1.4.151. Contained within their report for the laser altimeters, Noptel provided information on their experience and data from real measurements against tarmac. This detailed that during precipitation and over very wet tarmac the signal reflectivity level could be reduced to 15%. The report further stated that the laser altimeter range could be degraded by up to 39% when compared to dry conditions. In Dec 12, Thales released a Tech Note stating that during stage 4 and 5 flight trials there were a number of occurrences where laser altimeters failed to operate correctly. This was noted to be worse when operating over relatively new, wet, tarmac. As a result a change to the VMSC software logic was introduced which reduced the height that laser altimeter performance would be evaluated, from the UR to 22m in GTOLS or 15m in ATOLS. The Panel concluded that it was most likely that the wet runway surface caused the Laser Altimeter 2 to produce an erroneous height reading during the final approach and it was a **Contributory Factor** to the accident. Annex A

1.4.152. **Recommendation**. The Panel recommends that the Hd UAST should review the suitability of the Watchkeeper laser altimeters especially in wet conditions and consider the requirement for an alternative and/or complimentary solution for measuring precise height.

Vertical Acceleration and Pitch Rates experienced by the UAV

1.4.153. The Panel considered the question: what caused the vertical accelerations and pitch rates to exceed the WoW1 algorithm values? The Panel elected to investigate whether the accelerations or associated pitch rates were generated internally within the UAV or externally due to environmental factors.

1.4.154. **Change in Vertical Acceleration**. In the early development stages of the Watchkeeper, a physical Weight on Wheels (WoW) device was attached to the undercarriage but it was subsequently removed as it was deemed unreliable, especially over rough surfaces. Instead, the VMSC was programmed to detect landing indirectly using a pseudo WoW1 algorithm. Changes in vertical acceleration are sensed by accelerometers housed within the INS/GPS Units and can be detected in 3 instances: Annex A

a. Sudden changes in vertical forces due to aerodynamic turbulence.

b. Induced vertical deceleration resulting from a change in flight path.

c. Actual ground contact.

Once the accelerometers sense a change in vertical acceleration and pitch rate, that exceeds the required threshold for 'Ground Touch', they will continue to monitor for satisfaction of the complete algorithm.

1.4.155. **Pitch Rate**. The VMSC will sample and add the pitch rate to detect a nose down manoeuvre due to momentum and turning moments once the main undercarriage has touched the ground. If the change in vertical acceleration and pitch rate magnitude is greater than a set parameter, 'Ground Touch' will be registered within the VMSC and latched (unless superseded by an 'Air Jump'). Changes in pitch rate will be detected in 3 instances: Annex A

a. When the UAV has experienced aerodynamic turbulence.

b. When the UAV is making a deliberate pitching (nose down) manoeuvre.

c. When the main landing gear has touched down and inertial forces cause the UAV to rotate in a progressive nose down attitude.

Accelerometers

1.4.156. The analysis of the VMSC data telemetry showed both INS/GPS units to be reading consistently when compared against each other. The readings were also consistent with the visual data from witnesses and the Payload video. This gave the Panel no reason to suspect that the units were producing erroneous or spurious accelerometer readings. The impact event was clearly seen as part of the VMSC download and the exaggerated nose down attitude was deconstructed using this and other available data. From the VMSC download it became apparent that there were 2 occasions (at 16.89m AGL and 15.05m AGL) when the VMSC registered ground touch. Annex A

1.4.157. The INS/GPS units had played a pivotal role and were tested by the manufacturer under strict supervision of the Defence AIB. The tests looked for calibration errors, air data errors and any other un-serviceability within the two units. The accident units proved to be very robust and reliable despite having been subjected to the UAV impact. As a direct result of the comprehensive testing, the Panel eliminated the INS/GPS units as a cause of any erroneous accelerations or pitch rates and hence considered them **Not a Factor** in the accident. Annex A

Pitot Static system analysis.

1.4.158. The Panel continued the investigation into the Watchkeeper Pitot Static systems, their associated feeds into the Athena INS/GPS units and the subsequent effects on the VMSC outputs to the flight control systems.

1.4.159. **System overview**. There are 2 dual redundant pitot systems fitted to the Watchkeeper. Both the Kollsman and Space Age pitot probes supply static and total pressure to each of the INS/GPS units. The VMSC uses static and total pressure measurements from both pitot probes to provide dynamic pressure, but Angle of Attack (AOA) and Angle of Slip (AOS) are supplied by the Kollsman pitot probe only. The VMSC monitors the readings from both pitot systems and averages the result. However, should the readings differ significantly; a voter will disqualify the pitot input that is out of limits.

1.4.160. **Initial analysis**. During the initial analysis of the VMSC data, the Panel found that the Kollsman pitot had produced erroneous readings during the approach and had been disqualified by the VMSC prior to 'Ground Touch' sensing (Fig 18). The Panel needed to understand the possible cause of the disqualification and its effect on the UAV's performance and whether it was a factor in the accident. Annex A

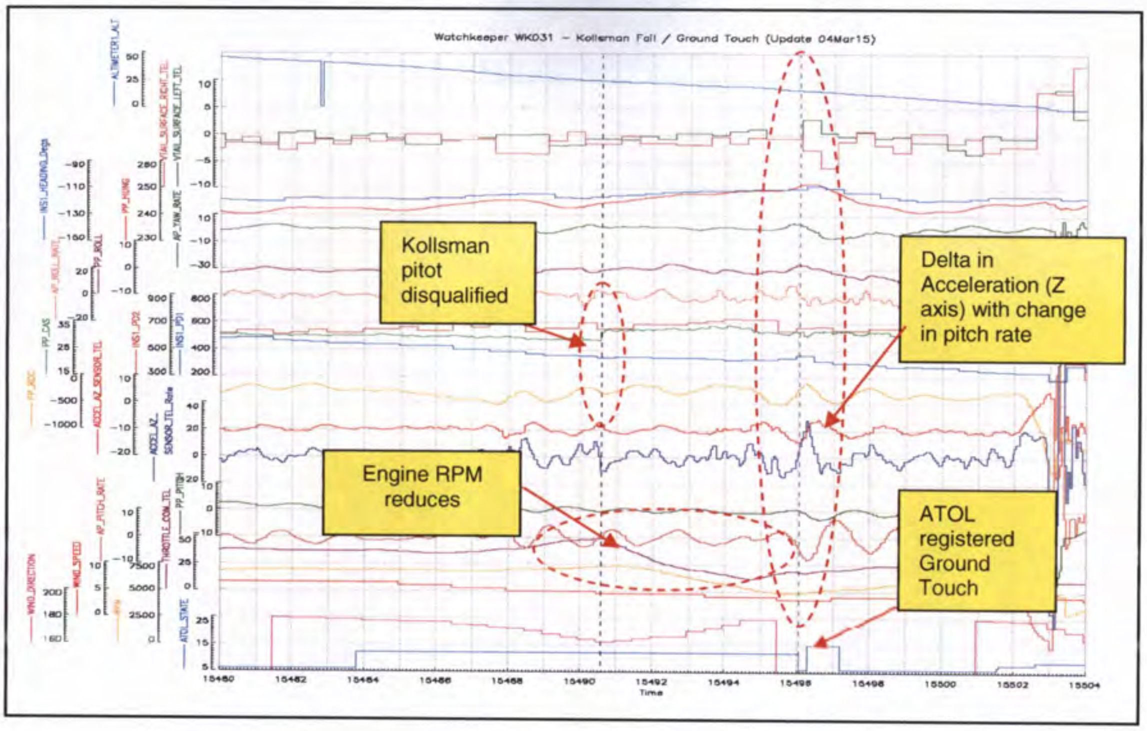

Figure 18 – VMSC Data Kollsman Pitot disqualification

1.4.161. **Pitot System disqualification**. The VMSC data in Fig 18 shows the effect the failure the Kollsman Pitot had on Calibrated Air Speed (CAS) and engine RPM. One of the main parameters used by the VMSC FCS is Present Position (PP) CAS, which is an averaged reading of the Space Age Pitot data (INS1_PD2) and data from the Kollsman Pitot (INS1_PD1). The data in Fig 18 shows that PP CAS followed an averaged reading between the two diverging pitot inputs. As the graph illustrates, the INS1_PD1 reading started to drop off, which indicated that the Kollsman Pitot System was potentially partially blocked. After a period of approximately 10 secs the VMSC, which was monitoring the two pitot inputs from both INS/GPS units, disqualified the input from the Kollsman Pitot and reverted to solely using the Space Age pitot. Annex A

1.4.162. **Possible cause of Kollsman Pitot blockage**. The reliability of the Kollsman Pitot System as originally installed had been problematic in adverse weather conditions and was identified as an area for improvement. A lack of a dedicated water drainage system on the Kollsman pitot system had contributed to suspected partial system blockages and the associated effects on UAV performance. This particularly occurred when water was ingested beyond the probe heater and settled at the lowest point within the pipes. Due to this issue Kollsman pitot pipe lines were increased to ¼" diameter and a secondary Space Age pitot was fitted which also had ¼" pipes and a drainage system. Annex A

1.4.163. **Water ingress**. Water was found in the Kollsman probe the day after the accident. However, Fig 19 illustrates the damage caused to the nose cone of the UAV after the accident. The Kollsman probe was bent in an upwards direction (in relation to how the aircraft was lying on the airfield post impact) and was left uncovered at the scene overnight during inclement weather. Therefore, the Panel believe that it is possible that water was ingested post-accident. However, analysis of the data from the GFCC logs, the GCS VR and the WCAs displayed to the crew all point to a partial pitot pipe blockage before the accident which was becoming progressively more blocked over time. Therefore, the Panel concluded that the most likely cause for the disqualification of the Kollsman pitot air speed readings by the VMSC was water ingress in the pitot pipe and Annex A the associated partial blockage.

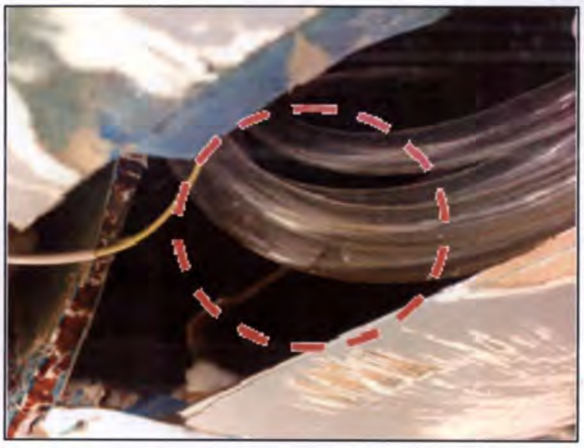

Figure 19 - WK031 Nose and Kollsman Pitot Probe Damage and Fluid found in Pipes

1.4.164. **Recommendation**. The Panel recommends that the Hd UAST should review the performance of the Kollsman Pitot System, and if appropriate incorporate a drain point.

Secondary effects of Pitot disqualification

1.4.165. **Engine RPM**. During the initial divergence of air speed indications, engine speed increased by only a small margin to compensate. Following the disqualification of the Kollsman pitot, the CAS increased and engine speed reduced to idle within a period of 3 secs. This happened because the VMSC was now using the Space Age pitot as its primary source for air speed. At this stage in the ATOL landing process the VMSC was maintaining WK031 on a 3° glide slope. Analysis of the data showed that once the air speed had stabilised, the throttle moved to increase engine RPM to maintain the glide slope. This coincided with the first 'Ground Touch' being sensed, and when WK031 was still at 16.89m AGL. The Panel needed to understand if there was a relationship between engine RPM and the change in vertical acceleration. Annex A

1.4.166. **Flight path**. The Panel modelled the response of WK031 to the change in PP CAS when the Kollsman pitot was disqualified. The Panel tested the theory that a significant change in engine RPM could induce a dynamic oscillation or instability large enough to exceed the 'Ground Touch' logic threshold. The tests were conducted using the U-TacS Hybrid Simulator; 12 flights were completed and results recorded. Analysis of these results demonstrated that it was possible to induce a noticeable dynamic oscillation following a Kollsman pitot disqualification due to an associated engine RPM rapid decrease followed by an increase. However, it became apparent to the Panel that this effect was dependent on which flight segment the UAV was in, whether it was in straight and level flight or on its landing approach post the CP, and ultimately if the UAV was flying to maintain an air speed or a glide slope. Annex A

1.4.167. **During cruise**. The straight and level conditions of route flight for Simulator Flight 6 (Fig 20) were deliberately selected to discount the influence of the ATOL landing process and the 3° glide slope. Analysis of the data showed that when the Kollsman pitot was disqualified, similar to WK031, the engine RPM reduced but this is where the similarity ended. Very quickly an obvious dynamic instability was established, which supported the theory being tested that the threshold for 'Ground Touch' could, if the dynamic instability was large enough, be reached. Annex A

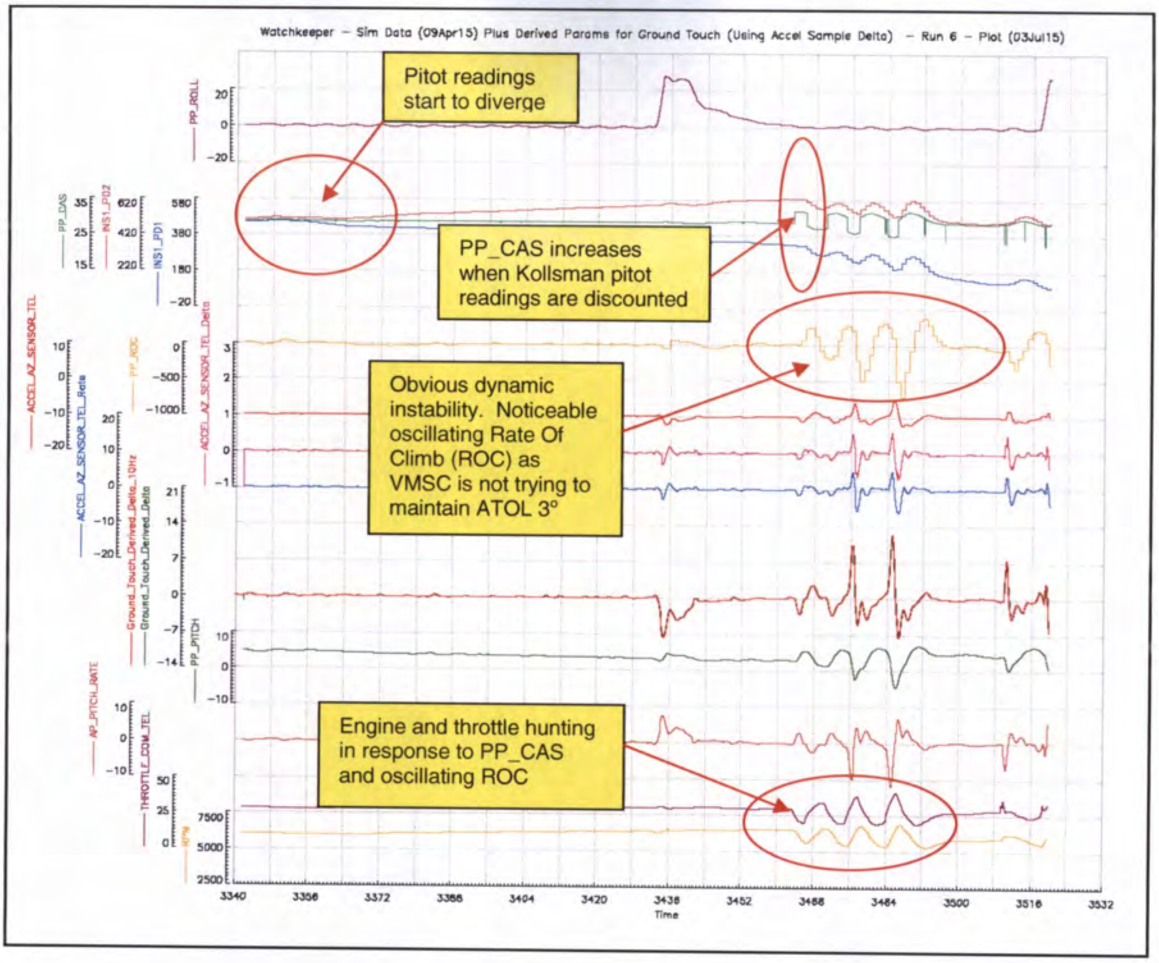

Figure 20 - Simulator Flight 6 - Straight and Level

1.4.168. **During approach**. The conditions for Simulator Flight 9 (Fig 21) were matched as closely as possible to replicate the WK031 accident flight. Analysis of the data showed that when the Kollsman pitot was disqualified, the engine RPM initially started to reduce. However, unlike Flight 6, the RPM change had minimal effect on pitch and the Panel concluded that this was due to the overriding priority of the VMSC to maintain the 3° glide slope, and not air speed, as in the cruise. The lack of instability displayed during the landing phase, as a result of the UAV prioritising the 3° glide slope over its air speed, allowed the Panel to discount the relationship between engine RPM and the change in vertical acceleration experienced when the Kollsman pitot was disqualified. The Kollsman pitot therefore was **Not a Factor** in the accident. Annex A

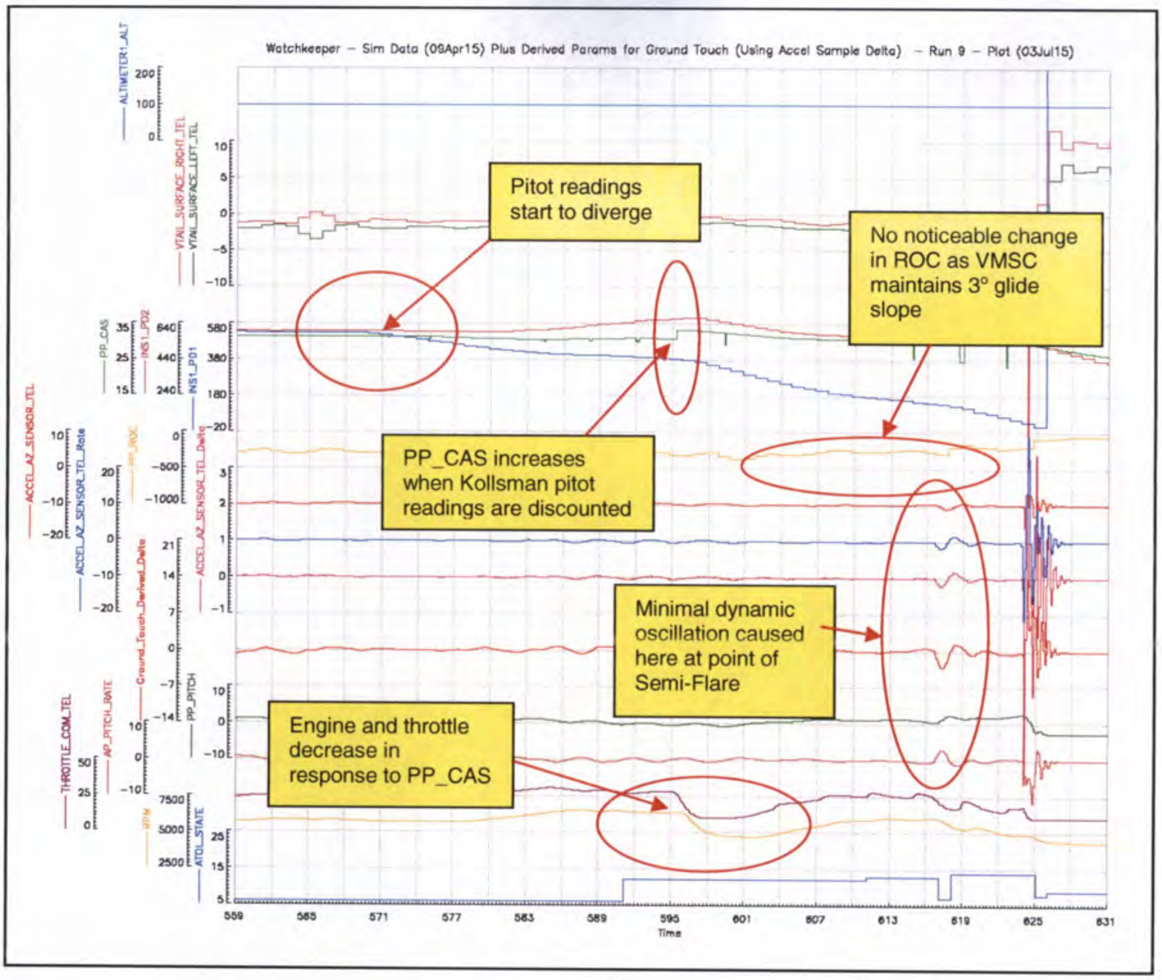

Figure 21- Simulator Flight 9 - Replicate of WK031 Accident Sortie

1.4.169. **Conclusion**. The Panel concluded that, within the limited scope of these tests, the vertical accelerations and pitch rates were not induced by erroneous internal signals within the INS/GPS units or from large changes in engine RPM as the UAV continued on its 3° glide slope. Therefore, the Panel concluded that the most likely cause of changes in vertical acceleration and associated pitch rate was that from a wind gust or turbulence in the vicinity of thunderstorm activity.

Assurance

1.4.170. **Introduction**. Although it is clear from the findings of this report that there was no malfunction within the VMSC and that the landing logic performed as programmed, it would appear that the landing logic did not perform as anticipated. It was therefore important to establish the level of VMSC assurance adopted during the procurement process leading to eventual certification. Although WK031 was flying under a Military Flight Test Permit (MFTP) as opposed to a Release to Service (RTS), the assurance process for the MFTP and the initial Release to Service (iRTS) were concurrent and the evidence used to underpin the iRTS was also used to underpin the initial MFTP.

1.4.171. **Military Air Systems Certification Process (MACP)**. Type Airworthiness Authorities (TAAs) responsible for the introduction of new UK military Air Systems that will be operated in the Service Environment on the Military Aircraft Register (MAR), should ensure that they are certified in accordance with the MACP (Fig 22), that comprises the following 6 phases:

Phase 1 – Identify the requirement for, and obtain, organizational approvals.

Phase 2 – Establish and agree the Type Certification Basis (TCB)[28].

Phase 3 – Agree the Certification Programme.

Phase 4 – Demonstrate compliance with the TCB.

Phase 5 – Produce Final Report and issue Certificate.

Phase 6 – Undertake post-Certification actions.

1.4.172. **Tailored MACP**. An individually tailored version of the MACP was applied to new military registered Air Systems that were post main gate approval and had not reached RTS by 1 Sep 11. In these cases, the MAA determined which of the 6 phases applied and provided detail in the Certification Assurance Strategy. For projects undergoing the Tailored MACP, the TCB was approved under legacy arrangements. The Air System Airworthiness Strategy (RA1220) details the approach to the TCB, and it is articulated in detail in the Type Certification Exposition (TCE) produced by the TAA as part of the MACP Phase 4 activities. The Certification Programme was owned and managed by the TAA and agreed with the MAA, and formed part of the Integrated Test, Evaluation and Acceptance Plan (ITEAP). In order to demonstrate compliance, the TAA provided the MAA with the evidence identified in the Certification Programme. Where the certification evidence did not demonstrate compliance with the TCB, the TAA assessed the consequent risks of the non-compliance. The TAA was required to demonstrate to the MAA that this risk assessment has been endorsed by the relevant Operating Centre Director (OCD) and accepted by the Duty Holder (DH) chain.

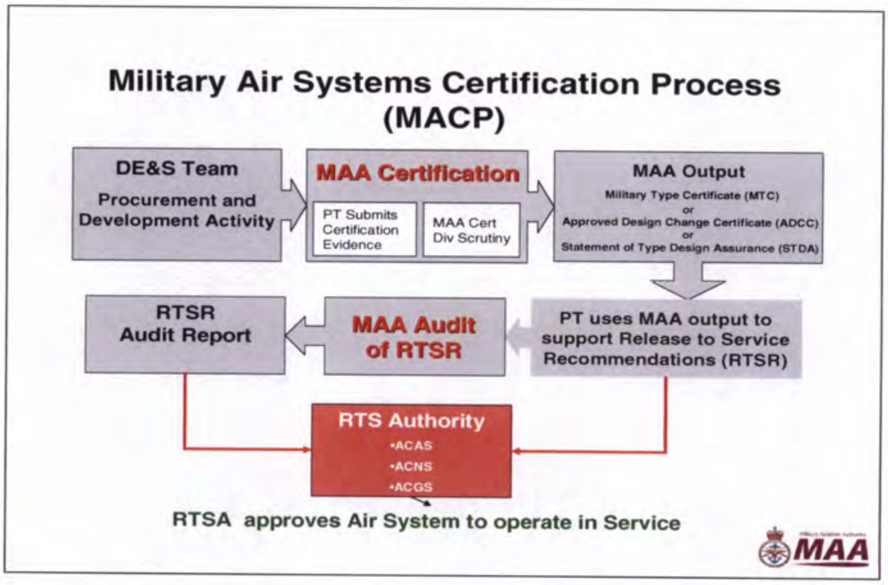

Figure 22 - Military Air Systems Certification Process

[28] The TCB for the Type Design of the Air System is included in the Air System Airworthiness Strategy and involves: selection of the applicable airworthiness codes; a clear statement as to which versions of the selected codes are to be applied; and the identification of any Special Conditions.

1.4.173. **Statement of Type Design Assurance (STDA)**. A tailored application of the MACP normally resulted in the MAA issuing an STDA to the TAA, underpinned by an MAA produced Type Certification Report (TCR). The STDA identified the extent to which the MAA had been able to assure the certification evidence provided and detailed any areas where the evidence was unavailable, incomplete or not understood. The possible levels of assurance were; Full Assurance, Substantial Assurance, Limited Assurance or No Assurance. The STDA, together with the underpinning TCR, would then be used by the TAA in support of the initial RTSR made for the new Air System.

Assurance for the Watchkeeper iRTS

1.4.174. In Aug 05, Thales UK was awarded the contract for the development, manufacture and initial support phases of the Watchkeeper programme. Watchkeeper UAS activity was originally contracted under JSP 550 series documents and Aviation Publication 67 (AvP 67) regulations. However, recognizing the legacy nature of the project and the limited opportunity that the MAA had to influence the process, the Watchkeeper programme followed a 'Tailored' approach to the application of the MACP. Exhibit 36

1.4.175. During 2012-13, Thales produced a target RTS for the WK UAS OCU[29] variant which the UAST and the Release-to-Service Authority (RTSA) developed to produce a military RTS. In the Panel's opinion there was a perceived lack of confidence by the UAST in the robustness of the Thales assurance process[30] which led the UAST to carry out a desk top review of the available evidence. The UAST identified within the Designer's Software Development Plan[31] that the SCADE[32] Editor and SCADE-KCG (Qualified Code Generator) was used as a significant part of the VMSC software development process. An industry review identified that the use of SCADE tools was considered an appropriate formal method for high integrity software development.[33]

1.4.176. Additionally, members of the UAST conducted a certification audit of the formal approach with the Designer in Jul 13, to provide a level of software assurance sufficient to underpin the RTS. Of note, the audit found that that the application of the SCADE tool was arguably the strongest element of the development process. The UAST used the evidence from the audit[34] to support the Type Certification Exposition (TCE) for the WK OCU variant. Given that the evidence would be retrospective, the Type Certification Basis was based on Def Stan 00-970 parts 9 and 11, supplemented by those other parts deemed relevant to WK UAS design, along with Def Stan 00-55[35] and RTCA/DO-254 against which the TAA elected to comply for software[36] and Complex Electronic Hardware (CEH) respectively. Exhibit 41 Exhibit 53 Exhibit 54

[29] The WK UAS was introduced into service using an incremental approach starting with the Operational Conversion Unit (OCU) variant, which was intended to be operated in limited training and environmental conditions.
[30] Inferred from conversation with Unmanned Aerial Systems Project Team (UAST) during fact finding meeting at DE&S Bristol, 8 Jun 15.
[31] UN_26625E-00 Rev C Software Development Plan for UAV, Aug 10
[32] SCADE is a commercial product used to design critical software.
[33] 30130725 Discussion Paper on The Designers use of Formal Methods, UAST, Jul 13.
[34] Software Audit Out-brief notes, UAST, 01 Aug 13
[35] Minutes of the Watchkeeper Software SQEP Panel from Mar 13 indicate that PCMO had written to The Designer, advising them to use Def Stan 00:55. This position was retrospectively accepted by the SQEP panel.
[36] Both Def Stan 00:55 issue 2 and RTCA-DO178B software standards would have been acceptable means of compliance with Def Stan 00:970, the difference between them relates to depth of rigour in different phases of the software development lifecycle. Def Stan 00:55/2 approaches software assurance through early proof of the absence of flaws and bugs in the written source code; this is done through the use of Formal Methods. DO178B approaches software assurance through proving the absence of flaws and bugs in the operating system; this is done through the use of planning, standard code development, coupled with extensive verification & validation testing once the code has been developed. 00:55/2 relies extensively on evidence from the start of the software development lifecycle; DO-178B relies more heavily on process evidence throughout the development lifecycle. Since the start of 2015, UAST have been working on new software

1.4.177. The TAA submitted the TCE for the WK UAS OCU variant during Aug 13 which included an annex discussing an assessment of confidence that WK VMSC had been developed under an appropriate Safety Integrity Level 3 (SIL3)[37] process. Several arguments were put forward in the TCE that claimed a level of confidence in the integrity of the VMSC software. Exhibit 36 Exhibit 41

1.4.178. Following MAA review and assessment, the WK TCR was published in Sep 13. In the TCR, the MAA considered that none of the arguments put forward in the TCE provided sufficient evidence that gaps in meeting the requirements of the chosen Standard (Def Stan 00-55) had been mitigated. The TCR used the example of the software specification that had been developed using plain text rather than the numerically precise approach required. The TCR went on to say that plain text is notoriously ambiguous and it might have been expected that some kind of argument would be developed and presented to demonstrate that ambiguities introduced at that early stage had not been propagated through the system. Therefore, the overall premise that they increased confidence in the integrity of the software was not convincing.

1.4.179. However the TCR contained the following conclusion:

> 'Evidence that the MAA has been able to assess, together with its wider involvement in the programme to date, has demonstrated a strong commitment at all levels to delivering an airworthy system that fully complies with the MRP. A number of the recommendations made in this TCR are, therefore, intended to pull together existing work more explicitly to demonstrate compliance with the MACP. Consequently, the TCR reflects findings of significant assurance for the limited TCB scope that was subject to enhanced evidence gathering for this TCE in each of the structures, systems and propulsion areas, together with at least limited assurance for the critical VMSC software. Therefore, in the context of excellent engagement and wider MAA involvement with WK UAS certification activities, it is recommended that D (Tech) issues a STDA at this stage that provides **Limited Assurance** for the WK UAS, including the flight critical VMSC OFP software, but that notes the absence of evidence presented for the other SIL3 software and CEH items: the VMSC Monitor, PCDU-CPLD and RFC.'

1.4.180. The TCR also contained a number of recommendations for further work that were required to be undertaken in order for this STDA to remain valid. The recommendations were categorized into: Exhibit 41

a. Those that should be addressed before iRTS; those that should be addressed in order for the MAA to consider revising the Level of Assurance based on the VMSC Monitor[38], PCDU[39] CPLD[40], RFC[41] and CEH items.

b. Those that should be addressed before the WK UAS ES2 variant RTS, but not later than 31 Aug 14.

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strategies for all programmes, incorporating compliance through the new Def Stan 00:55 issue 3 and DO178C. Consequently, there is a new MCRI to support future Watchkeeper software certification.

[37] The SIL is a measure of safety system performance or probability of failure with SIL 4 having the highest level of safety integrity, and SIL 1 the lowest.

[38] The VMSC Monitor compares the status of the 2 parallel computers contained within the VMSC.

[39] Power Control and Distribution Unit.

[40] Complex Programmable Logic Device

[41] Reversionary Flight Controller

1.4.181. On the basis of the evidence presented, the degree of MAA engagement throughout the project and the recommendations made in the TCR, the MAA Tech Director issued an STDA dated 20 Sep 13, which provided **Limited Assurance**[42] for the WK UAS. In the STDA, the MAA Tech Director reiterated the TCR recommendations for further work required in order for the STDA to remain valid with end date of no later than 31 Aug 14. Exhibit 36

1.4.182. Three days before STDA expiry (28 Aug 14) the TAA requested an extension. In this letter the TAA provided an update on the Structures and Systems elements of the Compliance Assessment against DS 00-970, as well as a Software and CEH update as requested in the STDA assurance letter. It was not until the 4 Nov 14 that MAA Cert Div DH replied, granting an extension to the STDA with a new backstop of 31 Dec 15 and noted some concerns with respect to the Software Integrity Level 3 (SIL3) software and CEH elements of Watchkeeper. MAA Cert Div DH had reviewed the report with respect to the TAA's progress in these areas and made the following observations: Exhibit 37 Exhibit 38

> *'Whilst it was understood that the TAA were not requesting an uplift of the level of assurance, MAA Cert Div noted some concerns with respect to the SIL3 software and CEH elements of Watchkeeper. Specialists within MAA Cert Div reviewed the extension request addressing the TAA's progress and made the following recommendations to be addressed in order for the MAA to consider increasing the assurance level in these areas prior to the Equipment Standard 2 (ES 2) variant's RTS:*
>
> ***Independence*** *– Whilst there is evidence of appropriate ITE involvement it is unclear, particularly in the Verification & Validation assessments, whether an appropriate level of independence had been achieved in each stage of the production of the product (i.e. there is only a single statement in the main report without any underpinning discussion in the compliance table).*
>
> ***Assurance Levels*** *– The assurance level definition was appropriate however, the ITE assessments were often optimistic. Def Stan 00 970 states, "were appropriate standards applied?" while the report carries the simple statement "yes" without referencing the relevant standards and how they were applied.*
>
> ***Reliance on process evidence*** *– There appeared to be a significant reliance on process evidence, most significantly in relation to verification elements of the assessment, the principal question of verification adequacy does not appear to have been addressed.'*

1.4.183. Despite these observations, MAA Cert Div DH granted an extension to the STDA with a new backstop date of 31 Dec 15 with the following conditions:

a. An update on the UAST's proposed plan addressing the observations raised to be presented to the MAA for review by 1 Dec 14.

b. Further evidence to support the assurance of the Structures, Systems and Propulsion areas of Watchkeeper to deep dive detail to be presented to

[42] Effective compliance with the Tailored application of MACP demonstrated, except for some areas where significant non-compliances had been identified or where MAA involvement had been limited.

the MAA for review by 5 Jan 15.

c. The MAA are to be informed of any changes to the design, IAW RA1500, if they are considered to be major.

1.4.184. It is clear that the issue of an STDA forms an intrinsic and essential part in the MACP and the granting of an RTS. Throughout the previously highlighted chain of events, there is a reoccurring emphasis on STDA validity and expiry. Both the original STDA and the letter granting an extension have "back-stop" dates that bound the validity of the STDA. Furthermore, the letter from the TAA to the MAA requesting an extension to the STDA acknowledges this restricted validity. Therefore, the Panel noted that, according to the available documentation, between 28 Aug 14 and 4 Nov 14, the Watchkeeper UAS was being flown in theatre by the British Army without a valid STDA and, therefore, a valid RTS.

1.4.185. In the opinion of the Panel, the current fusion of STDA certificate with what is ostensibly audit feedback is confusing, particularly with respect to the implications of target dates for completion of identified actions. The MAA may wish to consider a standalone certificate that is valid until rescinded and a separate feedback report, outlining the further activity expected of the UAST and the dates by which this is to be completed. In the event that deadlines are missed, progress is inadequate or a specific safety concern comes to light, the MAA would then reserve the right to rescind the certificate until the required corrective action has been taken. This would leave no room for ambiguity, as a positive act of rescindment would leave the holder under no illusion of the STDA's status, or the implications of its being withdrawn.

Assurance for the Watchkeeper MFTP

1.4.186. As already stated, WK031 was flying under a Military Flight Test Permit (MFTP) as opposed to a Release to Service (RTS). Regulatory Article RA5202 details the process leading to the issue of an MFTP. UAS flown under an MFTP are not required to follow the MACP certification process. Underpinned by a Declaration of Compliance submitted by Thales, the first Watchkeeper MFTP was issued on 30 Mar 10. U-TacS were operating WK031 under an MFTP issued by the TAA on 10 Oct 14 and a current Flight Authorisation Certificate signed on 14 Oct 14, valid for 1 month authorising flights in accordance with the MFTP.

Exhibit 30
Exhibit 49

1.4.187. This MFTP was underpinned by new Form 100A[43] and 100C[44] Declarations of Compliance from Aug 14 and a suite of Thales Approval for Use justifications. These forms explicitly identify the aircraft type as WK450 UAV Subsystem (for UK trials) and the applicable variants as OCU and OCU_60 models. These variants had already achieved their iRTS a year earlier, and so carried over the evidence, concerns and assurance from that release process which has been discussed in the previous paragraphs.

Exhibit 50
Exhibit 51
Exhibit 52

The Safety Assessment.

1.4.188. The RTS states that "ATOLS is a 'complimentary means of landing', the minimum requirement being the VMS based GTOLS, and as such does not feature in the Safety Assessment". The Panel made an **Observation** that the RTS statement is incorrect and the Safety Assessment (on which the RTS is based) does discuss ATOLS. It states that it is a complimentary means of landing and not a primary or secondary flight control and as such ATOLS was allocated a SIL 1 rather than SIL 3. However, the Panel

Exhibit 34
Annex A

[43] MOD Certificate of Design for a System.

[44] MOD Certificate of Design for use by organizations approved for the design and modifications and Special Installations in Aircraft.

found that, in the event of Laser failure or disqualification, height information derived from ATOLS takes primacy over a height derived from GTOLS. Therefore it is considered by the Panel to be a redundant rather than complementary system which is contradictory to the RTS and Safety Assessment definitions. Additionally, there is an argument that ATOLS should be considered a Landing Aid. As such, a Eurocontrol Experimental Centre Report[45] lists Navigation aids and Landing aids as requiring an Integrity level of Critical ($3x10^{-8}$)[46]. The Panel concluded that if the ATOLS can be used as the primary landing system then it should be an afforded the appropriate integrity level of SIL 3 in the Watchkeeper Safety Assessment. Additionally, it is the opinion of the Panel that had the ATOLS been assured to SIL 3, the flaws in the VMSC landing software logic sequence might have been identified.

System Integrity Management.

1.4.189. System Integrity[47] Management[48] is primarily about supporting type airworthiness and validating design assumptions. The aim of Integrity Management is to use a planned programme of measures and processes to counter the many threats to platform integrity by ensuring risks to airworthiness are tolerable and As Low As Reasonably Practicable (ALARP). Watchkeeper System Integrity Management was reviewed as part of the investigation to identify if the landing logic software had been identified as having the potential to compromise system integrity. Annex A

1.4.190. During the development of the WK Design eSafety Case (eSC) the PCMO developed a 'Failure Mode, Effects and Criticality Analysis (FMECA) document[49] for the Watchkeeper UAV subsystems. Research established that the FMECA, developed in 2005, had been completed using the Reliability and Maintainability software[50] and was performed for the flight operational mode, which included the take-off and landing phase. The stated purpose of the FMECA was to identify potential weak points and deficiencies in design in order to detect failure modes and then evaluate their effect on system operation. The team found limited evidence in the FMECA for the condition encountered by WK031. Annex A

1.4.191. During correspondence it was identified that the PCMO had used the information in the FMECA to create and build their Fault Tree Analysis (FTA) and accompanying flow diagrams. These FTA were referenced within the eSC and then used to build the Design Hazard Log. From the Design eSC, the UAST created the Equipment Safety Assessment Report (SAR) and the WK Equipment Hazard Logs[51], which were built in eCassandra[52]. The Hazard Logs extracted data from Version 11 of the PCMO eSC for the initial identification of hazards and accident scenarios, which were then modified to address known issues and employment risks. During the investigation the team found limited evidence in the FTA and the Equipment Hazard Logs for the condition encountered by WK031: laser altimeters deselected with 'Master Override' selected. With the changes being introduced with Equipment Standard 2 (ES2) and the expected compliance with Def Stan 00-970, there is an opportunity to review the FMECA Annex A

[45] European Organisation for the Safety of Air Navigation, Eurocontrol Experimental Centre, Navigation Data Integrity Model, Report No 276, Dec 1994.
[46] SIL 3 equates to $10^{-7} - 10^{-8}$ probability of failure.
[47] 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.
[48] System Integrity Management is detailed in MAA Regulatory Article 5720, 5721 and 5722.
[49] Document Number 26664E-00 Rev C FMECA Report prepared for U-TacS by The Designer.
[50] R&M software – RAM Commander ™, Version 7.6.
[51] Equipment Hazard Logs are a qualitative assessment informed by engineering and military judgement as well as quantitative data.
[52] eCassandra is an MOD-preferred risk management tool used extensively within the Air Sector.

document. This would enable the deficiencies in design and potential weak points that have been exposed by WK031 to be identified and a new FTA to be created that analyses the use of 'Master Override' and specifically looks at the condition encountered by WK031.

Conclusion

1.4.192. In conclusion, the Panel agreed that the level of assurance undertaken during the certification process was compliant with standing regulations. The Panel noted that, given the retrospective nature of the assurance process, it would have been highly unlikely that, given the available evidence, a level of assurance of the VMSC greater than 'Limited' would have been achieved at the time of the accident. The Panel concluded that, although somewhat unclear, the STDA validity date was a method of ensuring that every effort had been made to achieve the highest level of assurance possible. However, it is the opinion of the Panel that the ATOLS should have had a SIL 3 rather than SIL 1, and the other SIL3 software and CEH items (the VMSC Monitor, PCDU-CPLD and RFC) should have been afforded the same significance as the 'Flight Critical VMSC software' in the original assurance process prior to iRTS. Finally, it is the Panel's opinion that the failure of the FMECA document to identify the potential failure mode in the landing logic when MO was selected was a **Contributory Factor**. Additionally, the Panel considered that the level of software assurance of the VMSC and in particular the ATOLS was a **Contributory Factor**.

1.4.193. **Recommendation**. The Panel recommends that MAA Technical Director should review the issuing process and subsequent management of the Statement of Type Design Assurance (STDA) with respect to validity.

1.4.194. **Recommendation**. The Panel recommends that the Hd UAST should consider revising the statement in the RTS concerning the status of ATOLS and its consideration in the Safety Assessment.

1.4.195. **Recommendation**. The Panel recommends that the Hd UAST should review the ATOLS Safety Integrity Level (SIL) and consider increasing it from SIL 1 to SIL 3.

1.4.196. **Recommendation**. That Hd UAST should, as part of Equipment Standard 2, conduct a review of the PCMO Watchkeeper Failure Modes Effects and Criticality Analysis (FMECA) document and develop a new Fault Tree Analysis, which considers the entirety of the Take-Off and Landing sequence and in particular the use of Master Override and its effect on the landing logic.

Other Factors

Maintenance

1.4.197. During the investigation, the Panel noted that some members of the U-TacS maintenance team at WWA had little or no aircraft experience or knowledge prior to joining the company. However, it was established that U-TacS have their own in-house training matrix and MAA Design Approved Organisation Scheme (DAOS) accreditation which was valid until 25 Jan 15. U-TacS hold a DAOS certificate for: platform design and development, modifications to and installations in UAV systems under the limitations prescribed by the UAV design organisation for structure, aerodynamics, weight, centre of gravity and systems. Additionally, Reconnaissance Management Systems; Ground Control Stations; test, integration and flight trials of UAV Systems and ground test facilities. More recently U-TacS achieved Maintenance Approved Organisation Scheme Witness 6

(MAOS) accreditation, satisfying the MAA of their maintenance SQEP capability. In addition, the Panel found no evidence that there were any short comings in U-TacS maintenance practices and therefore this was **Not a Factor** in the accident.

1.4.198. A documentation audit was carried out by the Panel which found that U-TacS had adopted their own Aircraft Maintenance Log similar to that of the MoD Form 700C. The audit found no major documentation errors; however there were some references to the now superseded Joint Aircraft Publication (JAP). The Panel observed from the documentation that independent inspections were not being called up in the standard Manual of Maintenance and Airworthiness Process (MAP) format, which had been referenced on occasion, following fitment of the V-Tails during a Before Flight Service (BFS). The inspection form itself was raised; however there was no separate signature for this being carried out, and both the fitment of the V-Tails and raising of the independent were encompassed in the mechanical section signature for the BFS. Annex A

1.4.199. **Recommendation**. The Panel recommends that AM(MF) reviews and amends the documentation process for independent inspections to align with direction from the Manual of Maintenance and Airworthiness Process (MAP).

Lack of GCS Flight Data Recorder.

1.4.200. The Watchkeeper system captures data on the VMSC and does not have a separate Flight Data Recorder (FDR) capability, or Ground Control Station playback facility[53]. During research it was identified that whilst not part of the original Watchkeeper requirement to have an FDR, Def Stan 00-970 stipulated that a crashworthy FDR should be fitted. During the review of Watchkeeper Def Stan 00-970 Non and Partial Compliances (Aug 2013) it was noted that the TAA, supported by a SQEP Panel had deemed that there was no requirement to have a FDR. The lack of an FDR made the analysis of data much more problematic as all the individual systems with non-volatile memory had to be checked, downloaded and collated. This took time and effort and the data was not always in a readable format. The Panel had no easy access to a complete play back facility from the GCS and could not confirm what captions and warnings the crew had seen on their screens during flight WK031. The Panel concluded that the provision of a dedicated FDR would expedite future incident or accident investigations. Annex A

1.4.201. **Recommendation**. The Panel recommends that the Hd UAST should review the requirement for the Watchkeeper system to have a Flight Data Recording capability to enable easy access to data post incidents or accidents.

V-Tail Quick Release Fasteners

1.4.202. During the inspection of the UAV it was noted that Quick Release Fastener locking devices had been used to secure the V-tail assembly on to the flying control actuator shaft. The Panel thought this worthy of further investigation to confirm if the design was fit for purpose to lock a primary flying control surface as it was noted there was no further secondary locking device. Notwithstanding that the Watchkeeper was not designed to Def Stan requirements, a review and interpretation of Def Stan 00-970[54] indicated that the V-tails would be classed as a 'Grade A' component[55]. The design Annex A

[53] Hermes 450 did not have a FDR or VMSC but used a central computer to manage the mission and flight.
[54] Def Stan 00-970 Part 1/13 Sect 4 Leaflet 1 General Design Detail Grading of Aeroplane Parts and Assemblies and the Grading Requirement
[55] DEF STAN 00-097 Part 1/13 Sect 4 4.1.6. Grade A – A part shall be a Grade A if deformation or failure of the part would result in one or more of the following: (a) Structural collapse (b) Loss of control (c) Failure of motive power (d) Unintentional operation (e) Incapacitating injury (f) Unacceptable un-serviceability or maintainability.

criteria being that if it were to fail there would be a change in aerodynamic characteristics, which would result in a loss of control. In terms of locking, 'Grade A' components shall be provided with a secondary means of retention such that, once the fastener is placed in position, the secondary retaining device becomes automatically effective, preventing it from dropping out of position even though the usual retaining device may have been omitted. The FMECA had not identified the loss of a V-tail through failure of the locking QRF as a potential deficiency in design and mode for failure. It was noted that this section of the Def Stan was not considered during the MACP and no component grading was carried out during the TCB process. Although this had no effect on the outcome of this accident it may contribute to a future accident and is therefore considered an **Other Factor**.

1.4.203. **Recommendation**. The Panel recommends that the Hd UAST should conduct a review of Watchkeeper component grading against DEF Stan 00-970 Part 1 Section 4

1.4.204. **Recommendation**. The Panel recommends that the Hd UAST should review the Watchkeeper V-Tail Quick Release Fastener locking device and retrofit a secondary locking device to comply with the design criteria for Grade A components.

Aircraft Post-Crash Management (APCM)

1.4.205. Following the accident, the crash alarm was sounded by ATC and the crew of WK031 pressed the emergency power cut off switch. The UAV came to a stop on the left hand (southern) edge of the runway. WWA Rescue Fire Fighting Service (RFFS) were on scene within 1 min from their position at the end of the runway. The U-TacS recovery team were also on site within 1 min from their position near the Air Traffic Control (ATC) Tower. Witness 2

1.4.206. The qualified UAV-p that was tasked to be in the ATC Tower to monitor the weather during the sortie on 16 Oct 15 was also the Aircraft Post-Crash Management Incident Officer (APCMIO). He had left the tower approximately 15 mins prior to the accident and was in the WWA UAV centre. He did not hear the crash alarm or 'Tannoy' but was informed of the accident approximately 5 minutes after the initial impact. Exhibit 13

1.4.207. When the PCMIO arrived at the scene he liaised with the RFFS and the WWA Incident Commander and was informed that, with the help of the Deputy Flight Line Manager (DFLM), the aircraft had been made safe. The emergency battery had been disconnected because of concerns with a minor fuel leak and the High Intensity Strobe Lights, which were still functioning, providing a possible ignition source. Of note, the ATS/UAS Manager reported that the RFFS crew were unable to immediately electrically isolate the UAV as there was no external isolation point and it therefore required the Thales ground crew to remove a panel to access the battery isolation switch. Exhibit 13 Exhibit 39

1.4.208. With the UAV made safe, the DFLM considered that specialist agencies were not required to assist with the fuel leak as he was confident that this could be easily contained using matting that was part of the equipment on the fire truck. Exhibit 13

1.4.209. The DFLM cordoned off the area (50m past the point of impact and 20m past the point where the UAV came to rest) with metal pickets placed into the grass and mine tape. The Flight Line Manager (FLM) collected the Company camera and took photos to record the evidence. The Panel observed that, although an attempt had been made to Exhibit 13 cover the UAV with a tarpaulin to protect it from the rain, the Kollsman Pitot tube was left uncovered overnight and therefore susceptible to water ingress[56].

1.4.210. The GCS crew were then asked to retire to the WWA UAV centre and write individual statements. Once they had left the GCS it was secured with the power still on and all documentation was removed and placed at the Incident Control Point (ICP) in a secure designated area. With respect to external reporting, the WWA Air Traffic Services (ATS) Manager[57] stated that he did make a conscious decision not to dial 999 because he considered that the aircraft did not involve injury to any people, there was no fire and he was aware of a potential public relations issue. Exhibit 13 Witness 2

1.4.211. WWA has adopted the definitions of Accident and Serious Incident as set out in Regulation (EU) No 996/2010 (which include UAS) to determine whether a particular accident/incident is to be considered reportable. Since WK031 was on the MAR, occurrence reporting should be in accordance with Regulatory Article (RA) 1410. The WWA Emergency Orders and Supplementary Instruction UA 01/44, Operation of Watchkeeper UAS, do not include any guidance with regards to military registered aircraft or reference to RA 1410. Although WA orders do state that in the event of a reportable Accident or Serious Incident, the civilian Air Accident Investigation Branch (AAIB) is to be contacted as soon as possible, there is no such instruction to contact the Defence Air Accident Investigation Branch. Witness 2 Exhibit 46

1.4.212. Although initially treated as a Ground Incident, the ATS Manager re-assessed the situation as a Reportable Accident and contacted the AAIB who in turn passed the details to the Defence AIB who deployed a team of 3 investigators to WWA, Aberporth at 1240hrs on 16 Oct.

1.4.213. **Recommendation**. The Panel recommends that the Hd UAST should introduce an external isolation point for the Watchkeeper Emergency Battery.

1.4.214. **Recommendation**. The Panel recommends that the Air Traffic Services (ATS) Manager West Wales Airport (WWA) should amend the Airport Emergency Orders to include reporting procedures for accidents/incidents involving military registered aircraft.

Damage categorisation for WK031 UAV

1.4.215. The WK031 UAV was categorised as Cat 5 (Scrap). Exhibit 44

Summary of Findings

1.4.216. **Cause**. The sequencing of the landing logic within the Vehicle Management System Computer functioned as designed but not as intended. The VMSC commanded the post landing actions (V-Tail full deflection to pitch the nose down) whilst the UAV was still airborne, after recognising a false 'Ground Touch'.

1.4.217. **Contributory Factors**. The Panel identified 15 Contributory Factors.

a. The selection of Master Override (MO).

[56] As a result it was difficult for the Panel to ascertain if any water ingress had occurred pre or post-accident.
[57] WWA ATS Manager is also the FISO.

b. The 20m 'Ground Touch' window as designed.

c. 'Ground Touch' algorithm sensitivity.

d. The plethora of Flight Reference Card (FRC) emergency drills relating to MO, coupled with the paucity of information relating to implications of use had led to the procedural normalisation of MO operation.

e. Insufficient MO information within the Aircraft Documentation Set (ADS) that resulted in a lack of understanding about MO, its logic sequence and the consequences of its use.

f. Insufficient information flow within U-TacS with regards to the use of MO.

g. The lack in operator knowledge and training in relation to MO, the 20m 'Ground Touch' window and the landing logic.

h. Normalisation of MO use.

i. Operator currency and training pressures.

j. The unstable weather conditions.

k. Lack of crew situational awareness of the weather.

l. Disqualification window with MO selected is too high for the laser altimeters to be effective.

m. The wet runway surface caused the Laser Altimeter 2 to produce an erroneous height reading during the final approach.

n. The failure of the FMECA document to identify the potential failure mode in the landing logic when MO was selected.

o. The level of software assurance of the VMSC and in particular the ATOLS.

1.4.218. **Other Factors**. The Panel identified 4 factors that, whilst not causal or contributory in this accident, may cause or contribute to a future accident:

a. The programmed flight path at West Wales Airport (WWA) Rwy 26 has a compressed landing approach from Connect Point (CP) to Final Approach Point (FAP).

b. The Crews' perceived restriction of Danger Area activation might encourage the use of MO.

c. The apparent lack of weather limitations (cloudbase and visibility) in the RTS, Thales FOB and MFTP.

d. The order of the emergencies contained within the FRCs.

1.4.219. **Observations**. The Panel made 2 observations that were not relevant to the accident but worthy of consideration to promote better working practices.

a. The role of Observer was not clearly defined.

b. The RTS statement is incorrect and the Safety Assessment (on which the RTS is based) does include ATOLS.

PART 1.5 – RECOMMENDATIONS

Recommendation		Analysis Reference
1.5.1.	**Introduction**. The following recommendations are made in order to enhance Defence Air Safety:	
1.5.2.	**MAA Tech Director should:**	
	a. Review the issuing process and subsequent management of the Statement of Type Design Assurance (STDA) with respect to validity.	1.4.174-185/192
1.5.3.	**Hd UAST should:**	
	a. Review and modify the landing logic, with respect to sequencing, the use of the 20m Ground Touch window and Weight-on-Wheels (WoW) sensing, to ensure that 'Ground Contact' is not declared whilst the UAV is still airborne.	1.4.41 – 54 & Annex A
	b. Review and amend the Watchkeeper Aircraft Document Set to include comprehensive and consistent information on the use of Master Override.	1.4.59 - 68
	c. Consider the provision of real-time weather information in the GCS that can be accurately related to actual UAV position.	1.4.115-125
	d. Consider modifying the landing logic when Master Override is selected, to reinstate disqualified laser altimeters if both laser altimeter readings become valid post disqualification.	1.4.142-144
	e. Review and modify the landing logic for laser altimeter disqualification, post the Underrun Point when Master Override is selected, to ensure that it is within laser altimeter unit performance limits.	1.4.146-147
	f. Review the suitability of the Watchkeeper laser altimeters, especially in wet conditions and consider the requirement for an alternative and/or complimentary solution for measuring precise height.	1.4.149-151 & Annex A
	g. Review the performance of the Kollsman Pitot System, and if appropriate incorporate a drain point.	1.4.158-163 & Annex A
	h. Consider revising the statement in the RTS concerning the status of ATOLS and its consideration in the Safety Assessment.	1.4.188
	i. Review the Automatic Take-off and Landing System (ATOLS) Safety Integrity Level and consider increasing it from SIL 1 to SIL 3.	1.4.188/192
	j. As part of Equipment Standard 2, conduct a review of the PCMO Watchkeeper Failure Modes Effects and Criticality Analysis (FMECA) document and develop a new Fault Tree Analysis, which considers the entirety of the Take-Off and Landing sequence and in particular the use of Master Override and its effect on the landing logic.	1.4.189-192 & Annex A

	k. Review the requirement for the Watchkeeper system to have a Flight Data Recording capability to enable easy access to data post incidents or accidents.	1.4.200 & Annex A
	l. Conduct a review of Watchkeeper component grading against DEF Stan 00-970 Part 1 Section 4.	1.4.202 & Annex A
	m. Review the Watchkeeper V-Tail Quick Release Fastener locking device and consider retrofitting a secondary locking device to comply with the design criteria for Grade A components.	1.4.202 & Annex A
	n. Introduce an external isolation point for the Watchkeeper Emergency Battery.	1.4.207
1.5.4.	**Thales AM (MF) should:**	
	a. Review and amend the Release Statement for Watchkeeper Trials, which underpins Watchkeeper Military Flight Test Permits, to include cloud base and visibility limitations.	1.4.88-93
	b. Review and amend the documentation process for independent inspections to align with direction from the Manual of Maintenance and Airworthiness Process.	1.4.197-198
1.5.5.	**Thales Head of Flying (HoF) should:**	
	a. Review the Watchkeeper UAV approach routes and height into West Wales Airport (WWA) and amend if appropriate to minimise the possibility of a Velocity Deviation During Approach ATOL abort.	1.4.39
	b. Review and amend where necessary, the distribution processes within Thales and U-TacS in order to ensure that all personnel are aware of, and have access to, all relevant operating and technical information in a timely fashion.	1.4.67-68
	c. Review and amend the Watchkeeper Training Syllabus to include comprehensive training on the landing logic and the effect of the ATOL system overrides.	1.4.71-75
	d. Amend the Thales Flying Order Book to direct that a Suitably Qualified Experienced Person is positioned in the ATC Tower during poor or deteriorating weather throughout the period of the sortie.	1.4.95-96/ 99
	e. Amend the Thales Flying Order Book to clarify the operator roles and specify a currency requirement for the Payload Operator position.	1.4.98
	f. Amend the Thales Flying Order Book to include guidance and standardisation on the content required in the Authorisation Sheets.	1.4.102-103
	g. Review and amend the advice for operating the Watchkeeper UAV in the vicinity of thunderstorm activity, to include avoidance criteria.	1.4.115-125
	h. Review the requirement for an Observer and, if deemed a necessary role, ensure that Observers are suitably trained to fulfil that role.	1.4.128-136

1.5.6.	**ATS Manager WWA should:**	
	a. Amend the Airport Emergency Orders to include reporting procedures for accidents/incidents involving military registered aircraft.	1.4.205-212

PART 1.6 – CONVENING AUTHORITY COMMENTS

1.6.1 Watchkeeper 031 (WK031) was being operated by a civilian crew at West Wales Airport when it crashed during an attempted landing following the selection of Master Override (MO). This was used to force the aircraft to land on its first approach (rather than auto-abort) in an attempt to avoid deteriorating weather. Readers may be aware that following this accident another Watchkeeper, WK006, crashed at Boscombe Down also following selection of MO. Whilst the circumstances surrounding this second crash are different, the cause is likely to be very similar and also related to the selection of MO, its impact on the Vehicle Management System Computer (VMSC) and the issue of poor weather. This Service Inquiry (SI) deals with the first accident (WK031) only and any comparison with the second will be made when the WK006 SI is published later in the year. This SI has taken a significant time to complete, but has been technically complex with a wide range of stakeholders and involving many requests for information. Lessons from this accident are already being taken forward that will improve safety of the Watchkeeper UAV. As well as the technical aspects of this incident, the SI has exposed a range of issues with regard to the operation of the Watchkeeper system which will need fixing if we are to avoid the loss of further platforms and realise the aspiration to operate this asset outside military controlled airspace. I commend the SI Panel and the Defence Accident Investigation Branch for the way this SI has been handled, and the DE&S and Industry for their wholehearted assistance and openness in their support to this investigation. I agree the findings including the cause, contributory factors, other factors and observations. However, the causal statement that the VMSC functioned "as designed but not as intended" whilst true, I will express in a more straightforward manner by saying the VMSC logic was not fit for purpose. While they might be beyond the purview of this safety-related SI, there are clearly broader lessons for Defence to learn here in relation to how we first procure and then introduce this type of complex capability into front line service.

1.6.2 The Panel identified 15 contributory factors linked to the cause. These factors can be grouped into 3 areas of concern: firstly, the behaviour of the VMSC following selection of MO; the information available to crews regarding the use of MO in the Flight Reference Cards (FRCs), its Aircraft Document Set (ADS), the Integrated Electronic Training Programme (IETP) and within U-TacS; and finally, the impact of poor weather conditions. The reader will need to delve into the main body of the report to get a thorough understanding of these issues. However, for those with a passing interest, following selection of MO to prevent the air vehicle auto-aborting the landing, various safety protections were removed from the system which then allowed the VMSC to command post landing actions (V-tail pitch down) whilst the vehicle was still airborne. The crew did not appreciate the risk due to a lack of clarity across the FRCs, ADS and IETP regarding the selection of MO. For example, the Watchkeeper FRCs contain 38 cards which permit the use of

MO 'as required' but do not amplify the consequences of its use. The Panel considered that the ADS was insufficient in its coverage of the use of MO and the information flow regarding MO was poor across Thales and U-TacS. Accordingly, and not unexpectedly, during interview, the crew gave differing descriptions of how MO worked and the possible consequences of its use in the circumstances. Finally, and of the most concern, was the lack of weather limitations (cloud base and visibility) in the Watchkeeper Release-to-Service, Thales Flying Order Book and the Military Flight Test Permit. This omission, in the Panel's view, encouraged crews to fly in marginal weather conditions that could be a hazard to the vehicle. The UAV is not an all-weather platform, but without prescribed limitations crews expectations were that it could cope with far worse weather than it actually could.

1.6.3 Fundamentally, this expensive accident was caused by the unexpected actions of the VMSC following the selection of MO during a recovery in poor weather conditions. The VMSC commanded the post landing actions (V-Tail full deflection to pitch the nose down) whilst the UAV was still airborne, after recognising a false 'Ground Touch'. There is little doubt that Watchkeeper is a highly complex platform, particularly when in its landing phase and it has become clear that this complexity is not fully understood by the operators. There are a number of technical issues that will need to be resolved and crews will need to be more aware of the various failure modes to safeguard the platform in the future. Urgent Safety Advice recommending that the deficiencies in the VMSC landing software logic be corrected was issued to the Type Airworthiness Authority on 09 February 2015.

Director General Defence Safety Authority

