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Research Project:

# CIMSCY

# Crew Immersion Suits Conspicuity

An agency of the European Union

# Crew Immersion Suits Conspicuity (CIMSCY)

## EASA.2017.C20

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# Final Report

## Overview

This report is offered in fulfilment of contract EASA.2017.C20: Crew Immersion Suits Conspicuity (CIMSCY) Study. The context of this work derives from the AAIB (Air Accidents Investigation Branch) report into the Morecambe Bay accident in 2006 [1]. The AAIB report details the crash of a helicopter transporting employees to an oil and gas platform. One recommendation resulting from the report (Paragraph 1.15.3, page 37) concerns improving the conspicuity of aircrew when in the water following a crash:

*"The operating crew were wearing dark blue immersion suits … The immersion suit and un-inflated life jacket are designed to have low reflectivity in order to reduce internal reflections on the instrument panels and windscreens of the cockpit, during helicopter operations. However, the rescue crews commented that the yellow immersion suits worn by the passengers were noticeably more conspicuous, when using the helicopter's searchlight in the darkness, than the blue immersion suits worn by the pilots."*

This observation was developed into Safety Recommendation 2008-036 in the final accident report:

2008-036 It is recommended that the European Aviation Safety Agency (EASA) investigate methods to increase the conspicuity of immersion suits worn by the flight crew, in order to improve the location of incapacitated survivors of a helicopter ditching. (p65).

In this report, we address this recommendation. We examine in detail the potential to exploit retroreflective materials to increase the conspicuity of aircrew in a rescue scenario. We include as an annex to this report a detailed literature review that includes an overview of offshore oil and gas helicopter operations, and detailed discussion about the capabilities of the aircraft equipment used and the underlying concepts relating to conspicuity (Annex 1, p71).

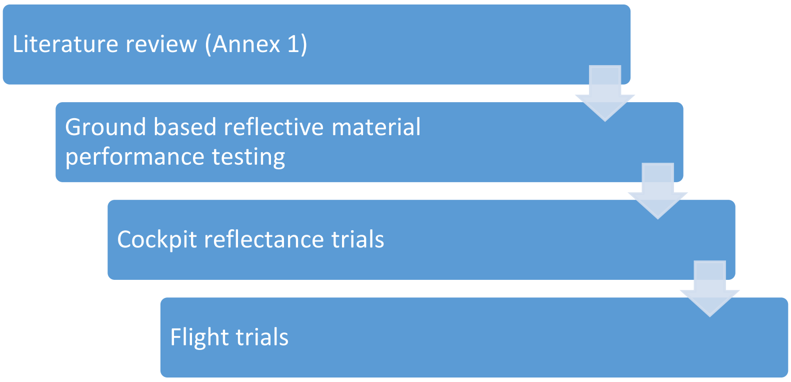
The main body of this final report details the development of interventions and their testing to improve the conspicuity of casualties by day and by night. The performance of different retroreflective materials were tested using a range of illumination sources and cameras on board an AgustaWestland AW189 aircraft used by Bristow Helicopters Ltd for UK Search and Rescue (SAR). A selection of these materials were then applied in a specific configuration to a current regulation immersion suit and their reflective properties were evaluated in the cockpit by experienced SAR pilots as subject matter experts (SMEs). A high fidelity field trial was then conducted to evaluate the performance of the modified immersion suit in a simulated SAR mission in the UK. Finally, based on the work conducted, we report twenty-four detailed findings and make six recommendations on how the ETSO standard for immersion suit design may be evolved in the future.

# The Search and Rescue Operation

The activities in the main body of this report were conducted in conjunction with Bristow's SAR operation at MoD St Athan, South Wales, UK. A search and rescue operation is a key stakeholder in any discussion of conspicuity as they regularly search for casualties at sea, and as such, rely on rapid identification for a successful rescue. UK SAR is conducted under the auspice of HM Coastguard. In 2011, the helicopter operator Bristow was awarded the contract to provide the 24-hour service in bases across the UK. A fleet of AgustaWestland AW189 and AW139s are operated by aircrew comprising pilots and medically trained personnel. Technology on-board the aircraft assists with search including a range of searchlights and high-resolution cameras. Searchlights that deliver white light also have the option to filter out the visible spectra to produce only the IR spectra. Typically when searching for a human target, thermal imaging is the most suitable FLIR mode in both day and night conditions. Pilots also use night vision googles (NVG) to assist in their search in night-time operations.

# Structure of this report

The main body of this report is structured around the activities conducted following the extensive literature review. This literature is presented as an annex to the report. Given the level of detail in the review across the technological and human dimensions of the problem, this work is best treated as standalone.




# Scope

The findings of this study must be placed in context which is given predominantly in the method sections in this report. One key element of the scope was the exclusion of any active life-saving aids. We recognise that the overall lifesaving system comprises lifejackets with active devices, locator beacons (etc.). Our findings are scoped specifically at modifications the immersion suit. We of course accept that in reality a range of active and passive devices might be used to locate casualties.

We also draw reader attention to the nature of the study as an evaluation of a modification rather than a controlled experiment. In the course of our studies, we have maintained consistency between factors in the sea trials. For example, the type of suit, the type of search conducted. However, high levels of experimental control are not possible to achieve in highly dynamic operational environments. We have balanced the need for control against the need to demonstrate high external validity of the modifications.

# Findings and conclusions

In this section, we propose twenty-seven key findings and six recommendations that can be traced to the experimental work and evaluation trials completed as part of the contract. The mapping between findings and evidence is made explicit in the result sections of this report.

We have of course applied caution to the scope of the findings and recommendations. Given the complexity of the trials, a limited number of repetitions have been conducted. However, this must be balanced against the high external-validity of the trials and the use of the trained aircrew and SAR equipped aircraft. We reiterate that these studies have been conducted in the United Kingdom using the specific assets and equipage available to HM Coastguard and Rescue services. Again, this limitation must be balanced against wider adherence to the International and European rules governing such operations.

We have cross-referenced the finding numbers (prefixed 'F') in the body of the report: This draws attention to the evidence that supports a particular finding. We have cross-referenced the recommendation numbers (prefixed 'R') with relevant findings. Findings are divided into six broad areas: general findings, findings supported by the literature review, findings supported by the ground based materials performance testing, findings supported by the cockpit reflectance trials and findings supported by the flight trials.

Overall, we find scope to substantially increase the area of retroreflective material used on the immersion suits. In the specific configurations of tape used in our trials, we have found tolerable cockpit reflections using over 2500$cm^2$ of retroreflective tape applied to crew immersion suits. This area is over eight times the minimum standard currently specified. We have found that the colour used in passive retroreflective systems (immersion suits, life jackets etc.) is predominantly white or silver. During our research, we have noted that benefit may derive from consideration of other colours. Anecdotally, the white, high contrast glitter across the sea may actually impair identification of white reflections from white or silver coloured retroreflective tapes. Colours such as yellow, red or orange have high colour contrast against the colours that are found in marine environments: white, blue, green, brown. We also note that assistive software currently in development is able to automatically detect contrasting colours. For example, the new Moving Target Identification (MTI) software from EuroAvionics has this capability. Another advantage that we have found using the orange tape in particular is the lower colour contrast with the high-conspicuity, orange immersion suit itself. Pilot comment indicate higher user acceptance of this lower colour contrast with the existing orange immersion suit worn inside the cockpit.

Overall, we do not find advantage for the infrared specific reflective tapes. Indeed, our research has shown that the *all* reflective tapes used in the study reflect in the near infrared spectrum in addition to the visible spectrum. Assuming this property of the retroreflective tapes, any future system that could exploit IR would be able to use the IR reflections from the coloured, highly conspicuous tape. Indeed, we note that black, retroreflective IR tape necessarily occludes large areas of high-conspicuity colour on the immersion suit while not offering specific advantage during search using the current technology.

Finally, we remain concerned that the lifejacket-immersion suit lifesaving system is being considered in isolation in the relevant regulations. We have not found evidence to propose merging to the standards. However, improvements in the immersion suit such as the addition of retroreflective tapes to the upper-body area may be rendered inadequate by the wearing of a matt-black lifejackets over the top. In isolation, these elements may meet all standards but when considered as a system, a reduction in conspicuity and probability of detection may follow.

| ID | Area | Finding |
|---|---|---|
| F 01 | General | Bristow specify high conspicuity orange immersion suits for their SAR aircrew in accordance with ETSO-2C503 (11.1). |
| F 02 | General | Survitec immersion suits used by Bristow SAR teams have two bands of SOLAS approved, silver retroreflective material positioned around the ankles of each leg in accordance with ETSO-2C503 (11.3). These bands are of approximately 260cm$^2$ each, creating an overall area of retroreflective material of approximately 520cm$^2$ on a large size immersion suit. |
| F 03 | General | There is scope to increase the area of retroreflective material on the immersion suits beyond the 400cm$^2$ standard (IMO SOLAS 83, Chapter III, Resolution A.658 (16), Annex 2) to which the ETSO standard is cross-referenced. |
| F 04 | General | The current ETSO standard requires a minimum of 300cm$^2$ of retroreflective material on an immersion suit (ETSO-2C503 (11.1). The current IMO standard requires 400cm$^2$ (IMO SOLAS 83, Chapter III, Resolution A.658 (16), Annex 2). |
| F 05 | General | The current regulation lifejacket covers a significant proportion of the immersion suit. The interaction between the lifejacket and the immersion suit needs to be considered both explicitly, and collaboratively to prevent occlusion of retroreflective material on an immersion suit. |
| F 06 | General | Improving thermal insulation of immersion suits may lead to a reduced heat signature of a casualty in the water. Successfully identifying casualties relies heavily on the FLIR system. |
| F 07 | Literature review | Additional retroreflective material should exploit the location of parts of the body that define human movement [2] and/or are above the waterline to maximise conspicuity. |
| F 08 | Literature review | To be visible at a range of angles of incidence, the position of retroreflective material should be positioned around curved surfaces of the body (for example around the shoulders). |
| F 09 | Literature review | Retroreflective materials should be placed such that a person can be detected regardless of their position or orientation in the water (e.g. on front/back, facing away/towards). |

| ID | Area | Finding |
|---|---|---|
| F 10 | Literature review | Consideration of the spectral coverage should be given when replacing broadband light sources with LED light sources. LED light sources typically show narrower spectral emission [3]. |
| F 11 | Literature review | There is scope for manufacturers to modify the photopic performance and colour coordinates of the coloured tapes to satisfy the SOLAS standard or a revised SOLAS standard. |
| F 12 | Literature review | Using coloured retroreflective tape would be compatible with future use of colour recognition software . |
| F 13 | Ground based testing | The orange, silver and yellow retroreflective materials tested reflect in the near infrared in addition to their visible reflection. |
| F 14 | Ground based testing | As judged by aircrew, the orange, silver and yellow retroreflective materials tested yield the best subjective brightness at night. |
| F 15 | Ground based testing | As judged by aircrew, the yellow and orange retroreflective material tested yield the best subjective colour contrast by day. |
| F 16 | Reflectance trials | Reflectance trials using a range of retroreflective materials having a total area of 2000cm$^2$ were found to have tolerable cockpit reflectance by aircrew when positioned in the configuration tested. This is in addition to the 520cm$^2$ of white retroreflective material already applied to the immersion suit used, giving a total surface area of tape of 2520cm$^2$. |
| F 17 | Reflectance trials | Black, infrared retroreflective materials do not generate any noticeable cockpit reflections using an area of tape of 2000cm$^2$ when positioned in the configuration tested. |
| F 18 | Reflectance trials | Black, infrared retroreflective material necessarily occludes the high conspicuity colour of the immersion suit by the equivalent area of black tape used. |

| ID | Area | Finding |
|---|---|---|
| F 19 | Reflectance trials | User acceptance of the increased area of retroreflective material was higher when the colour contrast of the retroreflective material to the immersion suit was lower: i.e. orange immersion suit, orange retroreflective material. |
| F 20 | Reflectance trials | Increased surface area of retroreflective material can be applied to the back of the immersion suit without risk of additional cockpit reflectance (ETSO-2C503/ 11.2). |
| F 21 | Reflectance trials | Moving reflections have the greatest potential for distraction within the cockpit. |
| F 22 | Flight trials | The FLIR operator relies predominantly on a heat-signature to locate casualties. |
| F 23 | Flight trials | In daytime conditions, unaugmented vision (eyeballing) presents significant challenges to aircrew due to occlusion by waves and low contrast against the sea. |
| F 24 | Flight trials | In the daytime conditions, there is evidence that the addition of retroreflective materials *does not improve* conspicuity when using unaugmented vision. |
| F 25 | Flight trials | In night-time conditions, there is evidence that the addition of retroreflective materials *improves* conspicuity when using augmented vision. This is most apparent using NVGs and FLIR, and the HDIR camera mode in combination with a searchlight. |
| F 26 | Flight trials | No evidence for a specific advantage of using infrared filtered illumination in search has been found in these trials. |
| F 27 | Flight trials | Within the scope of conditions tested in the flight trials, in the absence of a heat signature, the use of the immersion suit modified with the orange retroreflective materials in the proposed locations may improve likelihood of detection in night-time conditions using augmented vision (NVG and FLIR and HDIR camera mode). |

# Recommendations for standards

| ID | | Recommendation | Supporting findings |
|---|---|---|---|
| R | 01 | We recommend that the area of retroreflective material on aircrew immersion suits, specified in ETSO-2C503 (11.3), should be increased. | F02, F03, F16, F20, F24. |
| R | 02 | We recommend that the position of the additional retroreflective material should favour parts of the body that define human movement [2],taking advantage of curved surfaces and areas of the body likely to be above the waterline. This requirement could be included as part of ETSO-2C503 (11.3). | F07, F08, F09, F22. |
| R | 03 | We recommend that any additional retroreflective materials should be of minimal colour contrast to the immersion suits. This requirement could be included as part of ETSO-2C503 (11.2). Coloured materials would need to be SOLAS approved. | F19. |
| R | 04 | We recommend that the differences in standards between IMO ((IMO SOLAS 83, Chapter III, Resolution A.658 (16), Annex 2) and ETSO (ETSO-2C503/ 11) for the area of retroreflective material should be addressed. Specifically the ETSO standard cross-references the IMO standard that is not the same. | F04. |
| R | 05 | We recommend that no specific requirements for an IR passive retroreflective system are included in the ETSO-2C503 standard. | F13, F18, F25. |
| R | 06 | We recommend that revisions to standards that include immersion suits should be transparently evaluated in respect of standards pertaining to lifejackets (for example, ETSO-2C504). We remain concerned that the current regulation matt-black lifejackets with minimal retro-reflective materials can potentially occlude high conspicuity devices on an immersion suit. | F05. |

# Materials pre-testing

## Aim and Summary

The aim of the material pre-testing was to quantify the performance of a range of retroreflective materials in both day and night-time conditions. The aircraft searchlights, in both white light and IR modes, illuminated various material samples. Different modes of the on-board FLIR camera were used to capture images of the materials. In addition, images of the samples through pilot NVGs were also captured in night-time conditions.

We conclude that the coloured (yellow, orange and red) Orafol tapes perform best in terms of brightness of reflection in both the visible and IR regions, and also provide useful contrast to the monochrome background when using the appropriate FLIR camera (F15, F16).

## First Runway Test

## Method

### Design

Six different types of tape were exposed to illumination sources on board an AgustaWestland AW189 SAR aircraft at a distance of 1000ft (~305m). This distance was chosen so that it was far enough that the material samples would not be trivially obvious to the FLIR system and the pilots, and close enough so that the samples would still be in view. For example, 1000ft (~305m) is equivalent to a typical search altitude of 500ft (~152m) with a 60° depression angle of the search light, assessing a target at a horizontal distance of 866ft (~264m). Samples were tested individually so that the reflections from one tape did not interfere with another.

### Materials

Six different tape samples were tested: silver 3M Scotchlite, silver Orafol Oralite, yellow Orafol Oralite, orange Orafol Oralite, red Orafol Oralite, matte black Exium Tactical IR. Details of the tapes are given in Table 1. The two silver tapes currently hold maritime 'Safety Of Lives At Sea' (SOLAS) approval. According to Orafol, the coloured tapes could be granted SOLAS approval, without altering the properties and performance of the tapes. Indeed, we note that the Royal National Lifeboat Institution (RNLI) at Port Talbot, South Wales, UK use red Orafol Oralite with SOLAS approval on their helmets.

Tape covering an area 148×210mm was adhered to a non-reflective, matt black square of plastic for testing. A square of this matt-black plastic was used as the control condition. Images of the tape samples are shown in Figure 1.

Two types of illumination were used: white and IR light. This was provided by the pilot spotlights since the Trakka Beam (main search light) is not permitted for use below 200ft (~61m) due to its high power and heat generation. The pilot spotlights are the same type of light source as the Trakka Beam (high intensity xenon gas-discharge with 4000K colour temperature giving broad spectral emission in the range 400nm to >2000nm) but of lower intensity, and so the results are directly comparable. Firstly, the spotlights were used in white light mode, providing light in the visible spectrum. Secondly, the spotlights were used in their IR mode, with narrowband (estimated at 50-100nm) emission centred on 840nm provided by a high power LED.

The forward-looking infrared (FLIR) system can implement one of four different cameras depending on the search scenario (Table 2). All four cameras were tested.

| Sample number | Appearance | Brand | SOLAS Approval | Notes |
|---|---|---|---|---|
| 1 | Silver | 3M Scotchlite Reflective | Yes | - |
| 2 | Silver | Orafol Oralite FD1404 Imo Flex | Yes | Used on the current regulation immersion suit (Survitec 1000 Series) |
| 3 | Yellow | Orafol Oralite GP340 | No | Colour is formally termed 'lime'. Microprismatic construction designed to be abrasion resistant for outdoor clothing. Used by the emergency services, for example. EN ISO 20471:2013 approved. |
| 4 | Orange | Orafol Oralite GP340 | No | Microprismatic construction designed to be abrasion resistant for outdoor clothing. Used by the emergency services, for example. EN ISO 20471:2013 approved. |
| 5 | Red | Orafol Oralite VC 104+ | No | Designed for rugged outdoor use such as HGVs.ECE 104 reg 48 approved. |
| 6 | Black | Exium 13147 Tactical ID Systems – Black REDeye | No | Black coated tape designed to filter out the visible reflection leaving only the IR spectra – covert ops. |

*Table 1 - Details of the tapes used in pre-testing.*

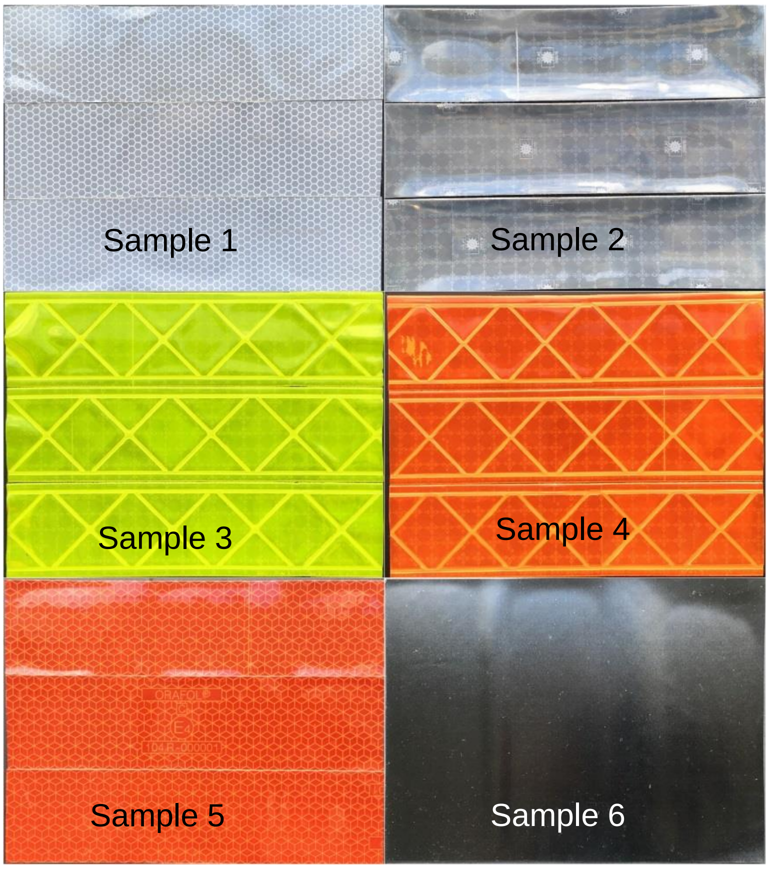



*Figure 1 - Images of the tape samples used for the testing, see Table 1.*

| FLIR Mode | Abbreviation | Application |
|---|---|---|
| High Definition Thermal Imaging | HDIR | Thermal imager (3-5µm) blended picture with high definition camera. Most applicable when looking for human targets with strong heat signature with respect to the environment. |
| Short Wave Infra-Red | SWIR | Detects IR reflection (e.g. from retroreflective materials). |
| High Definition Low Light (Colour) | HDLL | Optimised for low light conditions. |
| High Definition Electro Optical (Colour) | HDEO | Regular high definition video with image stabilisation. |

*Table 2 –FLIR camera modes available for the trials.*

## Procedure

A matt-black trolley was used to present the samples of tape to the aircraft equipment, see Figure 2. The trolley was positioned on a closed runway at the 1000ft (~305m) marker at night. The aircraft was taxied out to the runway and remained stationary with rotors running in idle throughout the test so that all SAR systems could operate without ground power. The first set of images was taken with no lights illuminating the samples as a control condition. The FLIR operator cycled through the camera modes with the focus fully zoomed out and then fully zoomed in. Next, the samples were illuminated by the light sources: firstly white, followed by IR. All images were captured by the screen capture feature of the FLIR system and downloaded at the end of the trial. An example image is shown in Figure 3. In addition to the FLIR camera data, images taken through the pilot’s NVGs were also captured. Figure 4 shows an example NVGs image during the trial.

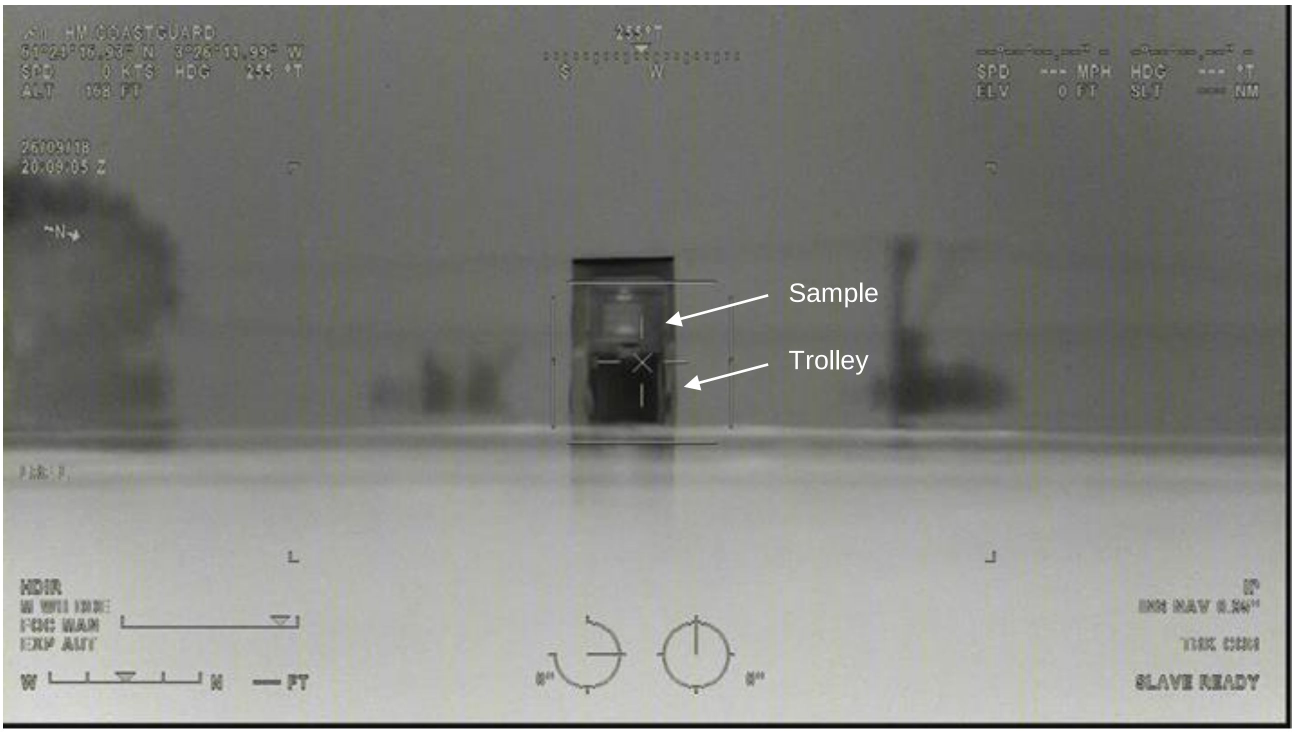


*Figure 2 – Example of HDIR Image showing the trolley.*


*Figure 3 – Example FLIR image of the tape reflection.*

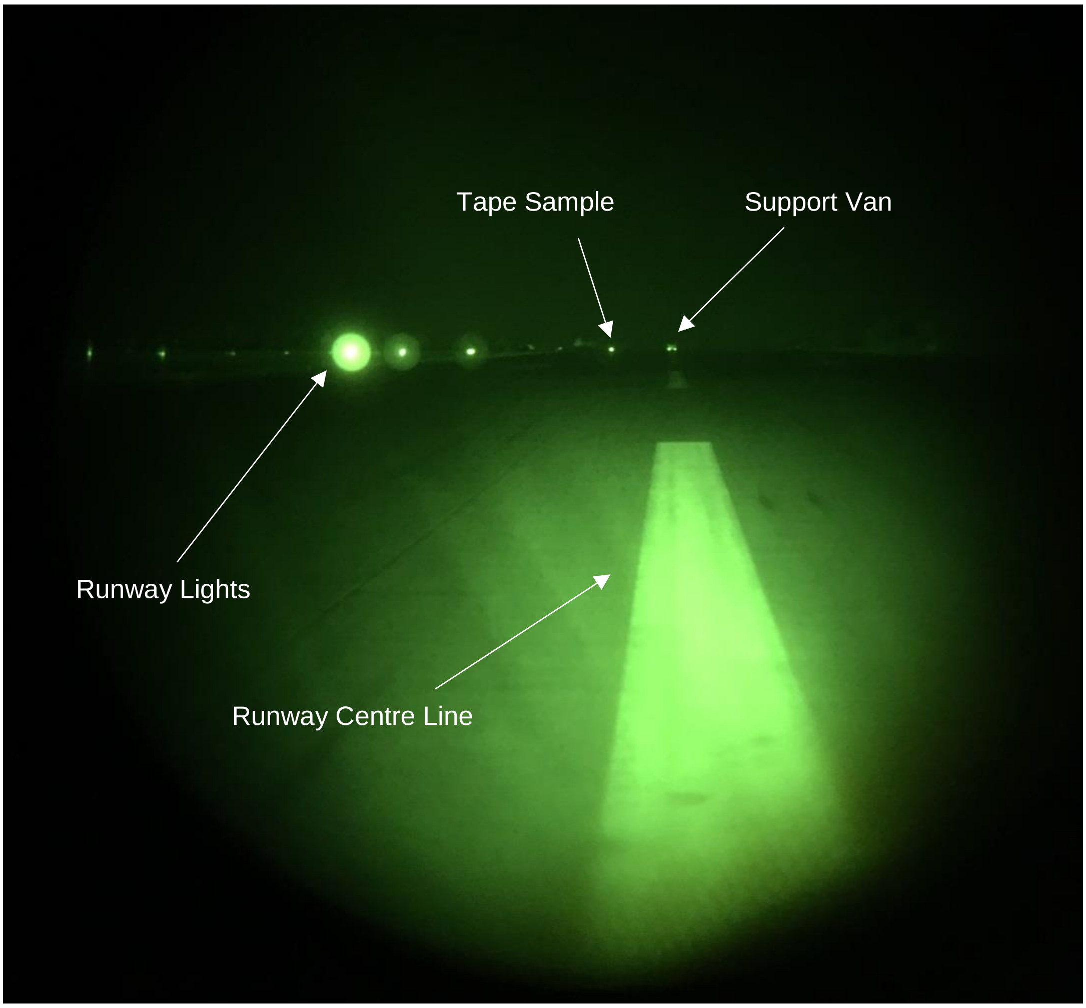



*Figure 4 – Example NVGs image as viewed by the pilots from the cockpit.*

# Results

Images of all test conditions are shown in this section, Figures 5-19. Images are shown for each FLIR camera mode (HDIR, SWIR, HDLL and HDEO) and NVGs. Three illumination conditions are presented: control (negligible ambient light - too low to measure on the light meter), white and IR light from the pilot spotlights.

Results indicate that when the samples are not illuminated by any light source they are only visible to the HDIR camera (Figure 5). In this case, no clear leader in terms of conspicuity emerges from the samples.

When illuminated by white light all samples are visible (Figure 12). The four Orafol tapes (samples 2, 3, 4 and 5) provide the brightest reflection (at the minimum auto-exposure) on the SWIR, HDLL and HDEO cameras (Figure 11, 12, 13). The coloured variants (yellow, orange, and red) provide visible contrast against the monochrome background of the HDLL and HDEO cameras (Figures 12 and 13).

All samples are visible with the HDIR (Figure 15) and SWIR (Figure 16 ) cameras when illuminated with an IR light source, indicating that all samples retroreflect in a corresponding IR spectra to the aircraft equipment (F 13). The HDLL (Figure 17) and HDEO (Figure 18) cameras are not compatible with an IR light source and as such, the samples are not visible using this equipment. The four Orafol tapes (samples 2, 3, 4, and 5) show the brightest reflection (at the minimum auto-exposure) on the SWIR camera (Figure 16) (F 12).

Considering the NVG images, when not illuminated, the samples are not visible (Figure 9). However, when illuminated by both white and IR light, the four Orafol tapes (samples 2, 3, 4, and 5) provide the brightest reflection (Figure 14, 19). During the trial, pilots commented that with both the white and IR light sources, the brightest reflections as seen in the NVGs were from the Orafol silver, yellow and orange tapes (F 14). It was also noted that with the white light source, reflections from the yellow and orange tapes were brightest, followed by the silver Orafol tape.

## Control trials across all cameras and NVGs. No illumination

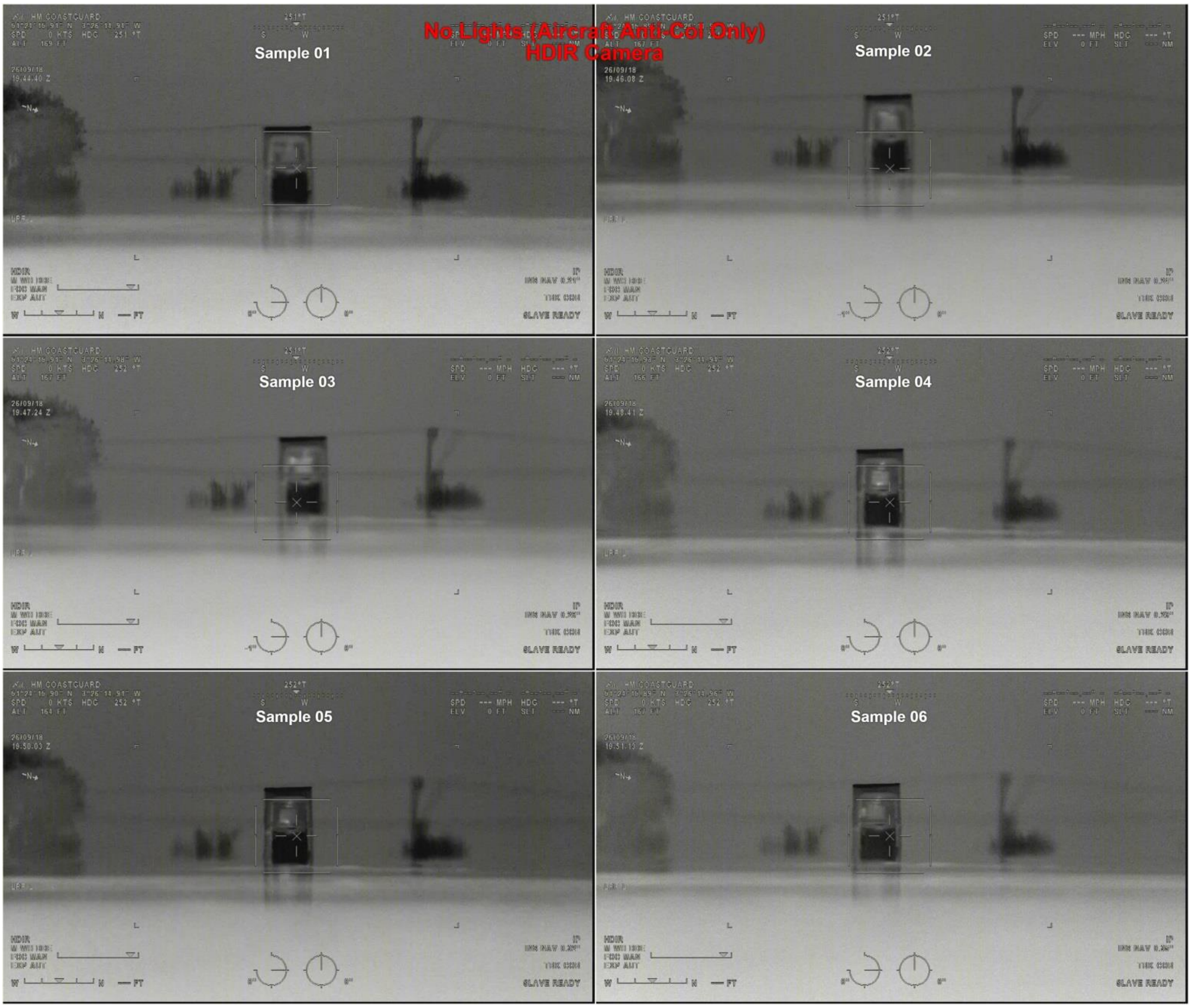



*Figure 5 - No illumination (control), HDIR camera.*

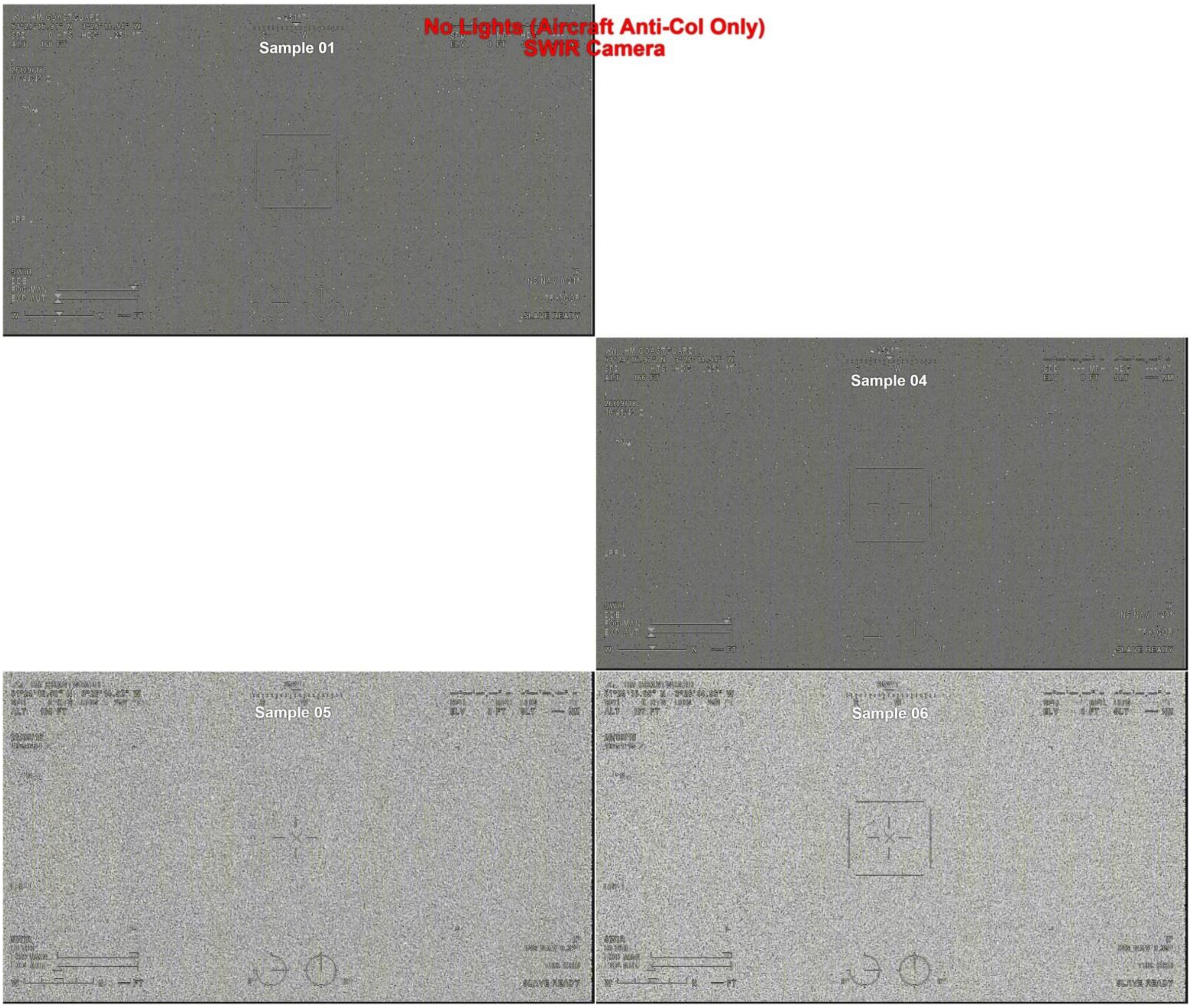



*Figure 6 – No illumination (control), SWIR camera.*

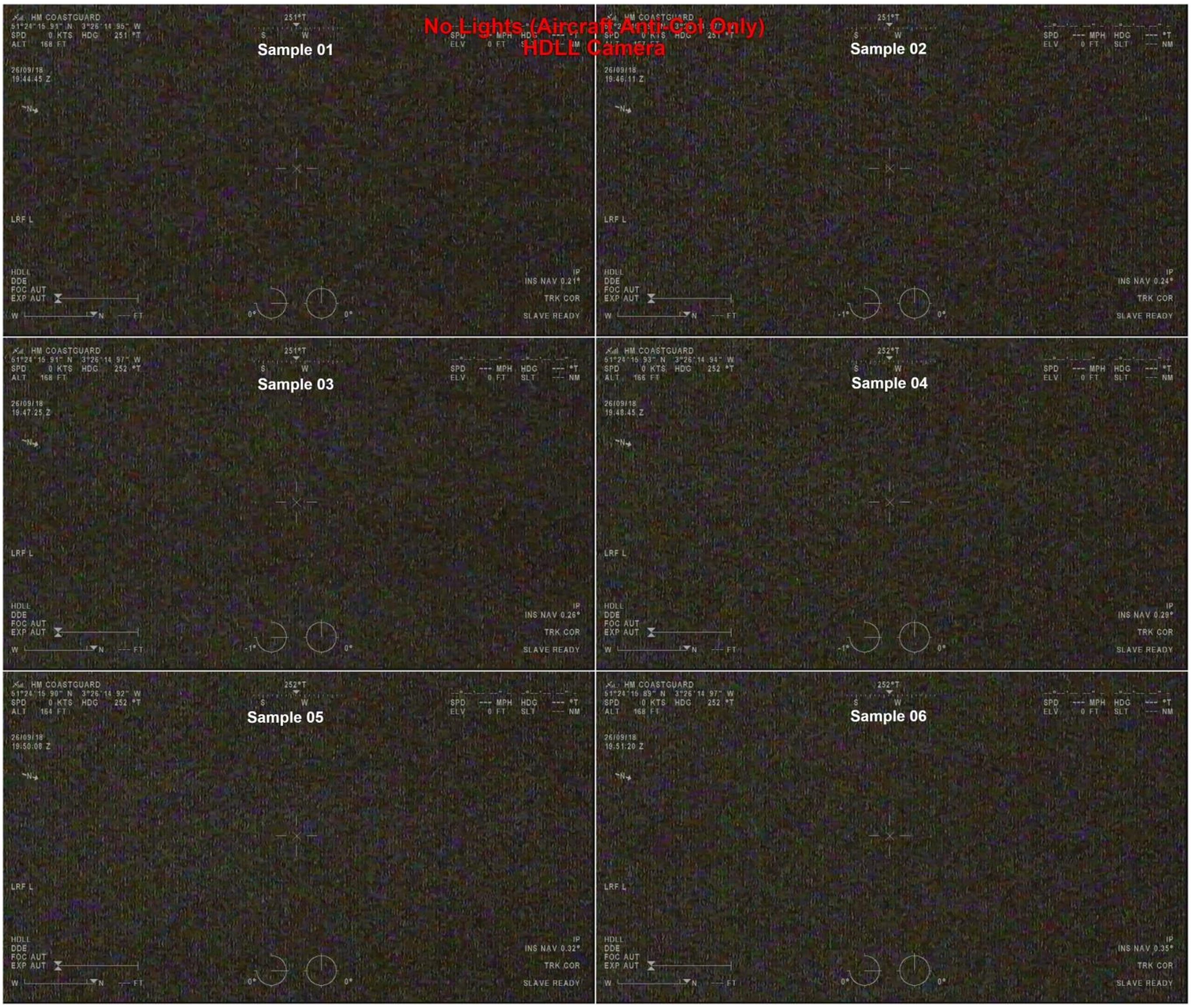



*Figure 7 - No illumination (control), HDLL camera.*

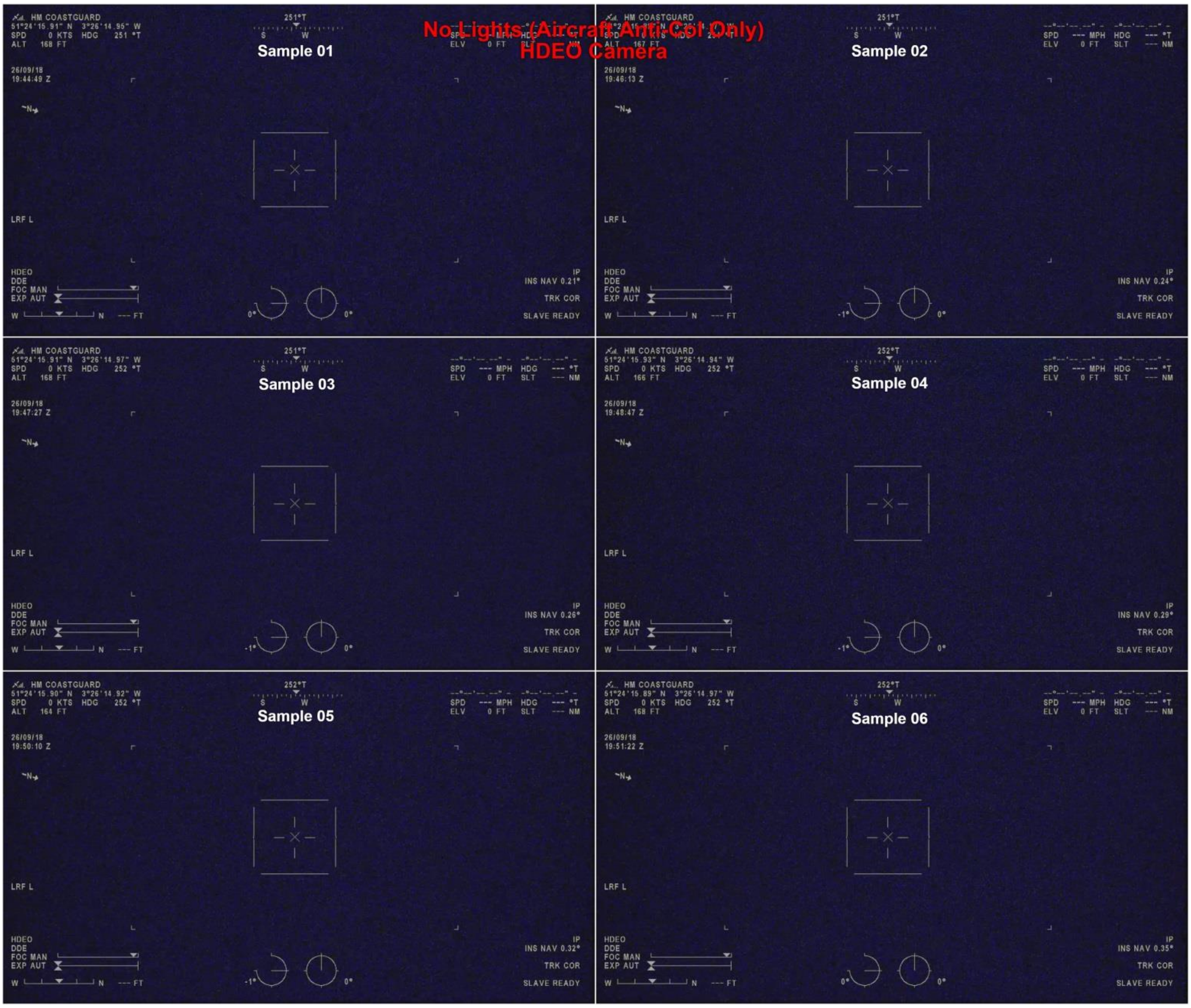



*Figure 8 – No illumination (control), HDEO camera.*

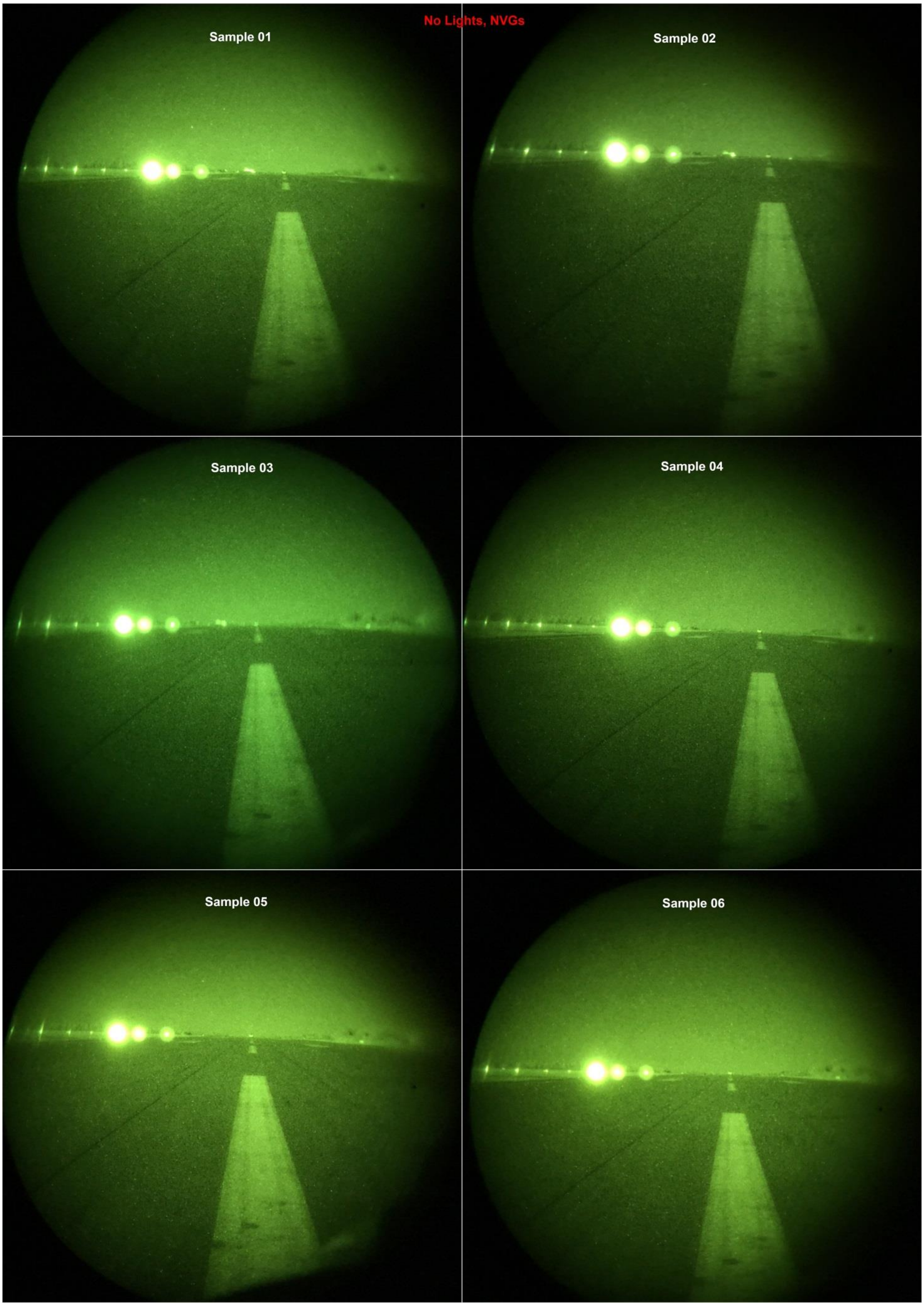



*Figure 9 - No illumination (control), NVGs.*

## Trials across all cameras and NVGs using white-light

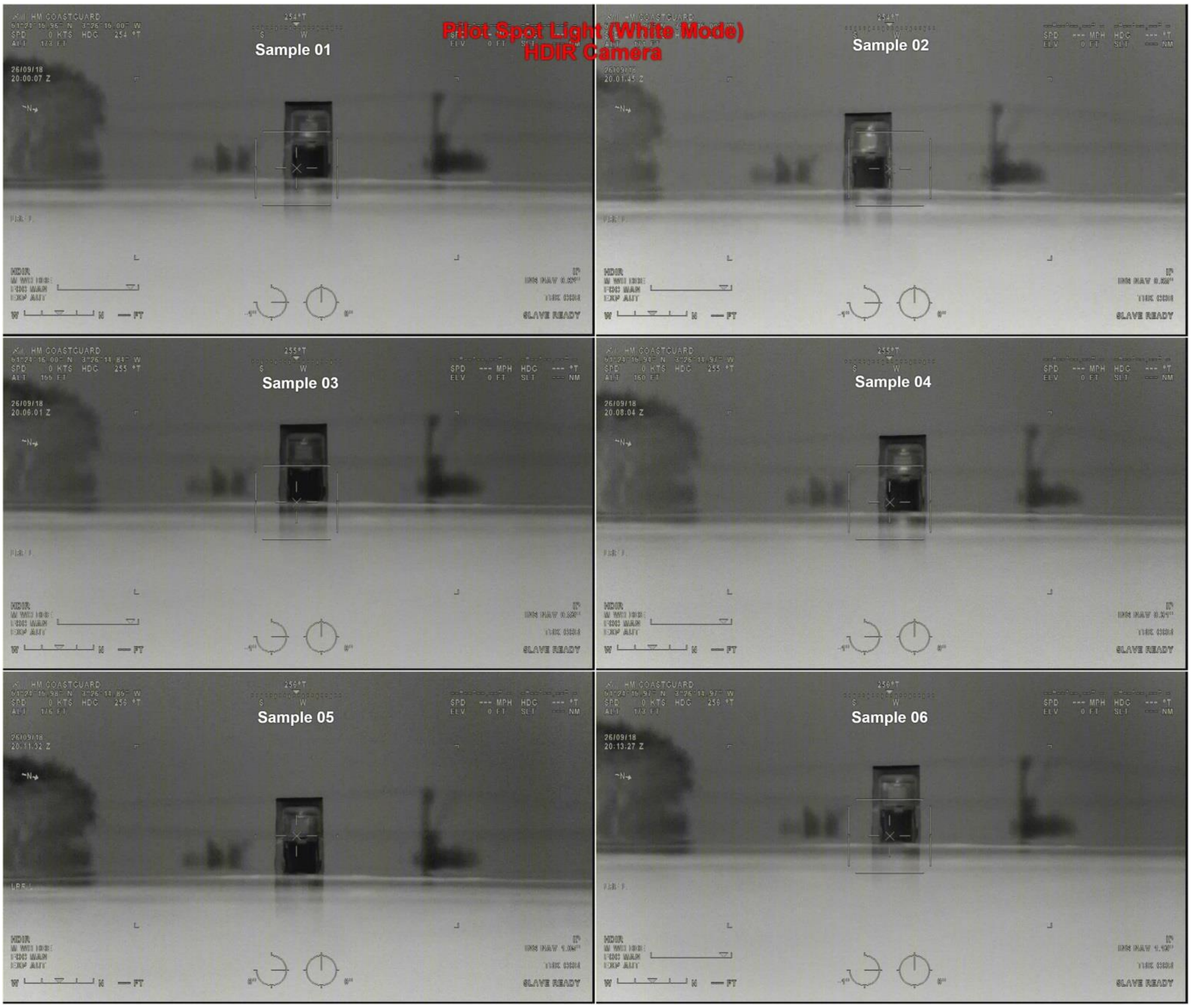



*Figure 10 – White light illumination from pilot spotlights, HDIR camera.*

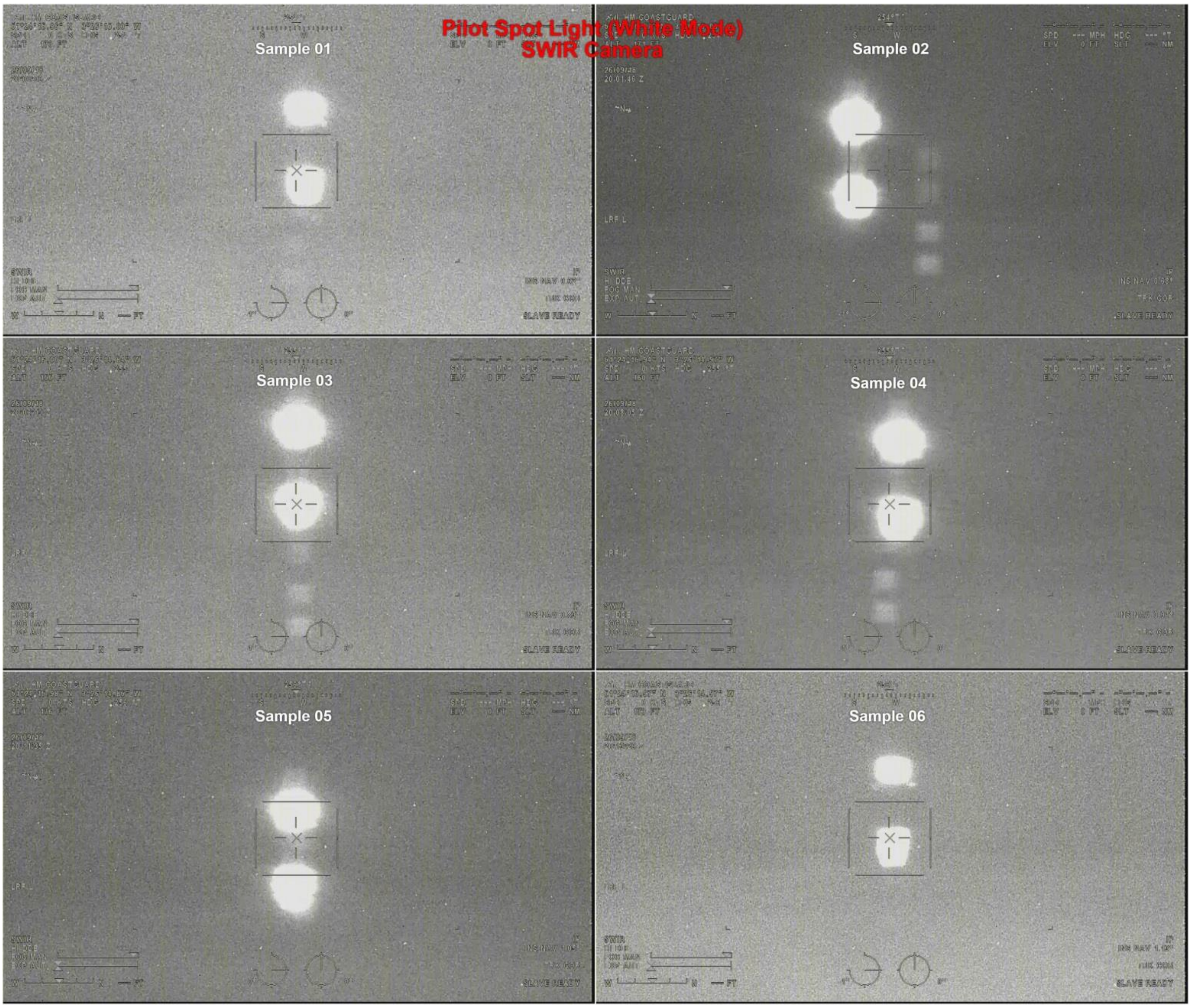



*Figure 11 – White light illumination from pilot spotlights, SWIR camera.*

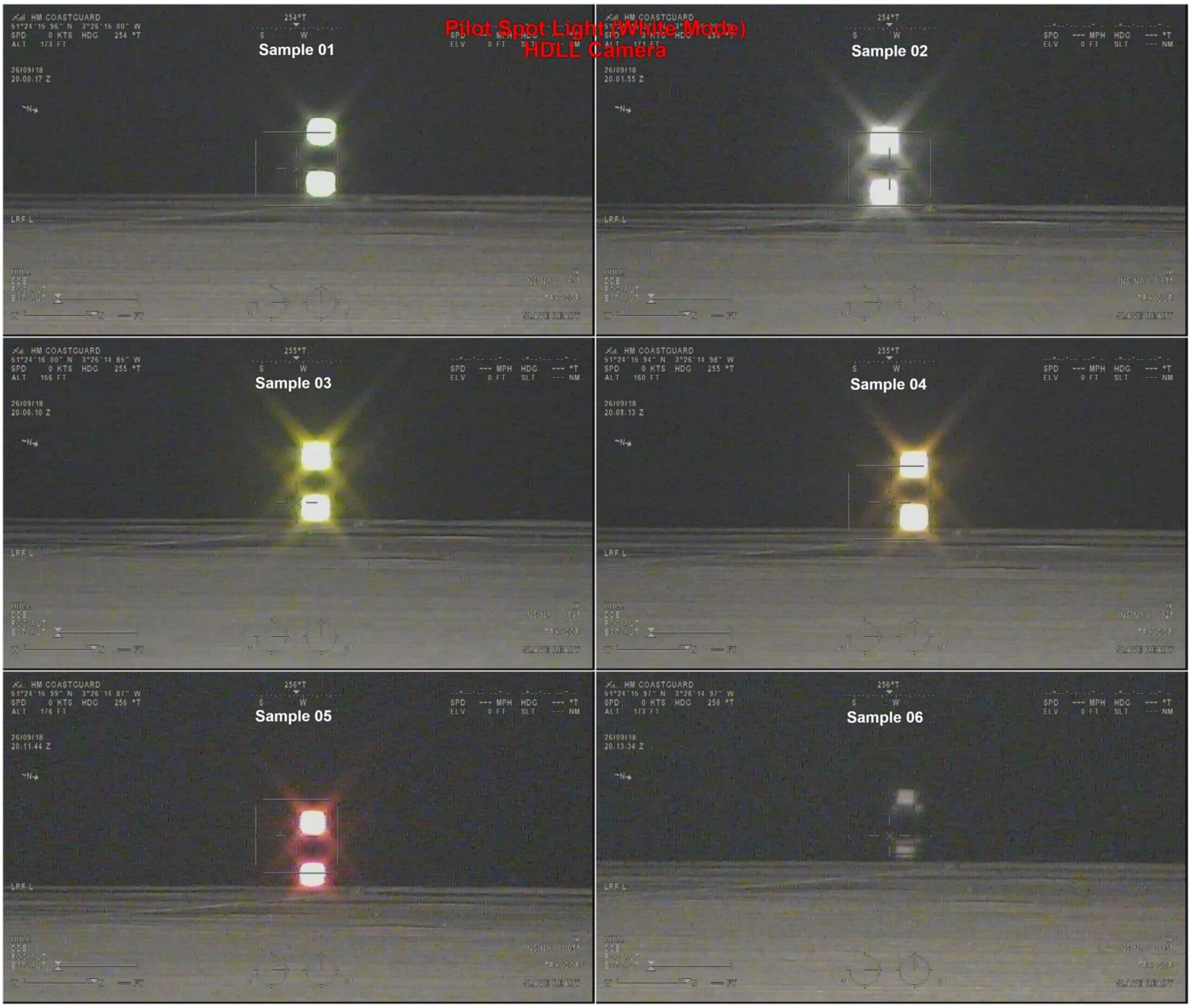



*Figure 12 – White light illumination from pilot spotlights, HDLL camera.*

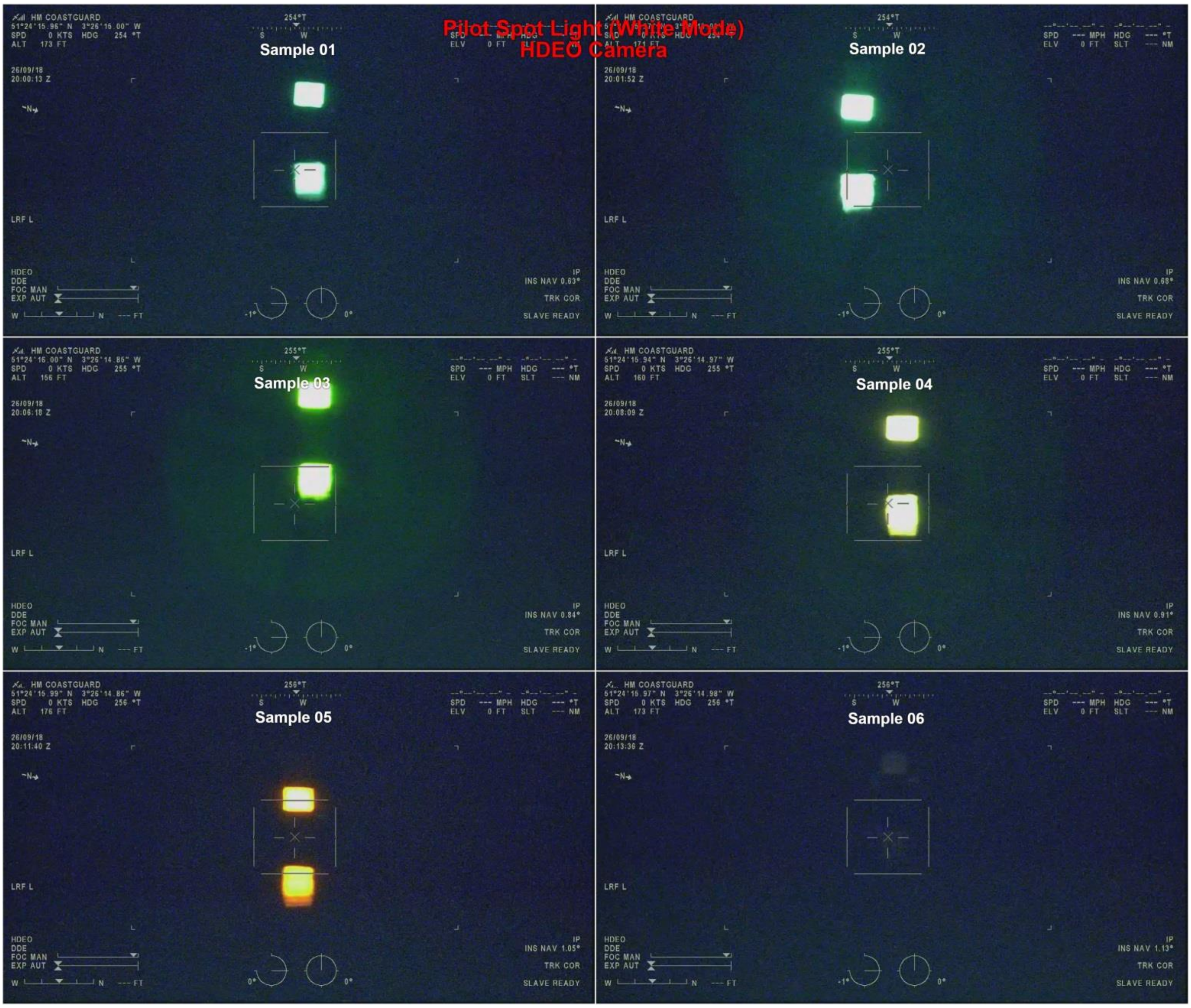



*Figure 13 – White light illumination from pilot spotlights, HDEO camera.*

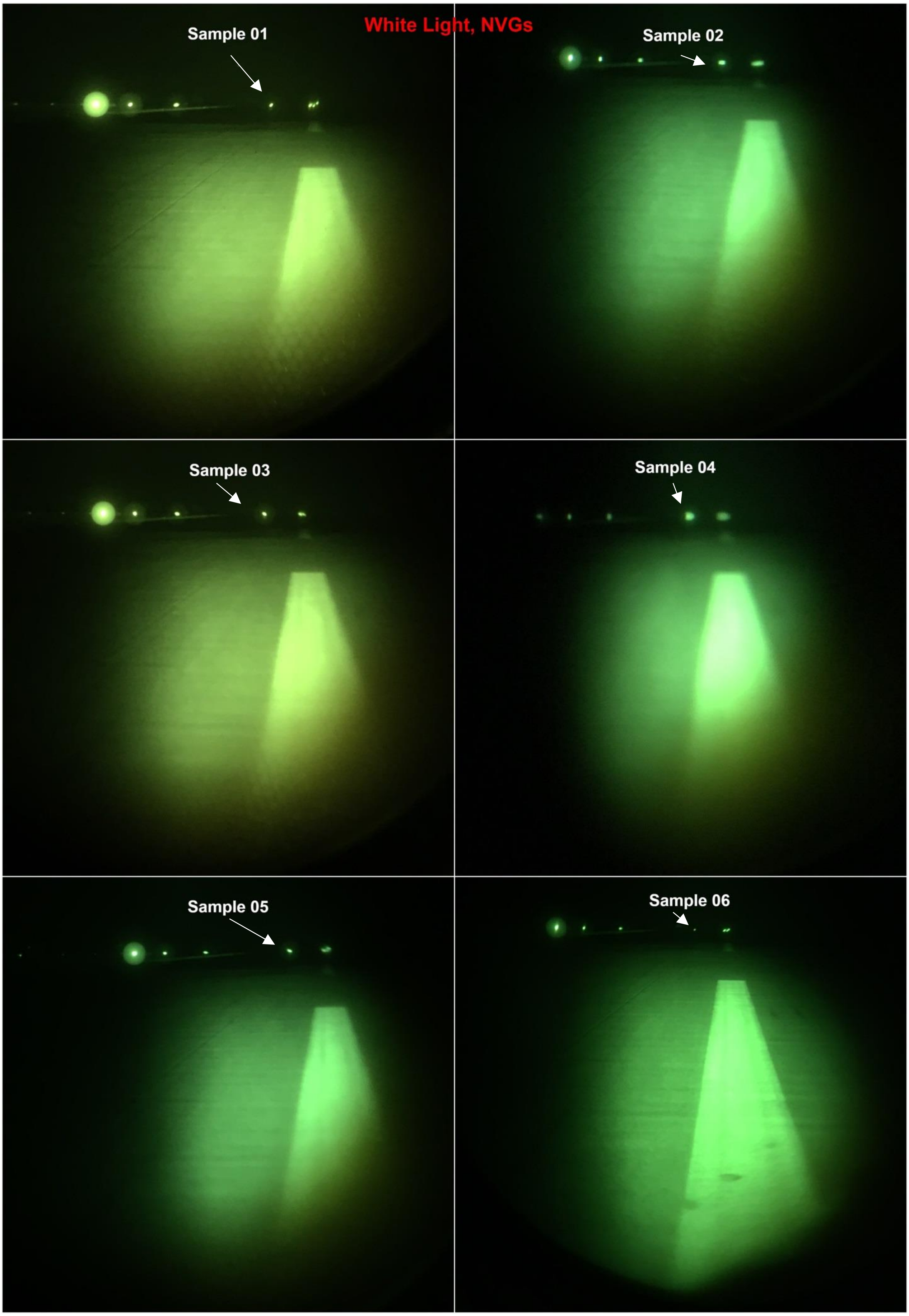



*Figure 14 – White light illumination from pilot spotlights, NVGs.*

# Trials across all cameras and NVGs using IR-light

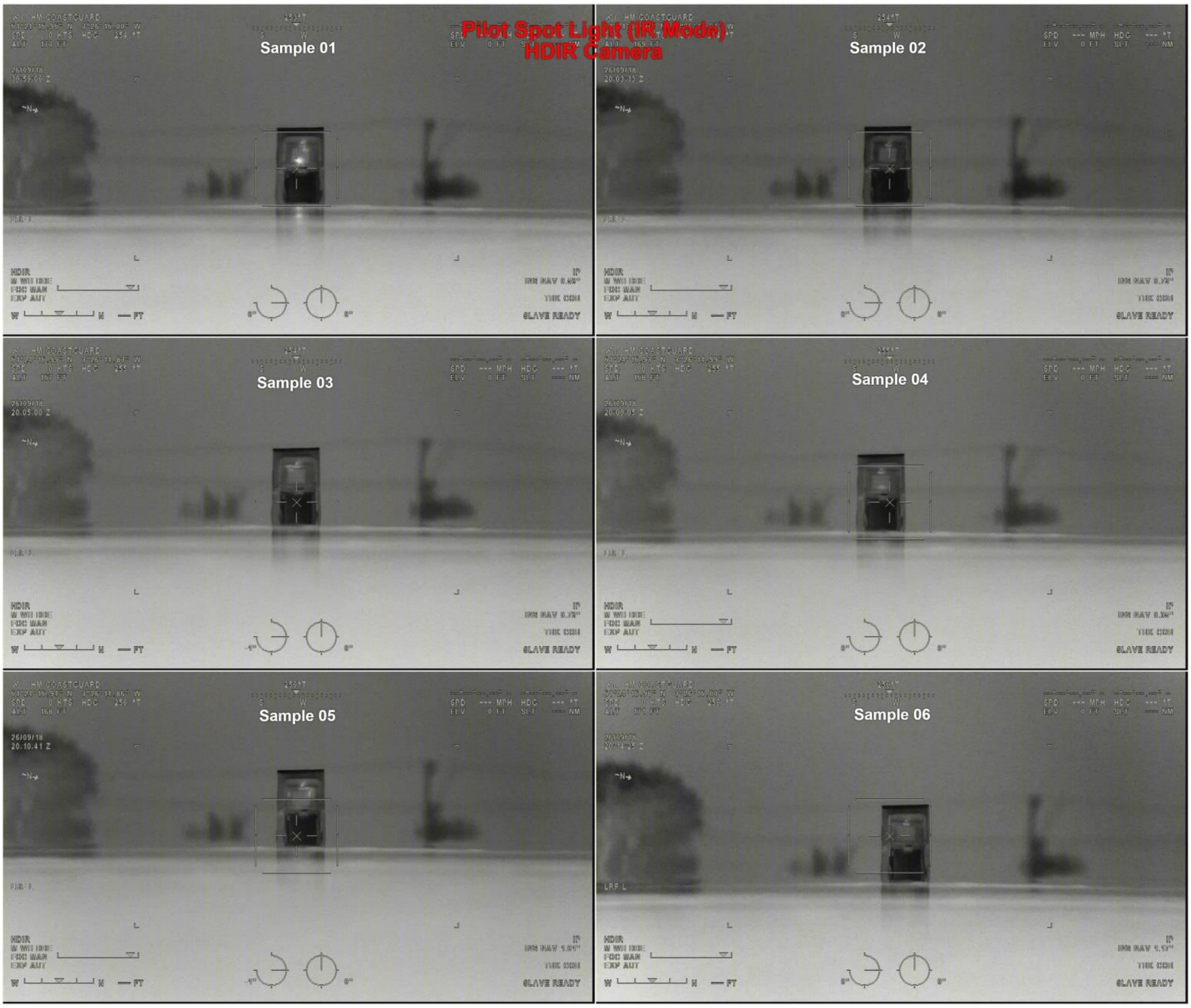



*Figure 15 – IR light illumination from pilot spotlights, HDIR camera.*

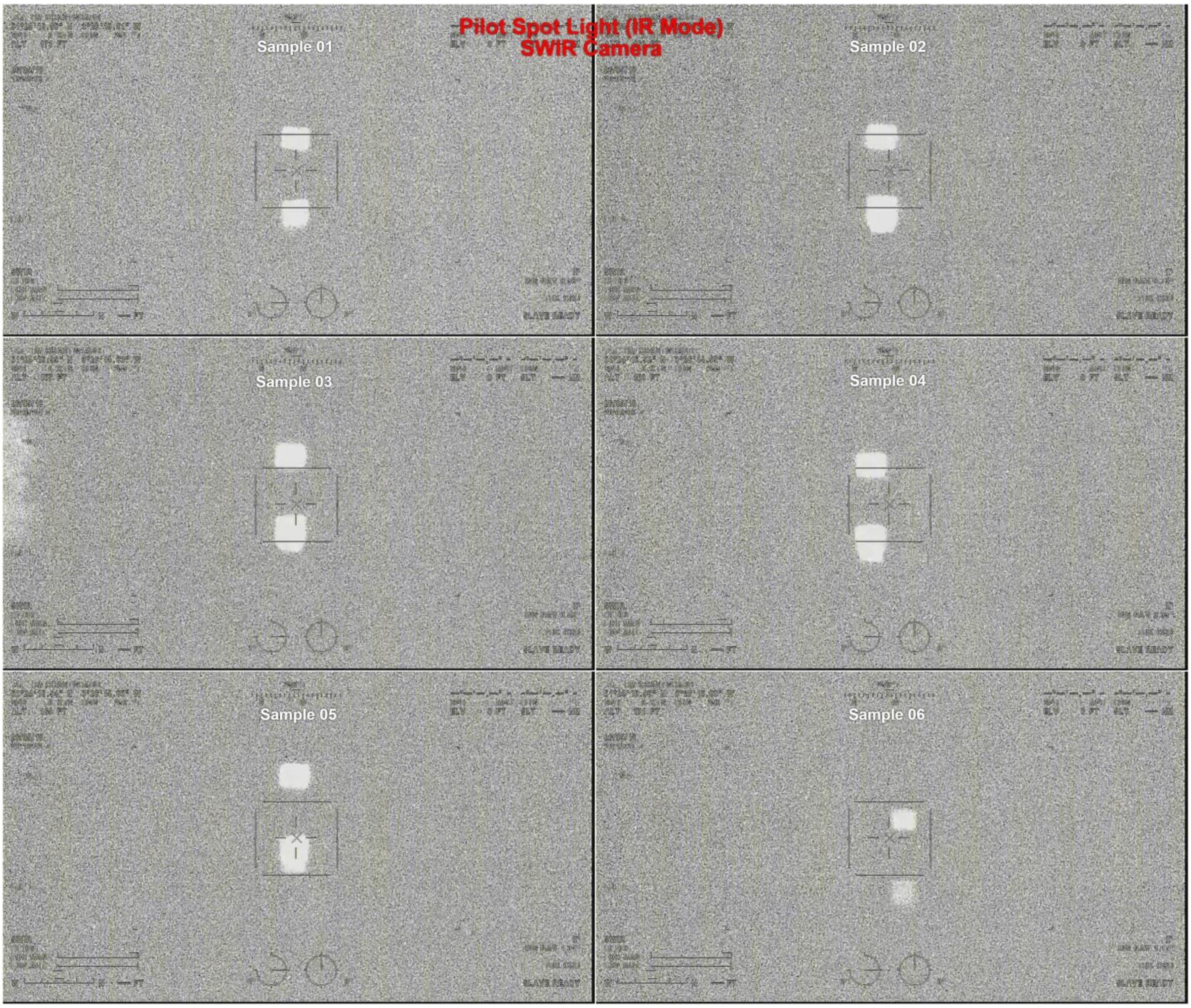



*Figure 16 – IR light illumination from pilot spotlights, SWIR camera.*

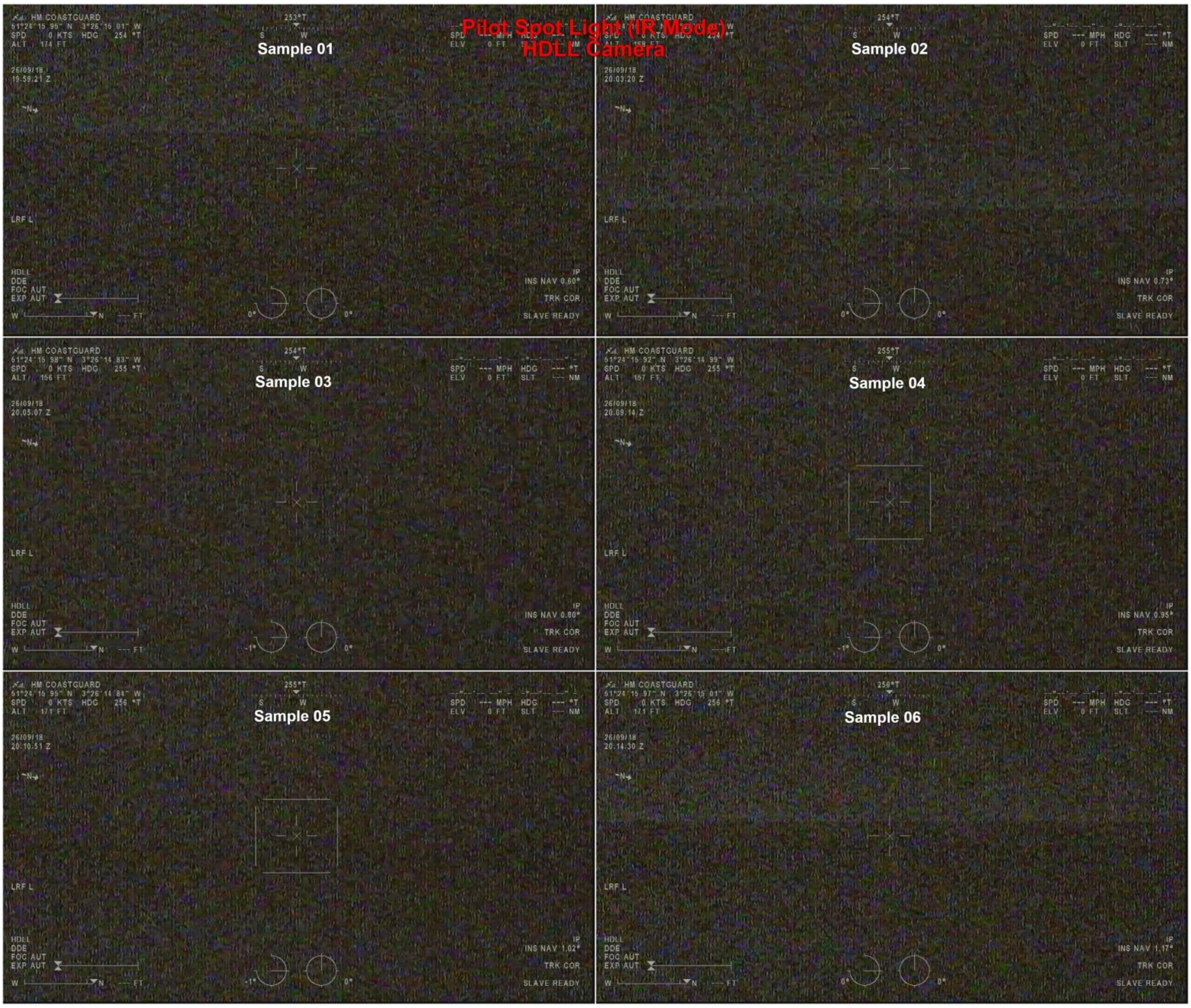



*Figure 17 - IR-light illumination from spotlight, HDLL camera.*

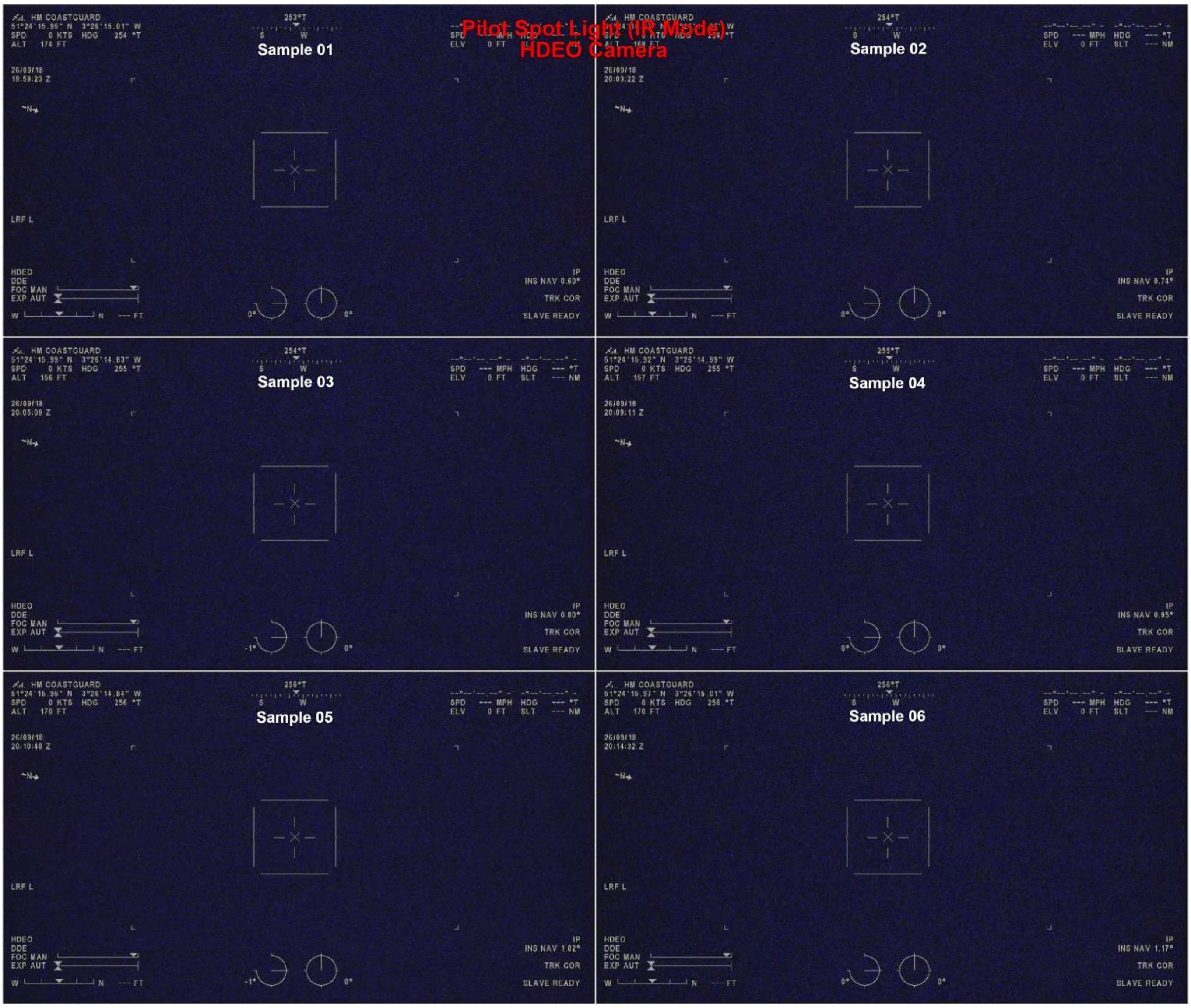



*Figure 18 – IR light illumination from pilot spotlights, HDEO camera.*

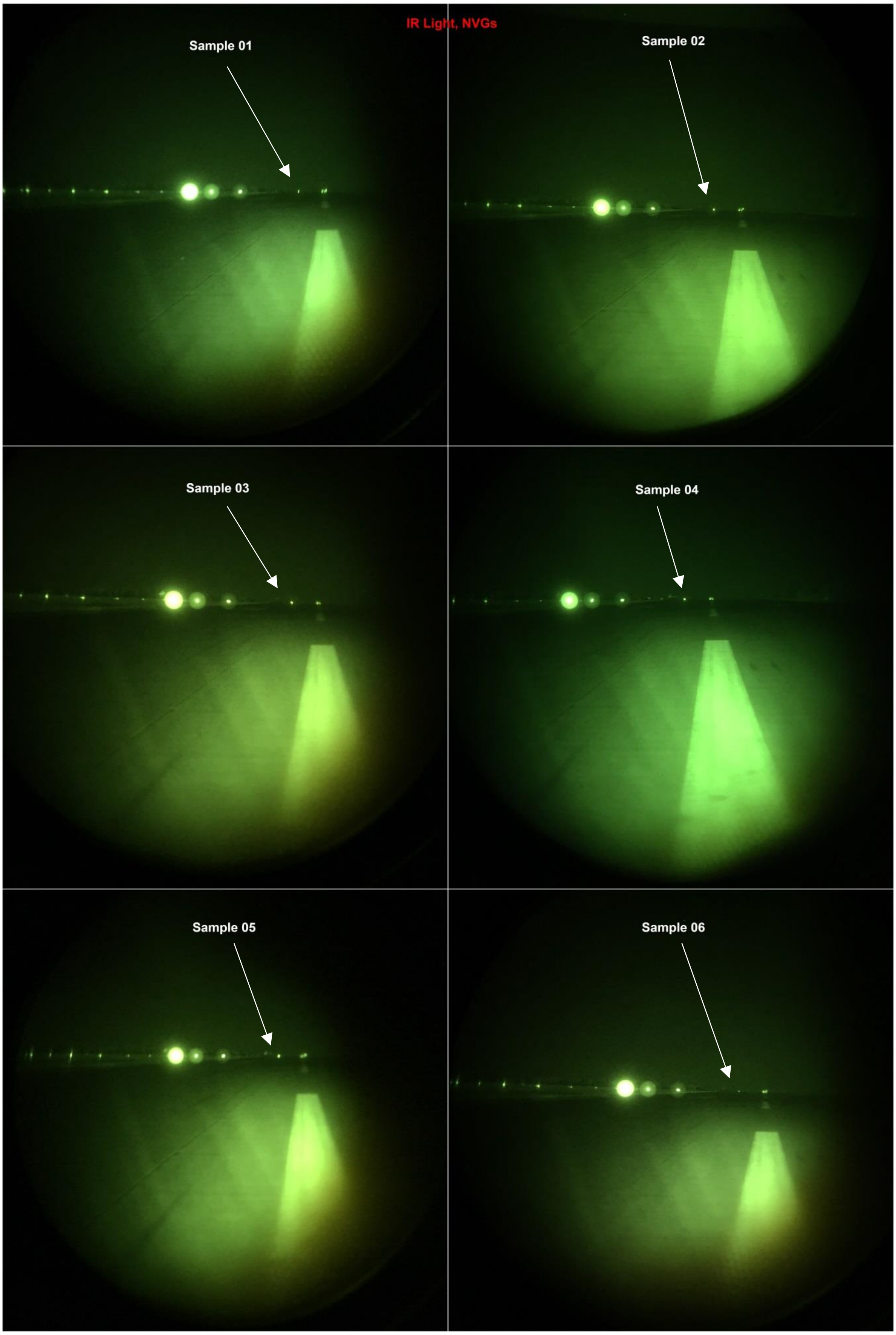



*Figure 19 – IR light illumination from pilot spotlights, NVGs.*

# Second Runway Test

## Method

### Design

This test was designed to augment the results of the first runway trial with data comparing the tapes side-by-side in both daylight and night-time conditions. A board with all samples attached, was positioned 1000ft (~305m) away from the aircraft as in the first runway test. The FLIR system and pilot spotlights were operated under ground power. The six different tapes as used in the first runway test were attached to a matt-black board, side by side. Tape samples were organised with sufficient separation to reduce reflection between the different tape samples.

### Materials

Figure 20 shows the spatial arrangement of the samples on the board.

For the daylight test, no illumination was used. In the night-time test the pilot spot light was used to illuminate the samples with both white and IR light.

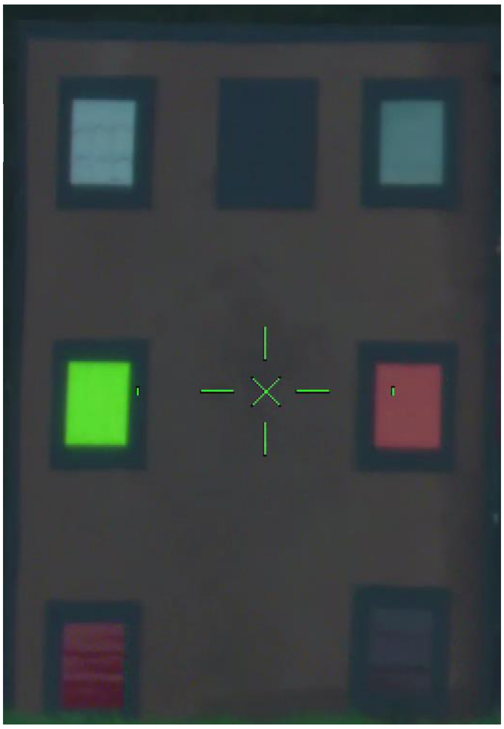



*Figure 20 – Layout of the tape samples on the board for the second runway trial.*

## Procedure

The board displaying the samples was positioned on an elevated area adjacent to the main runway. The board was held in place by two observers who were in radio communication with the aircraft. The aircraft was towed out to the parking area outside of the hangar and supplied with ground power. The aircraft used the laser sight to confirm a distance of 1000ft (~305m) to the samples as to allow a direct comparison of the results with those of the first runway test. The FLIR operator focused the camera on the samples and cycled through the various camera options. This was repeated with the camera fully zoomed out, and with the camera zoomed in sufficiently to fill the screen with the display board. The test was conducted in both daylight and night-time conditions. In the dark, the samples were illuminated by the pilot spotlights, firstly with conventional white light then with the IR filtered light. The video footage of all tests was recorded by the screen capture feature of the FLIR system and screen shots taken for the analysis.

# Results

The first set of images shown in Figure 21 were taken in daylight conditions. The second set of images, Figure 22, were taken at night-time with the samples illuminated with the pilot spotlight set to white light mode. The final set of images, Figure 23, were taken at night-time with the samples illuminated with the pilot spotlight set to IR mode.


*Figure 21 – Daylight test, zoomed in. HDEO camera top left, HDLL top right, HDIR bottom left, and SWIR bottom right.*

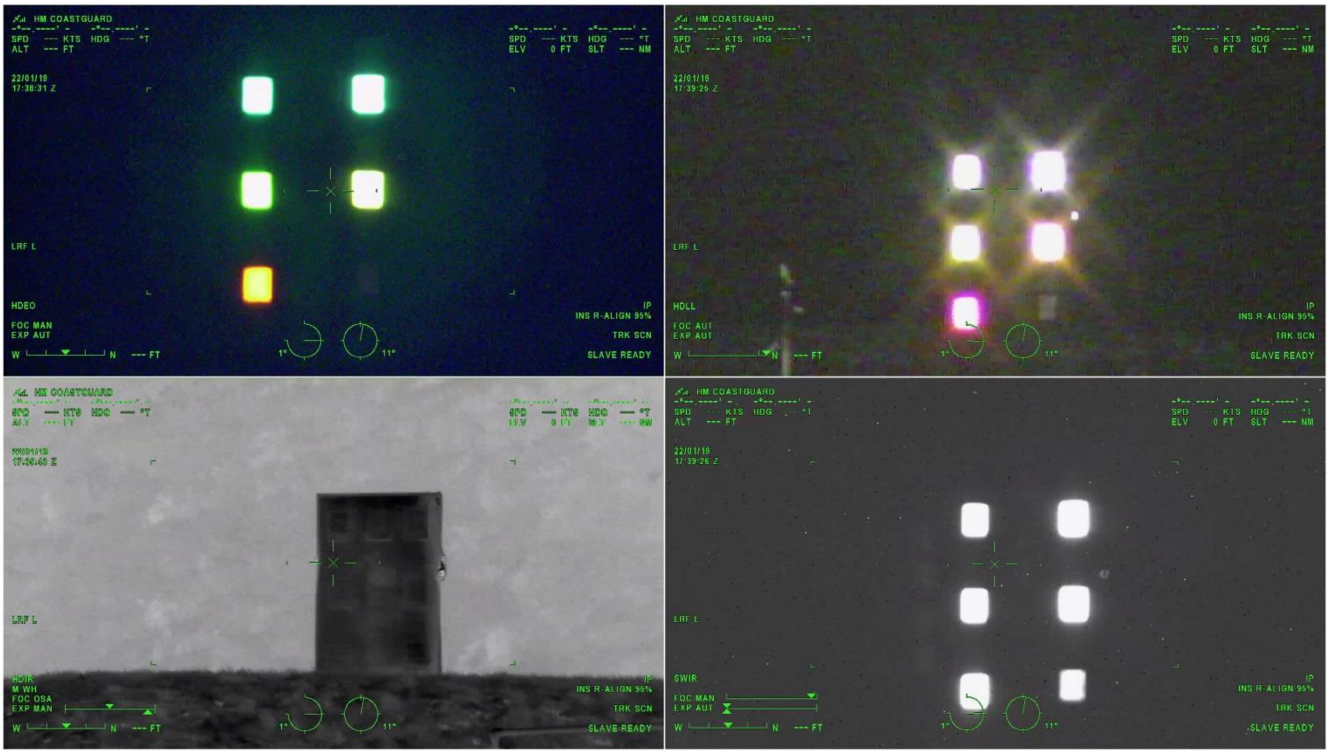


*Figure 22 – Night-time test, zoomed in, samples illuminated with white light. HDEO camera top left, HDLL top right, HDIR bottom left, and SWIR bottom right.*

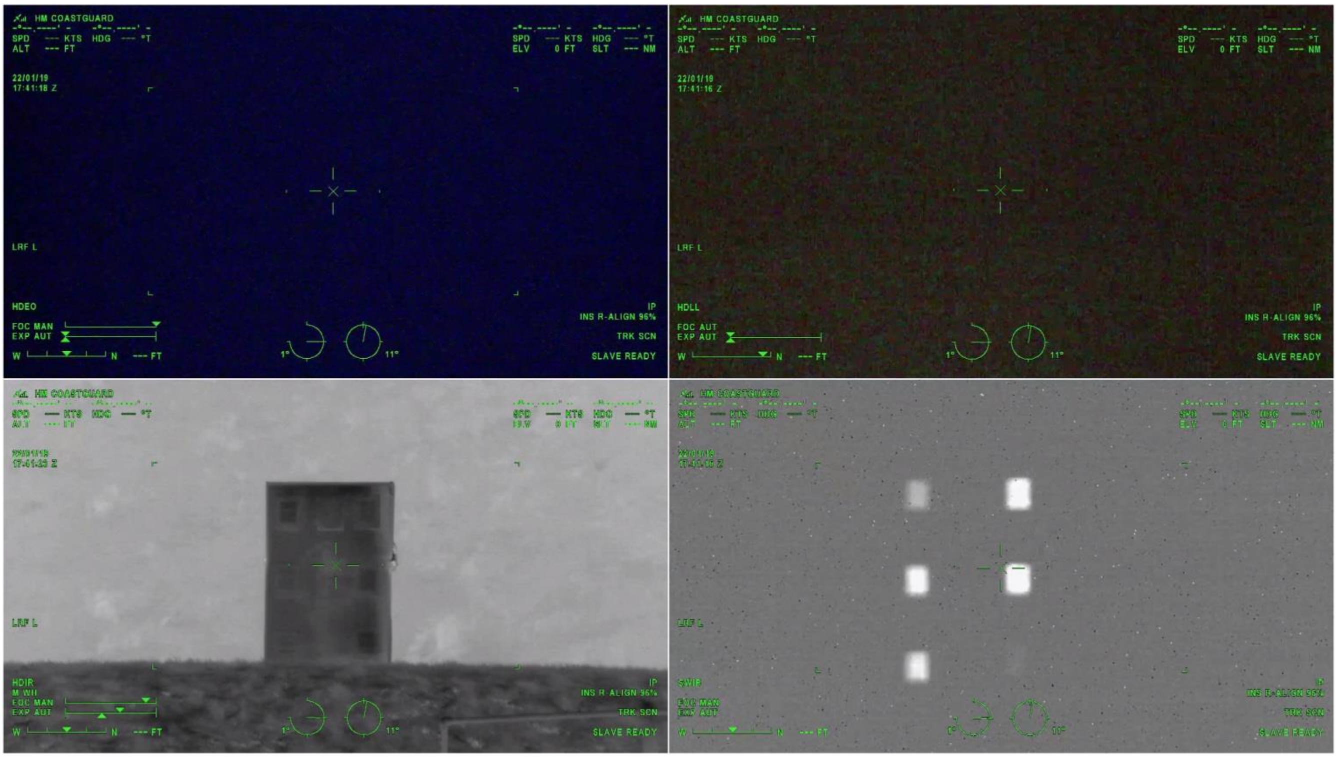


*Figure 23 – Night-time test, zoomed in, samples illuminated with IR light. HDEO camera top left, HDLL top right, HDIR bottom left, and SWIR bottom right.*

With reference to Figure 21, all samples are visible to all cameras in the daylight. Using the HDIR and SWIR cameras the level of reflection from all samples appears similar. However, using the regular and low light HD cameras (HDEO and HDLL) the coloured tapes, particularly the yellow and orange colours, provide colour contrast against the dark background, similar to what may be expected at sea. Therefore, in terms of daylight conspicuity, we conclude that the yellow and orange Orafol tapes perform best (F 15).

With reference to Figure 22 the black IR tape does not perform as well as the other tapes with all camera options during the night-time test with white light illumination. Using the regular and low light HD cameras (HDEO and HDLL) the silver, yellow and orange Orafol tapes give the brightest reflection, with the silver 3M tape, and then the red Orafol tape appearing less bright. The silver 3M and silver, yellow and orange Orafol tapes give reflections that are bright enough to cause camera lens blooming in the HDLL mode. Again, the coloured variants provide colour contrast against the black background. Using the SWIR camera, the brightest reflection is from the Orafol silver, orange and red tapes (F 14).

As expected, in the night-time test with IR light illumination, the samples are only visible with the SWIR camera, (Figure 23). In this case, the black IR tape is least conspicuous, followed by the silver 3M tape. The silver and orange Orafol tapes give the brightest reflections (F 12).

We conclude that for night-time conspicuity, when searching with either white or IR light sources, the silver and orange Orafol tapes perform best (F 14). This result is consistent with the first runway trial where the tapes were tested in isolation.

# Cockpit Reflectance Trials

## Aim and Summary

In this trial, a number of different tapes were applied to current regulation immersion suits Survitec 1000 series) in a pre-determined configuration, based on recommendations from the literature review and runway testing, to assess potential reflections in the cockpit. The design exploited areas of the body which define human movement [2] (F 07), areas likely to be above the water when treading water or floating (F 09), and avoided the areas covered by the life jacket, see Figure 24.

We conclude that when applied in this configuration, additional reflective tape was found to be tolerable inside the cockpit by the pilots (F 16). Furthermore, the orange tape blends well with the orange suit leading to reduced colour contrast, which was reported as favourable by the pilots (F 19). The final suit design to be tested in the flight trials uses this orange retroreflective tape.


*Figure 24 - Survitec 1000 Series immersion suit incorporating orange Orafol Oralite GP340.*

# Method

## Design

SMEs made subjective judgements about the reflectivity of the suits within the cockpit environment. These judgements were captured diagrammatically and any comments were recorded by the observer. All participants completed the test whilst wearing all suit configurations (unmodified suit, suit with silver tape, and suit with orange tape, suit with black tape) in both day and night-time conditions. Light readings from three different areas of the cockpit were taken and the average level of illumination is reported together with relevant environmental conditions. The researcher completed a sequence of different movements designed to capture typical movements made by pilots when controlling the aircraft. These movements are detailed in Table 3. Figure 25 shows the observer (researcher) working through the specified movements inside the cockpit in both day and night conditions.

| Movement | Notes |
|---|---|
| Full travel of the cyclic and collective | Right hand circular movements at waist height between legs, and left hand up/down movements at waist height on left side of body. |
| Full travel of the foot pedals | One leg almost fully extended with the other bent at the knee and vice versa. |
| Reaching forwards (e.g. To set altimeter) | With right hand. |
| Reaching upwards (e.g. To set windshield anti-ice) | With right hand. |
| Seat adjustment | Forwards, backwards, up and down. |

*Table 3 - Movement protocol used in each reflectance trial.*


*Figure 25 - Observer wearing an identical suit as the pilot during the daylight (left) and night-time (right) reflectance trials. Note the raised arm in the left image: one of the pre-specified cockpit movements.*

## Materials

Suits were modified using three of the six tape samples were tested in the reflectance trials to cover a range of silver, coloured, and black variants. The following configurations were tested:

1. Unmodified immersion suit (Survitec 1000 series) – Control condition.
2. Suit modified with silver Orafol Oralite FD1404 Imo Flex (SOLAS  Approved).
3. Suit modified with orange Orafol Oralite GP340.
4. Suit modified with black Exium Tactical ID Systems REDeye.

The Orafol Oralite SOLAS already on the suit around the ankles, remained on the suit during the trials. Pilots also wore current regulation Viking life jackets thought the tests.

The literature review has already detailed that no current configuration of reflective material on the body is directly applicable to the application described. As such, a pragmatic approach was taken. The current suits have retroreflective tape only around the ankles. The modified design (Figure 26) sought to achieve two aims. Firstly, to add more area of reflective material to increase the probability of detection due to increased conspicuity. Secondly, to apply tape defining the extremities of the body: the legs, shoulders and arms. Tape on the arms was positioned on the inside of the forearms since crew report that casualties may wave at rescue crews (F 07). The design also took advantage of curved surfaces, such as the shoulders, to provide a range of angles of incidence for any reflection of light (F 08, F 09).

## Procedure

The trial involved a pilot (test participant) donning a randomly selected suit configuration (Figure 27), with an identical suit also worn by the observer (researcher). The pilot was seated in the commander's seat (right-hand side of the cockpit). In both day and night conditions, the pilot was asked to sketch in areas on a cockpit schematic, see Figure 28, any areas of the windscreen or instruments where reflections of the suit were apparent when working through the list of predetermined movements, see list above. The pilots were also asked to rate the level of reflectance from 0 (not perceptible) to 4 (just intolerable). An example cockpit schematic with pilot's sketches from the trial is shown in Figure 29. The observer recorded any other relevant comments made by the pilot, and data relating to the lighting conditions on the test card (Figure 30).

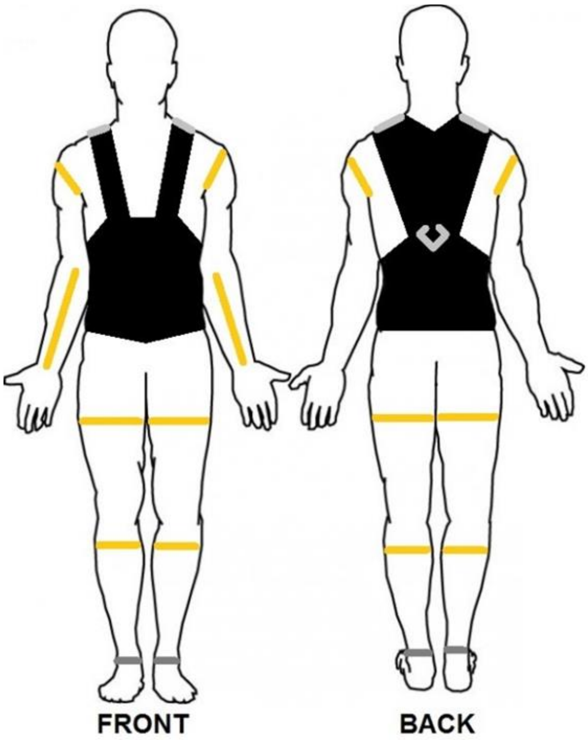



*Figure 26 - Configuration of tape used in the cockpit reflectance trials.*

*Figure 27 - Pilot wearing modified immersion suits.*

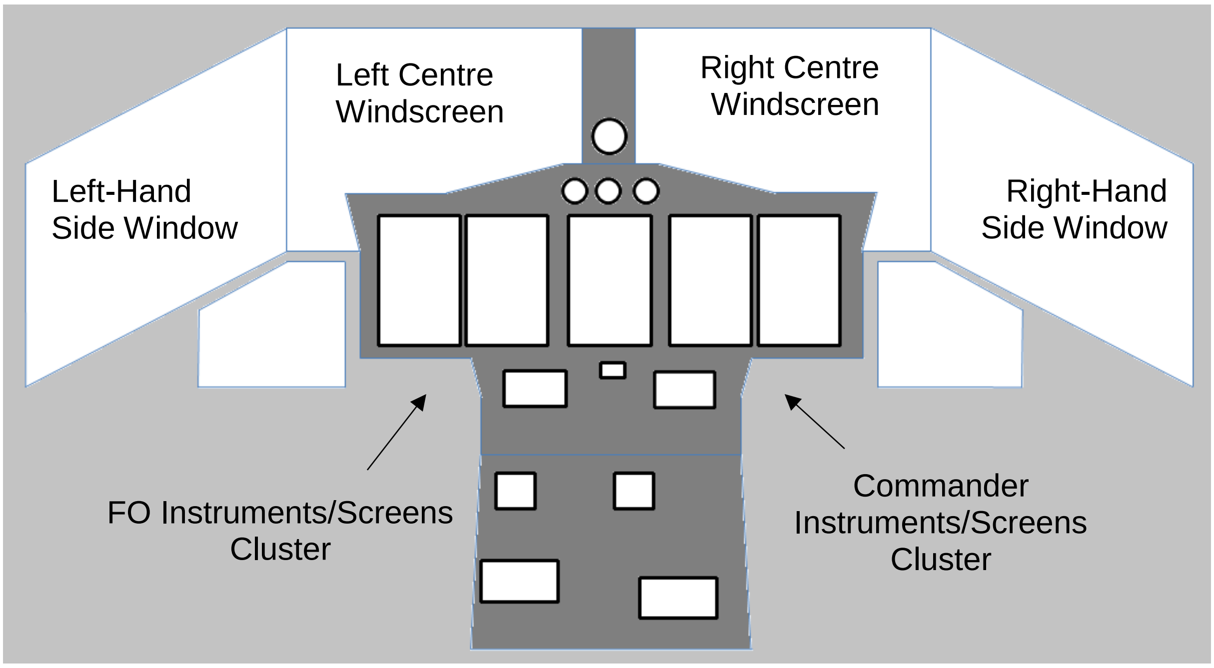



*Figure 28 - Cockpit schematic for pilot to annotate reflections in the cockpit.*

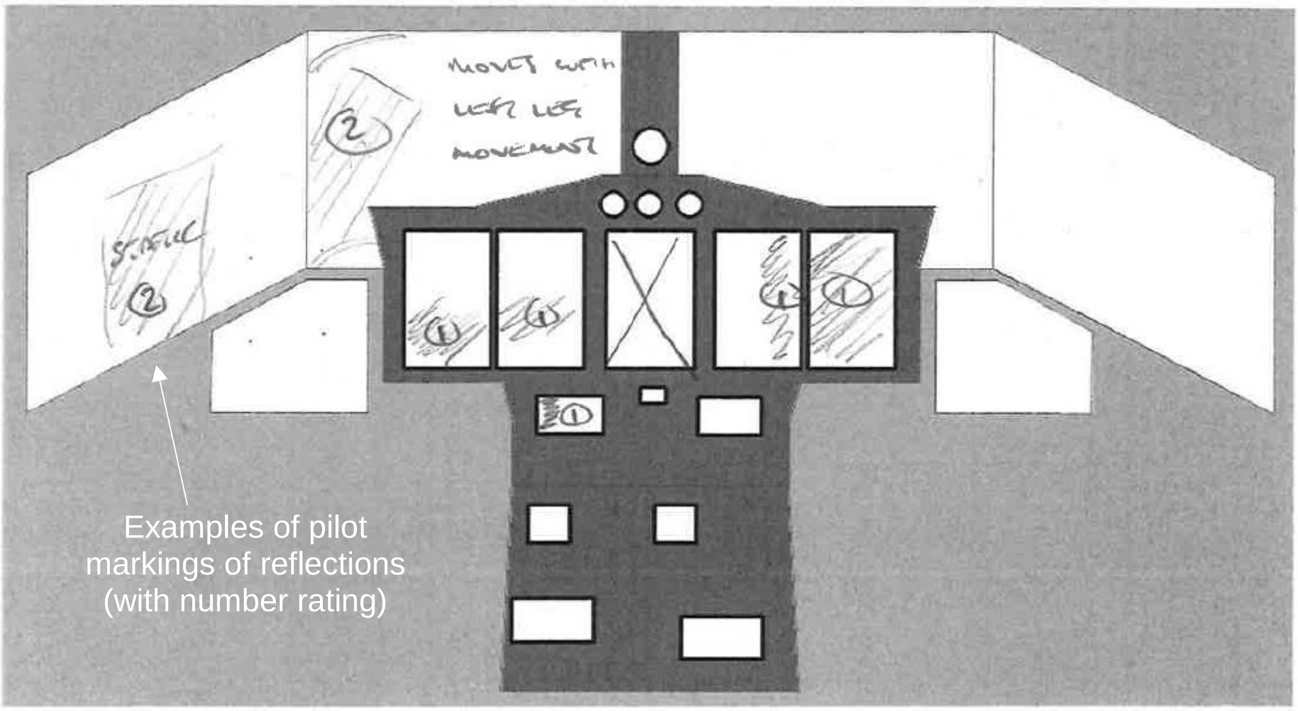



*Figure 29 - Example test card with pilot's annotations during reflectance trial.*

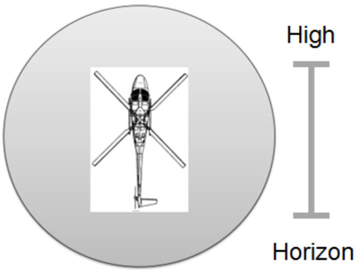
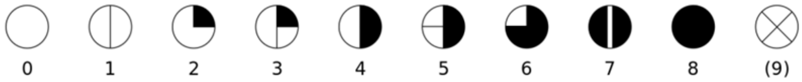
| | | | |
|---|---|---|---|
| **Test No.** | | **Date** | |
| **Aircraft** | | **Time** | |
| | | | |
| **Pilot** | | **Observer** | |
| | | | |
| **Sun/Moon Position** | **Cloud Coverage** | | |
|   |   | | |
| **Light Level Reading** | | | |
| | | | |
| **Pilot Comments** | | | |

*Figure 30 - Test card completed by the observer during the reflectance trials.*

# Results

The daylight tests were carried out at different times of day so that the sun was at different positions in the sky. Data was collected with the sun high and low, at positions varying from 10-12 o'clock with respect to the aircraft orientation, with cloud cover varying from 0-5 Okta, and in direct/non-direct sunlight. Average light meter readings in the cockpit were taken before each test. Daytime light readings varied between 1400-5800lx.

Tests were also conducted at dusk with the sun set below the horizon but with sufficient light to be regarded by the pilots as daytime operations. In these cases, the light readings varied between 10-120lx.

Finally, cockpit reflectance trials were conducted at night-time. In these trials, data was collected for moon positions from 10-12 o'clock, cloud cover from 4-8 Oktas, and with light meter readings ranging from 0.2-3.4lx.

All results from the trials were collated for each of the suit configurations for both daylight tests, Figures 31-34, and night-time tests Figure 35. There were no reports of level 4 (just intolerable) reflections inside the cockpit throughout the testing, both day and night-time (F 16). In two trials, pilots reported areas of level 3 reflectance: just uncomfortable. These reports relate to the orange and silver Orafol tapes. Both reflections occurred in the left-hand side window and originate from the co-pilot's shoulder hoops. These particular tests were conducted in bright direct sunlight and the pilot commented that the reflections contained 'hotspots' due to the folds and creases in the reflective tape as a result. However, it was noted, that the pilot found the reflections from the orange tape less distracting than the reflections from the silver tape due to the reduced colour contrast against the orange immersion suit (F 19). Throughout all tests there were nine reported reflections of level 2 (just acceptable) and 27 of level 1 (just perceivable), mostly occurring in daylight conditions.

When testing the immersion suit with the black tape applied, the pilots reported no reflections in the cockpit, describing the effect more as an "absence of orange (from the suit)" (F 17). Pilots commented that although the black tape reduces the reflection from the suit itself, applying black tape to the orange immersion suit may reduce its conspicuity in daylight conditions (F 18).

In 70 percent of all trials, pilots reported some reflection in both the left-hand side window and the left centre windscreen originating from the co-pilot. In general, the level of reflection in the left centre window was lower than in the left-hand side window. As a result, the pilots reported that since the reflections in the left-hand side window are predominantly in the peripheral vision when flying normally, the generally higher reflections here are acceptable (F 16). In comparison, pilots reported reflection in the right-hand side window in 25% of cases, and reported no reflections at all (no cases) in the right-hand centre windscreen.

Pilots also reported that reflections which have potential to move can lead to the greatest distraction (F 21). In particular the lower leg tapes when operating the foot pedals. Based on this finding, we recommend either positioning the lower leg tape further down the leg so that it definitely sits below the knee bend when the pilot is sitting down, or to remove this section of tape completely. In a search situation, this portion of tape is likely to be underneath the waterline if the casualty is treading water.

In 20 percent of all tests, pilots reported some reflection in the FO instruments/screens, all level 1 (just perceivable). In 40 percent of cases, pilots reported some reflection in their own

instruments, again all level 1 apart from 2 cases which where daylight tests involving the control condition suit (no additional tape) and the suit modified with silver Orafol tape (F14).
In total, for the same number of tests, 13 reflections were recorded in night-time conditions compared to 33 reflections in daytime conditions. Therefore, there is more potential for unwanted reflection during daylight conditions, however it is acknowledged that the position of the sun/moon and whether the suit is in direct/indirect light may have a large effect on any perceived reflections. Clearly, significantly more test cases would be required to systematically gather data for all such conditions, however, the sample set provided for this report covers a varied range of conditions.

In general, we conclude that the tape around the shoulders have the greatest potential for distraction as a result of unwanted reflections. However, pilots acknowledge the benefit of additional tape in these areas to aid conspicuity of a casualty in the water for reasons described above. The orange tape, despite leading to a slight increase in the number of reflections recorded compared to the unmodified suit, is the most suitable for suit modification due to reduced colour contrast of the reflections. The positioning of the tape on the suits, in terms of flexibility and comfort, was also reported to be acceptable. Clearly, additional reflective material may be applied to the back of the immersion suit without risk of cockpit reflection (F 20).

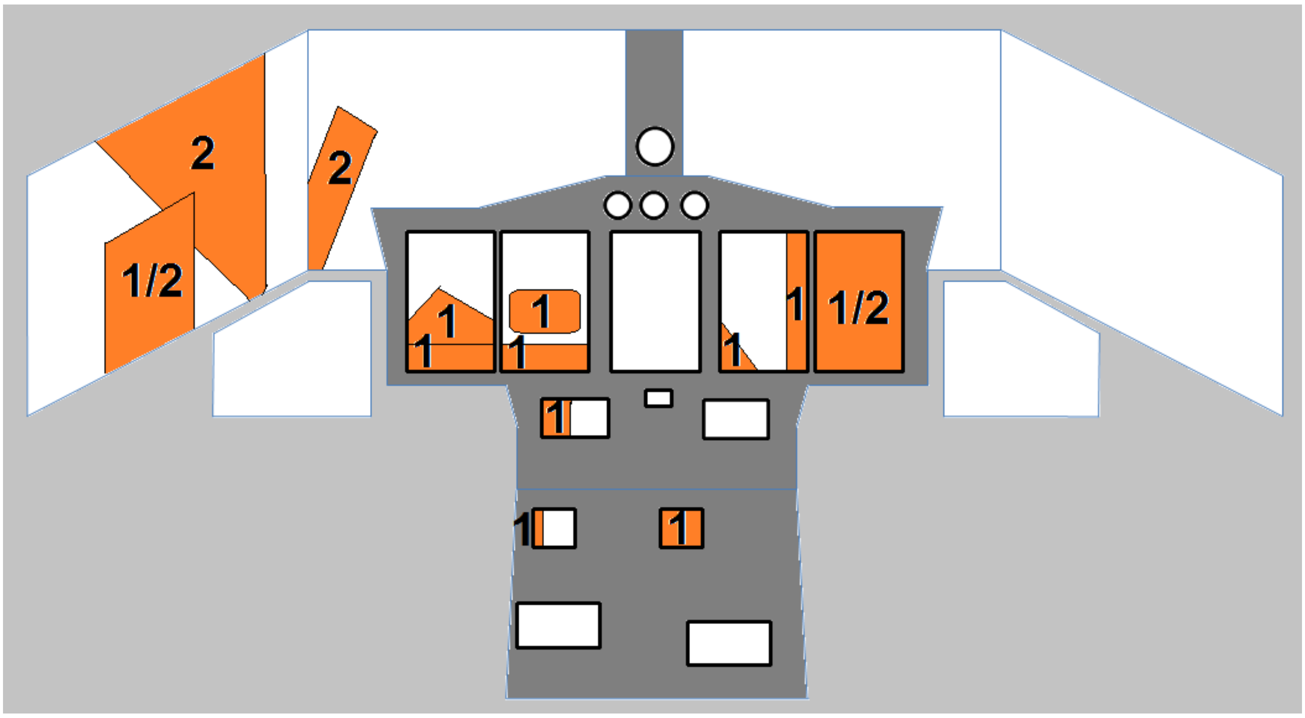



*Figure 31 - Combined reflectance trial data for daylight tests, current regulation suit.*

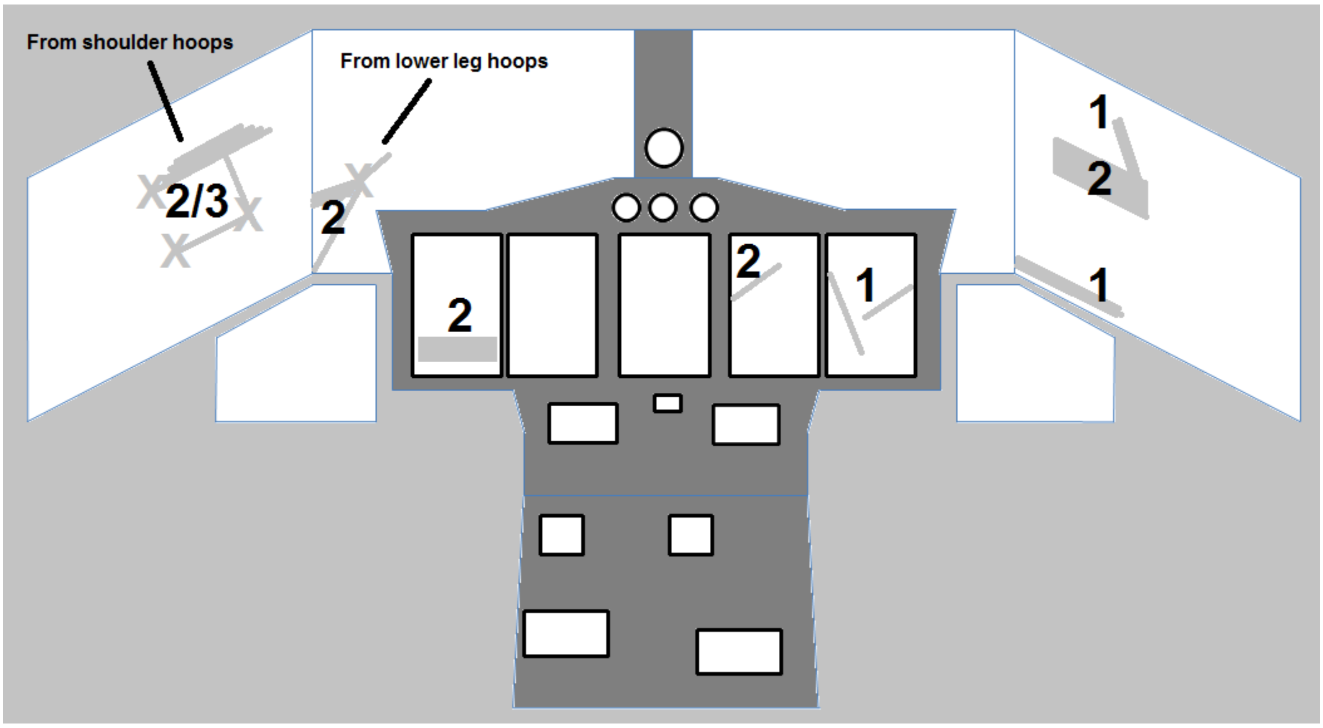



*Figure 32 - Combined reflectance trial data for daylight tests, suit with silver tape modification (X's denote "hotspot" glint areas).*

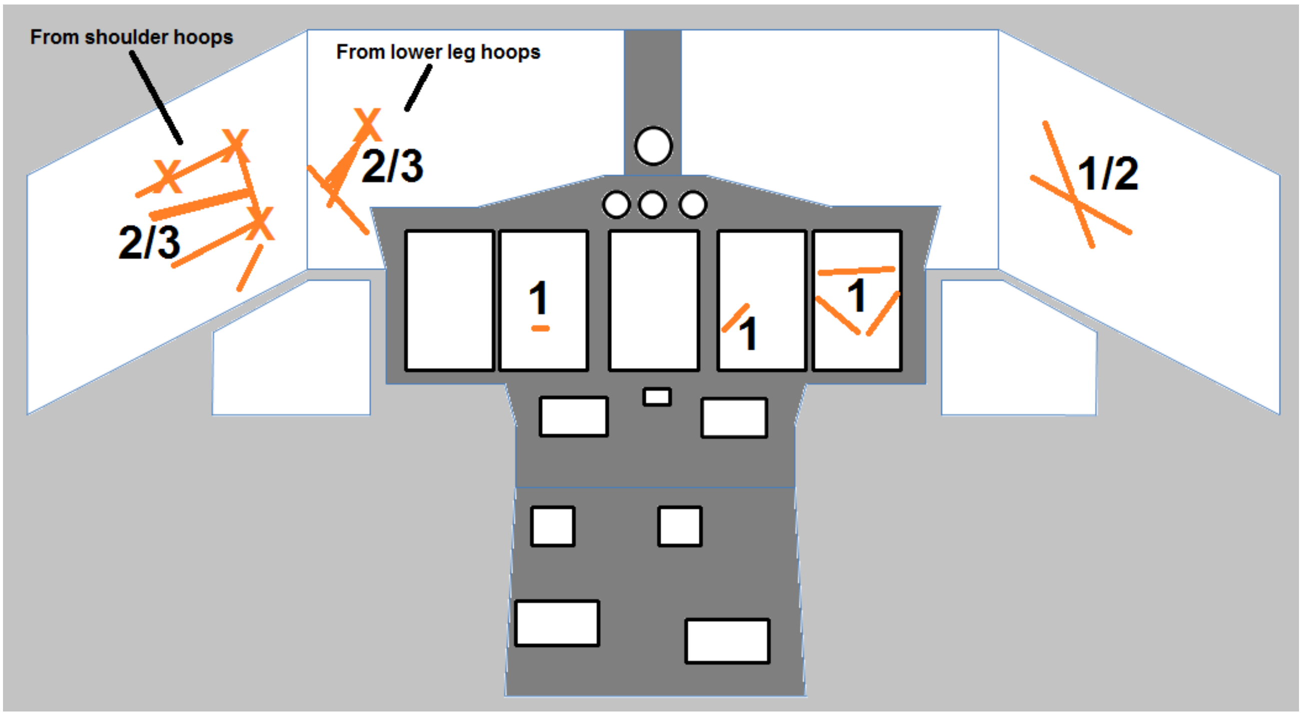



*Figure 33 - Combined reflectance trial data for daylight tests, suit with orange tape modification (X's denote "hotspot" glint areas).*

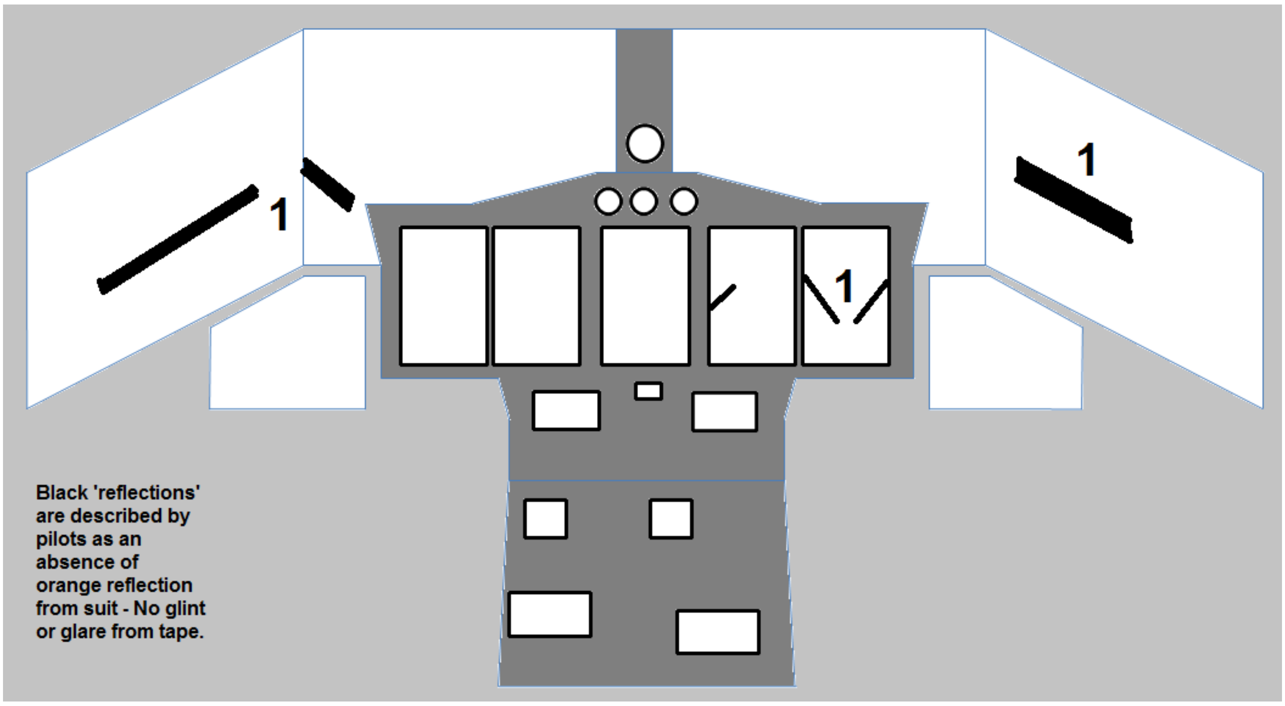



*Figure 34 - Combined reflectance trial data for daylight tests, suit with black tape modification.*

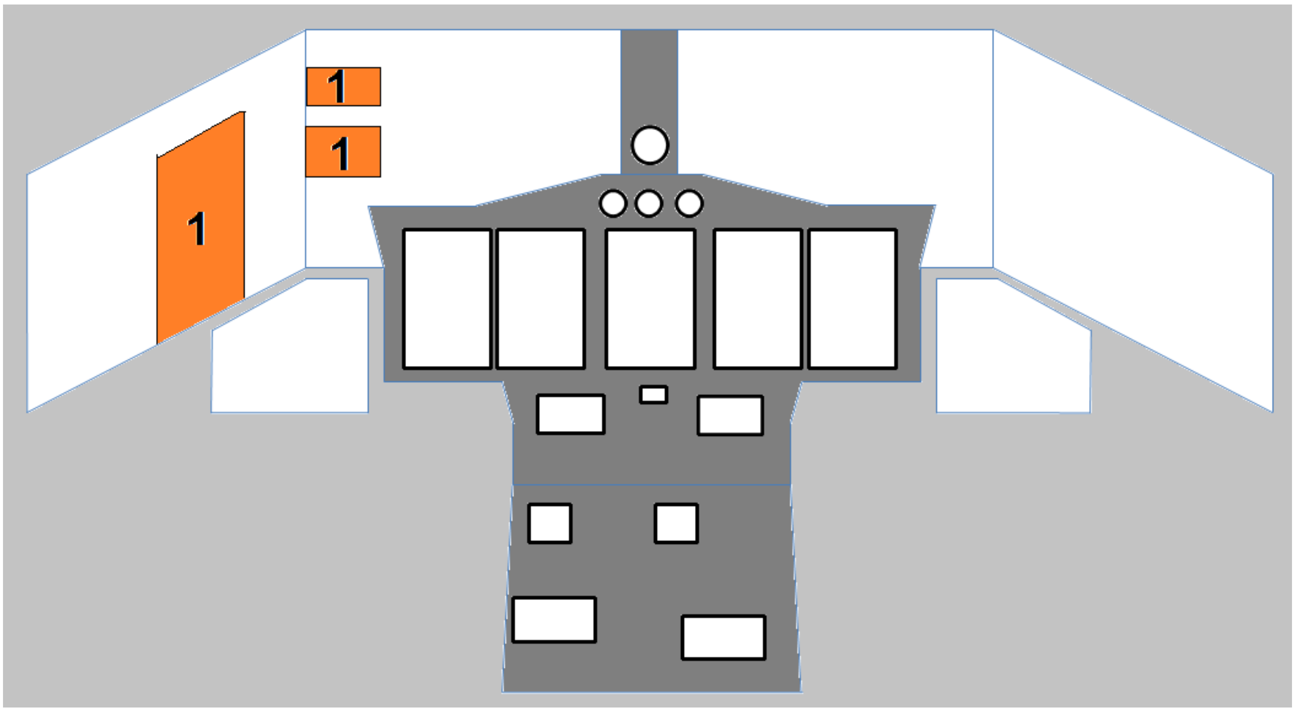



*Figure 35 – Combined reflectance trial data for night-time tests, current regulation suit.*

# Flight testing

## Aim and Summary

In this series of tests, the modified and unmodified immersion suits were compared in a realistic search scenario. Using life-size manikins dressed in the modified and unmodified suits, trials were developed to test a range of conditions.

Results of the night-time trials favour the modified suit (F 25). The target was visible from almost twice the distance with the FLIR camera, and from a 50 percent greater distance with the pilots using NVGs than the unmodified suit. The pilots also noted the benefit of reflectance from the tape, apparent on NVGs from a substantial distance, to aid conspicuity and subsequent rescue(F 27).

Results from the daytime trials remain inconclusive. The modified suit did not provide a higher probability of detection, or visibility from a greater distance (F 24). The trial was conducted in a calm sea in daylight and so represents the 'best-case' scenario. The very fact that the orange tape reduces colour contrast with the suit may be related to the equivocal performance (F 23). In addition, no thermal-imaging techniques were used which typically drive a search in normal search circumstances (F 22).

## Method

### Design

The flight tests were designed to assess any conspicuity benefit secured by using the modified immersion suit as compared to the current regulation suit. The metric used to establish the performance of the modified suit is the distance between the aircraft and the target when spotted by the aircrew. This distance can be measured using GPS markers in flight. This distance is important since target acquisition from a greater distance means less time is taken during the search.

Training manikins were positioned by a support boat at distances along a predetermined flight path at sea. The aircraft tracked this flight path, searching for the target in the typical way as defined by IAMSAR [4]. By day, the pilots search by eyeballing, by night they use NVGs. The FLIR operator typically uses the HDIR camera mode. In all of the flight trials described below, the searchlight was parked at 12 O'clock fully defocused. The FLIR operator would then sweep within the range of the searchlight, approximately between 10 – 2 O'clock. Image and/or colour recognition was not used throughout since the software update has not been fully rolled out to all UK SAR aircraft.

Once the target has been identified, the pilot drops a GPS marker using the on-board systems then proceeds to fly directly over the target and drop a second GPS marker. From these markers, the distance from where the target was first spotted may be calculated.

### Materials

Two training manikins, colloquially known as 'Dead Freds', were used for the flight testing. In order to confirm the position at which the manikins would float in the water, the equipment was tested in a swimming pool (Figure 36). The manikins were dressed in the modified and unmodified immersion suits with life jackets. The wrist and neck seals were taped up with matt-black tape to prevent water from leaking into the suit and potentially submersing the manikin. Foam pads in the manikin's chest and leg pockets were arranged so that the manikins floated on their backs. Finally, a secure location to affix a personal locator beacon (PLB) was identified so that the manikin could be located using its GPS transmission in the event that the aircrew could not locate the target using the proposed search methods.

*Figure 36 – Training manikin (Dead Fred) being tested for appropriate flotation in a swimming pool.*

Prior to the trial, the manikins and other equipment underwent final preparations to be ditched in the Bristol Channel. This included securing the orange Orafol tape to the modified immersion suit. Reflective tape on the manikins' heads was covered with matt-black tape as not to interfere with the reflections from the suit itself. Furthermore, reflective tape and the flashing lights on the PLB were covered with black tape. Finally, the wrist and neck seals were taped up as to avoid water leaking into the suit. The prepared manikins are shown in Figure 37.

*Figure 37 - Prepared dummies in the unmodified (left) and modified (right) suit.*

# Flight Trial 1: Cardiff Bay

## Flight Planning

Two landmarks were identified which would define the predetermined flight path from Lavernock Point (a distinctive peninsular approximately 7 miles south of Cardiff) to Steep Holm (a small island in the Bristol channel approximately 8 miles south-east of Lavernock point), see Figure 38.

The crew also identified a time window for safe operating conditions for testing to include times for slack water (high or low tide), weather conditions, lighting, and sea state (height of waves). It was important, due to the high tidal flows of the Bristol Channel, to conduct the tests within 45 minutes either side of slack water so that the manikins would not drift too far away from the target zone. Furthermore, it was important for the visibility, sea state and lighting to remain as consistent as possible throughout the tests.

The aircraft was to track north-south and south-north along the track line with the pilots searching for the target by eye/NVGs and the FLIR operator searching using the camera equipment. As soon as the target was spotted from the aircraft by one of the crew, the pilot would mark the GPS location of the aircraft, fly to directly above the target and mark another GPS location. Using this procedure allows the distance between the point at which the target was first spotted and the target to be calculated later. These tests were repeated for the unmodified and modified immersions suits in both north-south and south-north directions for all conditions.

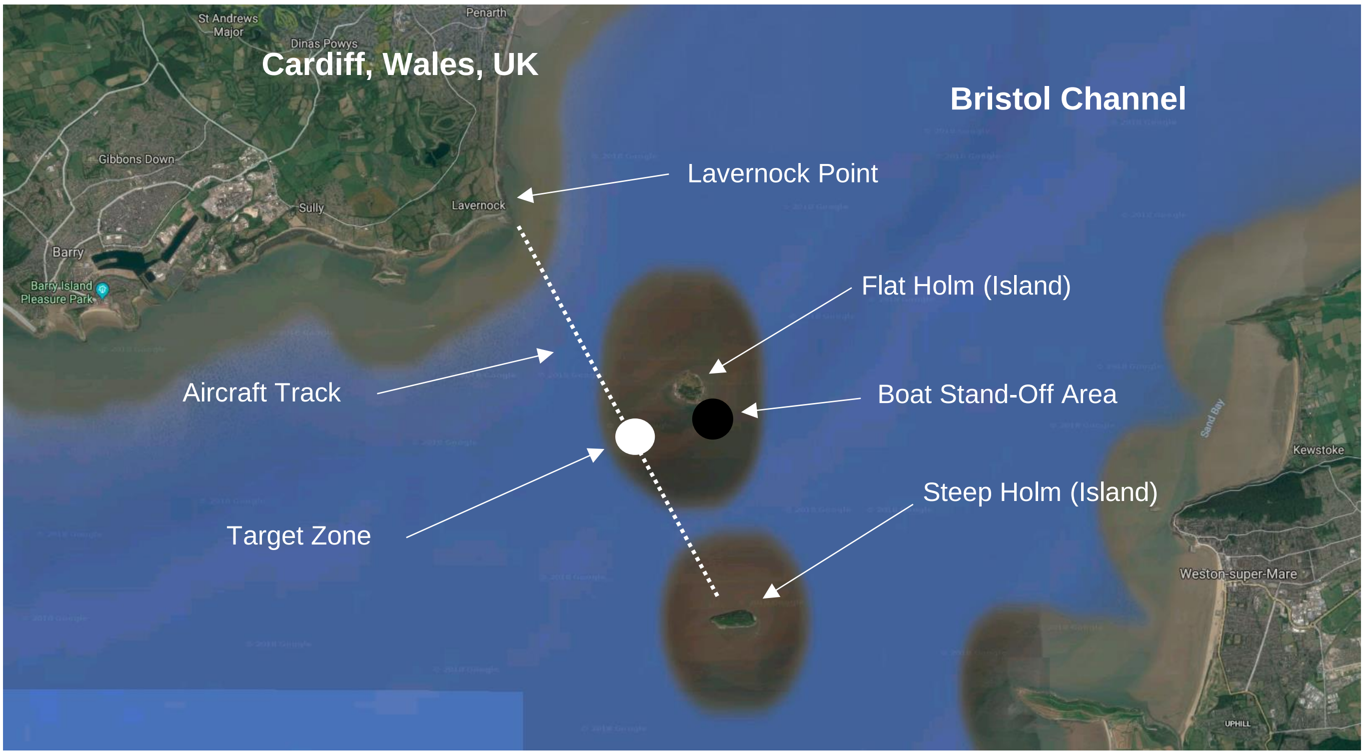



*Figure 38 - Flight trial 1 plan.*

# Results

Weather data for the test area was acquired from METAR-TAF. Clear visibility with a high cloud base, above the search altitude, and insignificant wind was forecast. The Penarth sea temperature was 13.9°C on the day of the test with WMO sea state code 2 (smooth conditions with wave heights of 0.1-0.5m). The time window for slack water at 16:23 was identified to allow sufficient light before sunset to complete the daylight testing, following into the night-time testing after official civil twilight at 17:03. The weather forecast of 11-13°C with sunny intervals/scattered cloud, and low chance of rain presented favourable conditions for the time of the test. The forecast for a southerly wind of 11mph (approximately 10kts) also reduced the risk of the manikin drifting from the search area.

The planned take-off time for the helicopter was 15:15 on Wednesday 14th November 2018, allowing 15 mins to transit to Lavernock Point to begin the first daylight search at 15:30. The support boat planned to depart Cardiff docks approximately 30 mins prior to the first search (15:00) and transit to the target zone. The boat was then required to ditch the first target in the water, see Figure 39, and vacate the search area to the stand-off area, close to Flat Holm, to await instructions via radio from the aircraft.

The helicopter made two passes north-south and south-north at 300ft (~91m) with the non-flying pilot recording all relevant data regarding the search attempt on the test card provided by the researchers. On completion of the first trial, the aircraft radioed the support boat to change the target. The SAR crew then repeated the trial. Following the second daylight search a stand-by period of approximately 45 minutes was required to wait for official civil twilight.

Figures 40 and 41 show the completed test cards for the two day trials (2 passes for both the unmodified and modified suits). It is seen that the target was spotted once in each test out of 2 passes. It appears from these initial results that the sun position is not a critical factor in whether the target is spotted or not, since the target was spotted in the first trial (south-north) when the sun was at 8 o'clock, but not in the second trial (south-north) when the sun was at 8:30 o'clock. It is also apparent that the direction in which the target is facing does not increase/decrease the probability of detection. It is seen that in the cases where the target was spotted, the unmodified suit was identified from a greater distance that the modified suit. However, since the tape applied to the suits is the same colour of the suit, and the SAR crew are relying on spotting the target with the naked eye. The modifications made to the suit are not likely to improve the conspicuity of the target during daylight conditions (F 24). A recommendation may be to consider a more brightly coloured lifejacket (F 05).

It was also commented by the pilots that although the sea was relatively calm (WMO states 2/3) the waves are still large enough to obscure a human target (F 23). Furthermore, these initial tests highlight the SAR crew's reliance on the thermal imaging software to identify a target by its heat signature when searching in these conditions (F 22). In order to focus on the performance of the reflective tape, the use of a heated manikin was not appropriate.

## Night-time trials

Figure 42 shows the completed test card for the first night-time trial (1 pass before the search was aborted). As is typical for night-time operations, the aircraft searched from 500ft (~152m). Despite favourable conditions, and the use of the Trakka Beam in white light mode, NVGs worn by the pilots, and the FLIR operator using the HDLL camera, the target was not spotted on the first pass.

Regrettably, no further data was captured for the night-time trials since the crew had to respond to an emergency SAR call.

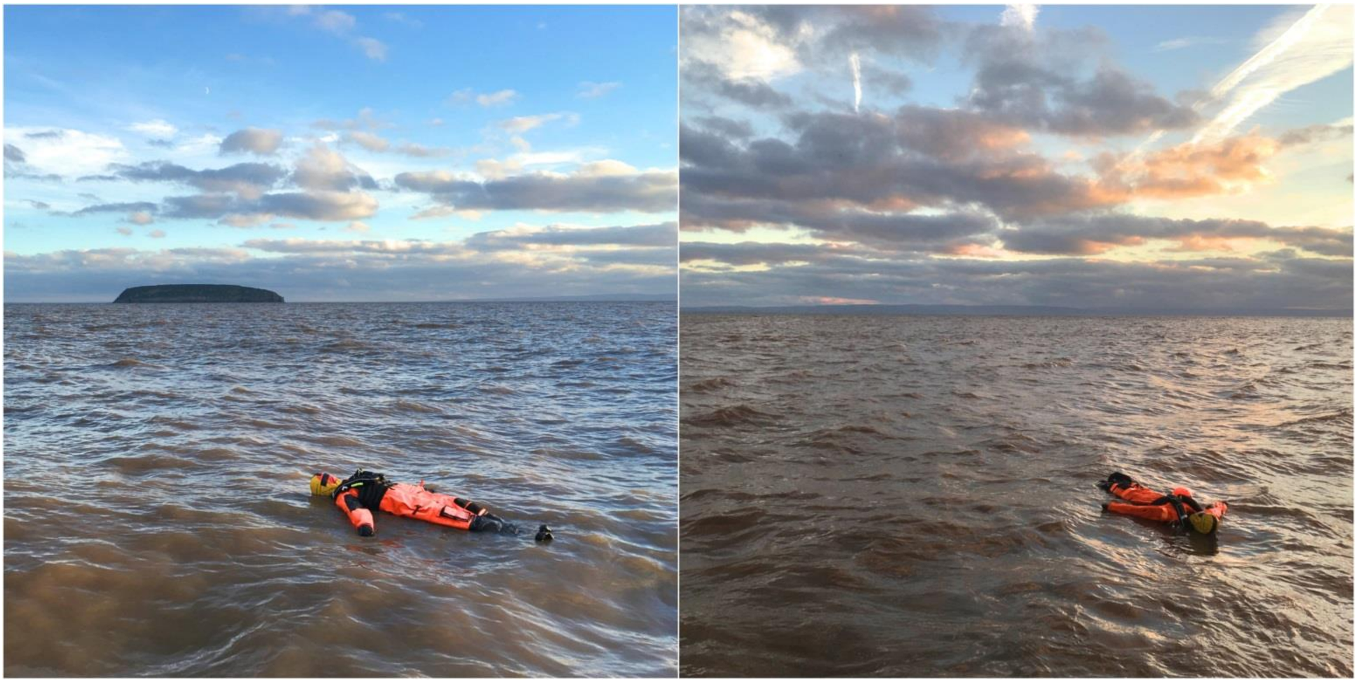


*Figure 39 - Manikin at sea wearing the current regulation suit (left) and modified suit (right).*

**Day Test 1: Current Regulation Suit – Standard Search**

| | | | |
|---|---|---|---|
| Flight Test No. | 1 | Date | 14/11/2018 |
| Aircraft | AW-189 | Registration | G-MCGW |
| | | | |
| **Crew** | | | |
| Commander | Ware | FO | Dale |
| Rear Crew 1 | Stubbings | Rear Crew 2 | O'Grady |
| | | | |
| **Conditions** | | | |
| Air Temp | 12°C | Pressure | 1019hPa |
| Visibility | 25km | Sea Temp | 13.9°C |
| Wind Speed | 13kt | Wind Direction | 180° |
| Weather | CAVOK; Cloud cover 3 oktas. | Sea Conditions | WMO sea state 3 |
| | | | |
| **Pass 1 South to North** | | **Pass 2 North to South** | |
| Time Search Start | 15:50 | Time Search Start | 16:00 |
| Search Ground Speed | 40kt | Search Ground Speed | 40kt |
| Search Altitude | 300ft | Search Altitude | 300ft |
| Time Target 1 Identified | 15:54 | Time Target 1 Identified | Not identified |
| Crew Member Spotted | Rear crew | Crew Member Spotted | - |
| Equipment Used | MK1 eyeball | Equipment Used | - |
| Distance to Target | 616.4m | Distance to Target | - |
| Casualty Position in Water (Direction facing/upright/on back) | On back facing away from the aircraft | Casualty Position in Water (Direction facing/upright/on back) | - |
| Sun Position | 8 o'clock | Sun Position | 2 o'clock |
| Target GPS Location | N51 21.98 W003 07.9 | Target GPS Location | |

*Figure 40 - Daylight trial 1 completed test card.*

**Day Test 2: Modified Suit – Standard Search**

| | | | |
|---|---|---|---|
| Flight Test No. | 2 | Date | 14/11/2018 |
| Aircraft | AW-189 | Registration | As Test 1 |
| | | | |
| **Crew** | | | |
| Commander | As Test 1 | FO | As Test 1 |
| Rear Crew 1 | As Test 1 | Rear Crew 2 | As Test 1 |
| | | | |
| **Conditions** | | | |
| Air Temp | 13°C | Pressure | As Test 1 |
| Visibility | As Test 1 | Sea Temp | As Test 1 |
| Wind Speed | As Test 1 | Wind Direction | As Test 1 |
| Weather | As Test 1 | Sea Conditions | As Test 1 |
| | | | |
| **Pass 1 North to South** | | **Pass 2 South to North** | |
| Time Search Start | 16:04 | Time Search Start | 16:40 |
| Search Ground Speed | 40kt | Search Ground Speed | 40kt |
| Search Altitude | 300ft | Search Altitude | 300ft |
| Time Target 1 Identified | 16:12 | Time Target 1 Identified | Not identified |
| Crew Member Spotted | Co-pilot (Dale) | Crew Member Spotted | - |
| Equipment Used | Mk1 eyeball | Equipment Used | - |
| Distance to Target | 420.8m | Distance to Target | - |
| Casualty Position in Water (Direction facing/upright/on back) | On back, facing the aircraft. | Casualty Position in Water (Direction facing/upright/on back) | - |
| Sun Position | 22:30 o'clock (behind cloud) | Sun Position | 08:30 o'clock (behind cloud) |
| Target GPS Location | N51 21.94 W003 07.52 | Target GPS Location | - |

**Comments on Day Test 2:** FLIR MTI discovered some targets (could have been anything) but not Fred. The FLIR MTI has the software that detects movement.

*Figure 41 - Daylight trial 2 completed test card.*

**Night Test 1: Modified Suit – Standard Search**

| | | | |
|---|---|---|---|
| Flight Test No. | 3 | Date | 14/11/2018 |
| Aircraft | AW-189 | Registration | As test 1 |
| | | | |
| **Crew** | | | |
| Commander | As test 1 | FO | As test 1 |
| Rear Crew 1 | As test 1 | Rear Crew 2 | As test 1 |
| | | | |
| **Conditions** | | | |
| Air Temp | 12 degrees | Pressure | As test 1 |
| Visibility | 25km | Sea Temp | As test 1 |
| Wind Speed | 14kt | Wind Direction | 170° |
| Weather | CAVOK; Cloud 2 Oktas. | Sea Conditions | As test 1 |
| | | | |
| **Pass 1 North to South** | | **Pass 2 Aborted for SAR Ops** | |
| Time Search Start | 17:04 (1 minute after official civil twilight) | Time Search Start | |
| Search Ground Speed | 40kt | Search Ground Speed | |
| Search Altitude | 500ft | Search Altitude | |
| Time Target 1 Identified | Not identified | Time Target 1 Identified | |
| Crew Member Spotted | | Crew Member Spotted | |
| Equipment Used | White light; NVG; FLIR HDLL | Equipment Used | |
| Distance to Target | - | Distance to Target | |
| Casualty Position in Water (Direction facing/upright/on back) | - | Casualty Position in Water (Direction facing/upright/on back) | |
| Moon Position | 12 o'clock High | Moon Position | o'clock |
| Target GPS Location | - | Target GPS Location | |

*Figure 42 - Night-time trial 1 completed test card.*

# Flight Trial 2: Swansea Bay

## Test Planning

With the support of the Royal National Lifeboat Institution (RNLI) Port Talbot in conjunction with Bristows SAR St Athan, a second flight trial was planned for the evening of Thursday 7th February 2019 to gather data in night-time conditions.

Night-time trials were scheduled to begin at 18:00 so that it was sufficiently dark: sunset was forecast for 17:15 with civil twilight occurring at 17:50. The light level for Port Talbot at 18:00 was forecast to be 0.14 millilux. There was a south-westerly wind forecast of speed 24mph (~21kts) gusting 32mph (~28kts) and an 80% chance of rain. Thick cloud was forecast with a waxing crescent moon. As such, negligible ambient moonlight was predicted for the time of the trials. The sea temperature was 9°C with very rough conditions due to the wind (WMO sea state code 6).

## Detailed Procedure

A briefing was given to the helicopter crew by the research team in conjunction with the chief test pilot (also captain for the shift) following the shift handover at 13:00 on 7th February at the SAR base at MOD St Athan. The crew planned to get airborne from St Athan by 17:45 to transit to Port Talbot by 18:00 to begin the first trial. A working radio frequency was designated for the trial.

The research team then returned to Port Talbot lifeboat station to brief the lifeboat crew. Port Talbot RNLI have a small D-class rib, see Figure 43 , capable of carrying a maximum of 4 people: a helmsman (essential), additional lifeboat crew (essential), one researcher (essential) and one training manikin. Multiple pick-ups/drop-offs of the manikins back to shore were required.

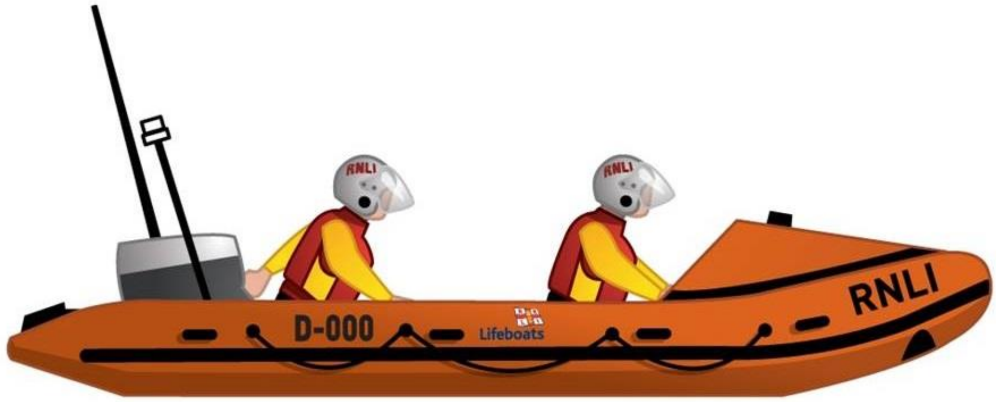



*Figure 43 - RNLI D-class lifeboat.*

Safety concerns were highlighted by the lifeboat crew due to the forecast for very rough sea conditions and the size of boat in operation. It was recommended that the trials take place in the "small side" – a sheltered area of Swansea bay where the sea would be calmer (approximately WMO sea state code 4), see Figure 44.

The crew planned to launch the lifeboat from the main ramp outside of the station at 17:30. The boat would transit to the "small side", deploy the first manikin, and return to the shore of the “small side”, where additional crew on the beach would secure the boat.  The boat would then radio the aircraft to inform that the first series of search trials were prepared.


*Figure 44 - Satellite image of the night-time trial test area.*

The aircraft, in transit from MoD St Athan, would then track north-westerly along the coast from the Porthcawl direction, see the view from the aircraft in Figure 45. Prior to the start of the search, the FLIR system would be set to record the screen capture and intercom radio. Upon reaching the search area, the aircraft would search as per the IAMSAR guidelines [4] for the specific conditions (details to be recorded on the test card by the non-flying pilot). Upon any crew member spotting the target, a GPS marker was recorded. The aircraft would then fly directly above the target and drop a further GPS marker. Additional details on the test card was completed by the non-flying pilot while the aircraft was re-positioning. Upon reaching the original starting position, the aircraft then repeats the search procedure as necessary. Due to the wind direction and speed, the aircraft was not able to search in both directions as in the daylight trial. One pass of each configuration was recorded.

On completion of the first series of searches, the aircraft radioed the lifeboat to change the target. The aircraft would then stand-off in a safe south-easterly location at sufficient distance as not to be visual with the activities in the search area.

The lifeboat would then pick-up the second target from the shore, transit out to sea to recover the first target. The lifeboat crew would then deploy the second target and return to shore with the first. On reaching the shore, crew on the beach would secure the boat. The lifeboat crew would then make a radio call to the aircraft to inform that the second series of search trials were prepared.


*Figure 45 - View from the aircraft of the search area.*

The aircraft would then repeat the search process. On completion of the second series of searches, the aircraft would radio the lifeboat. The aircraft would then transit back to base at St Athan and stop the FLIR recording. The boat would then transit out to sea to collect the second target and return to shore. The lifeboat would be recovered from either the shoreline or the River Afan depending on conditions.

On landing back at base, a member of the helicopter crew downloaded the FLIR camera recording and debriefed as normal, recording and details pertinent to the search trials and filling in any missing details on the test cards.

On arriving back at base, the lifeboat crew should debrief as normal, recording any relevant details and/or comments regarding the search trials.

# Results

5-6m waves (WMO sea state code 6) prevented the small D-class boat from launching from the main ramp until a sufficient gap in the waves was identified. The initial launch from the ramp was rough and potentially dangerous, see Figure 46, justifying the decision to conduct the trials in the “small side”. The boat transited out to sea, around the harbour wall, and into the middle of the “small side”. Here, the lifeboat could deploy and recover the targets safely, and without risk of the targets drifting out to sea.

The first trial began at 18:04 in thick cloud (visibility of 6 km). Due to the wind speed and direction, the aircraft flew crosswind, tracking along the coast, with a north westerly heading. The search altitude was 500 ft (~152 m). The Trakka beam was fully defocused and oriented in the 12 O’clock. The search procedure was the same for each trial, with the final pass taking place at 18:45. By this time, light rain had begun to fall and the cloud base had descended to 600 ft (~183 m), but visibility was not affected.

*Figure 46 - Lifeboat launch.*

Figures 47-50 show the completed test cards for the 4 trials:

1. Modified immersion suit, white search light
2. Modified immersion suit, IR search light
3. Current regulation immersion suit, white search light
4. Current regulation immersion suit, IR search light

| | | | |
|---|---|---|---|
| Flight Test No. | **1** | Date | 07/02/2019 |
| Aircraft | AW189 | Registration | G-MCGX |
| | | | |
| **Crew** | | | |
| Commander | DALE | FO | STRACEY |
| Rear Crew 1 | GREEN | Rear Crew 2 | HATCH |
| | | | |
| **Conditions** | | | |
| Air Temp | 8 °C | Pressure | 1008 hPa |
| Visibility | 6 km | Sea Temp | 9 °C |
| Wind Speed | 22 kt | Wind Direction | 260 ° |
| Weather | Overcast 700ft, Rain | Sea Conditions | V. Rough (WMO Sea State code = 6) |
| | | | |
| Time Search Start | 18:18:15 (dark) | | |
| Search Ground Speed | 38 kt | | |
| Search Altitude | 500 ft | | |
| Time Target 1 Identified | 18:18:28 | | |
| Crew Member Spotted | FLIR Operator | | |
| Equipment Used | HDIR | | |
| **GPS location when spotted** | 51 34.15N, 003 47.52W | | |
| **GPS location of target** | 51 35.03N, 003 48.52W | | |
| Casualty Position in Water (Direction facing/upright/on back) | Side on, head to right, face up | | |
| Sun/Moon Position | Thick Cloud O'Clock | | |

*Figure 47 - Test Card 1: Modified suit, white light.*

| | | | |
|---|---|---|---|
| Flight Test No. | **2** | Date | 07/02/2019 |
| Aircraft | AW189 | Registration | G-MCGX |
| | | | |
| **Crew** | | | |
| Commander | DALE | FO | STRACEY |
| Rear Crew 1 | GREEN | Rear Crew 2 | HATCH |
| | | | |
| **Conditions** | | | |
| Air Temp | 8 °C | Pressure | 1008 hPa |
| Visibility | 6 km | Sea Temp | 9 °C |
| Wind Speed | 23 kt | Wind Direction | 250 ° |
| Weather | Low Cloud, Drizzle | Sea Conditions | V. Rough (WMO Sea State code = 6) |
| | | | |
| Time Search Start | 18:24:20 (dark) | | |
| Search Ground Speed | 40 kt | | |
| Search Altitude | 500 ft | | |
| Time Target 1 Identified | 18:24:45 | | |
| Crew Member Spotted | Commander | | |
| Equipment Used | NVGs | | |
| **GPS location when spotted** | 51 34.32N, 003 47.58W | | |
| **GPS location of target** | 51 35.06N, 003 48.51W | | |
| Casualty Position in Water (Direction facing/upright/on back) | Feet away (diagonally left), face up | | |
| Sun/Moon Position | Thick Cloud O'Clock | | |

*Figure 48 - Test Card 2: Modified suit, IR light.*

| | | | |
|---|---|---|---|
| Flight Test No. | **3** | Date | 07/02/2019 |
| Aircraft | AW189 | Registration | G-MCGX |
| | | | |
| **Crew** | | | |
| Commander | DALE | FO | STRACEY |
| Rear Crew 1 | GREEN | Rear Crew 2 | HATCH |
| | | | |
| **Conditions** | | | |
| Air Temp | 8 °C | Pressure | 1008 hPa |
| Visibility | 6 km | Sea Temp | 9 °C |
| Wind Speed | 23 kt | Wind Direction | 250 ° |
| Weather | Low Cloud, Drizzle | Sea Conditions | V. Rough (WMO Sea State code = 6) |
| | | | |
| Time Search Start | 18:39:40 (dark) | | |
| Search Ground Speed | 40 kt | | |
| Search Altitude | 500 ft | | |
| Time Target 1 Identified | 18:40:42 | | |
| Crew Member Spotted | FLIR Operator | | |
| Equipment Used | HDIR Camera | | |
| **GPS location when spotted** | 51 34.25N, 003 47.53W | | |
| **GPS location of target** | 51 35.07N, 003 48.56W | | |
| Casualty Position in Water (Direction facing/upright/on back) | Feet away, face up | | |
| Sun/Moon Position | Thick Cloud O'Clock | | |

*Figure 49 - Test Card 3: Current regulation suit, white light.*

| | | | |
|---|---|---|---|
| Flight Test No. | **4** | Date | 07/02/2019 |
| Aircraft | AW189 | Registration | G-MCGX |
| | | | |
| **Crew** | | | |
| Commander | DALE | FO | STRACEY |
| Rear Crew 1 | GREEN | Rear Crew 2 | HATCH |
| | | | |
| **Conditions** | | | |
| Air Temp | 8 °C | Pressure | 1008 hPa |
| Visibility | 6 km | Sea Temp | 9 °C |
| Wind Speed | 23 kt | Wind Direction | 250 ° |
| Weather | Low Cloud, Drizzle | Sea Conditions | V. Rough (WMO Sea State code = 6) |
| | | | |
| Time Search Start | 18:45:00 (dark) | | |
| Search Ground Speed | 40 kt | | |
| Search Altitude | 500 ft | | |
| Time Target 1 Identified | 18:45:36 | | |
| Crew Member Spotted | FLIR Operator | | |
| Equipment Used | HDIR Camera | | |
| **GPS location when spotted** | 51 34.36N, 003 47.57W | | |
| **GPS location of target** | 51 35.06N, 003 48.52W | | |
| Casualty Position in Water (Direction facing/upright/on back) | Feet away, face up | | |
| Sun/Moon Position | Thick Cloud O'Clock | | |

*Figure 50 - Test Card 4: Current regulation suit, IR light.*

From the GPS coordinates recorded in the trials, the distances at which the SAR crew first identified the target was calculated. A summary of the results is given in Table 4.

In three out of the four trials, the FLIR operator identified the target first using the HDIR camera. This did not include the use of any image recognition software. Figure 51 shows an example of how the target looks when zooming in on the target using various cameras when illuminated with white light. In all cases, the target was visible at a distance of at least 1 km. However, the modified suit with the white search light was visible at almost 2 km, the greatest distance of all tests. The one case in which the pilot identified the target before the FLIR operator (modified suit with IR search light) was due to the pilot spotting a reflection from the tape while on NVGs, see pilot comments below (F 25, F 27). It must be noted however, that the FLIR searches with HDIR camera were aided by slight temperature differential between the target and the sea. Since the manikins had been stored in the lifeboat station overnight, they had not reached sea temperature by the time of the trials.

| **Suit** | **Light** | **First identified by** | **Distance (m)** |
|---|---|---|---|
| Modified | White | Pilot | 1733 |
| | | FLIR Operator | 1877 |
| Modified | IR | Pilot | 1462 |
| | | FLIR Operator | 997 |
| Current Regulation | White | Pilot | 985 |
| | | FLIR Operator | 1773 |
| Current Regulation | IR | Pilot | 970 |
| | | FLIR Operator | 1405 |

*Table 4 - Summary of second trial results.*


*Figure 51 - FLIR images of the target using HDIR (top), HDLL (middle), and HDEO (bottom) cameras (white light illumination).*

From the pilot perspective, using NVGs, the modified suit was visible from at least 50 percent greater distance than the current regulation suit throughout the trials (F 27). This was mainly due to the searchlight catching an area of reflecting tape (likely to be the shoulder hoops due to the orientation of the target in the water) and causing an obvious reflection in the NVGs. This led to increased conspicuity of the target at greater distances.

When searching using only IR light, the distance at which the targets were visible was reduced by approximately 400m on average (F 26). This was the case for both the FLIR camera operator and the pilots on NVGs. When searching with IR light, the HDIR camera is still preferred by the FLIR operator over the SWIR camera. In this search, the camera and searchlight were not slaved. The FLIR operator was free to use the camera and searchlight as preferred. Although some reflection in the short wave infrared is seen, see Figure 52, the target is not as conspicuous as with the HDIR camera. Therefore, an IR only search is not recommended.

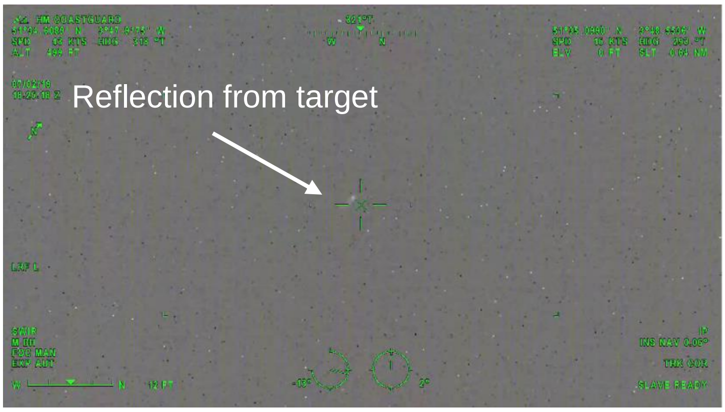



*Figure 52 - SWIR camera image of the target when using IR light only.*

During the trials involving the modified suit, pilots noted that there was:

*“An obvious glint from the tape, visible on NVGs, when sweeping with the Trakka beam.”*

*“[The glint was] …more intense when the light was focused in on the target [leading to] …a good chance of spotting from the reflection alone.”*
(F 25, F 27).

When the unmodified suit was trialled, the pilots found that the target was:

*“Not obvious through NVGs.”*

Pilots also noted that:

*“There were times when, even though we knew where it [the manikin] was, we couldn’t see it through NVGs… the FLIR operator was able to identify the target sooner was due to the slight temperature differential between the dead Fred and the sea.”*

From the video footage of the search, we note that the hoops of reflective tape around the shoulders on the modified suit is a key modification to the immersion suit to aid conspicuity. At a range of angles of incidence, the tape provides an obvious reflection (F 08), white on the HDIR camera, and orange on the HDLL and HDEO cameras, providing good contrast, see Figure 51. By taking advantage of the curved surface of the shoulder on the upper part of the torso allows the tape to be visible for a range of body positions and orientations in the water (F 09).

# Flight Trial 3: Stornoway

## Test Planning

A third sea trial was planned in conjunction with Bristows SAR Stornoway, Isle of Lewis, Scotland. A private vessel, Azula, operated by Stornoway Seafari was coordinated to provide boat and crew support for the trial. RNLI Stornoway also offered support in terms of additional equipment, backup vessel and crew support if required. A sequence of trials were planned for the evening of Wednesday 13th March 2019 to gather data in night-time conditions.

Night-time trials were scheduled to begin at 19:30. Sunset was forecast for 18:20 with civil twilight occurring at 19:00. The weather forecast was for light rain, partly cloudy, with a westerly wind of speed 16-28mph (14-25 knots). The air temperature was predicted to be 6°C at the start of the trial, with a sea temperature of 7.8°C, and WMO sea state of 3.

## Detailed Procedure

A briefing was given to the helicopter crew by the research team to convey the main objectives and structure of the trial sequence. Final preparations were discussed with the aircrew on the morning of the trial at Bristows SAR base at Stornoway Airport. The captain of the aircraft then accompanied the research team to a brief with the Azula boat crew. A suitable search area was discussed: clear of the shipping lane into and out of Stornoway harbour, clear of the extended centreline of the runway at Stornoway Airport, and sufficiently far out at sea so that the aircrew are continually searching over water. A location approximately 1 mile of the coast of Upper Bayble was identified. The boat would deploy the appropriate target, and stand-off in a sheltered area close to the coast. The aircraft would then fly parallel with the coastline, at a distance of approximately 1 mile, searching for the target. Each pass (one in each direction of each test configuration) would begin 2 miles from the search area to ensure that the target is not visible from the start point. The research team would be on-board the boat to coordinate the trial via a designated radio frequency if necessary. Figure 53 shows a map of the search area.

The boat planned to launch at 19:00 and transit to the search area. The boat crew would then deploy the first target, with a personal locator beacon (PLB) attached in case the helicopter was unable to locate the target. The boat would then transit to the stand-off area ready for the first pass of the aircraft at 19:30. A radio call would be made to the aircraft to confirm that the first target was in position.

The aircraft would take-off at 19:30 and make the short transit to the start point for the first pass: approximately 2 miles north-east of the search area. The FLIR operator should orient the Trakka beam at 12 O'clock fully defocused. The FLIR operator should then begin the video recording. To maintain consistency with previous trials, the aircraft searched at 40 knots ground speed and at 500ft (~152m). The pilots or FLIR operator would announce over the intercom as soon as the target was identified. The pilot would then proceed to fly directly above the target and make an "on top" call. This method allows the GPS coordinates relevant to each search trial to be recovered from the recordings, and the distance at which the aircrew first identified the target to be calculated. The aircraft would then proceed to the turnaround point, approximately 2 miles south-west of the search area, ready for the second pass in the opposite direction. This method is designed to reduce the effects of both the target orientation in the water, and the moon position.

Two passes in each configuration were planned (8 passes total):

1. Modified immersion suit, white search light
2. Modified immersion suit, IR search light
3. Current regulation immersion suit, white search light
4. Current regulation immersion suit, IR search light


*Figure 53 – Map of the Stornoway trials search area.*

On completion of the first series of searches, the aircraft makes a radio call to the boat to change the target. The aircraft hovers and illuminates the target to help with this process. In the event that the target is not found, the aircraft may use the PLB to locate. The aircraft then stands-off in a north-easterly location at sufficient distance as not to be visual to the activities in the search area to prepare the next set of trials.

The boat recovers the first target, attaches the PLB to the second target, deploys the second target, and returns to the stand-off area. The boat then makes a radio call to the aircraft to initiate the second series of search trials. See Figure 54 for a screenshot from the FLIR camera of the boat crew swapping over the targets.

The aircraft repeats this search process. On completion of the second sequence of searches, the aircraft radios the lifeboat to recover the second target. The aircraft hovers and illuminates the target to assist with this process. In the event that the target was not found, the aircraft uses use the PLB to locate. The boat then recovers the second target and returns to Stornoway harbour. The aircraft then transits back to base at Stornoway airport and stands down.

On landing back at base, the aircrew debrief as normal, recording and details pertinent to the search trials and filling in any missing details on the test cards.

On arriving back at base, the boat crew debrief, recording any relevant details and/or comments regarding the search trials.

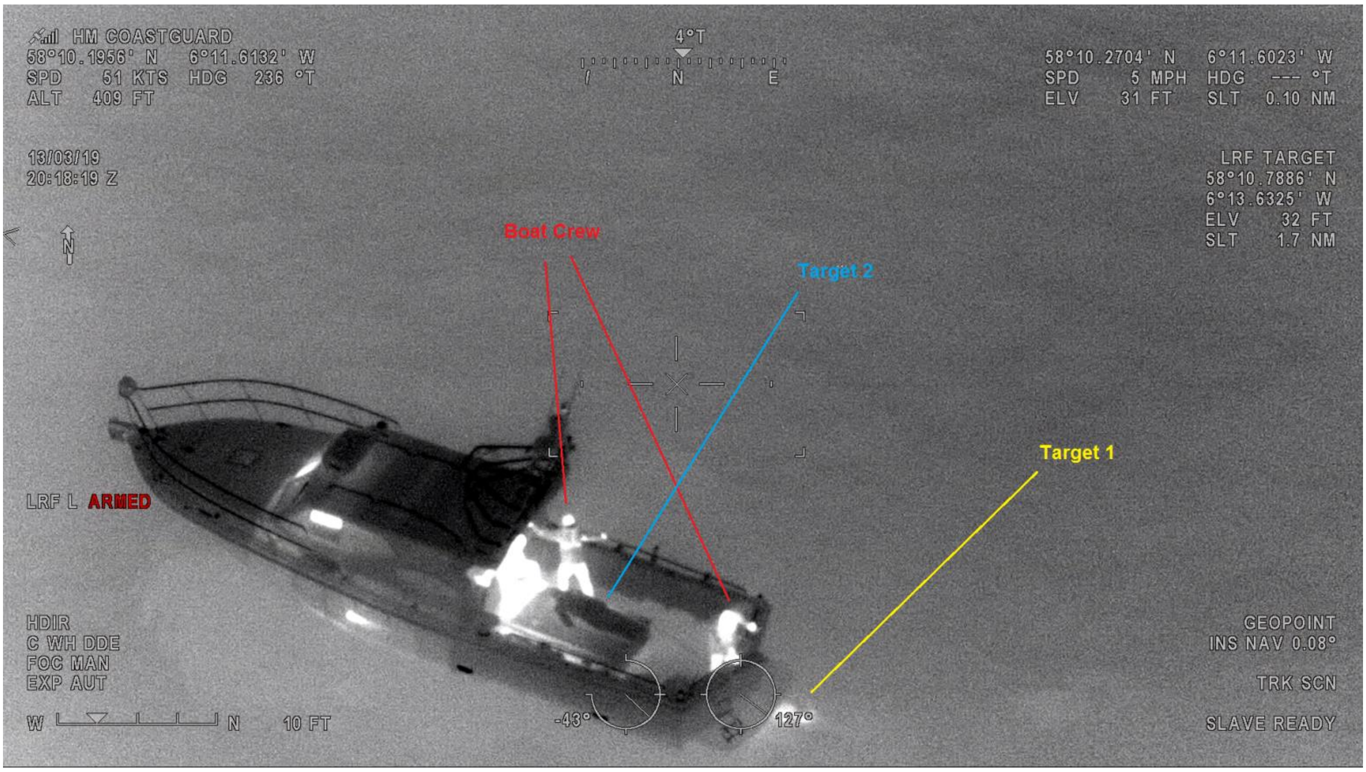



*Figure 54 – Screenshot from the FLIR camera of the lifeboat crew recovering the first target from the rear of the boat, ready to deploy the second target on the deck.*

# Results

Note that the aircraft used for these trials was a Sikorsky S-92. The on-board SAR equipment however, including the FLIR system, Trakka beam, and NVGs are the same.

Figures 55-58 show the completed test cards for the 4 conditions:

1. Modified immersion suit, white search light
2. Modified immersion suit, IR search light
3. Current regulation immersion suit, white search light
4. Current regulation immersion suit, IR search light

From the FLIR camera and the intercom recordings, the distances at which the SAR crew first identified the target was calculated. Table 5 shows a summary of the results for all 8 passes.

| Suit | Light | First identified by | Distance (m) |
|---|---|---|---|
| Modified | White | Pilot (NVGs)<br>Pilot (NVGs) | 1054<br>922 |
| Modified | IR | Pilot (NVGs)<br>Pilot (NVGs) | 893<br>1021 |
| Current Regulation | White | Not Found<br>Not Found | - |
| Current Regulation | IR | Not Found<br>Not Found | - |

*Table 5 - Summary of third trial results.*

**Flight Test Card: Modified Suit, White light.**

| | | | |
|---|---|---|---|
| Flight Test No. | 1 | Date | 13/03/18 |
| Aircraft | S92 | Registration | G-MCGL |
| | | | |
| **Crew** | | | |
| Commander | Smith | FO | McMullan |
| Rear Crew 1 | Stables | Rear Crew 2 | Dicks |
| | | | |
| **Conditions** | | | |
| Air Temp | 6 °C | Pressure | 993 hPa |
| Visibility | 12 km | Sea Temp | 7.8 °C |
| Wind Speed | 14 kt | Wind Direction | 210 ° |
| Weather | F1600, B2400, light rain | Sea Conditions (WMO State) | 3 |
| | | | |
| **Pass 1** | | **Pass 2** | |
| Time Search Start | 19:47 | Time Search Start | 19:54 |
| Search Ground Speed | 40 kt | Search Ground Speed | 40 kt |
| Search Altitude | 500 ft | Search Altitude | 500 ft |
| Time Target 1 Identified | 19:50:14 | Time Target 1 Identified | 19:56:54 |
| Crew Member Spotted | Pilot | Crew Member Spotted | Pilot |
| Equipment Used | NVGs | Equipment Used | NVGs |
| **GPS location when spotted** | 58° 10.4327 N | **GPS location when spotted** | 58° 10.0331 N |
| | 6° 11.0676 W | | 6° 12.4699 W |
| **GPS location of target** | 58° 10.2184 N | **GPS location of target** | 58° 10.2323 N |
| | 6° 11.5822 W | | 6° 11.6450 W |

*Figure 55 – Test card from Stornoway trial 1.*

**Flight Test Card: Modified Suit, IR light.**

| | | | |
|---|---|---|---|
| Flight Test No. | 2 | Date | 13/03/18 |
| Aircraft | S92 | Registration | G-MCGL |
| | | | |
| **Crew** | | | |
| Commander | Smith | FO | McMullan |
| Rear Crew 1 | Stables | Rear Crew 2 | Dicks |
| | | | |
| **Conditions** | | | |
| Air Temp | 6 °C | Pressure | 993 hPa |
| Visibility | 12 km | Sea Temp | 7.8 °C |
| Wind Speed | 14 kt | Wind Direction | 210 ° |
| Weather | F1600, B2400, light rain | Sea Conditions (WMO State) | 3 |
| | | | |
| **Pass 1** | | **Pass 2** | |
| Time Search Start | 20:02 | Time Search Start | 20:08 |
| Search Ground Speed | 40 kt | Search Ground Speed | 40 kt |
| Search Altitude | 500 ft | Search Altitude | 500 ft |
| Time Target 1 Identified | 20:03:50 | Time Target 1 Identified | 20:09:58 |
| Crew Member Spotted | Pilot | Crew Member Spotted | Pilot |
| Equipment Used | NVGs | Equipment Used | NVGs |
| **GPS location when spotted** | 58° 10.3960 N | **GPS location when spotted** | 58° 10.0251 N |
| | 6° 10.7368 W | | 6° 12.4713 W |
| **GPS location of target** | 58° 10.2630 N | **GPS location of target** | 58° 10.2774 N |
| | 6° 11.6171 W | | 6° 11.6638 W |

*Figure 56 – Test card from Stornoway trial 2.*

**Flight Test Card: Unmodified Suit, White light.**

| | | | |
|---|---|---|---|
| Flight Test No. | 3 | Date | 13/03/18 |
| Aircraft | S92 | Registration | G-MCGL |
| | | | |
| **Crew** | | | |
| Commander | Smith | FO | McMullan |
| Rear Crew 1 | Johnson | Rear Crew 2 | Dicks |
| | | | |
| **Conditions** | | | |
| Air Temp | 7 °C | Pressure | 992 hPa |
| Visibility | 12 km | Sea Temp | 7.8 °C |
| Wind Speed | 25 kt | Wind Direction | 205 ° |
| Weather | F1600, B2400, rain | Sea Conditions (WMO State) | 3 |
| | | | |
| **Pass 1** | | **Pass 2** | |
| Time Search Start | 20:30 | Time Search Start | 20:36 |
| Search Ground Speed | 40 kt | Search Ground Speed | 40 kt |
| Search Altitude | 500 ft | Search Altitude | 500 ft |
| Time Target 1 Identified | Not Found | Time Target 1 Identified | Not Found |
| Crew Member Spotted | - | Crew Member Spotted | - |
| Equipment Used | - | Equipment Used | - |
| **GPS location when spotted** | N | **GPS location when spotted** | N |
| | W | | W |
| **GPS location of target** | N | **GPS location of target** | N |
| | W | | W |

*Figure 57 – Test card from Stornoway trial 3.*

**Flight Test Card: Unmodified Suit, IR light.**

| | | | |
|---|---|---|---|
| Flight Test No. | 4 | Date | 13/03/18 |
| Aircraft | S92 | Registration | G-MCGL |
| | | | |
| **Crew** | | | |
| Commander | Smith | FO | McMullan |
| Rear Crew 1 | Johnson | Rear Crew 2 | Dicks |
| | | | |
| **Conditions** | | | |
| Air Temp | 7 °C | Pressure | 992 hPa |
| Visibility | 12 km | Sea Temp | 7.8 °C |
| Wind Speed | 25 kt | Wind Direction | 205 ° |
| Weather | F1600, B2400, rain | Sea Conditions (WMO State) | 3 |
| | | | |
| **Pass 1** | | **Pass 2** | |
| Time Search Start | 20:42 | Time Search Start | 20:48 |
| Search Ground Speed | 40 kt | Search Ground Speed | 40 kt |
| Search Altitude | 500 ft | Search Altitude | 500 ft |
| Time Target 1 Identified | Not Found | Time Target 1 Identified | Not Found |
| Crew Member Spotted | - | Crew Member Spotted | - |
| Equipment Used | - | Equipment Used | - |
| **GPS location when spotted** | N | **GPS location when spotted** | N |
| | W | | W |
| **GPS location of target** | N | **GPS location of target** | N |
| | W | | W |

*Figure 58 – Test card from Stornoway trial 4.*

**Aircrew comments:**

- With regards to the use of FLIR, it was “almost unworkable with that much moisture in the air”.

- In reference to the modified suit, the added tape provided a “solid reflection as seen from the cockpit”.

- With regards to the use of white/IR modes of the Trakka beam for searching, “flying on IR mode is more comfortable in rain, but the reflections from the suit were more obvious on white light mode”.

- With regards to the chosen search altitude, “500ft is not the best altitude to search at in these conditions”. The pilots felt that the probability of detection would be increased with a search altitude of 200ft. However, to maintain consistency with previous trials we maintained the requirement to fly at 500ft.

Firstly, it is concluded from the results and the aircrew comments in the debrief, that the modified immersion suit provides good reflection when searching with either white or IR light illumination (F 25, F 27)). This allowed the target to be found in all cases using the modified suit. In contrast, when testing the current regulation suit, the target was not identified in any of the trials (F 25). The additional reflective tape on the modified suit provided a glint, visible on NVGs, despite poor weather conditions. The sea state (WMO code 3) was not a limiting factor in the search in terms of the target being obscured by the swell. The search altitude was sufficient to observe between the crests and troughs of the waves. The sea state during the second flight trials in Port Talbot were more severe (WMO code 4), however the SAR crew were able to identify the target from approximately twice the distance than in the third flight trials in Stornoway. Therefore, we conclude that the weather, specifically rain leading to reduced visibility and reflection of the search light back into the cockpit, is the most obstructive search condition experienced throughout all of the three flight trials.

It was noted that the use of FLIR in rain is not optimal. In all cases where the target was found, the pilots identified the target before the FLIR operator. The FLIR operator was only able to locate the target on the FLIR screen once, having received direction from the pilots as to where to look. Figure 59 shows a screen shot of this example. The image clearly shows the manikin oriented with his legs pointing away from the aircraft diagonally left and arms out. The white spots show a strong reflection from the shoulder hoops of tape. The image also suggests a slight heat differential between the dummy and the sea.

The results also show that the use of white/IR light illumination does not significantly affect the distance at which the target is first visible. This result contradicts the results from the second sea trial where the use of white light illumination allowed the target to be identified from approximately 400m greater distance on average than with IR illumination. This finding in the Stornoway trials is predominantly due to the ineffectiveness of the FLIR camera due to rain. The pilots commented that in such conditions, they would prefer to either fly with IR illumination to reduce the reflection of light from the water droplets back into the cockpit, or fly at a lower altitude with white light illumination.

Finally, it is seen from the trials that the casualty position in the water did not affect the distance at which it was first identified. For the north-south passes the average distance at which the target was spotted was 973.5m compared to 971.5m for the south-north passes. This result also negates the effect of the moon position, although mostly obscured by cloud.


*Figure 59 – Screen shot from the FLIR HDIR camera (Modified suit, White light).*

The results of the third flight trials therefore reflect favourably on the modified suit design, strengthening the results of the second flight trials. However here, the poor weather and visibility highlighted the importance of a strong reflection when colour contrast and/or a heat signature cannot be relied upon. The hoops of tape, particularly around the shoulders, which utilise the curved surfaces of the body and hence have a large range of angles of incidence for reflectance, are concluded to be the most significant modification to the suits.

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Fontygary Leisure Park in Barry, who generously allowed us to use their pool facilities to test the flotation properties of the manikin.

# Annex 1

## Review of performance of retroreflective tapes and their potential compatibility with SAR equipment

# ANNEX 1 Crew Immersion Suits Conspicuity (CIMSCY)

## Review of performance of retroreflective tapes and their potential compatibility with SAR equipment

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Department: Transport Systems

Date: 25th April 2019

# Executive Summary

**Introduction and Scope**

This report is in part-fulfilment of the final deliverable for the Crew Immersion Suits Conspicuity Project (CIMSCY) (EASA.2017 C.02). The context of this work derives from the AAIB report into an accident in Morecambe Bay 2006, involving a helicopter crash at night. The helicopter crew wore dark immersion suits that were inconspicuous, and this was considered to have hindered their recovery. In this report we detail relevant aspects of helicopter search and rescue operations and examine in detail the potential to exploit newer retroreflective materials to support conspicuity of the flight crew in a rescue scenario.

**Methodology**

A literature review was conducted covering various aspects of this task, including Search Theory, human perception, the optics of remote detection of casualties during search and rescue operation, and retroreflective materials, also known as glint tape. The review covers both academic and commercial sources of information, since much of the information concerning materials and SAR equipment for example is commercial in nature. The report considers both conventional (white or silver) retroreflective materials as well as coloured and infra-red variants. Interviews were conducted with search and rescue (SAR) crew, representatives of a manufacturer of non-ITAR (International Traffic in Arms Regulations) infrared retroreflective tape and of a supplier of a high specification SAR detection turret. The information obtained in the interviews provided important context with which to refine the ongoing literature review. Finally, the level of brightness of different materials under different lighting conditions was analysed to provide approximate quantification of the task and inform the later test phase of this project.

**Findings**

Helicopter borne SAR is a remote sensing task involving human perception. For the initial detection phase, the latter can involve the following properties of an image: brightness, form, pattern, colour, movement and modulation. A key early finding has been that SAR operations increasingly make use of the superior optical resolution of imaging cameras and image analysis software to detect small (3 pixels or more) areas of an image that present differently to the background scene. For the distances to target considered in this report, the operation relies on brightness and colour contrast. Brightness contrast may be confused by reflections from the sea, including the reflected sky and “glitter”, the specularly reflected light from sources such as the sun, moon and other searchlights in the area. Colour contrast therefore remains as the most reliable indicator of a target and is used in image analysis software.

The justification for air crew to wear dark flight suits is that they present minimal confusion in the cockpit, avoiding reflection of light onto the control panel and transparencies, thereby improving perception of the outdoor scene. However, this study has found a diverse and possibly evolving attitude towards flight suits. Many helicopter crew wear bright orange flight suits in a sizeable fraction of operations (e.g. 60%). Where flight crew choose to wear dark cotton flight suits (e.g. in 40% of operations) this may be partly because of improved human comfort in hot conditions, as well as reduced levels of reflection.

Retroreflective materials can improve the conspicuity of a target significantly when conditions are dark and a searchlight can be used. They are used sparingly; if the difference in area of use is taken into account, retroreflective tape can improve the brightness of a target by at least 30 times, raising its brightness above that of the background for many environmental conditions. These materials are designed for use with a searchlight. Materials are available with coloured filter overlays that remove certain wavelengths from the reflected light and therefore reduce overall brightness, and there are two material families based on SOLAS-approved tape. Filters are available with different visible colours and as a visible-blocking (infra-red only) filter, available commercially in the EU without ITAR and in “marine grade” product. None of these filtered materials meets the SOLAS (Safety Of Life At Sea) guideline for conspicuity of immersion suits.

Some of the visible products come close, however the IR grade material cannot meet the guideline because it is dark in the visible region.

IR retroreflective tape is compatible with the conventional searchlight used in SAR and requires night vision goggle (NVGs) or a CCD camera to be seen, so therefore can only be detected via brightness contrast since colour contrast is not available. Somewhat counter-intuitively, the CCD camera can be a visible camera; this is because its response extends into the short-wave infra-red (SWIR) region of 700-900nm that the tape is designed for. Information about IR retroreflective tape is difficult to find, since much of the original development and use is restricted under ITAR. It is not known to what extent the “SWIR” camera used in SAR might respond, but some response is expected. The mid IR “thermal imager” is unlikely to respond.

**Conclusions and recommendations**

A key finding of this study has been that colour contrast of a target is critical to the early detection phase of helicopter-borne SAR over the sea. Therefore there may be potential to improve the conspicuity of flight suits in several ways:

1. To provide bright orange cotton flight suits for hot conditions, ensuring human comfort without compromising conspicuity.

2. To use coloured (orange) retroreflective tapes, increasing colour contrast especially at large distances and making use of image recognition software, which is reported to detect a minimum of three orange pixels in a scene. As the coloured tape does not meet the SOLAS guideline, it would have to be provided in addition to the SOLAS-recommended quantity of SOLAS-approved tape. Alternatively, the SOLAS standards would need to be modified.

3. Where crew choose to use dark flight suits in order to reduce cockpit reflection (rather than for human comfort) the use of IR retroreflective tape should increase the suit conspicuity without significantly affecting cockpit reflections. However, this would not make the suit as conspicuous under all conditions as either orange fabric or standard retroreflective tape.

4. IR retroreflective tape would be detectable using a standard searchlight with CCD camera or NVGs (Night Vision Goggles). It cannot meet the SOLAS standard for retroreflectivity.

5. The use of IR retroreflective tape only provides a potential advantage in respect of reducing cockpit reflections in the visible region. Compared to conventional tape, it would not reduce cockpit reflections in the SWIR region, relevant to NVG flying. There is no advantage to the detection of SAR targets of using IR tape rather than conventional tape, as the IR tape would be no brighter in the SWIR region than its conventional counterpart.

The test phase of this project should include the following aspects:

1. Conspicuity tests of coloured (e.g. orange) retroreflective materials, with and without image recognition software.

2. Conspicuity tests of IR filtered retroreflective material using NVGs and CCD cameras, benchmarked against conventional material.

3. Pilot feedback on the potential use of IR retroreflective tape on flight suits, benchmarked against more conventional application of standard tape.

4. A number of functional tests concerning IR retroreflective tape, to check its compatibility with SAR equipment in the spectral range 900nm-2.5μm, where data is unavailable.

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# List of abbreviations

| | |
|---|---|
| AAIB | Air Accidents Investigation Branch |
| CAA | Civil Aviation Authority |
| CIE | International Commission on Illumination |
| EASA | European Aviation Safety Agency |
| ETSO | European Technical Standard Order |
| HM | Her Majesty's |
| IAMSAR | International Aeronautical and Maritime Search and Rescue |
| ICAO | International Civil Aviation Authority |
| IMO | International Maritime Organization |
| IR | Infra-red |
| ITAR | International Traffic in Arms Regulations |
| MIR | Mid Infra-red (generally 3 – 16μm; 3 – 5μm in the context of this report) |
| NIR | Near Infra-red (900nm – 3 μm) |
| NVG | Night Vision Goggles |
| OED | Oxford English Dictionary |
| SAR | Search and Rescue |
| SOLAS | Safety Of Lives At Sea (standard owned by the IMO) |
| SWIR | Short Wave Infra-red (700-900nm) |
| UK | United Kingdom |

# 1 Introduction and scope

The context of this work derives from the AAIB (Air Accidents Investigation Branch) report into the Morecambe Bay accident in 2006[1]. This report details the crash of a helicopter transporting employees to an oil and gas platform. One recommendation resulting from the report (Paragraph 1.15.3, page 37) concerns improving the conspicuity of aircrew when in the water following the crash:

*"The operating crew were wearing dark blue immersion suits … The immersion suit and un-inflated life jacket are designed to have low reflectivity in order to reduce internal reflections on the instrument panels and windscreens of the cockpit, during helicopter operations. However, the rescue crews commented that the yellow immersion suits worn by the passengers were noticeably more conspicuous, when using the helicopter's searchlight in the darkness, than the blue immersion suits worn by the pilots."*

In this report we detail relevant aspects of the search and rescue operations and examine in detail the potential to exploit newer retroreflective materials to support conspicuity of the flight crew in a rescue scenario.

# 2 Operational context

This section gives an operational context to the work. It draws on written procedural elements of the Search and Rescue task. In addition, interviews with current flight crew and flight engineers were conducted at HM Coastguard (Humberside). Discussions were conducted with key members of the Bristow team (Chief Pilot, Head of Flight Operations and the Director of UK Search and Rescue). Finally, discussion was held with five current transport pilots at the Aberdeen departure terminal.

## 2.1 Oil and gas transport operations

Offshore oil and gas operations in the United Kingdom use helicopter transport to transfer employees from the mainland to offshore oil platforms. As with all aircraft operations, these types of operation carry risk and in the last ten years serious accidents involving fatalities have prompted reviews of the safety of such operations more generally[2]. The operations are conducted over the sea and can involve unfavourable weather conditions seriously affecting visibility and raising aircrew workload. In addition, landing on an offshore platform is challenging, given the range of movement and the confined space in which to manoeuvre.

In response to these risks, passengers on such operations are subject to enhanced safety briefings and procedures. These procedures include a practical element including underwater escape from a submerged helicopter at a land based facility. In addition, detailed safety briefings and safety materials are given and made available prior to the flight. The safety card shows the variety of safety features provided to passengers in the event of an accident in which they must escape from the aircraft. Of particular note are the orange and yellow, high colour-contrast materials used to form the suits. In addition retroreflective strips are visible on the sleeves. These strips reflect light effectively improving visibility.

## 2.2 Flight crew suits

Flight crew wear flight suits which are compatible with their flying role. Historically, reactions of aircrew to flight suits has not been overly positive. As early as 1987, Gaul *et al.* identify thermal comfort including lack of ventilation and restrictive movement as two key areas of concern[3]. However, more recently, Taber *et al.* report that notwithstanding the reported discomfort of heat stress resulting from wearing a flight suit, evacuation performance remained unimpaired[4]. As suggested in the AAIB requirement, reflective materials in the cockpit can have detrimental effects on safe performance due to reflections onto instrument panels and windows (etc.). Sources of light that is subsequently reflected can be internal or external to the aircraft. Internal light sources include task lighting, tablet computers used for operational tasks or illuminated instruments. External light sources include platform or airport lighting. As such, any adjustment to materials, or inclusion of reflective materials, must take this into account. We have found many examples of dark-coloured flight suits in variously blue, grey, brown and black colours. It is to these dark suits that the AAIB alludes. Such colours are not conspicuous and the SAR team at Humberside have indicated that even during the day, the contrast of these colours against the sea is minimal.

In our visit to the oil and gas teams in Aberdeen, we noted that the majority of aircrew wear a bright orange suit with a variety of conspicuity aids such as retroreflective tape on the extremities of the body. However, in warmer weather, the thermal comfort of these suits is such that many crew will use a black cotton suit instead. This suit has no conspicuity aids. One crew member that we spoke to indicated that when sea surface temperatures are above 10°C in combination with low cross-wind, these suits are preferred. This crew member indicated that, in his experience, this style of suit would be used for about 40% of the year; a non-trivial proportion. If thermal comfort is the main reason for choosing cotton flight suits over high visibility suits, this raises the question of whether bright orange cotton suits with the same level of thermal comfort could be made available.

## 2.3 Search and Rescue (SAR) operations.

Search and rescue (SAR) operations are under the joint auspices of the International Civil Aviation Authority (ICAO) and the International Maritime Organization (IMO). In the UK, airborne search and rescue is a government function undertaken by HM Coastguard services. Since 2013, this service has been contracted to the Bristow Group[5].

The aircraft predominantly used in SAR operations are the twin-engine, four bladed Agusta Westland 189 and Sikorsky S-92. Two flight crew operate the aircraft. Two technical crew operate the winch used for rescue and the electronic equipment on board the aircraft used to detect casualties and assets. Generally, airborne operations would take place as part of a wider system of search and rescue including other aircraft, ships and land-based command and control services.
Aircraft equipped for search and rescue in the UK have advanced features to aid the identification of casualties in both land and sea operations. Visual imagery and illumination of an area are provided by a turret mounted at the nose of the aircraft. The turret contains a suite of camera technology and a paired, directional searchlight. The turret and searchlight are computer controlled by the technical crew and used in a defined way to search for a target using visible identification or through examination of infra-red heat signatures. However, crews also search with the naked eye if appropriate.

Very high levels of illumination can be achieved by the aircrew. The searchlight can flood an area with a number of different wavelengths of light including IR. In addition, bright lights, both fixed and on gimbals, mounted underneath the aircraft can direct light downwards. Images from the camera can be electronically interrogated using software that can examine colour or movement differences with the surroundings. In this way a casualty wearing even a small amount of a bright, contrasting colour can be identified and rescued.

The early foundation of Search Theory was formulated by Johnson[6] who analysed the results of some 2,000 observations of military targets under different conditions of illumination with image intensifiers and human observers. This was then used to establish criteria for four stages of target discrimination, shown in Table 1. Of most relevance to this study is the initial detection phase, which was considered to require 1.0 ± 0.25 pixels of resolution across the target (in the dominant dimension for the target) in order for 50% of human observers to be able to detect the target. This number varies with the degree of contrast offered by the target, its aspect ratio and degree of clutter in the image. If aspect ratio and clutter are fixed, this represents a suitable metric for performance testing.

*Table 1. Johnson criteria for target discrimination, from [12], showing the threshold required for 50% of observers to discriminate a target.*

| Discrimination level | Required cycles (resolvable pixels) on target, $N_{50}$ | Description |
|---|---|---|
| Detection | 1.0 ± 0.25 | Object of significance |
| Orientation | 1.4 ± 0.35 | Object aspect |
| Recognition | 4.0 ± 0.8 | Class of object (human, aircraft) |
| Identification | 6.4 ± 1.5 | Member of class |

Lawson *et al*. later developed a time-dependent model to relate the probability of detection to the time an observer spent looking at the field of view. The details are reported by Ratches[7] and are given below, with variables listed in Table 2.

$$P = P_\infty \left[1 - \exp\left(\frac{-\tau}{mt}\right)\right] \qquad \tau = 6.8\text{s}\,\frac{N_{50}}{N} \qquad (1)$$

*Table 2. Variables relating to equation (1), the search model developed by Lawson et al. and reported in [12].*

| **Variable** | **Unit** | **Description** |
|---|---|---|
| $P$ | unitless | Overall probability of detection |
| $P_\infty$ | unitless | Probability of detection if the observer has an infinite amount of time |
| $m$ | FOV | Number of sensor fields of view over the whole field of regard |
| $t$ | s | Amount of time spent by observer looking at a single field of view |
| $N$ | Cycles or pixels | Number of actual resolvable cycles or pixels across a target's critical linear dimension |
| $N_{50}$ | Cycles or pixels | Required number of resolvable cycles or pixels across the target for 50% of observers to detect |

The consequences of this model for night-time search and rescue operations are as follows. The size of the target and the resolution of the equipment used in the search are fixed, therefore N, the number of resolvable pixels across the target in a single dimension, is inversely related to the distance of the helicopter to the target. The time spent observing a single field of view is inversely proportional to helicopter speed. m, the number of fields of view within the field of regard (i.e. within the whole area to be searched), is determined by the field of view of the sensors at a particular magnification and is inversely proportional to the distance of the helicopter.

It should be noted that this early work was completed using lower resolution imaging equipment than is available on modern SAR. It is questionable whether a target comprising a single pixel would be as noticeable to a human observer using a high resolution camera and display, since individual pixels are now so small that they may only be discerned at very high levels of contrast (e.g. black on white, with little clutter). However, for some types of image contrast, image analysis software is able to highlight areas of interest within the image to the human observer. Such software is now capable of detecting three pixels in an image based on colour contrast, and of highlighting areas of the image showing unusual movement. The requirement of a minimum of 1-3 pixels for detection has important consequences for the types of contrast that may be detected, discussed later

Modern search and rescue planning is more nuanced, taking into account both what is known about the target, the capability of the equipment used and local environmental conditions. The overarching doctrine of search and rescue is provided to the international community through the International Aeronautical and Maritime Search and Rescue (IAMSAR) manual. These international publications contain an agreed international set of minimum requirements for SAR and is jointly published by ICAO and the IMO. It should be noted that the provision of SAR is not restricted to rotorcraft. The IAMSAR manuals detail ship based operations and operations that include fixed wing aircraft. The IAMSAR documentation comprises three parts. Volumes One[8] and Two[9] detail the management and process requirements of SAR. Volume Three[10] is more procedurally oriented and is available as a ring binder, which can be easily carried by aircraft or ships to quickly inform key parts of policy or process.

Volume two of the manual contains a variety of guidance on search planning and techniques deriving from search theory. The origins of search theory were developed in the late nineteen-forties and in the early nineteen-fifties, the specific application of target acquisition was considered. Clearly, any search and rescue operation will demand the location of one or more rescue targets, in a range of environments. Such targets will need to be differentiated from distractor entities. Such distractor entities could comprise friendly aircraft in a military scenario or floating debris in a search and rescue scenario. As early as 1969, Erickson *et al*. showed that increasing the number of scans that an observer made increased performance to give correct target detection[11]. Furthermore, the contrast of the target was a key performance-shaping factor. Better detection was predicted by greater contrast. From these early empirical studies the idea of modelling search as probabilities rather than a specific asymptotic performance gained traction. Given a point datum, for example the approximate location of a target, it is more likely that the target will be found around this point. Targets could include aircraft, ships, objects or casualties. As such, a search area can be defined and a specific flight pattern generated such that an aircraft can be flown in an optimal way to include the areas in which the target would be found. As time elapses, a structured approach can be taken to predict the most likely location of the target. Different conditions can be modelled using a range of constants to predict the most efficient search pattern for a rescue operation. This approach covers operations where an approximate datum point or line can be acquired by the SAR team and those operations in which the target area is only generally specified, for example a large area of sea.

In the UK SAR operations these kinds of computations are performed automatically by software and a wide variety of data sources can be integrated to achieve an optimum search pattern. Computational models of search have been detailed by Sjaardema *et al*.[12]. When using modern aircraft, the search pattern can be uploaded by the flight crew into the flight control computer and then flown automatically over an area.

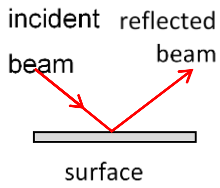
Clearly, acquisition of the target is the overall goal of the search process. Visibility of casualties is paramount. High visibility achieved through the use of reflective materials or contrasting colours, most often yellows, oranges and reds, can allow faster target acquisition by the search crew when considering the visibility of the target to the naked eye. Rapid target acquisition improves the chances of survival, reducing the severity of hypothermia or dehydration in protracted rescue operations. Conspicuity is addressed specifically in European Technical Standard Order (ETSO) 2C502 (2006)[13]. ETSO-2C502 demands that all passengers wear highly conspicuous colours (paragraph 13.1, p 4) and that where possible crew should wear the same (paragraph 13.2, p 4). The weaker demand on crew stems from the potential for visual interference by light from reflective surfaces on the flight suits itself.

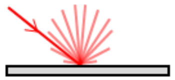
## 2.4 Equipment to aid visibility in the visible and near infra-red

SAR crew use a variety of equipment to assist with these tasks. Here, we introduce briefly the key equipment relevant to the scope of this report.

For the crew to see a target, there are two potential processes that take place. The first involves a light source: light must travel from a light source, strike the target and be reflected towards a detector. The options for each of these are shown in Table 3. In the second process, the target itself represents a source as it emits radiation in the mid infrared region of the spectrum. This is considered in
Table 4.

*Table 3. Target detection in the visible and near IR.*

| Light sources | Reflection | Detection |
|---|---|---|
| During daylight hours the dominant light source is **the sun**, from which light may arrive directly (on a sunny day) or indirectly (scattered through clouds). As shown in Sunlight has a broad spectral range covering both the visible region (400-700nm) and short-wave infrared (SWIR, which for the purpose of this report we limit to the 700-900nm region). The sun is freely available, powerful (typically much more powerful than a searchlight at several hundred metres), and the human eye is well-adapted to make the most of it, such that it provides good colour contrast. However, the SAR crew has no control over sunlight: its position, strength, variability in atmospheric conditions or presence of cloud cover. | A **specular reflection** is what most people consider when they use this term, corresponding to the type of reflection created by a mirror. Specular reflections, for example from the surface of the sea, can be a cause of glitter in received images. This can even be a problem in cloudy conditions, because light with a glancing angle of incidence to seawater is more strongly reflected. Therefore when the surface of the water is disturbed e.g. by waves, there are constantly changing levels of reflection from small areas of water.   | The **human eye** is an excellent detector of visible light. Its response varies from person to person, but the mean overall spectral response is considered to follow the CIE Photopic Response Curve[14]. Many standards involving visibility to humans (including standards developed to test retroreflective tapes) are normalised to this spectral curve. The naked eye cannot respond to wavelengths in the infrared (IR) region. |

| Light sources | Reflection | Detection |
| --- | --- | --- |
| At dawn or dusk, sunlight dominates but its spectrum is modified by its passage through an increased atmospheric pathlength. |  A **diffuse reflection** is what enables most people to see an everyday object. Light striking the object is reflected over many directions and a small proportion of this is received by the eye or another detector. White-painted walls and white paper are examples of good, strong diffuse reflectors. | In low light conditions, there are not enough photons for the eye to detect with a good signal to noise ratio. The eye also needs to be augmented in order to detect light in the IR region. **Night vision goggles (NVGs)** amplify low levels of light striking them, with re-emission in the visible region enabling the eye to act as a detector. They can be sensitive to a broad spectrum covering the visible and SWIR regions, or the SWIR only.<br>A phosphor converts the received energy into visible emission, typically with a green colour. Most NVGs are monochrome, i.e. they can neither distinguish nor display colour. Some modern NVGs overlay the intensified image on top of a direct visible image. |

| Light sources | Reflection | Detection |
|---|---|---|
| During night-time, there may or may not be significant levels of **moonlight**, with a broadband visible spectrum (it is reflected sunlight after all). The level of SWIR radiation can be high relative to the visible as a result of so-called “night glow”. An example spectrum of light available from the night sky. | A **retroreflector** returns a beam of light along the same path as it arrived (or almost the same). Examples of retroreflectors include the white areas of road signs, “cat’s eyes” used as markings on roadways, white painted road markings, bicycle reflectors and so-called glint tape. The terms “retroreflective tape” and “glint tape” are used interchangeably in this report.  | Two high definition **cameras** are available as options on SAR turrets: the first for standard conditions and the second for low light conditions. Here, the detector itself is responsive to both visible and SWIR light, and the signal to noise ratio of the low light camera is superior to that of the human eye in low light conditions. |
| For night-time flights the background light can be augmented using a powerful **searchlight** with broadband emission in both the visible and SWIR regions. Filters are available to restrict emission to different regions: red or amber in the visible, and SWIR only. Searchlights often aim to have a high quality white, broadband spectrum that provides good colour contrast for the human eye. | | **Image processing software** is recently available with two modes: one to identify and highlight a minimum of 3 orange pixels in the visible camera image, the second to identify and highlight any movement that appears significantly different to the background scene. |

## 2.5 Equipment to aid visibility in the mid infra-red

All objects will emit radiation in the IR or microwave region to some extent as a consequence of their temperature; where there is a net difference in the level of emission of two objects, this can be recorded as a contrast in a thermal image. The basis of infrared imaging of targets in the sea is that there is a contrast between the IR emission of a warm human body and that of the cold seawater. Most immersion suits are insulated and therefore the outer surface will be at a similar temperature to the water, with much reduced contrast. However, most (but not all) expose the user's face, which would still provide image contrast, though over a much smaller area and without providing the body's form.

Table 4. Target detection in the mid IR.

| Light source | Reflection | Detection |
| --- | --- | --- |
| All objects are constantly emitting and absorbing radiation in the infrared or microwave regions, depending on their emissivity and temperature. Both the **human body** and the sea itself emit radiation in the mid IR region of interest, the 3-5µm region. Both have high emissivities approaching unity, therefore there is available contrast based on the **temperature difference** between the two. An immersion suit, whose job is to prevent loss of heat and will therefore have a surface temperature close to that of the sea, offers little opportunity for thermal contrast. A person's face is likely to be visible a therefore present a thermal contrast. However, this depends on the design of the immersion suit (some suits have hoods and face masks, but are more likely to be worn by passengers than crew). | Infrared radiation from other sources can reflect from the sea in a similar manner as seen in Table 3. Radiation from the sun in this region is considerable and likely to dominate over the emission from the target, therefore thermal imaging is most likely to be used in dark or dim conditions. At night, the sky behaves as a low temperature emitter and therefore reflected light from the night sky is unlikely to significantly degrade thermal contrast between a human body and the sea. | A **thermal imaging infrared camera** using an InSb detector array is available on the turrets considered here, with a response in the 3-5µm region of the mid infrared. This region is considered to be an atmospheric window, since it avoids major absorption bands of water vapour. Although the emission from a human body is not at its peak in this region (see Figure 14, p.45), the region does offer superior contrast between the body and the sea at temperatures of below 15°C, which is the trigger temperature for wearing immersion suits. |

# 3 What is conspicuity?

While search theory can be used to plan the execution of a search in an efficient manner given a set of resources, a target must still be detected and identified. This work is scoped to consider the visual acquisition of casualties in the sea and as such this section will consider strategies to improve conspicuity in these circumstances. Conspicuity is defined in the dictionary as ‘clearly visible’ (OED, 2018). The human visual system is capable of sensing and processing vast amounts of visual data in the environment. Necessarily, perceptual and cognitive processes play a role in constraining what is perceived and how to constrain the visual demand. As such, something that is illuminated and present in the environment may not necessarily be conspicuous. Lesley (1995, p17) defines conspicuity as the degree to which an object may ‘stand out from its surroundings’[15]. Engel defines the quality of conspicuity as not requiring extensive visual search: an object will ‘pop-out’ from the background[16]. A signal target may have low conspicuity when considered against the background visual scene. A casualty dressed in darker clothes may well be technically visible, but inconspicuous when viewed against a rough sea.

The human visual system is fundamentally a contrast processing system[17]. Reference to the physiology of the visual system makes this distinction clear. Retinal ganglion cells in the eye which respond to light process differences. These cells have two parts, an inner and an outer receptive field (Figure 1). Consideration of this arrangement shows that if a high, constant amount of illumination is presented in a visual scene it is likely that the inhibitory and excitatory areas will cancel each other out. However, if contrast is present in the form of lines, shapes or colour then different patterns of light and dark will be perceived as different degrees of relative inhibition and excitation. This is the essence of line perception which is required to perceive edges and the differences between background and foreground. Spatial frequency is another variable which affects contrast and is related to the distance at which a target is viewed. Modulation of a target’s contrast (e.g. the use of flashing lights, for example used by runners and cyclists) is a further parameter, which makes use of the brain’s additional sensitivity to rapid changes where the frequency of the modulation is significantly different (usually faster) than that of changes to the background scene. Where both colour contrast and modulation are used, the effects are enhanced, for example a flashing red light is more conspicuous than a flashing white light in an urban environment.

Different, high contrast spatial frequencies are shown in Figure 2. Different visual channels have different response depending on the different frequencies used and contrast reduces when spatial frequencies in an object cannot be resolved.

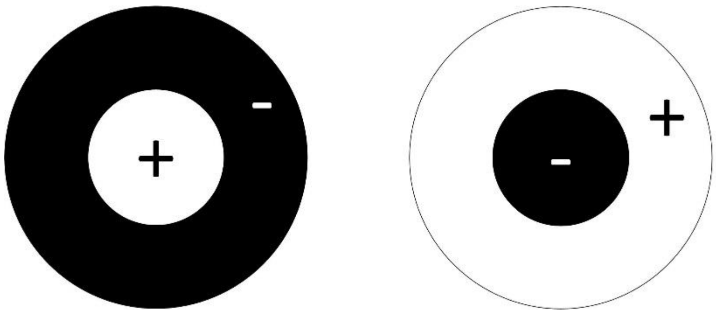



*Figure 1. Representation of cells in the eye showing inhibitory (dark, -) and excitatory (white, +) surrounds.*

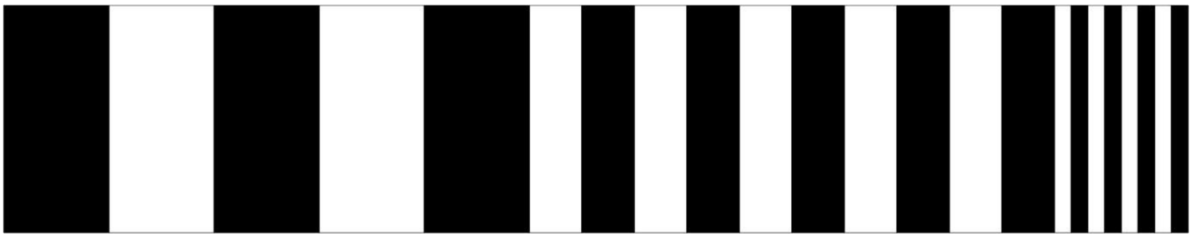


*Figure 2. Example of low (left) and high (right) spatial frequencies in a black and white image.*

A specific application of these properties of the visual system is the examination of road traffic accidents involving pedestrians, which has been reviewed by Langham and Moberly[18]. Sullivan and Flannagan reported that pedestrians are approximately 3 – 7 times more likely to be struck by vehicles at night once other factors such as fatigue and alcohol have been accounted for[19]. Van Bommel and Tekelenberg report that contrast is a key variable when considering pedestrian conspicuity[20]. It is rare for brightness to be the limiting factor for conspicuity, especially in an urban environment where many of these studies have been based. Rather, the limiting factor may be the ability to distinguish the target from clutter, i.e. other objects and sources of contrast within a scene. Making a scene brighter may simply amplify everything, including both the target and any clutter, and therefore may not necessarily improve the probability of detection. Indeed, van Bommel and Tekelenberg found that the addition of light can actually reduce contrast sensitivity[20]. In an applied study of motorcycle riders, Hole *et al.* also argue that brightness contrast is a key parameter of conspicuity [21]. So-called contrast enhancers such as retroreflective tapes can be especially useful in generating very high visual contrast when exposed to illumination such as car headlights[22]. Camouflage also takes advantage of this effect. Conversely, natural camouflage contains no straight edges and uses colours that are representative of the background of a visual scene. In this way, detection of lines or moving edges is very difficult and as such, a target is far more difficult to acquire.

The location of retroreflective tape to improve pedestrian conspicuity has also been studied. Moberly and Langham (2002) found that detection performance improved when pedestrians were moving rather than stationary[23]. Luoma *et al.*[22] and Luoma and Penttinen[24] found that conspicuity could be increased further in moving pedestrians by positioning retroreflective tape in accordance with the principles of biomotion. In other words, retroreflective areas should be positioned on major joints and extremities. However, Moberly and Langham[23] did not find any significant improvement in anthropomorphic configurations of retroreflective materials overall. Arguably, pedestrians have more predictable visual profile than casualties in the sea: most generally they are upright and moving forward. This is not the case in SAR where casualties may be in a variety of positions, with only part of the body visible, and subject to the movement of the sea. As such, any attempt to configure tape in an anthropomorphic way must take this into account. The attitude of the casualty may also depend on the type of suit being worn and the extent to which it provides buoyancy to the legs. The procedure for donning a suit is designed to expel excess air from the suit (and especially the legs)[25] so as to ensure that the legs are not buoyant, otherwise it is possible for the wearer to drown by being flipped into a face-down position or to be unable to escape from the helicopter. This report therefore concentrates on scenarios in which suits only protrude above sea level at the head, shoulders and potentially the arms.

Interviews with SAR crew allowed us to explore the relevance of these aspects of conspicuity for airborne SAR over the sea. This confirmed that the crew rely to a great extent on colour contrast where this is available; in contrast to urban environments, natural environments tend to have blue, green or brown colours and therefore there is a high degree of colour contrast with yellow, orange or red objects. Aspects of conspicuity and their relevance to different operational aspects of SAR are summarised in Table 5.

*Table 5. Summary of aspects of visual conspicuity and their relevance to SAR operations.*

| Parameter | Time to spot existing target | Time to realise area is clear | Distance over which target can be seen |
|---|---|---|---|
| Visibility / brightness | Brightness must be above detectable threshold. Additional brightness does not necessarily improve conspicuity. | Brightness must be above detectable threshold | Brighter objects will be seen from further away |
| Form / shape | Human brain quickly recognises human-like forms | Unaffected: SAR looks for anything and everything by default | Form / shape is only a factor at distances close enough for form to be resolved |
| Movement | Clutter (e.g. reflections from sea) and targets likely to have similar movement unless targets are moving limbs | Movement of clutter lengthens time taken | Movement is a factor at shorter distances; shadowing by waves is a factor at longer distances and for very large waves |
| Colour | Colour contrast to background sea decreases time taken. Not applicable to peripheral vision. | Colour only a factor if suits definitely coloured (crew suits may be dark) | Colour contrast fades over long distances as a result of incomplete resolution of the coloured object and coloured light being mixed with scattered light of other colours |
| Modulation | Flashing targets more quickly noticed and can involve peripheral vision | Scan of area could be quicker if only looking for modulation | Modulation enables discrimination from background light and therefore detection at longer distances |

# 4 What is colour?

As noted in the previous section, colour contrast is an important element of conspicuity and interviews with SAR pilots revealed that they make great use of the colour contrast of targets with the sea. The human eye contains three types of colour receptors that are broadly responsive to blue (400 to 500 nm), green (500 to 580nm) and red (580 to 700nm) light. When the amount of light received by the three types of receptor is different, the brain interprets this as a colour. Different individuals and cultures can perceive colour differently. The brain is capable of compensating for some changes in the overall spectrum of light illuminating a scene, with the consequence that the colour surrounding an object can change its perceived colour. Scientifically, the three variables associated with colour can be plotted as brightness of the red, green and blue receptors (the RGB scheme often used by colour displays) or as the hue, saturation and lightness. Representation of colour was standardised by the International Commission on Illumination (CIE) using a 2D chart, the standardised CIE chromaticity diagram. If two colours on the chart are mixed additively, the resulting colour of the mixture lies on a straight line between the original two colours. The colours of monochromatic light at different wavelengths across the visible spectrum are shown around the edge, and the internal space shows different colours that can be perceived as these colours mix. One dimension is missing: that of the degree of darkness or lightness of the colour, which requires a third axis. The sea colours are therefore the high-brightness colours without any darkening.

A colour may be created by the presence of light in one narrow region of the spectrum, or an absence of light in another region that occupies the opposite side of a colour wheel. The detected colour of an object may be created by placing a coloured filter in front of a white light source, or by the inherent capacity of the object to absorb and not reflect certain wavelengths of light. Red or orange colours show the greatest potential for colour contrast and therefore it is no accident that many immersion suits and other potential targets are coloured red or orange.

Light containing a balanced mix of blue, green and red is perceived as white or grey (depending on the amount of light received), and high quality white light sources are required for proper colour rendition. Sunlight is considered to be a white light source; although the sun appears to be yellow, this is because a proportion of its blue emission has been scattered by the sky. On a cloudless day the yellower light from the sun and the bluer light from the sky mix to provide good colour contrast. Thin clouds can remix these yellow and blue fractions and give a better impression of the original whiteness of sunlight. At dawn or dusk, sunlight passes through a longer distance and therefore direct sunlight can be more yellow or red in colour.

For measurement of retroreflective tape, test bodies mandate the colour spectrum of light to be used from a standard tungsten halogen lamp, which also has a generally white colour and in addition is easy to control and reproduce, which is important for consistent measurements.

# 5 What is glint tape and how can it be used?

The term "glint tape" is commonly used to refer to retroreflective tape typically applied to clothing, safety signs and warnings etc. Retroreflective paint is used in road markings, and the cat's eyes used for road marking purposes are examples of bulk retroreflectors. Three different types of reflection can be identified: standard mirror-like or specular reflection, diffuse reflection and retroreflection. These were introduced in Table 3 and are illustrated again in Figure 3. Many retroreflective materials are designed for use on roadways, where observation distances are much shorter than those that apply to SAR.

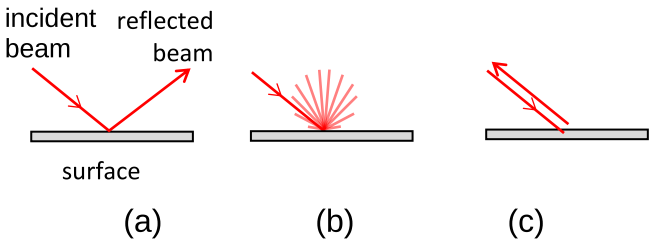



*Figure 3. Simplified geometry of different types of reflection: (a) specular reflection, (b) diffuse reflection, (c) retroreflection*

Reflections within the cockpit are undesirable and can come from a variety of sources. NVG-compatible cockpits use dark materials wherever possible, including black paint on the inside walls, to reduce reflections from the window and better facilitate visibility of the external scene under dark conditions. Both diffuse and retroreflected or specular reflections from clothing could cause problems under these conditions, however it is understood that UK Royal Air Force pilots wear standard white retroreflective tape on their helmets without problems[37]. For non-NVG flying, reflections of light sources from clothing and other objects could create perceptual clutter within the cockpit and cause confusion for pilots who need indication lights to be conspicuous. Diffuse reflections from clothing are likely to cause less of an issue than retroreflected or specular, because the latter reflections are within a narrower cone with the potential to create bright spots around the cockpit. Having said that, SAR helicopter pilots frequently wear bright, conspicuous flight suits with retroreflective tape and often use an iPad or similar tablet strapped to the knee, which is likely to be a brighter source of illumination than a reflected beam.

## 5.1 Optical performance of retroreflective tape

A retroreflector generally does not send the reflected beam back on exactly the same path along which it came, but reflects it within a narrow cone, as shown in Figure 4(a). Otherwise, light would be reflected straight back to the original light source and could not be observed by a detector slightly to one side. Figure 4(b) shows a simplified view of the standard test geometry for retroreflectors, which specifies both the entrance angle (angle that the incident beam makes to the normal to the surface) and observation angle (angle from the incident direction at which the test detector aperture is placed).

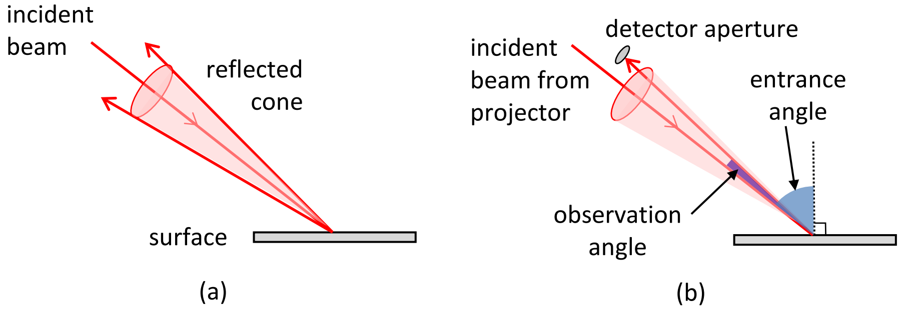



*Figure 4. (a) Expanded geometry of the retroreflection process, showing that the reflected beam takes the form of a narrow cone. (b) Simplified test geometry, showing the entrance angle and observation angle of the test[27].*

SOLAS (Safety Of Lives At Sea) standards are controlled by the International Maritime Organisation[26], of which most members of EASA are signatories (the exception being Liechtenstein). The SOLAS standard for retroreflective tape specifies that photometric testing be performed to the ASTM (formerly American Society for Testing and Materials) standard for retroreflectors (ASTM E809[27]), which specifies the test geometry and type of lamp to be used for the measurement. The result is a measurement of the coefficient of retroreflectivity, $R_A$, the key optical performance parameter. $R_A$ is the ratio of the incident to reflected light, normalised for the solid angle subtended by the detector aperture, and spectrally referenced to the CIE photopic response of the human eye. A standard lamp must be used with a known spectral output, which enables visibility according to the eye's photopic response to be compared between labs.

The test for retroreflectivity is exacting because the relevant observation angles are very small (1° or less). Apertures must be small (25mm or smaller) and the test distance long (15m) to permit resolution of angles to fractions of a degree. Consequently, there are few labs worldwide that are capable of measuring this parameter. Those labs that are set up for this have standardised lamps and might not be capable (without some development to ensure alignment and comparability) of testing using different illumination or detectors with a different spectral response.

*Table 6. Key elements of SOLAS standard for photometric performance of retroreflective materials[28]*

| Parameter | Details |
|---|---|
| Light source | CIE standard illuminant A:<br>“This is intended to represent typical, domestic, tungsten-filament lighting. Its relative spectral power distribution is that of a Planckian radiator at a temperature of approximately 2,856 K” [29] |
| Detector | Not mandated; relative measurements are made in the test so precise specification is not important (but its spectral response is mandated) |
| Spectral response | Measurement made in lumens or lux, therefore normalised to CIE standard photopic response of human eye |
| Coefficient of retroreflectivity, $R_A$ | Measures the luminance of the target, in cd/m$^2$, normalised by the illuminance from the lamp onto the target, in lux. |
| Geometry | Distance from source / detector to target: 15m<br>Apertures of source and / or detector: 26mm or 13mm, depending on observation angle |
| Observation angles | 0.1°, 0.2°, 0.5°, 1.0° |
| Entrance angles | 5°, 30°, 45° |
| Minimum values of $R_A$ | Equal to the specification of 3M Scotchlite; see Table 9 |
| Performance when wet | At least 80% of dry $R_A$ values should be maintained when running a continuous film of pure water over the material at a specified angle. |

Although IMO resolution A.658 requested that the Marine Safety Committee of the IMO keep the resolution under review, it has not been superseded since its adoption in 1989. Is the standard relevant to airborne SAR? The observations angles and entrance angles are highly relevant, most of them lying within the range of angles that will be encountered in airborne SAR. Spectrally, the standard relates to the perceived brightness of reflected light by the human eye, when the lamp illuminating the scene is a tungsten halogen lamp whose colour temperature lies within the “warm white” range. There are two factors for airborne SAR that might bias the perceived colour towards the bluer end of the visible spectrum than was intended in this standard. Firstly, the searchlight has a higher colour temperature and bluer output than CIE standard illuminant A. Secondly, if retroreflective tape is primarily used during night-time operations, observers may have a scotopic (nigh-time adapted), rather than photopic, spectral response. The CIE standard scotopic curve has increased response at the bluer end of the spectrum.

### 5.1.1 Interpretation of test data

The ASTM test for retroreflectivity is well-designed, since it measures the ratio of emitted to retroreflected intensity and is therefore robust against a number of possible measurement errors. To enable comparability between test laboratories, the dimensions of the test are specified to high tolerance. Because the test relates to the visibility of the material by people, measurements are made in lumens or lux, SI units that are the equivalent of the Watt or Watt.$m^{-2}$ respectively, in both cases normalised to the CIE standard photopic response curve for the human eye. The coefficient of retroreflectivity $R_A$ describes the relative intensity of light returned to a detector at a range of different entrance and observation angles as shown in Figure 4 (b). Note that the current test is not optimised for detection by a CCD camera, whose responsivity as a function of wavelength is very different to that of the human eye, for example being more responsive at longer wavelengths up to around 900nm.

As mentioned above, the spectral output of the test lamp is specified. CIE “standard illuminant A”, specified in the SOLAS standard, is a tungsten halogen lamp where the filament is operated at a specified temperature so as to give a particular white output. Materials were initially designed for use on roads with illumination from vehicle headlamps and test conditions were specified at a time when headlamps typically used tungsten halogen bulbs. The type of searchlight used in SAR typically has a bluer output than this tungsten halogen lamp. Does this matter? The retroreflective materials considered here are likely to give a broadly spectrally flat level of retroreflection over the visible range. Any materials used in construction of the tapes will likely also have a spectrally flat (and minimal) absorption over the visible region; if not they would have a slight colour tinge. Therefore our judgement is that, broadly speaking, the comparison between materials is likely to be valid even if the illumination lamp is different to that used in the standardised tests.

As Figure 10 illustrates, the range of observation angles in the SOLAS test is highly relevant to airborne SAR. SAR may also take place over much narrower observation angles, and test data implies that for at least one material, performance might be better at these narrower angles. However, testing at such narrow angles is likely to be impractical over the more limited distances involved in photometric testing (a distance to the target of 15m) so it is unlikely that data at narrower angles could be obtained.

### 5.1.2 Conclusions

1. The coefficient of retroreflectivity $R_A$ is the key figure of merit for retroreflectors and relates directly to the perceived intensity of light (in lumens per solid angle) returned to the detector.

2. Measurements made to ASTM E810-03 (specified in the SOLAS standards for various safety aids) are comparable between laboratories, thus may be used to compare performance of different materials.

3. Testing to SOLAS standard ASTM E810-03 uses geometries for light source, target and detector that are highly relevant to airborne SAR.
4.

## 5.2 Environmental performance of retroreflective tape

The SOLAS standard recommends extensive environmental testing of flexible materials. Details are summarised in Table 7. Many retroreflective materials may be purchased from online suppliers and may be capable of offering good quality photometric performance to the required standard, being based on similar technology to the commercially available materials. However, anecdotal evidence suggests that the environmental performance of many of these materials may be compromised by the use of low quality (presumably low cost) materials and adhesives[37]. SOLAS and similar accreditations ensure high technical standards, quality control and traceability, and the aerospace industry is a leader in such matters, especially where they relate to safety. The SOLAS environmental standards are considered by us to be appropriate for airborne SAR and SOLAS-grade materials are considered a good starting point for any use of standard (white) or modified glint tape.

*Table 7. Key elements of SOLAS standard for environmental performance of retroreflective materials[28]*

| Parameter | Details |
|---|---|
| Accelerated weathering | No discoloration, cracking, blistering, dimensional change when tested over 750 hours (type 1 materials, not intended for continuous outdoor exposure) in a sunshine weatherometer. |
| Seawater immersion | No blistering, delamination or corrosion when immersed in salt water solution for 16 hours followed by 10 minute recovery. $R_A$ should remain at or above minimum standard except near cut edges. |
| Salt spray | Expose to saline mist for 120 hours followed by cleaning in detergent; RA should remain at or above minimum standard. |
| Flexibility | No cracking after 4 hours at -30°C then bending round a mandrel. |
| Tensile strength and adhesion | Tensile strength (per 25 mm) without support ≥ 16N, with support ≥330N, adhesive strength ≥ 16N. |
| Folded storage | Two pieces of material of size 100mm x 100m, placed face-to-face between glass plates with an applied weight of 18kg at 65°C for 8 hours; shall show no adhesion or peeling. |
| Temperature | Dry conditioning at 65°C (24 hours) followed by -30°C (24 hours); no evidence of cracking or distortion, $R_A$ values at or above minimum standard. |
| Fungus | Exposure to mildew via soil burial for 2 weeks, then wash. $R_A$ values to be at or above minimum standard and material should not be removable. |
| Soil resistance and cleaning | Soil with a medium containing carbon black, mineral oil and mineral spirits, and leave for 24 hours. Wipe and rinse with mineral spirits then clean with detergent / water. No significant visible damage. |

## 5.3 Quality control for material supplied the SOLAS standard

The IMO specifies stringent quality control procedures for SOLAS approved materials and this is a particular distinguishing feature of SOLAS materials compared with lower cost lookalikes. Key aspects of the quality control are[30]:

1. Regular, repeated testing using approved test authorities.

2. Traceability of materials via a printed code on the tape itself, designating the number of the test authority and the year of manufacture.

3. High quality record-keeping to support traceability.

It is for these reasons that we would recommend the use of approved suppliers for such materials; printing a fake code onto a lookalike material could be a relatively straightforward process.

## 5.4 Recommendations for fitting according to SOLAS standard

Annex 1 to the SOLAS guideline covers recommendations for use and fitting of retroreflective materials to life-saving equipment, including immersion suits. Note that this annex includes recommendations and guidelines rather than mandated minimum standards. In relation to immersion suits, the standards states[28]:

"Immersion suits should be fitted with patches of retro-reflective material with a total area of at least 400cm$^2$ distributed so as to be useful for search from air and surface craft from all directions.

For an immersion suit that does not automatically turn the wearer face up, the back of the suit should be fitted with retro-reflective material with a total area of at least 100cm$^2$

retro-reflective materials should be such as will meet the minimum technical specification given in Annex 2".

Annex 2 of the guideline describes the technical specifications, which have been summarised in Table 6 and Table 7. Guidelines for placement are also covered and shown in Figure 5.

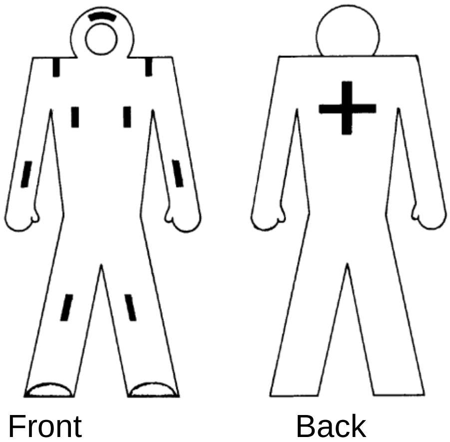



*Figure 5. Diagram showing guidelines for the fitting of retroreflective tape to immersion suits, taken from the SOLAS standard[28].*

In our opinion, there is scope for improvement in both the amount and positioning of retroreflective tape to immersion suits, based on interviews with SAR helicopter crew and reported images of people wearing immersion suits, some of which provide buoyancy to the legs. Specifically:

1. Many suits provide a ring of tape around both ankles; this is suitable for suits that provide buoyancy to the legs but otherwise may be irrelevant.

2. Dead people are understood to float face down with the lower back close to the water's surface, therefore the tape should be located on the lower back if recovery of bodies is considered important.

3. Materials only retroreflect efficiently over a range of entrance angles up to around 30°, therefore tape should be applied onto curved surfaces and only a proportion of the applied tape (half of what is visible to a nearby observer) can be considered detectable at long distances.

4. Shoulders and arms are important locations; we suggest a ring of material around each forearm and a hoop over each shoulder.

5. For suits with hoods, the back and sides of the head should have tape applied, as the head may be the only part of the body above the surface of the water.

6. A total area of 400cm$^2$ of applied tape sounds large, but results in only a small proportion of material being detectable when the wearer is mostly immersed in water and viewed from one direction only.

Suppose that a wrist requires tape to be applied over a diameter of 15cm with a width of 2.5cm. The area of tape applied would be 2.5cm × 50cm = 125cm$^2$. The projected detectable area would be half the diameter multiplied by the thickness, ie 7.5cm × 2.5cm = 19cm$^2$. Thus, only 15% of applied material would be detectable and then only if the wrist were elevated above the water. If 60% of applied materials ends up above the water, the detectable area could reduce to 10% of the area of material applied, or 40cm$^2$.

## 5.5 Coloured retroreflective tape

A variety of filtered (coloured) retroreflective materials is available, for example in red retroreflectors for bicycles, vehicle rear registration plates, coloured "cat's eyes" used at the edges of roads, and retroreflective tapes that are covered with a coloured filter to obscure selected portions of the visible spectrum. An example of coloured tapes in shown in Figure 6.

*Figure 6. Examples of retroreflective tape with overlaid coloured filters. Taken from [31].*

The principle of operation of coloured glint tapes is illustrated by comparing Figure 7, showing the spectral reflection of white tape, with Figure 8, showing the spectral reflection of coloured tape.

The incoming spectrum of light can be considered to be generally “white”, ie having little variation in intensity across the visible spectrum. A coloured filter is overlaid onto the white retroreflector to absorb unwanted portions of the spectrum and reflect only light of the desired colour. These coloured materials are unlikely to meet the SOLAS standard because the filters all act to remove a proportion of the incident light and the level of retroreflected light would therefore be reduced compared to white material.

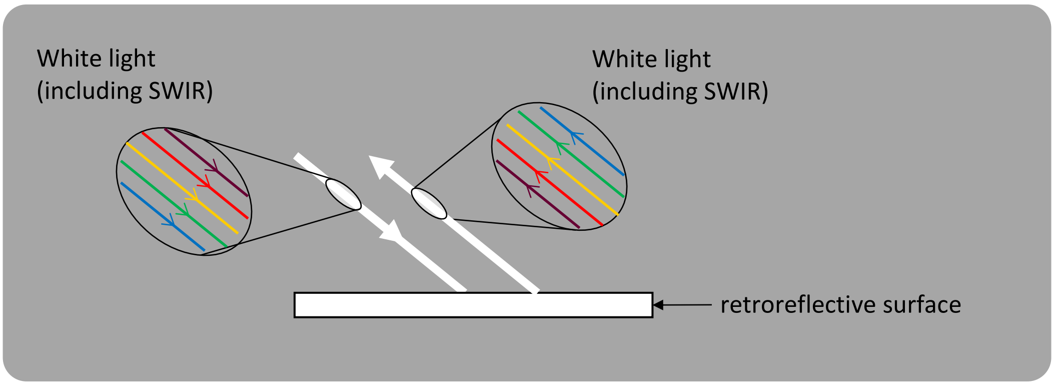



*Figure 7. Principle of operation of conventional (white) glint tape, showing incoming and reflected white light that contains the full visible and SWIR spectrum.*

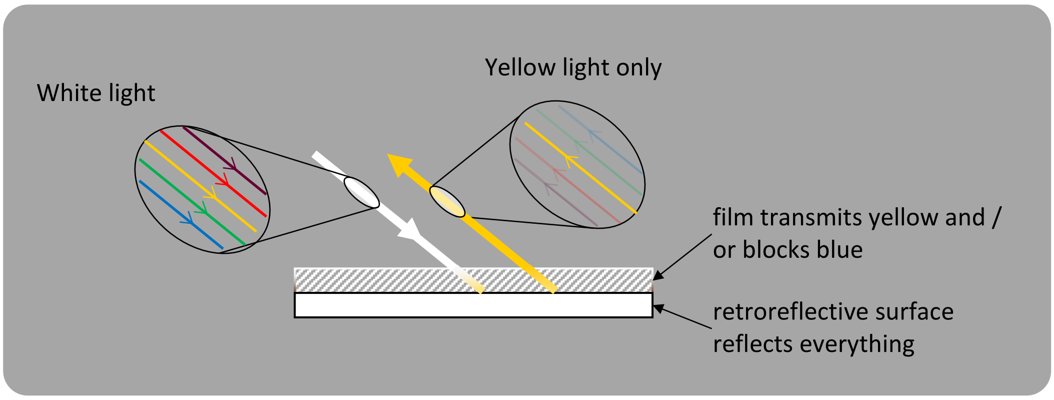



*Figure 8. Principle of operation of coloured (yellow) glint tape, using an overlaid filter that blocks selected portions of the visible spectrum.*

## 5.6 IR filtered retroreflective tape (“IR Glint tape”)

The term “IR glint tape” refers to a broadband retroreflector over which has been laid a visible blocking and IR transmitting filter. Such materials appear black to the human eye but are reflective in the short-wave IR. This process is illustrated in Figure 9, and can be compared to that for conventional (white) glint tape in Figure 7. Materials are typically designed for operation in that region of the SWIR where typical generation III night vision goggles (NVGs) respond, ie 700-900nm. An important conclusion of this mode of operation is that an IR-only light source is not required to see a reflection from IR tape; the standard searchlight used in SAR contains sufficient light in the SWIR for IR glint tape to reflect, and standard visible cameras or NVGs are responsive in the 700-900nm region.

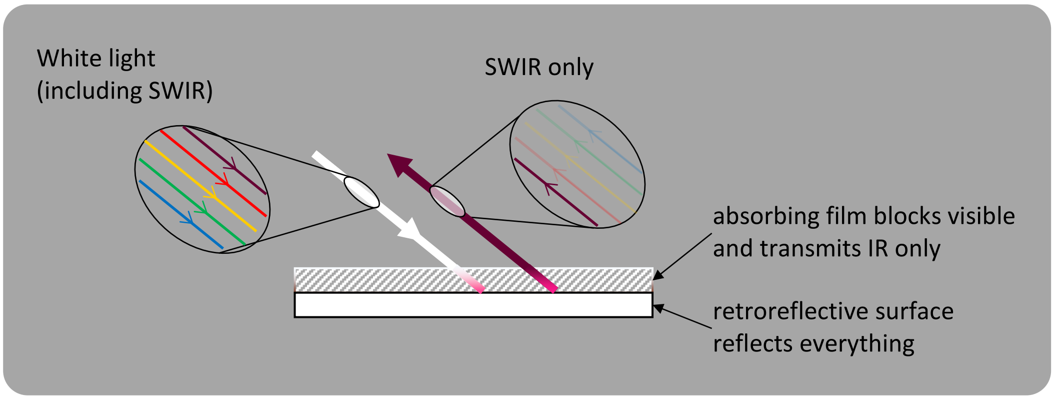



*Figure 9. Principle of operation of "IR glint tape", using an overlaid filter that blocks the entire visible spectrum and allows transmission of light in the SWIR region.*

IR glint tape was developed initially for use in covert operations by the armed forces. The principle was that only friendly forces would have equipment capable of illuminating and detecting light in the SWIR region of the spectrum. Covert personnel using IR glint tape would therefore be detectable by friendly forces. However, unfriendly forces would most likely only be using visible light to illuminate and detect potential targets, and IR glint tape would not return sufficient light in the visible region with which these targets could be detected. US-made IR glint tape can therefore be subject to ITAR restriction (International Traffic in Arms Restriction), controlled by the US Government. It is not possible to obtain information about such products without an appropriate data license, or to pass it on to other bodies without a license. The information on this report has therefore concentrated on non-ITAR products.

IR glint tape does not reflect light in the visible region and therefore by definition cannot meet the SOLAS standard for retroreflective tape. An immersion suit could only therefore meet this standard if the IR tape were to be applied in addition to visible white retroreflective tape.

Because of their use in covert operations, IR glint tapes were designed to be invisible to a human observer reliant on use of the visible spectrum only. In SAR operations, such covert operation is not required. So what potential advantages could use of IR glint tape offer? We can consider several possibilities.

Does IR glint tape offer reduced levels of reflection in the cockpit? This is considered in Table 8. There is one circumstance in which there is potential benefit: the SAR crew uses NVGs for the search process, and the ordinary flight crew uses the unaided eye for flying. There is a possible advantage to air crew who require dark flying suits, since potentially undesirable visible reflections from the tape in the cockpit would be blocked. For all other circumstances, the requirements of visibility to SAR contradict the requirement to minimise cockpit reflections. Note that some NVGs offer only the intensified image whereas others overlay the intensified image over a directly obtained visible image; both options are considered separately in Table 8.

*Table 8. Effect of retroreflective tape on a target's flight suit, on (a) visibility to SA crew and (b) potential reduction in cockpit reflections.*

| Requirements of target visibility for SAR crew | | | | Potential reduction in cockpit reflections for ordinary flight crew | | | |
|---|---|---|---|---|---|---|---|
| | Observation aid used in cockpit | | | Flying aid used in cockpit | | | |
| Material worn by target | Unaided eye | NVG | NVG + unaided overlaid | Material worn by crew | Unaided eye | NVG | NVG + unaided overlaid |
| White (visible + IR) tape | ✓ | ✓ | ✓ | White (visible + IR) tape | ✗ | ✗ | ✗ |
| IR-only tape | ✗ | ✓ | ✓ | IR-only tape | ✓ | ✗ | ✗ |

Would there be any benefit to night-time visibility of IR tape? There is little benefit to the SAR process in the use of IR glint tape in dark conditions, especially as the night sky may contain relatively high levels of light in the SWIR region, with the potential to reflect from the sea to increase clutter and reduce contrast with retroreflective tape. Pilots flying using NVGs would be able to detect standard white retroreflective tape just as easily (if not more so).

Would there be any benefit in terms of maintaining night-time adaptation of the SAR crew's vision? If night-time adaptation were important to SAR crew, there might be a benefit to reducing the overall level of lighting in the cockpit. However, this would be marginal, since there would only be a problem within the cockpit resulting from the presence of bright lights in the cockpit, an undesirable situation which visible tape would add to. Use of IR – only tape on dark flight suits might help but only if used alongside an overall reduction in other lights, such as coming from tablet computers strapped to the crew's knees and other sources. Modern SAR operations as practised by Bristow do not require night-time visual adaptation, since night-time observers use NVGs and low light cameras. It has not been established whether night-time visual adaptation is required by ordinary flight crew, and if so whether use of IR glint tape would make any difference to this in the cockpit.

In summary,

1. IR retroreflective tapes do not require the use of IR-only light sources or detectors; their design should be capable of reflecting the IR portion of the white light emitted from SAR searchlights and be detected by visible cameras or NVGs. The planned trials should include a compatibility check on this function.

2. Use of IR retroreflective tape by a target is unlikely to provide any advantage in SAR operations.

3. Use of IR retroreflective tape would only offer an advantage in those circumstances where ordinary air crew cannot wear suits with visible conspicuity aids. This should be explored experimentally.

## 5.7 Commercially available retroreflective tape

There are two types of retroreflective tape technology that are currently available, based on (i) microspheres and (ii) corner cube arrays (also known as prismatic retroreflectors). Both these technologies are commercially available in Europe without ITAR restriction and with SOLAS approval. Both materials may be purchased with overlaid filters, either visible coloured filters or IR transmitting only.

Microsphere based materials have retroreflection within a relatively wide cone and are therefore considered better for off-axis observation[32]. This tends to occur at shorter observation distances, for example with an observer in a car and illumination from vehicle headlights. Corner cube type retroreflectors tend to concentrate the light into a narrower cone and are therefore considered to perform better for longer observation distances such as those involved in SAR, where the angle between observer and light source is smaller[32]. Performance data on the two main types of commercially available tape is consistent with this conclusion.

A commercially available adhesive tape based on the use of microspheres is sold by 3M as Scotchlite™ SOLAS grade 3150A[33]. A tape based on the use of corner cube retroreflectors is sold by Orafol as Oralite® FD1404[34]. The photometric performance of the two materials is compared in Table 9.

*Table 9. Comparison of performance of two commercially available retroreflective materials with SOLAS accreditation.*

| | Coefficient of Retroreflectivity $R_A$, according to IMO A.658 (16) / cd $m^{-2}$ $lux^{-1}$ | | | | | |
|---|---|---|---|---|---|---|
| | 3M Scotchlite [33] | | | Orafol Oralite [34] | | |
| Observation angle / ° | Entrance angle / ° | | | Entrance angle / ° | | |
| | **5** | **30** | **45** | **5** | **30** | **45** |
| **0.1** | 180 | 140 | 85 | 1000 | 575 | 150 |
| **0.2** | 175 | 135 | 85 | 700 | 400 | 100 |
| **0.5** | 72 | 70 | 48 | 160 | 75 | 50 |
| **1.0** | 14 | 12 | 9.4 | 25 | 15 | 10 |

Figure 10 shows these results plotted for a selected observation angle (0.1°) and entrance angle (5°). The range of observation angles most relevant to SAR in this report (see Table 20, p.39) is also shown in Figure 10. Note that the range of angles includes angles that are smaller than the smallest test angle; for the purposes of estimation, we have assumed a worst case scenario, that the retroreflectivity at observation angles smaller than 0.1° is equal to that measured at 0.1°, however the data suggests that retroreflectivity might be increased at smaller angles for the Orafol material. Testing at such small angles in a laboratory would likely be impractical.

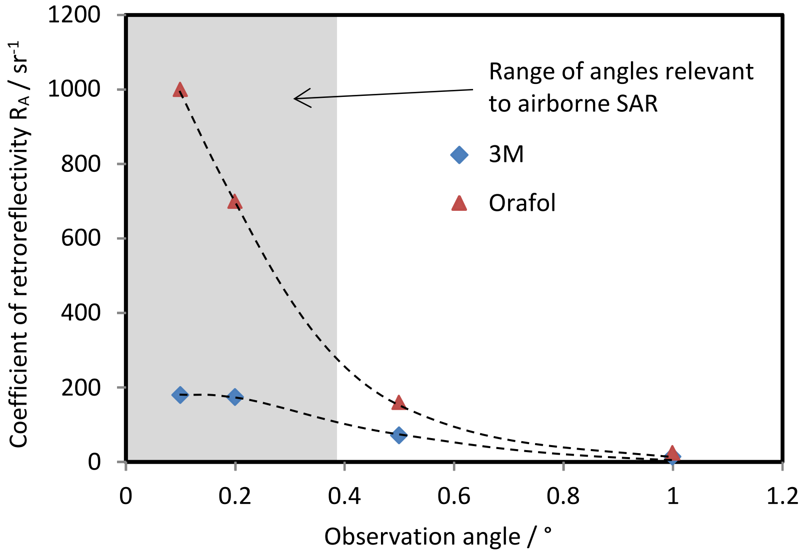



*Figure 10. Coefficient of retroreflectivity as a function of observation angle, plotted for 3M and Orafol SOLAS-standard materials, for a single entrance angle (5°). The dotted lines are hand-drawn splines and used for later estimates in this report.*

## 5.7.1 Commercially available coloured glint tape

Several companies market coloured retroreflective tape for the purpose of enhancing conspicuity in different environments, and these are especially used in road transport for example to help indicate direction of travel (for example, red or orange at the rear of a vehicle). The most relevant material to this report is the coloured marine grade adhesive tape supplied by Orafol. Key photometric performance data is shown in Table 10. Material properties have not been reported over the entire range of viewing angles of the SOLAS standard, however the range does cover those observation angles most relevant to airborne SAR. Performance data suggests that the material would not quite meet the SOLAS standard for retroreflective tape, however the performance for yellow and orange tapes comes close and appears to exceed the photometric standard over most observation and entrance angles. The yellow tape appears brightest, presumably because this colour lies closest to the peak of human visual brightness perception.

*Table 10. Performance of coloured retroreflective material, commercially available from Orafol and designed for the marine environment (Oralite VC310 Marine)[35]. This is a comparable tape to the Silver Orafol tape used in the flight trials which is also SOLAS approved. Shaded regions are expected to exceed the SOLAS photometric criteria[28].*

| Material colour | Coefficient of Retroreflectivity $R_A$, according to IMO A.658 (16) / cd $m^{-2}$ $lux^{-1}$ | | | | | |
|---|---|---|---|---|---|---|
| | Observation angle | | | | | |
| | **0.1°** | | **0.2°** | | **0.5°** | |
| | Entrance angle | | | | | |
| | **4°** | **30°** | **4°** | **30°** | **4°** | **30°** |
| Red | 200 | 115 | 120 | 72 | 28 | 13 |
| Orange[a] | 475 | 265 | 280 | 160 | 64 | 30 |
| Yellow | 800 | 450 | 470 | 270 | 110 | 51 |
| Green | 200 | 115 | 120 | 72 | 28 | 13 |
| Blue | 95 | 50 | 56 | 32 | 13 | 6 |

*[a]Now discontinued for commercial reasons*

Although the overall brightness of such tapes is, by definition, lower than that of the white tape on which they are based, there may be increased scope for provision of colour contrast. The orange and red tapes would offer the greatest potential for colour contrast compared to the colour of the sea. As red is perceived as less bright to the human eye, the orange tape might offer the best compromise. Unfortunately, the orange material is now discontinued for marine grade material, but the data shows what was previously technically achievable. If an orange colour is desirable, a different grade of material is available that provides this for use on road vehicles.

*Table 11. Performance of coloured retroreflective material, commercially available from Orafol and designed for use on road vehicles (Oralite VC612 Flexilite)[36]. Shaded regions exceed the SOLAS photometric criteria[28].*

| Material colour | Coefficient of Retroreflectivity $R_A$, according to IMO A.658 (16) / cd $m^{-2}$ $lux^{-1}$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Observation angle | | | | | | | | |
| | **0.2°** | | | **0.5°** | | | **1.0°** | | |
| | Entrance angle | | | | | | | | |
| | **5°** | **30°** | **45°** | **5°** | **30°** | **45°** | **5°** | **30°** | **45°** |
| Silver | 750 | 375 | 120 | 110 | 60 | 20 | 28 | 14 | 4 |
| Red | 130 | 65 | 20 | 20 | 10 | 4 | 5 | 2 | - |
| Fluorescent orange | 200 | 100 | 30 | 45 | 20 | 8 | 8 | 4 | 2 |
| Yellow | 525 | 260 | 85 | 80 | 45 | 14 | 20 | 10 | 3 |
| Fluorescent yellow | 295 | 145 | 45 | 45 | 23 | 7 | 11 | 5 | 2 |
| Fluorescent lime | 420 | 200 | 70 | 65 | 33 | 10 | 15 | 8 | 2 |
| Green | 130 | 65 | 20 | 20 | 10 | 4 | 5 | 2 | - |
| Blue | 55 | 25 | 8 | 8 | 4 | 1.3 | 2 | 1 | - |

Coloured retroreflective materials are not referred to in the SOLAS guidelines, and these tapes would not meet the photometric performance criteria. Although the first material has been designed for marine conditions, the information reported by the manufacturer does not suggest that it has been tested to the same environmental standards, though it does fall within the same product family. Given the fact that the yellow tapes nearly meet the photometric criteria, there may be scope to tweak the applied filter so as to increase the proportion of light reflected (increasing the spectral window) in order to fully meet it. There may also be scope to review the guidelines in order to accommodate materials that have lower overall brightness than standard white retroreflective tapes, but increased conspicuity. This therefore would be an appropriate element of this project’s test phase.

The coloured materials reviewed here would not meet the SOLAS standard and therefore any immersion suit that did comply would have to have coloured tapes applied in addition to the prescribed quantity of white tape. If the areas of tape are small and not resolved by the imaging system, it is likely that the level of colour contrast provided by the orange tape would be diluted by the white light reflected from the white tape. This is a further aspect to be considered in testing, to see whether a mixed white and orange solution would be recognised by either humans or by the orange colour recognition software, as the latter may require a specific colour threshold to be met.

In summary,

1. Commercially available marine grade materials are a good starting point for coloured tapes with potential to meet most of the SOLAS photometric and environmental criteria.

2. The performance date presented in this section confirms that high quality coloured glint tapes are unlikely to meet the SOLAS standard. Most of the coloured material in the same product family as the present highest brightness (Orafol) SOLAS –approved material would not comply.

3. This project’s test programme should consider the potential for enhanced conspicuity of coloured retroreflective material, applied on its own or in additional to standard white material, despite such coloured material not fully meeting the SOLAS requirements for overall brightness.

### 5.7.2 Commercially available IR glint tape

Both 3M and Orafol tapes are used as the basis for UK-manufactured IR glint tape, without ITAR. Data for the IR blocking filter used in these products was obtained from the manufacturer. Both the 3M and Orafol SOLAS grade tapes are available commercially, overlaid with the visible light-blocking coating without ITAR restrictions. The manufacturer suggests that the coating is stable under marine conditions[37], but has not tested the combined product to SOLAS environmental standards. There is anecdotal evidence that the 3M product has significantly lower brightness in the SWIR, whereas the Orafol product is much more visible in comparison[37]. The manufacturer suggested that this was because the base 3M material did not perform so well in the SWIR, however the difference might simply be a result of the fact that the Orafol product is generally more visible, especially at low observation angles.

We might ask, what level of optical performance would we suspect for these products? As mentioned previously, testing to the ASTM standard for retroreflectivity using CIE standard illuminant A, by definition, concentrates on the visible region and the test does not measure SWIR performance. Apart from the presence or otherwise of filters, the base materials used in the manufacture of the 3M and Orafol products are unlikely to show significant degradation in the SWIR. The Orafol product has an especially simple mode of operation based on reflection from thin layer of aluminium, and likely to exhibit broadly similar optical behaviour in the SWIR.

However, SOLAS approval by definition requires reflection in the visible region of the spectrum and therefore so-called IR glint tapes (or visible-blocking glint tapes) would not be able to meet the SOLAS standard while their visible-blocking properties remained efficient.

## 5.8 Summary and conclusions

SOLAS-approved tapes, or tapes originating from the same product families, with an appropriate chain of custody are recommended for use on equipment for SAR including crew immersion suits. Other retroreflective tapes (including IR tapes) may be purchased (for example from ebay and Amazon). Although they may appear visually to have similar photometric performance, their environmental performance, especially when exposed to seawater, may not be suitable.

The SOLAS standard refers to minimum performance criteria that are identical to the performance of the 3M tape, and may have been based on that product because it was first to market. The Orafol tape has superior performance for long-distance use.

Both the 3M and Orafol SOLAS approved tapes have been tested for use at sea according to the International Maritime Organisation standard. It is possible to buy these tapes coated with an IR filter without ITAR restriction within EASA member states.
When coated with an IR filter, the optical performance will be degraded in the IR and there will be no retroreflection in the visible. Therefore, such tapes would not meet the SOLAS standard for retroreflective tape as this standard specifies a minimum performance in the visible. There is anecdotal evidence that the 3M product is significantly degraded when coated with an IR filter.

# 6 Equipment currently used in SAR

## 6.1 Cameras and turrets

An example of a camera turret mounted on an aircraft is shown in Figure 11. There are two main turret types in use in civilian applications in Europe, made by FLIR and Wescam. Of these, the FLIR turret is installed on the SAR helicopter fleet operated by Bristow in the UK. Performance data for these two systems is summarised in Table 12 and Table 13, respectively. The FLIR system operated by Bristow in the UK includes the most advanced or highest resolution options available, and will be used in testing. Installed in the turret are a mid IR thermal imaging camera (MIR or MWIR for Mid Wave Infra-Red), high resolution CCD camera, one of which can be used in low light, and a short wave infra-red (SWIR) camera. It includes additional image analysis software with two useful functions:

1. Colour detecting function. According to the manufacturer, this software can detect a minimum of three orange pixels and highlight this to the operator. The software is designed for the initial phase of SAR and has enabled operators to fly high and scan a large region more efficiently than previously.

2. Movement detecting function. This function analyses movement of selected groups of pixels and compares them to the overall movement of the scene, therefore removing the effects of overall gross movement of the image cause by the velocity of travel of the aircraft, as well as typical relative movement of objects in the scene, potentially including waves.


*Figure 11. Example of a detection turret mounted at the front of an AW189. To the side of the aircraft is the searchlight.*

*Table 12. Performance data for FLIR Star Safire 380-HD[38]. Shaded regions indicate those options installed on Bristow SAR helicopters in the UK and therefore to be included in project testing.*

| Cameras | MWIR Standard | MWIR Option | Colour CCD | Colour NIR CCD | SWIR |
|---|---|---|---|---|---|
| Sensor type | InSb MWIR | InSb MWIR | Si | Si | InGaAs |
| Resolution | 640 x 512 pixels | 1280 x 720 pixels | 720p/1080p | 720p/1080p | 720p/1080p |
| Wavelength | 3-5 µm | 3-5 µm | 400-900 nm | | |
| Fields of View | 30° to 0.25° | 30° to 0.25° | 29° to 0.25° | 55° to 1.5° | 28° to 0.25° |
| Laser Payloads | Rangefinder | Illuminator | Pointer | Pointer | |
| Laser class | Class 1 (eyesafe) | Class 4 | 150 mW | 650mW | |
| Laser power | “Up to 25 km” | 1 W or 2 W | Class 3b | Class 4b | |

*Table 13. Wescam MX-15 specifications[39]*

| | **MX-15 standard** | | **MX-15 true HD** |
|---|---|---|---|
| Sensor #1 Thermal Imager | a - Thermal Imager | b - High Definition Thermal Imager | |
| Type | InSb, cooled mid-wave staring array | InSb, cooled mid-wave staring array | InSb, 3rd gen cooled mid-wave staring array |
| Resolution | 640 x 512 Pixels | 1280 x 1024 Pixels | 640 x 512 |
| Fields of View | 26.7° to 0.54° | 35.5° to 1.2° | 26.7°, 5.4°, 1.1°, 0.36° |
| Sensor #2 Low light camera | Color Low-Light Continuous Zoom | | Color Camera with Zoom Lens |
| Type | 2 Megapixel color low-light HD | | 2 Megapixel Color HD |

| | **MX-15 standard** | | **MX-15 true HD** |
|---|---|---|---|
| Fields of View | 2.9° to 40.0° - 1080p | 1.9° to 27.3° - 720p | 0.69° to >27.6° - 1080p<br>0.46° to 27.6° - 720p |
| Sensor #3<br>Spotter | Daylight Step-Zoom Spotter | | Color Camera with Single Channel Spotter [1] |
| Camera Type | 2 Megapixel Color HD | | 2 Megapixel Color HD |
| Fields of View | 0.92° to 0.37° 1080p<br>0.61° to 0.24° 720p | | 0.15° to 0.61° 1080p<br>0.10° to 0.41° 720p |
| Sensor #4<br>Day/Night Spotter | a - Low-Light Spotter<br>(Used with Sensor #3) | b - SWIR Spotter<br>(Used with Sensor #3) | Charge Multiplied with Dual<br>Channel Spotter |
| Camera Type | Electron multiplied CCD | InGaAs | Charged Multiplied CCD (Mono)<br>0.22° to 0.44° 1080p<br>0.15° to 0.44° 720p |
| | Sensor #5 - Laser Rangefinder (LRF)1 | | |
| Laser Type | Eyesafe | | Erbium glass (eyesafe) |
| Wavelength | 1.54µm | | 1.54µm |
| Pulse Rate | 12 pulses/min | | 12 pulses/min |
| Range | 20km | | 20km |

| | **MX-15 standard** | **MX-15 true HD** |
| --- | --- | --- |
| Range Resolution | ±5m | ±5m |
| | Sensor #6 - Laser Illuminator (LI)2 | |
| Laser Type | Diode (ANSI Class 4) | Diode (ANSI Class 4) |
| Wavelength | 860nm | 860nm |
| Modes | Continuous, Pulsed | Continuous, Pulsed |
| Beam Power | 350mW or 700mW | 350mW or 700mW |
| Beam Divergence | Wide, Narrow, Ultra Narrow | 1.5 x 1 mrad or 6 x 4.5 mrad |

*1 Dual channel option also available, similar specs*

# 6.2 Light sources

## 6.2.1 Sunlight and the night sky

Sunlight is a dominant source of light during daylight hours, either obtained directly from the sun (with blue light scattered out), as scattered blue light from a clear sky, or as recombined white light from clouds. The ASTM standard reference solar spectrum used in materials testing. Sunlight is equivalent to a broadband, blackbody emission but at sea level it also exhibits several sharp absorption bands of different atmospheric gas species. Sunlight peaks in the visible region and also contains SWIR radiation to wavelengths of around 2.5µm[40].

Light from the night sky can include moonlight, with a similar characteristic to sunlight, though at much reduced intensity. The night sky also includes comparatively high levels of “night glow” in the SWIR and NIR regions, from 700nm to 1.9µm. This is independent of the moon’s phase. The relatively high level of nightglow is the reason why many night vision systems use the SWIR region of the spectrum.

## 6.2.2 Searchlights

Searchlights are primarily designed for low light / night-time operations, since at other times the level of sunlight available is likely to dominate. The light source installed on Bristow SAR helicopters in the UK is the Trakkabeam 800, plus a rotatable filter accessory that includes filters for SWIR only, “red glow” (designed to preserve night-time adaptation while allowing some visibility) and coloured filters for amber and red. Table 15 shows the filters available for the Trakkabeam A800. Other searchlights in common use include the Spectrolab Nightsun and Thommen HSL-1600 (see Table 14). All are based on the use of high power xenon short arc lamps and have broadly similar properties. Direct comparison of the brightness of these lamps is made difficult by a lack of complete reported performance data. Both the Spectrolab and Thommen products have the same peak illuminance for narrow (4°) beams. The Thommen searchlight has superior total visible output to the Trakkabeam 800. The illuminance at 1km distance appears to be a benchmark used in reported lamp specifications, therefore this is a suitable benchmark distance for the calculations in this report and for practical testing.

The Trakkabeam A800 has a lower electrical power requirement than similar products provided by Spectrolab and Thommen. All three use the same technology, so this raises the question of whether the Trakkabeam lamp is less bright than the alternatives. The company claims that its proprietary optics make more efficient use of the light emitted from the arc than a conventional lamp, and allow the use of a lower power source. Performance data on the total visible output is ambiguous since it is not specified whether this is the output from the arc lamp only or the searchlight beam, after the collimation optics. Data on the peak illuminance would allow comparison but has not been reported for the Trakka searchlight.

*Table 14. Searchlights in common use for helicopter-borne SAR.*

| Parameter | Trakkabeam A800[41] | Spectrolab Nightsun XP[42] | Thommen HSL-1600[43] |
|---|---|---|---|
| Lamp type | Xenon arc lamp | Xenon arc lamp | Xenon arc lamp |
| Electrical power / W | 800 | 1600 | 1600 |
| Visible output total (luminous flux) | 22,500 lumens | Not stated | 60,000 lumens |
| Peak illuminance (with narrowest beam) | Not stated | 32 lux at 1km | 32 lux at 1km |
| Beam width | 4° to 13.3° | 4° to 20° | 4° to 20° |

Table 15. Filter accessories available with the Trakka A800 (shaded boxes are installed on Bristow SAR helicopters). Taken from [44].

| Description | Relevant wavelengths | Notes (from [44]) |
|---|---|---|
| White light – no filter | All | |
| Infrared only | 820, 880 , 920nm | |
| NVIS friendly white light | | When visible light is required during NVG mode |
| Red glow | 680nm | Best for close-in work such as winching operations. Reduces loss of night vision. Has IR signature for working with, or without NVGs |
| Amber | 480 to 500nm | Cuts through smoke, moisture and vegetation, less visual feedback, better colour definition & contrast. |

For later calculations, we require the illuminance of the searchlight projected spot in lux. The Trakkabeam A800 shares optics with the M800, for which the illuminance across the spot is relatively even and the spot size is well-defined (the diameter at which the illuminance drops to 40% of its peak value). As there is relatively little light projected outside the intended beam spot, we assume that the total luminous flux of 22,500 lumens is all contained within the spot. At a distance of 1km for example, the spot diameter is 230m on the widest focus setting and the resulting mean illuminance across the beam is estimated at 0.54 lux. A similar calculation for the Thommen HSL-1600 on its widest setting yields 0.65 lux (the total luminous flux is higher but the beam is wider on the widest setting).

The lamps of Table 14 are likely to be spectrally similar in the visible region, however their IR performance could vary slightly depending on the materials chosen for the optics used to collimate and direct the beam. The Trakkabeam A800 is therefore likely to be representative of other searchlights especially in the visible region, and suitable for assessment of colour contrast.

An IR-enhanced searchlight is available from Spectrolab[45], consisting of a standard xenon searchlight surrounded by a ring of high power LEDs emitting in the 700-900nm range, which would be visible to typical NVGs. Performance data reported by the company does not enable technical comparison of the additional benefit of the LED illumination in the SWIR region, however reported images suggest that SWIR visibility is enhanced. LEDs are highly power-efficient (especially in the IR) and the light tends to be more controllable than that from an arc lamp, because it comes from a more concentrated source. IR-enhanced searchlights could therefore offer advantages for image brightness for detection by both CCD cameras and NVGs. They could enhance the IR brightness of both standard (white) and IR retroreflective materials, making both appear brighter on a CCD camera.

The laser illuminators provided on SAR turrets are not intended to illuminate a scene. Rather, they are used once a target has been detected, during operational handover to another aircraft or sea vessel.

In summary:

1. The Trakkabeam A800 is installed on Bristow helicopters and will therefore be used for the test phase of this project. Its spectral performance is likely to be representative of other searchlights and will therefore be suitable for assessing colour contrast. A lack of performance data that is comparable between products makes its brightness difficult to compare to other searchlights.

2. Light sources enhanced by high power SWIR LEDs could increase target visibility of both standard (white) and IR retroreflective materials when viewed in the SWIR using a CCD camera or NVGs.

3. Testing over distances of 1km should be practical and can be related to performance benchmarks used to specify searchlights.

## 6.3 Night vision goggles (NVGs)

Night vision goggles amplify light received over a certain spectral range (including SWIR) and re-emit this amplified light in the visible (usually green) so that low levels of SWIR radiation can be seen by a human observer. They require power for the amplification process, often via batteries, and modern (generation 3) NVGs are light and compact enough for helmet mounting. Monocular (one input image, one output image), binocular (one input image, two output images) and binocular (two input images, two output images) are available. Most NVGs used in civilian SAR are helmet mounted, binocular generation 3 devices that respond to radiation in the 600-900 nm region and may also respond in the visible region depending on the manufacturer. NVGs that respond in the visible may include different visible filters to prevent blooming from cockpit displays. It is understood that there is a wide variety of NVGs in use in civilian SAR, however most are based on similar "generation 3" technologies.

*Table 16. Performance comparison of different commercially available NVGs.*

| Parameter | ITT 4949 (Now Harris AN/AVS-9) | Exelis (now Harris) F5032 |
|---|---|---|
| Spectral response | Visible to 900nm | Not stated |
| Generation | 3 | 3 |
| FOV | 40° | 40° |
| Angular resolution | 0.8 mrad- | 0.8 mrad |
| Gain | 5000 | Not stated |

Most generation 3 NVGs use auto-gating technology to adjust image brightness for different conditions. The power to the intensifier tube is turned on and off continuously at a high frequency that is not apparent to the user. By varying the duty cycle of the gating, the auto-gate function acts to vary the effective gain of the image intensifier so as to produce a visible image whose overall brightness remains approximately constant. The response time of the auto-gating system to change in levels of illumination is around 0.25s[46].

The consequence of autogating for any project test programme is that users cannot be asked to rate the brightness of objects, since this may be adjusted by the autogating system. Instead, users may be asked to state at what distance they can see an object, or the level of detail (form) in a test pattern. However, if several objects are visible in the field of view, the brightness of the nearest may dominate the autogater and prevent the user from seeing a distant object or more detailed target that might have been visible had the nearer objects been removed.

Most NVGs are monochrome, in that they detect across a wide spectrum and display with green light only, with no opportunity for colour contrast. Adams Industries (US) is a manufacturer of colour NVGs, however these are ITAR restricted and sold to US companies only[47].

A question has been raised concerning whether NVGs might be susceptible to "blooming" (saturation of the display caused by relatively high levels of light in particular areas) as a result of use of the searchlight and its potential to reflect from nearby parts of the helicopter into the cockpit. It is very unlikely that there is any projected part visible from the cockpit that would be capable of being illuminated by the searchlight during the search phase of operations. This might be a possibility during the rescue / recovery phase, however alternative light are available to support that phase of operations. The possibility for blooming from the searchlight should be investigated further in the test phase of this project, both experimentally and during interviews with crew.

## 6.4 Conclusions

A number of conclusions can be drawn from this section for the project test programme:

1. Testing will make use of standard issue Bristow equipment including a high specification FLIR SAR turret and Trakkabeam A800 searchlight. The FLIR system should be tested using software image analysis options including both colour and movement recognition. NVGs should be of generation 3 (which is likely), however, because of the wide variety of NVGs in use, there may be differences even between issued items. The brand and model number of test NVGs should therefore be noted and identical NVGs used for comparable tests.

2. Test results should be broadly comparable between alternative searchlights and turrets used in this application. In particular, the spectral response of different systems is often similar, with differences being confined to levels of light power available or imaging resolution. This will allow for appropriate assessment of colour contrast for example.

3. Tests involving NVGs should be carefully designed in order to avoid any potentially confounding factors created by the operation of NVG auto-gating.

4. Searchlights are benchmarked partly using an operating distance of 1km, which could be a suitable distance for testing under night-time conditions.

5. The possibility of NVG blooming from the searchlight should be investigated during the test phase of this project.

# 7 How glint tape fits into SAR operations

This section considers how the above elements may come together to establish visual contrast for objects on water. The effects of the water surface are also considered. A series of “back of the envelope” calculations is presented for simplified conditions to illustrate the extent of the detection problem and the effect of using retroreflective tape.

## 7.1 Geometry and resolution

To enable comparison of different types of reflector, we first have to consider the SAR geometry. This varies considerably with conditions, however we know that SAR helicopters are flown at altitudes ranging from 200ft to 1500ft, and with horizontal distances to the target of between 0 to 2km. For the purpose of this section however, we concentrate on night-time operations, for which the operating distance may be limited by searchlights. A standard benchmark distance for searchlight brightness is 1km and some manufacturers claim visibility to 1.6km in good conditions. This section therefore chooses a horizontal distance of 1km for benchmarking purpose, which for an altitude of 1500ft (460m) gives a total distance to the target of 1.1km. The envelope of detectable geometries may be changed according to circumstance and environmental conditions by operators, and can be predicted in advanced using a number of different software models. It is not the purpose of this section to explore all possible detection geometries, and conditions, but to compare the performance of different combinations of light sources and detectors used to detect different types of reflective materials.

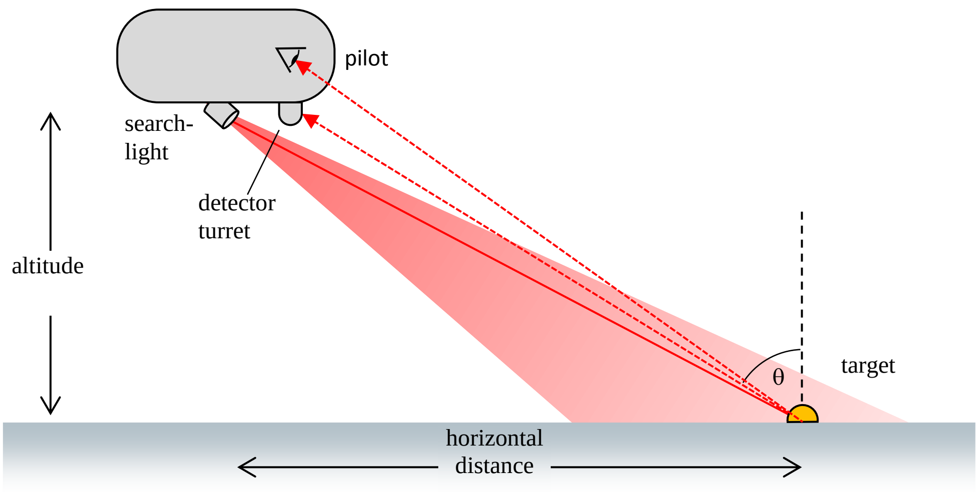



*Figure 12. SAR geometry used in this section. The searchlight is not necessarily used in all missions but is shown here for completeness.*

We have therefore compared the levels of returned light from 3 different scenarios to illustrate the range of optical conditions relevant to the initial “detection” phase of SAR. These are shown in Table 17.

*Table 17. Analysed scenarios covering the range of geometries relevant to the detection phase of SAR.*

| **Scenario** | **Altitude / ft** | **Horizontal distance to target / m** | **Total distance to target / m** | **Angle of optic axis to sea surface normal** |
|---|---|---|---|---|
| High up, pointing straight down | 1500 | 0 | 457 | 0° |
| High up, pointing sideways | 1500 | 1000 | 1100 | 63° |
| Low down, pointing sideways | 200 | 1000 | 1002 | 87° |

Calculations below are based on the following parameters, drawn from Table 14: a mean illuminance across the beam of 0.54 lux at 1km and beam width of 13.3° (the largest available for the Trakkabeam A800, most likely to be used during the early phase of detection, 40% of peak illuminance)[41]. We can use this data to calculate the illuminance of the 3 scenarios above, at the edge of the field of view (FOV) of the searchlight, making the worst case assumption that the illuminance here is 40% of the mean. The true value will be higher, but to calculate this would require knowledge of the distribution of light within the beam, which is not reported in the searchlight datasheet. We can also calculate the optical resolution for light collection for different detectors in use, and these are shown in Table 18.

*Table 18. Resolution of different potential detectors used in SAR.*

| Detector | Angular resolution / ° | Smallest resolvable size for each scenario / m | | |
|---|---|---|---|---|
| | | Scenario 1 | Scenario 2 | Scenario 3 |
| Human eye | 0.02 [48] | 0.16 | 0.38 | 0.35 |
| NVGs | 0.04 [a] | 0.35 | 0.85 | 0.77 |
| FLIR visible cameras (both types) | $7 \times 10^{-3}$ [b] | 0.06 | 0.13 | 0.12 |

*[a]Calculated from Table 16*

*[b]Calculated by matching camera resolution of 1920 pixels to maximum FOV of searchlight of 13.3°*

It is apparent that for any of the modelled scenarios, the technical resolution of the CCD cameras typically used in SAR outperforms that of the human eye. Use of NVGs improves the human eye's ability to detect low levels of light but at the same time will degrade its natural resolution. This does not mean that they could not detect a bright spot from an object smaller than the resolution, but that the contrast of that object would be reduced, as though the additional light were averaged over the minimum resolvable spot.

There are important consequences for this report:

1. Neither the human eye nor NVGs have sufficient acuity to resolve pattern or form of human targets at the distances shown here.

2. Although the CCD cameras used in SAR are capable in principle of resolving a casualty at the distances concerned, without software augmentation the human operator still has to notice the small number of pixels concerned.

3. If the initial detection phase were to rely on pattern or form, fields of view would have to be narrower than the wide fields of view considered here, by lower flying and / or greater magnification of CCD cameras. Consequently the swath of sea covered would be narrower and area coverage would take longer.

4. If pattern or form are not available, detection relies on contrast of brightness or colour of the whole (or averaged) target against the background scene.

## 7.2 Light from a diffuse reflector

The pattern of reflected light from an object is described by the bidirectional reflectance distribution function (BRDF)[49]. The BRDF of important targets observed in remote sensing is a topic of much research. For matte targets, we can approximate the BRDF as follows for the purpose of illustration. An ideally diffuse reflector scatters light in all angles relative to the normal to the surface. Of this, a small proportion may be scattered back to a detector. For real materials there is also often a small proportion of light that is specularly reflected, however this depends on the surface properties and is minimal for a matte surface.

More light is reflected in a direction normal to the surface than in directions with large angles to the normal. So what happens when the surface is curved? More light will be received from the areas normal to the detection axis than from areas where the normal lies at an angle to the detection axis. For simplicity, if we model the target as a sphere, this acts as though it is equivalent to a flat surface normal to the incident beam, whose area is 0.24 times the projected area of the ball. Using this ideal object as a baseline comparator, we can calculate the brightness of light returned from a searchlight for the three different scenarios identified in Table 17.

*Table 19. Modelled brightness of returned light in lumens $sr^{-1}$ $m^{-2}$ from a typical searchlight, reflected diffusely from a spherical target.*

| Scenario | Mean illuminance of searchlight at target / lux[a] | Returned luminance / lumen $sr^{-1}$ $m^{-2}$ [b] |
|---|---|---|
| 1. High up, pointing straight down | 2.6 | $59 \times 10^{-3}$ |
| 2. High up, pointing sideways | 0.45 | $10 \times 10^{-3}$ |
| 3. Low down, pointing sideways | 0.54 | $12 \times 10^{-3}$ |

*[a] Calculated for Trakkabeam A800 using widest illumination setting of 13.3° (half angle)*

*[b] Assumes spherical object returns 20% of incident light into a perfectly Lambertian diffuse reflection.*

The unit of luminous intensity, lumens per steradian, is also known as the candela, and originated in considering the number of standard candles that would have equivalent brightness to a source. Although these luminous intensities might be measurable by each of the detectors, they are very low, and unlikely to be discriminated from the background on the basis of brightness alone. It is no surprise that it is difficult to see a target at a distance of 1km using a searchlight. Crew wearing dark flight suits would return much lower levels of light than those given in Table 19.

## 7.3 Light from a retroreflector (glint tape)

Retroreflectors are designed to be used with a searchlight positioned close to the detector. The closer the detector is to the searchlight, the better. A retroreflector would return light from the sun if the sun was almost directly behind the detector, however this requires either prior knowledge of the target's position on the part of the pilot, or a rather time-consuming search pattern, and therefore isn't relevant.

We have modelled the performance of the two types of retroreflective tape that are commercially available in Europe with no ITAR restriction. The observation angle relevant to airborne SAR is given by the distance between the searchlight and the camera turret and / or pilot and the distance to the target in each of the 3 scenarios. This gives a range of observation angles of 0.3° to 0.001°, as shown in Table 20, calculated on the simplifying assumption that the helicopter remains horizontal (if the front of the helicopter were to dip down from the horizontal, all observations angles would reduce and returned levels of light would increase).

*Table 20. Range of observation angles for SAR using the searchlight and detector positions for the three SAR scenarios.*

| Scenario | Observation angle / ° | |
|---|---|---|
| | Searchlight to detector turret | Searchlight to pilot's eye |
| High up, pointing straight down | 0.38 | 0.19 |
| High up, pointing sideways | 0.07 | 0.07 |
| Low down, pointing sideways | $9 \times 10^{-3}$ | $1.5 \times 10^{-3}$ |

For these observation angles, we can estimate the coefficient of retroreflectivity from Table 9 and Figure 10. We assume that, for observations angles below 0.1° (for which we have no data), the value of RA is equal to that at 0.1°. These values are plotted in Table 21

*Table 21. Assumed or interpolated values of the coefficient of retroreflectivity for the three scenarios analysed in this report.*

| Scenario | Searchlight to detector turret | | Searchlight to pilot's eye | |
|---|---|---|---|---|
| | 3M | Orafol | 3M | Orafol |
| 1. High up, pointing straight down | 110 | 300 | 175 | 740 |
| 2. High up, pointing sideways | 180 | 1000 | 180 | 1000 |
| 3. Low down, pointing sideways | 180 | 1000 | 180 | 1000 |

Now we can make a comparison with the brightness of a diffuse light reflector of the same dimensions as used in the previous section. First, we have to correct for the spherical nature of the object, which exhibits a change in entrance angle over its surface. Although RAs at low entrance angle are high, there is a greater projected area of surface at larger entrance angles. By correcting for this area and averaging over the surface, it is possible to show that a sphere of material behaves approximately as though it is a surface of the same projected area with a certain fraction of $R_A$ at the lowest entrance angle. We recognise also that at angles greater than 45° the retroreflectivity cannot be assumed, therefore we also consider the retroreflectivity beyond that angle to be zero. The resulting fractions of peak $R_A$ are then approximately 12% and 7.5% for the 3M and Orafol material, respectively. The reason for the difference is that the 3M material maintains its retroreflectivity over a wider range of entrance angles than the Orafol material. Using these values, we can reproduce the calculation for the brightness of an object (again a 20cm diameter sphere) in each of the three scenarios. The results are shown in Table 22.

*Table 22. Modelled brightness of returned light in lumens $sr^{-1}$ $m^{-2}$ from a typical searchlight, retroreflected from a spherical target.*

| Scenario | Illuminance of searchlight at target / lux[a] | Observation angle / ° | Returned luminous intensity / lumen $sr^{-1}$ $m^{-2}$ [b] | |
|---|---|---|---|---|
| | | | 3M | Orafol |
| 1. High up, pointing straight down, searchlight to turret | 2.6 | 0.38 | 35 | 59 |
| 1. High up, pointing straight down, searchlight to pilot | 2.6 | 0.19 | 56 | 140 |
| 2. High up, pointing sideways, searchlight to turret | 0.45 | 0.07 | 10 | 34 |
| 2. High up, pointing sideways, searchlight to pilot | 0.45 | 0.07 | 10 | 34 |
| 3. Low down, pointing sideways, searchlight to turret | 0.54 | $9 \times 10^{-3}$ | 12 | 41 |
| 3. Low down, pointing sideways, searchlight to pilot | 0.54 | $1.5 \times 10^{-3}$ | 12 | 41 |

*[a] Calculated for Trakkabeam A800 with widest beam setting of 13.3° (half angle).*

*[b] Assumes spherical object.*

The benefit of using retroreflective tape now becomes clear. For the same area of spherical object, even the worst retroreflective material is 600 times brighter or more for scenario 1 and over 1,000 times brighter for scenarios 2 and 3. Although the 3M material maintains its retroreflectivity over a wider range of entrance angles than the Orafol material, the Orafol material performs better than the 3M for a spherical object and would perform even better for a cylindrical object, such that the Orafol material becomes brighter than a diffuse object by a factor of approximately 1,000-3,000.

### 7.3.1 Comparison of diffusely reflected with retroreflected light

We have shown above that, for a given area, a retroreflector returns orders of magnitude more light to the observer than a diffusely reflective material. However, we need to consider how much area of each material there is, given that SAR may be operating at the limits of resolution.

We have modelled our scenarios so far based on curved (spherical) objects, namely a ball of 20cm diameter. A casualty whose head and shoulders are above the water might present a total observable area equivalent to 10 times that of the ball, or 3,100cm$^2$. This represents the potential area of diffusely reflective material that might be available. The total level of returned light (which might be split into multiple pixels in a camera, for example) is given in Table 23.

Retroreflective material is applied sparingly to immersion suits and other safety equipment. Partly this is because of cost and practicality, but also it is because the tape acts to concentrate the reflected light into a narrow cone, thereby reducing the potential for scattered light to be visible from all angles. We would not necessarily wish to cover an object in glint tape, because its visibility in sunlight (where scattered light from the sky is dominant) might be reduced. Glint tape is visible in scattered light, otherwise it would look dark in normal conditions unless viewed using a light source close to the observer. But the level of scattered light might nevertheless be reduced. There is a compromise to be made: to cover a small proportion of the area of an object such that the brightness of the object in scattered light is relatively unaffected (eg by up to 10%) while ensuring significant levels of retroreflectivity in dark conditions with a searchlight.

The SOLAS guideline is to apply 400cm$^2$ of retroreflective material to an immersion suit. Even if the shoulders and head are prioritised to take around half the tape, from any one direction perhaps half of that tape will be available for retroreflection. This gives a total area of 100cm$^2$ available for retroreflection, compared to the single 20cm diameter ball modelled in Table 19, which had over 300cm$^2$. The resulting brightness from this smaller area is compared to that of the suit in Table 23. The calculation is based on the use of 3M tape, the worst of the two considered in this report, because its performance is equal to the minimum level recommended by the SOLAS standard.

*Table 23. Apparent brightness of 3,100cm$^2$ of diffusely reflecting fabric compared with 100cm$^2$ of retroreflective tape, each covering a spherical object, for different modelled scenarios under searchlight illumination.*

| Scenario | Brightness to the turret camera / lumen sr$^{-1}$ | | | Brightness to the pilot / lumen sr$^{-1}$ | | |
|---|---|---|---|---|---|---|
| | Fabric suit | 3M | Orafol | Fabric suit | 3M | Orafol |
| 1. High up, pointing straight down | $18 \times 10^{-3}$ | 0.35 | 0.59 | $18 \times 10^{-3}$ | 0.56 | 1.4 |
| 2. High up, pointing sideways | $3.2 \times 10^{-3}$ | 0.10 | 0.34 | $3.2 \times 10^{-3}$ | 0.10 | 0.34 |
| 3. Low down, pointing sideways | $3.8 \times 10^{-3}$ | 0.12 | 0.41 | $3.8 \times 10^{-3}$ | 0.12 | 0.41 |

Table 23 reveals that, for application of retroreflective tape just meeting the SOLAS guideline, the tape is 20-30 times brighter than the diffusely reflecting object. Because of the difference in available reflective area, the relative brightness of the retroreflective tape is much reduced. Given that the available area of tape (100 $cm^2$) is such a small proportion of the overall area of the visible suit (3,100 $cm^2$), there is potential to increase the area of reflective tape applied to the suit and / or life jacket by perhaps a factor of 3.

Our conclusions of this modelling are:

1. At the limits of resolution for SAR, the benefit of retroreflective tape is reduced by its use over a small proportion of an immersion suit. However, even if the tape only covers 3% of the available area, the suit's brightness increases by a factor of 20-30.

2. Retroreflective tape should be prioritised to those areas most likely to be above the water and over curved areas so as to guarantee that a proportion of the material retroreflects efficiently.

3. There is potential to increase the brightness of a suit by increasing the area of retroreflective tape by a factor of 3, without reducing the area available for diffuse reflection by more than 10%.

4. Given that equipment and materials involved in SAR are expected to be broadly spectrally "flat" across the SWIR (apart from where filters are used), these principles are likely to apply similarly to IR glint tape.

## 7.4 Reflected light from the sky

A further effect is present for SAR. During the day, a small proportion of light from the sky is reflected by water (see Figure 13). Although the reflected proportion is small, it acts to reduce contrast with light that has penetrated the surface, the latter being reduced by absorption and scattering effects considered above, such that reflected light could dominate over light reflected by objects submerged by 0.5-30cm. During night-time operations, for a searchlight beam striking the water at an angle, a proportion of that light will be reflected from the water surface and not even reach the retroreflective tape. For glancing angles this proportion can be high and will reduce the contrast of both submerged and floating objects.

The proportion of light specularly reflected from the top of a flat surface of water is given by[50]

$$R_{\perp} = \left[\frac{\sin(\theta_i - \theta_t)}{\sin(\theta_i + \theta_t)}\right]^2 \qquad R_{\parallel} = \left[\frac{\tan(\theta_i - \theta_t)}{\tan(\theta_i + \theta_t)}\right]^2 \quad (2)$$

Where $R_{\perp}$ and $R_{\parallel}$ are the amplitude reflectivities for light polarised perpendicular and parallel to the plane of incidence, respectively, and $\theta_i$ and $\theta_t$ are the angles of incidence and transmission, respectively. According to Snells' Law, $\theta_t$ is given by

$$n = \frac{\sin\theta_i}{\sin\theta_t} \qquad (3)$$

Where n is the refractive index of water, equal to 1.33[58].

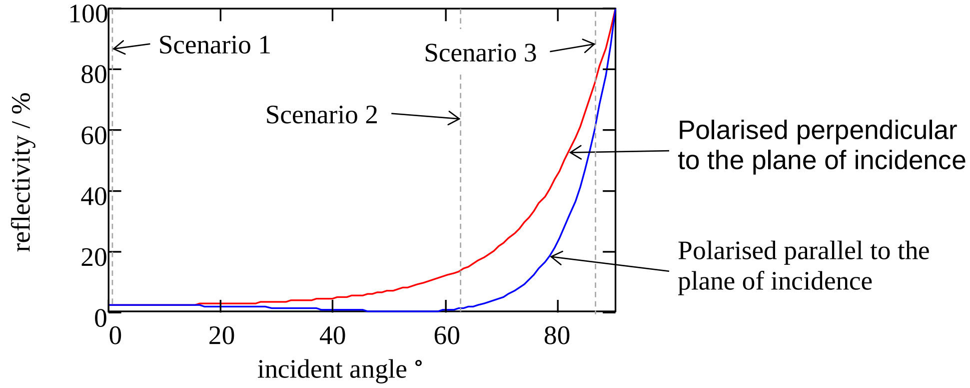



*Figure 13. Reflectivity of pure, smooth water at different angles of incidence, calculated using equations (2) and (3). Refractive index of water taken from [51]. SAR operations cover almost all angles of incidence from 0 to 87°.*

In is clear from Figure 13 that the light reflected from the sea may be polarised, especially for angles of incidence in the range 40-60°. This is the reason why polarising sunglasses provide relative immunity to glare from water, and may offer an opportunity for improved discrimination of targets from seawater reflections in SAR. The polariser would block 50% or more of the incoming light (since all sources used for flood illumination are unpolarised) but could increase contrast. At the high angles of incidence, almost all the light falling on the sea surface is reflected. Kyba et al have recently pointed out that moonlight is more likely to occur with a lower illuminance of between 0.05 and 0.2lux[52]. The level of light returned from our diffuse reflector at this level of illumination is compared to that of the sea for each scenario in Table 24.

*Table 24. Modelled brightness of returned light in lumens sr$^{-1}$ from a moonlit night, reflected diffusely from a spherical target, compared with that reflected from the sea. Reasonable maximum and minimum values of moon brightness are given for Europe.*

| Scenario | Illuminance of moonlight at target / lux[52] | Returned luminous intensity / lumen sr$^{-1}$ m$^{-2}$ [a] | | |
|---|---|---|---|---|
| | | Diffuse reflector | Sea (reflection of clear moon) | Sea (reflection of light cloud) |
| 1. High up, pointing straight down | 0.05<br>0.2 | $1.1 \times 10^{-3}$<br>$4.6 \times 10^{-3}$ | 16[b]<br>63[b] | $3.4 \times 10^{-4}$<br>$1.3 \times 10^{-3}$ |
| 2. High up, pointing sideways | 0.05<br>0.2 | $1.1 \times 10^{-3}$<br>$4.6 \times 10^{-3}$ | 57<br>230 | $1.2 \times 10^{-3}$<br>$4.8 \times 10^{-3}$ |
| 3. Low down, pointing sideways | 0.05<br>0.2 | $1.1 \times 10^{-3}$<br>$4.6 \times 10^{-3}$ | 560<br>$2.2 \times 10^{3}$ | $12 \times 10^{-3}$<br>$48 \times 10^{-3}$ |

*[a] Calculated for Trakkabeam A800 and spherical target*

*[b] Geometry could only arise for limited times in the tropics (ie moon directly overhead), hence written in grey as impossible for EASA member states*

The calculation in Table 19 confirms that the brightness of moonlight diffusely reflected from a target will be very low, and impossible to discriminate from reflected light from the sea for light cloud conditions for all but very close operation. The reflection of a clear moon in water is potentially bright, as we might expect. This confirms the role of searchlights in night-time SAR. The luminous flux from a searchlight (Table 19) is significantly greater than that of the moon for all scenarios covered. However, even these high levels of brightness might be difficult to discriminate from the reflection of the night sky by the sea, for light cloud conditions. However, targets using retroreflectors (Table 22) will present a brightness contrast for conditions except where there is a clear reflection from the moon.

A further effect may also be present in night-time conditions. So—called visual “glitter” is the result of reflections from a strong light source (such as the moon or other searchlight) from the waves. As the waves move, different small areas of water enter and leave the region of high reflectivity, resulting in a dancing, glittering effect. The luminous intensity of the glitter could be greater than that of a retroreflective tape returning light from the light source, and could be manifest as many localised spots over a large area, making any other bright spots in the image difficult to discriminate. It is possible that the image analysis movement detector might help to discriminate glitter from the target, but the large difference in brightness between the two makes this task difficult. If the target is a diffuse reflector, the examples in Table 24 show that the glitter from the moon could dominate by 4-5 orders of magnitude. If the target has 100cm$^2$ of visible retroreflective tape illuminated by a searchlight, comparison with
Table 23 shows that this could be reduced to a factor of 2-3 orders of magnitude, which would still be difficult.

Glitter may have been a factor in the Morecambe Bay accident that inspired this study. Our interviews with SAR crew revealed anecdotal evidence (not referred to in the original investigation report) that the background scene was complicated by the presence of multiple searchlights from seagoing vessels in the area, turned on in response to the incident. Given that all the searchlights will have a similar white output, there is potential for colour contrast to improve the probability of detection in these conditions. In other words, if the target is a different colour from the sea, there may be the possibility to discriminate it.

In summary:

1. Even when using a searchlight, diffusely reflecting targets can be difficult to discriminate from the reflected night sky in seawater, if brightness of the target is the only source of contrast available.

2. For retroreflective targets, the light returned from the searchlight should appear brighter than the reflected night sky in seawater, but not brighter than the reflection of a clear moon or of reflected “glitter” from the moon, created by waves.

3. Given that level of nightglow in the SWIR is of the same order of magnitude as moonlight, these conclusions should be broadly similar for retroreflection and diffuse reflection in that region of the spectrum.

4. Glitter from the moon or other searchlights may add clutter to the background scene, making discrimination of a target on the basis of brightness difficult. Colour contrast would help in these conditions.

## 7.5 Infrared emission

We can assume that the temperature of the water lies between zero and 15°C, the latter being the temperature that requires use of an immersion suit. The potential temperature of the skin is dependent on various factors, therefore the calculations show the results for a range of values. Power et al have measured mean skin temperatures for volunteers wearing immersion suits while immersed in water of 8.5°C or 10.9° under different sea conditions[53]. They found that skin temperatures fell over time to between 26°C and 30°C after 3 hours; we have used these figures in calculations. For much colder conditions we expect the temperature difference between sea and skin temperatures to be greater, since the body will expend more energy in maintaining its core temperature, however the skin temperature might still drop over longer periods of time. The IR emission from these surfaces then depends on the emissivity multiplied by the Planck emission for a black body[50]. The emissivity of water has been extensively studied, both in pure form[58] as well as seawater[54], the latter both when roughened by waves and smooth. The colour of human skin has been shown to have little effect on its thermal emissivity in the mid IR. If we take the emissivity of skin to be close to unity[55] and that of water to be 0.95, the resulting Planck emission is shown as a function of wavelength in Figure 15. The calculation has been limited to the 3-5μm region, because this is the region of coverage for the IR cameras installed on SAR helicopters in the UK.

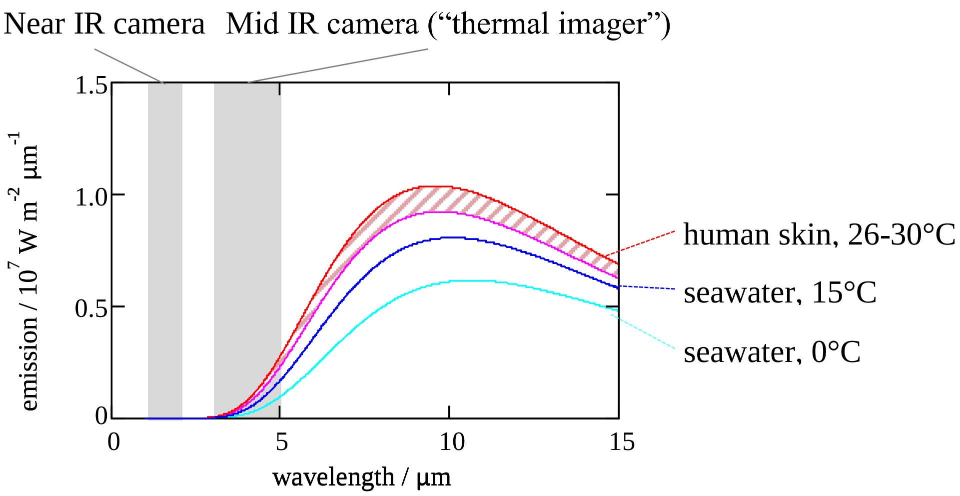



*Figure 14. Infrared thermal emission from human skin in the range 26-30°C and seawater at temperatures of 4°C and 15°C. Shaded regions show typical spectral response of infrared cameras used in SAR.*

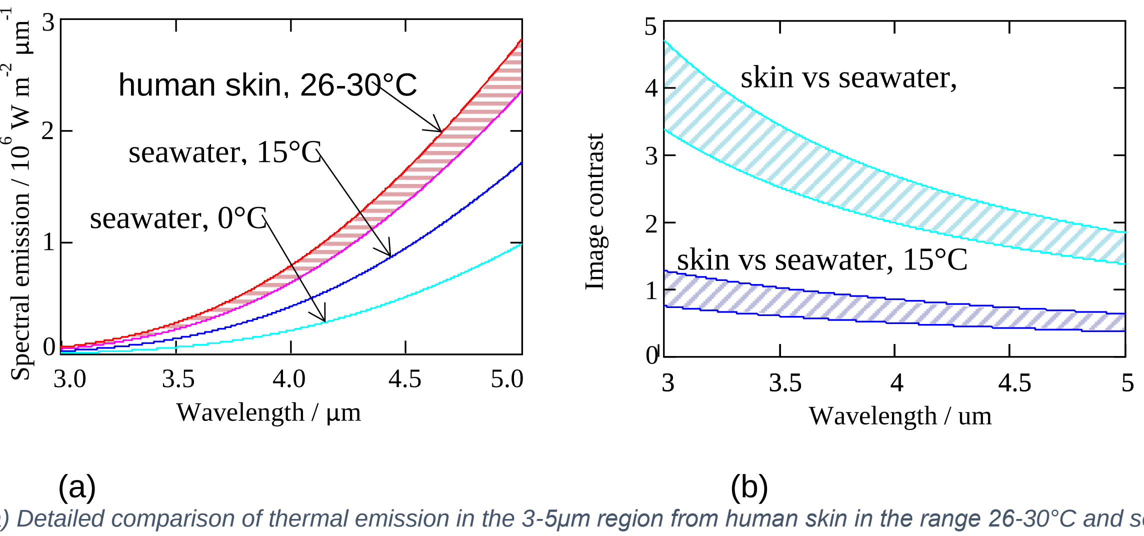



*Figure 15. (a) Detailed comparison of thermal emission in the 3-5μm region from human skin in the range 26-30°C and seawater at temperatures of 4°C and 15°C. (b) Corresponding image contrast between human skin and seawater.*

Although the contrast between seawater and the human body is not large, cameras often autorange the detected image so as to enhance the contrast, by showing only a selected region of the scale. This makes warm objects much more apparent. The limit to conspicuity is then given by the noise limit of the camera, known as the noise equivalent temperature difference (NETD), which for a high quality thermal imager in this range could typically be 50mK. There may also be other factors that improve the contrast, depending on viewing conditions: the refractive index of the sea plays a part in reducing the effective emission of seawater especially at glancing angles of incidence, increasing effective contrast.

A key conclusion from this analysis is that a mid IR camera is needed to detect the relative warmth of the human body. Although the searchlight has an IR component and the IR tape has retroreflection in the IR region, these are likely to be limited to the SWIR and near IR regions, with a possible cut-off wavelength somewhere in the 2-3µm range, depending on the materials used. It is possible that neither the IR glint tape considered in this study, nor standard searchlight used in SAR, will provide a response in the mid-wave infrared (MWIR) region of 3-5µm, and if this is the case, test plans need not use a test mannequin whose thermal profile matches that of the human body. This supposition should be tested in the first part of the experimental programme.

## 7.6 Wet and underwater objects

The transmission of light in seawater is dominated by two processes: absorption (by pure water, dissolved matter and particles present) and scattering (mainly by particles). The reader will be familiar with the idea that the clarity of seawater is highly variable. In the worst case, light transmission is dominated by scattering and this can be enhanced particularly in estuaries[56]. Light scattering effects are more pronounced at shorter (blue) wavelengths and much less pronounced at longer (red and infrared) wavelengths, but nevertheless they can still be significant.
There has been considerable research into the transmission of seawater in the visible (400-700nm) region, however there have been few reports covering the near infrared region of 700-900nm. Doxoran *et al* have considering the scattering coefficient of highly turbid waters[56], whereas several authors have measured the absorption coefficient of pure water[57,58].
Table 25 summarises experimental measurements of absorption and scattering coefficients in natural seawaters. The effects of absorption and scattering are additive according to the Beer-Lambert Law, such that the transmission $T$ through and distance $d$ of water is given by:

$$T = \frac{I}{I_0} = 10^{-(\alpha_a + \alpha_s)d} \qquad (4)$$

where $I$ = transmitted light intensity, $I_0$ = initial light intensity, $\alpha_a$ = absorption coefficient and $\alpha_s$ = scattering coefficient.

*Table 25. Absorption or scattering coefficients of seawater in the visible and infrared, and its consequences for light intensity reduction according to equation (4).*

| Effect | Absorption or scattering coefficient / $cm^{-1}$ | | Conditions |
|---|---|---|---|
| | Visible (550nm) | SWIR (700-900nm) | |
| Absorption of pure water ($\alpha_a$) | 0.02 | 0.9 (800nm) | Laboratory, [58] |
| Absorption of phytoplankton, dissolved matter etc ($\alpha_a$) | 0.005 to 0.7 | < 0.1 (to 750nm) | Mediterranean, Baltic, North Sea, Atlantic, [59] |
| Scattering by particles ($\alpha_s$) | 1.5 to 100 (555nm) | 1.2 to 90 (767nm) | Estuaries: Tamar, Elbe, Gironde, [56] |
| Total combined effect | 1.5 to 100 | 2.1 to 90 | Dominated by scattering in estuaries |

| Consequence | Distance of water (*d*/2) / cm | | Conditions |
|---|---|---|---|
| Distance at which light intensity *T* reduced to 10% | 33 to 0.5 | 24 to 0.6 | Based on reflection at each depth, double pass |
| Vertical depth of object for viewing angle of 87° (scenario 3) | 1.7 to 0.03 | 1.3 to 0.03 | |

Note that for the largest angles of incidence considered (Scenarios 2 and 3) the level of light reflected from the water is significant; the water may therefore act to increase the projected area of the target and its apparent brightness.

If a retroreflector sent photons back exactly along the path they arrived on, there would be no effect of optical scattering: each photon would be scattered on its return path in exactly the same way and would remain within the narrow cone of detectable back-reflected light. However, this is not the case. Each type of retroreflector displaces the photons by a small amount laterally and therefore, for scattering particles of a similar or smaller diameter (which most are), the return path scattering will be different, and many photons are removed from the narrow cone of detectable light.

The consequence is that the visibility of any object, including a retroreflector, cannot be taken for granted for depths of below a few mm in water, though visibility at depths of up to 20cm might be possible for non-estuarine waters with low levels of reflected light from the sky. The effect of the water would cause a reduction of returned light intensity of 10% for a water depth of between 5mm (worst case) and 30cm (best case) (note that the light must pass twice through the water in this case). Because of this reduction, any calculations in this report about the level of returned light take the simplifying assumption that submerged tape is not detectable.

Water that splashes onto an immersion suit must also be considered. The reader will be aware that retroreflective tapes used in standard workwear are relatively unaffected by droplets of rain. The reasons are as follows. First, the material itself tends to encourage the formation of water beads, which run off. Old, worn material is less likely to form effective beads of water. Second, the droplets themselves can change the direction of light passing through them via refraction, however because they are significantly larger than the lateral displacement of the light by the retroreflector, this effect is minimal. Third, the depth of water present is only a few mm, and therefore unlikely to have a significant effect on transmission, even for the most turbid waters. Indeed, the SOLAS standard for retroreflective tapes[60] specifies that measurements of retroreflectivity shall not be degraded by more than 80% when tested in a continuous flow of clean (tap or distilled) water. Therefore the apparent brightness of a retroreflective tape is unlikely to be significantly reduced, but in estuaries with significant splashing eg from waves, there might be a measurable reduction in brightness.

In summary:

1. Any part of an immersion suit or other safety equipment that is submerged under water can be considered invisible to SAR equipment.

## 7.7 Spectral compatibility of SAR equipment

Figure 16 shows the spectral responses of different equipment involved in SAR, including sources, detectors and potential target materials. The data has been compiled from a variety of sources: standard irradiances from the sun and night sky, knowledge of the type of lamp used in the searchlight, standard photopic response of the human eye, calculation of human body emission , examples of NVGs in use, detector turret specification, informal knowledge of filter wavelengths (inferences made), measurements and inferences concerning potential materials.

Data on retroreflectivity over different entrance and observation angles is not generally available and it may be that the specialist laboratories who test retroreflectivity in the visible could not do such testing without investment in their apparatus. However, such detailed testing is not considered so important, since the mechanism of retroreflectivity is only marginally affected by wavelength. Instead, the effect of wavelength is related to absorption of light by materials used in the retroreflective films. Especially as the wavelength lengthens into the IR region, many materials experience a cut-off beyond which they can no longer transmit light. The wavelength at which this occurs depends on the materials used and their depth; typically such effects can occur in the 2-4μm region. For example, silica and other glasses that may be used as a window for lights, can have absorption bands in the 2-3μm region and a cut-off beyond 3.5μm, and many polymers can show absorption beyond 2μm. Once into an absorption region, the effect of entrance θ is to increase the distance travelled through the material by $1/(\cos\theta)$, therefore higher entrance angles will experience a greater reduction in retroreflectivity. The consequence of this is that within the SWIR region corresponding to the response of NVGs, the proportion of photons that are retroreflected will be similar to that at any wavelength in the visible, and the cone of angles over which retroreflection takes place will also be similar. Therefore, instead of detailed testing over different angles, a better approach is to test the visibility of commercially available tapes using existing light sources and detectors.

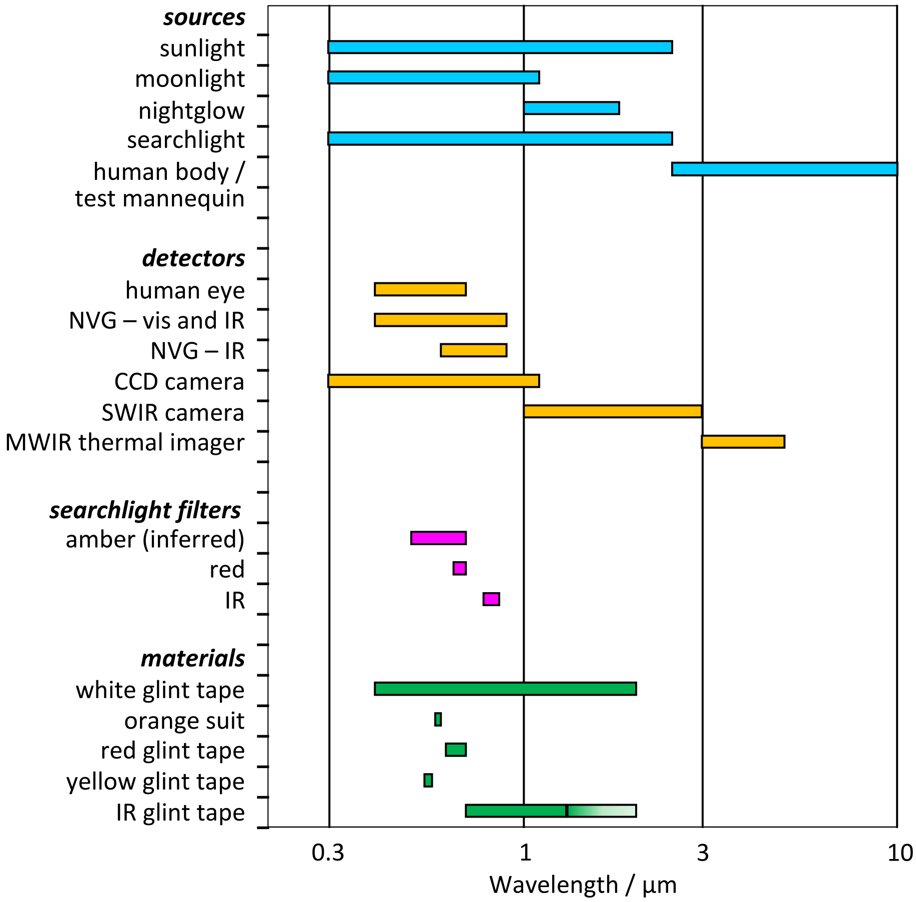



*Figure 16. Spectral responses of equipment involved in SAR, compiled from a variety of sources. Some of this information has been inferred where detailed measurements are not available.*

The following conclusions can be drawn from this consideration of spectral response:

1. Testing of glint tape may be limited to the emission spectrum of the searchlight and need not involve use of a thermal imaging (MWIR) camera.

2. A test mannequin that matches the IR emission of the human body is not required for testing since its emission will not be detected by any of the equipment necessary for testing glint tape. Although there is a small degree of overlap between the response of the SWIR camera and the human body emission, in the region 2.5-3µm, the emission in this region is very low. A functional test of this assertion may be made using a human body without immersion in water.

Data on a number of aspects of spectral response was unavailable, and therefore the following functional tests would fill gaps in our knowledge:

1. Visibility of different colours of glint tape (including IR tape) using a searchlight and cameras operating in different wavelength bands.

2. Visibility of white and coloured glint tape (including IR tape) using a searchlight with installed filters.

## 7.8 Enhancement of conspicuity

This review began with consideration of the element of visual perception that can provide detection of a target. Here, we consider which aspects of these are enhanced by the use of retroreflective tape. We also consider issues for the cockpit, since the decision to use conspicuous or dark flight suits has supposedly rested on their effect on conspicuity of cockpit indication light and reduce unwanted reflections from windows. The effect of different types of retroreflective tape in each of these areas is summarised in Table 26.

Retroreflective tape has potential to improve the brightness of a target significantly compared to the use of a bright diffusely reflective material, even when we take into account the sparing use of retroreflective material. For this to be achieved, the SOLAS guidelines on the amount of material used should be met, and placement should be prioritised to those areas likely to be above water. When applied to different parts of the suit (e.g. around wrists, ankles, on head and shoulders) there is potential to improve perception of the human form. However, this is more relevant to the later phases of SAR and unlikely to be perceived during the initial detection phase, which operates at the limit of resolution. There is potential for coloured tapes to improve colour contrast of a target.

## 7.9 Conclusions

1. Retroreflective tape is designed to be detected in the visible region. Especially at long distances, the amount of light reflected from a searchlight back to a detector is significantly higher than for a diffusely reflecting object such as orange fabric.

2. For the reflection from glint tape to be detected by a mid IR camera, a mid IR light source needs to be used. The light sources typically used in SAR are designed to have high levels of visible and near IR, but may have some mid IR content.

3. We should assume that submerged objects, including retroreflective tape, are not visible either to the eye or to detection equipment.

4. If the position of such tape on clothing is to be prioritised, it should be placed in those locations least likely to be submerged in rescue operations. Note however that a number of images of people wearing immersion suits in water show that their feet are close to or above the top of the water. Dead bodies are understood to float with the lower back close to the water surface. Therefore, there is an argument for placing glint tape around the ankles and on the lower back.

5. Splashing by water is unlikely to cause significant problems unless present in highly scattering (eg muddy) estuaries.

6. Colour contrast remains an important factor in conspicuity and may have provided contrast against white glitter in the background scene during the Morecambe Bay SAR operations.

*Table 26. Summary of effects of glint tape on conspicuity and potential issues associated with its deployment*

| Form of contrast | Type of retroreflective tape | | |
|---|---|---|---|
| | Visible, white | Visible, coloured | Infrared |
| Effects on conspicuity | | | |
| Visibility / brightness | Increased for human eye, NVGs, CCD cameras, the more used the better. Uncertain for SWIR camera, unlikely for mid IR camera | Increased for human eye, visible CCD camera (but not by as much). Uncertain for low light CCD and SWIR camera. Unlikely for mid IR camera | Increased for NVGs and low light CCD camera, uncertain for SWIR camera, unlikely for mid IR camera. |
| Form / shape | Can enhance form / shape used in targeted locations on body | Can enhance form / shape used in targeted locations on body | Can enhance form / shape used in targeted locations on body |
| Movement | Movement of arms could be enhanced | Movement of arms could be enhanced | Movement of arms could be enhanced |
| Colour | Limited effect (white contrasts with dark sea but not reflections from sun / clouds / moon) | Strong positive effect especially for red and yellow tape | No colour information available with NVGs – display is monochrome |
| Issues | | | |
| Cockpit reflections – daytime flying | Could be problematic for forward-facing elements of suits<br>Rear-facing elements not problematic? (RAF fly with tape in cross shape on helmets[37]) | Could be problematic for forward-facing elements of suits, however SAR pilots fly with bright orange suits and RAF fly with tape on helmets<br>Rear-facing elements not problematic? | Slightly increased reflection from light at glancing angles of incidence as IR filter has smooth surface sheen |
| Cockpit reflections – night-time flying | As above, but worse? (reduced overall background light, individual reflections more conspicuous) | Main source of light for reflections is inside cockpit. Potential for coloured clutter within cockpit. | As above, but worse? |
| Cockpit reflections – NVG flying | Limited effect – cockpit lights already NVG compliant | Limited effect – cockpit lights already NVG compliant. | No effect since tape is designed to be NVG-visible. Potentially problematic for forward-facing elements of suits. |

# 8 Critical issues for testing and use

Here, we bring together a number of recommendations for testing taken from the previous sections of this report.

## 8.1 Equipment

Testing will make use of standard issue Bristow equipment including a high specification FLIR SAR turret and Trakkabeam A800 searchlight. NVGs should be of generation 3 (which is likely), however, because of the wide variety of NVGs in use, there may be differences even between issued items.

The spectral performance of the Trakkabeam A800 is likely to be representative of other searchlights and will therefore be suitable for assessing colour contrast.

Test results should be broadly comparable between alternative searchlights and turrets used in this application. In particular, the spectral response of different systems is often similar, with differences being confined to levels of light power available or imaging resolution. This will allow for appropriate assessment of colour contrast for example.

Tests involving NVGs should be carefully designed in order to avoid any potentially confounding factors created by the operation of NVG auto-gating.

## 8.2 Functional and onshore tests

Testing of the coefficient of retroreflectivity of glint tape is not required in the IR region, since the mechanism of retroreflectivity is only marginally affected by wavelength. These tests concern not the retroreflectivity, but the potential for absorption of radiation by the materials and coatings concerned. Testing should include:

1. Brightness of different visible colours of retroreflective tape (including IR tape) using a searchlight and cameras operating in different wavelength regions.

2. Brightness of white, coloured and IR retroreflective tape using a searchlight with installed filters

3. Brightness of a test object containing different proportions of orange and standard tape, tested with human beings and using image analysis software to see whether the resulting diluted colours may be detected by the software.

4. Brightness of different areas of the image of a test mannequin wearing a flight suit and imaged using the searchlight and SWIR (1-2.5μm) camera, comparing image differences when heated and unheated.

5. Pilot feedback on the potential use of IR glint tape in flight suit materials, benchmarked against more conventional suits that are bright orange and use conventional tape applied to the same areas.

Testing should include both types of commercially available SOLAS approved retroreflective material as the base material. Given that the coefficient of retroreflectivity is difficult to measure at low observation angles (below 0.1°) in test laboratories, a subjective test should be made to observe such materials at lower angles (over longer distances). This is particularly relevant to the material manufactured by Orafol.

It would be helpful to benchmark the conclusions of our illustrative estimates of object brightness using SAR planning software, if this is available.

## 8.3 SAR detection

1. Testing over distances of 1km should be practical and can be related to performance benchmarks used to specify searchlights. Testing should ensure that optical resolution of the target is similar to that in real SAR operations. Testing should therefore use long distance to targets (e.g. 1km) or target size should be scaled down.

2. Test mannequins are appropriate objects for a test, since they have the right proportions and attitude for a potential casualty. They may not need to be heated to provide a thermal infrared signature; the functional tests above will be used to confirm this experimentally.

3. Tests should include both standard retroreflective material applied according to SOLAS guidelines, as well as coloured retroreflective material applied in addition to standard white material, using the optimum proportions identified in the onshore tests.

4. If conditions allow, tests should include the effects of reflected light on seawater from the reflected night sky and from a nearby searchlight.

# 9 Conclusions

Airborne search and rescue over the sea is a difficult remote sensing operation involving both human perception and technical optics in the visible and infrared regions. The appearance of the sea differs from the land in a number of respects:

1. It is generally more uniform in colour, with colour min the blue / green region of the CIE chromaticity diagram.

2. Reflections from the sea are dominated by light reflected specularly from the sky rather than diffusely from objects.

3. In images, these reflections move with wave motion and with the relative motion of the helicopter.

4. It may contain significant white “glitter” with a dancing motion.

5. Much of the body of a casualty is obscured by being underwater.

Target detection requires generation of contrast between the target and the background, and this may be performed at the limits of optical resolution where pattern and form cannot be distinguished. A consequence is that colour contrast of a target is an important aid to the early detection phase of helicopter-borne SAR over the sea. Therefore, there may be potential to improve the conspicuity of flight suits in several ways:

1. To provide bright orange cotton flight suits for hot conditions, ensuring human comfort without compromising conspicuity.

2. To use coloured (orange) retroreflective tapes, increasing colour contrast especially at large distances and making use of image recognition software, which is reported to detect a minimum of 3 orange pixels in a scene. As the coloured tape does not meet the SOLAS guideline, it would have to be provided in addition to the SOLAS-recommended quantity of SOLAS-approved tape.

3. There may be untapped potential to improve contrast using other developments of technology (outside the scope of this project) for example using modulation and polarisation.

4. Where crew choose to use dark flight suits in order to reduce cockpit reflection (rather than for human comfort) the use of IR glint tape would increase the suit conspicuity but would not make the suit as conspicuous under all conditions as either orange fabric or standard retroreflective tape.
5. IR glint tape would be detectable using a standard searchlight with CCD camera or NVGs. It cannot meet the SOLAS standard for retroreflectivity.

The use of IR glint tape only provides a potential advantage in respect of reducing cockpit reflections in the visible region. Compared to conventional tape, it would not reduce cockpit reflections in the SWIR region, relevant to NVG flying. There is no advantage of using the tape to SAR targets as the tape would be no brighter in the SWIR region than its conventional counterpart.

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