monitors and controls the various systems on the AV where real time information is relayed via the data links to the GCS for display on the client server Human Computer Interface (HCI).

f. The Vehicle Management System Computer (VMSC). The VMSC is the AV central computer, which directly controls the VMS. It is mounted in the forward section of the fuselage. The VMSC is a single LRU; it houses dual redundant computers primarily responsible for controlling the VMS. An in-built VMS monitor compares the health status of the two computers (Side A and B) and will determine which side to utilise, with Side A having primacy in normal operation. The VMSC is a software-based system, which interfaces with other LRUs in the VMS to monitor and control the AV. A simplified diagram of VMSC interfaces is shown in Figure 4. The VMSC responds to the pre-programmed flight mission plan and reacts dynamically to real time commands received from the GCS via the data links. It is designed to automate routine tasks, through all phases of flight from engine start, take off, landing and engine cut.

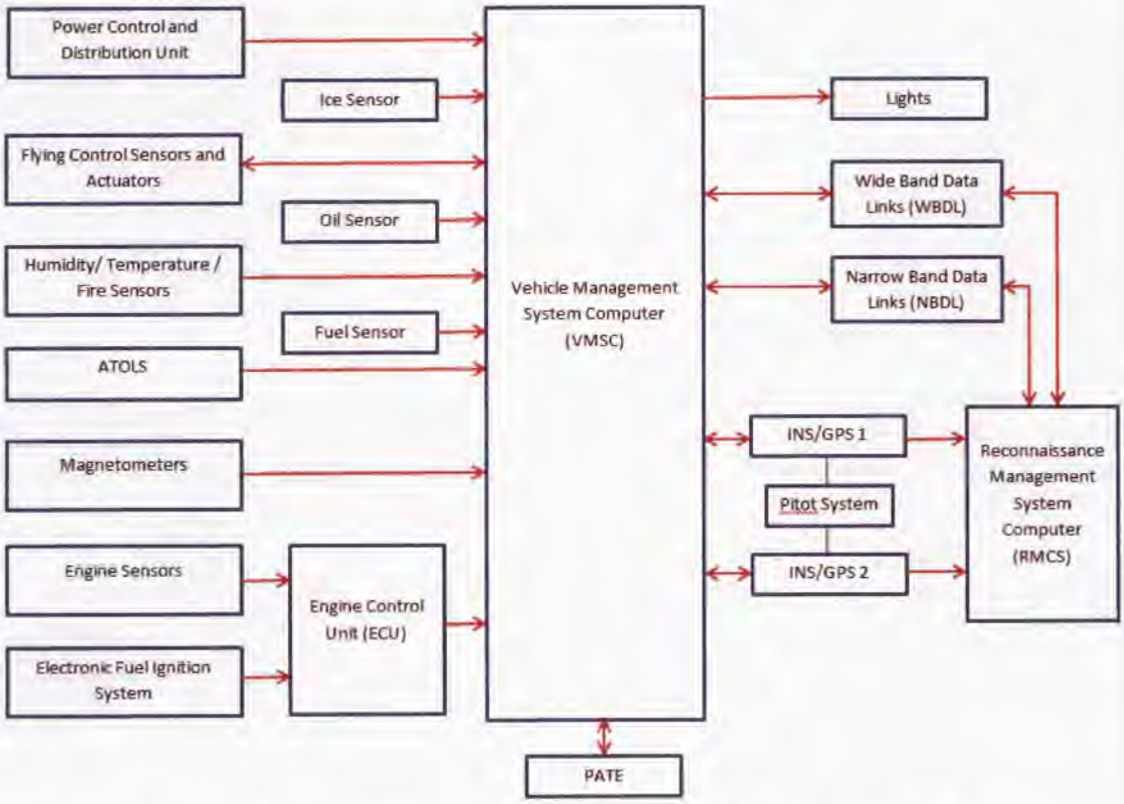

Figure 4 – A simplified block diagram of the VMSC interfaces.

1.2.14. VMSC Function. The VMSC controls all aspects of AV flight dynamics, power, propulsion and navigation. It is a flight critical system that contains the entire flight control software. Its primary role is to calculate all changes in atmospherics and aerodynamics to maintain the AV in a safe and controlled flight attitude by applying the correct control surface error corrections. The software within the VMSC is programmed to control power switching, redundancy, failure management and status monitoring for all LRUs. The VMSC contains all of the logic, algorithms and coding designed to calculate flight paths, loiters, take-offs and landings, glide slopes and predicted landing points and utilises the integral Flight Control Software (FCS) to achieve this. The VMSC software is designated as Safety Integrity Level (SIL) 3[1].

1.2.15. The VMSC is designed with redundancy; it has 2 sides, Side A and Side B. Side B (the redundant side) shadows Side A (the primary active side). Every input from the VMS is passed to each side and processed simultaneously; however, only the output from the active side passes back to the various VMS LRUs. Ergo only the controller outputs will control the AV (normally Side A). Both sides are monitored with a firmware circuit, which assess performance and determines whether to swap from the active controller (Side A) to the backup (Side B) when a problem is detected. Should both sides fail, further redundancy is provided by the Reversionary Flight Control (RFC), which will attempt to fly the AV straight and level until a VMS reset is successful.

Functional Description of Key Line Replaceable Units

1.2.16. In order to understand the implications of all the data, and to assess what caused the accident, a basic understanding of the functions of the various LRUs relating to the VMSC, electrical power distribution and engine is required (see Figure 4).

1.2.17. Engine Function. The engine drives a propeller to generate thrust for take-off and powered flight. The engine also drives the water pump, oil pump and the cooling fan. The engine is started with a starter alternator, which then provides electrical power for operating all of the AV systems. The engine is controlled by an Engine Control Unit (ECU) which controls the Electronic Fuel Injection (EFI).

1.2.18. Engine Control Unit Function. The Engine Control Unit (ECU) receives data from engine sensors, which it interprets and compares to demand from the VMSC engine maps. The ECU then adjusts the fuel quantity, fuel injection timing, and ignition spark timing against RPM. The ECU is powered by the Power Control and Distribution Unit (PCDU) and has redundancy with the back-up battery.

1.2.19. Electronic Fuel Injection (EFI). The Electronic Fuel Injection (EFI) is composed of the ignition system and the fuel system. It is comprised of duplicate Crank Position Sensors (CPSs), ignition coils and leads, spark plugs, Barometric air pressure sensors and an injector and throttle (including the TPS).

1.2.20. Power Control and Distribution Unit Function (PCDU). The PCDU is a combination of a Generator Control Unit (GCU) and Power Distribution System (PDS). The PCDU is located in the forward section of the AV along with the back-up battery.

[1] SIL is a quantified level of safety system performance, with SIL 4 being the highest and SIL 1 being the lowest. SIL levels are defined using the DefStan 00-56 which uses requirements grouped into 2 broad categories: hardware safety integrity and systematic safety integrity.

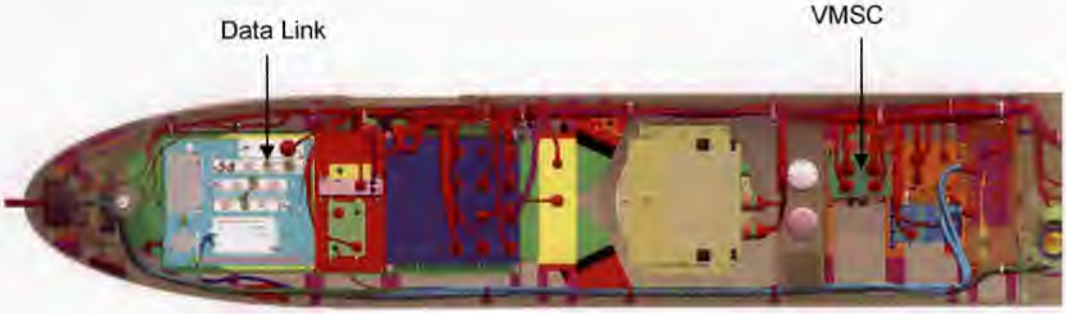

Figure 5 – Diagram of Front Compartment.

1.2.21. Electro Magnetic Interference (EMI) Shielding. The EMI modification was installed on 6 ES2 AVs, including WK043 in order to reduce electrical interference. This consisted of a metal cage placed around the ignition coil, located on the engine.

1.2.22. Flight Control. The flight control surfaces include ailerons and flaps, installed in the main wing and moving V-Tails that serve as a combined rudder and elevator (see Figure 3). All flight control surfaces are moved by dual electrically redundant single linkage electro-mechanical actuators located in the wings and rear fuselage, under the control of the VMSC; this forms a closed loop positional feedback control system. The Flight Control System (FCS) within the VMSC maintains the AV flight within a pre-designated operational envelope providing a safety margin against structural and flight limitations.

1.2.23. Data Links. The AV utilises 2 data-links:

a. Wide-Band Data Link (WBDL). The WBDL provides the primary means of communication between the GCS and the AV. It is used to transmit and receive command/control and status data and Full Motion Video (FMV). It can also be used to pass voice and data between ground elements of the system and the AV and external systems (via the LMAR). The WBDL is used to provide positional information to the AV during take-off and landing from the Automatic Take-Off and Landing System (ATOLS).

b. Narrow-Band Data Link (NBDL). The NBDL provides a secondary means of command and control of the AV from the GCS (via the GDT and ADT). It also provides positional information to the AV during take-off and landing from the ATOLS system. The NBDL can also be used for distributing imagery from the GCS to Tactical 3rd Parties.

Ground System Elements

1.2.24. Ground Control Station (GCS). The GCS is a 20ft long, specifically designed, ISO-type container used by the crew for planning missions, command and control of the AV and its sensor payloads during missions (Figure 6). It is a self-contained unit containing the main computing infrastructure for the WK system. It provides the operators with a safe work environment, which is air-conditioned and temperature controlled at all times during operation. Each GCS can accommodate a Pilot (P1), a Payload Operator (P2), UAV Commander (UAV Cdr), as well as space for 2 other crew.

Figure 6 – Exterior of GCS.

1.2.25. The GCS is fitted for BOWMAN secure military tactical Communications (Comms). It also houses a V/UHF ground radio for direct Comms with Air Traffic Control (ATC). Ground crew outside the GCS generally use handheld VHF radios to communicate with the ATC tower and the GCS. Further details of the GCS are as follows:

a. Ground Flight Control Computer (GFCC). All flight command instructions for the AV are processed by the GFCC, which checks the validity and safety of commands including; terrain clearance, air-space compliance and glide ranges to Emergency Recovery Locations (ERLs). In the absence of an input from the GFCC, the AV is designed to follow an Emergency Lost Link Procedure (LLP); if communication cannot be restored, the AV transits to an appropriate ERL. The AV is protected from erroneous inputs from the GFCC as the AV's higher integrity VMSC will only accept valid commands from the GFCC.

b. Ground Mission Control Computer (GMCC). The GMCC provides the monitoring and control function to the AV payloads and the data links. It also acts as a conduit for data flowing from the data-links to the Client Server (CS) and for communication between the CS and the GFCC. The Operators interface directly with the GMCC through a dual set of Hard Keys and Joysticks, and indirectly through a keyboard, mouse and monitors (Figure 7).

Figure 7 – Interior of GCS; note the computer screens are also known as Human Computer Interface (HCI).

c. Client Server (CS). The CS provides the interface for operators and is used for mission planning. With the exception of take-off and landing commands and some safety-related functions, the AV is routinely commanded by the CS interface (the GFCC ensures operators commands are valid, prior to uploading to the AV). The mission monitoring function of the CS monitors and displays the AV status and can display the AV position, airspace and route information on a moving map, or imposed on satellite imagery.

d. Ground Data Terminal (GDT). The GDT is a collection of external ground equipment (Figure 8) which can be located up to 1 km from the GCS, connected by multi-core optical cable. It comprises antennae, control units and modems for both the WBDL and NBDL. Both data-links receive and transmit encrypted command, control and AV status data and the WBDL has the facility to relay imagery back to the GCS.

Figure 8 – GDT.

1.2.26. Automatic Take-Off and Landing System (ATOLS). ATOLS is a system which allows the AV to perform automatic take-offs and landings. It comprises a Ground Radar Unit (GRU) and a Ground Beacon Unit (GBU) next to the runway at accurately surveyed points and an Airborne Beacon Unit (ABU) in the AV itself. Figure 9 shows an example layout and the location of the different systems on the airfield.

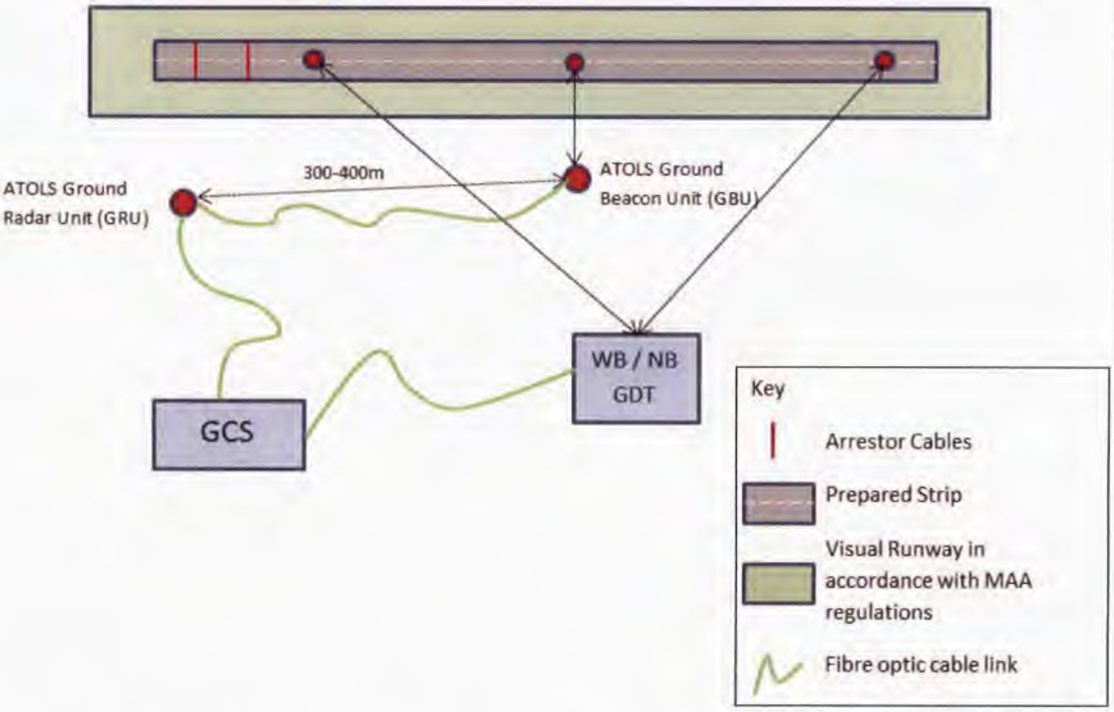

Figure 9 – Example layout of WK Launch and Recovery site.

1.2.27. Arrestor System. The arrestor system is used to bring the AV to a smooth stop following a landing or aborted take-off. The arresting hook on the AV catches the arresting cable laid across the runway. Adjustable braking drums hold the cable taught and provide tension and hence a braking force when the AV 'takes the cable'.

1.2.28. Portable Aircraft Test Equipment (PATE). The PATE is a Toughbook computer that is normally housed within the Flight Line Support Control Unit, a modified Pinzgauer vehicle (Figure 10) which is also used to tow the AV during airfield /strip operations. The PATE performs:

a. AV functional system tests.

b. Pre-flight checks.

c. Engine start.

d. Data upload/ download.

e. Support to fault diagnostics to LRU level including payloads.

Figure 10 – A Pinzgauer vehicle equipped with a PATE towing WK to departure point.

PART 1.3 NARRATIVE OF EVENTS

NARRATIVE OF EVENTS

1.3.1. **Overview**. At 1036hrs on 24 Mar 2017, a WK ES2 build AV, with military registration WK043 took off from West Wales Airport (WWA). The sortie (Flight 611) was part of a ES2 type conversion training sortie run for the training benefit of RA pilots and instructed by Thales / UTacS personnel. After take-off from WWA, WK043 was commanded to Fly To Coordinates (FTC). Shortly into the flight, numerous alerts and warning captions appeared on the HCI indicating that there were some issues with the AV. Significant AV engine Revolutions Per Minute (RPM) fluctuations, indicating readings above and below the normal operating range and outside the RPM the engine is physically able to produce, were observed by the GCS operating crew. The AV was flown out towards the Sea Emergency Recovery Point (Sea ERP) whilst controllability checks were conducted. The alerts and warning captions continued and increased in frequency until the AV appeared to lose the ability to maintain height and heading. All telemetry was lost with the AV at 1056hrs. West Wales Radar reported a last known position over Cardigan Bay 4nm North-West (NW) of Aberporth airfield. Post-Crash Management Action was initiated. There were no injuries sustained to personnel or bystanders and no damage to infrastructure.

Exhibits 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12.
Witness 2
Witness 1
Witness 4
Witness 5
Witness 8
Witness 3

Exhibit 132

SORTIE PREPARATION

1.3.2. **Previous 24 Hours**. Following a week of flying that saw the conclusion of delivery of the Train the Trainer (TtT) package to the senior RA Tactical UAS Warrant Officer (TUAS WO)[2], there were two RA crews in WWA to start the ES2 conversion. The second crew who were P1 and P2 of Flight 611, had previously flown on 22 Mar 2017 utilising WK 043. They had not flown in the previous 24 hours and were well rested. On the 24 Mar 2017 the student crew, Authorising Officer (AO), UAV Cdr and Aircrew Instructor (AI) arrived at work and attended the FOO Morning Brief at 0800 hrs. The crew were within prescribed crew rest periods.

Witness 1
Witness 2
Witness 3
Witness 4
Witness 5
Exhibit 13

1.3.3. **Aim of the Sortie**. The aim of the Flight 611 was to conduct an ES2 Conversion Training Flight for P1 and P2 who had recently graduated from the WK Pilot Conversion to Type Training (CTT) on the OCU build standard in Oct 2016. This sortie was the second flight for both P1 and P2 since completing WK CTT, and their second flight operating an ES2 build standard WK. The training and development of the crew was part of a planned programme to deliver enough trained ES2 pilots to begin Operational Field Trials (OFT) later in 2017 when a Military Release to Service (RTS) was being sought for the ES2 build standard WK.

Exhibits 13, 14, 15, 16, 17, 18 and 19.

1.3.4. **Sortie Plan**. The plan was to take-off from WWA and operate in segregated airspace to the NW of Aberporth airfield. The objectives of the sortie were to conduct start-up, taxi, take-off then an air exercise in Danger Area D201, which involved basic WK handling and payload operation prior to recovering to the airfield to land. This was a repeat of the exercise from the 22 Mar 2017 but with the P1 and P2 reversing their roles within the GCS. The sortie was due to last for 2 hours

Exhibits 20, 21, 14, 22,

Witness 4
Witness 5

1.3.5. **Weather** The Area forecast for MOD Aberporth range, which encompasses Cardigan Bay, was issued at 0739hrs and showed that there were no

Witness 1
Exhibit 21

[2] from Army Aviation Standards (AAv Stnds)

significant weather events forecast. With scattered clouds, good visibility and light winds, the weather was in limits for the planned activity.

1.3.6. **Pre-Flight Maintenance**. Flight Servicing was commenced at 0700hrs on 24 Mar 2017 and WK043 was recorded as having a fuel load of 50kg. It had 2 operational payloads fitted; a Radar turret fitted in the forward payload section and an EOP in the rear payload section.

Witness 7
Witness 9
Witness 10
Exhibit 23

1.3.7. **GCS Set up** The crew left the Ops building but were informed by the PATE Technician that they could not crew into the GCS until 0917hrs as they were still running through the GCS set up scripts. GCS crew in, during which the Flight Execution Log Author (FELA) noticed that the Ice Flight Mode ON and Fwd haz Power OFF captions were displayed; this was noted in the FELA log. The pre-flight checks were observed by the UAV Cdr and the AI. Control of the AV was passed to the PATE crew on the Pinzgauer for the engine start. During the engine start, the RPM was seen to only reach 6250RPM before dropping to 5000RPM, then was recovered to 7150RPM and idle of 3700RPM. The UAV Cdr and FELA discussed the unusual RPM readings with the Deputy Flight Line Manager, who explained the PATE touchscreen was inadvertently touched by the RA PATE Operator who was under supervision of the UTacS PATE Technician.

Exhibits 24, 4, 25, 26 and 9.

1.3.8. At 1010hrs the AV Flight Servicing Certificate was coordinated. At 1011hrs the PATE Operator reported via radio that the engine test was successfully passed and also relayed the two fault codes that were present on the final screen: BIT_644_DL_WB-NO_COMM and BIT_649_DL_NB_NO_COMM. The P2 acknowledged the codes with 'Roger'; the AI confirmed that the codes were normal and 'due to taking the AV in and out of the air picture'. At 1014hrs the P2 requested the AV be towed to the departure point and at 1015hrs the UAV Cdr signed for control the aircraft.

Exhibit 24

Exhibit 4

1.3.9. **Sortie Overview**. The AV was launched at 1036hrs and flew towards and within its designated segregated airspace until it crashed at 1056hrs. Figure 11 shows route flown by the AV during its sortie, as transmitted by the VMSC and recorded by the GCS.

Exhibit 11

1.3.10. At 1043hrs and during the initial climb the P2 noticed that the reported payload footprint on the AV was inaccurate compared to the true heading, the P2 also noted that the FMV window displayed the opposite report of the payload mode; when Port was commanded, it displayed Starboard. The P2 and the UAV Cdr worked through the payload issues referring to Flight Reference Cards (FRCs) where required. Whilst climbing through 4000ft AMSL[3], an *ECU Throttle Posn Difference* message was displayed. The FRCs stated that this caution may result in degraded engine performance, and that controllability checks should be conducted and the AV should land ASAP. Before the crew could conduct controllability checks, the caution cleared. The same caution was repeated 1 minute later and cleared in seconds. The next caution that appeared was *ECU Tacho Fail*, which the FRCs stated indicated that RPM was above 9000RPM or below 2000RPM, which may be the result of a RPM sensor failure or invalid reading. Concurrently the RPM displayed in the HCI was seen to fluctuate and the AV appeared to be unable to climb satisfactorily.

Exhibits 26, 24, 7, 10, and 11.
Witness 4
Witness 5
Witness 2
Witness 8
Witness 3

Exhibits 27, 28, 9, 1 and 2.

[3] Above Mean Sea Level

Exhibit 25

Figure 11 – VMSC flight data trace of WK043 from take-off to crash.

1.3.11. At 1046hrs the AI instructed the crew to FTC, which directed the AV to fly to coordinates over the sea and carry out controllability checks in accordance with their FRCs. The crew continued to observe further caution messages of *ECU Tacho Fail* and *ECU Tacho low RPM*, the latter of which cleared quickly. At 1051hrs the AI directed the Pilots to prepare a distress call (PAN–PAN[4]) that was to be sent to West Wales Radar. A *PCDU Rectifier Voltage Fail* message was then displayed, for which

Exhibits 24, 25 and 26.
Witness 4
Witness 5
Witness 2
Witness 8

[4] A Pan-pan call is a situation of URGENCY whereby a condition concerning the safety of an aircraft or of some persons on board (or within sight) exists.

the FRCs instructed the crew to "Land ASAP". This warning cleared in seconds, and another warning of *GFCC – No Comms with UAV*, appeared. Meanwhile the indicated RPM was cycling from 0 to above 11000 RPM in quick succession. Witness 3 Exhibit 10

1.3.12. The crew were conducting their immediate actions and checks in accordance with FRCs, whilst commanding the AV to fly to the Sea ERP to maintain safe separation from other traffic and habitation. The P2 conducted visual checks of the aircraft using the EO Payload, and nothing was obvious and visually out of place or obstructing any control surface of the AV. At 1053hrs the UAV Cdr requested the presence of the available Senior Engineer to assist in understanding all the Warnings Cautions and Advisories (WCA) were indicating within the GCS. Witness 4 Witness 5 Witness 2 Witness 8 Witness 3

1.3.13. At 1055hrs the crew sent their PAN call to WWA. Also at 1055hrs, and in quick succession, the following cautions were displayed: *VMS Comms from GCS Fail, Failover to Non-active CPU (VMS CPU B), VMS Failure, VMS CPU B is active, Servo Throttle Posn Rpt Fail, Servo Right V Tail Posn Rpt Fail, ECU throttle posn difference*. These cautions all appeared within 3 seconds and were quickly followed by a warning of *ECU Throttle Stuck*. As the crew was dealing with this warning they were presented with 4 more cautions including *ECU Tacho Fail, ECU Throttle Posn Diff, ECU Tacho Low RPM* as well as *ADU Velocity Sensor Failure* warning. Exhibits 24, 25, 26, 10, 29 and 30.

1.3.14. At 1056hrs no further WCA were seen as the data-links were lost. Through the view of the EO payload the AV was seen to spiral downwards in an uncommanded RH barrel roll until telemetry was lost at 1056hrs 43secs. West Wales Radar was informed of the telemetry loss and they confirmed that they had also lost contact on their screens.

TIMELINE

1.3.15. The timeline from prior to take-off to the GCS being quarantined was:

a. **0800-0900 hrs**. The Morning Brief and pre-flight brief was held in the FOO building.

b. **0900 hrs**. The crew left the Ops building but were informed by the PATE Technician that they could not crew into the GCS until 0917hrs.

c. **0917 hrs**. GCS crew into the GCS.

d. **1010 hrs**. The AV Flight Servicing Certificate is coordinated. Witness 8 Witness 7 Witness 9 Witness 10 Exhibits 10, 11 and 24

e. **1012 hrs**. The two fault codes that were present on the final screen: BIT_644_DL_WB-NO_COMM and BIT_649_DL_NB_NO_COMM were reported to the GCS crew.

f. **1013 hrs**. The UAV Cdr and FELA discussed the unusual RPM readings with the Deputy Flight Line Manager.

g. **1015 hrs**. The UAV Cdr signed for control the aircraft. WK043 was towed out to the departure point. Exhibit 27

h. **1019 hrs**. WWA take off clearance received. The crew conducted a take-off brief in the GCS. Exhibit 28

i. **1036 hrs**. WK043 took off from Runway 07.

j. **1047 hrs**. First 3 *ECU Throttle Difference* cautions and *ECU Tacho Fail* caution.

k. **1049 hrs**. *ECU Throttle Difference* and *ECU Tacho Fail* cautions.

l. **1052 hrs**. *ECU Tacho Fail* and *ECU Tacho Low RPM* cautions.

m. **1055 hrs**. *PCDU Rectifier Voltage Fail* warning and *VMS Comms from GCS Fail, Failover to Non-Active CPU, VMS CPU B is Active, Servo Throttle Position Report Fail* and *Servo Right VTail Position Report Fail* cautions.

n. **1056 hrs**. *ECU Throttle Stuck* and *ADU Velocity Sensors Fail* warnings.

o. **1057hrs Onwards**. No further contact with WK043. GCS crew confirmed loss of contact with the AV with WWR.

p. **1058hrs**. UAV Cdr informs the duty Post Crash Management Incident Officer (PCMIO) that the GCS has lost contact with WK043 and WWR has also lost contact with the AV.

q. **1103hrs**. Post-Crash Management Plan initiated by PCMIO. PCMIO contacted with Deputy Chief of Defence Staff Duty Officer (DCDSDO). Exhibit 31 Witness 12

r. **1107hrs**. PCMIO contacted Defence Accident Investigation Branch (DAIB).

s. **1125hrs**. GCS quarantined and locked.

PART 1.4 – ANALYSIS AND FINDINGS

ASSESSING THE EVIDENCE

METHODOLOGY

Definitions

1.4.1. **Air Safety.** Air Safety is defined in the Military Aviation Authority (MAA) Master Glossary as '*the state of freedom from unacceptable risk of injury to persons, or damage, throughout the life cycle of military air systems. Its purview extends across all Defence Lines of Development and includes Airworthiness, Flight Safety, Policy, Regulation and the apportionment of Resources. It does not address survivability in a hostile environment.*' Therefore, this report considers both the risk to both the safety of personnel and to equipment. Exhibit 32

1.4.2. **Accident Factors.** The Panel used the following definitions to categorise factors considered when determining the findings of the investigation:

a. **Causal Factor(s).** A causal factor is a factor that led directly to the accident or incident. Causal factors in isolation or combination with other causal or contributory factors and contextual details, led directly to the accident.

b. **Contributory Factor(s).** A factor which made the accident more likely to happen, but did not directly cause it. Therefore, a contributory factor in isolation would not have caused the accident. Equally, if a contributory factor was removed, the accident **may** still have happened.

c. **Aggravating Factor(s).** A factor which made the outcome of the accident worse. Aggravating factors did not cause or contribute to the accident, therefore, if an aggravating factor was removed, the accident **would** still have happened.

d. **Other Factor(s).** A factor which played no part in the accident in question, but is noteworthy in that it could cause or contribute to a future accident.

e. **Observation(s).** In addition to identifying and categorising the accident factors as described above, the Panel made a number of observations. These are points or issues, identified during the course of the SI, worthy of note to improve working practices and have a positive effect on improving overall air safety.

1.4.3. **Probabilistic Language**. The DAIB Probability Terminology Table (Figure 12) is designed to facilitate standardised communication of uncertainty in DSA Accident and Incident reporting. The terminology used in this table is based on terms published by the Intergovernmental Panel on Climate Change (IPCC) in their Guidance Note for Consistent Treatment of Uncertainties, as well as the Australian Transport Safety Bureau (ATSB) in their paper on Analysis, Causality and Proof in Safety Investigations.

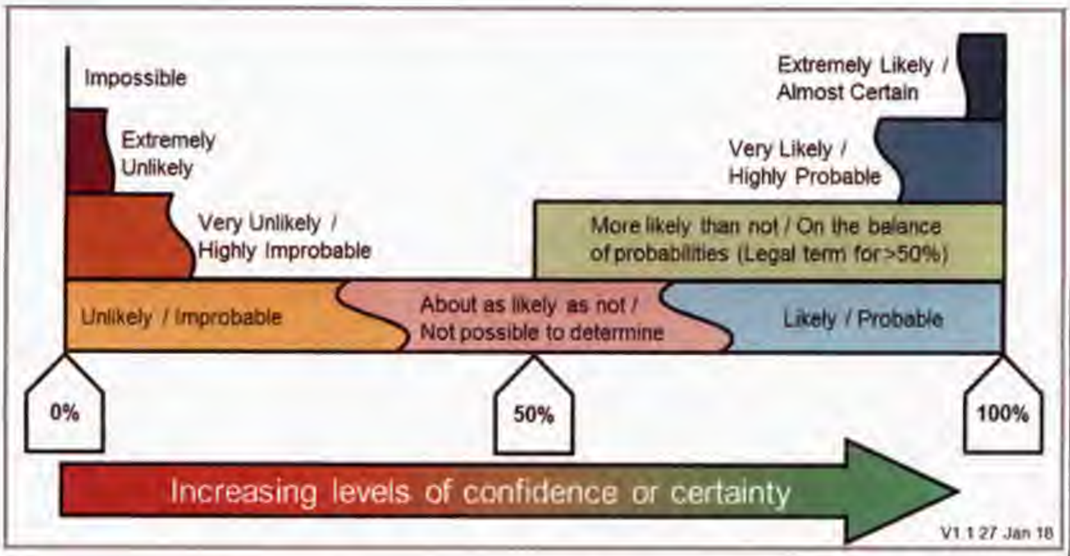

Figure 12 - DAIB Probability Terminology Table.

Available Evidence

1.4.4. The Panel had access to a variety of evidence, which was collected either during the course of the investigation or from the Triage Investigation conducted by the Defence Accident Investigation Branch (DAIB). The following lists the types of evidence and any specific limitations.

1.4.5. **Physical Evidence and Wreckage**. The WK AV crashed into Cardigan Bay and despite radar data from West Wales Radar and Global Positioning Satellite (GPS) data from the AV and Ground Control Station (GCS), there remained a wide possible impact area. A Chief Salvage and Mooring Officer (CSALMO) search was initiated on 28 Mar 2017, and data from the towed sonar array was analysed; one area of interest was identified and a recovery operation launched. Exhibits 33, 34, 35 and 36.

1.4.6. To date, the main wreckage has not been located; however, light items of composite airframe have sporadically washed ashore[5]. Not all items have serial numbers that could be used to identify whether the wreckage is from WK043 or WK042 that also crashed in Cardigan Bay on 3 Feb 2017. Exhibit 37

1.4.7. **Witness Testimony**. The Panel interviewed a range of personnel, and recorded these as witness testimony; they also had access to written statements collected as part of the DAIB triage. The Panel considered the evidence from the following:

a. The GCS Crew of WK043 (Pilot (P1), Payload Operator (P2), Flight Execution Log Author (FELA), Aircrew Instructor (AI) and UAV Commander).

b. UAV Tactical Systems Ltd (UTacS) maintenance personnel.

c. Royal Artillery(RA) Launch and Recovery personnel.

Witness 2
Witness 3
Witness 4
Witness 5
Witness 8
Witness 7
Witness 9
Witness 10
Witness 11
Witness 13
Witness 14

[5] Right Hand Flap Assembly found on a beach West Wales (not confirmed as WK043). Undercarriage and Wheel Assembly found on a beach on the Isle of Man confirmed WK043. Centre Wings Structure Assembly found on Newquay beach West Wales confirmed WK043

d. Army Aviation Standards (AAvn Stds).

e. Royal School of Artillery(RSA) Instructors.

f. Flight Authoriser.

g. Post-Crash Management Incident Officer (PCMIO).

h. Defence Equipment and Support (DE&S) Unmanned Air Systems Team (UAST) Deputy Programme and Trials Manager.

Witness 18
Witness 17
Witness 16
Witness 6
Witness 1
Witness 12
Witness 15

1.4.8. **Flight Data**. The WK043 Vehicle Management System Computer (VMSC) has not been recovered, so the Panel had access to a limited number of parameters of flight data; only those parameters transmitted by the VMSC to the GCS. This data was also recorded in the 'sniffer room' by use of a 'wireshark'[6] connection to a computer terminal in the adjacent building. This capability is primarily for test engineers to monitor flight-tests and evaluation, and although Flight 611 was not a test flight, the 'sniffer room' was actively recording on 24 Mar 2017 providing the Panel with additional data. The data recorded included the time, duration and type of WCA that were displayed to the crew in the GCS. It also contained basic performance data such as engine RPM, heading, and pitch angle.

Exhibits 1, 2, 3, 5, 10, 11, 38, 39 and 40.

1.4.9. **Cockpit Voice Recordings (CVR)**. The GCS[7] used during 24 Mar 2017 is fitted with one area microphone in addition to the five microphone headsets utilised by the crew[8]. The area microphone began recording as soon as power was applied to the GCS; the Panel was therefore able to hear activity in the GCS throughout the start-up, pre-flight checks, AV handover from Launch and Recovery to the GCS crew, take-off, sortie activity and the subsequent immediate post-crash actions.

Exhibit 41
Exhibit 24

1.4.10. **Graphical Data Analysis Software (GDAS)**. The flight data and CVR were combined, by QinetiQ[9] to produce a graphical representation of the flight. This enabled the Panel to visualise the attitude of the AV combined with real-time cockpit display, including the WCA, and to hear the crew's comments throughout.

Exhibit 26

1.4.11. **Orders, Procedures and Guidance**. The AV was operating from a civilian airfield by a civilian organisation, but was conducting training of military personnel. The relevant orders, procedures and guidance for all organisations involved were reviewed:

a. Regulation and Procedures.

(1)MAA Regulatory Articles.

(2)Flying Order Books (Joint Helicopter Command ((JHC) and Flight Operations Organisation in WWA).

(3)Military Flight Test Permit (MFTP).

[6] Wireshark is network protocol application used to help capture and analyse data.

[7] The GCS in use on 24 Mar 2017 was serial number WB009.

[8] At the time of the accident WB009 GCS set up allowed the Pilots to hear the WCA tones whilst the AV was in the air, but not those whilst on the ground. The UAV Cdr, AI and FELA would not be able to hear any tones but would be able to see them presented visually on the HCI.

[9] Aircraft Data Analysis Team, Engineering & Operations Department.

(4)Standard Operating Procedures (SOPs).

(5)Contractor Flying Organisation Exposition (CFOE).

(6)Air Safety Management Plans (ASMP).

(7)Training Documentation.

b. Flying Operations.

(1)Authorisation Sheets

(2)Logbooks.

(3)Training Record Folder(s) (TRFs).

(4)Flight Reference Cards (FRCs).

(5)Sortie Planning.

(6)Known Problems and Workarounds.

c. Maintenance.

(1)AV F700 and archives.

(2)GCS Logbook and archives.

(3)Ground System Equipment Logbooks.

(4)Engineering Authorisations.

(5)Record of F760s and F765s.

(6)Technical Queries (TQs).

(7)Interactive Electronic Technical Publication (IETP).

(8)Flight Line Reference Cards (FLRCs).

d. Additional Safety and Investigation Reports.

(1)Defence Aviation Safety Occurrence Report (DASOR).

(2)WK031 Service Inquiry Report.

(3)WK006 Service Inquiry Report.

(4)WK043 Human Factors Report from RAF Centre of Aviation Medicine (RAFCAM).

(5)WK043 DAIB Triage Report. Exhibit 42

1.4.12. **Manufacturer and Design Authority Resource**. With no physical wreckage and therefore no VMSC to provide complete flight data, the Panel utilised supplementary technical information supplied by the Prime Contractor Management Organisation (PCMO), Thales.

Assessing Accident Factors

Exhibit 43

1.4.13. **Human Factors (HF)**. The Panel were assisted in assessing the HF element by a Subject Matter Expert (SME) from the RAF Centre of Aviation Medicine (RAFCAM). The SME was either present at interviews or had access to the audio and transcribed interviews undertaken by the Panel. A HF Report was produced and considered by the Panel when determining the findings of the investigation.

Exhibit 6, 25 and 26.

1.4.14. **Technical Factors**. The DAIB assisted the Panel in assessing technical factors relating to the crash of WK043, provided links to other organisations and specialists such as 1710 Naval Air Squadron (1710 NAS), and QinetiQ for assessing flight data and reviewing manufacturer technical data.

1.4.15. **Organisational Factors**. The Panel also considered organisational factors. The AV was operated by civilian contractors at a civilian airfield, but with military operators supported by a military Launch and Recovery Team.

1.4.16. **Services**. The following is a list of organisations that assisted the Panel:

a. DAIB.

b. RAFCAM.

c. JHC Safety Assurance.

d. DE&S UAST.

e. WK042 SI[10].

f. 1710 NAS.

g. 47 Regiment Royal Artillery (47 RA).

h. WK Training Facility (WTF).

i. Army Headquarters Capability Combat Support (Army HQ CAP CS).

j. Thales.

k. UTacS.

l. QinetiQ.

m. MAA.

n. UAS Test Evaluation Flight.

o. Handling Squadron (HS).

[10] The Wk042 and WK043 SIs were running in parallel conducting independent investigations, although collection of common evidence was coordinated.

DETERMINING THE CAUSE OF THE ACCIDENT

EVENTS

1.4.17. **Introduction**. With no physical wreckage to examine, the Panel relied on analysing data transmitted by the AV to the GCS, voice recording from the crew in the GCS, the video from the EOP, GFCC logs, and PATE logs. This was supported by documentary evidence such as AV logbooks, orders, publications etc. Lines of inquiry were developed focussing on engine performance and control, and the VMSC following initial analysis and review of the triage report conducted by DAIB.

1.4.18. **Sortie Overview**. A full Narrative of Events can be found in Section 1.3; the following extracts have been included to refresh the reader and to highlight key events relevant to the analysis. The GCS voice recordings show that on 24 Mar 2017 at 1012hrs the PATE Operator reported the presence of BIT codes 644 and 649 on the pre-flight test scripts to the GCS crew. These codes referred to no established data-link communication to one side of the VMSC. The BIT[11] codes had been seen frequently by the crews at WWA and it was common[12] to fly with them present. The codes were acknowledged by P2, and the AI commented they were normal, subsequently the P2 called for the AV to be towed to the runway threshold; the AV took off at 1036hrs.

Exhibits 13, 24, 26 and 44.
Witness 2
Witness 3
Witness 4
Witness 5
Witness 8

1.4.19. At 1047hrs the first in a series of engine, throttle and RPM WCA appeared. The crew carried out Immediate Actions in accordance with FRCs and commanded the AV to transit to the Sea ERP. At 1055hrs the VMSC Side A failed over[13] to Side B. At 1056hrs the AV entered an un-commanded dive and crashed into Cardigan Bay.

DATA ANALYSIS

1.4.20. **Warnings, Cautions and Advisories (WCA)**. There were 21 WCA between 1047hrs and 1056hrs when the AV data-link was lost. The crew were able to follow the FRCs for the initial cautions, conducting controllability checks. However, before any further remedial actions could be taken, the cautions self-cleared between 1 and 20 seconds after appearing without crew input; often the cautions were repeated shortly after clearing.

Exhibits 1, 2, 3, 4, 45 and 14.

1.4.21. The list of WCA presented to the crew on the Human Computer Interface (HCI), (as shown in Figure 7 in Section 1.2), is summarised at Figure 13 with the time, description, category, likely cause and significance of each. For example, an errant Throttle Position Sensor (TPS) would result in an "*ECU Throttle Position Difference*" caution.

Exhibit 46, 47 and 48.

[11] A Built In Test (BIT) is used to assess the serviceability of individual system components; each type of failure is assigned a code to assist maintainers in isolating the fault and assessing serviceability.

[12] From analysis of 96 flights (evidence 167), 45 were flown with either or both BIT codes 644 and 649 on VMSC B.

[13] Failover is the switching to a redundant or standby system upon the failure or abnormal termination of the previously active application.

Serial	Time (Hrs)	WCA displayed on HCI	Category	Cause (BIT Code)	Significance
1	1036	VMS ER Site Select Fail	Caution	AV has insufficient Height or Speed to reach the ERP	A standard caution on T/O due to AV location and attitude.
2	 1047 1049 1055 1056	ECU Throttle Position Difference (x3) (x1) (x1) (x1)	Caution	Unknown BIT_689 ECU_TPS_DIFF ECU_TPS ECU	Implications that the engine performance may be degraded and a controllability check should be conducted.
3	 1047 1049 1052 1056	ECU Tacho Fail (x1) (x1) (x1) (x1)	Caution	Unknown: BIT_354 ECU_L_COMM ECU_TACHO Or BIT_896 ECU_ENGINE_PERF ECU_TACHO	Indicates RPM more than 9000 RPM or less than 2000 RPM; RPM sensor report has failed or RPM reading is invalid. Implies if the RPM is incorrect for the current flight mode, automated functions may perform incorrectly.
4	 1055 1056	ECU Tacho Low RPM (x2) (x1)	Caution	Unknown	
5	1055	PCDU Rectifier Voltage Fail	Warning	Unknown – cleared after 4 seconds without crew input. BIT_1920 PCDU_REC_1_V_OUT_OF_RNG RECTIFIER_VOLT_OUT_OF_RNG Or BIT_1935 PCDU_REC_3_V_OUT_OF_RNG RECTIFIER_VOLT_OUT_OF_RNG	The emergency battery connects and supplies remaining electrical load. However, the battery did not connect and all systems retained functionality.
6	1055	VMS Comms from GCS Fail	Caution	Unknown	

7	1055	Failover to Non-Active CPU	Caution	Unknown: BIT_1246 VMSC_MON_CPU_A VMSC_MON__CPU_A	The VMSC monitor has switched from Side A to Side B.
8	1055	VMS CPU B is Active	Caution	CPU B is active: BIT_831 VMSC_CPU_B_IS_ACTIVE	Central Processing Unit (CPU) B is the Active CPU – however in this instance it is in Stand by (STBY) flight mode.
9	1055	Servo Throttle Position Report Fail	Caution	CPU B is in STBY flight mode – believes the AV is on the ground and all engine controls should be at idle/ neutral.	Evidence that CPU is in STBY and believes the AV is on the ground.
10	1055	Servo Right VTail Position Report Fail	Caution	CPU B is in STBY flight mode – believes the AV is on the ground and all flying control surfaces should be at neutral.	Evidence that CPU is in STBY and believes the AV is on the ground.
11	1055	ECU Throttle Stuck	Warning	RPM above 6000 and throttle command below 10%.	CPU is in STBY and ground mode expecting the throttle to be at idle (less than 10%) but engine is powering the AV (RPM is about 6000).
12	1056	ADU Velocity Sensors Fail	Warning	Data from all 4 Air Data Units (ADUs) is disqualified.	Likely due to attitude of the AV.

Figure 13 – Warnings Cautions Advisories and explanation.

1.4.22. Of note, is the failover of VMSC Side A to Side B at 1055hrs. The WCA prior to this event are evidence of a potential underlying issue with the engine, the sensors, the ECU or the VMSC leading to a swap from Side A to Side B. The WCA following this event are related to the status and flight mode of VMSC Side B.

Witness 2
Witness 3
Witness 4
Witness 5
Exhibit 11

1.4.23. It was the crew's opinion that the WCA indicated an issue with the engine, but without the physical wreckage to examine the Panel has not been able to determine this with any degree of certainty. However, the Panel examined the flight data, which indicated that there was RPM spiking as detailed in the following Flight Data Analysis section.

1.4.24. **Flight Data Analysis**. The AV was in constant communication with the GCS, to which it sent a limited range of flight data. The flight data was recorded from the various computers that form the GCS: Application Computers (APC 1 and APC 2) and the CS.

Exhibits 1, 2, 3, 4 and 5

1.4.25. The flight data is recorded 4 times a second, and includes, but is not limited to the following: Flight Mode, Fuel Weight, External Air Temperature, Heading, Pitch Rate and Angle, Calculated Air Speed, etc. The flight data was decoded, compiled and the parameters the Panel determined the most relevant are presented graphically in Figure 14.

Exhibit 49

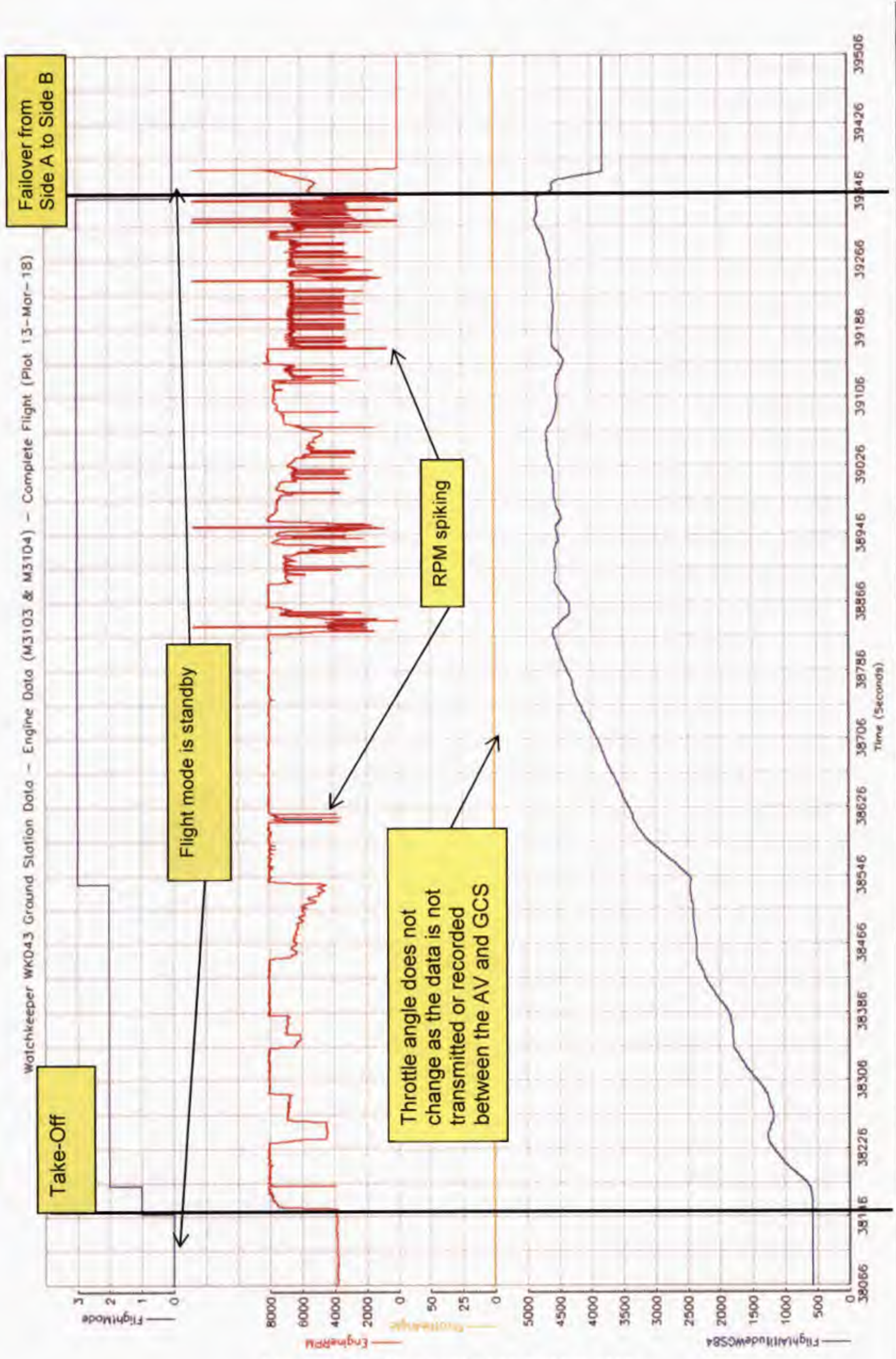

Exhibit 50

Figure 14 – General parameters plot.

1.4.26. **Flight Mode**. Figure 14 shows the flight mode, which changed during the various stages of the flight from standby, to take off, to fly to coordinate. At the time the VMSC Side A failed over to Side B, the flight data recorded that the flight mode changes back to standby, which the Panel has confirmed that Side B was in standby mode; it was functional, but not in the correct mode to actively control the AV in flight. Exhibits 25, 51, 26, 52, 53, 49, 54, 55, 56 and 57.

1.4.27. The Panel examined the following parameters in more detail due to their relevance to engine performance, in relation to the WCA seen by the crew during the sortie, or an anomaly in the data:

a. **RPM**. The engine RPM can be seen to fluctuate and 'spike' (between 0 and 12000 values) from approximately 12 minutes into the flight.

b. **Fuel Demand vs Flow**. The flight data shows that the fuel flow rate matched the RPM. This is consistent with standard system operation, as the fuel rate is calculated in the GCS[14] using the RPM data from the VMSC in the AV. Ergo, this data cannot be used to assess whether the RPM or ECU was correct. Exhibits 58 and 51.

c. **Throttle Position and Engine Wide Open Throttle (WOT) Checks**. The WOT checks, conducted as part of the Before Flight Servicing (BFS), were inadvertently interrupted by one of the PATE Operators when the touch screen was hit trying to point out a figure on the display. The test was restarted and concluded with no errors presented on the PATE. The data from the GCS shows the throttle angle stuck at 0.923[15] during the flight and there is no change. However, a Thales response to a Technical Query states that there is a known defect; the throttle parameter recorded in the GCS is not being updated, and work is on-going to rectify the fault. Witness 6 Witness 7 Exhibit 59

The data confirms the presence of the RPM spiking noted by the GCS crew, which can be linked to ECU tacho, RPM and throttle WCA (see Figure 15). However, there is no parameter or information about the cause of the spiking, and no evidence that the data reflects the physical performance of the engine. As a result, the Panel assessed additional sortie data from data logs.

1.4.28. **Data Log Analysis**. The additional data files from the GCS and 'sniffer room' are complex data sets recording every parameter of the flight transmitted by the VMSC. They contain all of the warnings and cautions recorded, the severity, validity and more detail on the sub-system of the cause. There are WCA codes recorded throughout the flight, the data reports them as 'VALID' when acknowledged by the crew or 'INVALID' if not yet acknowledged. The data further categorises the different WCA as either [Major] or [Critical] depending on the sub-system affected. A review of the data confirmed the WCA that were accurately reported to the crew in the GCS. The data also recorded the time at which the WCA appeared and cleared; furthermore there are a number of other WCA that were only present in the data logs for seconds, which cleared automatically. The files also provided definitive evidence that Side B was in standby mode when the VMSC failed over from Side A, and the recorded throttle angle was constant at "0.923". Exhibits 1, 2, 3, 5, 10, 11, 38, 39, 59 and 60.

1.4.29. The additional data files from the PATE, confirmed the presence of BIT codes 644 and 649 as actual faults. The data files also confirmed the serviceability of the AV prior to take-off.

[14] A function of the Ground Flight Control Computer

[15] A figure between 0 and 120 is used to determine the throttle position.

1.4.30. **Conclusion**. Initial evidence pointed towards the AV having an engine fault. The crew saw the RPM fluctuating and were presented with a series of WCA advising them of issues with the RPM and throttle. Whilst conducting their immediate actions in accordance with FRCs, manoeuvring the AV to the Sea ERP, the VMSC failed over from the active Side A to its redundant Side B, which had remained in standby mode. Shortly afterwards the AV lost control and crashed. Exhibits 25, 51, 26, 52, 53, 54, 55, 56, 49 and 57.

1.4.31. Having reviewed the available data from the flight and ground system elements the Panel has confirmed that the RPM spiking was the cause of the engine related WCA recorded before the failover. However, the Panel was not able to establish a definitive cause for the RPM spiking; the flight data, specifically the engine parameters analysis was inconclusive. Furthermore, there is no conclusive evidence in the data to determine whether the engine WCA are related to the VMSC Side A failover to Side B. However, there was evidence that once the VMSC had failed over from Side A to the redundant Side B, the VMSC was in Standby flight mode. Therefore, the Panel considers the failover of the VMSC from Side A to Side B whilst Side B was in standby mode was the **Causal Factor**.

DETERMINING THE CAUSE OF VMSC FAILOVER

1.4.32. The previous section discussed the possible relationship between the flight data, engine WCA and the VMSC failover. However, the Panel was unable to establish any immediate relationship. Therefore, the following section will examine the VMSC data recorded by the GCS in more detail and attempts to establish the reason for the failover.

1.4.33. The VMSC is the AV central computer; it controls all aspects of AV flight dynamics, power, propulsion and navigation. It is a flight critical system that contains all of the flight control software. The VMSC has dual redundancy; the computer has 2 identical processing cores Side A and Side B, and each side is capable of controlling the AV independently with no degradation in system capabilities. Each VMS processing core has its own set of peripherals, memories and power system; the 2 sides are completely isolated from each other; the only connection is the output drivers and receivers. Exhibits 61, 62, 63, 64 and 65.

1.4.34. Side B shadows Side A; both sides are monitored with a firmware circuit, which monitors performance and determines whether and when to swap from the active Side A to the redundant Side B. Should both sides fail, further redundancy is provided by the Reversionary Flight Control (RFC), which will attempt to fly the AV straight and level until a VMSC reset is successful. Exhibits 66, 67, 68, 69, 70 and 71.

1.4.35. The VMSC receives data from the ECU on the communication channel for RPM (from CPS), TPS, Engine Barometric Air Pressure, Engine Water Temperature, Engine Air Temperature, Injection time and Fuel Pressure.

1.4.36. The Functional Requirement Specification (FRS) for the VMSC and the Inter-active Electronic Technical Publication (IETP) lists only four designed reasons for the VMSC monitor to failover from the active VMSC Side A to the redundant Side B. The following are the listed reasons why the VMSC monitor would switch to Side B: Exhibits 72, 73 and 74.

a. **Memory Failure**. An internal hardware memory failure is a credible reason for a VMSC failover. However, none of the WCA associated with Exhibits 1, 2, 3, 5, 10, 11, memory failure were present on Flight 611. Additionally there was no record of the associated BIT code in the data logs. Therefore, the Panel does not consider this a likely cause for a failover in this instance.

75, 38, 39, 59 and 73.

b. **Inertial Navigation System (INS) / Global Positioning System (GPS) Failure**. Failure of the INS and GPS units is another credible reason for a VMSC failover. This occurs if both INS and GPS units fail a BIT, and would present a caution to the GCS crew alerting them that there was no communication to both units, which would cause the VMSC to failover. There was no evidence of INS or GPS failure during Flight 611. Therefore the Panel does not consider this a likely cause for a failover in this instance.

Exhibits 1, 2, 3, 5, 10, 11, 75, 38, 39, 59 and 73.

c. **VMSC Cycle Time**. The VMSC collects data from the systems' sensors and inputs at 50 msec intervals. The data from Flight 611 indicated that the VMSC had suffcient capacity and was not experiencing cycle time overruns. Therefore, the Panel does not consider this a likely cause for a failover in this instance.

Exhibits 1, 2, 3, 5, 10, 11, 75, 38, 39, 59 and 73.

d. **Servo Pulse Train Failure**. The VMSC measures an analogue signal from the servos operating the V-tail, ailerons, flaps, nose wheel and throttle; these servos have dual redundancy. The pulse train signal is generated internally by the VMSC, which controls these servos. Should 2 servos from the same group report an incorrect pulse train, the VMSC will failover. There was no record of the associated BIT code in the data logs; the servo WCA that were recorded in the accident timeline are due to the failover to Side B in standby. Therefore, the Panel does not consider this a likely cause for a failover in this instance.

Exhibits 1, 2, 3, 5, 10, 11, 75, 38, 39, 59, 75, 76, 77, 78 and 73.

1.4.37. Having established that the four designed reasons for failover have been dismissed as credible causes, other 'generic' causes were examined:

a. **Software Failure**. A software discrepancy or malfunction may cause a VMSC failover. The VMSC software fitted, Version 74, was also operational in a number of different VMSCs fitted to other AVs; none of these VMSCs have reported any software issues. The software states and compatibility of key LRUs was correct (PCDU, ECU, VMSC). The Panel determined that software failure was unlikely to have caused the VMSC failover. Therefore, the Panel does not consider this a likely cause for a failover in this instance.

Exhibits 1, 2, 3, 5, 10, 11, 75, 38, 39, 59, and 73.

b. **VMSC Monitor Relay**. The VMSC monitor will swap to the non-active VMSC if it loses the 'keep alive' signal from the active VMSC. It may also swap if the power supply is interrupted. Again, there are no associated symptoms, BIT codes or WCA to support a problem with the monitor relay. Therefore, the Panel does not consider this a likely cause for a failover in this instance.

Exhibits 1, 2, 3, 5, 10, 11, 75, 38, 39, 59, and 73.

c. **VMSC Input Power**. A problem with the power from the PCDU may also cause a swap. There was a *PCDU Rectifier Voltage Failure* warning during Flight 611, but there is no evidence of power interruption as systems continued to function normally after the WCA and the Emergency Battery was not activated. Furthermore, ESL and Thales have conducted tests in order to try to replicate the failover. Their initial thoughts were a power surge could account for a failover, and this may have been supported by the PCDU voltage WCA seen just prior to the failover. However, testing concluded that a change in the VMSC internal12V power supply would not cause failover. Therefore, the Panel does not consider this a likely cause for a failover in this instance.

Exhibits 1, 2, 3, 5, 10, 11, 75, 38, 39, 59, and 73.

d. **Major Hardware Failure**. The VMSC is comprised of sub-units: arrays, switches, processors etc. Should one of these items fail, the VMSC would failover to Side B. There was insufficient data recorded by the GCS and no associated WCA during Flight 611 to indicate that this was a likely cause for the VMSC failover. However, ESL and Thales also conducted parallel reliability studies and identified that certain capacitors and fuses in the VMSC were not meeting reliability requirements. The Panel's research uncovered historical evidence of VMSC failures due to blown fuses; with 5 out of 40 VMSC failures were found to have an open circuit on inspection. ESL and Thales have concluded that a hardware failure of a capacitor or fuse in the VMSC is a likely cause for a failover from Side A to Side B. However, without the VMSC from the wreckage, and analysis of any physical damage it was not possible to confirm. Having considered all of the designed and generic reasons for what could cause a failover to Side B; it is the opinion of the Panel that a major hardware failure is on the balance of probabilities, the reason for the failover.

Exhibits 79, 80, 81, 82 and 83.

Exhibit 81

1.4.38. **Conclusion**. The Panel, with assistance from Thales has eliminated the known design reasons for the failover, assessed the likelihood of other generic reasons, and determined that on the balance of probabilities, the likely cause for the VMSC failover was a hardware failure of a fuse or capacitor. The Panel has been unable to determine whether this was related to the RPM spiking and the associated engine WCA. However, the Panel has concluded the failover of the VMSC to Side B should not have resulted in a loss of control as the VMSC is designed with multiple layers of redundancy. Side B should have been shadowing Side A and taken control of the AV when the monitor switched active control. The Panel has established that VMSC Side B was live but in standby mode and this is covered in the following section. Therefore, the Panel conclude that the failover from Side A to Side B was a **Contributory Factor** to the accident.

1.4.39. **Recommendation: The Panel recommends that the Head of Unmanned Air Systems task Thales to introduce more reliable hardware components in order to improve the reliability of the Vehicle Management System Computer (VMSC).**

DETERMINING THE CAUSE OF VMSC SIDE B IN STANDBY MODE DURING FLIGHT

1.4.40. The Panel established the most likely cause of the VMSC failover as a hardware failure within VMSC Side A. The Panel also established that BIT codes 644 and 649 were present at the end of the BFS, which refers to no data-link with one side of the VMSC. The following section will establish the significance of these codes and the lack of data-link and their relationship to the VMSC Side B being in standby mode.

1.4.41. **Data-Links**. The AV relies on a data-link between the VMSC and the GCS via the Ground Data Terminal (GDT) for flight control. There are 2 data-link channels, wide band and narrow band, which are connected as part of the BFS and monitored throughout operation. However, should this link be interrupted during flight, and the AV is unable to receive commands from the GCS, it is designed to enter Lost Link Procedure, following an operator-defined lost link route whilst trying to re-establish a link.

Exhibits, 66, 67, 68, 69, 70 and 71.

1.4.42. **VMSC Monitor**. An in-built VMSC monitor compares the health status of the two computers (Side A and B) and will determine which side to utilise, with Side A having primacy in normal operation. The VMSC monitor receives a 'stay alive' signal from both sides of the VMSC, which provides a regular 'heartbeat' update to the VMSC monitor to indicate that it is operational. This is a simple signal which does not indicate flight mode status. Therefore, on 24 Mar 2017 the monitor detected that Side A was no longer functional, but was not able to determine whether Side B could actively control the AV. VMSC Side B was operational, 'alive' and awaiting a command to change modes from standby to take-off, which will only occur as part of the take-off sequence. As Side B was operational, despite being in the incorrect flight mode, there was no reason for the monitor to switch to RFC. Exhibit 61

1.4.43. **Flight Modes**. The VMSC has a number of modes: standby, service, take off, Fly to Coordinate (FTC), and route. After power has been applied to the AV, the BFS is completed and the PATE is disconnected, the VMSC will remain in standby mode until it receives a command to enter a new mode. These commands are received by the independent sides of the VMSC through the data-links; if no data-link is connected on either band to either side, then the unconnected side of the VMSC cannot receive the command to change flight mode. Exhibits 72, 84 and 85.

1.4.44. Figure 15 is a diagram representing the Ethernet connections in the AV between the VMSC and the data-link interface, the User Inter-face Units (UIUs) . The WB and NB UIUs, housed in the Air Data Terminal, are independent and both use Ethernet Field Programmable Gate Arrays (FPGA) to connect to the independent sides of the VMSC; a total of four connections. The BIT codes 644 and 649 mean no Ethernet connection to the data-link UIU has been established to one side of the VMSC, Side B as illustrated.

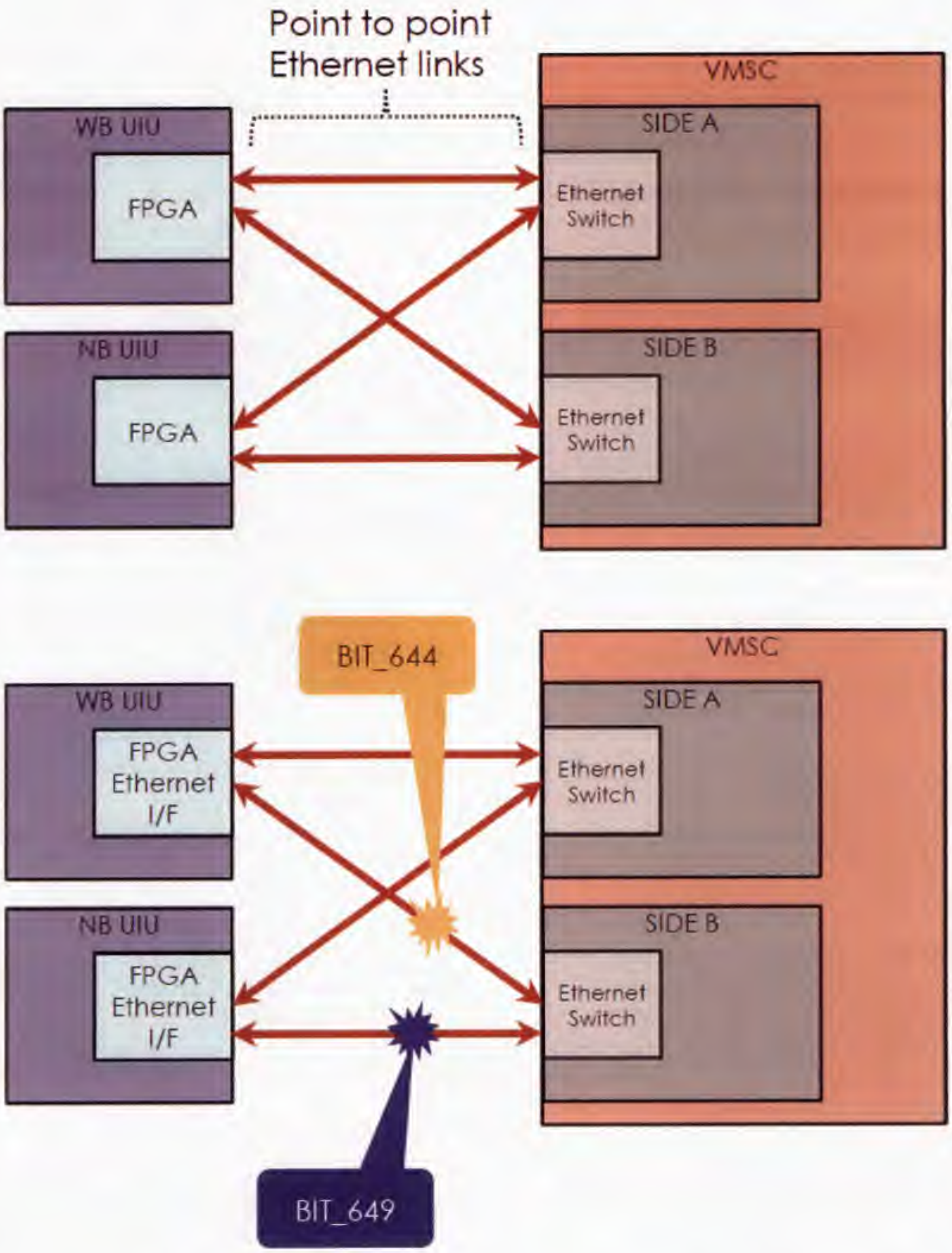

Exhibit 86

Figure – 15 Diagram of Ethernet connections between VMSC and data-links (UIUs).

Exhibit 84

Exhibit 85

1.4.45. **No Data Link Communication**. The data links between the GCS and the VMSC are established as part of the BFS. This is an automated connection and check carried out by test computers in the PATE. Any failure of the data-link is reported as a warning BIT code to the PATE Operator at the conclusion of the test. There are 2 BIT codes that relay this information: BIT_644 (DL_WB_NO_COMM) and BIT_649 (DL_NB_NO_COMM).

Witness 04
Witness 05
Witness 06
Witness 07

1.4.46. **Pre-Flight**. On 24 Mar 2017 the PATE Operator confirmed BIT codes 644 and 649 during the BFS as present on VMSC Side B only, which was reported to the GCS crew via radio. The P2 acknowledged the codes, but as they were a regular occurrence (as detailed in para 1.4.18) and believed to be related to other pre-sortie activity, the crew proceeded with the take-off. Therefore, the sortie continued with no data-link communication to VMSC Side B. Exhibits 1, 32, 3, 4, 5 and 25.

Exhibits 25, 26, 52, 53, 54, 55, 56, 49 and 57.

1.4.47. When the active Side A of the VMSC failed over to the redundant Side B, all control of the AV was transferred to Side B. However, Side B was in standby mode and had not received the command informing it that the AV had taken off and that it was at altitude over Cardigan Bay. Consequently, there were no active commands from Side B to the flight control system to keep the AV in level flight; this is supported by the WCA presented in the last minute of flight relating to servos and ADU, as Side B was processing data that should not be correct if it was still on the ground (see Figure 15).

1.4.48. **Conclusion**. The BFS concluded with the presence of BIT codes 644 and 649 indicating that there was no communication on either the wide or narrow band data-links to VMSC Side B. Therefore Side B did not receive the command to change modes and remained active but in standby. The Panel believed that had VMSC Side B been in the correct mode, then the failover from Side A to Side B would have occurred in accordance with the original design intent; Side B would have taken active control of the AV. The Panel considered that Side B being in standby, to be a **Contributory Factor**, and the Panel considers the inability of the system to determine the flight mode of the different sides of the VMSC as a **Contributory Factor**.

1.4.49. **Recommendation: The Panel recommends that the Head Unmanned Air Systems should task Thales to re-design the Vehicle Management System (VMS) to enable it to determine whether the redundant side of the Vehicle Management System Computer (VMSC) is in the correct mode and capable of actively controlling the Air Vehicle (AV).**

1.4.50. **Recommendation: The Panel recommends that the Accountable Manager (Military Flying) should issue technical information and advice about the Built In Test (BIT) codes 644 and 649 in extant technical documentation and operator information informing users of their significance.**

FURTHER ANALYSIS

1.4.51. **The History of BIT Codes 644 and 649**. The cause of the loss of WK043 was the failover of the VMSC Side A coincident to the redundant VMSC Side B being in standby (and therefore not actively flying the AV). Whilst there was an issue with Side A, the system was designed with redundancy and the AV should have remained in the control of the GCS crew with Side B active. The BIT codes reported before take-off warned of no communication with Side B, but the sortie was continued, as both the PATE Operator and GCS crew were of the impression that the codes were acceptable. The following section aims to identify why, historically, flights continued with these BIT codes present.

1.4.52. **Narrative Fault Reporting F760s**. The BFS concludes with the AV being connected via an umbilical cable to the PATE. The PATE computer runs through a series of processes that test individual systems on both Side A and Side B of the VMSC and other systems. At the completion of each stage the PATE Operator may be presented with a BIT code and a brief description. These can either result in rerunning that segment of the test to clear the fault, or the Operator seeking help from Systems Engineering[16] or the Royal Electrical and Mechanical Engineers (REME)[17].

1.4.53. The frequency of occurrence of BIT code 644 resulted in the submission of a fault report using a standard form, an F760, on 7 Mar 2013 by UTacS. The response was provided in a Fault Investigation Report form, a F761, which was released 17 Jun 2014. The response included information about testing conducted by Ferranti and ESL; it stated that the fault would clear once Side B become the 'active side' and if **either** BIT Code was present at the end of the pre-flight scripts, it was acceptable to ignore. Exhibit 87

1.4.54. The F761 Fault Investigation Report was the first time that BIT code 649 was mentioned in conjunction with BIT code 644. The text stated that either code is acceptable, but it did not explicitly state that disregarding both codes at the same time is acceptable. This is significant, as with only one of the codes, the VMSC will have an established data-link on one band (WBDL or NBDL) and will therefore receive the commands to change mode. This is covered in more detail in paragraph 1.4.43.

1.4.55. **F761 Technical Information and Proposed IETP Update**. Following the technical information in the F761 there was a proposal to update the IETP to promulgate this information. However, this specific update was never included in any subsequent versions of the IETP. Furthermore, the IETP does not make specific mention of BIT codes 644 <u>and</u> 649 in the Maintenance and Pilot Fault Lists[18]. Exhibits 47, 66, 67, 68, 69, 70 and 71.

1.4.56. There was a new maintenance procedure; an IETP Data Module (DM)[19] incorporated in IETP Version 5.1, which was released on 19 Aug 2013. This DM instructed technicians to replace the Air Data Terminal (ADT) and the VMSC should BIT codes 644 <u>and</u> 649 persist. This DM has been in all subsequent issues of the IETP, including versions 9.1 and 10.0, which were the versions in use on 24 Mar 2017. However, the Panel has been unable to find any evidence that this maintenance procedure was known about or followed by personnel at WWA. The Panel considered the lack of published technical information about BIT code 644 and 649 was a **Contributory Factor**. Exhibits 88, 89, 90, 91 and 92. Exhibit 87

1.4.57. **Problem Report and Issue Tracking**. Issues with the VMSC or data-links were tracked through a Thales database as a Problem Report (PR). The frequency of BIT code 644 was logged as a PR, with the proposal to update the IETP with the information from the original F761. However, this proposal was superseded by the later proposal to update the PATE test procedures (to prevent the cause of the BIT codes, which was believed to be an Ethernet switching issue). These changes were to be included in PATE software update Version 1.6.1. Exhibit 93

1.4.58. Again, this proposal was superseded by even later changes to the PATE software following a review between Thales and ESL in Oct 2014. These final updates were incorporated into PATE software Version 2.3.7 in Jul 2015; the PR was formally logged as closed in Dec 2015 on the authority of Thales Design Authority (DA) based on evidence gathered before the flight trials of the ES2 build standard were concluded. Exhibits 93, 94 and 95.

[16] For industry personnel

[17] If being operated by the RA

[18] The MFL and PFL list all of the identification codes of faults that may occur and be presented on the PATE or GCS

[19] DM - MK1 RPA-CE2-11-00-0001-420A-A: Fault Isolation Procedure for the Air Data Terminal (ADT) (BIT Code 644 & 649)

1.4.59. **VMSC No COMM**. Despite changes to the PATE, VMSC communication issues continued to be reported by all users throughout 2013 to 2017 as F760s. There were 2 x F760s from the WK Fce during deployed training in Apr 2016 that report the presence of BIT Codes 644, and there have been a further 22 x F760s raised since 2013 that were general "VMSC NO_COMM" faults. Thales identified a range of reasons for the generic VMSC failures from faulty switching units, to blown fuses to defective capacitors, but these may not be the causes of the original fault. However, only a small portion of the total flights with BIT codes 644 and/or 649 were reported.

Exhibit 79

Exhibit 42

1.4.60. Figure 16 captures the key dates for the reporting of BIT code 644 and subsequent proposed and completed actions to address the fault. It also contains the pertinent reports by both RA and WWA WK activity.

Date	Location	Event
07/03/13	WWA	The original F760 was raised: 760/WK/UTACS/WWA/2013/002, against VMSC #1024, for "DL_WB_NO_COMM" on the VMSC B fault list.
13/03/13	Thales	Thales raised Problem Report WKSYS1183.
17/04/13	32 RA WKSP	760/IUAS/0017/13 Fault code "DL_NB_NO_COMM" displayed in VMSC B fault list only was raised by the RA.
19/08/13		DM - MK1 RPA-CE2-11-00-0001-420A-A Fault Isolation Procedure for the Air Data Terminal (ADT) (BIT Code 644 & 649) incorporated in IETP Version 5.1.
10/04/14	Thales	WKSYS1183 was assigned for resolution in the PATE "Flight Scripts" by Elbit, however a "Mission Scripts" was developed which addresses the problem.
17/06/14	Thales	The response to the original F760 was received as a F761. Subsequently UFR1368 raised for IETP.
08/01/15 to 30/04/15	WWA	Between 8 Jan 15 and 30 Apr 15 there were 9 flights at WWA with both BIT codes. These were on WK004, WK002 and WK060.
10/07/15	Thales	WKSYS1183 was reported as fixed in the PATE MS update V2.3.7.
21/07/15	Thales	WKSYS1183 was accepted as resolved by Elbit, and labelled 'Solved' with a caveat to monitor through initial flight trials with the ES2 builds.
02/09/15 to 10/09/15	WWA	In Sep 15 there were another 3 flights all WK004 with both BIT codes.
10/12/15	Thales	WKSYS1183 Verification - Change made to PATE Mission Script v2.3.7. No problem seen during ES2 trials or acceptance testing, or during De-Icing testing at WWA. Thales agrees that the Problem Report can be closed.
04/04/16	AIB	UAS/CAMO/760/068/16 VMSC Fault code 644 (VMSC CPU B No Comm) raised during RA trg at AIB.
Mid 2016	WWA	Thales operators at WWA query what the BIT codes 644 and 649 mean; Sys Eng send the information from the F761 (Jun 14) and stated the codes were acceptable.
05/08/16 to 19/09/16	WWA	4 flights with both BIT codes on WK050 and WK048.
14/02/17	WWA	First VMSC version 2.20.74 with both BIT codes; WK043.
16/02/17 to 24/03/17	WWA	11 flights with both BIT codes all on WK043 (includes flight on 24 Mar 17).

Figure 16 – A timeline of events of BIT code 644 and 649 reporting and events

1.4.61. **Flights with BIT Codes 644 and 649**. Of 96 flights conducted at WWA, full flight data was available for 80. Analysis shows that 39 of the 80 flights had either or both codes recorded, and 25 of the 39 had VMSC Side B in standby. This includes data from both OCU and ES2 build standard AVs. Analysis concluded that if either BIT code 644 or BIT code 649 is present then Side B functions as normal and shadows Side A (including the flight mode). However, if both BIT code 644 and BIT code 649 are present, then Side B remains in 'standby' for the duration of the flight. Exhibit 42
Figure 17 shows flight data from WK043 Flight 607, a flight with both BIT codes, comparing the altitude and flight mode recorded by the 2 sides of the VMSC. The

altitude profile recorded is identical, but Side B does not change mode for the duration of the flight.

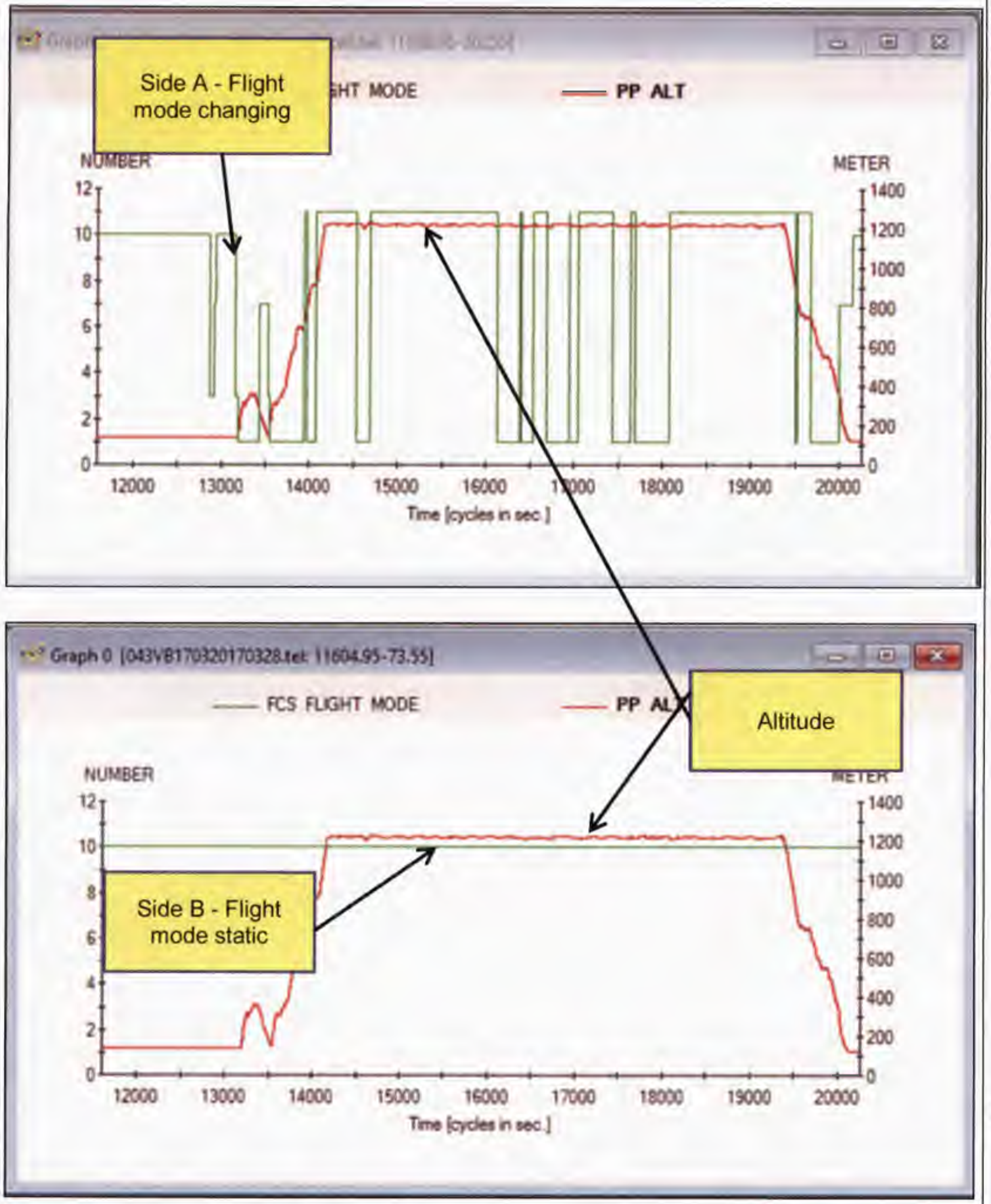

Exhibit 42

Figure 17 – VMSC Mode and Altitude against time from WK043 Flight 607.

1.4.62. **Authorising Flights to Continue with BIT Codes**. The advice from the Original Equipment Manufacturer (OEM) in the F761 was received in Jun 2014, though it was not formally published. There was an existing maintenance procedure (DM) in the IETP to rectify the AV should BIT 644 or 649 occur. However, flight data analysis has shown that between 1 Jan 2015 and 24 Mar 2017, there were 45 out of 96 flights at WWA with either one or both of the BIT codes, which indicated to the Panel that the IETP procedure was not being followed. Exhibit 42

1.4.63. **Technical Publications**. In addition to the IETP, the Panel examined the Flight Servicing Schedules and Flight Line Reference Cards (FLRCs) for authority to deviate from the extant technical procedure; no authority was found. Due to the T&E nature of the majority of WK operations at WWA, there are additional maintenance publications: Local Work Instructions (LWI) and Known Work Arounds. Again, the Panel could not find any mention of these specific BIT codes. However, there was a Technical Note drafted by Thales in May 16 that repeated the advice in the original F761, but it was the opinion of Thales that it may lead to confusion with another issue, so it was never published.

Exhibits 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109 and 87.

1.4.64. **Unexpected Failures and System Engineering Support**. The Panel could find no extant technical publication that authorised deviation from the IETP procedure; therefore, other mechanisms available to report and rectify unusual faults were examined. If a new or unexpected failure is uncovered at WWA, UTacS personnel are to contact System Engineering (Sys Eng) representatives for advice. Sys Eng personnel are based at UTacS HQ in Leicester, but can and do operate from WWA. The Panel can find no evidence of if, when and how often Sys Eng were contacted; there is no evidence of a recognised process for recording any advice or direction given by Sys Eng. Therefore, the Panel is unable to determine whether Sys Eng authorised UTacS personnel to disregard the BIT codes.

Witness 7
Witness 9
Witness 10
Witness 11
Witness 13
Witness 14
Exhibit 110
Exhibit 111

1.4.65. **Engineering Actions Post AV Acceptance by UAV Cdr**. The UAST issued 2 procedures (Leaflets 019 and 027 in the Topic 2(A)1[20]), which outline how maintenance or fault rectification can be conducted post-handover of the AV to the operating crew. However, due to the way work is divided between UTacS/Thales maintainers and operating crew, Leaflet 019 is not used by the FOO at WWA.

Exhibit 112
Exhibit 113

1.4.66. Leaflet 027 issued in Jan 2017 was applicable. This is a procedure for recording pre or in-flight events and acceptable maintenance post the coordination of the BFS. For example, a PATE Operator is able to re-run a test-script up to 3 times, if the test still fails then authorised personnel must be consulted and the incident recorded on Leaflet 027 Annex A; the Annex is to be returned to the UAST on a monthly basis. The Panel examined the 3 Annex A sheets and found no evidence this procedure was used to record instances of BIT codes 644 and 649 despite 12 occasions of both BIT codes displaying between 14 Feb to 24 Mar 2017.

Exhibits 114, 115, 116, 117 and 118.

1.4.67. The Panel examined the voice procedure and communication between the GCS and the PATE Operator. The PATE Operator does not request GCS acceptance or acknowledgement that BIT codes 644 and 649 are present, only a statement of fact is made. The P2 does not request clarification that WK043 has been declared serviceable, despite the presence of the codes; the P2 merely acknowledges what the PATE Operator has stated. During interviews, the Panel established that the GCS crew thought the codes were acceptable; the PATE Operator believed the GCS crew had a list of acceptable codes. Neither the PATE Operator or GCS crew thought they were taking responsibility for continuing with the sortie with the codes present. The Panel considers the lack of clarity of the voice procedure between the PATE Operator and the GCS crew as a **Contributory Factor**.

Witness 06
Witness 07
Witness 03
Witness 02

Exhibits 24, 13, 26 and 110.

1.4.68. It is unclear to the Panel why WWA continued to operate with these BIT codes, even seeking advice from the Sys Eng when there is a published IETP maintenance procedure to rectify these faults. Had the procedure not been adequate

Exhibit 110

Exhibit 111

[20] A Topic 2 (A) ((Topic 2(Army))) deals with the design modifications where Project teams (PT) need to promulgate specific information relating to their aircraft or equipment such as orders, special instructions and modifications. The Royal Navy and the RAF operate the same system but replace the letter in brackets with either a (N) for Navy and (R) for RAF.

there are a number of other mechanisms to highlight this to the Engineering Authority. It is also unclear who holds the risk for these flights; there is no authorised maintainer accepting the risk, and the codes occur before the UAV Cdr signs for the AV.

1.4.69. **Conclusion**. The BIT codes 644 and 649 have been displaying since 2013. Changes were made to the data-link system to prevent these codes, but there is no evidence that the changes worked, and there is no evidence that this failure was reported. An IETP maintenance procedure detailing actions to be taken when these codes appear was released in Aug 2013; it was not used on 24 Mar 2017, and the Panel found no evidence of authority to deviate from the IETP. Although the BIT codes were regularly seen during BFS at WWA, there is no documented process or authority to fly with them; the only Technical Note with any information was not published. Additionally, the processes put in place to clarify the maintenance that can be conducted during the start-up procedure were not used for reporting BIT codes 644 and 649. Had the codes been reported additional technical investigation may have been conducted, therefore the Panel considered the lack of reporting of these codes was a **Contributory Factor**.

Exhibits 66, 67, 68, 69, 70, 71 and 119.

1.4.70. **Recommendation: The Panel recommends that Unmanned Air Vehicle Tactical System Ltd (UTacS) Accountable Manager (AM) implement a documented and auditable process for seeking and obtaining technical advice from System Engineering (Sys Eng), which applies to all stages of maintenance in order to enable engineering authorities to conduct trend analysis.**

1.4.71. **Recommendation: The Panel recommends that the Unmanned Air Vehicle Tactical System Ltd (UTacS) Accountable Manager (AM) reviews the training provided to maintainers to ensure the processes for deviating from extant technical procedures are adhered to.**

1.4.72. **Recommendation: The Panel recommends that the Unmanned Air Vehicle Tactical System Ltd (UTacS) Accountable Manager (AM) review the levels of supervision of technicians to ensure extant publications are followed and deviation is correctly authorised.**

1.4.73. **Recommendation: The Panel recommends that the Unmanned Air Vehicle Tactical System Ltd (UTacS) Accountable Manager (AM) clarify the handover of responsibility for the Air Vehicle (AV) between the UAV Commander (UAV Cdr), Portable Aircraft Test Equipment (PATE) Operator and Launch and Recovery (L&R) team in order to prevent launching an unserviceable AV.**

1.4.74. **Recommendation: The Panel recommends that the Accountable Manager Military Flying (AM(MF)) implement a standard voice procedure for reporting and accepting pre-flight faults between the Ground Control Station (GCS), Launch and Recovery (L&R) team and the Portable Aircraft Test Equipment (PATE) Operator in order to clearly define responsibility and authority.**

1.4.75. **Engine RPM Spiking**. The Panel assessed the relationship between the WCA and the RPM spiking witnessed by the GCS crew during the flight and confirmed by the flight data, and found no correlation to the VMSC failover. Subsequent analysis of the reasons for VMSC failover established that it is likely to be a result of a hardware failure, and not because of the RPM spiking. This section will examine the reasons for the RPM spiking and any potential relationship to the accident in more detail.

1.4.76. **WK043 Engine and Propulsion System**. WK043 was fitted with the same engine (serial number #609) since production. It was modified with the Electromagnetic Compatibility (EMC) configuration and had a change of ECU; the ECU and VMSC software were at the correct standards on 24 Mar 2017. The EMC modification also includes an Electro-Magnetic Interference (EMI) spark plug shield, which was found to be cracked on the 25 Jan 2017. It was recorded in the AV serviceability log, (known as a F700 colloquially by UTacS maintainers) as considered to be within acceptable limits as defined in technical guidance issued by ESL. Figure 18 shows the key maintenance, upgrade and events of WK043's engine. Exhibits 120, 22, 20 and 121.

Date	Event
13/06/16 and 22/06/16	Production flights
16/06/16	RPM spikes first recorded on WK043
19/07/16	ECU removed
16/08/16	EMC modification
23/08/16	ES2 ECU fitted
01/11/16	End of single RPM spikes on WK043
09/01/17	VMSC 12FLT0008 replaced with 1024
24/01/17	Re-start of WK043 flying and RPM spikes
25/01/17	Cracked EMI shield

Figure 18 – Summary of key WK043 propulsion events. Exhibit 23

1.4.77. The majority of other WK flights with RPM spikes were limited to only a few spikes per flight. For WK043 the majority of the RPM spikes over its operational history were not sufficient to generate a caution in the GCS to alert the crew; only RPM above 9000 or less than 2000 will generate a caution. As there was no historical indication of a fault, there was no investigation and no trend analysis. The RPM data from 24 Mar 2017 (Figure 19) clearly shows that some of the spikes are high (over 9000) or low (under 2000) enough to cause a WCA, which were subsequently displayed to the GCS crew during Flight 611 and recorded in the flight data. Figure 20 shows the engine from start-up and WOT checks, to idle during towed taxi, to take-off. The first RPM spikes are seen at 1036hrs, shortly after take-off and again at 1043hrs before becoming the main feature of the RPM profile from 1047hrs. Exhibits 45, 46 and 72.

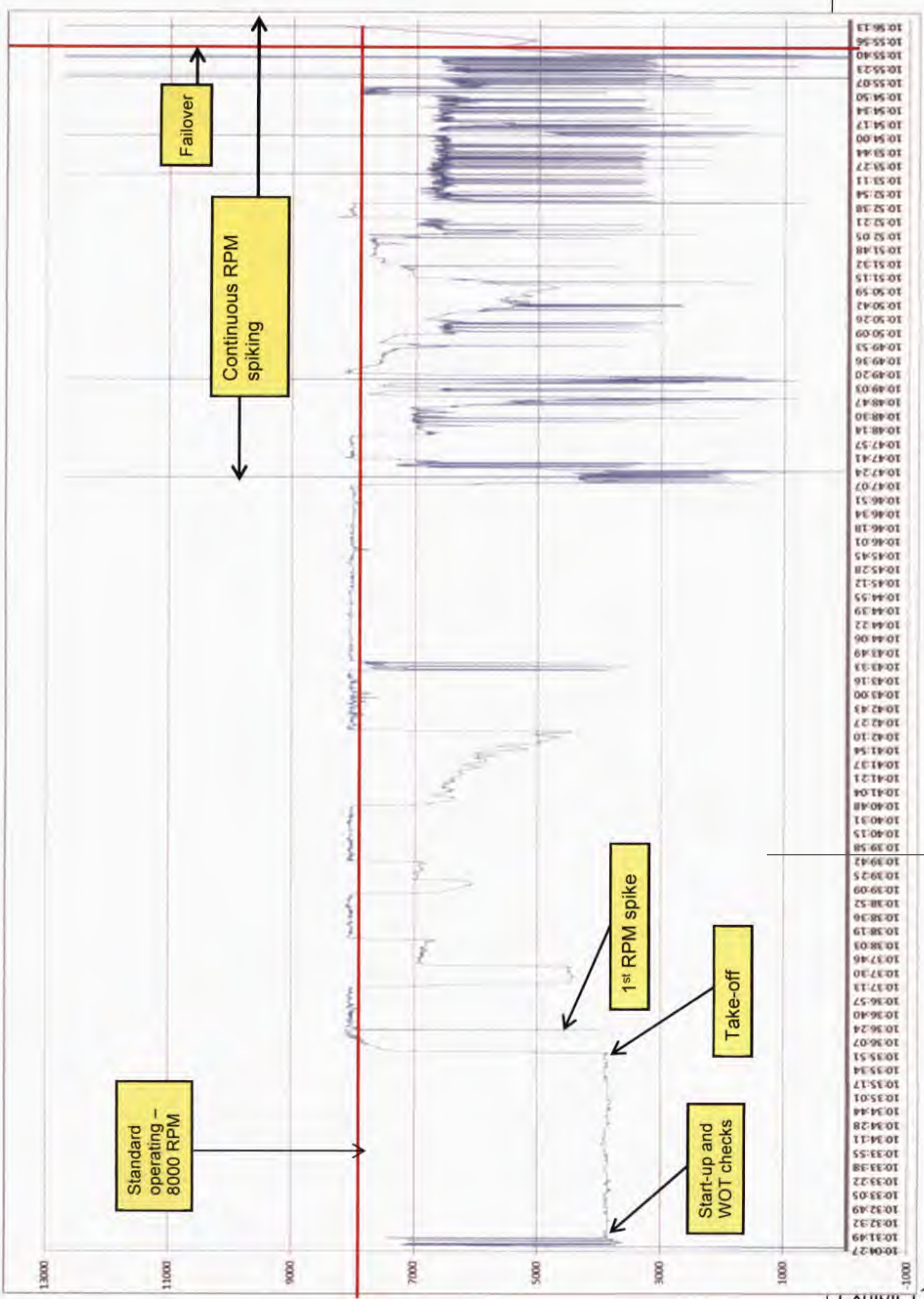

Figure – 19 Full RPM plot from Flight 611 on 24 Mar 2017.

1.4.78. In depth analysis of the flight data from the GCS shows continued abnormal behaviour of the RPM from approximately 12 minutes into the flight. Some of the reported spikes' amplitude and frequency are outside of normal engine operating parameters; it is not physically possible for the engine to go from 0 to over 12000 RPM in milliseconds. It is impossible for the engine or propeller speed to match the reported RPM spikes. The video captured by the EOP does not have the frame rate or resolution to confirm propeller RPM.

Exhibits 1, 2, 3, 4, 5, 45, 7, 10, 8, 54, 55, 56, 49 and 57.

1.4.79. The full RPM plot is at Figure 20; standard engine operating RPM is 8000 RPM, but spikes are seen at 1/3 and 1/2 values of this and at 0. The 0 RPM is likely a consequence of the programmed VMSC functional logic: if the reported RPM value is invalid according to either a reported BIT failure or an improbable fluctuation between the 50msec readings, then the "*VMSC shall set the RPM value to 0*". The Panel have determined that the readings of 0 and spikes are indicative of incorrectly reported RPM between engine sensors and the VMSC, rather than reflecting the physical operating parameters of the engine.

Exhibit 62

Exhibit 122

1.4.80. The RPM spiking, whilst not unique to WK043 was most prevalent on that airframe. Analysis of data from 83 flights of 15 different AVs provided by Thales shows 6 flights with single spikes on either Side A or Side B. By comparison, WK043 had 27 of 32 flights with RPM spikes recorded (see Figure 20). Half of the single incidents of spiking seen on other airframes were seen 0, 1/2 and 1/3 of the standard RPM range. The remaining 3 flights had momentary spikes of RPM above the maximum value of 8500 RPM.

Exhibit 72

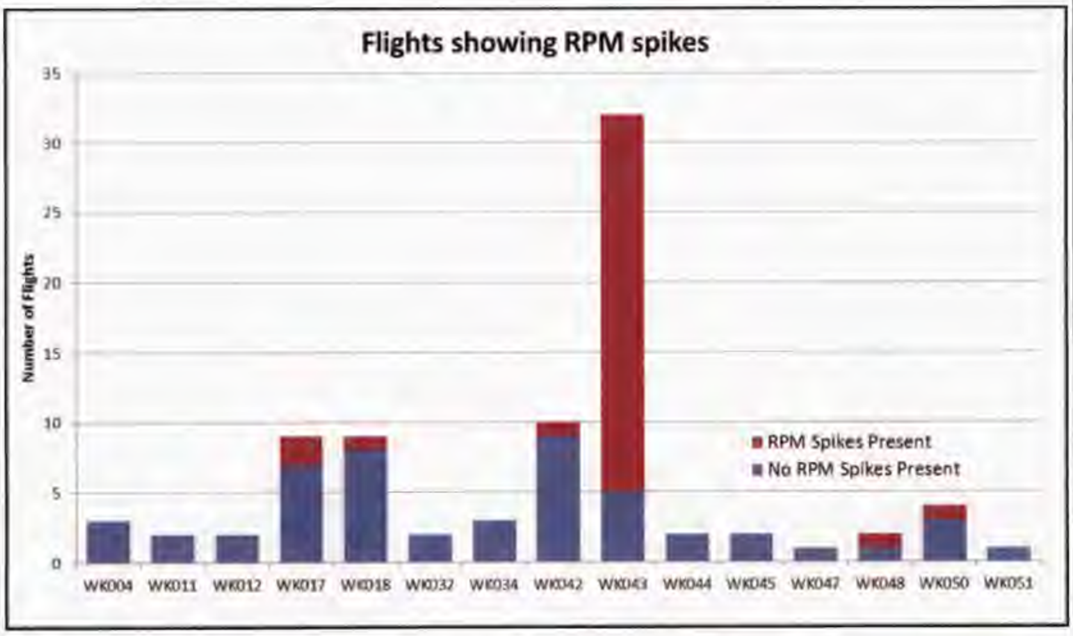

Figure 20 – Comparison of WK043 RPM spiking events with other tail numbers.

Exhibit 72

1.4.81. WK043 experienced RPM spiking from its production flight through to the crash on 24 Mar 2017; the magnitude and frequency of spiking worsening over time. The first WK043 RPM spike was recorded on 16 Jun 2016, and the AV continued to have single occurrences of RPM spiking until 1 Nov 2016. There was a short gap in flying, and the next WK043 flight on 24 Jan 2017 showed 3 RPM spikes; the following flight on 31 Jan 2017 had multiple spikes. There was another VMSC change from serial number 12FLT0008 to serial number 1024 on 9 Jan 2017; the same serial number of the VMSC that was the subject of the original F760 in 2013. However, there was no correlation between a single VMSC or build standard; the RPM spiking was seen on all four VMSCs fitted to WK043 at both OCU and ES2 builds (see Figure 21).

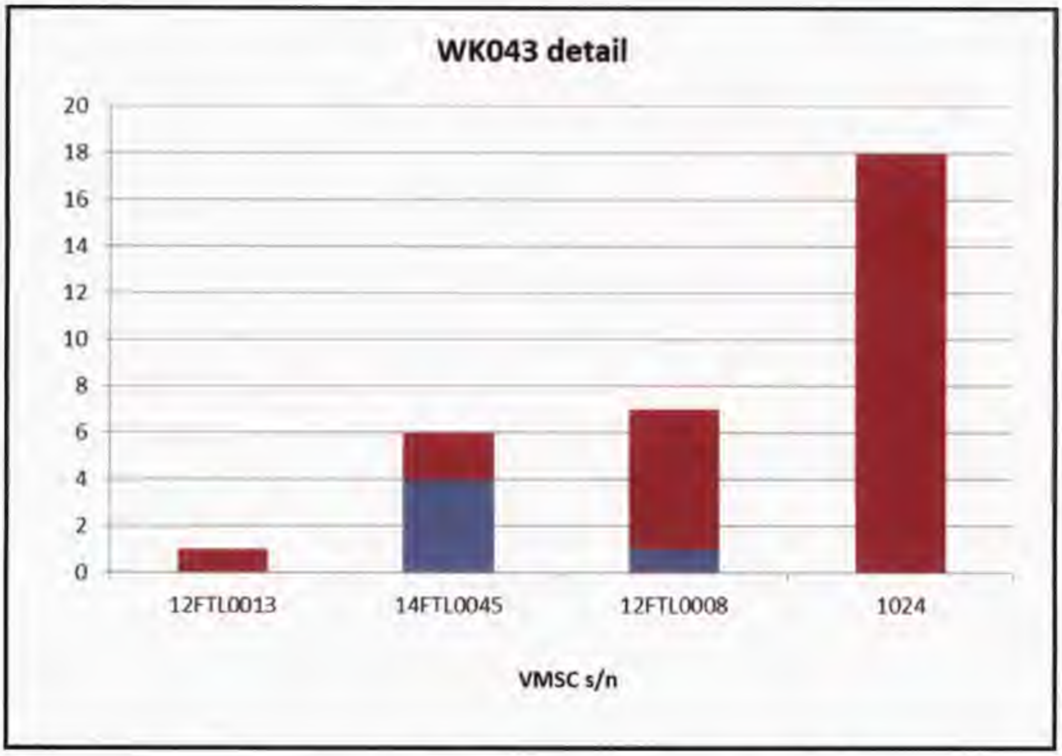

Exhibit 72

Figure 21 –The VMS computers that had been fitted to WK043 with the number of flights with RPM spiking.

1.4.82. The Panel believes that the RPM spikes are indicative of incorrectly reported RPM rather than reflecting the physical operating parameters of the engine. There is evidence for this, as flight data shows discrepancies between the data recorded on the two sides of the VMSC. There is flight data for both sides of a VMSC, with Side A reporting a single spike, but Side B reporting 2 spikes. If they were true RPM spikes rather than a potential signal or data issue, the spiking should be the same for both sides of the VMSC.

1.4.83. **Conclusion**. The RPM spiking has been seen on WK AVs other than WK043, across various VMSCs and different build standards. WK043 is the fleet leader in occurrences, with 27 out of 32 flights. There is no apparent link between which LRUs are fitted and the frequency and quantity of RPM spikes. There have been discrepancies between the data recorded by VMSC Side A and Side B. There does not seem to be an identifiable reason for the RPM spikes. There is no link to LRU changes, modifications, or to build standards or software. The Panel considers the RPM spiking to be an **Other Factor** in the accident.

1.4.84. **Recommendation: The Panel recommends that the Accountable Manager (Military Flying) *(AM(MF))* introduces post flight data and trend analysis in order to capture potential issues and anomalies that would not generate a Warning, Caution or Advisory (WCA)** to **inform both engineers and operators of issues.**

POLICY AND REGULATION

1.4.85. **Introduction**. The Panel has examined the technical reasons for the loss of WK043 and established that a failover from the active side of the VMSC to the redundant side, which was in standby mode, ultimately led to a loss of control and subsequent crash. This section will examine the policies, orders and regulations that were extant and applicable at the time of the accident.

1.4.86. WK043 was commanded by Thales and UTacS crew in supervision of RA pilots under training. They were operating under a Military Flight Test Permit (MFTP) in order to conduct ES2 conversion training, in preparation for Operational Field Trials (OFT) ahead of Release to Service (RTS) activity. WK043 was a military registered contractor operated AV from West Wales Airport (WWA). Exhibits 123, 124 and 125.

1.4.87. The Thales Flight Operations Organisation (FOO) was the management and regulatory body responsible for flight operations at WWA. The prime focus of the FOO was to conduct trials, test and evaluation (T&E) in support of the WK programme. In mid-2016, facing delays to the programme, a scoping request was made from DE&S to Thales to look at the options and assess their ability to deliver ES2 training (including live flying) under the MFTP umbrella at WWA rather than wait for RTS (more details can be found in Part 1.2). Exhibits 126, 127, 128 and 129.

CONTRACTOR FLYING APPROVED ORGANISATION SCHEME APPROVAL

1.4.88. **MAA-RA 2501 Contractor Flying Approved Organisation Scheme (CFAOS)**. In order for Thales WK flying at WWA to fully comply with MAA-RA 2501 and to be approved as a CFAOS organisation, they were required to submit a formal application, which would be endorsed by Ministry of Defence (MOD). This included submitting a Contractor Flying Organisation Exposition (CFOE), demonstrating that the Air Systems will be operated in accordance with limitations laid down in the MFTP, and ensure that the MAA is granted appropriate access for the purpose of determining initial and continued MAA-RA compliance. Exhibit 130 Exhibit 131 Exhibit 132

1.4.89. Thales was initially approved as a CFAOS organisation on 26 Aug 2015, with an updated approval issued on 11 Nov 2016, which was the extant version on 24 Mar 2017[21]. Therefore, Thales was an MAA approved CFAOS organisation when WK043 crashed in Cardigan Bay. There was an appointed Accountable Manager (Military Flying) AM(MF), an Air Safety Management System (ASMS), an Operations Manual and an MFTP; the Regulator (MAA) were content that Thales had provided sufficient evidence that they were safe to operate. Exhibit 133 Exhibit 134 Exhibit 135

1.4.90. **MAA-RA 1024 Accountable Manager (Military Flying).** The MAA-RA states '*that the AM(MF) shall act on behalf of CFAOS organisations to actively manage Air Safety via an ASMS to ensure that Risks to Life (RtL) are at least Tolerable and As Low As Reasonable Practicable (ALARP)*'. The AM(MF) is an appointed individual with legal responsibilities; the following lists the key responsibilities of the AM(MF) relevant to WK043: Exhibit 132 Exhibit 136

a. The AM(MF) is to ensure an Air Safety Management System is in place in accordance with MAA-RA 1200, in order to operate WK safely. An Air Safety Management Plan was in place.

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[21] UK/MAA/CFAOS.0014

b. The AM(MF) is to produce an Operations Manual, which conveys how the organisation meets the requirements of MAA-RAs and is safe to operate. This was covered off by the Flight Ops Organisation Flying Order Book and the compliance matrix.

c. The AM(MF) is to ensure that all flying activity is conducted in accordance with MFTP[22].

1.4.91. **MAA-RA 5202– Military Flight Test Permit**. MAA-RA 5202 states that '*MFTP authorisation of flights shall be conducted if all of the following conditions exist: where the design standard is not reflected in an extant RTS or flying outside the service environment, i.e. outside the recognised and agreed flight envelope*'. On the 24 Mar 2017, there was no extant RTS for the ES2 build standard. In order to conduct training on ES2 for RA pilots, the Type Airworthiness Authority (TAA) authorised the latest MFTP on 9 Dec 2016, which covered all flying activity that takes place at WWA. Exhibit 123 Exhibit 137

1.4.92. The MFTP lists the extant documentation in accordance with which the system must be operated in accordance with (all latest issue): IETP, FRCs, FLRCs, WK FOB, ES2 Known Issues. The Panel noted that the following: Exhibits 123, 46, 137 and 138.

a. There is no mention of the Known Problems and Work Arounds document. However, the OCU version of the document, which was attached to the P1 and P2 FRCs on 24 Mar 17, was not extant for ES2; the ES2 Known Issues document was issued instead.

b. The IETP in use at WWA was at issue 9.1, but issue 10 had been released by UAST on 30 Jan 2017 to go live at 0001hrs 7 Feb 2017. Exhibits 139, 140, 141, 142 and 143.

1.4.93. **IETP**. On 24 Mar 2017, WK043 was not being operated in accordance with the extant MFTP; WWA was using IETP issue 9.1 and not issue 10, the reasons for which are discussed further in paragraph 1.4.149. The Panel reviewed both versions of the IETP and established that the procedure for changing the VMSC should BIT codes 644 and 649 be present was in both. Furthermore, there was no additional information about flying with the BIT codes 644 and 649 in issue 10, which may have alerted maintainers to their significance. Exhibits 123, 139, 140, 141, 142, 143 and 144. Witness 11

1.4.94. **MAA-RA 1016 – Continuing Airworthiness Responsibilities**. MAA-RA 1016 explains the continuing airworthiness of a military registered air system. It states that '*registered air systems are required to be managed by an MAA approved Military Continuing Airworthiness Management Organisation (Mil CAMO)*'. The Mil CAMO supports the Aviation Duty Holders and Chief Air Engineers for their aircraft type; the WK Fce has an established Mil CAMO. For CFAOS organisations, the MAA-RA defines an Accountable Manager (Continuing Airworthiness) (AM(CAw)) as an individual responsible for running the organisation, including financial responsibility: Exhibit 145

a. **MAA-RA 1016(1)**. Identify an AM(CAw) who will have ***corporate authority*** for ensuring that all continuing airworthiness management activities can be financed and carried out in accordance with MAA-RAs.

b. **MAA-RA 1016(2)**. Aviation Duty Holders (DH) and AM(CAw) shall ensure that the tasks associated with continuing airworthiness of the Military registered

[22] From 2017 MFTP are known as Military Permit to Fly (MPTF)

air systems in their Area Of Responsibility (AOR) are managed by a Mil CAMO who is approved in accordance with MAA-RA 4941.

1.4.95. The AM(CAw) should be an identified SQEP individual and listed in the CFOE and the Continuing Airworthiness Management Exposition (CAME). The Thales WK CFOE Issue 2 was released 9 Dec 2016, but no CAME was submitted and no AM(CAw) had been identified. Thales was in the process of establishing an AM(CAw)[23]; there was no nominated individual that met all of the SQEP and financial requirements, and the CAMO activity was shared by a number of individuals, who are SQEP in their AORs. Thales has an established Continuing Airworthiness Post Holder (CAPH), listed in the CFOE, who is responsible for all continuous airworthiness activity and ensuring that the AVs are maintained in accordance with MAA- RA4050. Exhibits 146, 147, 148, 149, 150, 151 and 152.

1.4.96. **MAA-RA 4050 Continuing Airworthiness of Remotely Piloted Air Systems (RPAS)**. In addition to MAA-RA 1016, MAA-RA 4050 specific to RPAS states that for a '*Class II or III*[24] *RPAS the DDH or AM(MF) shall ensure that the air worthiness of the Air System is managed by an approved CAMO'*. The WK Fce DDH is supported by an established Mil CAM; the Thales FOO is supported by the CAPH and Design Authority, which in accordance with the MAA-RA1016, waivers them to allow them to operate without a CAMO for a period of 6 months. However, MAA-RA 1121 and 4050 states for periods over 6 months, a full CAMO must be established. Thales were in the process of establishing a full CAMO when WK043 crashed on 24 Mar 2017. Exhibit 153

1.4.97. **Thales Continuing Airworthiness Management Exposition (CAME)**. Whilst Thales had submitted a CFOE as part of the evidence to become a CFAOS organisation, they had not submitted a CAME. There was a WK Fce CAME, but this does not cover activity at WWA; it only covered WK 'forward fleet' which is those AVs directly attributed to the WK Fce. Exhibits 154, 155, 153 and 156.

1.4.98. **Compliance and Waivers**. Thales had approached the MAA CFAOS Branch and discussed the requirement for a waiver of non-compliance with RA1016, as there was no AM(CAw). The MAA CFAOS branch stated that RA1016 was under review, and due to be re-published by 31 May 2017; they also stated that they did not believe Thales needed a waiver, but the requirement for both the AM(CAw), CAMO and CAME would remain extant. Thales continued to operate with a single individual whose roles and responsibilities included design, modification, maintenance programme, monitoring fault reporting, test and evaluation and airworthiness. The Panel considered that a single individual was not sufficient to cover this vast area of responsibility. Exhibit 154 Exhibit 157

1.4.99. **Conclusion**. The Thales FOO, a CFAOS certified company, was operating under an MFTP that states the AV should be operated in accordance with the extant IETP, FRCs, FLRC and the FOB or other approved instructions. However, the incorrect issue of the IETP was in use so they were not operating in accordance with the extant MFTP, though given the content of both issues of the IETP this was considered **not a factor** by the Panel. Exhibits 139, 140, 141, 142 and 143.

1.4.100. Thales submitted a comprehensive Regulatory Article compliance matrix as part of the CFAOS application. The Panel has reviewed the matrix, all the regulatory publications and the documentation submitted by Thales in support of their Exhibit 135

[23] Thales appointed an AM(CAw) Dec 2017.

[24] The MAA classified WK as a Class III in Jun 2017.

application for CFAOS approval. The Panel conclude that less the absence of a CAME, the appointment of an individual as the AM(CAw) and establishing a CAMO, the remainder of the documentation was in order and they were compliant. The Panel **Observed** that whilst there was a single individual holding the responsibilities of a CAMO, that individual was also responsible for a broad and deep range of other design and programme responsibilities. It is the opinion of the Panel that this fell short of the stated requirement for a CAMO, and put a large burden of responsibility upon an individual who was too busy to cover the role effectively. The lack of an appointed AM(CAw) and CAME are considered **Other Factors** by the Panel.

1.4.101. **Recommendation: The Panel recommends that the Thales Vice-President Defence Mission Systems UK (VP DMS UK) should appoint a Suitably Qualified and Experienced Personnel (SQEP) Accountable Manager Continuing Airworthiness (AM(CAw)) to comply with the Military Aviation Authority – Regulatory Article (MAA-RA) 1016.**

1.4.102. **Recommendation: The Panel recommends that the Accountable Manager (Military Flying) *(AM(MF))* should produce a Continuing Airworthiness Management Exposition (CAME) for submission to the Military Aviation Authority (MAA) to comply with Military Aviation Authority – Regulatory Article (MAA-RA)4943.**

MAINTENANCE APPROVED ORGANISATION SCHEME APPROVAL

1.4.103. **MAA-RA 4800**. The MAA-RAs 4800 to 4849[25] outline the requirements for contracted maintenance organisations to gain MAA Maintenance Approved Organisation Scheme (MAOS) approval to maintain military registered aircraft. UTacS is the MAOS approved organisation for WK. Exhibit 158

1.4.104. UTacS first gained MAOS accreditation in 2015 following audits by the CAA and MAA, at UTacS facilities at WWA and Leicester in Feb 2015. Although the audit issued a number of Corrective Action Reports (CARs), UTacS went through corrective action procedures, and subsequently the MAA deemed that the implemented corrective actions addressed any non-compliances; as of 25 Jun 2015 they were awarded MAOS accreditation Exhibits 159, 160, 161 and 162.

1.4.105. **MAA-RA 4816 Maintenance Organisation Exposition**. MAA-RA 4816 states "*in order to obtain MAA approval, the contractor-run organisation must submit an Maintenance Organisation Exposition (MOE) that defines the requested scope of approval and the procedures to which they will adhere to in order to meet the requirements set by the RA 4800-4849 (MRP Part 145) series of regulations.*". Exhibit 165

1.4.106. **UTacS MOE**. The UTacS MOE Issue 10.A dated 20 Jan 2017 was extant at the time of WK043's crash. The document lists the responsibilities of key positions, outlines the safety culture and training policy for maintainers. Furthermore, it defines maintenance to encompass the replacement of an item at platform level, which is to be undertaken in accordance with the IETP or instructions when there is no IETP. The MOE also outlines the processes for reporting errors. However, the Panel established that the IETP was not being followed for BIT code 644 and 649, and the presence of these codes were not reported using the error management system. The Panel considered the non-use of the extant IETP procedure to be a **Contributory Factor**. Exhibits 163, 164, 110 and 111.

[25] Also known as the MRP 145.

1.4.107. **Continuing MAOS Approval**. As part of the continuing MAOS approval, the MAA conducted an audit in Jul 2017. A further 8 CARS were raised, including non-compliance with MAA-RA 4806 Assessment of Competence of Maintenance Staff. A number of the authorisation codes did not have a minimum standard for an individual to be endorsed to hold them. The MAA found that management staff were making subjective assessments of a candidate's competence for issuing authorisations. The audit recommended that minimum standards for qualification and competency for all authorisations be implemented. The authorisation of maintainers is analysed further in paragraph 1.4.247. Exhibit 166

1.4.108. **Conclusion**. The contractor organisation responsible for maintenance of WK at WWA was UTacS; a MAOS certified company. The company MOE states that maintenance should be carried out in accordance with the IETP or other approved instructions. The IETP maintenance procedure for BIT codes 644 and 649 was routinely not being followed, which the Panel considered was a **Contributory Factor**. Exhibits 159, 166, 162, 154 and 167.

1.4.109. **Recommendation: See Recommendation 1.4.71.**

AIRWORTHINESS AND ASSURANCE

1.4.110. **MAA-RA 1220 Project Team Airworthiness and Safety**. MAA-RA1220 states that the '*TAA should formulate an Airworthiness Strategy that defines the scope of the project, including the intended military use and a detailed approach to airworthiness management.*" This includes the production and maintenance of the Equipment Safety Assessment, which forms part of the total Air System Safety Case (owned by the ODH).

1.4.111. The Equipment Safety Assessment describes the design, provides a justification for the airworthiness of the design, details the evidence for airworthiness including appropriate test and trials analysis conducted by the Design Organisation (DO) and identifies the limitations and procedures needed to achieve the required safety level. There should be a Safety Assessment conducted by the DO, which initially demonstrates airworthiness and assists the TAA in conducting their own Safety Analysis. A Hazard Log should be generated to capture all potential accident sequences and their controls. Exhibit 157

1.4.112. **WK Equipment Safety Assessment**. The Panel reviewed the WK Equipment Safety Assessment for the OCU build standard, which is underpinned by the Design Safety Case, and had been independently assured. The VMSC is a key safety and control feature, and the Equipment Safety Assessment accurately describes the VMSC and its operation. However, it is the Panel's opinion that the assessment focuses on the internal software of each LRU, rather than understanding the interaction of the LRUs. For example, there is no mention of how the VMSC monitor functions, that it only receives the 'stay-alive' signal and is not able to tell which mode Side B is in, only that it has not 'pre-failed'. Exhibit 168 Exhibit 169

1.4.113. **Hazard Logs**. The Equipment Safety Assessment is built upon a structured argument from the safe design of the AV and ground elements up to how the system is maintained and operated. At the core of the argument is a review of all the potential accident sequences, failure mechanisms and hazards associated with operating the system: Exhibits 168, 169 and 126.

"It is UAST belief, with a high confidence, that all Air and Ground Hazards linked to the operation of the WK OCU system have been identified through the Hazard Review meetings and Air Hazard Log Review meetings held since

the Programme commenced. In particular, the end-to-end reviews of the Hazard Logs, Fault Trees and safety assessments contained in electronic hazard log (eCassandra)."

1.4.114. The failure of the VMSC is a key hazard, which can lead to an accident. The VMSC already included designed safeties; it had redundancy (Side B and Reversionary Flight Control). The safety design features were further mitigated by external 'controls', which include pre-flight testing of the VMSC by trained and authorised personnel.

1.4.115. In addition to a VMSC failure 'hazard', UAST also considered the possibility of an attempted take-off when the AV is non-airworthy. Again, there were design safeties including Built In Tests (BIT). This is further mitigated by procedural safeties including maintenance and pre-flight functional checks in accordance with approved documentation (the IETP) to ensure the AV does not take off in a non-airworthy condition. Personnel conducting these checks must be trained and authorised. Exhibit 168 Exhibit 126

1.4.116. **Conclusion**. Whilst there is no specific consideration of an AV taking off with only one side of the VMSC functioning, and no mention of BIT codes 644 and 649, there were controls and mitigations for an AV taking off in a non-airworthy condition (pre-flight functional checks and BIT). However, all of these controls and mitigation (pre-flight servicing checks and BIT) were nullified by events preceding the accident on 24 Mar 2017 as the BIT codes were ignored. Even though the DO did not consider the presence of BIT codes 644 and 649 as safety critical, the built in tests designed to warn of a failure were acknowledged as non-critical, maintenance personnel had not been following the correct procedures in the IETP for the BIT codes, and both the aircrew and maintainers were accepting the BIT codes without auditable authority.

1.4.117. The Panel **Observed** that the system and equipment safety arguments were heavily based on the Safety Integrity Levels of the LRUs, there was limited evidence of understanding the systems and systems interaction.

WK OPERATOR AND MAINTENANCE DOCUMENTS

1.4.118. **MAA-RA 1310 Air System Document Set**. MAA-RA 1310 states that '*Air Systems are highly complex pieces of equipment that can only be operated and maintained safely if there exists a set of publications that describes safe operating limitations, safe operating procedures and safe maintenance procedures'*. These publications are collectively known as the Air-System Document Set (ADS). The ADS needs to be amended through life so that it continues to reflect the as-operated and as-maintained configuration of the air system, and it is to be amended in a coherent and expedient manner. Exhibit 170

1.4.119. The extant ADS publications on 24 Mar 2017 are listed at Figure 22. The ADS is the responsibility of the TAA, who is required to:

a. Develop and maintain the ADS.

b. Define the scope of the air system aircrew publications and technical information.

c. Task OC Handling Sqn (OC HS) to provide independent judgement and advice on the acceptability of the aircrew publications in accordance with the Defence Aircrew Documentation Specifications (DADS)[26].

AP Number	Description	Issue	ANA	Date issued
AP101B-7900-14A	Flight Reference Cards	2	2,3	2/1/15
AP101B-7900-14A2	Known Problems and Work Arounds	3		3/7/16
AP101B-7900-14B	Flight Line Reference Cards	2	1,2	2/1/15

Figure 22 – The aircrew publications which were extant on 24 Mar 2017.

1.4.120. The following sections will assess whether the ADS was fit for purpose and provided sufficient information to crews to deal with emergency situations and examine the information that was being presented to them on 24 Mar 2017.

1.4.121. **Flight Reference Cards (FRCs)**. There were 21 WCA between 1047hrs and 1056hrs when the AV data-link was lost. The crew used the FRCs to manage the WCA and continue to operate the AV. The FRCs are individually issued, and the individual is responsible for ensuring they are at the correct amendment state. The P1 and P2 FRCs in use on 24 Mar 2017 were at the correct amendment state for OCU build, and contained both hand written and printed amendments for ES2 build. Exhibits 171, 172, 46 and 173.

1.4.122. ES2 FRCs were in the process of being developed; Handling Sqn, Army Aviation Standards (AAvn Stds) and the UAST had developed a set of FRCs that incorporated the changes with ES2, but they were not ready for issue. Exhibits 174 and 175.

1.4.123. The WK FRCs in use were an A5, 4 ring bound 2 inch thick booklet. The Known Problems and Workarounds, a separate booklet were also attached to the individual's FRCs. In reviewing the suitability of the FRCs the Panel noted the following:

a. The FRCs are a very large document, consisting of 263 double-sided pages of which 143 double-sided pages were dedicated to WCA.

b. There are Notes to Users in the front of the FRCs, but they do not outline the levels of severity or differences between warnings, cautions and advisories, other than to say that EMERGENCY ACTIONS printed in bold text are those that should be memorised and confirmed from the FRCs when time permits.

c. There is a discrepancy between different parts of the sections referring to alerts and not advisories:

(1)Section E1- E29 (Red fringed) will be displayed as Warnings in the GCS, but are headlined at E1 as Emergency Procedures.

(2)Section E31 (Yellow fringed cards) are Cautions but are headlined as Engine Emergency Drills

(3)Section F1 – F59 then reverts to Warning, Cautions and Advisories which is contradictory to the sections referred to in Section E of the FRCs.

[26] AP-00-001

d. The FRCs were for the original OCU standard build aircraft but had been amended 3 times since the original issue. The Panel reviewed evidence that ES2 FRCs had been developed and issued for local reproduction only. However, there was no funding approval for producing hard copies prior to 24 Mar 2017. The Panel were unable to ascertain why no local copies were produced at WWA.

e. Where there were hand-written amendments, there were found to be discrepancies between the P1 and P2 FRCs. Manuscript amendments were made in pen and pencil, with some evidence of erasing. On Page N61-N66 of P2's FRCs the whole section was crossed through and referred to a separate paper section not in the FRCs. Conversely, P1's FRCs contained no reference to another document. Exhibits 171 and 172.

1.4.124. **Conclusion**. It is the Panel's opinion that the FRCs were not user friendly, not easy to navigate and it was overly bulky for the requirements. Traditional FRCs were printed in A5 format to fit into flying clothing, but the WK crew operate in the GCS and with the amount of information contained in WK FRCs, it is the Panel's opinion that they would be better presented in an A4 format. The Panel considered this was an **Other Factor**. Additionally, checking the state of FRCs is a standard prerequisite sortie activity. The amendment state of the FRCs was checked on 24 Mar 2017, but it is the Panel's opinion that this check was not thorough enough; there were numerous discrepancies between the documents in use by P1 and P2. The Panel considered this to be an **Other Factor**. Exhibits 171, 172, 174, 175 and 43.

1.4.125. **Recommendation: The Panel recommends the Head of Unmanned Air Systems (Hd UAS) develop a set of Equipment Standard 2 Flight Reference Cards in a format that is easy to navigate, user friendly and fit for purpose to ensure crews can access critical information expediently.**

1.4.126. **Recommendation: The Panel recommends the Head of Unmanned Air Systems (Hd UAS) ensures consistent use of language for Warnings Cautions and Advisories (WCAs) within training material, Air-System Document Set (ADS) and Ground Control Station (GCS) in order to ensure the Ground Control Station crew can expediently deal with emergency situations.**

1.4.127. **Recommendation: The Panel recommends the Accountable Manager (Military Flying) (AM(MF)) ensures robust procedures exist for checking amendments to issued Air-System Document Set publications to ensure standardisation across all users.**

1.4.128. **Warnings, Cautions and Advisories (WCA)**. The WK043 accident specifically had high workload arising from the high volume of WCA, which required the crew to navigate through their inadequate FRCs. This conspired to negatively affect the ability of the crew to perform their tasks and respond to the emerging hazard. Exhibits 176, 177, 178, 179, 180, 181 and 43.

1.4.129. The number of WCA (21 in 9 minutes), how they were presented on the HCI, and then prioritised by the GCS crew (in accordance with the FRCs) was influenced by the language and information in the FRCs. The crew was overloaded and had difficulty in completing the appropriate actions in response to each WCA. However, much of the information listed for the WCA in the FRCs was not actionable by the crew; it was information only. The Panel believes that presenting WCA to the crew that they have no influence over distracted them from completing immediate Exhibits 1, 2, 3, 4, 5, 45, 7, 10 and 11. Witness 2 Witness 3 Witness 4 Witness 5 actions and assessing the situation and serviceability of the AV. The Panel considered the frequency and language of the WCA was an **Other Factor**. Witness 8

1.4.130. **Recommendation: The Panel recommends that the Head of Unmanned Air Systems (Hd UAS) tasks Thales to review and amend the frequency, relevance and crew actions of the Watchkeeper (WK) Warnings, Cautions or Advisories (WCAs) in order to reduce the likelihood of operators becoming overloaded during an emergency.**

1.4.131. **Known Problems and Workarounds**. Known Problems and Workarounds was at Issue 3 Jul 2016 on 24 Mar 2017; they are an approved document, checked by Handling Sqn, which contains workaround procedures for known errors or faults derived from information in the IETP[27]. These procedures should be incorporated into the WK ADS in the next issue, or when the fault is rectified by design and manufacture. The Known Problems and Workarounds are not a mandated publication in accordance with the MAA-RAs. The Known Problems and Workarounds are an A5 booklet, commonly attached to the rear of the individual's FRCs. Exhibits 182, 171 and 172.

1.4.132. The Panel noted that there is no mention of the BIT codes 644 and 649, although it has a section for BIT codes and others are listed and identified with additional advisory information. The lack of any information in the Known Problems and Workarounds regarding the BIT codes 644 and 649 is considered a **Contributory Factor** by the Panel. During the flight, the AI for WK043 stated the codes were due to taking the AV 'in and out of the air picture'; the AI was unaware that they were telling the crew and maintainers that there was no wide or narrow band data-link to Side B. The Panel **Observed** that information contained in the stand-alone document should be captured in the relevant mandated ADS. Exhibits 24, 25 and 26.

1.4.133. **Recommendation: See Recommendation 1.4.50.**

1.4.134. **Flight Line Reference Cards (FLRCs)**. The FLRCs for Flight Line Maintainers and Launch and Recovery (L&R) teams is equivalent to the FRCs for operating crew. They contain procedures and information in support of BFS, and launching and recovering the WK AV. They should be used to complement the IETP. They are contained in an A5 booklet. Exhibit 138

1.4.135. The Panel reviewed the FLRCs that were extant on the day of the accident and made the following observations:

a. On page A-3, point 4 states that '*These FLRCs aim to provide the best operating instructions and advice currently available. Although they provide guidance for most eventualities, they are not a substitute for sound judgement and good airmanship. Additionally, circumstances might require a detachment to depart from or modify the prescribed procedures and drills. Consequently, these FLRCs should not be regarded as a document which is to be adhered to inflexibly at all times, other than when mandatory limits are stated*'. It is the Panel's opinion that this is very open to interpretation by technicians and L&R teams, which could lead to misinterpretation and misuse.

b. On page A-3, point 5 states that '*where an item of equipment (hardware or software) fails a check or test, the appropriate technician or maintenance authority is to be informed*'.

[27] IETP v7 was the extant version when these Known Problems and Workarounds were developed

c. On page A-11, under 'PATE Operator Checks', it states that any errors or faults should be reported to REME.

1.4.136. **Conclusion**. The MFTP, MOE and CFOE all state that operations are to be conducted in accordance with extant publications and procedures, unless superseded by any authority during trials. Flight 611 was a training sortie, so the FLRCs should have been adhered too. The VMSC Side B failed its check and the appropriate maintenance authority should have been informed. Even given the belief of the DO, that the codes were not a flight safety hazard, the Panel considered the lack of reporting was a **Contributory Factor**. Exhibits 132, 123 and 163.

1.4.137. **Recommendation: The Panel recommends that the Unmanned Air Vehicle Tactical System Ltd (UTacS) Accountable Manager (AM) conduct a fundamental review of the standards and practices within engineering operations at West Wales Airport (WWA) in order to ensure compliance with policy.**

1.4.138. **Recommendation: See Recommendation 1.4.70.**

1.4.139. **Aircrew Manual**. The purpose of an Aircrew Manual is to provide military operators with comprehensive descriptive and management information of the type of air system they are operating. This should include a description of the systems and equipment, normal and emergency handling characteristics, procedures, and limitations, to enable the aircraft to be operated effectively and safely within its specified roles. This is defined in the Defence Aircrew Documentation Specification (DADS).

1.4.140. On 24 Mar 2017 there was no published Aircrew Manual for the WK AV. Exhibit 183
The Thales FOO is developing a 'Watchkeeper Pocketbook', which contains key operational and management detail that could form the genesis of an Aircrew Manual. However, this pocketbook is currently in draft, it is not endorsed and remains a broadly unregulated source of information. Exhibit 184

1.4.141. There are MAA-RAs[28] that outline the requirements for the ADS. However, it states that not all air systems will need all the documentation listed. WK006 SI (published Nov 2016) also recommended the introduction of an Aircrew Manual for the WK System.

1.4.142. **Conclusion**. The Panel considered that the publication of an endorsed Aircrew Manual would aid crews in dealing with emergencies, enhancing their knowledge of the system and be better able to diagnose issues; this was an **Other Factor**.

1.4.143. **Recommendation: The Panel recommends that the Head of Unmanned Air Systems (Hd UAS) should mandate the production of an Aircrew Manual to support the operation of the Watchkeeper (WK) system.**

1.4.144. **Operating Data Manual (ODM)**. An ODM enables aircrew to calculate performance specific to their aircraft and configuration. The ODM contains the scheduled performance and flight planning data to enable the aircrew to operate effectively, safely and in accordance with the procedures and regulations.

[28] MAA-RAs 5406 and 1310

1.4.145. An MAA audit of the WK programme and UAST in Jan 2015 also questioned the reliability of performance data used for planning and operation of the WK and other UAS platforms. The data in the ODM would aid the crew's understanding of the aircraft's performance, allowing them to quickly identify issues and assist them in dealing with an emergency more effectively. Although this is not a mandated publication, the Panel agree that an ODM should be published. However, this was considered an **Other Factor**. WK006 SI (published Nov 2016) also recommended the introduction of an ODM for the WK System, though there was no extant ODM for WK on 24 Mar 2017, it was only 5 months after the original recommendation had been published.

1.4.146. **Recommendation: The Panel recommends the Head of Unmanned Air Systems (Hd UAS) should mandate the publication of a Watchkeeper Operating Data Manual.**

1.4.147. **WK Interactive Electronic Technical Publication (IETP).** The IETP is a series of electronic documents that contains a variety of technical, safety and maintenance information. It includes description of functions of equipment, maintenance procedures, illustrated parts catalogue, servicing routines, fault lists for maintainers and pilots (MFL and PFL), operating and handling routines. Version 10.0 was authorised for use by all WK users from 0001hrs GMT on the 7 Feb 2017 and was extant at the time of the accident. However, the Panel established that WWA were operating whilst still using IETP version 9.1 on 24 Mar 2017. This is covered further at 1.4.148.d below. Exhibits 66, 67, 68, 69, 70, 71, 142, 140, 123, 139, 142, 143 and 144. Witness 11

1.4.148. The following are the Panel's assessment of the IETP:

a. **The Usability of IETP**. Users reported the IETP was not always clear, and it was difficult to find individual pages or procedures; the program is not intuitive to the user. This predominantly resulted in the user, having to utilise the search function for most queries. Witness 9 Witness 11 Witness 12 Witness 13

b. **Content of IETP**. The IETP is the principle source of all technical information for maintainers. However, users stated that although IETP had improved, there were still areas that did not contain sufficient technical information. Users also commented that they gained more knowledge from more experienced personnel than from the IETP. It was also stated that Unsatisfactory Feature Reports (UFRs) to amend or improve information took a long time to be incorporated. Witness 9 Witness 11 Witness 12 Witness 13

c. **Access to the IETP at WWA**. The technicians at WWA are limited due to only having access to two standalone laptops that host the IETP program. Both laptops were held within the flight line building at WWA and are either used there or moved to the maintenance hangar as and when required. Exhibits 185 and 186.

d. **IETP updates process at WAA**. An update to the IETP is issued formally by the UAST including a release letter with clear instructions for the date and time when the new issue is to be used. The letter is addressed all 'WK Users', but does not specifically name them. A letter from the UAST was released on 30 Jan 2017 warning of the release of IETP v10 ready for use 7 Feb 2017. However, WWA continued to use IETP v9.1, stating the Flight Line was waiting for a commercial covering letter. Delays to updating the IETP have occurred previously, but this has been due to waiting for the physical arrival of the discs containing the update. Exhibits 142, 143, 139, 140 and 141.

1.4.149. **Conclusion**. The Panel observed that the general content and layout of the IETP is not considered easy to use and lacks the depth and detail of information required. The Panel considers the IETP to be a **Contributory Factor** in the accident. Exhibit 43

1.4.150. **Recommendation. The Panel recommends the Unmanned Air Vehicle Tactical System Ltd (UTacS) Accountable Manager (AM) increase the ratio of Interactive Electronic Technical Publication access points to technicians and working locations at West Wales Airport (WWA) to improve accessibility.**

1.4.151. **Recommendation. The Panel recommends the Head of Unmanned Air Systems should amend the content and structure of information in the Interactive Electronic Technical Publications (IETP) to enable users to access more detailed information expediently.**

1.4.152. **Recommendation. The Panel recommends the Head of Unmanned Air Systems (Hd UAS) establish and follow a process to ensure all Watchkeeper Interactive Electronic Technical Publications (IETP) users formally report they have received and are using the correct version of the IETP from the date of issue.**

1.4.153. **Recommendation. The Panel recommends the Unmanned Air Vehicle Tactical System Ltd (UTacS) Accountable Manager (AM) establishes and follows a process for updating the Interactive Electronic Technical Publication (IETP) standalone terminals to include formal receipt of updates.**

SERVICEABILITY OF THE UNMANNED AIR SYSTEM

1.4.154. **Introduction**. This section considers the serviceability state of the AV at the time of the accident and the preceding weeks. The system as a whole was assessed, which includes the AV and the ground system elements and any of the ancillary equipment required to operate the AV. A detailed description of the operation of the sub-systems analysed in the following sections can be found in Section 1.3.

1.4.155. The facility at WWA was primarily set up to undertake testing, trials and evaluation (T&E), local training, maintenance and post manufacture production test flights. The ES2 Army conversion training was additional tasking on the organisation. The facility had AVs to facilitate T&E, modification and upgrades, post-production checks and the sustainment fleet in storage. Five of the AVs are in operation; they are MOD owned and allotted back to industry by UAST. Four are located at WWA with the fifth at MOD Boscombe Down for EMC trials. WK043 was one of the AVs allotted back to industry at WWA. All of the AVs at WWA are maintained by UTacS. Exhibits 187, 185 and 188.

1.4.156. The Panel examined all of the available AV and GE maintenance documentation and their archives. The Panel noted that UTacS has based their documentation and maintenance log on the traditional MOD aircraft serviceability logs the F700 system. Exhibits 189, 190, 191, 23, 192, 120, 115, 193, 194, 195, 196, 197, 198, 199, 185 and 188.

AV SERVICEABILITY

1.4.157. **WK043 AV History**. WK043 was registered on the UK Military Aircraft Register on 16 Nov 2015, and allotted to Thales on the 27 Jul 2016, with allotment number: WKR/UAV/005/16. The AV was found to have both an in date Engine Ground Exhibits 190, 23, 192, 120, Running Certificate (EGRC) and Flight Authorisation Certificate (FAC) issued by Defence Quality Assurance Field Force (DQAFF). The AV airframe had 1hr 26min flying hours (fg hrs) post production, when it was converted to Equipment Standard 2 (ES2) for trials in 19 Jul 2016. At the time of launch on 24 Mar 2017, the airframe fg hrs and engine fg hrs were recorded as 85hrs 13min and 114hrs 55min respectively. 200, 201, 202 and 203.

1.4.158. The complete AV F700 and archived log packs were assessed by the Panel, in particular the history of the Line Replaceable Units (LRUs) directly related to the potential causes of the accident, and the frequency of their replacement. The AV had several key LRUs replaced, for software updates and un-serviceability, summarised in Figure 23. The Panel cross-checked these against the on-board software log and the build list, and concluded that WK043 was fitted with the correct LRUs and software states at the time of the accident; incorrect software was **not a factor**. Exhibits 190, 23, 192, 204, 205 and 206.

LRU	Serial Numbers	Date
Power Control and Distribution Unit	#13FTL0032* #14FTL0035	03/10/16 19/07/16
Vehicle Management System Computer	#1024* #12FTL0008 #14FTL0045 (MF760) #13FTL0036 #1006	09/01/17 06/10/16 12/09/16 22/06/16
Reconnaissance Management System Computer	#0141* #0145 #0121 #0136 #1032 #0136 #1032 #FTL0033	09/01/17 10/10/16 26/09/16 19/09/16 02/09/16 02/09/16 30/08/16 15/08/16
Air Data Terminal	#00012* #00012 #0029 #046 #00024	17/01/17 12/10/16 25/08/16 22/07/16 30/06/16
High Integrity Data-Link Radio	#1021* #1004 #1022	25/08/16 22/07/16 30/06/16

Figure 23 – List of the key LRUs fitted to WK043. Note: *denotes fitted to AV at the time of the accident as detailed in the change of serviceability section.

1.4.159. The WK F700 includes an additional form, the build list, which details all of the items on the AV fitted with a serial number, including airframe, engine, LRUs and software standards. This should be updated every time a listed item is changed; the build list is used to manage the configuration of the AV in lieu of an electronic asset management system. Exhibit 23

1.4.160. The Panel noted that the software log and build list did not correspond. This error made it difficult to establish the configuration of the AV at the time of launch, but the Panel was able to use the archived change of serviceability forms to determine when items had been replaced. The Panel considers this is an **Other Factor** in the accident.

1.4.161. **Fuel**. The WK043 Flight Servicing Certificate lists the fuel state as 50kg at start-up. The flight data states there was 49.6kg at take-off, with approximately 46kg remaining at the time of the accident. Exhibits 206, 207, 208, 23, 27 and 51.

1.4.162. The DAIB investigators collected fuel samples from the fuel bowser during the triage investigation following the accident. 1710 NAS confirmed that the physical properties of the fuel, including density and total water content, were satisfactory. The chemical properties ascertained by Gas Chromatography Mass Spectrometry (GCMS) did not highlight any particular evidence of degradation or contamination with another petrol, oils and lubricant type material. Exhibit 6

1.4.163. It is the opinion of the Panel that fuel level or contamination was **not a factor** in this accident.

GROUND SYSTEM ELEMENTS

1.4.164. **Ground Control Station (GCS)**. The GCS is a self-contained unit from which the crew operate the AV. It hosts the client server and computer networks that communicate with the AV via the GDT. It contains a generator, a back-up generator and air conditioning systems. There are 5 GCS located at WWA, which are MOD owned and loaned to Thales; all are maintained by UTacS personnel. The GCS has a scheduled maintenance routine, which is detailed in the IETP. Exhibit 185

1.4.165. The GCS designated WB009 was in use on 24 Mar 2017 for controlling WK043; it was quarantined as part of the post-crash management. DAIB investigators, assisted by UTacS subject matter experts (SMEs), conducted initial assessments of its serviceability, and downloaded flight and GCS data. The Panel visited the GCS and witnessed the download of the Cockpit Voice Recording (CVR) on 24 May 2017. Exhibits 1, 2 and 3. Exhibits 13, 209 and 210.

1.4.166. The production and delivery of a GCS results in each station having multiple serial numbers allocated. This became apparent when the Panel was reviewing the GCS paperwork, and an error in archiving maintenance pages, meant the wrong GCS archive log pack was obtained during the accident triage. The correct archive log pack was subsequently requested and delivered to the Panel for assessment. Exhibit 211 Exhibits 189, 115, 193, 194, 195 and 197.

1.4.167. The GCS logbook also contains the servicing detail for the other ground elements. The GCS and other ground element BFS were signed for as completed on 24 Mar 2017. The on-board software log for WB009 states it was software standard 7.0.1 from 9 Nov 2016; the correct standard for ES2 and WK043. The Panel considers the serviceability of the GCS was **not a factor** in the accident.

1.4.168. **Ground Data Terminal (GDT)**. The GDT system is a portable, tri-pod-mounted antenna providing two independent data link systems, a WBDL and a NBDL. These provide two-way data and radio ground-to-air communications between the AV and the GCS. There are 3 sets of GDTs located at WWA, which are MOD owned and loaned to Thales; all are maintained by UTacS personnel. The GDT has a scheduled maintenance routine detailed in the IETP. There is a requirement for before and after flight servicing. Exhibit 185

1.4.169. GDT Set 3 was data-linked with WK043 and WB009 on 24 Mar 2017. The set had a BFS on the day, and was signed for as serviceable in the GCS logbook. The ground elements were set-up by 2 UTacS maintainers; a mentor and a new joiner receiving OJT. However, the Panel established that the mentor was not authorised to carry out that activity; the work was later checked and signed for by an authorised Exhibits 197, 212 and 213 Witness 7 Witness 9 Witness 13 technician. The RA L&R team that were at WWA[29] were not involved in the setup or post-crash management of the ground systems.

1.4.170. Whilst the GDT was set-up by unauthorised personnel, whilst also conducting training, there is no evidence that the GDT was not functioning correctly. However, the Panel considered this poor practice, only fully trained and authorised personnel should conduct set-up and maintenance of the WK AV and ground system elements. The Panel considered this was an **Other Factor**.

1.4.171. **Recommendation: The Panel recommends Unmanned Air Vehicle Tactical System Ltd (UTacS) Accountable Manager (AM) ensures only personnel who are correctly trained and authorised conduct the set up and maintenance of all elements of the Watchkeeper system.**

1.4.172. **Automatic Take-Off and Landing System (ATOLS).** ATOLS provides 3D position and velocity measurement for an AV to enable it to perform automatic take-off and landing. There are 2 sets of ATOLS equipment at WWA, one owned by the MOD, the other by Thales; both sets are maintained by UTacS personnel. The ATOLS has a scheduled maintenance routine detailed in the IETP. There is a requirement for before and after flight servicing. Exhibit 185

1.4.173. ATOLS Set 2 was in use on 24 Mar 2017. The quarantined set, including the Ground Radar Unit (GRU) Ground Beacon Unit (GBU) and the associated cabling were inspected and tested, by DAIB with SME assistance during the accident triage and found serviceable. However, the ATOLS maintenance logbook states that the set was out of date for a range of scheduled maintenance as of 10 Mar 2017. Exhibit 195

1.4.174. Despite the out of date scheduled maintenance and due to the nature of the accident, it is the opinion of the Panel that the ATOLS serviceability was **not a factor** in the accident.

1.4.175. **Portable Aircraft Test Equipment (PATE).** The PATE is primarily used for BFS, it can also be used to download flight and system data post-flight. There are 5 PATE laptops located at WWA, all MOD owned and loaned to Thales. There is also an industry own ground testing PATE not used for BFS. UTacS personnel maintain the PATE at WWA. Exhibit 185

1.4.176. The PATE laptop was not impounded by the DAIB team during the triage investigation. The Panel later determined that PATE laptop used on WK043 prior to the accident was serial number 0017, which was loaded with the software versions in Figure 24; all were the extant versions at the time of the accident. It is the opinion of the Panel that the serviceability and software state of the PATE was **not a factor** in the accident. Exhibits 214, 22, 20, 215 and 216.

Type	Version / Scripts
PATE software version	54.P.2.20.93
PATE flight scripts	54.PS.2.20.81
PATE mission scripts	3.0.7

Figure 24 – The PATE software on 24 Mar 2017.

[29] Under training for ES2

MAINTENANCE DOCUMENTATION

1.4.177. During the assessment of the maintenance documentation packs and archives the Panel noted the following documentation errors in addition to those already noted in the paragraphs above: Exhibits 189, 190, 23, 192, 120, 115, 193, 194, 195, 196 210, 197, 198, 199 and 185.

a. **AV Log Books**

(1)Incorrect forecasted dates on scheduled maintenance.

(2)Scheduled maintenance not being carried out at the correct periodicities without documented authority.

(3)Faults not being entered in to the Acceptable Deferred Faults (ADF) log; a cracked component was found, a change of serviceability entry raised, and a supplementary servicing raised to check for propagation, but no ADF raised.

b. **GCS Log Books**

(1)Missing Aircrew After Flight Declaration signatures and indication of serviceability state of GCS.

(2)Incorrect forecasted dates on scheduled maintenance.

(3)Scheduled maintenance not being carried out at the correct periodicities.

(4)Missing sheet closing supervisor signatures on a number of maintenance forms.

(5)Missing Erased By and Witnessed By signatures on GCS Keymat loading certificate.

(6)Incorrect use of register of control forms.

(7)Rolls Royce GCS repair report not signed.

c. **GDT Log Books**

(1)Missing maintainer After Flight signatures.

(2)Incorrect forecasted dates on scheduled maintenance.

(3)Scheduled maintenance not being carried out at the correct periodicities.

(4)Apparent serial number changes with no detailed change of serviceability sheets completed.

d. **ATOLS Log Books**.

(1)Missing maintainer After Flight Servicing signatures.

(2)Scheduled maintenance out of date.

(3)Incorrect forecasted dates on forecasted scheduled maintenance.

(4)Scheduled maintenance not being carried out at the correct periodicities.

1.4.178. **Conclusion.** The Panel **Observed** there were a number of errors in the AV, GCS and ground elements logbooks and paperwork. The Panel considered that these should have been captured by the Quality Management System and standard engineering document checks. However, these omissions and errors did not affect the serviceability of the WK AV and ground system elements. The Panel considered the errors and omissions in the logbooks were **not a factor**. Exhibit 217, 218, 219, 220, 221 and 222.

1.4.179. **Recommendation. See Recommendation 1.4.137.**

CONFIGURATION MANAGEMENT

1.4.180. The WK system is a complex mixture of ground and air elements. Each element can be further sub-divided into LRUs, which can be at different software states. The organisation at WWA is primarily for T&E; assets are modified and replaced on a frequent basis. Individual LRUs of the same type can have multiple modification states and come from different organisations. Witness 11

1.4.181. Despite procedures being in place, asset tracking and configuration control at WWA primarily relies on one post to manage, and requires that technicians correctly complete documentation. Personnel at WWA stated managing configuration is very difficult; owing to the fact that part numbers are not updated, engineering record cards or modification plates are not used, and only dymo tape labels on the casing of individual LRUs can identify the part and modification state. The Panel's review of maintenance documentation has highlighted inadequacies in relying on manually inputting serial numbers on paperwork each time a component is changed. Exhibit 223, 224, 225, 226, 227, 228, 229, 230, 167 and 23. Witness 11

1.4.182. Despite being detailed to do so, the AVs at WWA are not managed with GOLDesp[30]; the designated integrated maintenance and supply management software used by the WK Fce. In March 2016 the UAST had queried the lack of fleet visibility and configuration control at WWA, and Thales were tasked to provide timelines for the transfer of the AVs to GOLDesp, which would provide improved oversight and control of maintenance, repair and asset modification control. Exhibit 231 Exhibit 232

1.4.183. **Conclusion**. The Panel reviewed the software and asset configuration of the AV, WK043; all LRUs were at the correct software state, but the Panel was unable to confirm that the LRUs were the correct assets as listed in the logbooks, as no LRUs were recovered. The Panel considered configuration control was **not a factor** in the accident. However, the Panel considered the lack of an electronic asset management and tracking tool increased the workload on maintainers and increased the risk of the wrong LRU being fitted and is an **Other Factor**. As of Jan 2018, work was on-going at WWA to introduce an electronic asset tracker. Exhibits 200, 231, 232, 198, 223, 224 and 228.

1.4.184. **Recommendation: The Panel recommends the Unmanned Air Vehicle Tactical System Ltd (UTacS) Accountable Manager (AM) utilise a Ministry of Defence (MOD) approved asset management system to manage the serviceability and tracking of Aircraft Vehicle (AVs), Line Replaceable Unit (LRUs), ground elements and spares allocated to West Wales Airport (WWA).**

[30] Electronic asset management system

TRAINING, COMPETENCIES, QUALIFICATIONS, CURRENCY AND SUPERVISION

1.4.185. **Introduction**. Having reviewed the technical information, relevant policy and serviceability of the WK043 flight on 24 Mar 2017, this section will establish the level of training, relevant competencies, qualifications, currency and supervision of those involved in the activity by comparing recorded activity against these approved requirements.

1.4.186. **Overview**. At the time of the WK 043 accident, ES2 conversion training for military crews was in its infancy. Personnel were selected for conversion training to support Operational Field Trials (OFT), which were due mid-2017. The conversion training package was under assessment by Army Aviation Standards (AAvn Stds), to provide assurance to Commander WK Fce that the training was fit for purpose. ES2 live flying training was being delivered and supervised by Thales and UTacS Instructors at WWA; this followed ground school, synthetic training and emergency drills at the WK Training Facility (WTF), Larkhill. The RA pilots on 24 Mar 2017 were already qualified on WK, albeit on the previous OCU build standard; this was their second ES2 conversion sortie of the live-flying package.

Witness 1
Witness 2
Witness 4
Witness 5
Exhibits 22, 15, 16, 233, 19, 234, 124 and 125.

1.4.187. The MAA-RAs 2100 series cover aircrew training, qualification, competency and currency. The MAA-RAs 2300 series cover the operation of aircraft including the authorisation and supervision of flying. For operations at WWA, these were incorporated into the Thales Flying Order Book (FOB); Issue 9 was extant at the time of the accident. The FOB details the specific training, qualification, competency, currency, authorisation and supervision requirements for operations at WWA under the Thales FOO. Additionally the Crew Training Post Holder (CTPH) is responsible for producing and maintaining a 'whereabouts plan' (WAP), which provides an overview of FOO personnel currency, qualifications and competencies and their expiry dates.

Exhibits 235, 236, 132, 127, 237 and 238.

1.4.188. The Panel reviewed the qualification, competency and level of continuation training of the crew involved in the accident using the information in the Thales FOB and the Joint Helicopter Command FOB. These regulatory documents state the criteria that allow an individual to undertake the following duties:

a. Flight Authorising Officer (AO).

b. Aircraft Commander/ Captain (UAV Cdr).

c. Aircrew Instructor (AI).

d. P1 (Handling Pilot).

e. P2 (Payload Operator).

f. Flight Execution Log Author (FELA).

1.4.189. **WK043 Crew Configuration**. On 24 Mar 2017, the P1 was in the left hand seat and the P2 was in the right hand seat. The AI was directly behind the P1 and P2 positions in order to oversee their actions. In addition, WK043 had a UAV Cdr as the fourth crew-member; positioned behind the AI. This provided an extra layer of supervision for the RA student crew, with both an AI to train and a UAV Cdr to captain. Finally, WK043 had a FELA to independently log sortie activity.

Exhibit 125

CURRENCY

1.4.190. **Policy**. The Thales FOB currency requirements states that '*All UAV-pilots and UAV Cdrs must maintain flight currency*', as summarised in Figure 25. Individuals must be current to a minimum standard in 3 separate areas – live flying, simulator flying and simulator emergency drills. Exhibit 127

1.4.191. **Simulator Currency**. To remain simulator current a WK pilot is to fly as either P1 or P2 and conduct planned sorties and emergency training in the full task trainer or the hybrid rig[31] monthly, but with no more than 45 days between the P1 and P2 roles. Consecutive sessions should alternate between the P1 and P2 positions. The training is to be recorded in an individual's training folder. The Crew Training Post Holder (CTPH) is to maintain a record of emergencies practised. There are no additional requirements for the other crew roles such as UAV Cdr.

1.4.192. **Pilots Under Instruction**. The RA student pilots were not required to meet the Thales FOB currency requirements for P1 and P2. ES2 conversion training required students to be current to OCU standard and ES2 simulator current.

1.4.193. The crew qualification, competency and currency requirements stated in the FOB were broadly compliant with the MAA-RAs, however, the Panel **Observed** that qualification, competency and currency requirements as listed in the FOO FOB were not clearly defined against each specific role within the GCS. The Panel also noted that whilst there was a stated live-flying currency requirement for UAV Cdrs, there was no simulator currency requirement.

1.4.194. **Recommendation: The Panel recommends that the Accountable Manager (Military Flying) (AM(MF)) incorporates the qualification, currency and competency requirements for all Ground Control Station (GCS) crew roles, for both synthetic and live-flying in the Flight Operations Organisation (FOO) Flying Order Book (FOB).**

1.4.195. **Recommendation: The Panel recommends that the Accountable Manager (Military Flying) (AM(MF)) reviews the Ground Control Station (GCS) crew currency requirement, for both synthetic and live-flying, to ensure maintenance of an adequate level of competence and currency.**

[31] Full task trainer in the WK Trg Facility (WTF), Larkhill and the hybrid rig at UTacS Leicester

Role	Flight Currency	Recovery	Flight Requirements
P1	One flight within the previous 31 days flying as P1.	>31 days. Must fly with another current P1 supervising. The P1 supervisor may also act as a UAV Cdr or as the P2. No report required but Auth sheets are to be annotated with the nature of the flight and the UAV P1 is to record flight in log book as a currency regain flight. >60 days. Must fly a dedicated sortie in the Full Task Trainer (FTT) or hybrid rig as P1 (in addition to the monthly emergencies simulator session) before flying a check flight with a P1 supervisor as above. Report required in UAV-P trg folder. >90 days. CTPH is to convene a meeting to determine remedial training package which is to be approved by FOPH.	Data Checking Mission Upload Engine Start Taxi Take off One circuit with low overshoot Departure to operating area Establish datalinks Recover from operating area Land Shutdown
P2	One flight within the previous 60 days flying as P2.	>60 days Must fly with another current P2 supervising. The P2 supervisor may also act as a UAV Cdr or as the P1. Written report required and to be recorded in UAV-p training folder. > 90 days. CTPH is to convene a meeting to determine remedial training package which is to be approved by FOPH. > Written report is to be recorded in UAV-P training folder for recovery >90 days only	Flight requirements as above but with additional use of the payloads.
UAV Cdr	One flight within the previous 60days flying as UAV Cdr (can be either current UAV-p1 or UAV-p2).	>60 days. Must fly with current UAV Cdr supervising. The UAV Cdr supervising may also act as P1 or P2. The UAV Cdr may fly as either P1 or P2. A written report of the check flight is to be recorded in the UAV-p training folder for recovery > 60 days only.	
FELA	No competence	A Flight execution log author is to be used for non-trials flights but does not need a certificate of competence.	

Figure 25 – FOB Currency requirements.

1.4.196. **Crew Role Qualification and Competencies**. In addition to currency for P1, P2 and UAV Cdr, the Thales FOB states the requirements for individuals to hold additional roles and posts. These roles include: AO, FELA and AI. The requirements for these different roles are summarised in Figure 26. Exhibit 127

Requirements	Role					
FOO FOB (evidence 090)	FELA	AI	P1	P2	UAV-c	AO
Qualification						
Entitlement to conduct flying duties, as approved by AM(MF)			x	x	x	x
Certificate of Qualification on Type (CQT)		x	x	x	x	x
Flying Authorisers Course (FLAC) & Flying Supervisor Course (FSC)						X
Segregated Instrument Rating (IR) exam			x	x	x	x
Non-segregated IR exam and simulator skills test			x			
Competency						
CQT in Training Record Folder (TRF)		x	x	x	x	x
Certificate of Competency (CofC) to current build standard being operated in TRF		x	x	x	x	x
Signed as having read and understood FOB & extant Hot Poop	x	x	x	x	x	x
Two yearly independent competence check			x	x	x	
Currency						
One flight within 31 days			x			
One flight within 60 days				x	x	
One simulator flight within 45 days to include, practice in flight and ground emergencies			x	x		
IR procedures for flight in non-segregated airspace within 3 months			x			
6 monthly GCS evacuation drill	1	x	x	x	x	
Valid medical certificate		x	x	x	x	
Signed as having read and understood any new Hot Poop and changes to the FOB.	x	x	x	x	x	x
Signed as having read and understood the FOB and Hot Poop within the last 6 months.	x	x	x	x	x	x
FSC (and FLAC)[1] refresher training course (5 yr Validity)						x

Figure 26 – Currency requirements for Thales GCS crews[32].

UAV Commander

1.4.197. UAV Commander (UAV Cdr) is an appointed role, appointed by the Thales AM(MF). The Thales FOB states that all WK flights are to include a UAV Cdr as captain of the GCS Crew and is responsible for air safety in the GCS. A P1 or P2 position can also be the UAV Cdr, but on 24 Mar 2017, the UAV Cdr was a distinct member of the crew as an additional level of safety and supervision for training. Exhibit 127

1.4.198. **WK043 UAV Cdr Background and Experience**. The UAV Cdr on 24 Mar 2017 was an experienced UAV Cdr with over 7 years operating UAVs, having qualified as P1 and P2 for WK ES2 in Nov 2016. The UAV Cdr had experience of T&E during 30 years' service with the RAF, before starting at Thales in 2006. Witness 3 Exhibit 239

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[32] Note that the requirements for P1 and P2 have been greyed out; they were RA student crew and these requirements were not applicable for this sortie.

1.4.199. Immediately prior to WK043, the same individual was the UAV Cdr on 3 Feb 2017 when WK042 crashed, and had flown one hour as a P2 as recommended by the Military Authorised Medical Examiner (MAME) since that crash.	Exhibits 13, 22 and 20.
1.4.200. **Summary**. On the 24 Mar 2017, the UAV Cdr was an experienced UAV Pilot/ AC Comd. His Training Record Folder (TRF) and flying logbook showed that UAV Cdr was qualified, competent and current in all respects to undertake these duties. His currency was further verified by the Thales WAP and FOO Currency Tracker, showing that his currency was being managed by the Thales Crew Training Post Holder.	Witness 3 Exhibits 235, 239, 238, 240 and 241.
Aircrew Instructor	
1.4.201. An Aircrew Instructor (AI) is a SQEP individual who provides a training, checking and standardisation function to Defence Aviation to facilitate the delivery of operationally qualified crews to the Front line. Instructional ability is derived from practical experience and attendance on appropriate training courses, delivered by the Central Flying School (CFS).	Exhibits 127, 237 and 238.
1.4.202. In order to be appointed as a WK AI an individual must be an experienced UAV operator, have completed the CFS Aircrew Instructor Course (AIC), completed a Competence to Instruct course (CtoI) and have completed both a Conversion To Mark (CTM) and been issued a Certificate of Competence (CoC) on the aircraft build standard for which they will deliver instruction.	Exhibit 242
1.4.203. **WK043 AI Background and Experience**. The AI was an experienced UAV operator and former RA Soldier, with over 450hrs Hermes 450, including operational experience in Afghanistan. Leaving the Army, the AI was employed at UTacS as an AI in 2014, responsible for delivering OCU trg, before converting to ES2 and delivering ES2 training to the RA. The AI has 820hrs total on WK; 450hrs of which were instructional hours.	Witness 2 Exhibits 243, 244, 245 and 246.
1.4.204. **Summary**. The Panel found that the AI was correctly qualified and competent as defined by the Thales FOB in all respects. However, the Panel **Observed** that the AI had only completed his Conversion to Mark (CTM) on 16 Feb 2017 and therefore had limited experience on the ES2 standard aircraft, which is not ideal when instructing a new aircraft setup to relatively inexperienced pilots. However, this was **not a factor** in the accident.	Witness 2 Exhibits 243, 244, 245 and 246.
Pilot	
1.4.205. **WK043 P1 Background and Experience**. The Pilot (P1) joined the RA in 2009 and was selected for UAV training in 2011. The P1 was qualified to operate the Hermes 450 and has 501 hrs on type with 2 operational tours in Afghanistan during 2012 and 2013, prior to transferring to the WK programme in Oct 2015, which was completed in Oct 2016 with 40hrs on type.	Witness 4 Exhibits 247 and 248.
1.4.206. The P1 was selected for ES2 in late 2016 and began the Ground School at the WTF on 30 Jan 2017. On completion of theory, simulation and emergency drill training, the P1 moved to the live-flying phase at WWA. Having completed one ES2 sortie as the P2 on 22 Mar 2017.The sortie on 24 Mar 2017 was the second live ES2 sortie, but in the P1 position for the first time.	Witness 4 Exhibits 247 and 248.
1.4.207. **Summary**. The currency requirement for ES2 conversion training were that the RA pilots had to be OCU Standard qualified and current on simulator. In	

addition, the P1 had signed as having read and understood the WWA FOB; the P1 was current in GCS evacuation drills and in-date for an Aircrew medical. The Panel reviewed the P1 Training Record Folder, Flying Log book and the Army signatures sheet at WWA and found that the P1 was current and competent to be conducting training on ES2 conversion training.

Exhibits 249, 250, 247 and 248.

Payload Operator

1.4.208. **WK043 P2 Background and Experience**. The Payload Operator (P2) joined the Army in 2004, and had served within the RA in non-aviation related roles for approximately 7 years prior to being selected for UAV training. The P2 operated Hermes 450 aircraft over a 3 year period, accumulating 649hrs on type, prior to converting to WK in Oct 2016. The P2 had 40hrs on OCU build standard WK.

Witness 5
Exhibits 251 and 252.

1.4.209. The P2 was selected for ES2 in late 2016 and began the Ground School at the WTF on 30 Jan 2017. On completion of theory, simulation and emergency drill training, the P2 moved to the live-flying phase at WWA. The P2 had completed one ES2 sortie as the P1 on 22 Mar 2017. The sortie on 24 Mar 2017 was the second live ES2 sortie, but in the P2 position for the first time.

Witness 5
Exhibits 251 and 252.

1.4.210. **Summary**. The currency requirement for ES2 conversion training was that the RA pilots had to be OCU Standard qualified and current on simulator. In addition, the P2 had signed as having read and understood the WWA FOB; the P2 was current in GCS evacuation drills and in-date for an Aircrew medical. The Panel reviewed his Training Record Folder, Flying Log book and the Army signatures sheet at WWA and found that the P2 was current and competent to be conducting training on ES2 conversion training.

Witness 5
Exhibits 249, 250, 251 and 252.

Flight Execution Log Author

1.4.211. The role of the Flight Execution Log Author (FELA) is to log all the activities that occur during the flight from sortie briefing to debrief. There is no currency requirement for a FELA, but a FELA must read and sign for the FOB in the last 6 months. The FELA must also be current for the GCS evacuation drills.

Witness 8
Exhibits 127, 235 and 236.

1.4.212. **WK043 FELA Background and Experience**. The FELA is a qualified UAV pilot and trials officer with a broad scientific background. The FELA had recent operating experience as a WK P2.

Witness 8
Exhibit 253

1.4.213. **Summary**. The Panel reviewed the currencies relating to the FELA and found that the individual was compliant. With recent experience in Post-Crash Management, the Panel noted that the FELA provided the RA Pilots with clear direction on post-crash procedure, impounding documents and providing 'hot wash' statements.

Exhibit 253

Flight Authorising Officer

1.4.214. The Flight Authorising Officer (AO) is responsible for the supervision and safety of flying operations. The AO scrutinises the preparation, planning and conduct of all flights; it is a safety role. An AO is an appointed role; the AM(MF) issues a letter of delegation to the Flight Operations Post Holder (FOPH), which allows them to appoint individuals as AO in the FOO at WWA. The roles and responsibilities of an AO are detailed in MAA-RA2306, and implemented in the Thales FOB. To be eligible for appointment as an AO, an individual must be an experienced and qualified UAV pilot and have attended a Flight Authorisers Course (FLAC). The FOPH maintains a

Exhibits 132, 127, 237, 238, 254, 255, 256, 257, 258, 259, 74, 260, 261 and 262.
Witness 1

record of all those appointed as Flight Authorisers. There is no flight or simulator currency requirement for an AO.

1.4.215. **WK043 Authoriser Background and Experience**. To comply with the Thales FOB an AO is required to have completed the mandated FLAC within the last 5 years or a refresher Flying Supervisors Course (FSC) in the 5 years since completing a FLAC. The WK043 Flight Authoriser had completed the FSC in Sep 2015, so within the last 5 years. However, there is no evidence of attending the FLAC prior to the FSC. Exhibits 237, 238, 254, 255, 256, 257, 258, 259, 260, and 261

1.4.216. **Summary**. The Panel **Observed** that the AO was not qualified as defined in the Thales FOB and MAA-RAs because the evidence could not be provided. However, because of the AO's previous experience, it is the Panel's opinion that the AO on 24 Mar 2017 was competent to be an AO and was **not a factor**.

1.4.217. **Conclusion**. The crew of WK043 were all current, competent and qualified. However, there was no evidence that the AO had attended the mandatory training. The employment of an individual in an appointed role without evidence of completing mandatory training is considered by the Panel to be an **Other Factor**.

1.4.218. **Recommendation: The Panel recommends that the Accountable Manager (Military Flying) (AM(MF)) ensures the WK043 Flight 611 Flight Authoriser attends a Flight Authoriser Course (FLAC) before resuming Flight Authorising duties.**

1.4.219. **Recommendation: The Panel recommends that the Accountable Manager (Military Flying) (AM(MF)) employs a robust process for checking and recording qualifications before appointing individuals to a specific role in order to provide better visibility of qualifications and currency.**

MILITARY WK TRAINING AT WWA

1.4.220. **Background to ES2 Conversion Training**. As part of the WK Development, Manufacture and Initial Support (DMIS) contract, Thales was to requested to develop ES2 classroom training courseware to support steady state training. The Army would conduct the simulator and live ES2 flying training. Programme pressure, the delay to delivery of ES2 WK due to certification, led to UAST requesting Thales deliver all elements of the ES2 conversion in 2017. WWA was the only active WK flying location in the UK. Exhibits 132, 231, 263, 264 and 265.

1.4.221. **Courseware Development**. The ES2 conversion course initial Training Needs Analysis (TNA) was conducted by the Army in 2014, and the Thales Course Design Team developed the course from this initial TNA. WK Fce SMEs provided advice and reviewed the courseware as it was developed. The completed training course was still under review by AAvn Stds when the first course commenced in Jan 2017; the AAvn Stds team were only a few days ahead of the RA crews. The course was not fully Defence Systems Approach to Training (DSAT)[33] compliant on 24 Mar 2017, but it was developed in the 'spirit' of DSAT and is waiting for Programme Training Maturity Statement approval. The Panel considered that whilst this was not ideal, it prevented further unnecessary delays and the available SMEs considered the course was fit for purpose whilst going through the final stages of approval. Exhibits 266, 231 and 267.

[33] Defence Systems Approach to Training (DSAT) Quality Standard (QS) sets out the strategic principles to be applied to all individual training provided by, or on behalf of, the Ministry of Defence.

1.4.222. **Course Overview**. The WK ES2 Conversion course was designed to accommodate eight RA personnel on each course and last approximately 6 weeks broken down into three separate modules. Exhibits 12, 124, 125, 268, 269 and 270.

a. Ground School at the WTF Larkhill, which included: Mission Management and Planning, Controls of the AV, Payload Management, System Management and Simulator exercises.

b. Emergency Procedural Trainer at WTF, which included: Start Up Taxi and Take Off, Circuits, ES2 differences for data upload and HCI management during flight, General Handling and data link manipulation and data-link malfunctions.

c. Four Live Flying Serials at WWA. Each student pilot was to fly each serial as P1 and P2 for a total of 8 sorties over the period of the ES2 Conversion training.

1.4.223. **DSAT Compliance**. The Thales instructors developing the course did not have time to internally validate the courseware prior to the delivery of ES2 Course 1 in Jan 2017. Thales sought UAST agreement to delay courseware acceptance from Feb to May 2017, to allow them to focus on other ES2 supporting activity. This was agreed and explains the delay in signing of the Training Maturity Statement. The Panel assessed the evidence, and concluded that the ES2 operator courseware was broadly DSAT compliant and developed in line with the outline request for Thales to support the ES2 Training/ OFT Support. The Panel considered the lack of DSAT compliance was **not a factor** in the accident. Exhibits 266, 231 and 267.

1.4.224. **Ground School at WTF**. During the ground school for ES2 conversion training, the RA students received a number of centrally delivered presentations from the UTacS Instructors. During Mass Brief 1, the students were verbally briefed that operating with BIT codes 644 and 649 was acceptable; both the P1 and P2 diligently wrote this information in their note books. Students were further briefed that all other codes given from the PATE to the GCS crew required checking. Further investigation revealed that this information had been taught to the WTF UTacS instructor verbally by the Crew Training Post Holder (CTPH) at WWA during their own Instructor conversion training in Nov 2016. This information had been passed verbally by UTacS Sys Eng to the CTPH mid-2016 via telephone; the CTPH was seeking clarity on the meaning and appropriate actions to be taken due to the frequency of the BIT codes. The Panel determined that the verbal dissemination of the BIT code information from Sys Eng to CTPH to UTacS instructors onto RA student crews without a clear understanding of the significance of the codes was a **Contributory Factor**. Exhibits 271, 272, 268, 273 and 274.

1.4.225. **ES2 Trg Delivery at WWA**. To deliver this training at WWA, Thales and UAST reviewed the manpower and equipment requirements. This included a schedule of activity to meet the requirement, assurance and impact statements on the ability to deliver steady state training. A Risk Assessment[34] of ES2 training delivery against the main ES2 project delivery milestones and training at a small T&E unit concluded the following additional steps were required: Exhibits 124, 231, 266, 275, 242, 12 and 276.

a. Thales will provide approval to fly, flying operation and engineering supervision, Flight Authorisation and UAV Commanders, the Army will provide all the other required personnel.

[34] Training Risk and Hazard Analysis (TRHA)

b. Thales will require additional resource to deliver the required activity. This includes: 3 additional flying instructors, a Launch and Recovery instructor, uplift of maintenance manpower and a capability to further increase numbers of personnel during the period of additional flight trials.

c. The training would be limited to 21 RA pilots, 48 REME technicians and L&R teams.

d. All sorties to be conducted with a qualified WK AI and a qualified UAV Cdr to provide additional safety oversight.

e. Detailed programming to control the throughput of trainees and manage the workload, stress and fatigue of the flight line personnel. Exhibit 125

1.4.226. The proposed schedule of activity required Thales to accelerate the generation of the ES2 courseware, and trained 2 UTacS instructors from the WTF for ES2. However, this was only completed in early 2017 immediately prior to delivery of the ES2 Course 1 to RA Pilots, which commenced 30 Jan 2017. This prevented the instructors from gaining any more experience of the ES2 prior to then delivering training. This was evidenced in the WK043 AI's comments that the BIT codes 644 and 649 were due to 'taking the AV in and out of the air picture', and the verbal briefing of the BIT codes by UTacS instructors to the RA students.

1.4.227. **Conclusion**. The Panel **Observed** that the instructors only completed their conversion course a few weeks ahead of the first RA student crews. Additionally, the Assurance was only completed a few days ahead of the course. However, given the DO belief that the BIT codes were not safety critical, the Panel considered that this was **not a factor**. Exhibit 277

1.4.228. **ES2 Course Assurance**. Comd WK Fce directed AAvn Stds to assure that the ES2 courseware was fit for purpose in accordance with the JHC FOB. However, due to programme constraints, the AAVn Stds representative was a student on the instructors' conversion course. The assurance course and initial pilots course were run concurrently, with the latter starting only two weeks after the first. For this reason, the AAvn Stds representative did not complete the course and finish his assessment until mid-Mar 2017. As ES2 RA Cse 1 had already commenced the ground elements, a verbal report to the WK Fce Cdr was given on 20 Mar 2017 only 4 days before the accident. A formal written assurance report was submitted on 4 Apr 2017, ten days after the accident. Exhibit 43, 234, 270 and 276. Witness 16

1.4.229. **Assurance Report 4 Apr 2017**. The primary recipient of the report was the Cdr WK Fce, it was written as a military assessment of the ES2 trg and its suitability for RA crews. AAvn Stds commented on the course content and syllabus, evaluating course material and instructors, and the suitability of available training aids[35]. AAvn Stds took part in a full course and conducted live flying training. The AAvn Stds report notes the following: Witness 16 Exhibits 23 and 234.

a. '*The course has been designed without a single source document that details the differences between OCU and ES2 build standard which could lead to potential training gaps appearing during steady state operations under a RTS*'. The report recommends Thales produce a single source document that lists all changes to underpin the ES2 conversion.

[35] Watchkeeper (WK) Emergency Procedures Trainer (EPT) and Flight Simulation Training Devices (FSTDs)

b. '*The training is still reliant on OCU build standard IETP, Flight Reference Cards (FRCs) with Thales ES2 technical notes being used for the changed functionality*'. The report recommends Thales deliver ES2 information to enable completion of the ES2 FRCs and updated IETP.

c. '*Provision must be made to keep students that conduct conversion training current on ES2 to prevent skill fade and the need for further training delivery* '.

d. '*No internal validation of material prior to training delivery*'. The report recommends assurance is conducted prior to delivery on the first ES2 RA course.

e. '*The currency requirements for Industry differ from the WK Fce, but ES2 trained RA crews will need to maintain Industry standards of currency until OFT*'. However, the only place to conduct ES2 live flying currency is WWA, which is already busy with new ES2 courses, Industry currency and T&E prior to OFT.

1.4.230. There are clear indications of programme pressure, and the report noted this was articulated frequently at morning briefs during the instructors' ES2 course. The report also notes that the Thales and UTacS instructors should be able to deflect pressure from the students during their training at WWA. Witness 16 Exhibits 23 and 234.

1.4.231. **Conclusion**. The Panel considered the conduct of training at a primarily T&E unit due to programme pressures and time constraints. Delivery of the first course commenced before the assurance process was completed, which meant that the course had started before any potential changes could have been implemented. However, given the causal factors of the accident, the Panel considered this was an **Other Factor**.

1.4.232. **Recommendation: The Panel recommends that the Accountable Manager (Military Flying) (AM(MF)) has all courseware assured prior to delivery to the customer / students.**

1.4.233. **Launch and Recovery Training**. The L&R team is responsible for manoeuvring the AV prior to take-off, setting-up the ground elements, for example the arrestor stop gear; they also operate the PATE during the BFS. ES2 updates generated few changes to the general L&R process; most changes were improvements to the internal PATE systems to improve the time needed for a BFS. Witness 6 Witness 7 Exhibits 215, 278, 216 and 279.

1.4.234. RA L&R teams were to be trained by their own L&R instructors (who had previously been trained by UTacS at WWA); any RA L&R activity at WWA would be supervised by UTacS in accordance with DMIS. However, the L&R teams for UTacS and RA operate in subtly different ways. RA L&R teams were provided with an ES2 PATE update brief delivered at WTF before deploying to WWA. Exhibit 264

1.4.235. On 24 Mar 2017, a qualified RA L&R team were being supervised by UTacS flight line technicians for the take-off of WK043. The RA L&R Detachment Cdr made the following observations of the operations at WWA and specifically WK043 take-off: Exhibits 43 and 238.

a. A lack of structured interaction between the UTacS and RA L&R teams was compounded by poor communication; RA L&R teams frequently used their initiative for training opportunities.

b. RA L&R teams operate in accordance with the FLRCs, which states the AV can be released for take-off once the flaps move a full deflection. The WK043 L&R Det Cdr did not see the flaps move, so did not immediately signal release. However, the UTacS supervisor stated the V-tails had moved and released the AV. Witness 17 Exhibit 280

c. The L&R Detachment Cdr noted that WK043 accelerated quickly at take-off, which required the wing walker to take evasive action; additionally the L&R Detachment Cdr heard a high engine-note, which may have indicated an abnormally high RPM. The L&R Detachment Cdr wanted to abort the take-off and recall the AV, but was overruled by the UTacS supervisor. Witness 17 Exhibit 43

1.4.236. Although there were reported differences in the L&R procedures between RA and UTacS, the AV was successfully launched. Whilst the L&R Detachment Cdr stated the engine had an unusual engine-note. However, having analysed the flight-data, the Panel was unable to identify any other evidence to suggest there was actually a physical issue with the engine. The Panel considers that the L&R ES2 training was **not a factor** in the loss of WK043, but is discussed further in the Human Factors section.

1.4.237. **Royal Electrical Mechanical Engineers Training**. Although there were no REME technicians involved in the WK043 accident, the Panel investigated all ES2 training. There was planned ES2 training for REME technicians to be delivered by UTacS and Thales; a course had been designed. However, the WK Fce Mil CAM and CAE (Army) examined the courseware[36] and noted the changes to ES2 were software changes in the GCS and the PATE, they further determined that the course was not DSAT compliant. As the ES2 changes were limited to software updates, and this is not something REME technicians are taught, the decision was taken by WK Mil CAM not to send REME technicians to conduct ES2 trg at WWA. Exhibits 281, 124, 124, 231, 266, 275 and 282.

1.4.238. **Interagency WK Operating**. The WK operations at WWA were conducted by a mixed team of Thales and UTacS, with ad hoc military personnel. The Panel established that the organisations have subtly different roles and objectives, and consequently minor differences in their operating procedures; WWA is organised around T&E rather than for conducting continuous training. The additional sorties and subsequent maintenance required to meet the additional programme pressure was an issue raised by maintenance managers. However, this was also raised and mitigated in the TRHA with the recall of UTacS engineering personnel from elsewhere, such as Boscombe Down. Witness 4 Witness 8 Witness 4 Witness 9 Witness 10 Witness 11 Witness 13 Witness 14 Witness 6 Exhibit 43

1.4.239. The loss of WK043 highlighted the 'operating' differences between military and civilian organisations. For example the L&R Det Cdr observing the flaps and not the V-tail, RA GCS crews are authorised to set up their own GCS prior to launch, but at WWA this was done by UTacS personnel. There were no additional procedures introduced, which would have enabled RA crews to be better integrated, for example the RA L&R detachment was underutilised and did not know about the loss of WK043 until sometime after the incident.

1.4.240. In addition, there is also evidence of poor communication between the UTacS maintainers and flight-line technicians, and the FOO GCS flight crew. For example, changes in weather or equipment serviceability have required last minute

[36] Delta Identification Study

changes to sortie take-off times, which have not been communicated effectively between the organisations. This was evident on 24 Mar 17 when the GCS crew arrived at the GCS, but it was not ready and the sortie was delayed by another 17 minutes. Efficient communication was hampered by the physical location of the organisations, with GCS crew, flight planning and sortie briefings conducted in the main building, and the maintenance personnel and Flight Line Managers occupying offices in an adjacent building. Whilst there was a regular morning brief to discuss the daily flying programme, there was little evidence of pro-active communication beyond that. These issues were apparent before the arrival of a third organisation, the RA, which added a further dynamic as RA personnel were there to help conduct L&R in addition to operator training.

Witness 4
Witness 8
Witness 4
Witness 9
Witness 10
Witness 11
Witness 13
Witness 14
Witness 6
Exhibit 43

1.4.241. **Conclusion**. WK operations at WWA are complex, with a mixture of organisations and responsibilities. It was the Panel's opinion that there were clear indications of poor communication, misunderstanding and lack of information dissemination, even before RA training commenced. With all of the examples uncovered during the SI, the Panel considers poor inter-organisation communication to be an **Other Factor** in the accident.

1.4.242. **Recommendation: The Panel recommends that the Thales Head of Flying instigates a regular meeting between engineers and operators at West Wales Airport (WWA) to discuss the upcoming programme requirements, the effects on delivery of engineering and aircrew task, and to raise difficulties and concerns regarding aircraft maintenance in order to match resource to task.**

1.4.243. **Recommendation: The Panel recommends that the Thales Head of Flying introduces a process to clearly communicate all operational differences between Watchkeeper (WK) operations at West Wales Airport (WWA) and other WK operation, to include maintenance, Launch and Recovery and flying activity. This information is to be briefed to non-resident operators prior to commencing any activity at WWA.**

MAINTENANCE ORGANISATION - UTACS

1.4.244. **Training**. UTacS training strategy is centred on practical On the Job Training (OJT). However, all staff employed in maintainer roles have a technical background, though not all were aviation related. As part of their induction, new employees are shown the 'UAV Overview Training' presentation. They are then assigned a mentor for their specialisation, avionics or mechanical, who is responsible for overseeing the completion of their training.

Exhibits 283, 284, 285 and 286.

1.4.245. A training matrix defines which tasks and procedures employees must complete. Personnel complete each task at least 5 times; initially they are talked through the process by their mentor, before conducting the process under supervision, which assesses their competence. The mentor signs for completing the work until the individual is authorised. On demonstration of competence of each task, the training matrix is signed by the Line Maintenance Form 4 Holder (the Flight Line Manager) and an individual is then authorised to carry out that task without supervision. There was no evidence in the training matrix for assessing personnel's ability to use and interpret the IETP, though this is a module in the UTacS Guidelines document for Maintainer Trg Programme.

Exhibits 287, 288 and 283.

1.4.246. There is no formal WK training for UTacS personnel equivalent to a military aviation course. Personnel learn from their more experienced colleagues through

Exhibits 289, 284, 163,

OJT. However, this SI and the MAA Audit conducted in Jul 2017 have highlighted a number of training and procedural related errors, which the Panel believe would have been avoided had UTacS personnel had a more in-depth formal training programme. 159, 166 and 162. Witness 7 Witness 9 Witness 13

1.4.247. **Authorisation**. When an individual has completed their OJT and is deemed competent, they will be issued authorisations commensurate with their trade and position as determined by the Competency Assessment Board (CAB). Issuing authorisations ensures only trained and competent personnel are authorised to undertake that task. However, 'part-completed delegated Authority' can be issued if only part of the complete OJT is accomplished; the awarding of part-delegations is continuously monitored during the CABs. The CABs are held at least twice per year. Exhibit 284

1.4.248. Authorisations are recorded on an individual's Certificate of Competence form, which is signed by the individual, their line manager and then a Quality Assurance (QA) representative. Review and re-certification of an individual's certification is monitored by their line manager and the QA Team. Authorisations and competency is re-assessed on a 12-monthly basis. Exhibit 284

1.4.249. The Engineering Authorisations of the personnel involved with the preparation and launching WK043 were examined. All of the UTacS technicians were correctly authorised, in accordance with UTacS training policy. However, the Panel determined that individuals were supervising OJT tasks that they themselves were not authorised to carry out as discussed at paragraph 1.4.169. Exhibits 290, 291, 292, 293, 212, 213 and 283.

1.4.250. **Conclusion**. UTacS training is centred on OJT; there is no formal training course[37]. Personnel are authorised on experience rather than a combination of suitability, qualifications and experience. The OJT is not standardised as it is carried out by individually assigned mentors who are not formally trained instructors; there is no formal courseware or lesson plans for the various tasks new personnel must carry out as part of their competency assessment. The Panel considered the inconsistent standard of training for UTacS staff and a lack of UTacS staff understanding of the IETP to be a **Contributory Factor** in the accident

1.4.251. **Recommendation: The Panel recommends that the Unmanned Air Vehicle Tactical System Ltd (UTacS) Accountable Manager (AM) provides maintainers with a formal WK training course in order to improve the competence of UTacS maintainers.**

1.4.252. **Recommendation: The Panel recommends Unmanned Air Vehicle Tactical System Ltd (UTacS) Accountable Manager (AM) improves the relevance and effectiveness of the training for the use of the Interactive Electronic Technical Publications and other technical information in order to improve the competency of maintainers.**

[37] There is a formal WK 'Q' course for the REME.

HUMAN FACTORS

1.4.257. **Introduction**. The Panel was supported by a RAFCAM Human Factors SME to assess the training, qualifications and actions of the crew before and during the accident. In the course of the inquiry, the Panel recognised additional Human Factors to those accident Causal, Contributory and Other Factors already established. With the expertise of the RAFCAM advisor, the Panel was able to understand the fundamental Human Factor causes and provide suitable recommendations. Exhibits 294, 236 and 237.

1.4.258. **Crew Resource Management (CRM)**. CRM is a subset of aviation Human Factors; it is a set of training procedures that focuses on interpersonal communication, leadership and decision-making in the cockpit (or GCS in this instance). The WK043 crew was a 5-man team consisting of a UAV Cdr, AI, a P1 and P2 under instruction and a FELA. Whilst experienced WK operators, the ES2 build WK they were operating was new to them. The individual organisations all conduct mandatory Human Factors training, but there is no evidence that the CRM of a mixed organisation crew was considered. The mixed crew of Thales, UTacS, RA students, operating a new WK build standard with an unusually intense workload due to 21 WCA in 9 minutes, exposed collective CRM shortfalls. Exhibit 13, 25, 26, 24 and 43.

1.4.259. Throughout the flight, there were examples of poor communication; the crew was unsure of who was doing what and why. The P1 was asking about changing altitude, speed and position, but was not receiving clear responses from the AI. At the time, the AI was discussing the possibility of an engine failure with the UAV Cdr. There was confusion between the AI, P1 and UAV Cdr about when and how an emergency 'PAN' call was made to air traffic control and West Wales Radar. It took 4 minutes for the P1 to prepare and deliver a 'PAN' call; the P1 practised before sending the message, which confused the AI and UAV Cdr who thought the call had already been made. Had the initial 'PAN' call been made earlier, it is the Panel's opinion that unnecessary communication from West Wales Radar would have ceased, which would have removed an additional distraction during the confusing period of multiple recurring WCAs. Exhibit 13, 25, 26, 24 and 43.

1.4.260. Additionally, there was no explanation or discussion about why the AI instructed the P1 to send the AV to the Sea ERP and not return to WWA given the FRCs state the AV should be landed as soon as possible; though given the unknown condition of the AV the Panel believes sending the AV to the Sea ERP was appropriate. The UAV Cdr stepped out of the GCS to request engineering advice about the unusual number of WCA and RPM readings, and was not updated on progress or decisions made during the brief absence. The Panel **Observed** that there was no clear cockpit gradient, no clear leadership or delegation of tasks and that the presence of both an AI and UAV Cdr added confusion. Exhibits 294, 236, 237 and 125.

1.4.261. The Panel assessed the Human Factors training conducted by the individual organisations. The WK Fce conducts mandated individual and collective Human Factors training, as does the Thales FOO and UTacS. However, simulator training for the organisations is focussed on emergency drills, reacting to WCA and understanding the FRCs. Additionally, there was no consideration given to Human Factors or CRM during the Trials Risk hazard assessment of conducting RA training at a Thales T&E unit. The Panel considered that additional Human Factors or CRM training should be conducted during simulator sessions in order to expose crews to unusual scenarios in a safe training environment, for example how to prepare and deliver a 'PAN' call, and that it should be given due consideration when integrating mixed crews. Exhibit 43

1.4.262. **Conclusion**. During the accident on 24 Mar 17, there were identified shortfalls in CRM, especially given the mixed crew of Thales, UTacS and RA personnel. However, given the cause of the crash was a failover of VMSC Side A to Side B in standby, there were no actions the crew could have taken during the flight that would have prevented the accident. It is the Panel's opinion that the CRM was an **Other Factor**.

1.4.263. **Recommendation: The Panel recommends that the Watchkeeper Force Commander (WK Fce Cdr) review Human Factors (HF) training to include effective Crew Resource Management (CRM) to include managing cockpit gradient, distraction, and concurrent communications.**

1.4.264. **Recommendation: The Panel recommends that the Thales Head of Flying review Human Factors (HF) training to include effective Crew Resource Management (CRM) to include managing cockpit gradient, distraction, and concurrent communications.**

1.4.265. **Recommendation: The Panel recommends that the Watchkeeper Force Commander (WK Fce Cdr) integrate Crew Resource Management (CRM) training and decision-making into simulator sessions, especially during the management of aircraft emergencies.**

1.4.266. **Recommendation: The Panel recommends that the Thales Head of Flying integrate Crew Resource Management (CRM) training and decision-making into simulator sessions, especially during the management of aircraft emergencies.**

COMMON WK INCIDENTS HUMAN FACTORS

1.4.267. **Comparison to Previous WK Incidents**. One of the Panel's Terms of Reference was to assess whether there were any significant similarities to the causes identified in previous WK incidents. Whilst the Panel did not identify any significant technical similarities, there was a common Human Factors issue. Exhibits 176, 177, 178, 179, 180 and 181.

1.4.268. **Lack of system knowledge**. Across the 4 WK incidents, there is a common Human Factors theme of limitations of crew and engineering knowledge of how the AV operates, what the various alerts signify, and how to manage abnormal situations.

a. **WK031 16 Oct 2014**. In this accident, WK031 crashed on landing, as the crew selected Master Override during the landing sequence without being aware of the implications should there be a failure of one or more of the laser altimeters. In addition, the WK Student Notes for the Master Override did not include a description of the full functionality; additional information was contained in other documents. Exhibits 179, 180, 181 and 43.

b. **WK006 2 Nov 2015**. Similar to WK031, WK006 crashed on landing due to engaging the Master Override. Again, the crew were not aware of the meaning of messages displayed in the GCS. Exhibits 176, 177, 178 and 43.

c. **WK042 3 Feb 2017**. In this accident, WK042 crashed into the sea during a de-icing trial. There were indications that the crew had difficulty understanding the system operation in the final stages before the aircraft crashed. Exhibit 43

d. **WK043 24 Mar 2017**. A lack of understanding of the impact and significance of the BIT codes 644 and 649 directly contributed to the accident. Witness 1 Witness 3 Witness 9

1.4.269. During the WK043 investigation the Panel established clear shortfalls in the knowledge of WK operators and maintainers. Operators thought the BIT codes 644 and 649 were a result of taking the AV in and out of the 'air picture'. There was no evidence of consideration to the second and third order effects of the BIT codes, the combination of the BIT codes, and the resulting no data-link to Side B and what would happen to Side B if it did not receive the same information as Side A i.e. the command to change mode from standby to take-off.

1.4.270. This general lack of knowledge was compounded by poor training and a reliance on OJT from more experienced personnel (as discussed in paragraph 1.4.244), the usability, inconsistency and detail in the IETP (as discussed in paragraph 1.4.149), irregular feedback of technical information and trend analysis (as detailed in paragraph 1.4.83) and a lack of up to date published information (as discussed in paragraphs 1.4.46 and 1.4.63).

1.4.271. **Conclusion**. The WK system is a complex set of individual elements ranging from the AV to GCS to arrestor equipment. The AV and crucial data-links have multiple layers of redundancy, though without adequate technical knowledge and information, maintainers and operators were unable to fully understand the implications of the BIT codes 644 and 649. The same pattern is seen in the other 3 WK incidents, with decisions being made without having the full system knowledge. The Panel considered the current levels of published technical information to be inadequate and was an **Other Factor**.

1.4.272. **Recommendation: The Panel recommends that Head of Unmanned Air Systems (Hd UAS) evaluate the adequacy of the current level of system knowledge provided to operators and maintainers in technical publications in order to establish an appropriate level of system's knowledge for all those involved in WK operations.**

SUMMARY OF FINDINGS

1.4.273. **Causal Factors**. A causal factor is a factor that led directly to the accident or incident. Causal factors in isolation or combination with other causal or contributory factors and contextual details, led directly to the accident. The Panel identified the following causal factor:

a. The failover of the VMSC from Side A to Side B whilst Side B was in standby mode. (1.4.31).

1.4.274. **Contributory Factors**. A factor which made the accident more likely to happen, but did not directly cause it. Therefore, a contributory factor in isolation would not have caused the accident. Equally, if a contributory factor was removed, the accident may still have happened. The Panel identified the following contributory factors:

a. The failover of the VMSC Side A to Side B. (1.4.38).

b. VMSC Side B was in standby mode. (1.4.48).

c. The inability of the monitor to determine the flight mode of the different sides of the VMSC and therefore detect that VMSC Side B was not in the correct mode to actively control the AV. (1.4.48).

d. The lack of published technical information on BIT codes 644 and 649 explicitly stating the cause and consequences of the codes, and authority to deviate from the existing IETP maintenance procedure. (1.4.56).

e. There was a lack of clarity of voice procedure between the PATE Operator and the GCS crew resulting in no individual taking responsibility for continuing the sortie with BIT code 644 and 649. (1.4.67).

f. There was no formal reporting of the presence of BIT codes 644 and 649 during the BFS by personnel operating at WWA; there was no mechanism to alert the Engineering and Design Authorities to the issue. (1.4.69).

g. The IETP maintenance procedure *DM - MK1 RPA-CE2-11-00-0001-420A-A: Fault Isolation Procedure for the Air Data Terminal (ADT) (BIT Code 644 & 649)* was not being used by maintenance personnel at WWA. (1.4.106) (1.4.108).

h. The lack of any information in the Known Problems and Workarounds regarding the BIT codes 644 and 649. (1.4.132).

i. Lack of reporting. (1.4.136).

j. The general content and layout of the IETP is not considered easy to use and lacks depth and detailed information. (1.4.149).

k. The information passed from Sys Eng, to CTPH, to Instructors to RA student crews was verbal and unofficial; it informed them that operating with BIT codes 644 and 649 was acceptable. (1.4.224).

l. The inconsistent standard of training of UTacS maintainers, including any training on the use of the IETP was inadequate. (1.4.250).

1.4.275. **Other Factors**. A factor which played no part in the accident in question, but is noteworthy in that it could cause or contribute to a future accident.

a. The unmonitored RPM spiking reported by WK043, which worsened over a period of time. (1.4.83).

b. There was no appointed AM(CAw) or published CAME on 24 Mar 2017. (1.4.100).

c. The size and layout of the FRCs (1.4.124).

d. There were discrepancies between the P1 and P2 FRC amendments. (1.4.124).

e. The frequency and language of the WCA displayed to the GCS crew, and the explanation in the FRCs was inadequate. (1.4.129).

f. There is no endorsed WK Aircrew Manual (1.4.142).

g. There is no published WK ODM (1.4.145).

h. The AV configuration as detailed in the build list and software modification logs did not match due to poor aircraft documentation management. (1.4.160).

i. Unauthorised personnel were involved in setting-up ground system elements. (1.4.170).

j. An electronic asset management tool was not being used and the AV, GCS and ground equipment configuration control processes in use at WWA were inadequate. (1.4.183)

k. The FOO should not have employed an individual in an appointed air-safety role without evidence of their having completing mandatory training. (1.4.217).

l. Delivery of training at a primarily T&E unit commenced before the assurance process was completed. (1.4.231).

m. There was poor interagency communication between Thales, UTacS and RA personnel at WWA. (1.4.241).

n. There were shortfalls in the CRM in a mixed Thales, UTacS and RA crew. (1.4.262).

o. The level of system detail available to operators and maintainers was inadequate. (1.4.271).

1.4.276. **Observations**. In addition to identifying and categorising the accident factors as described above, the Panel made a number of observations. These are points or issues, identified during the course of the SI, worthy of note to improve working practices and have a positive effect on improving overall air safety. The Panel made the following observations:

a. There was a single individual holding the responsibilities of a CAMO, who was also responsible for a broad and deep range of other design and programme responsibilities. (1.4.100).

b. The WK Hazard Logs and Safety Case were reliant on the SIL of the individual LRU, and there was limited evidence of understanding the systems and system interaction. (1.4.117).

c. Information contained in the Known Work Arounds publication should be captured in other mandatory publications. (1.4.132).

d. The AV, GCS and ground equipment maintenance paperwork contained a lot of errors. (1.4.178).

e. The qualification, competency and currency requirements as listed in the FOO FOB were not clearly defined against each role. (1.4.193).

f. The ES2 conversion training instructors only completed their conversion training shortly before starting instructing. (1.4.204) (1.4.227).

g. The AO was not qualified as defined in the Thales FOB and MAA-RAs because the evidence could not be provided. (1.4.216).

h. There was no clear cockpit gradient, no clear leadership or delegation of tasks and that the presence of both an AI and UAV Cdr added confusion. (1.4.260).

Swiss Cheese Analysis

1.4.277. Reason's Swiss Cheese Analysis is a model used for risk management, based on the principle of layered defences. The layers of Swiss cheese represent the controls, mitigations and defences employed at various levels of an organisation that are in place to prevent accidents. The holes in the slices represent the weaknesses in each layer; when the holes line up there is an opportunity for an accident to occur.

1.4.278. In this instance, the levels are organisation, supervisions, preconditions and acts. The key point is normalising the acceptance of BIT codes with no auditable procedure or reference, which led to the VMSC Side B being in STBY flight mode. Although VMSC Side A failed over, the redundant Side B should have been available to take active control and it was not; this is why the AV crashed.

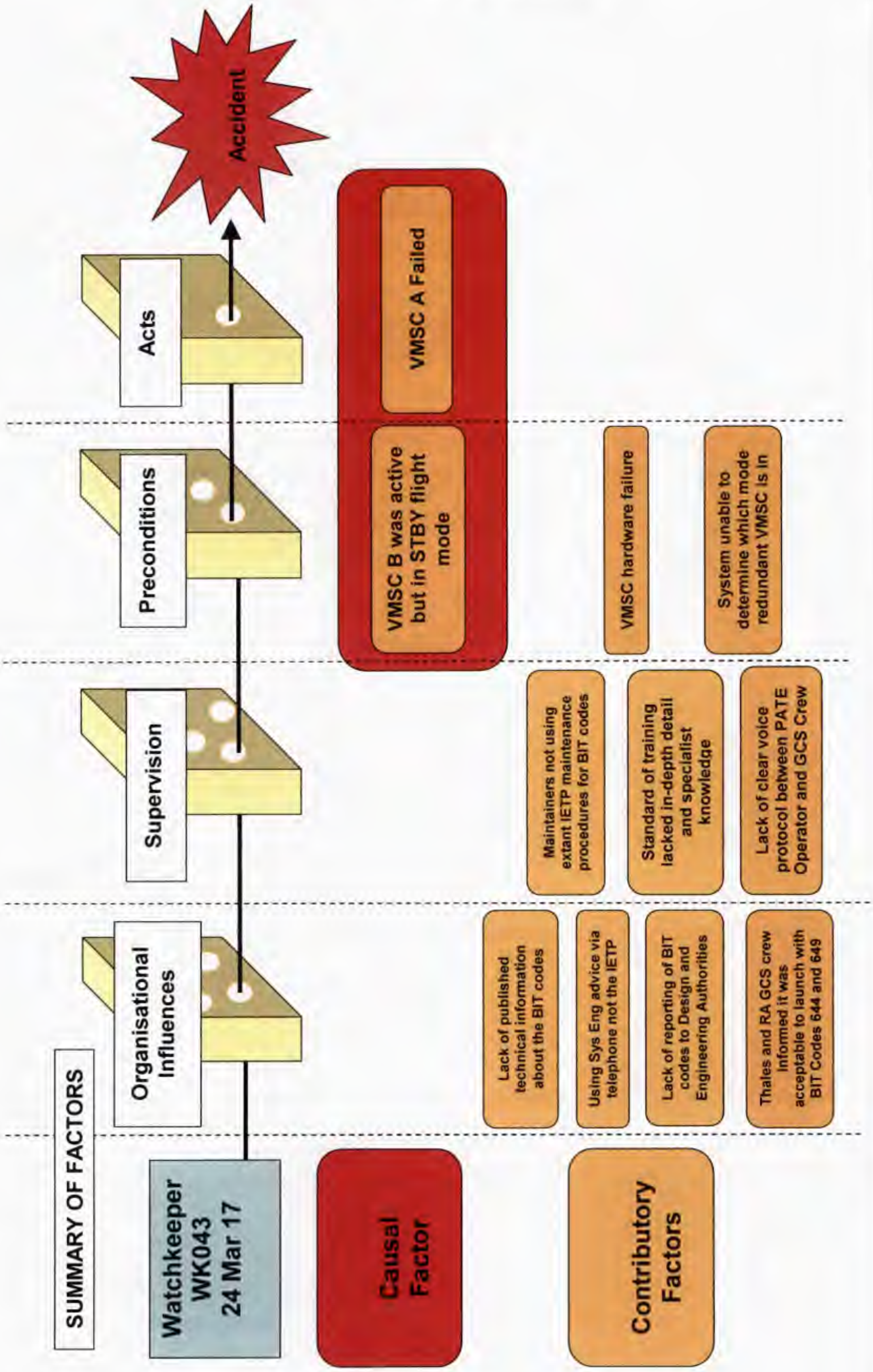

Figure 27 – Swiss Cheese Analysis of WK043 crash.

PART 1.5 – RECOMMENDATIONS

1.5.1 **Introduction**. In the report, the Panel identified 38 individual recommendations.

1.5.2 **Recommendations**. The Panel make the following recommendations in order to enhance Defence Air Safety:

1.5.3. **Thales UK**	Analysis Reference
a. The Panel recommends that the Accountable Manager (Military Flying) should issue technical information and advice about the Built In Test (BIT) codes 644 and 649 in extant technical documentation and operator information informing users of their significance.	1.4.50
b. The Panel recommends that the Accountable Manager Military Flying (AM(MF)) implement a standard voice procedure for reporting and accepting pre-flight faults between the Ground Control Station (GCS), Launch and Recovery (L&R) team and the Portable Aircraft Test Equipment (PATE) Operator in order to clearly define responsibility and authority.	1.4.74
c. The Panel recommends that the Accountable Manager (Military Flying) (AM(MF)) introduces post flight data and trend analysis in order to capture potential issues and anomalies that would not generate a Warning, Caution or Advisory (WCA) to inform both engineers and operators of issues.	1.4.84
d. The Panel recommends that the Thales Vice-President Defence Mission Systems UK (VP DMS UK) should appoint a Suitably Qualified and Experienced Personnel (SQEP) Accountable Manager Continuing Airworthiness (AM(CAw)) to comply with the Military Aviation Authority – Regulatory Article (MAA-RA) 1016.	1.4.101
e. The Panel recommends that the Accountable Manager (Military Flying) (AM(MF)) should produce a Continuing Airworthiness Management Exposition (CAME) for submission to the Military Aviation Authority (MAA) to comply with Military Aviation Authority – Regulatory Article (MAA-RA)4943.	1.4.102
f. The Panel recommends the Accountable Manager (Military Flying) (AM(MF)) ensures robust procedures exist for checking amendments to issued Air-System Document Set publications to ensure standardisation across all users.	1.4.127
g. The Panel recommends that the Accountable Manager (Military Flying) (AM(MF)) incorporates the qualification, currency and competency requirements for all Ground Control Station (GCS) crew roles, for both synthetic and live-flying in the Flight Operations Organisation (FOO) Flying Order Book (FOB).	1.4.194
h. The Panel recommends that the Accountable Manager (Military Flying) (AM(MF)) reviews the Ground Control Station (GCS) crew currency requirement, for both synthetic and live-flying, to ensure maintenance of an adequate level of competence and currency.	1.4.195
	1.4.218

i. The Panel recommends that the Accountable Manager (Military Flying) (AM(MF)) ensures the WK043 Flight 611 Flight Authoriser attends a Flight Authoriser Course (FLAC) before resuming Flight Authorising duties. 1.4.219

j. The Panel recommends that the Accountable Manager (Military Flying) (AM(MF)) employs a robust process for checking and recording qualifications before appointing individuals to a specific role in order to provide better visibility of qualifications and currency. 1.4.232

k. The Panel recommends that the Accountable Manager (Military Flying) (AM(MF)) has all courseware assured prior to delivery to the customer / students. 1.4.242

l. The Panel recommends that the Thales Head of Flying instigates a regular meeting between engineers and operators at West Wales Airport (WWA) to discuss the upcoming programme requirements, the effects on delivery of engineering and aircrew task, and to raise difficulties and concerns regarding aircraft maintenance in order to match resource to task. 1.4.243

m. The Panel recommends that the Thales Head of Flying introduces a process to clearly communicate all operational differences between WK operations at West Wales Airport (WWA) and other WK operation, to include maintenance, Launch and Recovery and flying activity. This information is to be briefed to non-resident operators prior to commencing any activity at WWA. 1.4.264

n. The Panel recommends that the Thales Head of Flying update Human Factors (HF) training to include effective Crew Resource Management (CRM) to include managing cockpit gradient, distraction, and concurrent communications. 1.4.266

o. The Panel recommends that the Thales Head of Flying integrate Crew Resource Management (CRM) training and decision-making into simulator sessions, especially during the management of aircraft emergencies.

1.5.4. **UTacS WWA should**

a. The Panel recommends that Unmanned Air Vehicle Tactical System Ltd (UTacS) Accountable Manager (AM) implement a documented and auditable process for seeking and obtaining technical advice from System Engineering (Sys Eng), which applies to all stages of maintenance in order to enable engineering authorities to conduct trend analysis. 1.4.70 1.4.138

b. The Panel recommends that the Unmanned Air Vehicle Tactical System Ltd (UTacS) Accountable Manager (AM) reviews the training provided to maintainers to ensure the processes for deviating from extant technical procedures are adhered to. 1.4.71

c. The Panel recommends that the Unmanned Air Vehicle Tactical System Ltd (UTacS) Accountable Manager (AM) review the levels of supervision of technicians to ensure extant publications are followed and deviation is correctly authorised. 1.4.72 1.4.109

d. The Panel recommends that the Unmanned Air Vehicle Tactical System Ltd (UTacS) Accountable Manager (AM) clarify the handover of responsibility for the Air Vehicle (AV) between the UAV Commander (UAV Cdr), Portable Aircraft Test 1.4.73

Equipment (PATE) Operator and Launch and Recovery (L&R) team in order to prevent launching an unserviceable AV.

e. The Panel recommends that the Unmanned Air Vehicle Tactical System Ltd (UTacS) Accountable Manager (AM) conducts a fundamental review of the standards and practices within engineering operations at West Wales Airport in order to ensure compliance with policy. 1.4.137 1.4.179

f. The Panel recommends the Unmanned Air Vehicle Tactical System Ltd (UTacS) Accountable Manager (AM) increase the ratio of Interactive Electronic Technical Publication access points to technicians and working locations at West Wales Airport (WWA) to improve accessibility. 1.4.150

g. The Panel recommends the Unmanned Air Vehicle Tactical System Ltd (UTacS) Accountable Manager (AM) establishes and follows a process for updating the Interactive Electronic Technical Publication (IETP) standalone terminals to include formal receipt of updates. 1.4.153

h. The Panel recommends Unmanned Air Vehicle Tactical System Ltd (UTacS) Accountable Manager (AM) ensures only personnel who are correctly trained and authorised conduct the set up and maintenance of all elements of the Watchkeeper system. 1.4.171

i. The Panel recommends the Unmanned Air Vehicle Tactical System Ltd (UTacS) Accountable Manager (AM) utilise a Ministry of Defence (MOD) approved asset management system to manage the serviceability and tracking of Aircraft Vehicle (AVs), Line Replaceable Unit (LRUs), ground elements and spares allocated to West Wales Airport (WWA). 1.4.184

j. The Panel recommends that the Unmanned Air Vehicle Tactical System Ltd (UTacS) Accountable Manager (AM) provides maintainers with a formal WK training course in order to improve the competence of UTacS maintainers. 1.4.251

k. The Panel recommends Unmanned Air Vehicle Tactical System Ltd (UTacS) Accountable Manager (AM) improves the relevance and effectiveness of the training for the use of the Interactive Electronic Technical Publications and other technical information in order to improve the competency of maintainers. 1.4.252

1.5.5. **UAST should**

a. The Panel recommends that the Head of Unmanned Air Systems task Thales to introduce more reliable hardware components in order to improve the reliability of the Vehicle Management System Computer (VMSC). 1.4.39

b. The Panel recommends that the Head Unmanned Air Systems should task Thales to ensure the Vehicle Management System (VMS) is able to determine whether the redundant side of the Vehicle Management System Computer (VMSC) is in the correct mode and capable of actively controlling the Air Vehicle (AV). 1.4.49

c. The Panel recommends the Head of Unmanned Air Systems (Hd UAS) develop a set of Equipment Standard 2 Flight Reference Cards in a format that is 1.4.125

easy to navigate, user friendly and fit for purpose to ensure crews can access critical information expediently.

d. The Panel recommends the Head of Unmanned Air Systems (Hd UAS) ensures consistent use of language for Warnings Cautions and Advisories (WCAs) within training material, Air-System Document Set (ADS) and Ground Control Station (GCS) in order to ensure the Ground Control Station crew can expediently deal with emergency situations. 1.4.126

e. The Panel recommends that the Head of Unmanned Air Systems (Hd UAS) tasks Thales to review and amend the frequency, relevance and crew actions of the Watchkeeper (WK) Warnings, Cautions or Advisories (WCAs) in order to reduce the likelihood of operators becoming overloaded during an emergency. 1.4.130

f. The Panel recommends that the Head of Unmanned Air Systems (Hd UAS) should mandate the production of an Aircrew Manual to support the operation of the Watchkeeper (WK) system. 1.4.143

g. The Panel recommends the Head of Unmanned Air Systems (Hd UAS) should mandate the publication of a Watchkeeper Operating Data Manual. 1.4.146

h. The Panel recommends the Head of Unmanned Air Systems should amend the content and structure of information in the Interactive Electronic Technical Publications (IETP) to enable users to access more detailed information expediently. 1.4.151

i. The Panel recommends the Head of Unmanned Air Systems (Hd UAS) establish and follow a process to ensure all Watchkeeper Interactive Electronic Technical Publications (IETP) users formally report they have received and are using the correct version of the IETP from the date of issue. 1.4.152

j. The Panel recommends that Head of Unmanned Air Systems (Hd UAS) evaluate the adequacy of the current level of system knowledge provided to operators and maintainers in technical publications in order to establish an appropriate level of system's knowledge for all those involved in WK operations. 1.4.272

1.5.6. **WK Fce should**

a. The Panel recommends that the Watchkeeper Force Commander (WK Fce Cdr) update Human Factors (HF) training to include effective Crew Resource Management (CRM) to include managing cockpit gradient, distraction, and concurrent communications. 1.4.263

b. The Panel recommends that the Watchkeeper Force Commander (WK Fce Cdr) integrate Crew Resource Management (CRM) training and decision-making into simulator sessions, especially during the management of aircraft emergencies. 1.4.265

PART 1.6 - CONVENING AUTHORITY COMMENTS

1.6.1. Watchkeeper (WK) registration WK043 crashed into the sea in Cardigan Bay off the coast of Wales, at approximately 1057hrs on 24 Mar 17. Sea searches failed to find and recover the main wreckage, with only light items of composite airframe subsequently washed ashore.

1.6.2. The Unmanned Air System (UAS) was under Thales operation[38]. It was conducting an Equipment Standard 2 (ES2) conversion sortie (Flt 611)[39] for the training benefit of Royal Artillery (RA) pilots. The sortie was flown from West Wales Airport (WWA). Flt 611 took off from WWA at 1036hrs, with a full ISR payload[40]. Not long after departing WWA, the crew experienced numerous alerts and warning captions. WK043 was flown out towards its 'Sea Emergency Recovery Point' to allow the crew to undertake flight controllability checks. The alerts and warnings continued and increased in frequency until WK043 appeared to lose height and heading control. Telemetry was lost with WK043 at 1056hrs.

1.6.3. I am grateful to the President of this Service Inquiry (SI) and her Panel for their Report, especially considering the lack of physical evidence available to them. It is logical in its analysis of the evidence and in making judgements on Accident Factors. I agree with its findings. If implemented fully, the recommendations it makes will help prevent a recurrence of a similar accident and assist in the successful delivery to the Army of the WK UAS capability. I hope findings from this SI will also be useful to the wider development of fully automated systems.

1.6.4. It's notable that the loss of WK043 on 24 Mar 17 was the 4th occasion a WK had been lost in an accident[41]. It followed the loss of WK042 on 3 Feb 17[42], only 6 weeks before, also at WWA. A 5th WK was to crash on 13 Jun 18 (WK050), again being operated by Thales from WWA[43] - WK050 is subject to a DSA Level Non-Statutory Inquiry (NSI) due to report in Spring 2019. In my Convening Authority's comments for WK042's SI, I placed these crashes in context, highlighting a number of themes I felt were associated with the operation of WK. I highlighted – the DO (and the MOD) not fully understanding how WK works, not making the most of simulation or from the exploitation of data, and providing a disproportionate level of complexity to those who fly WK. These are also pertinent to this accident and I will return to them in my summary.

1.6.5. Evidence initially suggested WK043 crashed owing to engine failure[44]; it didn't. WK043 crashed because of the failover[45] of the Vehicle Management System Computer (VMSC) from Side

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[38] Thales is the Prime Contractor Management Organisation (PCMO) and the Design Organisation (DO) for the WK system. As the PCMO, Thales leads an industry team of Cubic Corporation (data links), Elbit Systems Limited (ESL) (UA Air Vehicles), Marshall SV (ground station shelters and ground vehicles), Altman (programme safety) and UAV Engines Limited (AV engines). UAV Tactical Systems Limited (UTacS) is a joint venture company created by Thales and ESL to enable technology transfer, manufacture and UK support. UTacS provide crews and maintenance personnel at WWA.

[39] Equipment Standard 2 (ES2) upgrades the current WK, which is at an Operational Conversion Unit (OCU) standard. The accident occurred during the sortie annotated as Flight (Flt) 611.

[40] WK043 had 2 x operational payloads fitted – radar and Electro-Optic fits.

[41] Previous WK accidents, all of which were subject to DSA SIs, were WK042 at WWA on 3 Feb 17, WK031 at Boscombe Down Airfield on 2 Nov 15 and WK006 at WWA on 16 Oct 14.

[42] DSA SI/03/17 – Service Inquiry report dated 20 Apr 18 - Loss of Watchkeeper WK042 on 3 Feb 17.

[43] DAIB/18/016 Triage Report dated 15 Jun 18 – WK050 crash during attempted landing on 13 Jun 18.

[44] Engine failure was initially suspected, owing to 'RPM Spiking' and warnings and cautions recorded during the flight. This was discounted as the cause as no conclusive evidence could be found.

[45] Failover is a procedure by which a system automatically transfers control to a duplicate system when it detects a fault or failure.

A to Side B, whilst Side B was in the 'Standby' mode[46]. The lack of physical evidence prevents certainty, but on the balance of probabilities, the likely cause of this VMSC failover was due to a hardware failure of a fuse or capacitor. However, the failover from Side A to Side B should not have resulted in a loss of control of the aircraft, as the VMSC is designed with multiple layers of redundancy. Side B should have been shadowing Side A and taken control when the monitor switched active control. VMSC Side B was live, but it was in a 'Standby' mode. This failover was a key contributor in making the accident more likely, but the combination of Side B being in 'Standby' mode at the point of the VMSC failover from Side A to Side B caused the crash.

1.6.6. To explain what led to WK043's loss, I'll cover the hardware failure first as this explains the switchover from Side A to Side B. I'll then cover why Side B was in 'Standby Mode' and why this and its subsequent consequences were neither understood nor noticed. Before summarising, I'll comment on how Thales operations at WWA complied with policy and regulation.

Hardware Failure

1.6.7. If the VMSC experiences the failure of one of its many hardware components it is programmed to failover to Side B. For Flt 611 there was insufficient evidence to confirm with certainty that a hardware failure had actually occurred, however, studies conducted by ESL and Thales found certain fuses and capacitors in the VMSC were not meeting reliability requirements and furthermore, that a failure of a capacitor or a fuse in the VMSC was a likely cause of a failover[47]. This led to the conclusion that, on a balance of probabilities, a hardware failure was most likely to have caused the failover from Side A to Side B.

Side B in 'Standby' Mode

1.6.8. WK relies on a data-link between the VMSC and the Ground Control Station (GCS) for flight control. There are two data-link channels – wide band and narrow band – that are connected as part of the Before Flight Servicing (BFS) checks and monitored throughout operation. Should these data-links fail, the aircraft is designed to enter a 'Lost-Link Procedure', maintaining level-flight over a set coordinate. Whilst the VMSC receives signals confirming that Sides A and B are working, it does not know their mode of operation (eg, standby, takeoff etc). During Flt 611, the monitor detected that Side A was not functioning, but was not able to determine whether Side B could actively control the aircraft. It only knew it was 'alive'. The VMSC will stay in a 'Standby' mode until receiving a command to change. Independent sides of the VMSC receive these commands through data-links. If no data-link is connected, then the unconnected side will not receive the command to change to 'Flight' Mode. The WK system announces data-link failures as part of its Before Flight Servicing (BFS).

1.6.9. Before operation of the WK System numerous tests are completed to confirm it's safe and ready to operate. A number of these are BIT (Built in Test)[48] Codes. Analysis found when BIT Codes 644 and 649 were present together during BFS, they indicated no communication on either side of the wide or narrow band data links to VMSC Side B. This meant that Side B could not

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[46] The VMSC is the aircraft's central computer controlling all aspects of flight dynamics, power, propulsion and navigation. It has dual redundancy with 2 x processing cores – Side A and Side B. Each is capable of controlling the aircraft independently. Side A has primacy in normal operation, with Side B shadowing Side A. There is further redundancy should both sides fail provided through Reversionary Flight Control.

[47] The SI Panel's own research uncovered evidence that 5 out of 40 VMSC failures were found to have an open circuit on inspection.

[48] A BIT is used to assess the serviceability of individual system components. Each type of failure is assigned a code to assist maintenance.

receive the command to change modes and would remain in 'Standby'. Furthermore, analysis of BIT Codes 644 and 649 occurrences, found if either Code 644 **or** 649 were present, then Side B functions as normal and shadows Side A. However, if **both** Codes are present, then Side B remains in 'Standby' mode for the duration of the flight.

1.6.10. BIT Codes 644 and 649 occurring together was not wholly uncommon – WK043 conducted at least 11 flights from WWA with both codes present in the 6 weeks prior to it crashing [49]. For Flt 611, both Codes were reported, but operators of the Portable Aircraft Test Equipment (PATE)[50] and in the GCS thought these Codes appearing together was acceptable. It is also of note that this issue was found to affect both the Operational Conversion Unit (OCU) and the upgraded Equipment Standard 2 (ES2) aircraft.

1.6.11. BIT Codes 644 and 649 had been reported since 2013. Changes were made to prevent these codes, but there is no evidence that the changes worked. An Interactive Electronic Technical Publication (IETP) maintenance procedure detailing actions to be taken when these codes appeared was released in Aug 13 but was not used on the day of Flt 611[51]. The only Technical Note with relevant information on dealing with these codes was not published.

Policy and Regulation

1.6.12. The Thales Flight Operations Organisation[52] (FOO) had been conducting WK air operations at WWA since Apr 10, with UAV Tactical Systems Ltd (UTacS) providing both engineering and design production support. Flying at WWA was conducted under a Military Flight Test Permit (MFTP[53]), which listed what flying was permissible along with any constraints. The FOO is approved under the Military Aviation Authority (MAA) Contractor Flying Approved Organisation Scheme (CFAOS). The scheme includes a number of named post holders who are legally responsible within the organisation. Whilst Thales was largely found to be operating within MAA approval schemes, shortfalls were identified.

1.6.13. The most significant concerned the Maintenance Approved Organisation Scheme (MAOS), which effectively gave Thales approval to maintain military aircraft. Compliance with MAOS (MAA-RA 4816) requires a Maintenance Organisation Exposition[54] (MOE) and compliance with the IETP. The IETP was not followed regarding flight with BIT Codes 644 and 649 or for their reporting as part of the error management system. This non-compliance made the accident more likely. Furthermore, the WK Equipment Safety Assessment, built by the Unmanned Air Systems Team (UAST) within the DE&S, focused their system and equipment safety arguments on integrity levels (especially of software) of individual Line Replacement Units (LRU), rather than understanding the interaction between the LRUs.

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[49] There were numerous other reported occasions of both BIT Codes being present since the raising of the original report (F760) in Mar 13. For further example – at WWA, from 80 x WK sorties during which full flight data was recorded, 39 had either or both codes reported.

[50] The PATE compute runs through a series of processes that test systems on both Side A and Side B of the VMSC, and other systems.

[51] There was no authority to deviate from the IETP. Although these BIT Codes were regularly seen at WWA, there was no documented process or authority to fly with them.

[52] The FOO was the management and regulatory body responsible for flight operations at WWA.

[53] This was in accordance with MAA RA 5202, now incorporated into RA 5880. An MFTP is required for specified flights of a military air system without a valid Certificate of Usage or where the design build standard was not reflected in an extant RTS. The TAA authorised the MFTP for Flt 611 on 9 Dec 16.

[54] The MOE defines the requested scope of approval and the procedures to which they will adhere (MAA-RA 4800-4894 (MRP Part 145))

Summary

1.6.14. The crash of WK043 on 24 Mar 17 was the 4th occasion a WK had been lost in an accident, and a 5th (WK050) was to follow, crashing at WWA on 13 Jun 18. Whilst the cause of each crash was different (note the NSI for WK050 is yet to report), I mentioned I would return to a number of themes:

- **The Incomplete Understanding of the Full System, and how Sub-Systems Integrate.** An incomplete level of detailed technical understanding of the WK system, by the MoD and the DO in the UK, is a theme I highlighted for WK042. This has been reinforced in this SI and builds on the SIs for other WK losses[55]. Linked to this theme is the requirement for an appropriate simulation strategy, including the **urgent** need for a fully representational simulator for crew and support training. The advantages must now be compelling in minimising risk and cost to the capability, saving time and generating greater volumes of data for subsequent analysis.
- **The Need to Improve the Collection and Analysis of Data**. The need to do this was strongly evident from WK042's SI. This SI highlights shortfalls in post-flight data capture and analysis. This might have explained the RPM spiking, which initially indicated engine problems and engine failure as the Causal Factor. It also reinforces the requirement for WK to have a crashworthy and locatable Flight Data Recorder.
- **Crew and Engineer Workload**. I emphasise this point, as WK is largely crewed by NCOs from the Royal Artillery, whose selection and assurance is set for them to operate at a level below that for pilots of manned aircraft. Yet the plethora and complexity of information available to them would challenge the most competent manned-aircraft pilot. Here I refer to the high rate of Warnings, Cautions and Advisory (WCA) notifications, which can increase crew workload to unacceptable levels, increase the likelihood of error and can serve more to distract – WK's Flight Reference Cards (FRC) comprise 265 pages compared to the Wildcat AH1's 80 pages! The IETP's content and layout is too complex. The document lacks depth and detail. Indeed, both UTacS and Thales personnel were surprised when the SI found an IETP procedure for BIT Codes 644 and 649. Moreover, poor documentation is leading to a general reliance on existing collective knowledge rather than using the IETP, which is unacceptable. There is also an **urgent** need to publish endorsed Aircrew and Operating Data Manuals. Both would improve system understanding, which as mentioned above, is not good enough.

1.6.15. Finally, although WK's track record does not make for good reading, it's appropriate to place the accidents it has had within the broader context of the development of fully automated systems. There is much that is still novel in complex fully automated systems, especially those with advanced technology, designed to operate towards the boundaries defined by extant regulatory regimes. Innovation driven by the opportunities offered by fully automated systems, will require flexibility in defining what a reasonable and appropriate regulatory regime looks like, set against a clearly defined and realistic requirement. For WK, I have confidence in the commitment of the DO's most senior leadership in delivering a useful WK capability to the Field Army and their broader contribution to this important debate.

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[55] WK031 due to issues with the Master Override, WK006 was again the Master Override but a lack of detailed information, WK042 was not understanding the consequence of no drain holes in the pitot and the disqualification logic in the VMSC, and WK043 was a lack of understanding of the significance of the BIT codes 644 and 649, not asking enough 2nd and 3rd questions and not enough system understanding at the front line to question these decisions.

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DG DSA