1.4.42. **Analysis**. The Panel assessed that the UAV could have successfully landed with the MO selected and a laser altimeter failure/ altimeter height difference (Scenario 4) if the VMSC had not sensed a 'Ground Touch' early within the 20m window. Therefore, the Panel needed to understand the following: Annex A

a. What caused the laser altimeter height difference?

b. What caused the vertical accelerations and / or pitch rates to exceed the WoW1 algorithm values and sense a 'Ground Touch'?

c. Why post 'Ground Touch' did the system logic allow the UAV to continue normally to 5m AGL before commanding 'Free-roll'?

The Panel elected to answer the system logic question first in order to understand the cause and effect. The remaining two questions on laser altimeters and vertical accelerations / pitch rates are covered later in the report.

1.4.43. **System Logic Processes**. To understand more about the logic gates and associated timeline during the accident sortie, the VMSC data, GFCC logs and GCS voice recordings were interrogated in greater detail to ascertain whether the logic processes were in series, parallel or acting independently once the UAV was within the 20m window. The chronology of events during the approach and landing are detailed below (Table 3):

Annex A

Serial	Time to Impact	Event	Remarks
1	9m 22s	Thunderstorm moderate warning received from ATC	
2	5m 40s	Pilot selected 'Laser ALT DIFF' in GCS	Laser altimeters known to be unreliable in inclement weather conditions above 30m AGL (discussed later in report).
3	2m 46s	Pilot selected 'Master Override' (MO)	All 18 ATOLS overrides enacted.
4	1m 20s	WK031 reaches 'Connect Point' waypoint	Flaps deployed, laser altimeters and Air Beacon Unit (ABU) turned on.
5	20s	WK031 reaches Underrun (UR) waypoint and has an ATOLS 'lock'	With MO selected the system is now capable of allowing laser altimeter disqualification.
6	17s	Laser altimeter 2 disqualified	With MO selected, logic opens a 20m 'Ground Touch' window and disqualifies <u>both</u> laser altimeters.
7	7s	1st '**Ground Touch**' sensed	WoW1 logic registered for 200ms, followed by an Air Jump. WK031 height was 16.89m AGL
8	6s	2nd '**Ground Touch**' sensed	WoW1 logic registered for a second time. This activated and latched.
9	2s	At 7m ATOLS/GTOLS WK031 passed through 'Semi-Flare'/'De-Crab' in 50ms	
10	2s	'**Ground Contact**' registered for 1s	
11	1s	VMSC commands '**Free Roll**'	WK031 height 3.95m AGL. V-

			Tails commanded to full deflection.
12	0	WK031 impacts Runway 26	

Table 3 - Chronology of events for WK031

1.4.44. The Panel found that the 'Ground Contact' logic appeared to act as an 'AND' gate[9], with each of the following inputs required in any order before 'Ground Contact' could be registered by the VMSC:

a. 'Ground Touch' latched (WoW 1).

b. 'Semi-Flare'/'De-Crab' complete.

Therefore, the Panel needed to ascertain whether this event was repeatable.

Hypothesis testing

1.4.45. Having established that the UAV accelerometers experienced a change in vertical acceleration and pitch rate that caused the VMSC to register 'Ground Touch' whilst still airborne, the Panel elected to test the 'AND' gate logic theory.

1.4.46. The Panel utilised the Watchkeeper Hybrid Simulator at U-TacS, Leicester, to replicate the conditions and the sequence of events that resulted in the accident. The aim of this exercise was to establish if the events leading to the accident were a result of an intermittent VMSC software fault or a flaw in the VMSC landing logic, which could be present in future sorties.

1.4.47. Of note, the Hybrid Simulator[10] does not have an ATOLS capability and relies purely on the GTOLS landing system. For the purposes of the simulation, the required vertical acceleration and pitch rate were induced by increasing the magnitude and frequency of the induced turbulence after the UAV had reached the UR point. 16 flight profiles were conducted, the results were as follows: Exhibit 16

a. Test 1 - Normal landing in which Ground Touch and Ground Contact, followed by V-Tail full deflection (nose pitched down) occurred at the surface.

b. Tests: 3, 6, 7, 8, 14 –The same profile as WK031 was established with MO selected and one laser altimeter failed to induce a height difference. An inject of turbulence created conditions to simulate a vertical acceleration force felt by the accelerometers. These tests resulted in a large nose down attitude and subsequent impact with the ground.

c. Tests: 9, 10, 11 – Tests that self-aborted. The same profile as for Serial (b) was established, except in these tests MO was deselected at the CP (Test 9), before the UR point (Test 10) and after the UR point (Test 11). In all tests the UAV landing was self-aborted.

d. Tests: 15, 16 – GPS WGS84 height biased. The same profile as for Serials (b) and (c) was established except the WGS84 height was biased by ± 8m to emulate the consequences of an erroneous GPS height error. These

[9] An AND gate is a digital logic gate with two or more inputs and one output that performs logical conjunction. The output of an AND gate is true only when all of the inputs are true. If one or more of an AND gate's inputs are false, then the output of the AND gate is false.
[10] Hybrid Simulator uses identical LRUs as the real system.

tests resulted in Controlled Flight Into Terrain.

e. Tests: 2, 4 and 5 - These tests self-aborted because the introduction of turbulence prevented the UAV achieving its planned way points.

1.4.48. The test runs on the Hybrid Simulator demonstrated that the accident flight could be replicated repeatedly given similar UAV configuration and turbulent conditions. Of note, WK031 accident occurred with an ATOLS 'lock' (Para 1.4.41). The test runs indicate that given the same parameters, the accident is equally likely to occur in GTOLS approach mode. The Panel concluded that the Watchkeeper 'Ground Touch' logic did act as an 'AND' gate and although it functioned as programmed, it was not as intended. The logic was not robust in that it was blind to the order in which the criteria were met and latched, which increased the likelihood of premature declaration of 'Ground Contact'. It was concluded that the VMSC commanded the post landing actions (full V-Tail deflection to pitch the nose down) whilst the UAV was still airborne, after recognising a false 'Ground Touch'.

1.4.49. As a result of the findings from the test runs on the Hybrid simulator, the Panel issued a Safety Note to DG MAA (now DSA) dated 9 Feb 15, which contained the following recommendation: Exhibit 31

'The panel recommends that the UAST TAA ensures that the VMSC landing mode software logic when MO is selected is corrected to prevent a Ground Touch and Free Roll command being activated whilst the Aerial Vehicle (AV) is still airborne.'

1.4.50. As previously stated, in the case of WK031, the disqualification[11] of both laser altimeters, combined with the selection of MO, opened the 20m window. The Hybrid simulator runs demonstrated that this 20m window, combined with the 'AND' gate logic allowed the VMSC to sense and latch an early 'Ground Touch'. Therefore, the Panel concluded that the following were **Contributory Factors** to the accident:

a. The selection of MO

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

VMSC WoW 1 Algorithm Tolerance

1.4.51. As discussed at para 1.4.24, the fitment of a mechanical WoW switch to sense 'Ground Touch' had been previously tested and removed due to unreliability issues when operating from a rough, austere landing strip. As a result the VMSC Landing Logic relies on a software algorithm to register 'Ground Touch' which, on a normal approach, is enabled at 1m above the runway surface. Annex A

1.4.52. To ascertain if the 'Ground Touch' logic was fit for purpose, the Panel reviewed the available data from other WK flights flown from WWA where MO had been selected. This review revealed that there had been 26 recorded flights when the operator had selected MO during the landing approach; on 14 of these occasions, MO was then deselected prior to touch down. However, of the flights where the UAV had successfully landed with MO selected, flights UK260 and UK357 were identified as being of particular interest. Annex A

[11] Laser altimeter disqualification will be discussed at para 1.4.144.

1.4.53. Flight UK260 was of interest because the UAV landed without registering a 'Ground Touch'. It would appear that during non-turbulent environmental conditions, similar to those encountered by UK260, there is a risk that the landing algorithm threshold is not sensitive enough to register 'Ground Touch'. The landing sequence was completed when the UAV took the arrestor cable which caused 'Ground Touch' to register. Conversely, UK357 was of interest because of the similar weather conditions to those that prevailed at WWA during the recovery of WK031. Analysis of the data showed that during turbulent environmental conditions the software threshold for the 'Ground Touch' parameter could be triggered when the UAV was still airborne because it was too sensitive.

1.4.54. The Panel concluded that the WoW1 algorithm tolerances appeared incompatible with either high levels of air turbulence or very smooth air conditions. In the case of WK031, a combination of a 20m 'Ground Touch' window with MO selected and inappropriate 'Ground Touch' algorithm sensitivity increased the probability that an erroneous 'Ground Touch', due to turbulence, would be sensed prior to actual touchdown. Therefore 'Ground Touch' algorithm sensitivity was a **Contributory Factor**.

1.4.55. **Recommendation**. The Panel recommends that Hd UAST should 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.

Summary

1.4.56. In summary, the Panel assessed that the UAV could have successfully landed with MO selected and a laser altimeter failure/altimeter height difference if the VMSC had not sensed a 'Ground Touch' early within the 20m window. The Hybrid simulator runs demonstrated that this 20m window, combined with the 'AND' gate logic allowed the VMSC to sense and latch an early 'Ground Touch'. The Panel concluded that the WoW1 algorithm tolerances appeared incompatible with either high levels of air turbulence or very smooth air conditions.

Cause

1.4.57. The Panel identified the **Cause** of the accident as follows:

> 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'.

Further analysis

1.4.58. Given the cause described above, the Panel considered that three main events had to have taken place in order for the accident to have occurred. These three main events formed the basis for further analysis and are as follows:

a. Use of MO and its selection on the day of the accident.

b. Laser altimeter disqualification.

c. Change in vertical acceleration and pitch rate experienced by the UAV.

Master Override (MO) Selection

MO available information

1.4.59. To understand the decision to use MO, the Panel investigated what information was available to the U-TacS operating crew and their understanding of it. In addition, the Panel reviewed the information flow between the Designer, Thales and U-TacS.

1.4.60. **The Designer**. The Panel established that the Designer predominantly operated the UAV with an External Pilot (EP) available if there was a requirement to land the UAV from the first approach. This is in contrast to the U-TacS standard operating procedure, where <u>only</u> ATOL is used, a practice driven by the Army's original requirement to have a fully automatic capability for Watchkeeper. Furthermore, U-TacS did not have the trained personnel to use an EP[12]. Since The Designer considered the use of MO **only** for serious emergencies e.g. engine fire, they had no requirement to specifically develop MO procedures and provided little in the way of guidance, with respect to the use of MO, to U-TacS. However, an investigation report was released by the Designer to U-TacS following a previous incident which gave guidance that MO should only be used on **limited** occasions. No guidance was offered as to the definition of limited. Exhibit 17 Witness 1 Witness 7

1.4.61. **The Designer Training Notes**. The Designer had provided U-TacS employees with MS Powerpoint presentations during their initial training. These presentations contained one slide that gave limited information on the use of MO. In the Panel's opinion, given the intended operating procedure for UK Watchkeeper, there was insufficient information provided to the crews. Exhibit 18 Exhibit 57 Witness 4

1.4.62. **The Interactive Electronic Technical Publication (IETP)**. The IETP is a computer based package produced by Thales/U-TacS and the main source document from which student training notes are produced whenever possible. There are no other technical documents produced to support Watchkeeper operations. The Panel found that at the time of the accident the IETP computers at U-TacS were up to date with issue 5.1. However, the IETP contained no specific guidance on the use of MO and the associated implications.

1.4.63. **Flight Reference Cards (FRCs)**. There are 4 sets of Watchkeeper FRCs produced by Handling Squadron at MoD Boscombe Down; Normal/Emergency procedures, Known Problems and Work-Arounds, Enhanced Image Analyst procedures and Flight Line procedures. The FRCs were all at the correct amendment state at the time of the accident. Of these 4 document sets, 3 were used by the operating crew but only the Normal/Emergency FRCs have reference to MO. There are 3 scenarios covered by the FRCs where MO <u>must</u> be selected; these are as follows: Exhibit 19

a. **Card E-3**: In the event of fire indication, Master Override should be selected On.

b. **Card E-59:** In the event of a VMS failure indication, Master Override should be selected On

c. **Card E-78**: - If an ATOL Abort occurs, individual ATOLS Overrides should be attempted for subsequent landing(s). If individual overrides are

[12] U-TacS used the Designers EPs for early trials as a back-up only.

ineffective, Master Override should be selected On. This last step also refers to "*Warning 1: When Master Override is selected, the UA will continue to land and may land outside the TOL site runway parameters*".

However, the Panel noted that there were an additional 38 cards in the FRCs which permitted the use of 'Master Override….. as required' but provided no amplifying information with regards to the possible consequences of its use. As such, the severity of the possible outcome when MO was selected would not be readily apparent to the UAV operator. The Panel concluded that the plethora of emergency drills giving the operator the freedom to use MO, and the paucity of information relating to the implications of its use had helped normalise the procedural use of MO. Exhibit 19

1.4.64. **Operational Conversion Unit (OCU) Student Notes**. Thales was contracted to produce Student Notes for the OCU at the Royal School of Artillery (RSA) Larkhill. Thales then subcontracted Selex ES to produce two sets of notes: the Pilot System Familiarisation Notes and the Operator Student Notes. Within the Operator Student Notes, Section 159 'ATOLS Abort and Overrides' the following information was stated: Exhibit 20

a. 'If the UAV still auto-aborts in low cloud consider using additional overrides or Master Override.'

b. 'A MASTER override is also provided that overrides all of the above conditions that might cause an ATOL abort.'

c. 'Note: The master override should only be used in accordance with the appropriate emergency procedure.'

d. 'WARNING: Any OVERRIDE activated requires observer to assess the approach.'

e. Note: When MASTER override is selected all ATOLS overrides will be applied in a single action.

1.4.65. The Panel found that the OCU Student Notes produced by RSA Larkhill were being used by some U-TacS employees having completed the OCU at RSA Larkhill. RSA Larkhill stated that the Student Notes were presented as a training aid whilst on the course and become uncontrolled once the student had completed the course. Therefore, the Student Notes held by some U-TacS employees were private copies with no authority or official position in the day-to-day operations at WWA.

1.4.66. In addition, the Panel found that some practices contained within the Student Notes from Larkhill, whether by legacy or coincidence, were being adhered to by U-TacS. The absence of controlled Student Notes and an Operator's Manual severely restricted the amount of information in relation to MO being available to the crews. In the Panel's opinion, this was the driving force behind the requirement for unofficial, local notes/aide memoires being developed and disseminated among the crews. Exhibit 22 Witness 4

1.4.67. **U-TacS internal information flow**. The Panel investigated how information with regards to the use of MO was promulgated to U-TacS staff. An email relating to the use of MO was released by the U-TacS Flight Test Manager to several other U-TacS employees. This email was distributed on 26 Jan 12 referencing the Designers guidance Exhibit 22 Exhibit 24 Exhibit 25 and reinforcing that MO should only be used with extreme caution. This information was not promulgated within the Thales Flying Order Book (FOB), U-TacS Hot Poop[13] or Watchkeeper Training Notes. The only reference to MO within the FOB was a local procedure requiring an External Observer to be present when MO is used. Overall, the Panel concluded that there had been insufficient information flow within U-TacS with regards to the use of MO.

1.4.68. **Conclusion**. The Panel concluded that:

a. The plethora of emergency drills within the FRCs relating to Master Override (MO), coupled with the paucity of information relating to implications of use, had led to the procedural normalisation of MO operation and as such was **a Contributory Factor** to the accident.

b. There was insufficient MO information within the Aircraft Documentation Set (ADS) which resulted in a lack of understanding about MO, its logic sequence and the consequences of its use. This was a **Contributory Factor** to the accident.

c. There had been insufficient information flow within Thales and U-TacS with regards to the use of MO which was a **Contributory Factor** to the accident.

1.4.69. **Recommendation**. The Panel recommends that the Thales Head of Flying should 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.

1.4.70. **Recommendation**. The Panel recommends that the Hd UAST should review and amend the Watchkeeper Aircraft Document Set to include comprehensive and consistent information on the use of Master Override (MO).

MO Training

1.4.71. The crew members in the GCS at the time of the accident followed different training paths. The 3 fully qualified members of the crew completed their training with the Designer outside of the UK. Upon completion of this training they returned to the UK for simulator training with Thales in Crawley[14] and U-TacS in Leicester [15] before continuing on to live flying at WWA. The remaining crew member underwent Conversion To Type with the Royal School of Artillery at Larkhill prior to attending U-TacS Leicester for simulator training. On completion of these phases he commenced live flying at WWA. Exhibit 26

1.4.72. The current simulator syllabus conducted at U-TacS in Leicester for initial qualification consists of 11 sorties, 5 of which are emergency handling sorties. However, the syllabus does not explicitly state which of these sorties must include the use of MO. Furthermore, upon commencement of training at WWA, there is a requirement to conduct 6 live flying sorties where again the use of MO is not specifically detailed for training demonstration or practice. Exhibit 22

[13] Internal information document for operators.
[14] Software Integration Lab 7 Simulator.
[15] Hybrid Simulator.

1.4.73. **Continuation Training**. Operators already qualified on Watchkeeper are required to complete annual training iaw the Thales FOB. The annual simulator training requirement is for 5 sorties, of which, 2 sorties specifically include emergencies where again, the use of MO is not specifically stated for demonstration or practice.

Exhibit 22

1.4.74. **Training Notes**. As explained previously, the document set available to crews was limited to the IETP and FRCs. Up until 2013, new operators were taught using the original Designer and Thales presentations. These presentations were printed out and used as reference notes by the crews. There was no externally approved syllabus or Defence System Approach to Training (DSAT) accreditation for the early training. U-TacS determined the conversion syllabus through best practice, based on the original Designer training augmented by additional software training from Thales.

Exhibit 26

1.4.75. **Understanding of MO**. During initial interviews, the crew of WK031 all gave different descriptions of how MO worked and the possible consequences of its use. Given the varying levels of experience and information available, this was not unexpected. Crucially, in the case of WK031, the selection of MO led to a 20m 'Ground Touch' window being opened. None of the crew were aware that a 20m 'Ground Touch' window existed. The Panel concluded that the lack of operator knowledge and training in relation to MO, the 20m 'Ground Touch' window and the landing logic was a **Contributory Factor** in the accident.

Witness 1
Witness 3
Witness 4
Witness 5

1.4.76. **Recommendation**. The Panel recommends that the Thales Head of Flying should review and amend the Watchkeeper Training Syllabus to include comprehensive training on the landing logic and the effect of the ATOL system overrides.

Historical reasons to use MO and Normalisation

1.4.77. The following analysis referenced information on the use of MO provided by Thales, which detailed that, prior to the accident, U-TacS had conducted 394 sorties during which MO had been used on 25 separate occasions. Three members of the crew reported that they had used MO in the past. All four crew members had practiced its use in the simulator. The Panel therefore concluded that, while it was not used frequently, the use of MO was not an unusual event, having been used in approximately 6% of sorties. Thales provided a summary of the 25 occasions on which the MO was used (Table 4). On 4 of these occasions, MO was used for training purposes only and not for landing. Analysis of the remaining 21 occasions are included in Table 4.

Exhibit 27
Witness 1
Witness 3
Witness 4
Witness 5
Annex B

Previous use of Master Override (MO) by U-TacS operators			
MO deselected <u>prior</u> to touchdown			
Flight No.	Weather	System abort cause	Additional issues
UK060	Showers, BKN 2-3000ft, 350/12kts	Laser altimeter Difference	
UK163	OVC ST, base 2000ft, 300/8kt	Envelope Horizontal	**UAV landed 15m off centreline**.
UK164	SCT, 1/8 base 1500ft	Ground Proximity	Weather (Cloud near Connect point).
UK193	SCT 2-3000ft 250/10kts	No - training	
UK202	SCT 2000ft Tops 4000ft 040/9kts	Envelope Vertical	High approach at connect Point. **UAV landed heavy off centreline**.

UK204	Base 3500ft 310/12kts	ADU Velocity Sensor/ Envelope Protection	
UK224	100/03kts	No - GPS Denied	
UK263	BKN 3000ft 070/10kts,	Envelope Protection	High approach
UK293	360/5kts	Envelope Ground Proximity	
UK351	270/14kts	Envelope IAS (Speed)	Range/ airspace closure imminent
UK365	360/10kts	Envelope IAS (Speed)	
UK371	Fog 020/4kts	Envelope Ground Proximity	Poor weather (Fog)

MO selected to touchdown			
Flight No.	Weather	System abort cause	Additional issues
UK037	FEW, 220/5kts	Envelope Protection	
UK050	BKN 4-5000ft, Light/VRB	Laser Altimeter Fail / Vertical Envelope	Range/ airspace closure imminent
UK059	BKN 3-5000ft, 320/15G18	Envelope IAS (Speed)	Poor weather (Squall)
UK090	BKN 3500ft, 270/12kts	Laser altimeter Fail	
UK108	OVC ST at 450ft 280/6kts	ADU Velocity/ Estimated AOA & AOS	
UK126	OVC ST at 1000ft 250/5kts	Envelope Vertical/ Ground Proximity	Range/ airspace closure imminent
UK132 (GPS Denied)	Nil, 000/04kts	Envelope Horizontal	
UK143	FEW/SCT 800-1000ft, 050/10kts	Envelope Ground Proximity	Poor weather (Low cloud)
UK157	SCT/BKN 2-6000ft 020/3kts	Laser altimeter Fail	Range/ airspace closure imminent
UK260	Snow 360/12kts	Automatic abort. Then manual abort due too high on approach/	Poor weather (snow). **UAV landed long and fast**.
UK357	290/5kts	Ground Proximity/ Laser altimeter Fail	Poor weather
UK370	330/6kts	Land Status Timeout	Poor weather (low cloud)
UK371	020/4kts	Ground Proximity Warning	Poor weather (fog)
UK395	BKN 1200ft, 210/9kts +TSRA	No abort	Poor weather. **UAV crashed**.

Table 4 - Previous Use of Master Override (MO) by U-TacS

1.4.78. It can be seen that the most common reason why MO was selected was as a result of previous aborts experienced and/or the number of Warnings, Cautions and Advisories (WCAs). The second most common reason for using MO was that the crew perceived a need to land the aircraft expeditiously, either due to West Wales Range closure time (and associated Segregated Airspace) or the prevailing weather conditions. Annex B

1.4.79. The Panel identified that there were 4 situations when the MO was selected due to the inability to override an individual abort condition, specifically Indicated Air Speed (IAS). There were 3 occasions on which the landing was abnormal in some way (one where the UAV landed long and fast, and two off the runway centreline). On the remaining occasions that MO had been used the landing had been successful. It is the opinion of the Panel that such positive feedback would increase the likelihood of MO being used. Annex B

1.4.80. There were 4 occasions where MO was used to ensure the UAV was landed before the imminent de-activation of the Segregated Airspace. The Panel observed that there was some perceived pressure by operators to recover the UAV prior to the end of the slot. However, the Panel discovered that the Senior Duty Controller at National Air Traffic Services (NATS) has an operating instruction that allows for an extension to the D201-202 danger area activation times in the event that the UAV encounters weather or technical issues. The Panel concluded that, although this did not contribute to this accident, the perceived restriction of Danger Area activation might encourage the use of MO and was therefore considered an **Other Factor.** Annex B Exhibit 25

1.4.81. Over time, the frequency with which MO was used had remained relatively consistent. However, there was a trend towards engaging MO earlier in the recovery process. In the first ten times that MO was used for landing, there was an average of 2.2 aborted circuits before MO was engaged. In the next 11 occasions MO was used for landing, the average number of circuits before MO was engaged was less than one. Annex B

1.4.82. The 10^{th} use of MO for landing was the first time in which MO was used as part of the landing process, but deselected prior to landing. Of the subsequent 11 times MO was used during recovery it was deselected prior to landing on 7 of those occasions. Annex B

1.4.83. Of the remaining 4 occasions, 2 landings were attempted using and deselecting MO and were unsuccessful and MO was subsequently used all the way to landing. Of the remaining 2 instances, MO was engaged all the way to landing on the first time it was engaged. This experience gave the crews confidence that MO could be used successfully earlier in the recovery process to deal with adverse situations. It was perceived that MO could be deselected after those situations had been resolved or continued to be used through the landing process. Annex B

1.4.84. The Panel concluded that the lack of suitable overrides and the regular use of 'workarounds' contributed to normalisation. Additionally, the number of successful landings with MO selected confirmed its use as a viable option, despite a true lack of understanding (unknown at the time) by the crews at WWA as to exactly what safety defences had been removed. The Panel concluded that the normalisation of MO use was a **Contributory Factor**. Annex B

Events leading to the selection of Master Override (MO) on the WK031 Accident Flight

1.4.85. **Introduction**. In order to fully understand the pre-conditions affecting the crew's decision to select MO during the recovery of WK031, it was necessary for the Panel to review the following factors:

a. The forecast weather and associated UAV limitations.

b. Sortie plan, crew composition, qualifications and currency.

c. Authorisations.

1.4.86. Although much of this part of the investigation resulted in observations and recommendations, made by the Panel, that were not connected with the decision to use MO, they were included in this section of the report for completeness and to avoid duplication.

The forecast weather and associated UAV limitations

1.4.87. At 0624Z on 16 Oct 14, the Met Office issued an area forecast for the Aberporth range which described a large low pressure area to the west of the UK, bringing unstable air across the West Wales Ranges with the possibility of heavy showers and isolated thunderstorms (Fig 12). At 0627Z a Thunderstorm Warning was issued which stated that there was a 40% probability of a thunderstorm occurring in the Ranges between 0627Z and 1700Z. Additionally, a Thunderstorm Level Warning Low[16] was issued for WWA at 0647Z. The WK031 sortie was scheduled to take-off at 0915Z.

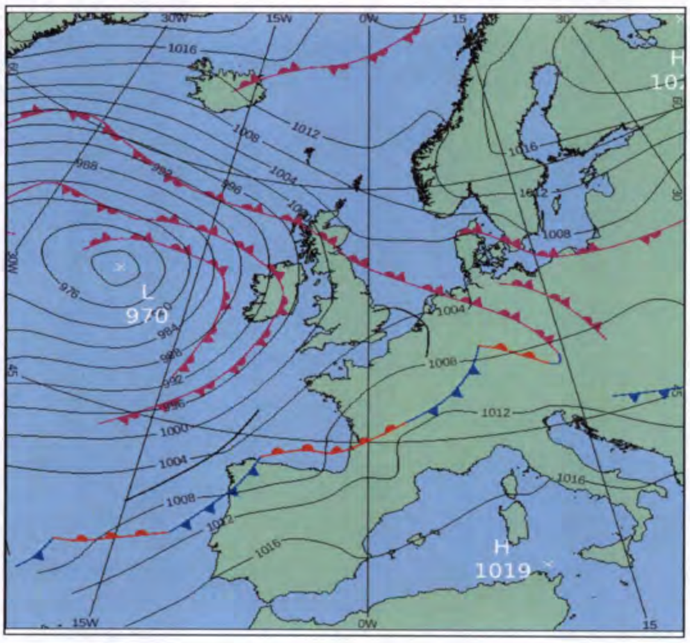

Figure 12 – Synoptic Chart for 1200Z, 16 Oct 14

1.4.88. **Weather Brief**. The crew of WK031 received a MET brief prior to the sortie which reflected the earlier forecast and indicated that there would be showers, cumulonimbus cloud and thunderstorms during the planned flying period. The forecast (Fig 13) stated that there would be a 30% probability that for a period of no more than 2 hours within the forecast period where thunderstorms and associated hazards of severe icing and turbulence would be present with winds of 180°/12kts temporarily gusting 20kts. The Panel considered this forecast in context of the weather limitations that the operators had to adhere to as stated in the MFTP, Thales FOB and Hot Poop. Exhibit 9

[16] Thunderstorms are not occurring at the present time (within 40km) and are not expected in the immediate future.

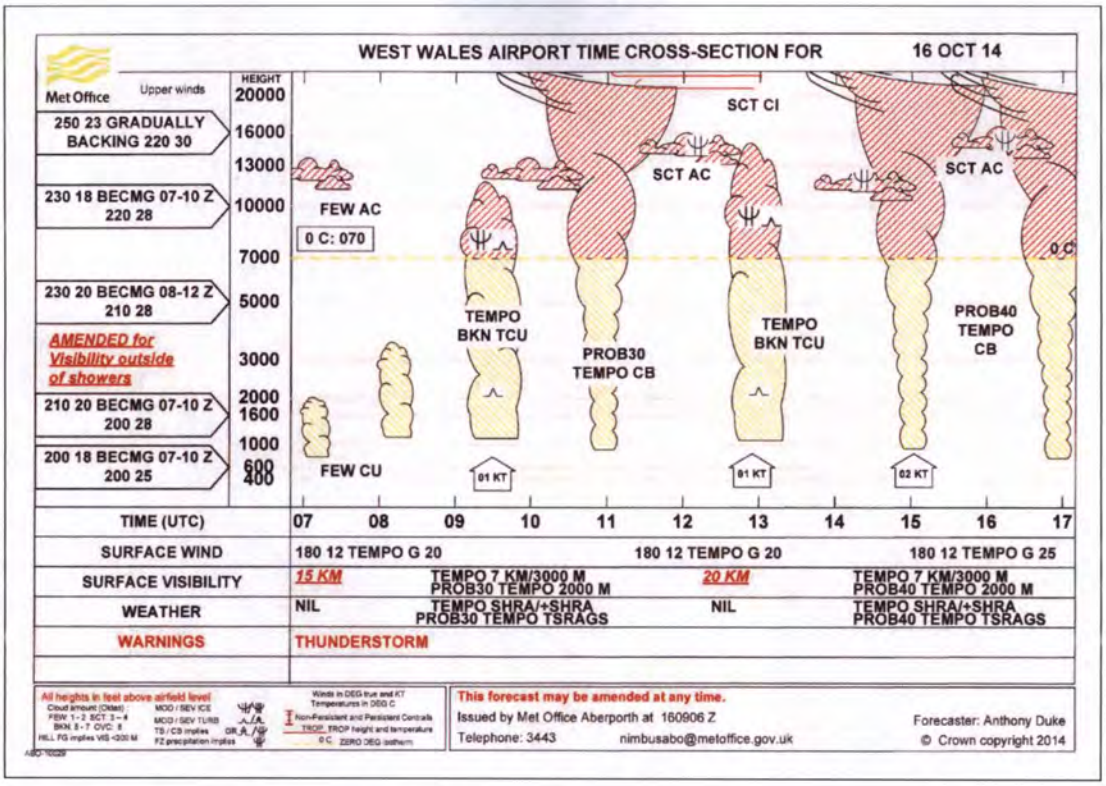

Figure 13 – West Wales Airport Weather Cross Section dated 16 Oct 15

1.4.89. **Weather Limitations**. The Thales FOB states that UAVs are not to be flown in adverse meteorological conditions, especially severe icing conditions, areas of turbulence and in areas where there is a thunderstorm risk. The FOB instructs crews to adhere to the weather limits laid down in the Military Flight Test Permit (MFTP) and/or Release to Service (RTS). The FOB does not make it clear what warning level of Thunderstorm risk is acceptable, i.e. LOW, MOD or HIGH. Furthermore, the FOB makes no mention of minimum cloud base or visibility limits for general flying. Exhibit 22 Exhibit 29 Exhibit 34

1.4.90. **Military Flight Test Permit (MFTP)**. The MFTP Release Statement for Watchkeeper Trials exhibit stated within the Environmental Section that; "Flight in lightning conditions or during Thunderstorm Level High is prohibited. WARNING: A DIRECT LIGHTNING STRIKE MAY RESULT IN LOSS OF THE UAV". In addition the MFTP has two amplifying notes: Exhibit 29

a. Note 1: Thunderstorm Level High is defined as a thunderstorm is occurring, or is expected to occur in the location of the UAV in the immediate future (normally in about 15mins).

b. Note 2: Flight in proximity to Cumulonimbus cloud greatly increases the risk of a lightning strike.

However, the MFTP Release Statement does not provide any guidance as to the distance by which thunderstorm activity should be avoided. The only cloud base or visibility limitation mentioned in the MFTP Release Statement relates only to the use of an external pilot (EP) and not to general flying. As U-TacS had no trained EPs, the Panel decided that, these weather limitations were irrelevant with respect to this accident. However, the Panel were surprised that the MFTP issue 15 contained no specific cloud base or visibility limitations to allow visual monitoring to take place during the approach or take-off. Furthermore, the Panel found no mention of cloud base or visibility limitations in previous versions of the MFTP used in earlier trials. The Panel understood that the system was capable of automatic landing and take-off in zero visibility, but as the UAV was being flown in flight test trials the Panel believes that it would be prudent to state in the MFTP that there should be an ability to visually monitor it during these phases of flight. Then, as confidence grew in the system, cloud base and visibility limitations could be reduced in subsequent issues of the MFTPs with incremental reductions in risk.

1.4.91. **Flying Order Book**. Equally, there is a requirement in the Thales FOB which states that: Exhibit 22

> '*WARNING any override activated requires an **observer** to assess the approach. Automatic ATOL aborts can be overridden via the override option on the AVDC. Note: not all fault conditions can be overridden. ATOL overrides are only set prior to recovery if an emergency has arisen or the first attempt to recover has aborted.*

To comply with this warning, the Panel are of the opinion that, there would have to be a sufficiently high cloud base and adequate visibility in order for the Observer to undertake their duty.

1.4.92. **Thales Hot Poop**. The only document that mentioned any relevant limitations relating to minimum cloud base and visibility (where an EP is <u>not</u> being used) was the Thales Hot Poop number 13 which was published as a result of a Safety Review Board (SRB). The SRB applied the limitation after concerns with the Pitot static systems when flying through cloud due to blockages of the Kollsman pitot probe. The Hot Poop stated that the following limitations shall be observed during flying at WWA: Exhibit 21 Exhibit 28 Exhibit 25

a. Weather Limitations in the MFTP are to be respected.

b. General weather limits[17]:

(1) Cloudbase – no significant cloud below 700ft AGL

(2) Horizontal visibility – 3.7km (Green).

1.4.93. **Conclusion**. The Panel observed that this omission of weather limitations (cloud base and visibility) in the Watchkeeper RTS, the Thales FOB and MFTP would affect all Watchkeeper operators. In the opinion of the Panel, the lack of weather limits in the key documents that regulate Watchkeeper operations might encourage crews to fly in marginal conditions and was therefore considered an **Other Factor**.

1.4.94. **Recommendation**. The Panel recommends that the Thales Accountable Manager Military Flying (AM (MF)) should review and amend the Release Statement for Watchkeeper Trials, which underpins Watchkeeper Military Flight Test Permits, to include cloud base and visibility limitations.

Sortie plan, crew composition, qualifications and currency

1.4.95. **Introduction**. The crew decided that the weather would be suitable for the planned sortie duration and that there would be sufficient gaps between the showers to enable the sortie to take place. The mission was planned as a joint Type Conversion Exhibit 8 Witness 1 Witness 9

[17] Weather state colour code Green = Base of lowest cloud layer 3/8 or more, is 700ft and/or surface visibility is 3.7km.

(Exercise FLY2) for the UAV-p1 and a currency sortie for the UAV-p2 undertaking Payload Management. The UAV-p1 was under instruction and supervision from the UAV-c. The AO, as one of only 2 available qualified instructors, was required to be in the GCS to monitor the UAV-p2 position. Due to the weather forecast and the fact that the AO was required in the GCS, it was agreed at the main sortie brief that another qualified UAV-p would be used in the ATC Tower to monitor the weather as the crew knew that it would be potentially changeable.

1.4.96. **Crew composition**. During interview, the AO recognized that, in hindsight, it was an unwise decision for the AO not to be in the ATC Tower but this decision was based on a lack of manpower, the paucity of flying and the fact that the UAV-p that was sent to the tower was not a qualified instructor. Additionally, the WK031 UAV-c stated in interview that his preference would have been for the AO not to be in the GCS. He added that ideally the AO should be in the ATC Tower, where he would have direct contact with the Met Office and could manage any inputs that were needed during the sortie. During interview the Thales Head of Flying (HoF) was not aware of any particular pressures to fly but accepted that there were not enough qualified individuals at WWA on the day of the accident to allow the AO to be in the tower. He also stated that, had the AO not been in the GCS, he might have had a better idea what was happening with the weather. One of the options available to the WK031 AO would have been to fly a PO, a position with no particular currency requirements, as opposed to a UAV-p2. This would have allowed the AO to utilise the available non instructor UAV-p as the Flight Log Keeper and allow the AO to be in the ATC tower to monitor the weather and still achieve the instructional element of the sortie.

Witness 1
Witness 3
Witness 8
Exhibit 22

1.4.97. **Qualifications**. The Panel noted that all crew members were correctly qualified for their role and that the AO and the UAV-c were current. However, the Panel also noted that there appeared to be some confusion with regards to the two roles of UAV-p2 and Payload Operator (PO). The AO entered the annotation PO into the authorisation sheets as opposed to UAV-p2.

1.4.98. **Currency**. The Thales FOB defines the flight currency requirements for all disciplines, as well as stating the recovery process from a loss of currency. UAV-p1, UAV-p2 and PO (Payload Operator) are listed as distinct roles that have their own currency and training requirements. According to the FOB, there were no specific currency requirements for the position of PO. It merely states that the PO must be suitably trained to be able to conduct the trial. If training is required for competency, it must have been completed within a suitably recent trial and timescale. It is the Panel's opinion that, since the PO is required to monitor the actions of the UAV-p1 during all stages of flight and complete challenge and response check lists, there should be stricter currency requirements for the position of PO.

Witness 1
Exhibit 22

1.4.99. **Conclusions**. The Panel observed that the crew composition on the day complied with regulations but was not ideal for the conditions, a situation not helped by the absence of any real-time weather information in the GCS. Additionally, the Panel noted that, whilst the UAV-p tasked with monitoring the weather was in the ATC tower for the majority of the sortie, he left the tower prior to recovery and the final approach and was therefore was not in a position to provide any feedback to the crew during the landing phase. However, the Panel concluded that, in this instance, he would not have had the time to intervene to prevent the accident and therefore was **Not a Factor** in the accident. The Panel concluded that the desire to fly in marginal conditions was driven by operator currency and training pressures and hence these were a **Contributory Factor**.

1.4.100. **Recommendation**. The Panel recommends that the Thales Head of Flying should 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.
1.4.101. **Recommendation**. The Panel recommends that the Thales Head of Flying should amend the Thales Flying Order Book to clarify the operator roles and specify a currency requirement for the Payload Operator position.

Authorisations

1.4.102. The AO attended the main crew brief and was fully conversant with the flight test cards, the proposed flight parameters and the prevailing and forecast Met conditions. The sortie was authorised by the AO in accordance with Section 300 of the Thales FOB and Regulatory Article 2306 on a 1575B Authorisation Sheet. Although the WK031 UAV-p2 was entered in the authorisation sheets as a PO with no mention of a currency requirement, during interview, the crew stated that it was their understanding that he was flying to regain UAV-p2 currency. In reply to a Request For Information (RFI) submitted by the Panel the Thales HOF stated that 'PO = UAV-p2' and that the PO annotation in the Authorisation Sheet should therefore be regarded as UAV-p2.

Exhibit 33

1.4.103. The details included on the authorisation sheet reflected the timings and the aims of the sortie; however the currency element of the sortie did not appear on it and the position of the AO as a member of the crew within the GCS in order to supervise the PO was also not annotated. The Panel observed that there was no set format or consistency to the handwritten crew position column headings within the Authorisation Sheets.

Exhibit 1
Exhibit 32

1.4.104. **Recommendation**. The Panel recommends that the Thales Head of Flying should amend the Thales Flying Order Book to include guidance and standardisation on the content required in the Authorisation Sheets.

The Accident Flight and events leading to the selection of MO

1.4.105. The following paragraphs detail the events of the accident flight leading to the selection of MO. Tables 5 to 9 include significant pre-flight events from the GCS Voice Recorder (VR). Extracted information from the VR covers a 1 hour period of the sortie leading up to the UAV impacting the runway.

1.4.106. **Pre flight**. The Panel discovered that, during the pre-flight checks, the crew identified that coordinates for the position of the Ground Data Terminal (GDT) had been entered into the Client Server (CS) incorrectly. The UAV-p1 re-entered the coordinates and continued the checks. It is important that the VMSC understands where that GDT is but, in this case, the GDT location was out by a matter of metres and the mistake was corrected and therefore was **Not a Factor** in the accident. Additionally, the ATOLS Ground Radar Unit (GRU) wasn't connected to the correct runway (Rwy). The previous days sortie had used Rwy 08 and the cables for Rwy 26 had not been connected. This was identified and corrected by the crew during the Pre Flight checks and was **Not a Factor** in the accident.

Witness 3

1.4.107. **Take-off and departure**. Following completion of the ground checks, WK031 was launched from Rwy 26 at WWA at 0915hrs. The weather was clear on take-off with surface wind reported as 180°/12kts. The UAV-p1 carried out 2 successful circuits to the semi-flare[18] using the normal automated systems; the landing was manually aborted by

Witness 1
Witness 3
Witness 4
Witness 5

[18] Semi-Flare. The UAV reduces its glide angle from 3^0 to 1.5^0.

the UAV-p1 each time as planned. The UAV was climbed to 5000ft Above Mean Sea Level (AMSL) and flown into the designated Danger Area D201 (West Wales Danger Area) (Fig 14) to conduct route flying and mission tasking. During this phase of flight the Narrow Band Data-Link dropped out on 4 occasions but rectified itself without crew intervention. Exhibit 1

1.4.108. **58 Minutes Prior to the Accident**. ATC[19] reported that the main weather activity seemed to be situated to the south-east of WWA with a line of showers running from Carmarthen which were moving towards the airfield (Table 5). ATC continued to report, from the radar picture, the leading edge of the first shower was about three to four miles to the south-west of Cardigan, about 8 miles away from the airfield. The crew acknowledged this report and informed ATC that they would try and do another 10 to 15 minutes tasking at medium level and then return-to-base (RTB). ATC replied by stating that visually to the south-west they were beginning to see misting, vapour and precipitation in the air and suggested that the crew should not wait too long before they recovered to the airfield. In the GCS, conscious of the deteriorating weather, the PO/UAV-p2 conducted payload sweeps, switching between electro-optical and infrared camera to establish the depth of the cloud and build a picture of the prevailing weather conditions. The weather sweeps indicated worsening weather conditions with building cumulonimbus clouds; however the crew were confident that in their current location they were on the periphery of the bad weather. The crew elected to complete a Synthetic Aperture Radar (SAR) task and then recover to WWA. Shortly afterwards, ATC informed the crew that, in their view, the line of showers would take 30 minutes to pass through WWA. The showers were mainly to the south-east with a clear area behind them. They added that it looked as though the showers would arrive in the WWA overhead in about 10 minutes. The AO briefed the crew that they would time their recovery to coincide with the anticipated gap between the showers. Exhibit 10 Exhibit 11

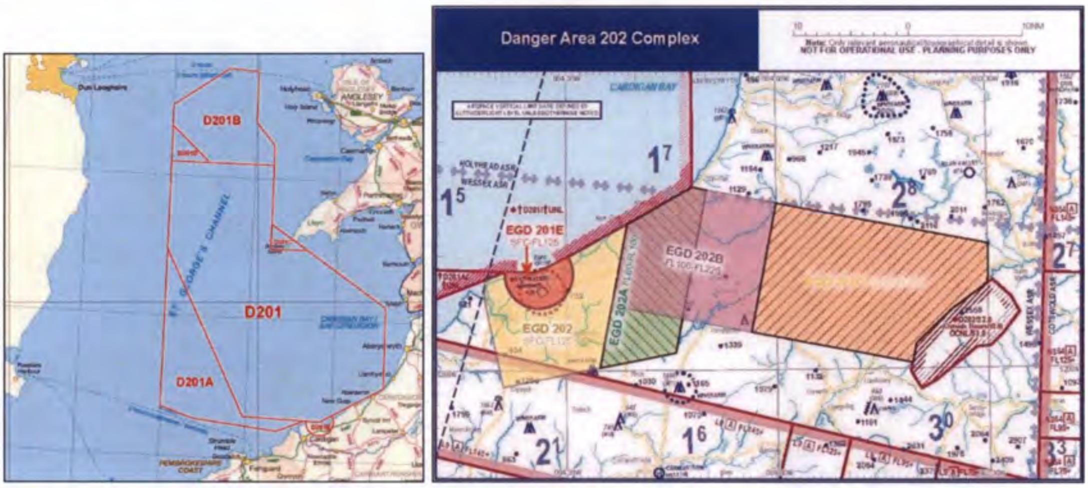

Figure 14 – D201 Complex and WWA Local Area

[19] West Wales Information

Serial	Time (Z)	Event/Location	Remarks
01	1014:30	West Wales Information (WWI) pass weather update via radio	ATC report that the main weather activity seemed to be situated to the south-east of WWA and was moving towards the airfield. Leading edge of the shower is 8 miles from WWA
02	1015:30	WWI pass weather update via radio	ATC were beginning to see misting, vapour and precipitation in the air and suggested that the crew should not wait too long before they recover to the airfield.
03	1016	GCS	UAV-p2 conducts payload sweeps to build a picture of the prevailing weather conditions.
04	1016:23	GCS	The crew elect to complete a SAR task and then recover to WWA.
05	1018	WWI pass weather update via radio	ATC inform the crew that showers would be overhead in about ten minutes and should pass through WWA in about 30 minutes.
06	1020	GCS	The AO briefs the crew that they would time their recovery to coincide with an anticipated gap

Table 5 – Accident Sortie Events 1014-1020Z

1.4.109. **43 Minutes Prior to the Accident**. The crew received transient AOA and AOS advisory captions which were interpreted as an issue with the pitot static system (Table 6). The crew perceived that these Warning, Cautions and Alerts (WCA) were transitory in nature, and something that could occur when flying through cloud. The warnings provoked a discussion between the crew about the relative humidity of 87%[20] and the fact that the UAV might be in cloud[21]. The AO stepped outside GCS to observe the local weather and reported that it was raining at the airfield but with a broken cloud layer. Shortly after this, ATC reported visibility at WWA of 4,000 metres in moderate to heavy rain with a line of showers running north-west to south-east moving north-east, tracking up the coast. They also informed the crew that there was a significant gap from about 5 miles offshore to about 10 miles offshore, which ATC believed was probably where the UAV was. ATC suggested that the crew may as well maintain the UAV's current operating area and they would let them know when conditions had improved. The crew inform ATC that they would probably be completed in about another 10-15 minutes and that they would give ATC a call when ready to recover and request a local area update.

Exhibit 10
Exhibit 11

[20] As measured by the UAV on board systems.
[21] Due to the nature of the EO/IR picture, it can sometimes be difficult to ascertain if the UAV is in cloud or skirting the top or bottom of the cloud layer.

Serial	Time (Z)	Event/Location	Remarks
07	1029:45	GCS. AOA, AOS advisory captions illuminate but do not latch on.	The crew discuss if the UAV might be in cloud. AO steps outside GCS to observe the local weather conditions.
08	1033:15	WWI pass weather update via radio	ATC report visibility at WWA of 4,000 metres in moderate to heavy rain with a line of showers tracking up the coast. ATC advise the crew to maintain the UAV's current position.

Table 6 - Accident Sortie Events 1029 -1033Z

1.4.110. **34 Minutes Prior to the Accident**. The crew passed a 30 min call to the ground crew which, given the 20 min transit, would equate to 10 more min on task (Table 7). The crew received an 'ADU Velocity Redundancy' caption which was again perceived to be related to the pitot static system and the fact that the aircraft was flying through cloud. The crew carried out the immediate actions for this caption and conducted a further weather sweep. The UAV-c concluded that they were skirting the tops of the cloud and he considered, but did not action, climbing 1000ft to remain above the cloud. The UAV-p2 then informed the crew that the UAV appeared to be in a pocket of clear air. Exhibit 10 Exhibit 11

Serial	Time (Z)	Event/Location	Remarks
09	1038:55	GCS. Radio call	Crew pass a 30 min recovery call to the ground crew.
10	1039:37	GCS. ADU Velocity Redundancy warning caption	Crew complete the immediate actions.

Table 7 - Accident Sortie Events 1029 -1033Z

1.4.111. **28 Minutes Prior to the Accident**. ATC inform the crew that WWA appeared to be in a significant gap between the showers and that the worst of the weather had just passed through and suggested that it seemed like a good time to recover (Table 8). They also advised the crew that the runway was extremely wet and shiny and that they might experience issues with the laser altimeters. The crew continued their SAR task for a further 6 min prior to commencing recovery. Exhibit 10 Exhibit 11

Serial	Time (Z)	Event/Location	Remarks
11	1044:31	WWI pass weather update via radio	WWA in a significant gap between the showers and that it seemed like a good time to recover.
12	1046:29	GCS	UAV-c states the intention to complete the SAR training and then recover the UAV
13	1049:23	GCS	UAV-c states the intention to complete the SAR task and then recover to WWA
14	1050:44	GCS	Crew commence recovery to WWA.

Table 8 - Accident Sortie Events 1044 -1050Z

1.4.112. **22 Minutes Prior to the Accident**. With the P1's training completed, the crew decided to recover the UAV and commenced a descent to 3000ft AMSL (Table 9). During the initial descent through cloud the Narrow Band Data Link was lost and then reacquired[22]. As the UAV descended to 2300ft WWA QNH[23] the 'AOS Estimators In Use' caption was displayed to the crew. The crew discussed the implications of this caption and referred to the FRCs which provided a description of the fault[24]. The PO had some difficulty in locating the correct caption and action list in the FRCs and had to be directed by the UAV-c to the correct card. There are 35 cards containing non ADU related emergencies separating the 'ADU Estimated AOS in Use' with an accompanying 'ADU AOS Sensor Redundancy Lost' and the less serious emergency that was displayed to the crew, 'ADU Estimated AOS In Use'. Probably as a result of this and a lack of familiarity with the FRCs, the UAV-p2 initially read the more serious emergency which instructed the crew to Land As Soon As Possible and use ATOL MO as required. The UAV-c redirected the PO to the less serious 'ADU Estimated AOS In Use' which instructs the crew to simply Land As Soon As Practicable and does not mention the use of MO. It is the opinion of the Panel that, although the PO's mistake was corrected by the UAV-c, the more serious FRC, which mentioned the use of MO, might well have influenced the crews' decision to use the MO later in the recovery. Exhibit 11

1.4.113. Shortly afterwards a transitory 'ADU Velocity Sensor Redundancy Lost' warning caption was displayed and was followed by an 'AOA Estimators In Use' warning caption which the crew elected to monitor. As the UAV entered the Air Traffic Zone (ATZ) for WWA, the AO stepped out of the GCS to assess the local weather and informed the crew that it was starting to get very grey outside. Additionally, the crew received a call from WWA ATC which stated that the Met Office had issued Thunderstorm Moderate for WWA and that WWA had a shower to the south west. WWA ATC suggested that the crew might be able to recover the UAV to WWA before the conditions deteriorated.

Serial	Time (Z)	Event/Location	Remarks
15	1055:23	GCS	Crew commence descent to 3000ft
16	1058:52	GCS. 'AOS Estimators In Use' warning caption,	The crew discuss implications and refer to the FRCs.
17	1059	Thunderstorm Level Moderate warning released	
18	1102:38	GCS. 'ADU Velocity Sensor Redundancy Lost' warning caption.	Transitory caption.
19	1102:42	GCS	AO steps outside the GCS and reports that it is starting to look grey outside.
20	1103:40	GCS. 'AOA Estimators In Use' warning caption,	AO instructs the crew to monitor the warning.
21	1103:55	WWI pass weather update via radio	WWI inform the crew that Thunderstorm Level Moderate is now in force at the airfield.
22	1108	GCS	AO re-iterates to crew that the airfield is now Thunderstorm Level Moderate.

[22] Wide Band Data Link (WBDL) was maintained throughout the recovery.
[23] Based on pressure altitude of the center point of the main runway Above Mean Sea Level (AMSL) at WWA.
[24] The VMS has switched to using estimated Angle of Slide slip (AOS). UAV has no redundancy for an AOS measurement. Additional fault of the same subsystem may lead to Flight Abort failure. Land as soon as practicable.

Table 9 - Accident Sortie Events 1055 -1108Z

1.4.114. **The Selection of Master Override (MO).** The crew discussed the use of overrides after the 'AOA and AOS Estimators in Use', and 'ADU Velocity Redundancy Loss' captions occurred (Table 10). The UAV-c asked the UAV-p1 what Override he would consider to prevent an overshoot on the approach and prolonged flight in the prevailing weather conditions. The UAV-p1 suggested use of the 'Laser Altitude Difference' override to deal with issues related to recovering in cloud. There was then a discussion of the thunderstorm warning changing from Low to Moderate, and a suggestion of also using the 'Ground Proximity' override. The AO then asked the crew what they could do to guarantee that the UAV would land from its first approach. The UAV-p1 stated the MO could be used, and the AO agreed. This was followed by the UAV-c stating that he was going to use MO to land the UAV. The UAV-p1 then selected the MO and the UAV-p2 informed ATC of the decision to land with MO. Exhibit 11

Serial	Time (Z)	Event/Location	Remarks
23	1109	GCS	Discussion ensues about the weather and the use of overrides that may be required.
24	1110:10	GCS	The UAV-p1 selects MO and thePO calls ATC with a request that they monitor the approach.
25	1113	UAV impacts the runway	
26	1113	Thunderstorm Level High warning released by the Met Office	

Table 10 - Accident Sortie Events 1109 - 1113Z

1.4.115. Throughout the sortie, the crew are aware of the possible deteriorating weather and the need to monitor the conditions in the vicinity of the UAV and at the airfield/GCS location. The forecast briefed prior to the sortie indicated that there was a low probability of thunderstorms with gaps of clear air between. As such the crew elected to fly the sortie with the aim of operating and recovering in the gaps.

1.4.116. The GCS crew were using all available methods to monitor the weather and were in continual dialogue with ATC. Also, the crew frequently discussed the prevailing conditions and amended their recovery plan accordingly. However, except for stepping out of the GCS and observing the local conditions, there was no provision within the GCS for the crew to directly monitor the wider area weather picture. Exhibit 11

1.4.117. Apart from the relayed weather information provided by ATC, the crew in the GCS are reliant on the EO/IR camera situated on the UAV for information regarding the conditions in the vicinity of the UAV, both in the operating area and in transit. The EO/IR camera has a very limited Field Of View (FOV)[25] and as such, it can be very difficult for the crew to ascertain cloud structure and depth. Additionally, once in cloud, it is near impossible to distinguish cloud type; Stratus can look remarkably similar to Cumulus/Cumulonimbus through the EO/IR camera. As a result, the Panel believe that it would be difficult for the crew to keep the UAV clear of thunderstorms when required to Exhibit 11

[25] For manned aviation, taken from the fixation point with both eyes, the combined field of view for a human is 130-135deg vertical and 200deg horizontally. The Watchkeeper IR Wide FOV is 13.5 x 10.8deg and the EO Wide FOV is 21.25 x 16deg.

penetrate cloud during a recovery.

1.4.118. The Panel has identified that unlike other UAVs such as Reaper and Predator, the Watchkeeper UAV cannot be manually flown in the traditional "Stick and Rudder" sense. The Reaper/Predator pilot can manually fly the UAV around cloud and inclement weather by simply positioning the flight path of the UAV to avoid cloud, based on his picture through one or both of his EO/IR cameras. Instead, Watchkeeper is manoeuvred in the air by the operator by placing "fly to" points on a map displayed in the GCS using a computer mouse. If the crew see cloud ahead and wish to avoid it, they must first approximate the position of the cloud, move the fly-to point and send the command to the UAV. This, combined with the UAV's slow speed[26], in the opinion of the Panel, can make it difficult for a UAV crew to always remain clear of inclement weather. If a recovery into a break in the weather is miss-timed, the crew might not be able to clear the area and avoid the showers/storms. Equally, if the weather conditions at the recovery airfield fall below limits, Watchkeeper did not have the capability to divert to an alternative airfield. Therefore, the Panel believes that, when planning and executing Watchkeeper sorties, there has to be a considerable degree of anticipation of events and forward planning to compensate for the lack of the UAV's speed and the unpredictable nature of the weather. Exhibit 48

1.4.119. Although ATC updated the crew on the weather radar picture and the actual conditions at the airfield, their advice as to when to recover, in the opinion of the Panel, seemed to be very reactive. As the previous paragraphs illustrate, the crew amended their recovery plan on a number of occasions based on the information passed by ATC regarding the local conditions. The provision of real-time or near real-time weather information in the GCS, including a weather radar picture which can be cross referenced with the position of the UAV, would greatly enhance the crew's situational awareness and their ability to avoid inclement weather. Exhibit 11

1.4.120. Despite a number of pitot static related warning captions, the Panel believe that the crew seemed very relaxed about the conditions and the UAV's ability to cope with the deteriorating weather conditions. During interview, the AO stated that the crew were aware that there was some shower activity and that the runway at WWA was wet. The crew understood that they were going to have to recover through cloud and he added that they were not unduly worried about this as it was something they'd done many times before. The AO further remarked that during the descent there were a couple of transient captions related to the pitot static system and a velocity redundancy lost caption, which, again, was not unexpected. He also commented that, although the amount of cloud was starting to increase, the conditions were not as bad as they had operated in the past and so the decision was made to continue with the recovery. Witness 1

1.4.121. What is clear to the Panel is that the first time the crew perceived the need to land with any urgency was following a call from ATC. During this transmission ATC informed the crew that the thunderstorm warning level had been raised from Low to Moderate and that there was a shower approaching. ATC further advised the crew that they might make it down before the shower reached the airfield. Exhibit 11

1.4.122. The decision to land with MO had been prompted by the AO but the three other crew members agreed with this decision before it was implemented. In interviews with the Panel after the accident, all crew members indicated that they were happy with the decision to use MO based on the information that they had at the time. The following Annex B Witness 1

[26] At approximately 60kts and dependent on the wind strength, the UAV would take 20 mins to recover from its operating location on 16 Oct 15 and land at WWA

factors were considered by the Panel that contributed to the decision to land using MO.

a. **Belief that UAV was Likely to Abort**. The Panel found evidence that the crew believed that the UAV was likely to have aborted the landing. On the GCS VDR the crew discussed the potential for the wet runway to cause issues with the laser altimeters. Such a perception was likely to have arisen, in the opinion of the Panel, as a result of the weather conditions, the previous warning captions that occurred and the crew's mental model of the UAV operation. The belief that the UAV is likely to abort was in line with the most common reason why MO had been used in the past.

b. **Desire to Land First Time**. There were a number of statements on the VDR which indicated that the crew intended to land the aircraft on the first attempt and this desire appeared to be related to the weather conditions. The importance of weather in the decision was also highlighted by the crew in interview, commenting that the crew did not wish to keep the UAV in the air any longer than necessary with an increasing thunderstorm risk and the associated risk of loss of control of the aircraft. The attitude that there was a need to land the aircraft soon was in line with the second common reason why MO has been used in the past.

c. **Knowledge of MO**. During interviews with the Panel, the crew reported that they were not aware that if the MO was activated and there was a failure/height difference of one or more of the laser altimeters, then the height at which the UAV opens the 'Ground Touch' window increases from 1m to 20m AGL. As a result the crew were not able to take into account the potential risk of a premature declaration of 'Ground Contact' when deciding whether or not to use the MO.

d. **Experience of MO Use**. From the available records, the Panel established that MO had been used on a number of occasions in the past, and in 90% of those situations there had been a landing with no reported abnormalities. Therefore, the crew perceived that the use of MO would be successful. Furthermore, The Panel has identified that there was a trend towards engaging MO earlier in the recovery sequence, such that it had been used without previously having a landing abort. As a result, it could have been perceived as normal and acceptable to use the MO at this stage of the recovery.

Conclusion on the selection of MO

1.4.123. The Panel found that although the weather briefed for the sortie was within the promulgated UAV limits, the decision to fly was marginal. Additionally, the lack of real-time weather information available to the crew in the GCS, the limited FOV through the EO/IR camera, the UAVs slow speed and the lack of a divert capability necessitated a considerable degree of forward planning to compensate for the unpredictable nature of the weather. Witness 7

1.4.124. Although the crew were continually monitoring the weather conditions and were aware that the conditions were deteriorating, the Panel perceived a feeling, gathered from the GCS transcript and subsequent interviews, that the UAV was an "all-weather" platform. It is the opinion of the Panel that there was an increasing expectation within the WK crews at WWA that the UAV would be able to cope with poor weather conditions. As experience was gained from the 394 previous Watchkeeper flights at WWA, crews became prepared to accept a reduced margin between the prevailing Witness 1 weather and the UAV weather limits.

1.4.125. The Panel found that the decision to engage MO was unsurprising given the crews belief that the UAV was likely to abort as a result of the prevailing weather conditions, the resultant desire to land first time and the experience gained from previous sorties where MO was used. The Panel noted that the order of the emergencies contained within the FRCs was misleading and might potentially lead the crew to action the wrong emergency. Therefore, the Panel concluded that:

a. The unstable weather conditions were a **Contributory Factor** to the accident.

b. The crew had a lack of situational awareness of the weather which was a **Contributory Factor**.

c. The order of the emergencies contained within the FRCs was an **Other Factor**.

1.4.126. **Recommendation**. The Panel recommends that the Hd UAST should consider the provision of real-time weather information in the GCS that can be accurately related to actual UAV position.

1.4.127. **Recommendation**. The Panel recommends that the Thales Head of Flying should review and amend the advice for operating the Watchkeeper UAV in the vicinity of thunderstorm activity, to include avoidance criteria.

Observer role

1.4.128. Once the decision had been made by the crew to select MO, the UAV-c instructed the UAV-p1 to call WWA ATC and inform the controller that they were selecting MO so that he could observe the landing.

1.4.129. In interview, the AO explained his understanding of the role and use of an Observer. He stated that the there is an agreement at WWA, when using MO, that the crew will inform ATC and use an External Observer. In the absence of a dedicated External Observer, the Air Traffic controller will act as the Observer. The Observer will visually monitor the UAV to ensure that, during the final phases of the approach, the UAV is lined up with the runway and that it is at the correct speed, pitch and height profile for that recovery. If it isn't, the Observer will inform the crew who have the option to abort the approach manually. Witness 1

1.4.130. The role of the Observer is mentioned in two documents, the Thales FOB and the Student Notes. Exhibit 20

1.4.131. Local flying orders do not talk specifically about the use of MO. However, the Panel did observe that despite this, a local procedure for having an Observer in place in the ATC Tower for all approaches where any override (including MO) is selected was in place. Exhibit 22

'*WARNING any override activated requires an observer to assess the approach. Automatic ATOL aborts can be overridden via the override option on the AVDC. Note: not all fault conditions can be overridden. ATOL overrides are only set prior to recovery if an emergency has arisen or the first attempt to recover has aborted*'.

1.4.132. The FOB states that for flights without an EP[27] an Observer may be nominated if deemed necessary by the Thales Safety Review Board (SRB) or HoF. The location and readiness of the Observer are to be controlled by the UAV-c. A Powerpoint training package exists within U-TacS for the formal training of Observers. Exhibit 35

1.4.133. The Student Notes state that the selection of any override requires an Observer to assess the approach. However, it should be noted that these notes are not official and once a student leaves RSA Larkhill, the notes become uncontrolled. Furthermore, they carry the cover notice that 'The information contained within these student notes are for training purposes only".

1.4.134. The Panel has established that historically at WWA the Air Traffic Controller has doubled up as the Observer, given his vantage point in the ATC tower. The Thales HoF stated that the Observer's role provided a rough check that the UAV was going to land on the defined runway strip. The Observer was instructed to call "ABORT, ABORT, ABORT" if he was sure the UAV was going to miss the runway. Once the UAV was safely engaged in the cable, the Observers role was complete. Witness 2 Exhibit 15

1.4.135. The Panel noted that, although the controller located in the WWA ATC Tower on the day of the accident had not completed an official Observer course, as directed by the Thales FOB, the Thales HoF considered that the controller was an effective observer due to his considerable experience in observing Watchkeeper operations.

1.4.136. In this instance, the Panel believe that an observer would not have had time to intervene to prevent the accident. The Panel made the **Observation** that the role of the Observer was not clearly defined and no formal training given.

1.4.137. **Recommendation**. The Panel recommends that the Thales Head of Flying should review the requirement for an Observer and, if deemed a necessary role, ensure that Observers are suitably trained to fulfil that role.

Laser Altimeter Disqualification

1.4.138. The Panel examined the laser altimeter design, its operation and its interaction with the VMSC in order to better understand what caused the laser altimeter height difference and subsequent disqualification.

Laser Altimeter operation

1.4.139. The laser altimeters are designed by Noptel as off the shelf components normally used in non-aviation orientated applications. Typical uses include speed and distance measuring devices such as speed cameras and electronic 'tape measures'. Noptel has stated that these altimeters are designed to be effective up to a distance of 30m. In the Watchkeeper system, there are two laser altimeters situated under the fuselage. These are used to offset GPS errors, they provide the 1m/20m height reference for the VMSC to open the 'Ground Touch' window and also detect ground proximity. Annex A

1.4.140. On approach, the laser altimeters are only used in the final stages of the landing and are automatically switched on by the PCDU, commanded by the VMSC. The height information is then fed into the VMSC and used to refine the system's accuracy.

[27] Initial U-TacS training sorties conducted by the Designer utilised their own EPs for UAV launch and recovery.

They do not operate during any other part of normal flight. Table 10 below illustrates the different scenarios of how the laser altimeters are used during both a normal and MO approach.

Watchkeeper Laser Altimeters operation during approach – Normal & Master Override (MO) selected scenarios				
	Scenario 1 Normal approach	**Scenario 2** MO Approach	**Scenario 3** MO approach + laser altimeter failure/ difference post Underrun (UR)	**Accident Sortie** MO approach + single laser altimeter difference post UR
Connect Point (CP)	Laser altimeters turned ON and tested. No height reference is accepted by VMSC, however Ground proximity is enabled.			Laser altimeters turned ON and tested. No readings accepted by VMSC.
Underrun (UR)	Bias correction to GPS height channel for GTOLS landing.			Bias correction to GPS height channel. UR crossed at 40.32m AGL.
Post Underrun (UR) Disqualification Window	Closed	Open VMSC can disqualify <u>both</u> altimeters due to single failure or difference from UR onwards.	Open VMSC can disqualify <u>both</u> altimeters due to single failure or difference from UR onwards.	Open At 35.14m AGL: Laser altimeter 2 suffers height difference for a duration of 3 secs. Both laser altimeters disqualified.
15m (ATOLS)/ 22m (GTOLS) Laser altimeter Disqualification Window	VMSC can disqualify an altimeter due to failure or difference from 15m/ 22m onwards.	Already open	Already open	Already open
20m ATOLS/ GTOLS Height Ground Touch Window	Closed	Closed	Open	Open
1m AGL Ground Touch Window	Open laser altimeters used.	Open laser altimeters used.	Already open	Already open

Table 11 – Laser Altimeters – Normal & Master Override (MO) Selected Scenarios

1.4.141. For all approaches, the laser altimeters are switched on and tested at the Connect Point (CP) but no height information is used by the VMSC for the landing Annex A process at that stage. Evidence provided during the investigation suggests that the first use of the laser altimeters occurs at the Underrun (UR) Point, where the VMSC uses the readings to apply a 'once only' bias to the GPS height channel to reduce inherent error and therefore refine height accuracy for the landing.

Laser Altimeter disqualification

1.4.142. The VMSC has the ability to disqualify one or both laser altimeters if it detects one of 4 possible criteria: Annex A

a. No communication between the VMSC and the laser altimeter.

b. The laser altimeter reports measurement failure for 300ms.

c. Reported laser altimeter height is less than a minimum value of 10m when the UAV crosses the UR.

d. There is a significant difference between the two laser altimeters post UR.

1.4.143. In normal operation (Scenario 1), the VMSC opens a disqualification window from 15m (ATOLS) or 22m (GTOLS) to allow the system the opportunity to remove one altimeter input and therefore maintain a consistent height channel using the remaining altimeter. However, with a single laser altimeter disqualified the system would normally abort the approach unless the operator had pre-selected an Altimeter Difference override. In the event of both laser altimeters failing then the use of MO would be the only option to prevent the UAV from aborting the approach.

1.4.144. With MO selected the logic changes to allow a disqualification window to open as soon as the UAV passes through the UR point. During the accident flight, the UAV passed the UR at 40.32m AGL before the system detected an altimeter difference for 3.5 secs at 35.14m AGL (Fig 15). The MO logic was designed such that if a discrepancy was registered for longer than 300ms then the VMSC would disqualify both altimeters. Therefore, on the accident flight, the Panel had identified that, the system logic opened up the 20m AGL window for 'Ground Touch' detection and only used the best of ATOLS/GTOLS height for reference above the runway. The Panel believes that it is important to note that both laser altimeters became re-matched at 32m which is well above the 20m 'Ground Touch' window. The Panel concluded that, had the landing logic been programmed such that the VMSC continued to monitor laser altimeter measurement performance, both altimeters could have been reinstated and WK031 could have potentially landed without further incident. Annex A

1.4.145. **Recommendation**. The Panel recommends that the Hd UAST should consider modifying the landing logic when Master Override is selected, to reinstate disqualified laser altimeters if both laser altimeter readings become valid post disqualification.

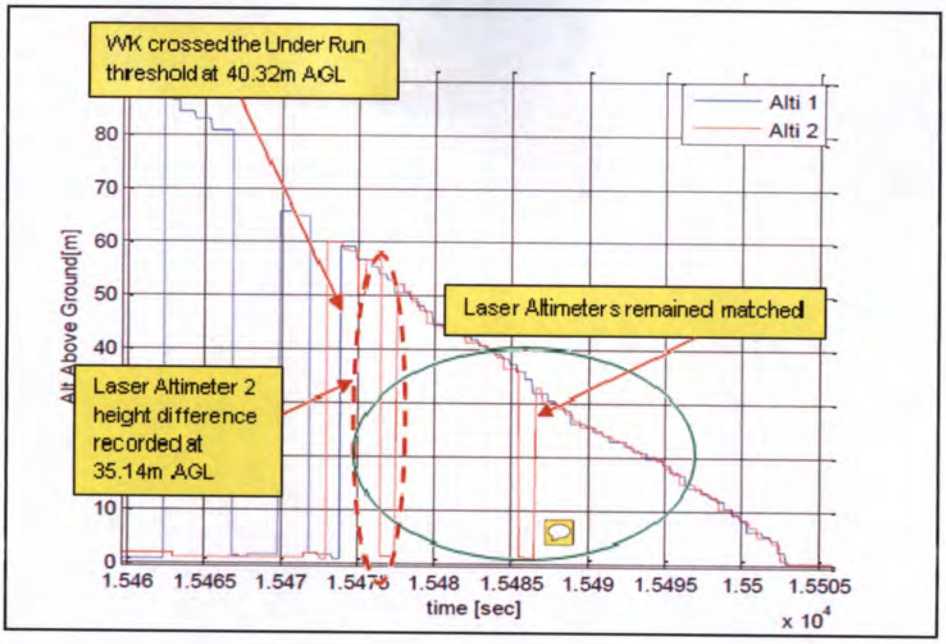

Figure 15 – Laser Altimeter Readings WK031 Accident Flight

Laser Altimeter 2 height difference

1.4.146. The Panel, with assistance from Defence AIB, had both laser altimeters tested and no latched faults were found within the Non-Volatile Memory of either unit. Therefore, the Panel needed to understand why laser altimeter 2 had not received a valid return during the 3 sec period of altimeter height difference. Further investigation identified that both the laser altimeter capability and the environmental conditions were of interest.

1.4.147. **Laser Unit Performance Capability**. As mentioned previously, the Noptel laser altimeters were designed to be effective up to a range of 30m, even though laser returns could be possible at greater ranges. The figure below (Fig 16) presents the results from one of the WK031 laser altimeters tested by Noptel that shows signal amplitude dropping off rapidly after 6m and continuing to tail off significantly by 30m. These results were considered typical and within the original unit specification. Therefore, if the UAV was being operated in MO with the associated disqualification window open from the UR point then the laser altimeters were more likely to suffer poor or no returns from the ground, due to the UAV being at a greater height than the specified (effective) maximum of 30m. This in turn would increase the likelihood of Altimeter Difference and subsequent disqualification as well as the opening of the 20m 'Ground Touch' window. Therefore, the Panel concluded that the disqualification window with MO selected was too high for the laser altimeters to be effective and was a **Contributory Factor.** Annex A

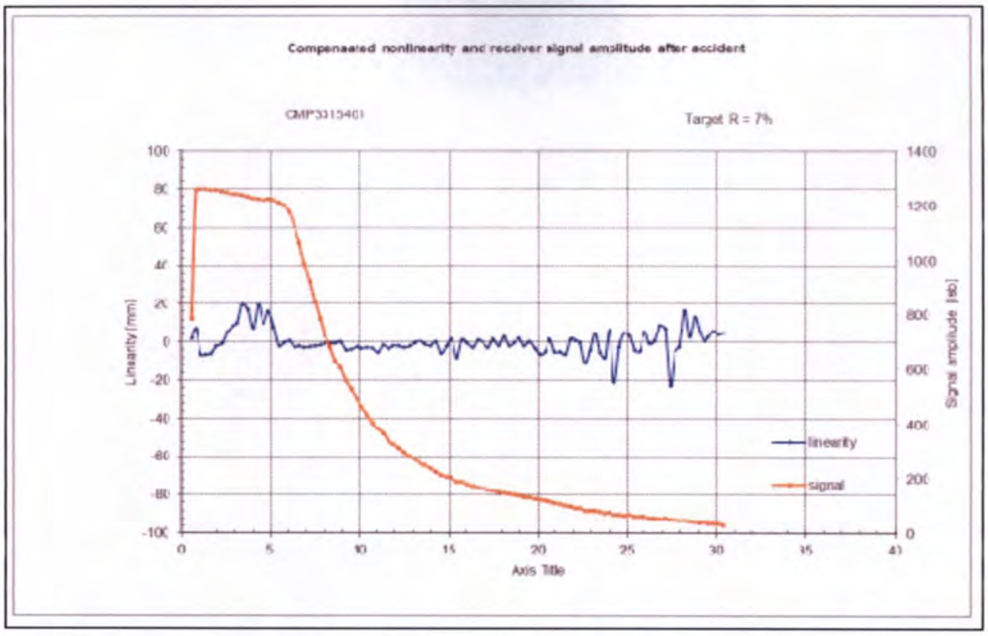

Figure 16 – Laser Altimeter Performance– Signal Amplitude verses Distance (m)

1.4.148. **Recommendation**. The Panel recommends that the Hd UAST should 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.

Environmental effects

1.4.149. Laser performance depends on the reflectivity of the target, transmission medium (air and water on surface) and angle of incidence. Dense water bearing cloud, rain or particulate rebound can result in the Lasers providing differing height information to the VMSC from the moment the UAV leaves the UR point. Known issues regarding Laser performance and wet runways have been well documented and from interview were considered by the Panel to be well understood by the flight crews. Annex A

1.4.150. **Analysis of Laser Altimeter Performance Over Wet Tarmac**. A review of the sensor video footage confirmed that the weather conditions at the time laser altimeter 2 failed was commensurate with the Thunderstorm Moderate warning and that the runway was very wet (Fig 17). Exhibit 12

Figure 17 – Photo taken of WK031 shortly after impact