Safety Science, Volume 130, October 2020, Article number 104903
DOI: 10.1016/j.ssci.2020.104903

Modified immersion suits for helicopter aircrew: Evidence for improved conspicuity from sea trials

Jim Nixon, Jane Hodgkinson and Christopher Bennett

Abstract

In this article we evaluate a modified immersion suit for use by helicopter aircrew. Helicopter aircrew operating over water are subject to international regulations which govern the personal protective equipment and clothing worn. Our modification increases the area of retroreflective material in a unique configuration. Highly reflective materials can cause unwanted reflections in the cockpit and data as to their efficacy in improving conspicuity in rescue at sea has not previously been captured. In this study we address this problem. Two methods were developed to test the acceptability and efficacy of a modified immersion suit to improve conspicuity in rescue operations at sea. Firstly, land-based trials employing subject matter experts were conducted to assess the tolerability of reflections in the cockpit from the modifications made to the immersion suit. Secondly, trials at sea using UK search and rescue teams captured data to assess the efficacy of the modification. Our results provide preliminary evidence for the acceptability of the modified immersion suit design and that the modification improves conspicuity in night time conditions, measured using the distance at which a target is detected. Our results support re-examination of the standard associated with passive lifesaving systems in helicopter aircrew immersion suit design to include an increase in the area of retroreflective material in the proposed novel configuration. Finally, our results support the use of coloured retroreflective tape to provide increased visual contrast, especially where this colour is coordinated with the main suit fabric.

Keywords

Conspicuous, Search and rescue, Helicopter, Immersion suit, Retroreflection, Lifesaving

Highlights

- The performance of a conspicuity modification for aircrew flightsuits was evaluated.
- New methods were used to test the modification in airborne search and rescue.
- Results indicate the modification can improve the conspicuity of casualties at sea.
- Modifications were broadly acceptable to flight crew.
- The area of reflective material on flightsuits could be increased.

1. Introduction

Offshore helicopter flights are a necessary element of, for example, offshore oil and gas operations but these operations incur a higher degree of risk than fixed-wing, civil operations (Great Britain. Parliament. Transport Committee, 2014). In Europe, passengers are required to wear safety immersion suits that demand the inclusion of a retroreflective system meeting the European Technical Standard Order (ETSO) 2C503, 2006. Retroreflective materials reflect light from a source, for example a searchlight, back to the helicopter with high optical efficiency. Refection from the illumination source delivers a visual cue that distinguishes it from the background. This visual cue is then detected by search and rescue (SAR) services. New technologies that exploit retroreflective materials using computer vision are also becoming available to assist aircrew (Lygouras et al., 2019; Gotovac et al., 2016). These developments mean that is likely that retroreflective materials will continue to be an important part of search and rescue operations in the future.

Improving the conspicuity through modification of the retroreflective material is one way to reduce the amount of time taken by crew to identify a target and this forms the focus of research presented in this article. Immersion suits are designed to be highly conspicuous allowing detection of a casualty by SAR operations in the event of an accident. However, widespread adoption of such highly conspicuous suits by *flight crew* in the cockpit presents unique challenges. The use of highly reflective materials in the cockpit could lead to distraction and unwanted reflections. The ETSO standard acknowledges this issue, allowing dark-coloured flight suits to be worn by crew if cockpit reflections are considered a risk to flight safety.

In 2006, a helicopter accident in Morecambe Bay, UK, resulted in the loss of the crew despite extensive searches of the area. The UK Air Accident Investigation Board (AAIB) report relating to the accident (AAIB, 2014) made specific reference to the lack of visual conspicuity of the crew flight suits being an aggravating factor, making rescue more demanding and decreasing the probability of detection and hence the chances of survival of the casualties involved. The report recommended that the potential for increased use of retroreflective tape on crew flight suits be investigated. We address this recommendation in this article.

For successful rescue, casualties must be identified by SAR services, in often challenging conditions. Airborne search and rescue is a high-technology service that demands skill and specialised equipment to support rapid identification of casualties from the air. The more conspicuous a casualty, the higher the likelihood of detection and subsequent rescue. Conspicuous is defined in the dictionary as 'clearly visible' (OED, 2018). SAR crew rely the naked eye together with an array of supporting technologies that allow enhanced visualisation of the scene across different regions of the spectrum. These regions include the visible region, near infrared (serviced by near infrared [NIR] cameras and night-vision goggles [NVGs]) and mid infrared (using thermal imaging cameras). Different cameras detect the heat signatures of casualties as well as light reflected from the suits worn by casualties. Light from the sun or moon may be diffusely reflected by the standard fabric used for the suit. Light from an on-board searchlight may be retroreflected by specialist materials applied to the suit. In this article we propose and evaluate a new modification made to personal protective equipment (PPE) worn by helicopter flight crew, specifically their immersion suits. The modifications made to the immersion suits are designed to improve the conspicuity of casualties at sea, improving the chance of rescue or recovery and increasing the likelihood of casualty survival.

The contribution of this article is fourfold. Firstly, we demonstrate an evaluation methodology for the potential for visual distraction of modifications to existing immersion suits in the cockpit environment. This methodology could be used to test a range of modifications to PPE, beyond those described here. Secondly, we introduce specific modifications to improve conspicuity and test these modifications. Thirdly, we present a methodology for testing the conspicuity of standard and modified PPE in a realistic SAR scenario at sea. Fourthly, we present evidence that the proposed modification improves conspicuity of casualties at sea in certain conditions. The data used to inform these conclusions has been captured using trials with current SAR pilots and full-scale sea-trials that are rarely available to the research community. We begin by considering the SAR service and the need for high conspicuity of casualties at sea in SAR operations. We then consider the regulatory framework that governs the PPE worn by aircrew operating in these environments. We proceed to explore the concept of conspicuity more widely and examine the literature associated with conspicuity and link this literature to the novel application presented in this research.

1.1 Search and rescue operations

SAR operations are under the joint auspices of the International Civil Aviation Authority (ICAO) and the International Maritime Organization (IMO). Procedures are documented in the three volumes of the International Aeronautical and Maritime Search and Rescue Manuals (IAMSAR), published jointly between ICAO and IMO (IAMSAR Volumes 1 -3, 2016). The goal of the search process is identification and rescue of the target. Rapid target acquisition improves the chances of survival, reducing the severity of hypothermia, dehydration or sunburn that can occur in protracted rescue operations. Helicopters are the preferred airborne platform used in SAR given their endurance and application to low-altitude tactical operations. In the UK, the twin-turboshaft Agusta Westland 189 and Sikorsky S-92 helicopters are employed. Typically, four flight-crew operate the aircraft: two pilots and two rear-crew. One of the rear crew is responsible for operation of the electronic equipment on board the aircraft used to detect casualties, and the other is a trained winch man. Rear crew are also medically trained to provide lifesaving care to casualties. Advanced features to aid the identification of casualties in both land and sea operations are available to crew. These features are supported by a suite of camera and lighting technologies together with the use of NVGs by the pilots. These technologies can exploit the variety of innovations present on lifesaving devices and other PPE to hasten target acquisition, including the passive retroreflective systems examined in this article.

1.2 Aircrew PPE and conspicuity

All helicopter pilots and their passengers flying over water are required to wear standard regulation PPE that includes immersion suits and life jackets. Immersion suits and life jackets typically have a variety of passive and active life saving devices. An example of an active device is a beacon that emits a locating signal on contact with water. In this article, we consider a passive lifesaving device, the retroreflective system that is typically provided using highly reflective materials positioned on the PPE itself.

PPE conspicuity is addressed specifically in the ETSO 2C503 standard (ETSO, 2006) ETSO-2C503 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 arises from potential visual interference from reflective surfaces on the flight suit *itself*. This interference represents a unique challenge for the provision of passive, retroreflective systems that increase aircrew conspicuity. We cannot simply increase the area of retroreflective material to reduce risk in rescue, without potentially generating *new* risks associated with glare or reflection from the retroreflective material in the cockpit. Our empirical and methodological contributions presented in this research can be used to inform changes to this standard and a way in which to test and evaluate modifications. Visual conspicuity has been studied in relation to PPE. Performance shaping factors relating to pedestrian and motorcyclist conspicuity are represented in the literature (for example Tyrell et al., 2016; Wali et al. 2019). Our research presents a study of conspicuity in a new domain, search and rescue at sea. Necessarily this domain presents significant challenges and constraints for the study of conspicuity.

Perceptual and other cognitive processes play a role in constraining what is perceived depending on the context and expectation (Edgar and Edgar, 2016). As such, something that is illuminated *and* present in the environment might not necessarily be conspicuous. Conspicuity is defined variously as the degree to which an object may 'stand out from its surroundings' Lesley (1995, p17) or objects that 'pop out' from the background (Engel, 1971). Environment is a key element of conspicuity. For example, an individual could be technically visible, but inconspicuous when viewed against a rough sea. Examination of road traffic accidents has furthered understanding of the factors that can modify conspicuity as applied to humans. Langham et al. (2002) 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. Van Bommel and Tekelenberg (1986) report that contrast is a key variable when considering pedestrian conspicuity. Contrast is the difference between the lightest and darkest areas of any scene. The higher the contrast between the object of interest, for example the target causality in a rescue operation, and the background, for example a rough sea, the greater the conspicuity. Making a scene brighter overall may simply amplify everything, *including* both the target, and therefore may not necessarily improve the probability of detection. Indeed, van Bommel and Tekelenberg found that the addition of light could actually reduce contrast sensitivity. In an applied study of motorcycle riders, Hole *et al.* (1996) also argue that brightness contrast is a key parameter of conspicuity. So-called contrast enhancers such as retroreflective materials can be especially useful in generating high visual contrast when exposed to illumination such as car headlights (Luoma et al., 1996). We employ retroreflective materials as the way in which to improve conspicuity in this research.

Choice of colour is also an important decision when considering retroreflective systems. For example, the lime-yellow colour applied to emergency vehicles in Europe is highly conspicuous in urban and rural environments given the background colours found in these environments. The literature on choice of colour is sparse. However, early experimental research demonstrates the effectiveness of reds, yellow and oranges in support of conspicuity (Michon et al., 1969). Later research continues to support the use of colour contrast in support of conspicuity of PPE (for example Tuttle et al., 2009; Vijayan et al., 2016).

The location of retroreflective material to improve pedestrian conspicuity has also been studied. Moberly and Langham (2002) found that detection performance improved when pedestrians were moving rather than stationary. Luoma *et al. (1996)* and Luoma and Penttinen (1998) found that conspicuity could be increased further in moving pedestrians by positioning retroreflective material in accordance with the principles of biomotion. Retroreflective areas should be positioned on major joints and extremities. Pedestrians have a more predictable visual profile than casualties in the sea; they are generally upright and moving forward. This is not the case in SAR operations where casualties may be in a variety of positions, with only part of the body visible, and subject to the movement of the sea. However, we use these principles pragmatically when specifying the location of the retroreflective materials on the modified suit.

1.3 Research aims

This research aims to evaluate a modification made to the passive, retroreflective system on a current regulation immersion suit to improve conspicuity, reducing the time taken to detect the target. To address this aim two studies are reported. Firstly, we develop a method to evaluate the reflectivity of different retroreflective materials compared to current regulation standard. This study meets the concern raised by both the UK AAIB and the caveat in the ETSO standard. Two colours of retroreflective material are compared to a current immersion suit: silver and orange. Silver tape is currently used in high-visibility applications and is available to marine standards. Resources allowed the testing of one colour in addition to silver. Orange was selected as the candidate, coloured retroreflective material. Orange is not a colour found naturally in marine environments and as such has good colour contrast with the predominantly blue, green and browns found in this environment. In addition, the orange coloured tape was available to an identical physical specification as the silver coloured tape. Secondly, we progress to a full-scale sea trial using the modified passive retroreflective system and compare this modification to the current regulation suit.

2. Cockpit Reflectance Trials

In this trial, a number of different retroreflective materials were applied to a current regulation immersion suit in a pre-determined configuration to assess reflections in the cockpit. The design exploited areas of the body that define human movement areas likely to be above the water when treading water or floating and avoided the areas covered by the standard issue life jacket.

2.1 Method

Design

A subject-matter expert (SME) panel made subjective judgements about the reflectivity of the suits within the cockpit environment. These judgements were captured diagrammatically on a card by the researcher that showed a cockpit schematic diagram incorporating displays and controls of the aircraft (Figure 1). Any other comments were recorded by the researcher. Environmental conditions were recorded on a card for each trial (Figure 2). All SMEs completed the test whilst wearing each suit configuration in turn (current standard suit, current standard suit with silver retroreflective material, and current standard suit with orange retroreflective material), in both day and nighttime conditions. Suit order was counterbalanced between the three participants. Light readings from three different areas of the cockpit were taken using an RS 136 Chroma meter, and the arithmetic means of these measurements are reported.

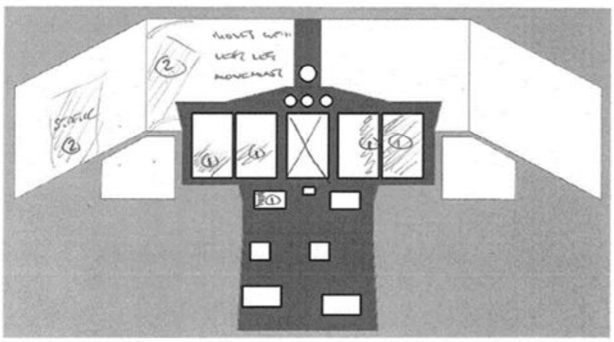

Figure 1 Example cockpit schematic on which reported reflection locations are recorded.

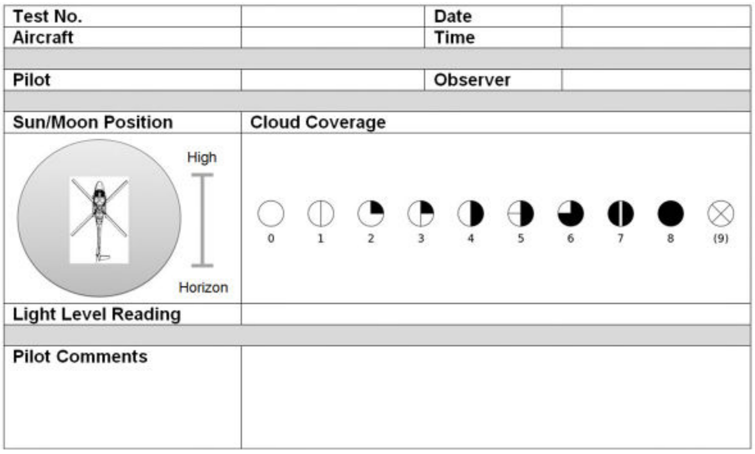

Figure 2 Test card completed by the researcher.

Participants

All SMEs gave written informed consent to participate in the study. SME's were current UK SAR captains. Table 1 shows additional details of SME experience. Age is shown in ranges to protect the identity of participants. We formed an expert panel consisting of aircrew currently employed in civilian UK SAR to complete the initial assessment of suit reflectance. Despite the modest sample size, we claim that the data collected is of high quality because such crew are trained in providing detailed, specific and repeatable information in cockpit environment in their roles.

Table 1 Details of SMEs who participated in the reflectance trials.

SME	Additional expertise	Age	Background	Reported hours across all types flown to the nearest 50 hours
1	Helicopter test pilot.	51-55	UK Royal Air Force	5000
2	Helicopter instructor, training officer, force standards officer.	35-40	UK Royal Navy	4000
3	-	41-45	UK Royal Navy	3500

Retroreflective materials

Immersion suits were modified using two different types of retroreflective material. Firstly, the silver, industry standard Orafol Oralite FD1404 Imo Flex (SOLAS Approved). Secondly, an orange coloured variant of this retroreflective material by the same supplier, reducing colour contrast with the orange suit while remaining highly reflective was also tested. The Orafol Oralite silver material already on the suit around the ankles remained on the suit during the trials. Pilots also wore current regulation life jackets throughout the tests.

No current configuration of reflective retroreflective material on the body is directly applicable to the application described. As such, a pragmatic approach was taken. The current suits have retroreflective material only around the ankles. The modified design (Figure 3, Figure 4) sought to achieve two aims. Firstly, to increase the area of retroreflective material to increase the probability of detection due to increased conspicuity. Secondly, to apply retroreflective material defining the extremities of the body: the legs, shoulders and arms corresponding with the literature associated with road-safety. Retroreflective material on the arms was positioned on the inside of the forearms since crew report that casualties may wave at rescue crews. 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.

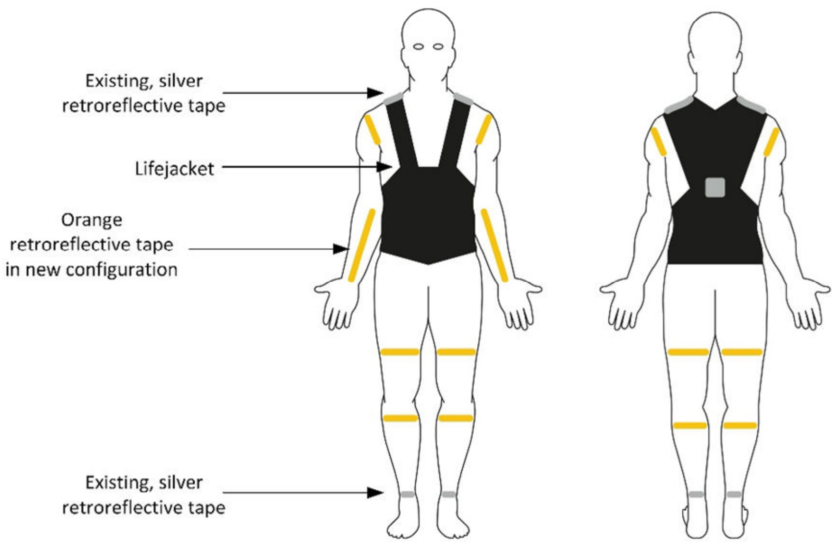

Figure 3 Configuration of retroreflective materials on immersion suit.

Figure 4 Test pilot wearing a current standard immersion suit modified with orange retroreflective materials.

Procedure

The donned a suit configuration and an identical suit was also worn by the researcher (CB). The SME was seated in the commander seat (right-hand side of the cockpit). In both day and night 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 2.

Table 2 Movement protocol used in each reflectance trial.

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.

The SME was asked to sketch any areas of the windscreen or instruments where reflections of the suit were apparent on a cockpit schematic when working through the predetermined movements. SMEs were also asked to rate the level of glare caused by reflectance on a published scale (Hopkinson and Collins, 1970). This scale ranges: not perceptible, just perceptible, just acceptable, just uncomfortable, just intolerable. The location of the reflections were recorded on the cockpit schematic. The researcher recorded any other comments made by the SME, and then recorded data relating to the lighting conditions on the environmental test card.

2.2 Results

Reflectance trials were conducted at different times of the day to capture a variety of different conditions (Table 3). Daylight tests were conducted in direct and indirect sunlight.

Table 3 Sun positon, cloud cover and cockpit light levels for reflectance trials.

Trial	Sun position	Cloud cover(Okta)	Light reading (lux)
Daylight	10 – 12 O'clock	0 - 5	1400 - 5800
Dusk	Below horizon	4 - 8	10 - 120
Night	N/A	4 - 8	0.2 – 3.4

Results from the daylight reflectance trials are shown in Table 4. Reflections reported in night conditions comprise three noted as 'just perceivable' in the left side window in the current regulation suit. No other reflections were noted in any other condition during night conditions and as such, these results are not tabulated. There were no reports of 'just intolerable' reflections in any trial and three reports of 'just uncomfortable' reflections. These reports arose during daylight testing of the suit modified with orange *and* silver Orafol retroreflective materials when in direct sunlight. Both reflections occurred in the left-hand side window and originated from the co-pilot's shoulder hoops. Furthermore, pilots commented that the reflections from the orange coloured retroreflective material were less distracting than the reflections from the silver retroreflective material due to the reduced colour contrast against the orange immersion suit. Across all trials, there were 13 reported reflections of 'just acceptable' reflections and 29 of 'just perceivable'. SMEs also reported that reflections that move could lead to the greater distraction, in particular, the lower leg retroreflective materials when operating the foot pedals. Based on this finding, the lower leg retroreflective material was positioned further down the leg so that it locates below the knee when the pilot is sitting down. This modification will reduce the risk of reflections in the lower left and right windscreens.

Results indicate that retroreflective material around the shoulders have the greatest potential for distraction because of unwanted reflections. However, SMEs acknowledge the benefit of additional retroreflective material in these areas to aid conspicuity of a casualty in the water for reasons described above. No intolerable reflections were reported across any of the modifications tested.

The positioning of the retroreflective material on the suits, in terms of flexibility and comfort, was also reported to be acceptable. Clearly, additional reflective retroreflective material may be applied to the back of the immersion suit without risk of cockpit reflection.

Table 4 Judgements from day reflectance trials.

Suit type	Location of reflection	Number of reflections reported at each scale point*		
		Just perceivable	*Just acceptable*	*Just uncomfortable*
Current Regulation Suit	Left Side Windows	1	2	0
	Right Side Windows	0	0	0
	Instruments	10	1	0
Suit with silver retroreflective material	Left Side Windows	0	2	1
	Right Side Windows	2	1	0
	Instruments	2	2	0
Suit with orange retroreflective material	Left Side Windows	0	3	2
	Right Side Windows	1	1	0
	Instruments	4	0	0

*No 'just intolerable' reflections were reported in any trial and as such this scale-point is omitted from the table

3. Flight testing

In this series of tests, the modified design and current standard immersion suits were compared in a series of realistic search scenarios at sea. Based on the outcome of the reflectance trial the orange retroreflective material was evaluated in the flight-testing. The orange colour has advantages in terms of colour contrast at sea and no evidence of intolerable reflection was found in the reflectance trials. In addition, SMEs reported the reduced colour contrast with the immersion suit less distracting. The flight tests were designed to assess any conspicuity benefit secured by using the modified immersion suit as compared to the current regulation suit.

3.1 Method

Design

Using life-size manikins attired in the modified and current standard suits, trials were developed to test a range of environmental conditions. Manikins were unanchored and allowed to float in the test area. The metric used to establish the performance of the modified suit is the distance between the aircraft and the target when detected by the aircrew. Manikin position, if detected by the crew, was derived by the aircraft overflying the manikin and marking the location electronically using a GPS marker. This distance was then computed post-flight using standard in-flight recordings, making this a robust measure. Being able to check the metric post-flight improved the reliability of the measurement since the research team were not permitted on board during the flight trials. This distance is important since target acquisition from a greater distance means less time is taken during the search. If a target can be detected from a greater distance, the probability of detection will increase since the SAR crew can search a larger area in the same time. Using a quantitative metric (observation distance) during the trials, rather than a simple detected/ not-detected decision, enabled us to measure differences in the performance of the two suit designs using fewer trials. This was an important factor when considering the time, operational cost and risk associated with offshore helicopter trials. Due to confidentially constraints, we are unable to report specific details of aircrew who participated in the trial. However, all aircrew who participated are suitably qualified and experienced for the role being currently operationally active. Training manikins were positioned by a support boat at distances along a predetermined flight path at sea. The aircraft searched at 40 knots ground speed and at 500ft (≈152m) in the typical way as defined by IAMSAR volume 2 (2016). The FLIR operator oriented the visible light source at the 12 o'clock position, fully defocused. Video recording of all trials was conducted using on-board cameras.

Flight trial design

Search areas were located in the three trial locations in the UK at Cardiff Bay and Port Talbot in Wales, and Stornoway in the Outer Hebrides, Scotland (Figure 5). A schematic of the approach followed for all flight trials is shown in Figure 6. A suitable search area for the trial, such that the SAR crew are continually searching over water, was agreed to ensure a safe and uncongested location in terms of both airspace and shipping. The search is large enough so that the exact location of the target is not trivially obvious to the SAR crew, but is confined to the defined scanning ranges of the crew when following the predetermined flight track. The two landmarks (noted A and B on the schematic) were identified, sufficiently far from the search area so that the target was not visible from the start points of the flight. For each location, and each suit type the aircraft tracked A to B and B to A along the track line with the pilots searching for the target by eye or NVGs and the FLIR operator searching using the camera equipment using their standard search protocols for the height. This gave rise to two passes for each suit type in each condition. The approximate drift of the manikin due to tidal flows was also considered to ensure that the target remained within the designated search area throughout the trial. Where possible, a period spanning either high or low tide provided the most stable condition with regard to tidal drift.

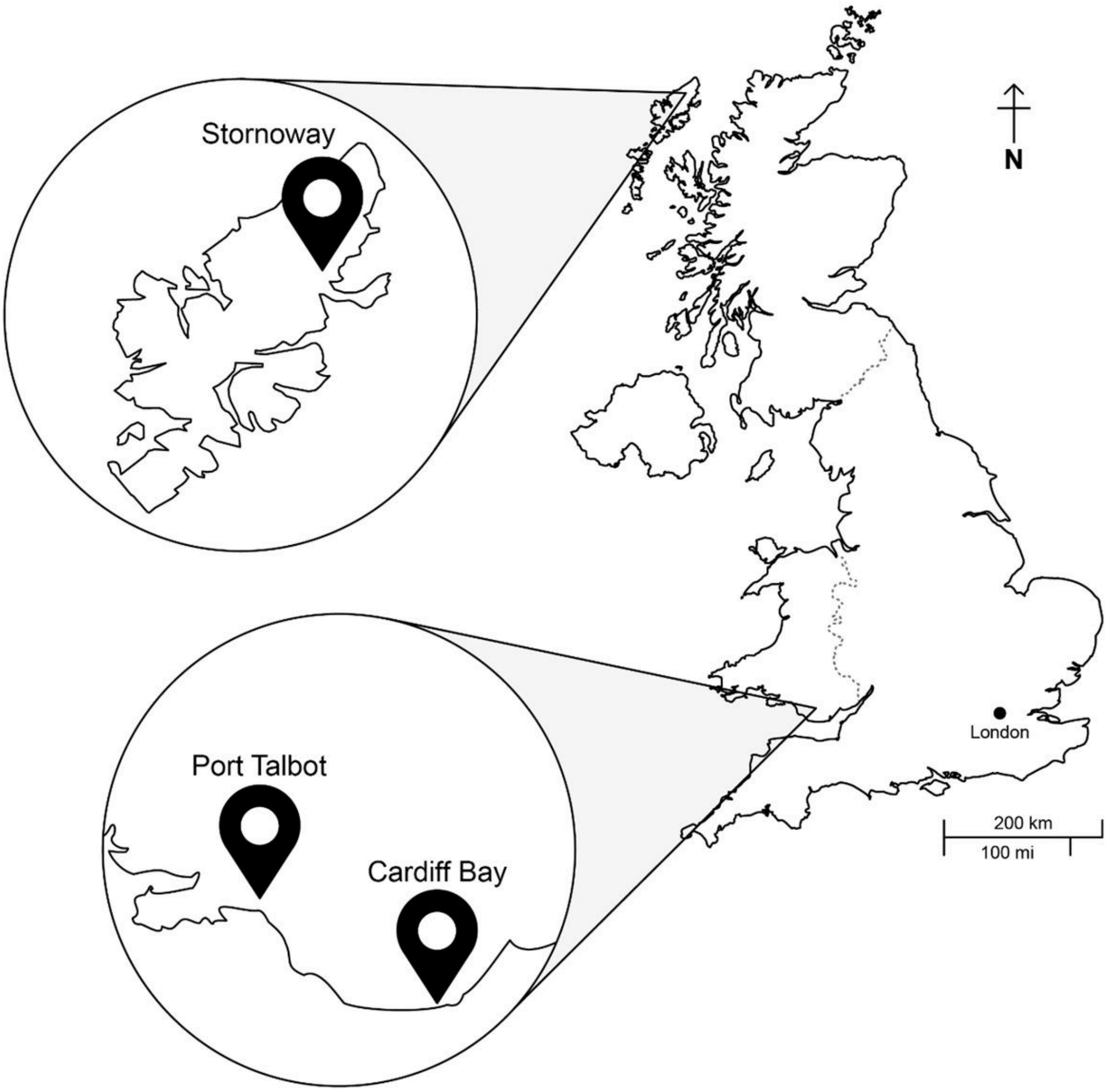

Figure 5 Approximate locations of the three sea-trials in the UK.

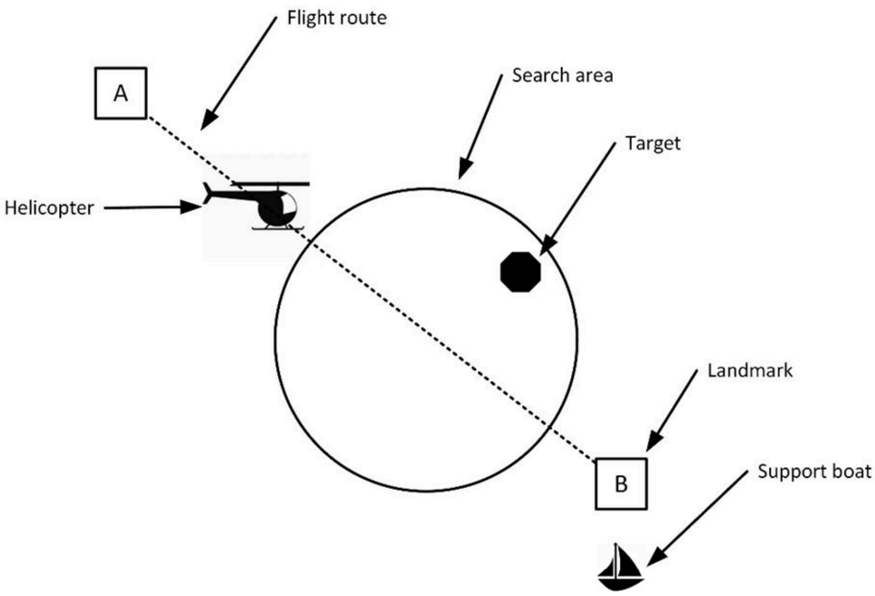

Figure 6 Schematic of trial procedure across all locations (not to scale).

Retroreflective materials

Manikins

Two adult, training manikins supplied by Ruth Lee Ltd. were used for the flight-testing. Training manikins are adult-size (height 1.8m, dry-weight 40 kg). Manikins can be heated or unheated to represent bodies that are alive or dead presenting an appropriate profile to the thermal imaging camera. These trials replicated a worst-case scenario. Training manikins were not heated and so thermal imaging using the FLIR camera was not available to the crew. A heat signature is highly conspicuous when viewed on the FLIR camera, and would dominate the detection process confounding the aim to test only the passive retroreflective modification. One manikin was dressed in the modified immersion suit and one in the current standard immersion suit, both with life jackets. All active systems on the lifejackets were disabled for the purposes of the tests. Retroreflective material on the manikin heads was covered with matt-black adhesive tape to prevent this from interfering with the trial. Foam pads in the manikin chest and leg pockets were arranged so that the manikins floated on their backs (Figure 7). Finally, a personal locator beacon (PLB) was attached to the manikin for recovery using GPS transmission in the event that the aircrew could not locate the target using the proposed search methods. Furthermore, retroreflective material and the flashing lights on the PLB were covered with opaque, black adhesive tape.

Figure 7 Training manikin (Dead Fred) being tested for appropriate flotation in the Bristol channel.

Test cards

Test cards were completed by aircrew and by the research team using details captured on the video footage. Test cards captured key contextual details about the flight and the conditions. Information captured comprised trial number and configuration, date, crew particulars**,** air temperature, ambient pressure, visibility, sea temperature, wind-speed and direction, weather and sea state.

Procedure

Initial briefing between the SAR crew, support boat crew, and the research team took place to ensure mutual understanding of the aims of the trial and of the required activities. Any specific safety or weather related impacts were identified at this initial briefing. Working radio frequencies were established to ensure that the aircraft, boat crew and researchers could communicate.

The support boat crew ditched the first manikin in the water and vacated the search area. On completion of the first series of searches, the aircraft radioed the lifeboat to change the manikin. The aircraft would then standoff in a safe location at sufficient distance to not see activities in the search area. Prior to the start of a search, the FLIR system would be set to record the screen capture and intercom radio. The aircrew would then search as described in the flight trial design. As soon as the target was detected from the aircraft by one of the crew, the pilot would mark the GPS location of the aircraft, fly directly above the target and mark another GPS location. In this way, the distance between the points at which the target was first detected can be computed.

The aircraft would then repeat the search process. On completion of the second sequence of searches, the aircraft would radio the lifeboat to recover the second target. The aircraft would hover and illuminate the target to help with this process. In the event that the target was not found, the aircraft used the PLB to locate the manikin. The support boat would then recover the manikin and return to shore. On landing back at base, a member of the helicopter crew downloaded the FLIR camera and intercom recordings. The aircrew then debriefed as normal.

3.2 Results

Results from all sea trials are shown in Table 5. Overall, we did not find advantage of the modified suit during daytime conditions. A lack of conspicuity advantage can be explained due to the high ambient light levels. During daylight hours, the level of sunlight dominates over and above any light from the searchlight that is retroreflected back to the aircraft. Therefore, retroreflective tape adds a minimal performance advantage. The daytime flight trials in Cardiff suggest that the sun position with respect to the crew's search arc was not a factor. Similarly, the casualty orientation in the water did not affect the distance at which the casualty was first identified since no particular direction of pass conferred an advantage. This initial trial highlighted crew's reliance of the thermal imaging technology when searching for a human target. Without this, the crew are simply searching by ‘eyeballing’ the approximate search area.

The flight trials in Port Talbot demonstrated that at night, using the FLIR technology and searchlights on-board the aircraft in conjunction with the retroreflective material, the modified suit was visible at greater distance compared to the current regulation suit. Furthermore, when using NVGs, pilots reported that the modified suit was visible due to an:

> *“Obvious glint from the orange [retroreflective] material originating from the shoulder hoops”.*

This area of retroreflective material is considered the key modification as it is likely to be above the water regardless of the casualty position in the water. This is evidence for the increased conspicuity of the modified immersion suit in nighttime conditions.

Further flight trials at night were conducted in Stornoway in poor weather and the results show a striking advantage of the modified suit. In the trials with the regulation suit, the casualty was not detected by the crew on either pass. Using the modified suit, the casualty was detected in both passes confirming that the moon position and casualty orientation in the water were not a factor in the success of the search. Despite bad weather and poor visibility, pilots noted:

> *“The [retroreflective] material provides good reflection of the search light when using NVGs”.*

This allowed the modified suit to be visible from approximately 1km. However, it was reported by the rear crew that the FLIR system is not effective in the rain suggesting that the weather is more of a limiting factor in a search scenario than the sea state. Again, this finding is evidence of the advantage of an increase in the area of retroreflective material on the modified suit, giving rise to increased conspicuity and increased likelihood of detection.

Table 5 Distance (m) at which target was detected for modified and unmodified suits.

Location	Time	Weather	Pass	Distance at which target identified (m)	
				Unmodified immersion suit	Modified immersion suit
Cardiff	Day	Clear. Visibility 25 km. Air temperature 12°C. Sea temperature 13°C Wind speed 13 kts at 180° Pressure 1019 hPa. WMO Sea state 3.	1	616	(Target not acquired)
			2	(Target not acquired)	421
Port Talbot	Night	Thick Cloud, light rain. Visibility 6 km. Air temperature 8°C. Sea temperature 9°C Wind speed 22 kts at 260° Pressure 1008 hPa. WMO Sea state 6.	1	1773	1877
Stornoway	Night	Cloud, rain. Visibility 12 km Air temperature 6°C. Sea temperature 7.8°C. Wind speed 14 kts at 210° Pressure 993 hPa. WMO Sea state 3.	1	(Target not acquired)	1054
			2	(Target not acquired)	922

4. Discussion

In this article, we have presented new evidence that increasing the area of retroreflective material on standard flight suits leads to a greater chance of detection by airborne search and rescue services at night. We demonstrated that cockpit reflections using a greater surface area of retroreflective material were tolerable to the expert SME panel engaged to make the judgements. This addresses one concern expressed in the ETSO standard about increased reflections in the cockpit. Using the modified suit with the orange retroreflective material, we proceeded to demonstrate improved conspicuity at night compared to the current regulation suit during live sea trials at a variety of locations and atmospheric conditions. This improvement was measured by using the time to detect the target by the crew. The improvement was particularly apparent when atmospheric conditions were poor. In poor weather conditions, the target could not be acquired when attired in the unmodified immersion suit. Moreover, we have developed and reported a methodology that captures the unique application domain in a structured and repeatable way.

Our results add to the currently limited body of knowledge on conspicuity in the search and rescue domain. Our findings are consistent with those from the wider road transport literature, aligning with van Bommel and Tekelenberg (1986) who argue for high-contrast for increased conspicuity. The high-contrast materials used in the night-trials explain the significantly increased conspicuity leading to successful identification of the target. In addition, our application of high colour-contrast using the orange retroreflective material aligns with findings in the road transport sector (for example Tuttle et al., 2009; Vijayan et el., 2016). Our research extends these findings into the new application domain of airborne search and rescue. We have also successfully embodied findings from biomotion studies (for example Luoma, Schumann and Traube, 1996) that advise application of reflective material to joints on the body. We have extended this research to include the inner-arms given the likely behaviour of casualties in the water in the application studied.

Our findings have implications for standards relating to immersion suits for crew operating at sea and the evolution of passive retroreflective systems more widely. Current standards dictate a minimum surface area of retroreflective material of 400 cm^2. Our results from the reflectance trials suggest that this surface area is conservative. Eight-fold increases without undue reflection or glare being experienced by crew could be achieved to add a conspicuity advantage to nighttime searches. Secondly, our results indicate that the configuration of the retroreflective material was effective in sea-conditions. This configuration was arrived at through consideration of the literature on conspicuity and our knowledge of the unique circumstances in which the immersion suit is used. This configuration of material could be considered for flight suits given appropriate durability and flexibility being achieved by manufacturers.

Naturally, there are limitations of the work conducted. Sea-trials are resource-intensive and are not without risk. As such, a limited number of repetitions were available to the research team. However, the external validity of our trials does carry weight when considering the sea trials conducted with operational teams. Collection of data from actual working environments, as reported in this article, is important in applied safety science (Rae et al., 2020). The reflectance trial methodology did not employ a moving aircraft, but instead used the aircraft in a static position. Of course, in an operation the aircraft would be moving and subject to a variety of light sources, in particular landing lights on sea-borne platforms. Any formal modification to the immersion suit would need to consider this in further testing. Nevertheless, tests in a static aircraft to establish the case for future flight trials is a valuable contribution of this research. A compromise between the anchoring of the manikin and the accuracy of location marker was made. Clearly the manikin was able to move between the identification by the flight crew and the flight movement to mark the location. However, in reality this movement took under one minute and the manikin was sufficiently far from the shoreline to arrest any large movements (> 1m) that, as a proportion of the total distance to target, could impact the validity of the results. Finally, we have only considered the passive lifesaving capabilities of modern immersion suits for aircrew. A variety of active lifesaving devices are available to industry. Clearly, these active devices will have a positive impact on conspicuity. However, it remains important that passive devices are as effective as possible since they do not require maintenance or power sources.

Future research into this area would need to accommodate full ergonomic trials of any modification made to clothing. In addition, reflectance trials during flight would need to be conducted. This activity is not trivial since regulatory approval would need to be sought to conduct such a trial. However, the present study provides evidence that such further research is warranted. In this study, we have limited our research to the passive retroreflective lifesaving system. However, in reality a suite of technologies are available both passive and active. One example of an active technology is a personal locator beacon. The ways in which these active and passive systems interact to support search and rescue teams is of interest to human factors research more broadly. Airborne search and rescue continues to adopt new technology to assist in the identification of casualties at sea. Software sensitive to very small areas of contrasting material can be employed to search a larger area, at a higher altitude in a shorter duration. Our results support the satisfactory inclusion of a high colour contrast material that could be exploited by these types of systems, reducing detection times and ultimately improving safety at sea.

Acknowledgements

This work was funded by the European Safety Agency (EASA). Agreement EASA.2017.C20. We gratefully acknowledge the time and patience by the following individuals and organisations throughout the duration of this research: Captain Alan Dale, test-pilot at Bristow SAR, for supporting and advising the project. Bristow SAR crews at St. Athan and Stornoway for coordinating and successfully completing the search aspect of the flight trials. Thanks also for welcoming us onto your respective bases. Bristow SAR crews at Humberside and Aberdeen for providing guidance and expertise in the early stages of the project. Captain Clark Broad, Flight Ops Manager at Bristow SAR, for arranging crew and resources for the trials. The Royal National Lifeboat Institution (RNLI), Port

Talbot led by Mr Clive Morris who organised the boat support for the second sea trial. RNLI Penarth who rescued a lost Dead Fred from the Bristol Channel following the first sea trial. RNLI Stornoway who provided additional equipment for the third sea trial. Mr Ryan Hopkins of Severn Offshore Services who provided boat and crew support for the first sea trial. Mr Gordon Maclean and Mr Chris Murray of Stornoway Seafari who provided boat and crew support for the third sea trial. Mr Andrew Bright of Orafol and Mr David Beer of Exium Tactical ID Systems for providing samples of reflective tape used in the trials, as well as expertise regarding the properties of their products. Mr Andrew Wilson of Survitec for providing Series 1000 immersion suits for testing. And finally, Fontygary Leisure Park in Barry, who generously allowed us to use their pool facilities in a quiet period to test the flotation properties of the manikin.

References

AAIB. (2014) Formal Report AAR 7/2008. Report on the accident to Aerospatiale SA365N, registration G-BLUN, near the North Morecambe gas platform, Morecambe Bay on 27 December 2006. Department for Transport, United Kingdom.

van Bommel W J M and Tekelenburg J. (1986) Visibility research for road lighting based on a dynamic situation. Journal of Lighting Research and Technology 18(1), 37-39.

Edgar G and Edgar H. (2016). Perception and attention: errors and accidents. In An Introduction to Applied Cognitive Psychology, Groome D and Eysenck M (Eds). Routledge: Oxford.

Engel F L. (1971) Visual conspicuity, directed attention and retinal locus. Vision Research 11, 563–576.

ETSO-2C503 (2006) Helicopter Crew and Passenger Integrated Immersion Suits. ETSO-2C503 ED Decision 2006/04/R. EASA, Köln, German, 2006.

Gotovac S, Papić V, Marušić Ž (2016) Analysis of saliency object detection algorithms for search and rescue operations, 2016 24th International Conference on Software, Telecommunications and Computer Networks (SoftCOM), Split, 2016, pp. 1-6, doi: 10.1109/SOFTCOM.2016.7772118.

Great Britain. Parliament. Transport Committee (2014) Transport Committee – Second report. Offshore helicopter safety. Available at: https://publications.parliament.uk/pa/cm201415/cmselect/cmtran/289/28902.htm (accessed 11th March 2020).

Hole G J, Tyrrell L and Langham M. (1996). Some factors affecting motorcyclists' conspicuity. Ergonomics 39, 946–965.

Hopkinson R G and Collins J B. (1970) The Ergonomics of Lighting. Macdonald: London, UK

IAMSAR Volume 1 (2016) International Aeronautical and Maritime Search and Rescue Manuals: Volume 1: Organization and Management. Tenth Edition. Published jointly between the International Civil Aviation Authority (ICAO) (Montreal, Canada) and the International Maritime Organization (London, UK).

IAMSAR Volume 2 (2016) International Aeronautical and Maritime Search and Rescue Manuals: Volume 2: Mission Co-ordination. Tenth Edition. Published jointly between the International Civil Aviation Authority (ICAO) (Montreal, Canada) and the International Maritime Organization (London, UK).

IAMSAR Volume 3 (2016) International Aeronautical and Maritime Search and Rescue Manuals: Volume 3: Mobile facilities. Tenth Edition. Published jointly between the International Civil Aviation Authority (ICAO) (Montreal, Canada) and the International Maritime Organization (London, UK).

Lygouras E, Santavas N, Taitzoglou A, Tarchanidis K, Mitropoulos A, Gasteratos (2019) A Unsupervised Human Detection with an Embedded Vision System on a Fully Autonomous UAV for Search and Rescue Operations. Sensors (Basel). 2019 Aug 14;19(16):3542. doi: 10.3390/s19163542. PMID: 31416131; PMCID: PMC6720834.

Langham M and Moberly N (2003). Pedestrian conspicuity research: a review. Ergonomics 46, 345-63.

Lesley G. (1995) Enhancing the daytime conspicuity of pedestrians through the usage of fluorescent materials. Color Research and Application 20, 117–123.

Luoma J and Penttinen M. (1998) Effects of experience with retroreflectors on recognition of night-time pedestrians: comparison of driver performance in Finland and Michigan. Transportation Research F: Traffic Psychology and Behaviour 1F, 47–58.

Luoma J, Schumann J and Traube E C. (1996) Effects of retroreflector positioning on night-time recognition of pedestrians. Accident Analysis and Prevention 28, 377–383.

Michon J A , Eernst J T and Koutstaal G A. (1969) Safety Clothing for Human Traffic Obstacles, Ergonomics, 12:1, 61-69, DOI: 10.1080/00140136908931028

Moberly N J and Langham M P. (2002) Pedestrian conspicuity at night: failure to observe a biological motion advantage in a high-clutter environment. Applied Cognitive Psychology 16, 477–485.

Sullivan J M and Flannagan M J (2002) The role of ambient light level in fatal crashes: inferences from daylight saving time transitions. Accident Analysis and Prevention 34(4), 487-98.

Oxford Dictionary of English (OED) (2010) Oxford University Press.

Rae A, Provan D, Aboelssaad H, Alexander R. (2020) A manifesto for Reality-based Safety Science, Safety Science, Volume 126

Tyrrell R A, Wood J M, Owens D A, Whetsel Borzendowski S, and Stafford Sewall A. (2016) The conspicuity of pedestrians at night: a review. Clin Exp Optom, 99: 425– 434. doi: 10.1111/cxo.12447

Tuttle S J, Sayer J R, Buonarosa M L (2009) The conspicuity of first-responder safety garments, Journal of Safety Research, Volume 40, Issue 3,191-196.

Vijayan A, Islam S, Jones M, Padhye R, Arnold L (2016) Degradation of fluorescent high-visibility colors used in safety garments for the Australian railway industry. J Safety Res. 2016 Feb; 56:1-7. doi: 10.1016/j.jsr.2015.11.008.

Wali B, Khattak A J, Ahmad N (2019) Examining correlations between motorcyclist's conspicuity, apparel related factors and injury severity score: Evidence from new motorcycle crash causation study, Accident Analysis and Prevention, Volume 131, 45-62.

Modified immersion suits for helicopter aircrew: evidence for improved conspicuity from sea trials

Nixon, Jim

2020-07-13

Nixon J, Hodgkinson J, Bennett C. (2020) Modified immersion suits for helicopter aircrew: evidence for improved conspicuity from sea trials. Safety Science, Volume 130, October 2020, Article number 104903

https://doi.org/10.1016/j.ssci.2020.104903