Class A HTAWS Warning Annunciation

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Class A HTAWS

Review of Alerting

Abbreviations and Acronyms

AGL	Above Ground Level
AHCAS	Advanced Helicopter Cockpit and Avionics System
AHRS	Attitude Heading Reference System
AMC	Acceptable Means of Compliance (EASA)
AVAD	Automatic Voice Alerting Device
CAA	Civil Aviation Authority
CAT	Commercial Air Transport
CFIT	Controlled Flight Into Terrain
CS	Certification Specification (EASA)
CWP	Central Warning Panel
DH	Decision Height
DMAP	Digital MAP
EASA	European Aviation Safety Agency
EGPWS	Enhanced Ground Proximity Warning System
EHSIT	European Helicopter Safety Implementation Team
ETSO	European Technical Standard Order
FAA	Federal Aviation Administration
FDM	Flight Data Monitoring
FFT	Fast Fourier Transform
FMS	Flight Management System
FND	Flight Navigation Display
FLTA	Forward Looking Terrain Avoidance
GPWS	Ground Proximity Warning System
GS	Ground Speed
HTAWS	Helicopter Terrain Awareness and Warning System
IAS	Indicated Air Speed
ICS	Intercommunication System
IFR	Instrument Flight Rules
ILS	Instrument Landing System
LRU	Line-Replaceable Unit
MFD	Multi-Function Display
MISD	Mission Display
MTOW	Maximum Take-Off Weight
NAVD	Navigation Display
NCO	Non-commercial Operations
NM	Nautical Mile
OEM	Original Equipment Manufacturer
PF	Pilot Flying
PFD	Primary Flight Display
PM	Pilot Monitoring
PNF	Pilot Not Flying
RA (also RADALT)	Radar Altimeter

RFM	Rotorcraft Flight Manual
RTCA	Radio Technical Commission for Aeronautics
SAR	Search and Rescue
SOP	Standard Operating Procedure
SPL	Sound Pressure Level
SPO	Specialised Operations
TAWS	Terrain Awareness and Warning System
TCAS	Traffic alert & Collision Avoidance System
TSO	Technical Standards Order
TT	Total Torque
VFR	Visual Flight Rules

Executive Summary

The introduction of TAWS has resulted in significant safety gains in fixed-wing operations. However, there is room for improvement in helicopter implementations, particularly in commercial offshore transport.

Earlier work, published in CAP 1538 and CAP 1519, focussed on improving the classic mode alerting algorithms for offshore operations and this work is progressing with the involvement of the OEMS. The research reported in this document aims to inform improvements to HTAWS alerting, particularly given reports of alerts being missed in operations. The lack of human factors guidance for helicopters in a form equivalent to that available for fixed wing aircraft (CS 25.1302) is a clear shortfall, as is the lack of a formal standard for Class A HTAWS. However, there are actions underway to address both of these areas.

One of the main recommendations from this research is the clear need to consider HTAWS as part of the larger helicopter system; ambient noise, communication levels, other auditory alerts, existing displays, headsets, earplugs, nuisance alerts and alert types all have a significant role to play in the effectiveness of any alerting strategy. In addition, there are opportunities to improve the system such as through the use of 'attensons' preceding voice alerts, or by adding tactile alerting.

The report begins with an introduction to TAWS and HTAWS before describing the various standards and regulations that relate to the system. Helicopter accidents with relevance to HTAWS are then reviewed in Chapter 3, along with a survey of the literature on auditory, visual and tactile alerting. This work agrees on the central importance of the auditory alerts. These should be designed to be clearly detectable and sufficiently attention-capturing, have an appropriate level of perceived urgency, possibly employing an 'attenson' tone before the spoken component of the alert. However, this approach must be balanced by consideration of likely nuisance alert rates, because alerts that are designed to be highly attention-capturing will also be more annoying and distracting when they are generated unnecessarily. Chapter 3 also raises the possibility of introducing a tactile alerting component to HTAWS, although this would require careful evaluation.

An assessment of the present visual HTAWS alerting strategies is presented in Chapter 4. This identifies many challenges in ensuring that visual alerts are presented with sufficient detectability, given the cluttered nature of the existing visual displays along with the need to avoid attracting attention too strongly away from more important visual information. This reinforces the importance of the auditory alerts, as well as the potential value of introducing a tactile alerting component.

A one-month survey of pilots' experience with HTAWS alerts was conducted and the results of the questionnaires are presented in Chapter 5, along with the results of complementary face to face interviews with line pilots. The results showed that many pilots do not think of the Mode 6 alerts as part of the HTAWS functionality, with some struggling to recall whether they had heard the call on their previous flight (Mode 6 alerts are generated on most flights). Very few could describe the full functionality of the system, but attitudes towards HTAWS were generally positive implying that any improvements that are made to the system are likely to result in operational safety benefits.

Chapter 6 describes work to develop and test a number of new alert tones for use in HTAWS. The testing showed very high performance levels in response to both these and the existing HTAWS alerts, even under subjectively high workload. However, the testing also highlighted the difficulty in producing a protocol that accurately reflects a cockpit with high workload and imperfect situational awareness, pointing to the need for future testing to be carried out in realistic simulators with experienced pilots. It also raised questions regarding presentation levels, background noise and masking in real-world cockpit scenarios.

Chapters 7 and 8 explore the situation with respect to presentation levels. They describe results from airborne testing with in-ear measurements of background noise, communication levels and alert presentation levels. This work suggests that many pilots are using earplugs for hearing protection and then compensating for the attenuation by increasing communication levels in the headset. However, this does not increase the alert level (which is independent of headset level) meaning that alerts may be presented at a considerably lower level than intended The results of the airborne testing show that, while the cockpit environment is noisy, the attenuation provided by the headsets can reduce this significantly meaning that the risk of alert being masked by ambient noise is relatively low. However, testing also showed that the pilot being measured set an ICS level that resulted in cockpit communications being presented at the same level as alerts, giving rise to the strong possibility of masking by communications. This highlights the potential value of introducing an ‘attenson’ tone before the spoken component of the alert, to ensure that the alert is clearly distinguishable from the other cockpit speech. Linking the volume of HTAWS alerts (and any other auditory alerts of similar or higher priority to HTAWS alerts) to the headset level set by the pilot should also be considered.

The report concludes with comments across 14 different areas and suggestions for further work.

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CAA: Jeff Houghton

CHC Helicopter: Steve O'Collard and all the pilots who took part in surveys, trials and interviews

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1 – Introduction

1.1 - Project Details

This document reports the findings of a project aimed at establishing the optimum means of alerting helicopter flight crews to Class A Helicopter Terrain Awareness and Warning System (HTAWS) alerts. The work was carried out between July 2015 and April 2018 and was commissioned, contracted and managed by the UK CAA on behalf of the UK CAA-run joint industry Helicopter Safety Research Management Committee (HSRMC)[1]. The work forms part of a project that is addressing UK AAIB Safety Recommendations 2011-060, -061, -062 and -063, and 2016-011, 012 and 013.

1.2 - Background

Following a number of notable helicopter accidents in the North Sea that were classed as Controlled Flight Into Terrain (CFIT), FlightDataPeople was contracted by CAA to support a joint industry project to improve the alert envelopes of Class A HTAWS. This programme used Flight Data Monitoring (FDM) data to tune the boundaries of existing alert envelopes and develop new alert envelopes for offshore helicopter operations in the North Sea. Following the production of the new and revised alert envelopes, the focus of the project turned to the associated alerting methodology for helicopter operations – an area that has seen relatively little applied research. This work is reported here.

1.3 - Scope

The alerting aspect of the HTAWS system represents the crucial link between system and pilot. As the report on the development of the new algorithms acknowledges (Civil Aviation Authority, 2017b), the alerts must be carefully designed to be distinguishable and informative. There may be a temptation to deploy research findings and experience from the fixed wing domain. Although this is undoubtedly valuable, helicopter operations, offshore in particular, are unique and distinct from fixed wing operations. Consequently, both the algorithms and alerting mechanisms may also need to be unique and distinct, and should be based on research conducted in the rotary wing environment.

As stated in the initial project specification, the overall aim of this work was “to identify the most suitable and/or practical warning methods (auditory, visual and tactile) for pilots to ensure that they respond appropriately to HTAWS warnings”.

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[1] The HSRMC comprises representatives from the European aviation authorities (UK CAA, CAA Norway and EASA), the UK, Norwegian and Canadian offshore oil and gas industry (Oil & Gas UK, Oil & Gas Norway, Shell Aircraft, C-NLOPB), the UK offshore helicopter operators (BHA, HeliOffshore), the European Helicopter Association (EHA), the UK MoD (DSTL), the Helideck Certification Agency (HCA), helicopter manufacturers (Airbus Helicopters, Sikorsky and Leonardo Helicopters), and the offshore renewable energy operators (RenewableUK).

2 - HTAWS Background

2.1 - HTAWS History and Description

2.1.1 - History

Throughout the history of aviation, CFIT has been a major cause of fatal accidents. In response to this hazard, the industry developed and implemented the Ground Proximity Warning System (GPWS), which automatically warned pilots if the aircraft was dangerously approaching the ground.

In addition to barometric altitude and vertical speed, early GPWS used height above ground (measured by the radio altimeter) and rate of closure to determine when the aircraft was in a potentially hazardous situation relative to the underlying terrain. Subsequent improvements incorporated airplane configuration (e.g. landing gear status) and ILS glideslope deviation. This 'basic' GPWS was mandated in many countries and was responsible for a worldwide reduction in the number of CFIT accidents. However, basic GPWS suffers from a serious limitation: because the radio altimeter does not look ahead of the aircraft, it is unable to predict a sudden change in terrain, for example, when encountering steeply rising ground.

In 1996, Honeywell introduced their Enhanced Ground Proximity Warning System (EGPWS) which was developed in order to overcome the above limitation. This system combines accurate positional knowledge (from the aircraft's navigation systems) with a three-dimensional map of the terrain to enable the system to look ahead of the aircraft as well as downwards. This generates alerts to the pilot if certain thresholds are breached.

The success of EGPWS on large passenger jets was judged to be such a benefit that many operators voluntarily adopted the system fleet wide; others followed when the system was mandated. With the regulatory requirement came the need to specify standards rather than adopt a manufacturer's product. These were promulgated under the name Terrain Awareness Warning Systems (TAWS).

TAWS has been required for aeroplanes carrying more than 9 passengers and with a MTOW above 5.7 Tonnes operated in commercial air transport since 2001, while basic GPWS had been required since the 1970s. This equipment has considerably reduced the number of CFIT accidents. Figure 2.1 (Gurney, 2006) shows the CFIT accident rate for fixed wing aircraft from 1965 – 2000 together with the points at which GPWS was adopted and mandated.

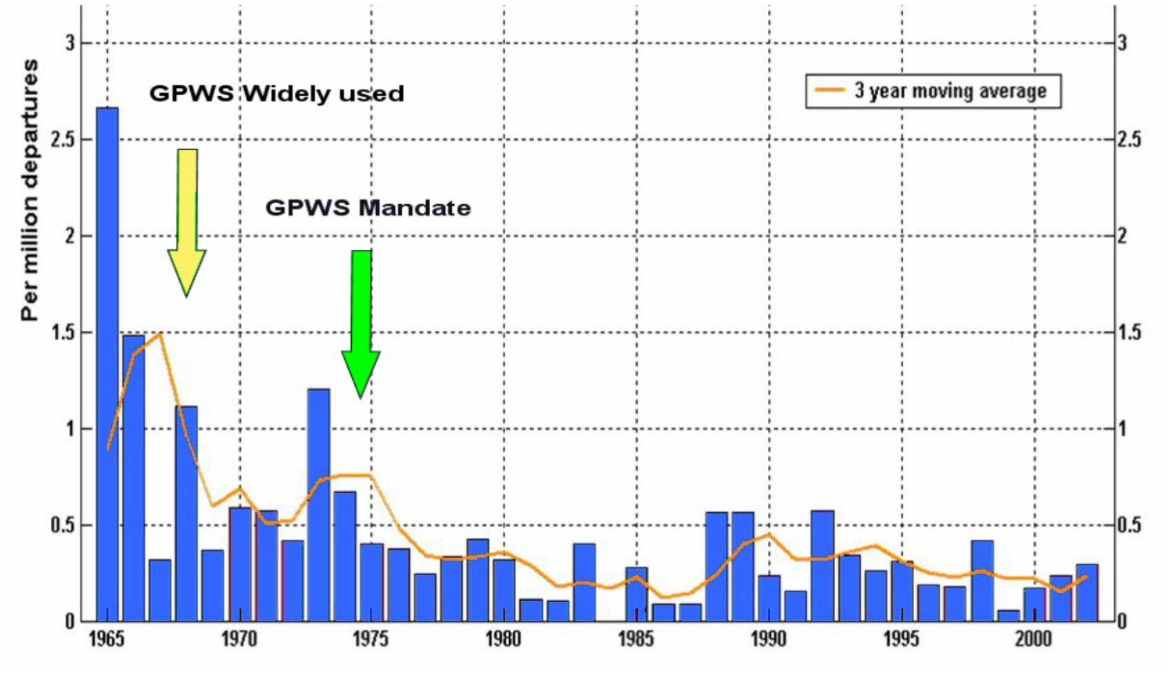

Figure 2.1 – CFIT accident rate for fixed-wing aircraft from 1965-2000 showing GPWS introduction (Gurney, 2006)

The introduction of alerting into helicopters stemmed from the accident to G-BEON on approach to St Mary's in the Isles of Scilly in 1983 (see section 3.2.3). This resulted in the introduction of Automatic Voice Alerting Device (AVAD) systems on offshore helicopters which is still mandated (see section 2.4).

A helicopter version of TAWS, HTAWS, which incorporated the AVAD functionality was subsequently installed on third generation offshore helicopters which entered service around 2005.

In their Preliminary Impact Assessment (EASA, 2017b), EASA wrote (see also 2.3.1):

> *"TAWS are reckoned to be one of the most important safety innovations by the aeroplane community. TAWS were initially not developed for helicopters and the first generations of TAWS would generate false warnings in helicopter operations, because normal helicopter operations are conducted at low altitudes with no intention to land. TAWS improvements for helicopters eventually led to the development of the Helicopter-TAWS (HTAWS) standard in 2008. Today, only a tiny minority of helicopters are equipped with HTAWS, and CFIT remains one of the major causes of helicopter accidents with fatalities or severe injuries."*

It should be noted, however, that the HTAWS standards referred to above (RTCA DO-309 and TSO/ETSO-C194) were designed for onshore helicopter operations and do not include a radar altimeter input. A system designed to those standards is therefore not capable of providing the mandatory AVAD functionality required for offshore helicopter operations.

The EC225 Flight Operations Briefing Note (FOBN) (Airbus Helicopters, 2014) on TAWS notes that:

> *"The look-ahead alert warning modes use information on an aircraft's position, height and track, in combination with inbuilt databases, to assess whether there is a threat ahead of the aircraft and alert against it if necessary. The look down alert warning is based on the original look-down systems and is a safety net should the other layers fail, since they use different sensor inputs and algorithm types. In practice, the look-*

> *ahead warnings provide significantly improved warning times and the older look-down alerts are desensitized to reduce nuisance warnings.”*

RTCA DO 309 (RTCA, 2008) states (see Section 2.3.2):

> *“The HTAWS, as defined within this document, is an alerting system. It is intended to provide terrain and obstacle aural and visual alerts. HTAWS is designed to reduce the risk of CFIT accidents by providing increased situational awareness of the surrounding terrain and obstacles, mainly during the cruise phase in Visual Meteorological Condition (VMC) and in Instrument Meteorological Condition (IMC) under Instrument Flight Rules (IFR). HTAWS is not intended to be used as an aid for navigation.”*

2.1.2 - Description

A full description of the operation of an HTAWS system is beyond the scope of this report.

However, the following summary description of the Honeywell Type XXII EGPWS system is taken from the S92 RFM.

> *“The EGPWS is designed to decrease instances of Controlled Flight Into Terrain (CFIT) by increasing pilot situational awareness. The EGPWS uses two sets of modes to protect against CFIT. Both modes provide visual and aural alerts when terrain/obstacle clearance is not assured. The basic modes (modes 2 through 6) are based on radar altitude. The basic modes prevent descent into level or evenly sloping terrain. The enhanced or “look ahead” modes are based on GPS position compared to terrain and obstacle databases. The look ahead modes prevent the aircraft from running into sharply rising terrain or man made obstacles. The EGPWS also provides a digital terrain map that allows the pilot to view the terrain and obstacles ahead.*
>
> *The EGPWS computer receives inputs from aircraft sensors to include radar altitude, barometric altitude, airspeed, vertical speed, pitch and roll attitude, magnetic heading, temperature, navigational radios, and FMS GPS. These inputs are combined with internal terrain and obstacle databases to predict when the aircraft will impact terrain or an obstacle. The system is designed to provide a warning to the pilot in sufficient time to take corrective action to prevent CFIT while avoiding unnecessary false alarms.*
>
> *Barometric pressure from the air data computer, radar altitude and GPS altitude are combined to create a geometric altitude. This special geometric altitude prevents serious errors due to a wrong altimeter setting, faulty altimeter or extreme cold weather.*
>
> *A terrain database tells the system the height of the terrain around the aircraft. It does this by dividing the world into small grid squares and assigning an elevation to each grid. The resolution of terrain data varies. Some grid squares are as small as 600 feet while others may be as large as 5 miles. The world is divided into nine overlapping regions.”*

In the onshore environment, the HTAWS map and associated colourings act as part of the situational awareness enhancement tool and also the alerting mechanism (see Figure 2.2). However, offshore the display is often a single colour (e.g. cyan).

Furthermore, operational experience from offshore Commercial Air Transport (CAT) in support of oil and gas exploitation has shown that current HTAWS are not optimised for those operations. Some current HTAWS are unable to display fixed obstacles such as large oil platforms with sufficient accuracy. Even if the accuracy is sufficient, keeping the obstacle database sufficiently up to date is impractical due to the large number of mobile obstacles.

As a result, many operators have deleted all offshore obstacles from their databases, meaning that, offshore, the terrain map will never change.

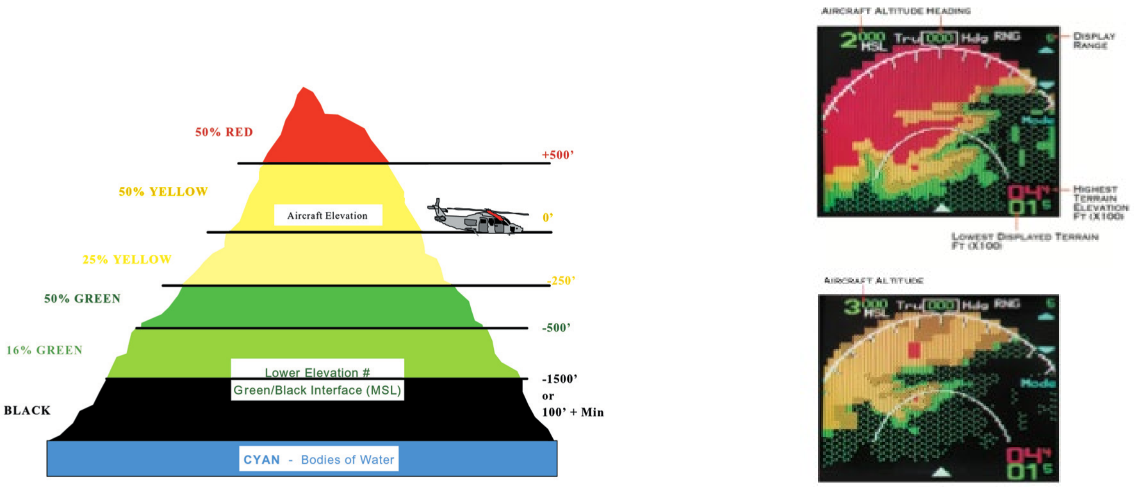

Figure 2.2 – Example of map colouring on Type XXII (Honeywell, 2004)

The different modes, their envelopes and their corresponding alerts are not trivial to understand, and this is particularly true when considering that EGPWS is only one of the many systems with which a pilot needs to be familiar when operating the aircraft.

EGPWS is a trade name for the Honeywell HTAWS (and fixed-wing equivalent) product. When the project was initiated, the only Class A HTAWS available was the Honeywell EGPWS system and, as such, many aircraft in operation today use EGPWS to provide the HTAWS function. Products are now available and in use from other manufacturers including Rockwell-Collins, ACSS, Garmin as well as proprietary aircraft manufacturer solutions.

2.1.3 Alerts

Anecdotally, the alerting strategy used in the Honeywell Mk XXII system has evolved from the initial days of GPWS.

The earliest GPWS systems employed a “whoop whoop” to alert the crew and early standards such as ARINC 594 and ARINC 562 refer to this sound. Later, a speech alert was added which followed the “whoop whoop” tone in order to help clarify the alert.

When GPWS was transitioned to helicopters, the alerts were carried over without the “whoop whoop”, leaving just the spoken alerts. Other brands of HTAWS do employ tones for some parts of the HTAWS functionality.

The aural alerts are accompanied by visual alerts, usually on the PFD but these vary considerably from type to type.

The S92 RFM describes the two modes of the system in the following way:

> *“The EGPWS uses two sets of modes to protect against CFIT. Both modes provide visual and aural alerts when terrain/obstacle clearance is not assured. The basic modes (modes 2 through 6) are based on radar altitude. The basic modes prevent descent into level or evenly sloping terrain. The enhanced or ‘look ahead’ modes are based on GPS position compared to terrain and obstacle databases.”*

The look ahead mode aims to give a caution when the aircraft is approximately 30 seconds from impact, and a warning when approximately 20 seconds from impact. These alerts are based on the aircraft predicted position, derived from the helicopter’s flight path vector relative to a terrain and obstacle database.

The ‘Classic Modes’ are summarised below, with a more detailed description of the Mk XXII available in the Honeywell Pilot’s Guide (Honeywell, 2004).

Mode 1	Excessive descent rate
Mode 2	Excessive terrain closure rate
Mode 3	Sink after takeoff
Mode 4	Too close to terrain
Mode 5	Excessive deviation below glideslope
Mode 6	Altitude call-outs, bank angle and tail strike.

2.1.4 Flight crew response

When flight crew have faith in the alerts a system is giving them, they will naturally tend to act on the information it provides. Conversely, a high false or nuisance[2] alert rate will tend to call alerts into question when they are generated and may delay or prevent action. A survey conducted in 2010 showed the level of HTAWS false or nuisance alerts in offshore helicopter operations to be high and this could be expected to affect pilot responses to an alert. Actions taken in the last 10 years to reduce the false or nuisance alert rate have had a positive effect, however, more can be done.

Clearly, the ideal situation is alerts that can always be trusted, are always heard and perceived and are always believed and acted upon. The first part of this trio (no nuisance alerts) has been partly addressed by removing the offshore obstacles from the obstacle database, and is being further addressed by the revised offshore envelopes described in Section 2.4. The work covered in this report aims to inform the second step (always heard and perceived). The requirement for alerts to be acted upon already exists as described below. The aim to have alerts “believed” will come in time as crew build faith in the reliability of the system.

CAA Specification 14 (CAA, 1976) from 1976 noted that:

> *“For a GPWS to be effective in preventing accidents it must be such that pilots will react promptly to a warning, and this will only be the case if unnecessary alarms are kept to a minimum.”*

The AW189 Rotorcraft Flight Manual (RFM) recommends the correct response on hearing a terrain or obstacle caution is to “*verify flight path and correct as necessary*”. The recommended response for a terrain or obstacle warning is “*immediately initiate manoeuvre to provide maximum terrain clearance, until alerts cease*”.

One operator defines the following in their SOPs when crew are presented with a Caution Terrain or Caution Obstacle alert:

Pilot Flying:	PF calls out observed height and intentions
Pilot Monitoring:	Verify flight path and monitor PF response
Notes:	Crew must verify the flight path and correct if necessary

For a Warning Terrain or Warning Obstacle or Pull Up alert the operator specifies two different conditions. Firstly, in IMC or at night where visual judgement of the situation is not assured:

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[2] Except in quotations, the following definitions (from AC 25.1322-1) will be used in this report:

False Alert - An incorrect or spurious alert caused by a failure of the TAWS including the sensor.

Nuisance Alert - An alert generated by a system that is functioning as designed but which is inappropriate or unnecessary for the particular condition.

Pilot Flying:	XXX ft, pulling up, maximum power and Vy set
Pilot Monitoring:	Monitor and call the Rad Alt height and trend during the terrain avoidance manoeuvre
Notes:	PF performs terrain avoidance manoeuvre. PM monitors flight path.

Secondly in VMC or where visual judgement of the situation is assured:

Pilot Flying:	PF calls out observed height and intentions.
Pilot Monitoring:	Acknowledge PF intentions and monitor as required
Notes:	PF evaluates the flight path with respect to terrain and obstacles and takes corrective action as necessary to recover safe terrain and obstacle clearance.

This second procedure acknowledges, albeit tacitly, that there will be times when the EGPWS generates an (nuisance) alert but it is safe to continue.

For an approach in IMC the operators usually mandate a go-around for an EGPWS call of Caution Terrain, Caution Obstacle, Warning Terrain or Pull Up.

2.2 – Fixed-Wing TAWS

2.2.1 - Occurrence database queries

In order to estimate the extent of safety issues and accidents which involved GPWS, a number of databases were queried.

An Air Safety Report (ASR) database from a now-subsumed fixed-wing airline was interrogated for the period 2003-2012 (but with 2006 missing). Approximately 23,000 ASRs were filed from around 675,000 flights. Of those 23,000 ASRs, 229 (1%) included the term GPWS.

Some of the issues encountered were:

- Erroneous triggers
- Trigger but with the condition assessed as safe
- A trigger was thought to be heard or seen, but was not recorded on the FDR. Assuming the alert was triggered, possible explanations for the lack of recording include too low a sample rate on the FDR or only a visual alert being generated.
- Mode failure or system inoperative

In general, the reports suggest that alerts are taken seriously. However, there were occasional reports of the crew believing they understood the reason for the alert, but being mistaken. This highlights the importance of reliable alerts that are always acted upon.

The AAIB web database was queried. Searching for the term “EGPWS” or “GPWS” in commercial rotorcraft accidents produced no results. Searching for “TAWS” produced the accident to G-REDU (see Appendix 1).

Querying the ATSB web database searching for EGPWS in the title gave 11 reports, all of which could be classified as ‘correct activation and response’, or ‘incorrect activation’. Searching for TAWS in the title gave 1 report discussing under-reporting on the ATR 72 fleet.

Querying v2.9 of the NASA Aviation Safety Reporting System database searching with the logic: “TAWS” OR “EGPWS” OR “GPWS” produced 2061 reports. Adding the restriction of “all aircraft” from Eurocopter, Sikorsky, Bell and Agusta made that number 0.

An MOR query was submitted to the UK CAA regarding EGPWS. 323 fixed-wing reports were returned from the period 2013 to 2015. After excluding those without a narrative and those of aircraft type BAE-ATP (of which there were a disproportionate number due to technical failures), there were 267 reports for analysis. Each report was analysed and classified in each of 4 categories: Flight phase; Type of alert; Class of alert; and Major actions taken. The results are presented below:

Flight phase	Landing / Descent	Take-off / Climb	Cruise	Unknown
Number	246	19	1	1

For alert type, the following classifications were used:

Standard	Considered as appropriate alarms during corresponding flight phase.
Spurious	According to description in narrative of reports.
Unknown	Was not clear whether it was a spurious or standard alert.
No alert	Crew mentioned not receiving alert when there should have been one.

Alert type	Standard	Spurious	Unknown	No alert
Number	150	51	64	2

Class of alert	Glideslope / Sink rate	Wind shear	Terrain	Flaps	Other
Number	125	73	47	13	9

Major actions taken?	Yes	No	Unknown
Number	153	94	20

Later discussion suggested that at least one helicopter operator submitted MORs involving HTAWS, but that they may have been classified under the title RADALT; RADALT faults were leading to spurious HTAWS callouts that were inhibiting crew communication.

2.2.2 – Relevant accidents

In this section, a small number of relevant accidents are discussed to highlight some of the issues relating to GPWS seen in fixed-wing operations.

Gulf Air 072

Gulf Air flight 072 was operated with an Airbus A320, registered A40-EK, travelling from Cairo to Bahrain, in 2000. The report (GCAA, 2014) states that the airplane had been cleared to land on Runway 12 at BAH, but crashed at sea about 3 miles north-east of the airport soon after initiating a go-around following the second landing attempt. The airplane was destroyed by impact forces, and all 143 persons on board were killed. Night, visual meteorological conditions existed at the time of the accident.

While performing a go-around, the crew received alerts of “Sink Rate” and “whoop whoop, pull up”. The aircraft was fitted with an Allied Signal Mark V GPWS Warning Computer. The CVR from GF-072 recorded the aural alerts associated with Mode 1 (Excessive Rate of Descent), during the last 11 seconds of the recording.

The Abnormal and Emergency section of the Gulf Air A320 FCOM contains procedures for response to GPWS alerts. For night or instrument meteorological conditions, the procedure states that flight crews are to "apply the procedure immediately; do not delay reaction for diagnosis." When WHOOP WHOOP PULL UP OR TERRAIN WHOOP WHOOP PULL UP sounds, the procedure calls for simultaneously doing the following:

AUTOPILOT.........................OFF

PITCH ....PULL UP (*Pull up to full back stick and maintain*)

THRUST LEVERS................TOGA

The FCOM states that GPWS response procedures are "memory items" that are to be applied without referring to manuals or checklists.

The report notes that:

> "the captain did not respond to either the initial GPWS "sink rate" alert or the subsequent "*whoop, whoop, pull up" warnings…the recovery study and simulator trials conducted as part of this investigation showed that if the captain had executed the response to the GPWS warning in accordance with the SOP, recovery was still possible."*
>
> *"As well, the CVR showed that neither the captain nor the first officer made any verbal response to the GPWS warnings before the impact. Instead, they continued to comment "gear up", and "flaps all the way (up)"* [they were dealing with a flap overspeed alert]. *Although the GPWS warnings indicated a grave and imminent threat to the aircraft, and continued to sound every second until the end, the CVR did not reveal any evidence that this dangerous situation was recognised by either the captain or the first officer."*
>
> *"… it appears that both the flight crew, the captain as well as the first officer, did not comprehend the criticality of the aircraft's attitude and increasing proximity to the ground."*
>
> *"To ensure that GPWS responses are accorded top priority, and that they are sufficiently practised, or over-learned, so that they become automatic, a specific GPWS training programme is essential."*

The Findings section includes the comments:

> *"The analysis of FDR and CVR recordings indicated that neither the captain nor the first officer perceived, or effectively responded to, the threat of the aircraft's increasing proximity to the ground in spite of repeated hard GPWS warnings, and continued addressing the comparatively low priority flap over-speed situation."*

and

> *"Inadequacy was identified in Gulf Air's A320 training programmes such as adherence to SOPs, CFIT, and GPWS responses."*

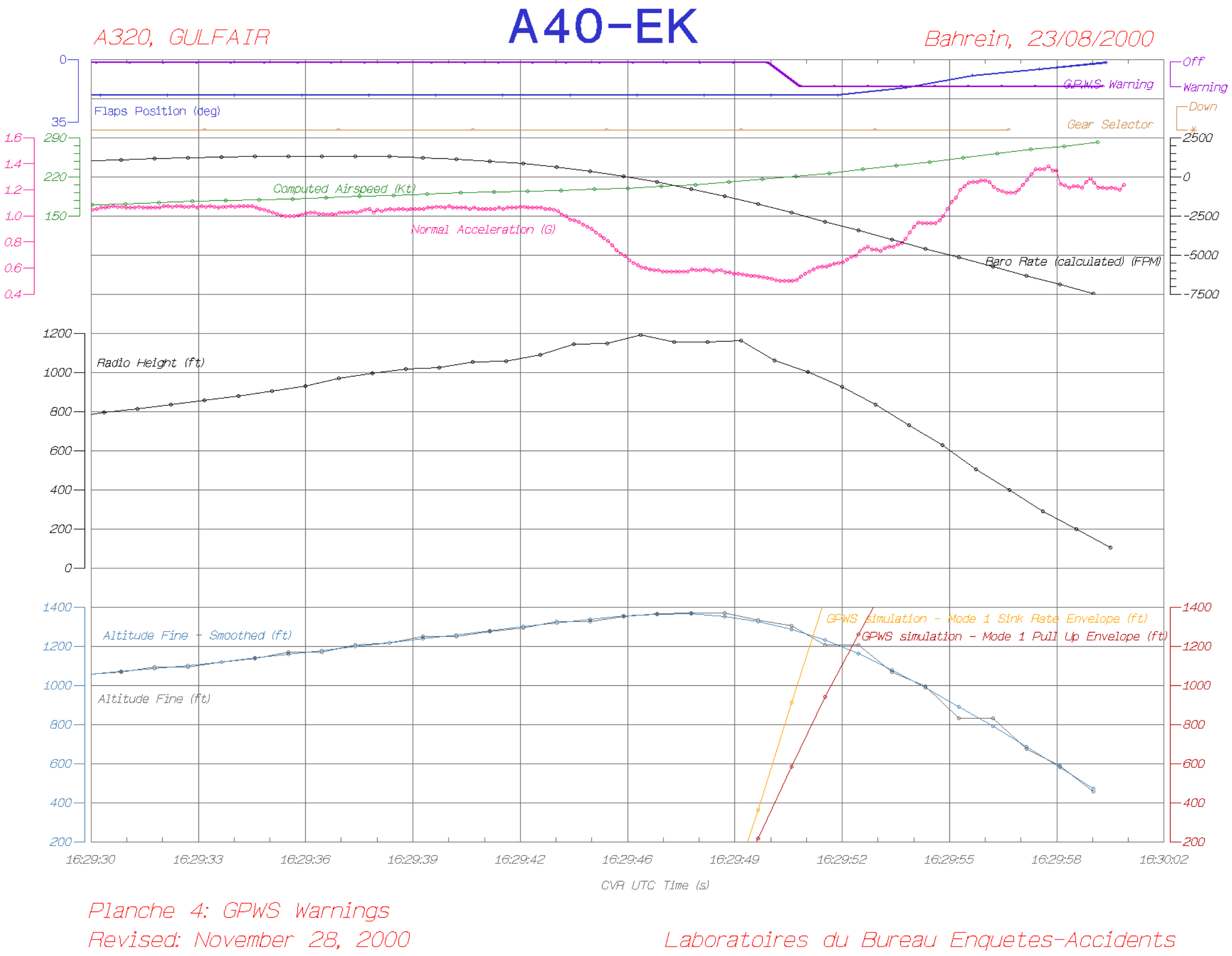


Figure 2.3 – Flight Data plot from accident to A40-EK

Aeroperú Flight 603

A different type of accident occurred to an AeroPerú Boeing 757 registered N52AW which impacted the sea whilst trying to return to Lima airport. On take-off, the flight crew realised that their altimeters were not working (due to tape over the static port). According to the report (*Accident of the Boeing 757-200 Aircraft on 2nd October 1996*, n.d.), whilst trying to control the aircraft, the crew were presented with an "*excessive number of alarms which, rather than helping, contributed to the confusion and chaos*".

The report translation notes of the flight crew that:

> *"In the end, they did not know what to pay attention to, and basically neglected the flight because of their concern with how to disconnect the alarms and, trying to find an adequate solution to the avalanche of problems which was accumulating, they did not pay attention to the recurrent repetitive GPWS alarms, and, because of their inadequate situational awareness, they did not take immediate action in response to the "too low – terrain" alarm."*

and

> *"The crew are over-saturated with erroneous information, such as the overspeed alarm, which sounds constantly for the last 12 minutes of the flight, and with correct information such as the stick shaker, sink rate alarm and "too low – terrain" alarm, which sound repeatedly and insistently. Confused by the saturation of sounds with*

> *different tones and intensities, they pay no attention, thinking that the alarms are fictitious, as stated by… the pilot-in-command.”*

SAAB 2000 G-LGNO

Another accident that has relevance occurred to a Saab 2000 aircraft, registration G-LGNO, near Sumburgh airport in December 2014. The AAIB report (Air Accidents Investigation Branch, 2016) summarises the accident:

> *“The aircraft was inbound to land on Runway 27 at Sumburgh when the pilots discontinued the approach because of weather to the west of the airport. As the aircraft established on a southerly heading, it was struck by lightning. When the commander made nose-up pitch inputs the aircraft did not respond as he expected. After reaching 4,000 ft amsl the aircraft pitched to a minimum of 19° nose down and exceeded the applicable maximum operating speed (VMO) by 80 kt, with a peak descent rate of 9,500 ft/min. The aircraft started to climb after reaching a minimum height of 1,100 ft above sea level.*
>
> *Recorded data showed that the autopilot had remained engaged, contrary to the pilots’ understanding, and the pilots’ nose-up pitch inputs were countered by the autopilot pitch trim function, which made a nose-down pitch trim input in order to regain the selected altitude.”*

The report also highlights a study into inattentional deafness in which:

> *“28 pilots of different experience levels were placed in a full motion flight simulator. They were given time to practise landings and then told to expect one of 5 different events to occur including an antiskid failure, an engine failure, a ground proximity warning and a landing gear failure. The aural warnings and visual indications associated with these conditions were shown to them. All the pilots were then given the landing gear failure scenario. Half the pilots were also given a windshear scenario (to simulate high workload) and the other half were not (to simulate normal workload). Of the pilots who were given the windshear scenario 57% failed to detect the aural gear failure warning. Of the pilots who were given the non-windshear scenario all of them detected the aural gear failure warning.”*

The study is then related back to the accident:

> *“…the alerting system on the Saab 2000 proved ineffective in this incident. Aural and visual alerting systems are less effective in situations when a flight crew is under stress, and if the flight crew is overriding the autopilot there is a high probability that they are doing so because of an unusual and possibly stressful situation. It is questionable whether any alerting system in this incident could have raised sufficient awareness among the flight crew to cause them to disengage the autopilot manually.”*

2.2.3 – Applicable fixed-wing regulations and standards

CAA Specification 14 (CAA, 1976)

Defines the technical requirements applicable in 1976 in order to have approval for a GPWS on a fixed-wing aircraft in the United Kingdom. The Specification notes that:

> *“2.3.2 The aural warning shall include a voice giving appropriate advice to the crew.*
>
> *2.3.3 The quality and level of the warnings shall be such as to ensure rapid perception by the crew, and will be the subject of assessment by CAA. It shall not be such as to interrupt communication between crew members.”*

RTCA DO-161A (RTCA, 1976)

Provides Minimum Performance Standards for Airborne Ground Proximity Warning Equipment and is referred to by many of the other standards.

TSO-C151c and ETSO-C151c

TSO-C151c (FAA, 2012b) and ETSO-C151c (EASA, 2016c) address the requirements and give minimum performance standard for Class A, B and C TAWS systems. Appendix 1 of the (E)TSO relates to Class A and B and appropriate extracts are included in Appendix 1 of this report.

FAR 25 and CS 25

CS 25, the Certification Specification for Large Aeroplanes contains section CS 25.1302 which is sometimes seen as the section that ensures the flight deck design is fit for purpose:

> ***CS 25.1302 Installed systems and equipment for use by the flight crew*** *(See AMC 25.1302)*
>
> *This paragraph applies to installed equipment intended for flight-crew members' use in the operation of the aeroplane from their normally seated positions on the flight deck. This installed equipment must be shown, individually and in combination with other such equipment, to be designed so that qualified flight-crew members trained in its use can safely perform their tasks associated with its intended function by meeting the following requirements:*
>
> *(a) Flight deck controls must be installed to allow accomplishment of these tasks and information necessary to accomplish these tasks must be provided.*
>
> *(b) Flight deck controls and information intended for flight crew use must:*
>
> > *(1) Be presented in a clear and unambiguous form, at resolution and precision appropriate to the task.*
> >
> > *(2) Be accessible and usable by the flight crew in a manner consistent with the urgency, frequency, and duration of their tasks, and*
> >
> > *(3) Enable flight crew awareness, if awareness is required for safe operation, of the effects on the aeroplane or systems resulting from flight crew actions.*
>
> *(c) Operationally-relevant behaviour of the installed equipment must be:*
>
> > *(1) Predictable and unambiguous, and*
> >
> > *(2) Designed to enable the flight crew to intervene in a manner appropriate to the task.*
>
> *(d) To the extent practicable, installed equipment must enable the flight crew to manage errors resulting from the kinds of flight crew interactions with the equipment that can be reasonably expected in service, assuming the flight crew is acting in good faith. This subparagraph (d) does not apply to skill-related errors associated with manual control of the aeroplane.*

This specification is supported by AMC 25.1302 which comprises 34 pages covering all aspects of cockpit design. Full discussion of this AMC is beyond the scope of this report, but one section is particularly relevant to helicopter operations:

> *"5.7.4 Flight Deck Environment*
>
> *The flight deck system is influenced by physical characteristics of the aeroplane into which a system is integrated, as well as by operational environment characteristics.*

> *The system is subject to such influences on the flight deck as turbulence, noise, ambient light, smoke, and vibrations (such as those that may result from ice or fan blade loss). System design should recognise the effect of such influences on usability, workload, and crew task performance. Turbulence and ambient light, for example, may affect readability of a display. Flight deck noise may affect audibility of aural alerts. The applicant should also consider the impact of the flight deck environment for non-normal situations, such as unusual attitude recovery or regaining control of the aeroplane or system."*

At present, there is no section 2X.1302 in either of the helicopter certification specifications, CS 27 and CS 29 (see Section 2.3.1).

ARINC Characteristics

ARINC 594-4 (ARINC, 1984) sets out the characteristics of a Ground Proximity Warning System (GPWS) designed for installation in commercial aircraft. ARINC 723-3 (ARINC, 1988) served as a "digital conversion" of ARINC 594.

ARINC 562 (ARINC, 2001) addresses the need for standard TAWS installations in older aircraft that have analogue equipment interfaces. The analogue unit is intended as a replacement for ARINC 594 equipment. ARINC 762-1 (ARINC, 2000) sets out the characteristics of a TAWS intended for installation in aircraft with digital signal interfaces and is constructed using ARINC 723 as the basis.

All of the documents focus mainly on the physical characteristics and electrical connections. Section 4.7 of ARINC 762 describes the Audio Outputs:

> *"4.7 Audio Outputs*
>
> *The TAWC* [Terrain Awareness and Warning Computer] *should have the capability to program the audio output level such that it can be harmonized, in volume, with the TCAS and windshear aural alert/warning levels. During certification flight testing, it should be possible to adjust the audio output levels.*
>
> *COMMENTARY*
>
> *The capability to adjust audio output levels must not be provided during regular flight operation.*
>
> *4.7.1 Audio Speaker*
>
> *The TAWC should provide an audio output capable of supplying up to 4 watts RMS instantaneous (2 watts RMS continuous) at 1000 Hz into 8 ohms.*
>
> *4.7.2 Interphone Output*
>
> *The TAWC should provide two (2) audio outputs supplying up to 40 milliwatts at 1000 Hz to a 600 ohm audio distribution system."*

ARINC 762 Attachment 6, which details the configuration module, notes that "*Default volume = 25 mW at 600 Ohm, 2 W at 8 ohm*" and describes the setting to change the volume.

In 2012, the SAE produced an Aerospace Recommended Practice, ARP5108A (SAE International, 2012) entitled Human Interface Criteria for Terrain Separation Assurance Display Technology. The document "*sets forth design and operational recommendations concerning the human factors issues and criteria for airborne terrain separation assurance systems. The visual and aural characteristics are covered for both the alerting components and terrain depiction/situation components.*"

However, the description also notes that *"Because of their unique operations with respect to terrain, rotorcraft will be addressed in a separate document."* This document does not yet exist.

2.3 - Regulations and Standards

This section describes the regulations and standards which are relevant to HTAWS insofar as they relate to alerting.

2.3.1 - FAR 27/29 and CS-27/29

CS-27 (EASA, 2016a) and CS-29 (European Aviation Safety Agency, 2016) give the Certification Specifications and Acceptable Means of Compliance for Small Rotorcraft and Large Rotorcraft respectively. The current version of both documents at the time of writing was Amendment 4, dated 30th November 2016.

CS 27.1322 and CS 29.1322 (and FAR 27/29.1322 which are harmonised) give requirements for "*Warning, caution, and advisory lights*" stating that:

> *"If warning, caution or advisory lights are installed in the cockpit they must, unless otherwise approved by the Agency, be:*
>
> *(a) Red, for warning lights (lights indicating a hazard which may require immediate corrective action);*
>
> *(b) Amber, for caution lights (lights indicating the possible need for future corrective action);*
>
> *(c) Green, for safe operation lights; and*
>
> *(d) Any other colour, including white, for lights not described in sub-paragraphs (a) to (c), provided the colour differs sufficiently from the colours prescribed in sub-paragraphs (a) to (c) to avoid possible confusion."*

FAA Advisory Circular 29-2C (FAA, 2016) contains MG 18 which is Miscellaneous Guidance on Helicopter Terrain Awareness And Warning System (HTAWS). Under *h. Installation Considerations* it states:

> *(2) Locate visual alerts in the pilot's primary field of view. HTAWS status and mode selection annunciation (i.e., inhibit, reduced protection mode, or other pilot selectable mode) should be as close to the pilot's primary field of view as possible to enable rapid assessment of HTAWS status and configuration. The terrain and obstacle display should be installed in a location that provides monitoring by the pilot(s) for identification of potential flight path conflicts. The terrain and obstacle display should be in a location similar to other multifunction displays, such as electronic maps and weather radar.*
>
> *(3) The installation should ensure that aural alerts are distinct and audible in all flight conditions.*
>
> *(4) The certification plan should include tests and analyses to assure that the visual and aural alerts are consistent with the alerting configuration of the rotorcraft flight deck in which the HTAWS equipment is installed. This is particularly important with retrofit installations, which may use previously installed alerting annunciations. The plan should consider that visual alerts are:*
>
> *(i) located in pilots' primary field of view, and*
>
> *(ii) consistent with their associated voice or aural call out.*

It also mandates that:

> *(3) Specific flight test points should be flown to assess:*

> *…(ii) performance of alerting displays and audio in all flight and lighting conditions;*

MG 19 gives further guidance on the use of colour and messaging on screens (see Chapter 4). One additional comment related to audio is:

> *"d.4.iii.B.3.(i) Use audio tones or voice messages. Keep the number of different tones to a minimum to decrease the possibility of confusion. Aircrew alerts are more noticeable when a combination of audio tone or audio message and a visual cue is used."*

In 2016, FAA Advisory Circular AC 29-2C Change 7 (FAA, 2016) added a Miscellaneous Guidance Section on Human Factors (MG 20). This includes advice on all aspects of human factors as it relates to design, but the following relates to the visual and audio alerts:

> *"Section 29.1322. The regulation specifically applies to lights. However, this section of the guidance also discusses audio alerts since there is simultaneous use with visual alerts to relay information to the pilot.*
>
> > *(A) With the advent of the integrated electronic multifunction display (MFD) systems, many manufacturers are presenting warnings, cautions, and alerts on MFDs instead of on separate annunciation panels. Consequently, this regulation is applied routinely to these integrated electronic displays.*
> >
> > > *(1) The use of red and amber for encoding purposes other than warnings and cautions can create confusion on these displays.*
> > >
> > > *(2) Use red only as a warning annunciation for emergency operational conditions when immediate flight crew recognition and action is required.*
> > >
> > > *(3) Use amber only for cautionary alerting and when immediate crew awareness is required and subsequent action may be required. Use white or another unique color for advisory annunciations of operational conditions that require flight crew awareness but may not require any action.*
> > >
> > > *(4) Use green only to indicate safe operating conditions.*
> >
> > *(B) Applicants should describe each warning, caution, and advisory light, including the expected pilot response. Consider establishing a well-defined color coding philosophy consistently across the cockpit. A well-defined and consistent color philosophy can greatly reduce the likelihood of confusion and interpretation errors.*
> >
> > *(C) Evaluations should be conducted in the rotorcraft using actual hardware. Testing should include a variety of lighting conditions. It is important that the selected colors maintain integrity (for example, red looks red, amber looks amber) and discriminability (that is, colors can be distinguished reliably from each other) from all potential viewing angles and under all expected lighting levels.*
> >
> > *(D) CAS panels should be easily seen and labels and messages easily legible in all lighting conditions. The lighting of the panel should balance with the rest of the cockpit. Modification of CAS panels, such as filtering for NVIS lighting, should be evaluated in all lighting conditions and pilot viewing angles to ensure the CAS legends are easily seen and legible.*
> >
> > *(E) Audio Alerts, Cautions, and Warnings:*
> >
> > > *(1) It is important to use audio alerts judiciously. Keep the number of audio alarms to the minimum necessary to provide the desired result.*

> *Too many alerts can become confusing, annoying, increase pilot workload, and detract from a pilot's primary flight responsibilities.*
>
> *(2) Spoken (voice) alerts can have advantages over other forms of audio warnings since they convey specific information without the pilot having to interpret a tone or revert to a visual display to determine the exact failure.*
>
> *(3) Regardless of the method chosen to present audio alerts, evaluate them to determine that they are readily detectable, easily heard under all ambient noise conditions, and quickly and correctly interpreted.*
>
> > *(i) Ensure that the alerting tone or voice message is of sufficient intensity (loudness) that it clearly stands out against all normal background noise.*
> >
> > *(ii) Audio levels should be easily set and controlled in the event one alert is overly loud and distracting (for example, an audio alert is diverted from a cockpit speaker to headsets, adjustment of the alert's volume may be necessary to compensate for the lower ambient noise of a headset vs. the ambient noise in a cockpit."*

CS 29.672 Stability augmentation, automatic, and power-operated systems has some interesting requirements that may be relevant to HTAWS, namely that "*A warning which is clearly distinguishable to the pilot under expected flight conditions without requiring the pilot's attention must be provided…*"

MG 20 provides additional guidance around this section:

> *Section 29.672.*
>
> > *(A) Section 29.672(a). Provide a warning signal that is distinguishable from other cockpit alerts. If an audio signal is used, the pilot must be able to discriminate it from all other cockpit audio alerts.*
> >
> > > *(1) Conduct evaluations in the rotorcraft during both ground and flight operations with varying levels of background noise.*
> > >
> > > *(2) Assess the discriminability of the visual and auditory alert in multiple alert scenarios, if applicable.*
> > >
> > > *(3) Applications that employ voice technology should meet these same criteria.*
> > >
> > > *(4) Conduct analysis, simulation or flight test to show that the system would not produce nuisance alerts when the rotorcraft is conducting normal flight operations.*

In a 2017 Preliminary Impact Assessment (PIA) (EASA, 2017b), EASA noted:

> *"Lack of Human Factors considerations in the design of helicopter cockpits (CSX.1302) in comparison to large transport aircraft which has benefited from an amendment to CS25.1302 in this area. A lack of human factor considerations in the design of helicopters has been a primary or contributing factor to a number of helicopter accidents/incidents."*

The PIA acknowledges that *"Currently the certification specifications for rotorcraft do not contain any specific requirements for a human factor assessment to be carried out*". However, EASA proposes to establish a Rulemaking Task, RMT.0713, entitled Reduction in human-factors-caused rotorcraft accidents that are attributed to the rotorcraft design (EASA, 2017a). The overall objective of RMT.0713 is understood to be to develop certification specifications for human factors in the design of rotorcraft cockpits. A Notice of Proposed Amendment (to the Certification Specifications CS 27 & 29) is scheduled to be published in Q1 of 2019.

2.3.2 - RTCA DO-309

The RTCA have published a document which details MOPS (Minimum Operational Performance Standards) for HTAWS equipment, designated DO-309. The latest edition is dated March 13, 2008 (RTCA, 2008) The DO-309 HTAWS does not have a radio altimeter input and therefore does not provide Classic Modes (see section 2.1.3) or the height alerting functionality (AVAD) required by the offshore helicopter operating rules noted in 2.1.1 and 2.4 below. Such HTAWS are analogous to aeroplane Class B TAWS. A description of the relevant contents is included here since it is one of the only relevant reference standards; there are no standards or certification requirements directly relating to the Classic Mode alert envelopes for helicopters, i.e. the equivalent of aeroplane Class A TAWS. There is no equivalent EUROCAE document to DO-309. Parts of DO-309 mirror aspects of (E)TSO-C151c (see below).

The introduction to DO-309 notes the prevalence of CFIT accidents in the period 1994-2004 and the potential for HTAWS, adapted from fixed-wing in a way that recognises the differences in rotary operations, to mitigate against this type of accident. As a result, the FAA requested that RTCA form a committee to develop MOPS for HTAWS and this resulted in the production of DO-309.

The committee was jointly chaired by Yasuo Ishihara of Honeywell and Bruce Webb of American Eurocopter. The working group included representatives from aircraft manufacturers, regulators, pilot's associations, avionics manufacturers, operators and special interest associations. Members of the working group were briefed that cost was a constraint and that RADALTs were considered too expensive, hence the reason to restrict the MOPS to Class B HTAWS.

The working group selected nine representative test scenarios from ten years of CFIT accident cases which were used as a basis to develop the test scenarios. One member of the working group noted that the choice of cases was driven mostly by the limited flight data that was available.

The MOPS "*defines the most beneficial alert/warning functions that support the unique flight characteristics of helicopters while at the same time attempting to minimize nuisance alerting".*

The MOPS mandates that *"The HTAWS shall provide aural and visual terrain and obstacle alerts"* and these are described below.

Auditory alerts

The standard makes a number of observations with regard to aural alerts, including:

> *"b. The HTAWS terrain and obstacle aural warning alert shall be periodic while the alert condition is in effect.*
>
> *c. The HTAWS should support an aural alert acknowledge function to suppress multiple terrain and obstacle aural caution alerts from a given event…The acknowledge function shall not suppress terrain or obstacle aural warning alerts.*
>
> *…*
>
> *e. The HTAWS aural alert volume level shall be configurable to accommodate varying flight noise levels.*
>
> *f. The aural alerts shall be clear, concise, and unambiguous. Each aural alert should start with 'caution' or 'warning' followed by a word or phrase identifying the hazard. 'Caution terrain' and 'warning obstacle ahead' are both clear and concise examples of aural alerts."*

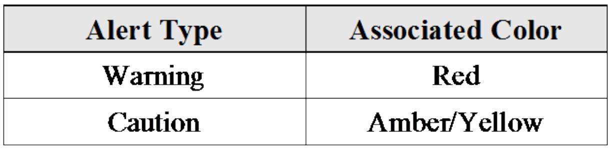
Furthermore, Section 3.2.2 requires that *"The aural alert level shall be sufficient for anticipated flight noise level*". A ground verification test (3.4.13) and a flight test including all phases of flight

(3.4.2.2) are one method to verify compliance with the requirement that *"HTAWS audio outputs shall be audible at operational RPM."* However, no mention is made of measurement protocols or desired levels and therefore this assessment is assumed to be subjective.

Visual Alerts

Similarly to the aural alerts, the standard notes a number of features with regard to visual alerts, including:

> *"b. The HTAWS shall provide continuous visual indications while caution and warning alert conditions are in effect.*
>
> *…*
>
> *d. Terrain or obstacles that generate alerts shall be displayed in a manner consistent with the caution and warning alert levels and be distinguishable from non- hazardous terrain or obstacles. The display feature shall be color coded as follows:*

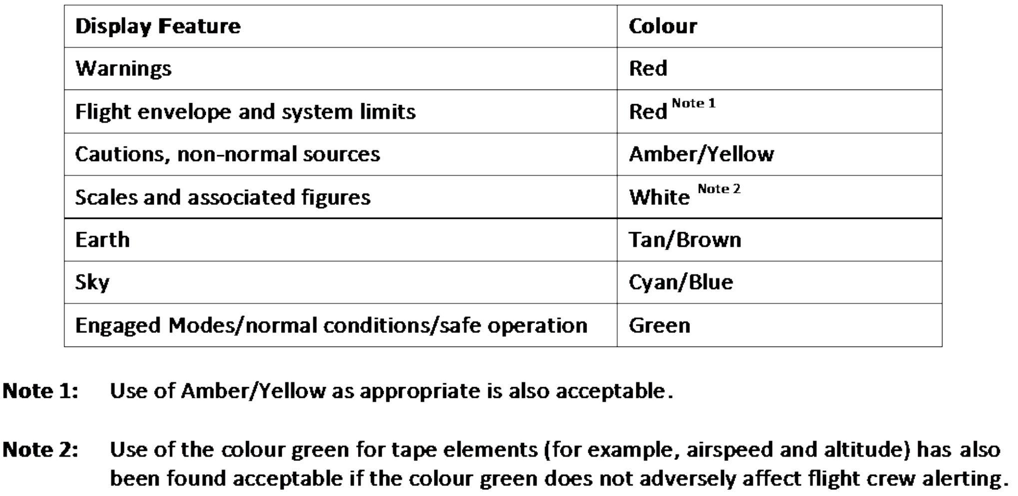


Alert Type	Associated Color
Warning	Red
Caution	Amber/Yellow

> *e. The colors and textures used for terrain and obstacle threats shall be consistent with other FAA and RTCA guidance (such as FAR 27/29.1322 and TSO C113) as well as intuitive and indicative of the immediacy of the threat.*
>
> *f. The selected colors shall complement the discrete visual and aural alerts that are presented to the flight crew. Accordingly, any colors that are used for the threat terrain and obstacle display should match the colors used for discrete visual"*

2.3.3 - TSO-C113a and ETSO-C113a

TSO-C113a (FAA, 2012a) and the European equivalent ETSO-C113a (EASA, 2016b) relates to Airborne Multipurpose Electronic Displays and Appendix 1 relates specifically to use of colour and provides the following table, shown here as Table 2.1.



Display Feature	**Colour**
Warnings	Red
Flight envelope and system limits	Red [Note 1]
Cautions, non-normal sources	Amber/Yellow
Scales and associated figures	White [Note 2]
Earth	Tan/Brown
Sky	Cyan/Blue
Engaged Modes/normal conditions/safe operation	Green

Note 1: Use of Amber/Yellow as appropriate is also acceptable.

Note 2: Use of the colour green for tape elements (for example, airspeed and altitude) has also been found acceptable if the colour green does not adversely affect flight crew alerting.

Table 2.1 – Display feature and colour as prescribed in Appendix 1 of (E)TSO-C113a

2.3.4 - TSO-C194 and ETSO-C194

TSO-C194 (FAA, 2008) and ETSO-C194 (EASA, 2012) address the technical requirements for an HTAWS system, and requires systems to meet the requirements of RTCA DO-309. However, no further guidance is given on the nature of aural or visual alerts. An RTCA special committee was proposed in 2013 to look at harmonising the colour depictions in DO-309 and TSO-C194 although this was not pursued.

2.3.5 – TSB Canada

In 2011, TSB Canada investigated an inadvertent descent in an S92A registered as C-GQCH (see Section 3.2.11). The report notes that:

> *“In 2012, the TSB’s Watchlist identified that there should be wider use of technology, such as TAWS, to help pilots assess their proximity to terrain. On 04 July 2012, TC issued regulations …requiring private and commercial turbine- powered aeroplanes, configured with 6 or more passenger seats and operating under IFR and/or night VFR, to be equipped with, and operate TAWS. However, these proposed regulatory changes apply only to aeroplanes, and are therefore not applicable to helicopters.”*

2.3.6 - Recent and future mandates

In 2014, the FAA mandated the fitment of HTAWS to HEMS aircraft. 14 CFR Part 135.605 (US Government, n.d.) entitled *Helicopter terrain awareness and warning system (HTAWS)*, states that:

> *(a) After April 24, 2017, no person may operate a helicopter in helicopter air ambulance operations unless that helicopter is equipped with a helicopter terrain awareness and warning system (HTAWS) that meets the requirements in TSO–C194 and Section 2 of RTCA DO–309.*
>
> *(b) The certificate holder’s Rotorcraft Flight Manual must contain appropriate procedures for—*
>
> > *(1) The use of the HTAWS; and*
> >
> > *(2) Proper flight crew response to HTAWS audio and visual warnings.*
>
> *…*

The FAA amendment also mandated the fitment of Radio Altimeters which were not required for Part 135 Helicopter CAT operations, since part 135.154 only referred to “airplanes”. 14 CFR Part 135.605 entitled *Radio altimeters for rotorcraft* states:

> *(a) After April 24, 2017, no person may operate a rotorcraft unless that rotorcraft is equipped with an operable FAA-approved radio altimeter, or an FAA-approved device that incorporates a radio altimeter, unless otherwise authorized in the certificate holder’s approved minimum equipment list.*
>
> *(b) Deviation authority. The Administrator may authorize deviations from paragraph (a) of this section for rotorcraft that are unable to incorporate a radio altimeter... The request for deviation authority is applicable to rotorcraft with a maximum gross takeoff weight no greater than 2,950 pounds…*

In Europe, a mandate to fit HTAWS for CAT operations (as described below) is due to come into force from the beginning of 2019. Commission Regulation 2016/1199 (European Union, 2016) amending Commission Regulation (EU) No 965/2012 (European Union, 2012) states, under the section entitled *SPA.HOFO.160 Equipment requirements,*:

> *…*

> *(c) Helicopter terrain awareness warning system (HTAWS)*
>
> *Helicopters used in CAT operations with a maximum certificated take-off mass of more than 3 175 kg or a MOPSC* [maximum operational passenger seating configuration] *of more than 9 and first issued with an individual C of A after 31 December 2018 shall be equipped with an HTAWS that meets the requirements for class A equipment as specified in an acceptable standard.*

Although there is currently no formal definition for Class A HTAWS, UK CAA has published 'informal' MOPS for HTAWS classic mode alert envelopes for offshore helicopter operations in CAP 1519. The industry is currently using this standard to develop modifications to classic modes in existing HTAWS (e.g. Honeywell EGPWS Mk XXII) for retrofit. EASA propose to cover these modifications in the short term with a Certification Memo. In the medium term, EASA intend to include the classic mode definitions contained in CAP 1519 in an ETSO for Class A HTAWS. In the long term, a EUROCAE Working Group exercise is being proposed to produce formal MOPS for Class A HTAWS; agreement to proceed was obtained at the 29 August 2018 EUROCAE Technical Advisory Committee meeting. It is proposed that the working Group will consider, inter-alia, further classic mode improvements deliberately omitted from CAP 1519 in the interests of expediency and improvements in alert form/format arising from this study."

In 2017 EASA issued a Preliminary Impact Assessment for comment which examined mandating HTAWS. The PIA noted that:

> *"A rulemaking task should consider mandating the installation of HTAWS on board the helicopter for the certain operations. The rulemaking task should only mandate HTAWS to be retrofitted to the current fleet if HTAWS standards are improved. An appropriate impact assessment for retrofit will need to be further developed. Based on the preliminary cost effectiveness analysis, HTAWS for the following operations are not to be considered: NCO, SPO, and CAT with small helicopters in VFR operations"*

If approved, this rulemaking task is expected to take 3 years, beginning in 2018. A call for nominations will be the next step in the process.

2.4 - Current Behaviour

2.4.1 - AVAD

It is worth noting the distinction between HTAWS / EGPWS and AVAD alerting. While the HTAWS system is used to provide the AVAD functionality, the look ahead and descent rate algorithms of HTAWS are very different to the 'simple' height alerts of AVAD.

The operational regulations requiring a radio altimeter with a voice alert were embodied in Europe under JAR OPS 3.660 and then adopted in EASA CAT.IDE.H.145 - see Appendix A of CAP 1519 (Civil Aviation Authority, 2017a). Originally provided by a discrete avionics system, this functionality is currently incorporated into HTAWS (Mode 6A in the Honeywell Mk XXII EGPWS).

2.4.2 – Suspend / Audio inhibit

On the EC225, the "check height suspend" button on the cyclic stick suppresses the DECISION HEIGHT call out for 3 min. The "ONE HUNDRED" call still sounds.

On the S92, the voice cancel feature allows the pilot to silence the active aural alert by pushing the VOICE CNCL button on either cyclic. Voice cancel works for all continuous aural alerts but only silences the alert one time per button push.

The audio inhibit feature allows the pilot to silence selected EGPWS aural alerts for five minutes by selecting AUD INHB on the MFD. Once audio inhibit is selected, the affected aural alerts will not be heard for five minutes or until audio inhibit is deselected. This feature will avoid nuisance aural alerts when the pilot knowingly conducts operations that would normally elicit EGPWS alerts. Honeywell (Honeywell, 2004) note that "*The Audio Inhibit switch is intended for EMS and SAR operations where the aircraft may be operating very close to terrain. Under normal operations this switch should never be needed*".

In response to the accident to G-REDU, the AAIB issued Safety Recommendation 2011-059:

> *"It is recommended that the European Aviation Safety Agency reviews the acceptability of crew-operated ON/OFF controls which can disable mandatory helicopter audio voice warnings."*

EASA's response pointed to the HSRMC work being performed on the HTAWS algorithms, described in CAP 1519 (Civil Aviation Authority, 2017a) and CAP 1538 (Civil Aviation Authority, 2017b).

2.4.3 - Documentation

It is worth noting that the operating envelopes and characteristics of the HTAWS are not trivial, even when studied away from the aircraft. It seems unreasonable to expect pilots to diagnose the reason for an alert, particularly in a high workload or emergency situation. Furthermore, different systems behave in different ways (and often with different algorithms), but often with differences being very subtle, yet crucial. The alerts should be clear and unambiguous. That said, the information regarding the system's behaviour should be accessible, accurate and easily understood.

Many pieces of documentation point to the Honeywell Mk XXII Pilot's Guide, despite that document having no information about the type-specific installation.

At present, to properly characterise the behaviour of one of the HTAWS systems required looking through around 1700 pages of study notes and 1100 pages of RFM. It requires information to be cross-checked and cross-referenced from multiple locations, often containing internal inconsistency. Similar inconsistencies are described with operators' Operations Manuals.

Another example of disagreement in the documentation relates to the Inhibit effect on GPWS Mode 6 aural (altitude) callouts. The RFM states (emphasis added):

> *"This mode inhibits the terrain and obstacle aural alerts, visual cautions and warnings and terrain/obstacles display <u>including GPWS Mode 6 altitude callouts</u>."*

whereas the training material states that the function will (emphasis added):

> *"remove Terrain Image with Obstacles symbols and alerts from displays and cancel all Forward Looking Terrain Avoidance (FLTA) and Ground Proximity Warning System (GPWS) audio alerts <u>with the exception of GPWS Mode 6 (Altitude aural Callouts).</u>"*

This could constitute a very large operational difference with the former possibly being a breach of regulation.

Similarly, one document suggests that after 5 minutes AUDIO INHIB will be reset automatically, while another states that AUDIO INHIB will begin to flash (but will not reset).

Tables 2.2 summarise the HTAWS behaviour for the S92. Some of the corresponding visual alerts are presented in section 4.3.

Mode	Description	Submode	Aural	Aural repeat while conditions exist	Visual	VOICE CNCL	AUD INHB
Look ahead (Enhanced) (requires IAS ≥70 kts)		Caution	“CAUTION TERRAIN, CAUTION TERRAIN” or “CAUTION OBSTACLE, CAUTION OBSTACLE”	Every 7 seconds	TERRAIN on ADI in yellow or OBSTACLE on ADI in yellow	✓	✓
		Warning	“WARNING TERRAIN” or “WARNING OBSTACLE”	Continuous	TERRAIN on ADI in red or OBSTACLE on ADI in red	✓	✓
1	**High descent rate**						
2	**Excessive terrain closure rate** (Inhibited when look ahead has high integrity)	Caution	“TERRAIN TERRAIN”	‘Closely followed by’	TERRAIN on ADI in yellow	✓	✓
		Warning	“PULL UP PULL UP”	Continuous	PULL UP on ADI in red	✓	✓
3	**Inadvertent descent after take off**	Caution	“DON’T SINK”	Sounds twice, then twice again each time RADALT decreases by 20%	DON’T SINK on ADI in yellow	✓	✓
4	**Insufficient terrain clearance**	4 - Caution	“TOO LOW TERRAIN”	Sounds twice, then twice again each time RADALT decreases by 20%	TERRAIN on ADI in yellow	✓	✓
		4A - Caution	“TOO LOW GEAR”	Sounds twice, then twice again each time RADALT decreases by 20% with gear up	GEAR on ADI in yellow & Red LDG GEAR illuminated on master warning panels	✓	✓

5	**Glideslope alert**	Soft alert	“GLIDESLOPE”	Twice then twice again as additional 20% below GS	Yellow alert on PFD	✓[2]	✓
		Hard alert	“GLIDESLOPE” (louder than soft alert)	Continuous	Yellow alert on PFD	✓[1]	✓
6	**Additional alerts**	Bank angle	“BANK ANGLE”	Sounds twice then suppressed until 20% increase in roll angle	none	✓	✓
		Tailstrike warning	“TAIL TOO LOW”	Continuous	none	✓	✓
		Specified radio altitude	Configured altitude(s) (eg “ONE HUNDRED FEET”)	Sounds once, resets at x+50ft Set at factory, not pilot adjustable	none	X	X
Radar Altitude Alert		Selected (bugged) altitude	“ALTITUDE”	Sounds once, resets at x+50ft	RADALT digital readout and analog pointer are yellow below RA	X	X

VOICE CNCL column shows a tick if the alert is inhibited by pushing VOICE CANCEL

AUD INHB column shows a tick if the alert is inhibited by selecting AUDIO INHIBIT

[1] **G/S CNCL** cancels Mode 5 warnings (rearms ≥ 2,000ft AGL, ≤50 ft AGL or changed ILS frequency)

Table 2.2 – Summary of S92 HTAWS Behaviour as described in the RFM

2.5 - New Envelopes

UK CAA CAP 1519 (Civil Aviation Authority, 2017a) describes new Offshore Helicopter Terrain Awareness Warning System Alert Envelopes which were developed in an earlier phase of this project. The research on which the envelopes are based is presented in CAP 1538 (Civil Aviation Authority, 2017b).

The modes supplied in CAP 1519 are intended to be used as replacements for the current classic modes when operating offshore. Full details are provided in the document, but a summary relevant to this work is given below in Table 2.1

Current Classic Mode	New Offshore Mode	Alert(s)
Classic Mode 1	Offshore Envelope 1	Sink Rate Pull-up
Classic Mode 2	Not used	
Classic Mode 3	Offshore Envelope 3A	Don’t Sink
	Offshore Envelope 3B	Check Airspeed
Classic Mode 4	Offshore Envelope 4A	Too Low Gear Too Low Terrain
	Offshore Envelope 4B	Too Low Terrain
Classic Mode 5	Unchanged	Glideslope
Classic Mode 6	Unchanged except to set fixed height alert as high as practicable	e.g. Altitude, Minimums, 100
-	Offshore Envelope 7	Check Airspeed

Table 2.1 – Summary of Offshore Modes given in CAP 1519

3 – Review of Accidents and Alerting Literature

3.1 - Introduction

In order to derive a comprehensive understanding of alerting in helicopter operations and how it might be optimised, this chapter integrates a consideration of relevant accidents (section 3.2) with a review of the applied and theoretical alerting literature (section 3.3) in order to derive a set of characteristics (section 3.4) that can inform the development of a best practice strategy for HTAWS alerting (described in the following chapters).

3.2 - Review of Accidents

The aim of this section is not to describe fully the accident sequence or the systemic causes of the accident, but merely to highlight points of possible relevance to HTAWS functions.

An initial selection of accidents was included in the original tender document. This was supplemented with additional accident reports that have been released since the tender was compiled. Also, Version 1.5 of the EHSIT database was interrogated to support the existing selection and add any other accidents of interest. The accident to G-BDII was added from this search. Further, more recent, accidents have been added as the reports have been released.

The following accidents and incidents are reviewed in detail in Appendix 2 for their relevance to HTAWS alerting.

G-BIJF	12th August 1981	Bell 212	1.3 mi SE of the Dunlin Alpha Platform
G-BDIL	14th Sept 1982	Bell 212	14 miles from the Murchison platform
G-BEON	16th July 1983	Sikorsky S-61N	Near St Mary's aerodrome, Isles of Scilly
G-BHYB	9th December 1987	Sikorsky S-76A	Near Fulmar A Oil Platform in the North Sea
G-BDII	17th Oct 1988	Sikorsky S61N	Near Handa Island off the north-west coast of Scotland
G-TIGH	14th March 1992	AS 332L	Cormorant 'A' Platform
G-HAUG	12th December 1996	Sikorsky S-76B	Omeath, Co. Louth
G-BLUN	27th December 2006	Aerospatiale SA365N	Morecambe Bay
G-REDU	18th February 2009	Eurocopter EC225LP	Eastern Trough Area Project (ETAP) Central Production Facility Platform
N2NR	23rd October 2010	Agusta A109A II	Shanlieve, Mourne Mountains, Northern Ireland

C-GQCH	23rd July 2011	Sikorsky S-92A	St. John’s, Newfoundland and Labrador, 200 nm E
G-WIWI	3rd May 2012	Sikorsky S-76C	Peasmarsh, East Sussex
G-WNSB	23rd August 2013	AS332L2	Sumburgh
OY-HJJ	6th November 2013	Eurocopter EC155B1	Clipper South Gas Field, North Sea
G-LBAL	13th March 2014	Agusta Westland AW139	Near Gillingham Hall, Norfolk
EI-ICR	14th March 2017	Sikorsky S-92A	Black Rock, Co. Mayo

3.2.1 Comments on review of accidents

There are a number of common or connected factors which appear in the reports reviewed above. Many are self-evident from the accidents, but are worth collating to help define the desirable characteristics of a new alerting system.

- A visual alert alone is not sufficient (e.g. the light on the RADALT in G-BEON, or the DH caption in G-REDU) to alert flight crews. The location of the RADALT has been an issue in a number of accidents, highlighting the complex visual scan patterns that may be adopted by flight crews,

  Observation 1: Visual alerts in isolation can often be overlooked due to task-focus or by being out of scan.

- In some accidents (particularly the earlier ones) crews would tend to work around what they considered to be nuisance alerts by, for example, bugging a height below 100 ft. There are anecdotal reports of crews disabling HTAWS systems and some aircraft routinely fly with the system deactivated (e.g. N2NR). These issues are likely to be exacerbated when the alerts in question are perceived by operators as brash and annoying.

  Observation 2: Nuisance alerts must be minimised to avoid workarounds or defeating of the alerting system by flight crews.

  Observation 3: Where possible, alerts should be designed in such a way as to minimise their perceived annoyance. However, annoyance is often related to perceived urgency (see section 3.3.1.3), thus there is a need to balance these factors carefully, with additional reference to likely nuisance alert rates; for example, if a system creates very few nuisance alerts then a high level of annoyance may be acceptable for the alerts if this also delivers a high level of detectability and urgency.

- There are inconsistencies, or a lack of guidance, in the operational use and design surrounding HTAWS systems, particularly in relation to the SUSPEND functionality. This may reflect an evolution from AVAD to HTAWS. A lack of practice at applying SOPs has also been highlighted (C-GQCH).

  Observation 4: SOPs need to be established for the use of, and response to, alerts. In addition, flight crews need practice at implementing these SOPs. (This is addressed by the recommendations from the G-REDU report.)

- In the accident to G-REDU, the TAWS system was not operating and the crew were unaware.

Observation 5: Flight crew should be made aware if the system is inoperative and will not provide alerts. (This is addressed by the recommendations from the G-REDU report.)

- In the accident to G-BIJF (which is one of the few accident flights where audio is openly available, since it was broadcast as radio traffic), an increase in noise level and fluctuation of frequencies can be heard.

Observation 6: It is important that aural alerts are detectible against the background noise which, in an accident, may differ from normal operations.

- In many of the accidents, an aural alert was provided but not with sufficient warning time to allow recovery. Warning times of around 3 or4 seconds are common.

Observation 7: Warnings need to be timely, with enough time available to allow recovery. (This has been addressed as part of the alert envelope study.)

- In a number of accidents (e.g. G-WIWI, G-BHYB) an alert sounded (or was likely to have sounded), but the flight crew reported that they did not hear the alert. In another accident (G-BLUN) no response to the aural alert is evident in the flight data.

Observation 8: It is possible for flight crew to reach a state (possibly through distraction or task focus) where an alert is detectible, but does not capture the attention or invoke a response. Alerts should be appropriately attention-capturing, although this can be challenging to define.

- A further issue is that of becoming accustomed to an alert. If an alert is heard, say, on every approach then there is a danger that pilots become accustomed to hearing it in the context of a normal landing. As a result, simply hearing the alert will not be sufficient to be made aware of a situation that requires an immediate response; instead, the pilot will have to decide whether the alert is part of a normal situation or is being heard at an inappropriate point, requiring a response. This calls into question the use of AVAD-style alerting for both ‘normal’ and ‘non-normal’ situations. Conversely, if the pilot habitually suspends the alert once an approach is established, then there is a risk that the alert will not sound when needed.

Observation 9: It should be clear to pilots that the situation requires immediate attention. An alert which is sometimes heard in normal operations requiring no action, and sometimes heard in emergencies requiring immediate action, may elicit slow responses in cases where action is required, and could even become routinely ignored by pilots. Ideally, in order to avoid this, an alert would only sound when pilot action was required.

3.3 - Principles of Auditory, Visual and Tactile Alerting

This section describes the relevant scientific literature on auditory, visual and tactile attention and alerting and considers how these findings might relate to the design of HTAWS alerts.

3.3.1 Principles of auditory alerting

A well-designed auditory alert should draw the attention of the operator to the situation requiring attention, provide some information about the nature of the situation, and guide the operator towards an appropriate course of action (Stanton & Edworthy, 1999). In order to fulfil these requirements in situations requiring many different alerts, either the operators must learn the meaning of many different abstract sounds or the alerts themselves must deliver the required meaning, which is most easily achieved by using speech for at least part of the alert. Each approach has advantages and disadvantages, as outlined in more detail below.

Tan & Lerner (1995) collected ratings from 36 human factors experts concerning how important they considered a range of attributes in designing an alert to signal an “imminent” crash (for an in-car crash avoidance alerting system). Five attributes received similarly high ratings: conspicuity (how easily detectable the sound is against the background noise); discriminability (how distinct the sound is from the other sounds in the environment); meaning (how clearly the sound suggests an imminent crash); urgency (the sense of importance delivered by the sound); and response compatibility (how naturally the sound prepares the operator to take the appropriate action).

3.3.1.1 Properties of auditory stimulus used

Level

The audibility of any alerts used is of critical importance in the case of helicopter operations, given the high levels of ambient cockpit noise that are typical. It is also possible that noise levels increase substantially during the build-up to an accident (see, for example, the accident to G-BIJF in Appendix 1 coupled with Observation 6, section 3.2.1). It is widely recommended that high-priority auditory alerts are presented at a level that is at least 15dB SPL above the masked threshold of the background noise e.g. (Hellier & Edworthy, 1999b; ISO, 2003; R D Patterson, 1990a). SPL is Sound Pressure Level, a way of measuring the amplitude of an acoustic signal. This issue is examined in more detail in Chapters 7 and 8.

Abstract sounds

The use in auditory alerting systems of abstract sounds (sometimes called ‘attensons’, or attention-getting sounds) has the advantage that the resulting alerts can convey information in a very short time, speeding the possible reaction time of the operator. For this reason, they have been recommended for use in imminent crash alerts (e.g. Campbell, Richard, Brown, & McCallum, 2007) where timing factors are critical. This was demonstrated, for example, by the accidents to G-BHYB, G-BDII and G-TIGH, in all of which it appeared that insufficient time was available to respond following an auditory alert (see Observation 7, section 3.2.1).

Abstract sounds can also be designed in such a way as to reduce the chances that they will be masked by the cockpit noise. For example, Patterson (1990) recommends that alerts comprise four or more components spread across the spectrum at levels that are appropriately high, in order to ensure that they are not susceptible to masking by the background noise (see also Hellier & Edworthy (1999a).

The obvious disadvantage of abstract sounds is that their meaning must be learnt in advance by the operator and then retrieved in the alerting situation before the alert can be understood and acted upon. Patterson (1982) suggested that skilled operators should be able to differentiate between six different alert signals without problems, because even naïve participants could learn to identify this number without difficulty. However, in complex systems (such as helicopter cockpits) that require a much larger number of alerts to many different possible situations, the exclusive use of abstract sounds is unfeasible.

Another advantage of abstract sounds in high workload environments is that the most basic properties of sound (such as pitch and timbre) are often processed even in the absence of focused attention, whereas semantic meanings are not (e.g. Broadbent, 1958; Cherry, 1953). For example, when participants attend to a message delivered to one of their ears and ignore a different message simultaneously delivered to the other ear, they will typically notice changes in the basic properties of the ignored message (e.g. a change from a male to a female speaker) while nevertheless being unable to report any of the content of the message. This suggests that an alert designed to deliver a clear change in the basic properties of the current sound (e.g. the sudden appearance of a pure tone) is more likely to be noticed than an alert that is defined by its semantic meaning (e.g. a spoken message).

Speech

The use of spoken alerts allows communication of relatively complex information, as well as differentiation between many different types of alert, without requiring any learning on the part of the operator. However, the use of verbal information also has disadvantages (as discussed, for example, by Smith, Stephan and Parker, 2004). The most significant of these is that speech-based alerts typically take longer to deliver than abstract alerts, and any resulting delay in corrective action could be critical in the build-up to an accident (see Observation 7, section 3.2.1). Speech alerts are also more likely to be masked by other sounds in the environment because, as well as masking from the general background noise, speech alerts are also open to informational masking from other speech sources in the cockpit (e.g. Brungart, 2001). Finally, pilots have been reported to perceive speech alerts as *"noisy, strident and intrusive"* (Dell, 2000; as cited in Johnson & Dell, 2003).

Auditory icons

It is possible to design non-speech sounds that deliver some level of meaning (e.g. the sound of screeching tyres could indicate the need for an operator to apply a brake). These types of sound are often referred to as auditory icons (e.g. Brazil & Fernström, 2011; Gaver, 1986) and can deliver some of the advantages of abstract sounds (in terms of short duration and reduced susceptibility to masking) while still retaining some capacity for information delivery. For this reason, auditory icons have been recommended as a useful option in the design of complex auditory displays (e.g. Campbell et al., 2007; Leung et al., 1997; Smith et al., 2004), especially where dimensional data must be represented (e.g. Adcock & Barrass, 2004). Indeed, some helicopters do already use a low rotorspeed auditory alert that reduces in frequency and cadence as the rotor slows, giving an auditory impression of a rotor slowing (JAA Helicopter Sub-Sectorial Team, *Auditory Displays - Review of Literature*). However, the range of situations that can be represented by auditory icons of this type is limited.

3D audio

Recently it has been suggested that binaural recording and presentation techniques might be useful in designing auditory alerts because of the '3D' audio perception that binaural presentation can achieve. For example, Haas (1998) found that the addition of 3D auditory alerts (both speech-based and auditory icons) to visual-only signals reduced helicopter pilot response times to simulated malfunctions. However, this study did not include a non-3D auditory control condition, so these results cannot be taken as evidence for the superiority of 3D over standard audio. Indeed, further research has failed to find performance advantages with 3D audio compared with stereo (Johnson & Dell, 2003). However, as acknowledged by the authors themselves, the stimuli used in this work were not particularly lifelike and did not use the 3D capability to its full potential. In any case, the complexity involved in delivering these kinds of stimuli (along with the mixed research results) precludes this approach from further consideration for this project.

Combinations of speech and abstract sounds

In the context of the HTAWS alerts, it seems unreasonable for operators to learn the required number of abstract alerts, so it would be sensible for the alerts to involve at least some speech, possibly combined with an abstract sound or auditory icon to improve detectability (as recommended, for example, by MoD, 1989). This approach would allow a high level of detectability without the need for operators to learn the meaning of each tone (which will be communicated by the speech component). However, the approach would also increase the total duration of the alert, and this would need to be taken into account in the design of the alert.

Repeat behaviour

The extent to which an auditory alert repeats, and the format in which it does so, is an important design consideration. Alerts that are designed to be highly attention-capturing can be severely distracting if they repeat continuously, often causing operators to prioritise the cancellation of the alarm signal at the expense of dealing with the underlying problem (e.g. Patterson, 1982). On the other hand, alarms that do not repeat are easily forgotten and, depending on the context, the lack of a repeat could also be misconstrued as indicating that the problematic situation has been resolved. In order to address these issues, Patterson (1982) proposed the use of an alert that varies in intensity across its repeats, starting forcefully (but not so loud as to provoke startle) then reducing to a level where conversation between operators can take place, then increasing again (to even louder level than before) if no action has been taken.

3.3.1.2 Urgency

There is a substantial amount of research to suggest that sounds are perceived as more or less urgent according to variations in certain acoustic properties. In general, perceived urgency has been found to increase with increased rate and/or pitch, and/or with increased random irregularity in the frequencies of the harmonics (e.g. Edworthy, Loxley, & Dennis, 1991). Of these, pulse rate appears to have the strongest effects on urgency perception (Hellier & Edworthy, 1999b). In the light of these findings, it has been argued that the intrinsic level of perceived urgency of an auditory alert should be matched with the gravity of the situation that it signals (e.g. Edworthy, Loxley, & Dennis, 1991; Patterson, 1982). Indeed, a 2004 study of the abstract auditory alarms used in the Canadian Forces CH-146 Griffon helicopter claimed, at that time, that: *“the triggering situations are not adequately conveyed by the acoustic parameters inherent in the alarms”* (Arrabito, Mondor, & Kent, 2004, pg. 821).

However, much of this research has investigated subjective urgency judgements in the absence of any other workload. By contrast, the more important question in the present context is whether sounds differ in their ability to capture attention and reduce reaction time (RT) (particularly under conditions of high workload). This is a particularly important point because findings based on measurements of perceived urgency do not always agree with findings using other measures. For example, in a higher workload situation involving an on-screen object tracking task, Burt et al. (1995) found no differences in RTs to stimuli that had previously been shown to be judged differently in perceived urgency. This implies that stimuli with higher perceived urgency ratings do not always elicit faster RTs, suggesting that perceived urgency should not be relied upon exclusively as a measure of the urgency with which a stimulus is likely to elicit a response in a more complex task. Nevertheless, Haas & Casali (1995) manipulated perceived urgency using variations in pulse format (sequential pure tones, simultaneous pure tones, or frequency-modulated tones), pulse level and pulse rate. They found that perceived urgency did indeed correlate with RT, such that RT decreased as perceived urgency increased. Similarly, Suied, Susini and McAdams (2008) demonstrated that reaction times to alerts presented during a visuomotor tracking task decreased as pulse rate increased, indicating that increases in pulse rate can improve the ability of a stimulus to capture attention and elicit faster responses when presented alongside a concurrent workload.

In the case of spoken alerts, there is some evidence to suggest that female voices may have an advantage over male voices in portraying urgency, because of the higher pitch and larger pitch range of female speech (Edworthy, Hellier, & Rivers, 2003). However, under high levels of cockpit noise, male voices appear to have an intelligibility advantage (Nixon et al., 1998), which is likely to be more important as an overall design consideration than the ability to portray higher levels of urgency (especially if the spoken message is accompanied by an abstract tone, which itself can be designed to deliver the required sense of urgency). Instead, it seems appropriate to choose the voice for the spoken messages with reference to the overlap of speech and noise spectra.

It is important to note that, although the majority of the research has investigated the acoustic properties that provide sounds with an intrinsic level of perceived urgency, cognitive factors have also been shown to affect urgency judgements. For example, Guillaume et al. (2003) found that learned associations (such as alternating high and low pitch being associated with an alarm siren) influenced people's urgency judgements in addition to the physical properties of the sounds.

3.3.1.3 Annoyance

The extent to which operators perceive alerts to be annoying is an important design consideration, because systems that are considered highly annoying are at risk of being suspended or disabled entirely (as seen, for example, in the accidents to G-BHYB, G-BLUN and G-REDU - see section 3.2 and Appendix 1). Research in general has suggested that alarms with a higher degree of urgency also tend to be perceived as more annoying (e.g. Edworthy et al., 1991; Tan & Lerner, 1995), although some parameters have been identified that can increase perceived urgency while having smaller effects on annoyance. For example, Marshall, Lee and Austria (2007) tested alerts consisting of series of pulses. They found that reducing the interpulse interval, increasing the pulse duration, increasing the abruptness of offset of the alert as a whole (i.e. whether or not the pulses fade out towards the end of the alert), and increasing the duty cycle of the entire alert (the proportion of the alert time for which the pulses is present) all increased urgency more strongly than they increased annoyance.

3.3.2 Principles of visual alerting

Visual alerts need to attract attention without interfering with the perception of other relevant information, much of which is likely also to be presented visually (Crébolder & Beardsall, 2009). The extent to which this is feasible in an environment as complex as a helicopter cockpit is a matter of debate: any alert that is sufficiently attention-capturing as to ensure its immediate noticeability would distract the operator from a range of other critically-important visual information. For this reason, visual alerts are not generally recommended for the delivery of time-critical warning information, but are instead suggested either as a means of delivering more continuous, lower-priority information or, in higher-priority situations, as a source of supplementary information alongside an auditory or tactile alert (Campbell et al., 2007).

3.3.2.1 Properties of visual stimulus used

Content

Similarly to auditory alerts, visual alerts can range from abstract displays (such as simple coloured lights), through iconic symbols (simple graphics that communicate some level of meaning, such as a picture of an oil can to indicate low oil levels) to alphanumeric displays that are able to communicate complex messages. The nature of the information to be presented will of course determine the choice of display type, however alphanumeric displays are not in general recommended for delivering time-critical information (Campbell et al., 2007).

Flash rate

Many of the design considerations relating to visual alerts concern their ability to attract attention, which can be influenced by several factors. Perhaps most importantly, the abrupt onset of a visual stimulus has been shown to be highly effective in attracting attention (Jonides & Yantis, 1988). Visual alerts are therefore often presented with an abrupt onset, and indeed are often made to flash (ensuring a sequence of onsets and offsets). In line with this approach, there is evidence that high flash rates (240 flashes per minute) are detected faster than lower flash rates (60 flashes per minute), however they also create stronger effects of glare and perceived annoyance (UNECE, 2002). It is also important to note that, if a button with alphanumeric information on it is set to flash, this can impair the operator from accessing the written information. The use of flashing borders (rather than entire buttons) can sometimes be a useful approach in order to counteract this problem.

Discriminability

The discriminability of a visual alert (i.e. the extent to which it is different from the other display elements around it) can also be important in determining how effectively it will capture attention. This is affected by a range of factors including size, luminance, contrast and lettering (Phansalkar et al., 2010). Items that are unique in some way (e.g. in shape, colour and/or size) tend to be more effective competitors for attention (General Motors Corporation and Delphi-Delco Electronic Systems, 2002; Theeuwes, 1992).

Location

Attentional capture by visual alerts is also determined by the location of the alert within the control interface. The general guidance is that high priority alerts should be located close to relevant displays (e.g. Wickens & Carswell, 1995) and within the stationary field of view (± 15° vertically from fixation; ± 30° horizontally, e.g. Phansalkar et al., 2010). These guidelines in fact allow for alerts to be positioned across fairly large areas of the display. For example, at a viewing distance of one metre from the display, ± 15° of visual angle gives a total range of around 52 centimetres from fixation, and ± 30° equates to double this distance. Because pilots do not maintain fixation on any one location (see section 3.3.2.3), locating alerts at the extremes of these distances from the centre of the display is inadvisable. However, alerts are often placed in somewhat peripheral locations, because of the requirement that they should not interrupt ongoing perception of other relevant visual information. The effects that this might have on the attention-getting qualities of the visual alert are unclear. On the one hand, visual acuity is known to reduce as retinal eccentricity increases, meaning that peripheral alerts are likely to receive less effective visual processing. For example, the contrast of peripheral information may need to be up to five times higher than that of fixated information in order to achieve a similar level of visibility (Ministry of Defence, 1996). On the other hand, however, peripheral vision can be sensitive to changes in contrast, which can drive attentional allocation and associated eye movements such that they are brought into full focus for further processing (Crébolder & Beardsall, 2009). It is important to note that this type of attention switching (away from the central display interface and towards the visual alert) could be counterproductive if it causes the operator to miss other critical information.

3.3.2.2 Perceived hazard level

Just as in the auditory domain, it has been argued that certain visual stimulus properties are inherently associated with greater or lesser degrees of hazard. For example, a faster flash rate has been associated with greater perceived hazard level (as have breaks in the flash pattern; Chan & Ng, 2009). Higher hazard levels have also been associated with the colour red (Braun & Silver, 1995; Chan & Ng, 2009; Chan & Courtney, 2001) and the colour orange, while blue, green and white are all perceived as relating to lower hazard levels (Braun & Silver, 1995).

3.3.2.3 Pilots' eye movements

Recent eye tracking research (Jarvis Bagshaw Ltd., 2016) recorded the eye movements made by EC225 pilots as they negotiated several scenarios in a flight simulator. This research did not examine eye movements in response to specific alerts; instead, the scan patterns that were observed in this study reflect a more voluntary, deliberately-controlled sequence of fixations, through which pilots gather the information that they require. For this reason, many of the central results from the work are not of direct relevance to the current project, and are not reviewed here. However, one of the main findings was that many pilots adopt either a “half-kite-shaped” scan pattern – in which their fixations fall more frequently on the bank angle indicator, heading and VSI than on other areas of the display– or a “kite-shaped” scan – in which the speed tape is added to the “half-kite” pattern (see Figure 3.1). HTAWS alerts are often presented inside the attitude indicator, which was fixated much less frequently than areas forming part of the scan pattern in this study. However, it is difficult to predict how this positioning would affect the detectability of the HTAWS alerts, because it is not necessary for a salient item to be fixated in order to be detected, and the HTAWS alerts are presented sufficiently close to the main scan paths to make it highly likely that they should at least fall into pilots' peripheral vision.

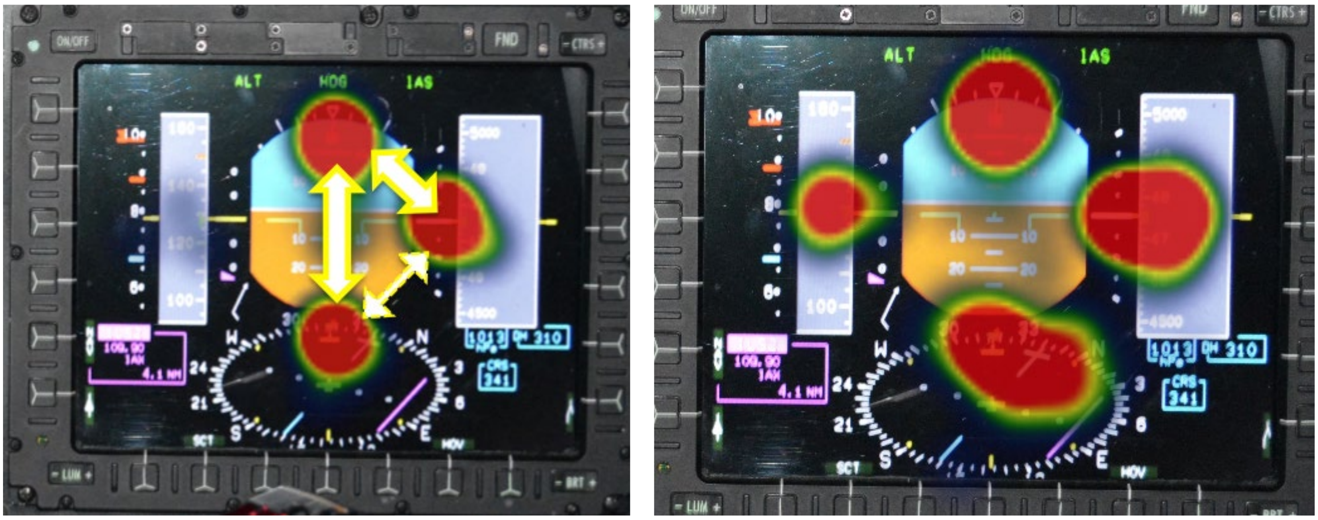


Figure 3.1 – eye movement heat map, from one pilot who exhibited the "half-kite-shaped" scan pattern (left panel, data from a two-minute period) and another pilot exhibiting the "kite-shaped" pattern (right panel, data from a three minute period). Both images are from Jarvis Bagshaw Ltd. (2016).

Another central finding from this research is that pilots differed substantially between one another in all aspects of their eye movement behaviour. This fact, along with the frequent need for pilots to look away from the display altogether (e.g. out of the cockpit), indicates that high priority alerting systems cannot rely on fixations falling on a particular place at a particular time. This highlights the importance of using sensory modalities that are less spatially restricted than vision (e.g. hearing) for presentation of alerts with high priority.

Indeed, the accident to G-BEON (see Section 3.2 - Review of accidents and Appendix 2) provides an example of a case in which a visual alert (the small amber radio altimeter light) was not noticed, most likely because of its distance from the pilot's focus of visual attention (outside the helicopter) and also possibly because of its relatively low discriminability (e.g. small size). This supports the approach of treating visual alert information as supplementary to a primary auditory and/or tactile signal (Campbell et al., 2007). In this case, the ability of the visual alert itself to attract attention is of less importance, because attention to the alert can be driven via the auditory and/or tactile route. This consideration, along with the practical difficulties involved in changing any aspects of the visual alert presentation, led the project to focus primarily on the design of the auditory alerts.

3.3.3 Principles of tactile alerting

The use of tactile alerts has been recommended for situations in which auditory alerts may be missed (Campbell et al., 2007), perhaps due to high levels of background noise or high levels of ongoing auditory workload (both of which are likely to apply within helicopter cockpits). Tactile stimuli have also been argued to receive relatively high processing priority, because they occur in peripersonal space (i.e. the space immediately surrounding the body; Ho & Spence, 2009), which could confer additional effectiveness in capturing attention in high workload situations.

More applied research has already demonstrated that tactile information can be used to improve complex performance (e.g. in a land-based deck landing task; Jennings et al., 2004).

And there is also direct evidence to indicate that tactile stimuli can act as effective alerts. For example, braking reaction times in a simulated driving task for front-to-rear-end collision avoidance were faster with tactile alerts than with visual, auditory, or no alerts (Scott & Gray, 2008). Similarly, tactile alerts signalling unexpected changes in an automated cockpit system were detected faster and more frequently than visual-only cues (Sklar & Sarter, 1999).

Some of the practical considerations around the use of tactile alerts relate to the requirement that the hardware used to deliver any such alerts must be reliably in contact with the operator's body at all times. Also, as with visual alerts, it is important to consider the effects of likely attentional capture to the location of the tactile stimulus. For example, if a tactile alert is delivered to a pilot's right wrist, the triggering of the alert is likely to direct attention to the right wrist, which may or may not be helpful for the response that is subsequently required. Any use of tactile alerts should thus consider their presentation location very carefully, with reference to the actions that are likely to be required at the time that the alerts are delivered. Because of the high priority with which tactile stimuli are likely to be processed, it is also essential to consider nuisance alarm rates in determining whether this would be a useful approach, because of the high levels of annoyance and distraction that incorrect tactile alerts are likely to cause.

3.3.4 Multisensory alerting

Given that each sensory modality has advantages and disadvantages in its use as a channel for delivering alerts, one possible approach is to combine alerts from different sensory modalities. There is evidence to suggest that this approach can deliver more effective alerts than presenting alerts in a single modality alone. For example, compliance behaviour has been found to increase with the addition of a spoken alert to a visual alert (Wogalter, Kalsher, & Racicot, 1993). In addition, auditory alert icons (siren, buzzer or security alarm) have been shown to increase perceived hazard levels compared with visual-only conditions (Chan & Ng, 2009). It has also been suggested that, under high workload, multisensory cues might capture attention more effectively than unimodal cues (Spence & Santangelo, 2009). However, it is dangerous to assume that different modalities have separate processing resources (e.g. Wickens, 1980) because research does not agree on this (e.g. Driver & Spence, 1998; Gallace, Tan, & Spence, 2007).

3.3.5 The influence of concurrent workload

Despite the focus of this review on identifying ways in which to make stimuli as noticeable as possible, it is critical to note that even highly salient stimuli can go unnoticed when attention is focused elsewhere, both in the visual domain (e.g. Mack & Rock, 1998; Simons & Chabris, 1999)) and in the auditory domain (e.g. Dalton & Fraenkel, 2012; Dehais et al., 2014; and note that the latter demonstrated these effects in a simulated cockpit environment). Indeed, increasing the visual load of a focal task has been directly shown to reduce detection sensitivity for concurrently-presented visual stimuli (e.g. Macdonald & Lavie, 2008), auditory stimuli (e.g. Raveh & Lavie, 2015), and tactile stimuli (e.g. Murphy & Dalton, 2016). Relevant examples of this phenomenon were arguably observed in cases G-BHYB, G-BLUN and G-WIWI (see Observation 8, section 3.2.1) all of which appear to have involved situations in which auditory alerts were presented by the system but not registered by the pilots. Thus, although the current work seeks to design alerts that are clearly-detectable and likely to capture attention, under situations of very high stress and workload the possibility remains open that even alerts of this type may be missed.

3.3.6 The influence of startle, freeze and denial

The startle response involves an automatic set of reactions to surprising and potentially threatening stimuli (see Martin, Murray, Bates, & Lee, 2015, for a review relating specifically to aviation contexts). Auditory stimuli with rise-times of less than 10 ms typically elicit a startle response, although very intense stimuli can elicit startle with slower rise-times (Åsli & Flaten, 2012). Tactile stimuli can also elicit startle (Flaten & Blumenthal, 1998) although typically this has been shown using airpuffs presented to the face, which would be unlikely candidates for tactile alerts in the present context! The startle response involves a range of rapid reflexes (such as eye blinks and head movements), which serve in part to bring the startling stimulus into the focus of attention. Simultaneously, an acute "fight or flight" physiological response is initiated more broadly throughout the body. This quickly dissipates if no threat is identified (e.g. in the case of a false alarm), however if the startling stimulus is assessed as posing a genuine threat then the stress response is maintained and increased.

There is evidence to suggest that cognitive and motor performance can be impaired for up to a minute following a highly startling stimulus (e.g. Thackray & Touchstone, 1983). Indeed, Martin, Murray and Bates (2012) argued that recent air accidents (e.g. Colgan Air Flight 3407 and Air France Flight 447) may have involved pilots experiencing these kinds of post-startle cognitive disruptions. It will therefore be important to design all alerts in such a way as to avoid startle where possible (e.g. using reasonable rise times for auditory stimuli).

However, although it is possible to design alerts in such a way as to reduce the chances of eliciting a startle reflex through high intensity or abrupt onset, an acute stress response is still likely to follow if the alert indicates a serious threat. In some people, this can lead to a freezing response, whereby they become incapable of taking action even when provided with clear directions (e.g. Leach, 2004). For example, Martin, Murray and Bates (2012, pg. 4) report the case of a pilot: "freezing after commencing a rejected takeoff at Toronto. … In this case he closed the thrust levers, but failed to brake or select reverse thrust, simply staring straight ahead. The aircraft ran off the end of the runway at 70 knots, killing several people." These authors also suggest that the phenomenon of denial, in which acute stress causes people to ignore the stress-inducing stimulus, can also be experienced by pilots during emergencies.

In sum, when faced with a life-threatening situation, people experience a range of physical and cognitive responses which may not always be supportive of effective action. Although pilots regularly practice responding to simulated emergencies, they can still be prone to effects of startle, freezing and denial when faced with genuine emergencies, partly because these are so rare in real-life operational conditions. It is impossible to design an alert that avoids these effects altogether. However, the use of a "caution" level alert (as a precursor to a more urgent "warning" alert) can draw the operator's attention at an earlier stage to potentially-dangerous circumstances, with the aim of encouraging them to take action before the situation becomes extreme. This approach must be balanced with the need to avoid nuisance alerts (see section 3.3.8) because alerts that are generated in response to smaller deviations from normal operations are in general more likely to be spurious, and this can also have serious impacts on the effectiveness of the alert system as a whole.

3.3.7 The influence of fatigue

Effects of fatigue are complex and hard to predict. For example, on the one hand, fatigue can 'narrow' the visual field (e.g. Regan, Lee, & Young, 2009) meaning that peripheral stimuli are less likely to be noticed. However, on the other hand, fatigue reduces executive control capacities (e.g. van der Linden, Frese, & Meijman, 2003), which could leave people more susceptible to attentional capture by alerts. The specific effects of fatigue will also vary according to the specifics of the particular task being carried out at the time. In addition, substantial individual differences have been identified in the effects of fatigue on performance (e.g. Van Dongen, Caldwell, & Caldwell, 2006). Thus, it is very difficult to take fatigue into account when designing alerting schemes.

3.3.8 The influence of false or nuisance alerts

Experimental studies using laboratory-based tasks have indicated that higher false or nuisance alert rates lead to reduced response rates – a phenomenon known as the ‘cry wolf effect’ – as well as slower responses in cases where responses are made (e.g. Bliss, Gilson, & Deaton, 1995; Getty, Swets, Pickett, & Gonthier, 1995). This may partly be explained by the observation that frequently-repeated false alerts are likely to cause an operator to become habituated to the alert signal, such that future responding to that signal is reduced (e.g. Breznitz, 1984). However, there also appear to be higher-level cognitive factors involved in the effect. For example, there is evidence that the ‘cry wolf effect’ may become more pronounced under high ongoing workload (e.g. Bliss & Dunn, 2000). It has also been shown that simply being told that an alert is more reliable can increase people’s frequency of responding to that alert, even if this information is not accurate (Bliss, Dunn, & Fuller, 1995). In addition, there is evidence that response rates to an alert increase if other nearby alerts are also active, even if those alerts relate to entirely separate issues (Gilson, Mouloua, Graft, & McDonald, 2001). Taken together, this evidence indicates that operators make extensive use of their prior experience of an alert’s reliability, and of their current assessment of the situation, in deciding whether or not to respond to an alert. False alert rate is therefore considered a critical parameter in the design and evaluation of alerting systems. Indeed, this issue was considered extensively in the development of the new HTAWS envelopes, which are intended to generate nuisance alert rates of less than 1 in 100 flights (see section 2.4 for a summary).

Interestingly, it has been argued that the designers of alert systems are likely to underestimate the chances of their system generating false alerts, because the system appears during testing to respond reliably to all the relevant inputs (e.g. Endsley & Jones, 2012). These authors argue that the accurate assessment of the hazard level of a particular situation can often require additional information that the alert system has not been designed to utilise, and that this lack of context is often the cause of false alerts.

3.4 - Remarks

Based on the preceding review, it is possible to define some desirable characteristics which can guide the development of an alerting strategy.

Visual alerts:

- Must be in field of view or on a screen that is being used.
- Based on previous failures to capture attention, they should be supported by an aural alert.

Aural alerts:

- Must be detectible against typical operational noise and possible raised accident noise levels.
- Must capture attention in a high workload situation.
- Must be timely (while preserving an appropriate balance between, on the one hand, the aim of providing as much warning time as possible – ideally through the use of precursor ‘caution’-level alerts – and, on the other hand, the need to keep nuisance alert rates as low as possible).
- Repeat behaviour must be carefully considered, including the possibility of varying the intensity of an alert across several repeats.

- Must not be ignored (heard, perceived and discarded). The nuisance alert rate will have an effect on this.
- If the alerts are designed to be highly attention-capturing, they are also likely to be highly intrusive and annoying when presented unnecessarily. The system must therefore be reliable and trusted by pilots to deliver accurate information.

Tactile alerts:

- Must be detectible against typical operational vibration levels and possible raised accident vibration levels.
- Must capture attention in a high workload situation.
- May be unhelpful if they draw attention to an irrelevant spatial location.

4 – Visual Alerting

4.1 - Background

As described in section 3.3.2, the fact that helicopter pilots are continually required to process large amounts of critically-important visual information, along with the observation that they make fixations over a wide area, including both inside and outside the cockpit, suggests that the visual component of the HTAWS alerting system should be seen as supplementary to the auditory component. This approach is in line with existing recommendations for the delivery of high-priority time-critical alert information (Campbell et al., 2007). In addition, the practical challenges involved in changing the visual alerting components of HTAWS would be significant. For these reasons, detailed examination and testing of possible improvements to the HTAWS visual alerting was not carried out within the current project. However, the current section compares the alerting regimes of the AW189 and S92 aircraft (presented in Section 4.3) with the existing guidance on the effective design of visual alerts, concluding with some broad suggestions for improvements that are likely to be effective.

4.2 - Visual Alerting Recommendations

Section 3.3.2 contained a review of literature on effective visual alerting. Based on that material, some recommendations have been extracted which are described below.

4.2.1 Location

The sources identified in the literature review recommend that high priority alerts be located ± 15° vertically from the point of fixation and within ± 30° horizontally from the point of fixation. It is also recommended to present the alert “close to relevant displays”.

It is interesting to compare these recommendations with the guidance in AC 29-2C Chg 7 MG 20 (see Section 2.3.1). Figure 4.1 shows the suggested range for primary and secondary fields of view and Figure 4.2 shows the same for vertical fields of view.

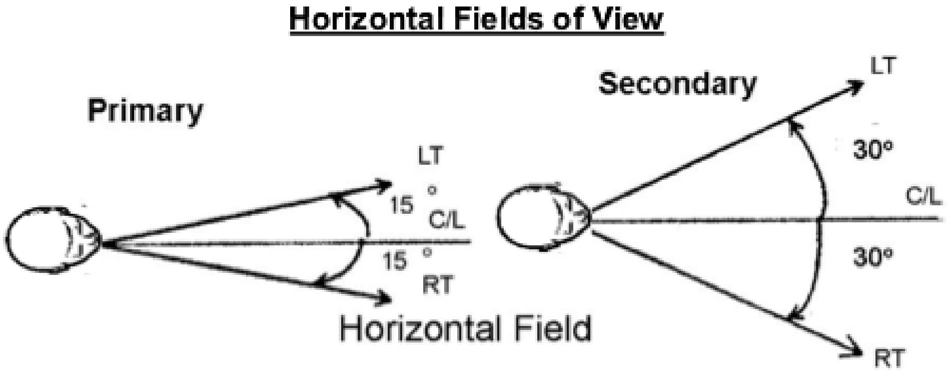


Figure 4.1 – Primary and Secondary Horizontal Fields of View as described in MG20

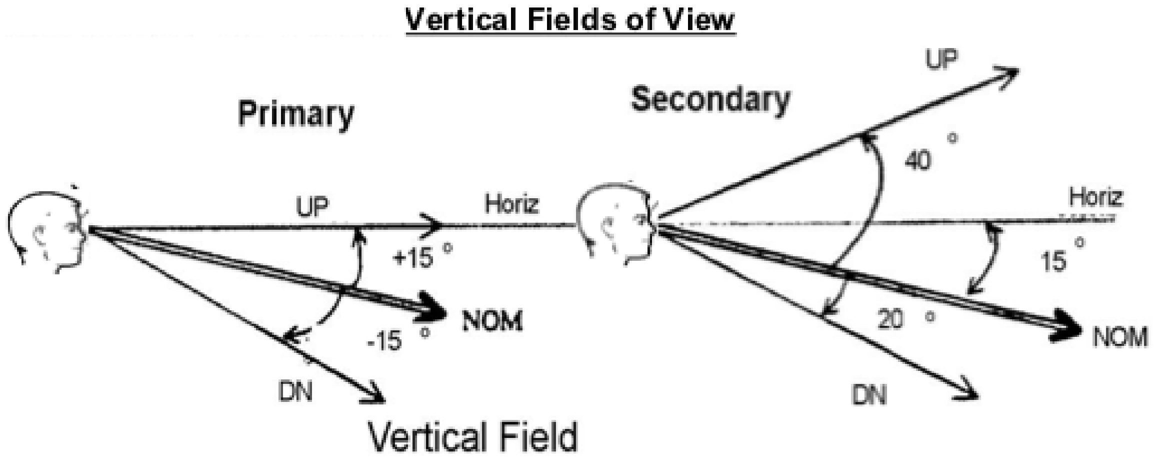


Figure 4.2 – Primary and Secondary Vertical Fields of View as described in MG20

MG 20 notes that:

“Examples of information normally placed in the primary field of view are:…Master warning or caution (or high priority warnings and caution messages if not providing a master warning or caution annunciator).”

MG18 on HTAWS also notes that the manufacturer should:

“Locate visual alerts in the pilot’s primary field of view. HTAWS status and mode selection annunciation (i.e., inhibit, reduced protection mode, or other pilot selectable mode) should be as close to the pilot’s primary field of view as possible to enable rapid assessment of HTAWS status and configuration.”

This means that the AC 29 Miscellaneous Guidance concurs with the sources identified in the current literature review in terms of vertical placement. The MG proposes tighter tolerances in horizontal placement since ± 30° horizontally is the Secondary field of view.

4.2.2 Size

No guidance is possible on absolute size because this will depend on the specifics of the display and the information that it must convey. In general, larger items will be more easily visible.

4.2.3 Colour / contrast

The literature suggests that higher hazard is associated with red and amber and lower hazard with blue, green and white. Also, high contrast is more visible and this is especially important if the information is presented to the periphery.

MG 20 notes that:

(1) The use of red and amber for encoding purposes other than warnings and cautions can create confusion on these displays.

(2) Use red only as a warning annunciation for emergency operational conditions when immediate flight crew recognition and action is required.

(3) Use amber only for cautionary alerting and when immediate crew awareness is required and subsequent action may be required. Use white or another unique color for advisory annunciations of operational conditions that require flight crew awareness but may not require any action.

(4) Use green only to indicate safe operating conditions.

4.2.4 Motion

The literature review suggests that movement (including blinking) can be detected fairly well in the periphery. High flash rates (240 flashes per min) are detected faster whereas low flash rates (60 fpm) minimise glare and annoyance.

However, MG 19 suggests that *"The use of flashing lights should be minimized." noting* that:

> *"Blinking information elements such as readouts or pointers can be effective methods of annunciation. However, the use of blinking or flashing should be limited because it can be distracting and excessive use reduces the attention-getting effectiveness. Use blinking rates between 0.8 and 4 Hertz, depending on the display technology and the compromise between urgency and distraction. If blinking of an information element can occur for more than approximately 10 seconds, there should be a means provided to cancel the blinking."*

Again, there is good agreement here with a range of 48 flashes per minute (0.8Hz) to 240 flashes per minute (4Hz) being proposed in MG 19.

4.3 - Visual Alerting Assessments

Figures 4.3 and 4.4 show images taken from AW189 manufacturer documentation detailing the location of HTAWS visual alerts. No such imagery was available in the S92 documentation and therefore photographs from the simulator are included as Figures 4.5 to Figure 4.13.

The lack of imagery in some documentation is a shortcoming since many pilots will not experience these alerts in normal operations. One of the pilots involved in the test described in Chapter 8 (where alerts were triggered deliberately) commented that they had forgotten that the gear alert was accompanied by a visual alert since they don't experience it in the simulator. This weakness mirrors the variable quality of the operational description of the HTAWS outlined in the previous chapter.

Red Messages

FLTA:

TERRAIN

OBSTACLE

GPWS:

PULL UP

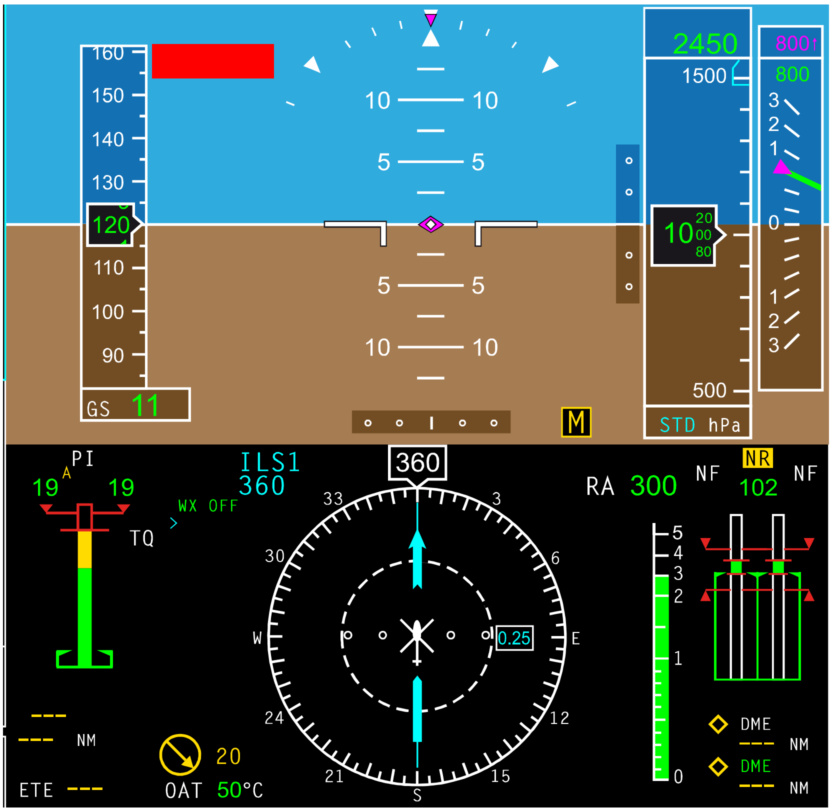


Figure 4.3 – Position and text of red TAWS Warning messages on PFD

Amber Messages

FLTA:

TERRAIN

OBSTACLE

GPWS:

TOO LOW GEAR

SINK RATE

DONT SINK

G/S

Figure 4.4 – Position and text of amber TAWS Caution messages on PFD

Figure 4.5 Terrain Caution full screen

Figure 4.6 Terrain Warning full screen

Figure 4.7 – Terrain Caution Expanded

Figure 4.8 Terrain Warning Expanded

Figure 4.9 Don't Sink Caution

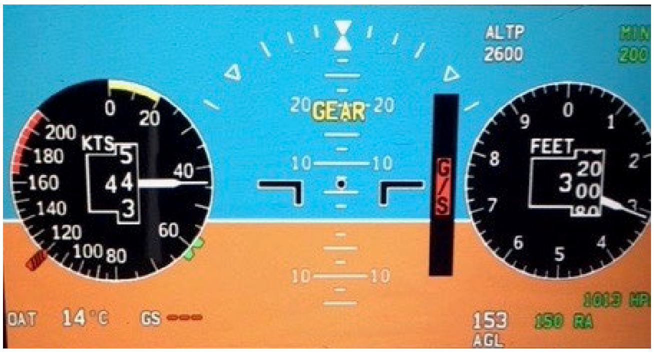


Figure 4.10 Gear Caution

Figure 4.11 Don't Sink and Gear Cautions

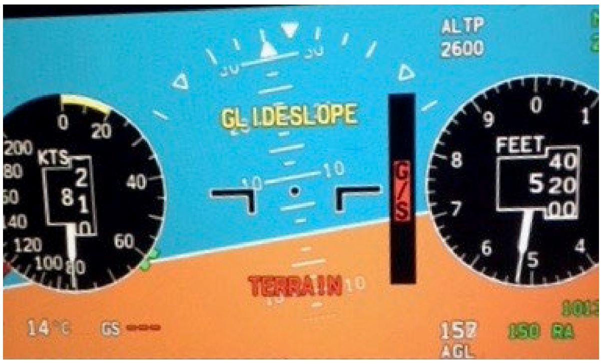


Figure 4.12 Glideslope Caution and Terrain Warning

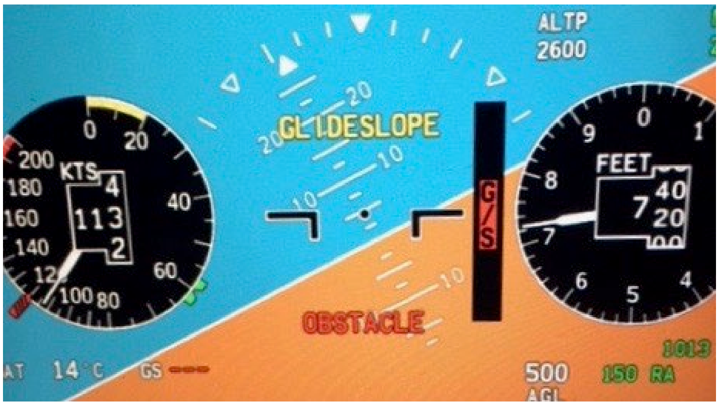


Figure 4.13 Obstacle Warning and Glideslope Caution

Table 4.1 summarises the outcomes of a consideration of the visual alerting strategies of the AW189 and S92 in the light of the recommendations described above. Blinking behaviour is not considered because, based on the documentation, it appears that all alerts remain continuously visible.

	Location	**Size**	**Colour/contrast**
Recommendations	Located ± 15° vertically from fixation and ± 30° horizontally Close to relevant displays	Larger is more easily visible but no guidance is possible on absolute size because depends on specifics of display	Higher hazard associated with red and amber, lower with blue, green and white High contrast more visible, especially important if presented to the periphery
AW189 cautionary amber alerts (both forward looking and GPWS)	Message (e.g. "TERRAIN", "OBSTACLE", "TOO LOW GEAR" etc.) displayed next to the top right of the speed tape	Width similar to that of the ADI, height similar to each increment on ADI scale	Black text on solid amber background rectangle
	This is somewhat peripheral although still likely to fall within the scan	Seems reasonable given need not to obscure relevant visual information	Appropriate for hazard level and appears clearly legible
AW189 warning red alerts (both forward looking and GPWS)	As for caution alerts	As for caution alerts	White text on solid red background rectangle
			Appropriate for hazard level, although white text on red may not be ideal for legibility
S92 cautionary amber alerts: TERRAIN, DON'T SINK, OBSTACLE (both look ahead and classic modes)	Message ("TERRAIN", "DON'T SINK", "OBSTACLE") superimposed on lower portion of ADI	Width similar to that of the ADI, height similar to two increments on ADI scale	Yellow text with black outline superimposed on display, so usually presented against orange 'land' segment (but extreme angles of pitch or roll might cause some or all to be presented against blue 'sky' segment)

	Seems reasonable, highly likely to fall within scan	Seems reasonable given need not to obscure relevant visual information	Appropriate for hazard level; contrast between yellow text and orange background is low, reducing visibility; use of superimposition also appears to reduce legibility
S92 cautionary amber alerts: GEAR, GLIDESLOPE (also applies to ‘hard’ version of GLIDESLOPE alert)	Message (“GEAR”, “GLIDESLOPE” superimposed on upper portion of ADI	Width similar to that of the ADI, height similar to two increments on ADI scale	Yellow text, outlined in black, superimposed directly on display, so usually presented against blue ‘sky’ segment (although extreme angles of pitch or roll might cause some or all of the text to be presented against orange ‘land’ segment)
	Seems reasonable, highly likely to fall within scan	Seems reasonable given need not to obscure relevant visual information	Appropriate for hazard level; contrast between yellow text and blue background appears reasonable; use of superimposition appears to reduce legibility
S92 warning red alerts: “TERRAIN”, and “OBSTACLE” (look ahead mode) and “PULL UP” (classic modes)	As for TERRAIN AND OBSTACLE caution alerts	As for TERRAIN AND OBSTACLE caution alerts	As for TERRAIN AND OBSTACLE caution alerts, except text is red
			Contrast between red text and orange background is higher than that of the yellow text used for the caution alerts, but the same concerns about visibility and legibility apply

Table 4.1 – Visual alerting assessments

4.4 - Summary

In general, many aspects of the visual alerting behaviour of the two aircraft types considered in this section seem reasonable given the constraints that are inherent to a visual alerting approach. It is possible that the detectability of the AW189 alerts could be improved if they were presented more centrally (possibly on the ADI as is the case in the S92), especially given that recent eye tracking evidence has suggested that many pilots adopt a half-kite scan pattern that does not routinely include the speed tape (Jarvis Bagshaw Ltd., 2016, as described in section 3.3.2.3). It is also possible that the legibility of the white lettering on red background used for the warning alerts in the AW189 could be improved by increasing the contrast. The legibility of the S92 alerts may be improved by presenting them against a background rectangle of solid colour, as is done for the AW189 alerts, in order to avoid the problems associated with superimposing the text on an already cluttered visual display. This would also have the advantage of allowing designers to choose a background colour that increases the contrast, both of the entire alert against the display but also of the text against the background. However, this approach may be challenging given the central location of the S92 alerts, because it would require obscuring sections of the ADI (whereas the current alerts are superimposed over the ADI, allowing more display elements to remain visible). An additional possibility might be to mirror the HTAWS visuals alerts on the coaming, as has been done for NVG ops, following agreement that classic radalt displays were not sufficiently compelling under high workload. However, overall, if one accepts, as argued in section 4.1, that the visual component of the HTAWS alerting system should be seen as supplementary to the auditory component, then these potential improvements to the visual behaviour are less important than those concerning the auditory alerts. In addition, any changes to the visual alerting would require extensive simulator testing in order to ensure they did not interfere with the large amounts of critical information that are presented visually to pilots.

5 – Pilot Questionnaires

5.1 - Introduction

Little data is available on the rate of HTAWS alerting making it difficult to quantify the extent of nuisance alerts. A survey of flight crews was therefore conducted in an attempt to provide this information. This chapter summarises a previous survey that was conducted, and describes the survey performed in support of this project and the results obtained.

5.2 - Previous Survey

In 2010 Bristow, CHC and Bond collaborated to survey flight crews on HTAWS / EGPWS nuisance alerts. Data on nuisance alerts were gathered over a two-month period using a paper form to capture data from crews. The number of reports generated by the exercise for Bristow and CHC are shown in Table 5.1. The number of flights performed by relevant aircraft in the same period is not readily available.

	S76	**S92**	**EC225**	**Total**
Bristow	22	26	48	**96**
CHC	-	97	35	**132**
				228

Table 5.1 – Numbers of reports from 2010 survey

In collaboration with Honeywell, the data provided by these forms were used to address various issues being encountered at the time, leading to an updated version of EGPWS.

The main issue which affected all types equipped with EGPWS MKXXII was the nuisance alerts created by the offshore obstacle database. For example, nuisance alerts were generated when landing on and taking-off from fixed platforms as the system registered them as obstacles and not landing sites. The decision was made by the operators to remove the offshore platform database as it gave an unacceptably high nuisance alert rate for fixed platforms and did not address mobile obstacles, due to inability to keep the database up to date with their locations. Other technologies, such as radar and AIS are considered to be more suitable for detecting the offshore obstacles.

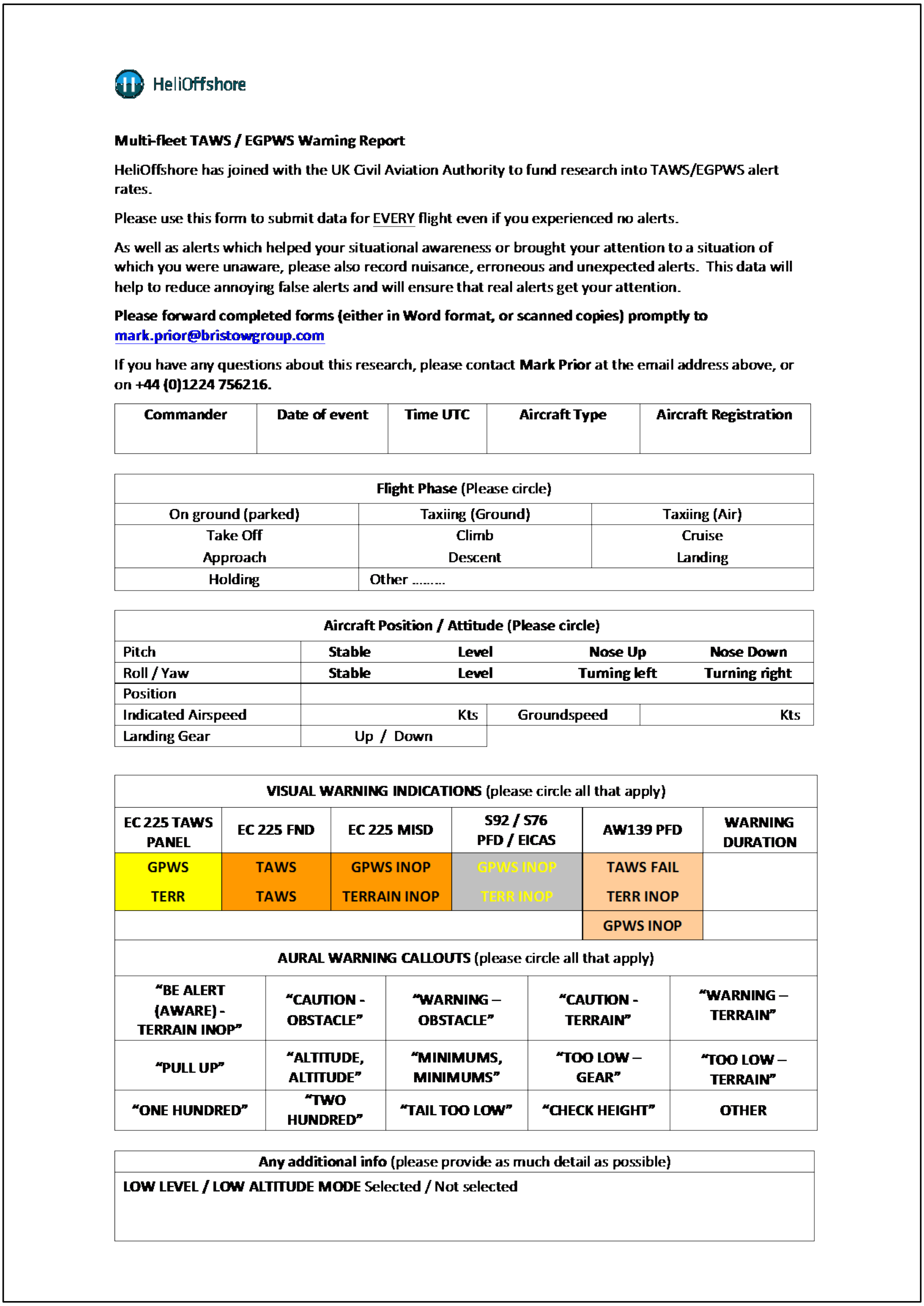
Additional issues were found with the EC225. In particular a high rate of nuisance alerts were experienced when approaching installations as Eurocopter (now Airbus Helicopters) had chosen to implement the look-ahead alerting algorithm based on airspeed rather than groundspeed; this sometimes resulted in the system remaining active close to landing. The EC225 also triggered a TAWS failure when flying above 150 kt with the gear down, which was a frequent offshore configuration. These issues were addressed in the EGPWS MKXXII V28 upgrade.

5.3 - Current Survey

In order to provide a level of consistency between the two surveys, the form from the 2010 survey was reused as a basis for the current survey. However, one significant difference between the two was that the latter asked for crews to complete a form for every flight, rather than only reporting problems or nuisance alerts. This was done to give some indication of the *rate* of alerts rather than just absolute numbers. (However, inferring rate data from the returned forms does assume that alert or non-alert flights are not preferentially reported, i.e. absence of bias is assumed.) The rate of alerts is of course highly relevant in the context of alert normalisation.

A second reason for requesting a report for every flight was to draw out any other issues that crews were experiencing with HTAWS that were not already known.

The form as supplied to flight crew is shown in Figure 5.1.



HeliOffshore

Multi-fleet TAWS / EGPWS Warning Report

HeliOffshore has joined with the UK Civil Aviation Authority to fund research into TAWS/EGPWS alert rates.

Please use this form to submit data for EVERY flight even if you experienced no alerts.

As well as alerts which helped your situational awareness or brought your attention to a situation of which you were unaware, please also record nuisance, erroneous and unexpected alerts. This data will help to reduce annoying false alerts and will ensure that real alerts get your attention.

Please forward completed forms (either in Word format, or scanned copies) promptly to mark.prior@bristowgroup.com

If you have any questions about this research, please contact **Mark Prior** at the email address above, or on **+44 (0)1224 756216.**

Commander	Date of event	Time UTC	Aircraft Type	Aircraft Registration

Flight Phase (Please circle)		
On ground (parked)	Taxiing (Ground)	Taxiing (Air)
Take Off Approach	Climb Descent	Cruise Landing
Holding	Other ………	

Aircraft Position / Attitude (Please circle)				
Pitch	**Stable**	**Level**	**Nose Up**	**Nose Down**
Roll / Yaw	**Stable**	**Level**	**Turning left**	**Turning right**
Position				
Indicated Airspeed	Kts	Groundspeed	Kts	
Landing Gear	Up / Down			

VISUAL WARNING INDICATIONS (please circle all that apply)					
EC 225 TAWS PANEL	**EC 225 FND**	**EC 225 MISD**	**S92 / S76 PFD / EICAS**	**AW139 PFD**	**WARNING DURATION**
GPWS	**TAWS**	**GPWS INOP**	**GPWS INOP**	**TAWS FAIL**	
TERR	**TAWS**	**TERRAIN INOP**	**TERR INOP**	**TERR INOP**	
				GPWS INOP	

AURAL WARNING CALLOUTS (please circle all that apply)				
"BE ALERT (AWARE) - TERRAIN INOP"	**"CAUTION - OBSTACLE"**	**"WARNING – OBSTACLE"**	**"CAUTION - TERRAIN"**	**"WARNING – TERRAIN"**
"PULL UP"	**"ALTITUDE, ALTITUDE"**	**"MINIMUMS, MINIMUMS"**	**"TOO LOW – GEAR"**	**"TOO LOW – TERRAIN"**
"ONE HUNDRED"	**"TWO HUNDRED"**	**"TAIL TOO LOW"**	**"CHECK HEIGHT"**	**OTHER**

Any additional info (please provide as much detail as possible)
LOW LEVEL / LOW ALTITUDE MODE Selected / Not selected

Figure 5.1 – Form as supplied to crews

5.3.1 - Returned forms

The survey period was 1 month (April 2016). 27 forms were rejected as either illegible, undated or outside of the survey period. 786 usable reports were received with an identifiable date, aircraft and crew, and these formed the basis of the survey.

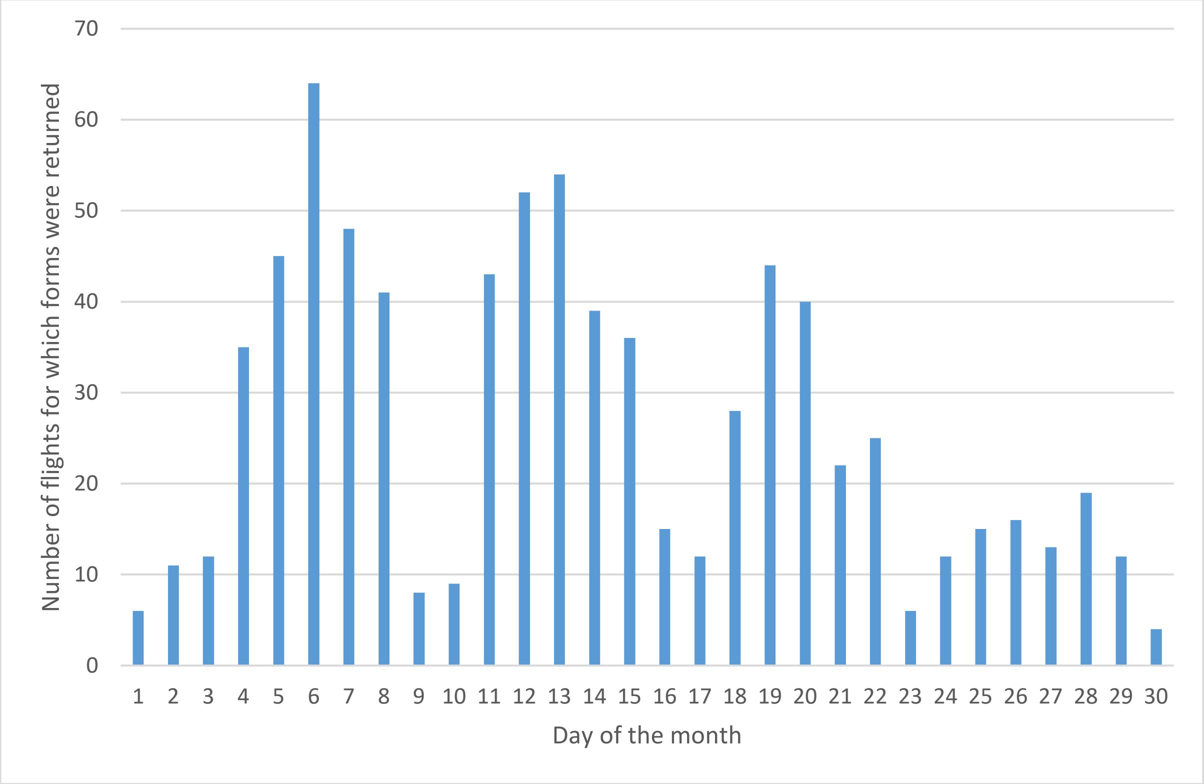


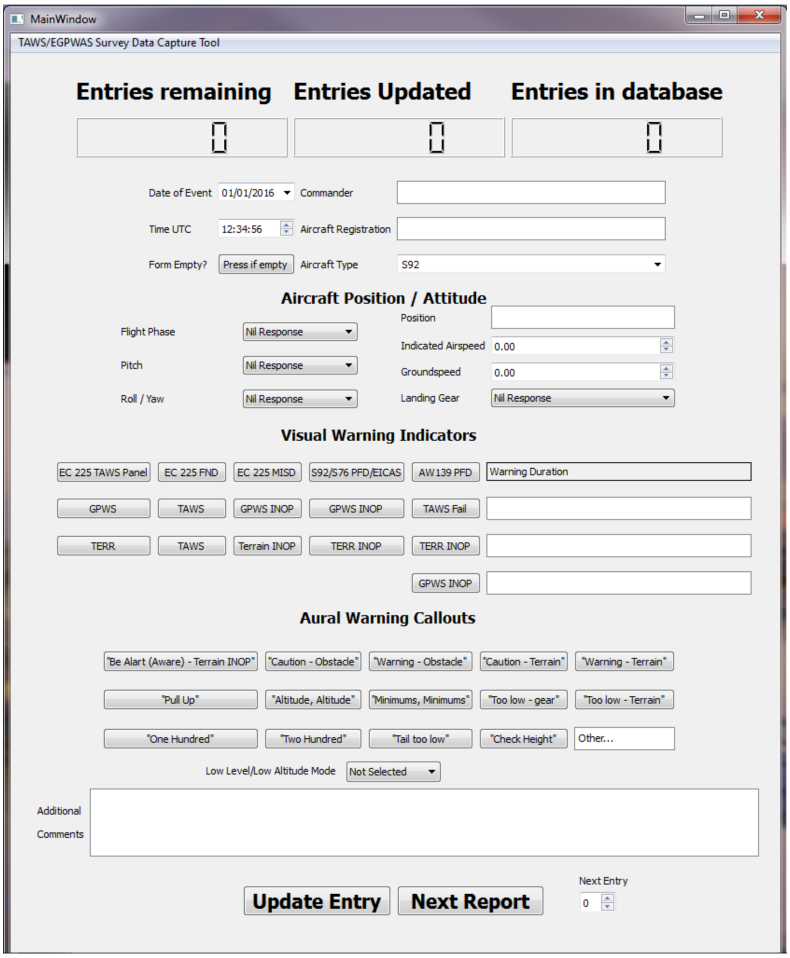
Figure 5.2 – Distribution of flights for which forms were returned

The distribution of flights across the month for which forms were returned is shown in Figure 5.2. This shows two clear trends. Firstly, more forms were returned on week days (starting 4th - 8th) which is to be expected based on the greater number of flights occurring during the week. Secondly, there is a general reduction in returned forms as the survey period progressed. This is most likely due to 'survey fatigue' in the flight crew. If a repeat survey is conducted in the future, it might be worth shortening the survey period to two weeks or reiterating to crews, half-way through the period, that their returns are appreciated and are providing useful information.

Approximately 10% of the forms were returned as edited Word files, but the majority were returned as PDF scans of hand-filled forms.

Forms were initially analysed to separate those which clearly represented a "Nil" return. Typical responses were phrases such as "NIL", "NO ALERTS", "OPS NORMAL" written across the page. The remainder were then transcribed for analysis.

Soon after beginning the transcription process, it became clear that manually transcribing the content of the scanned forms would be time-consuming and prone to significant errors. Therefore, a software tool was developed to allow the results to be transcribed more efficiently.



Entries remaining 0
Entries Updated 0
Entries in database 0
Date of Event 01/01/2016
Time UTC 12:34:56
Aircraft Type S92
Flight Phase Nil Response
Pitch Nil Response
Roll / Yaw Nil Response
Indicated Airspeed 0.00
Groundspeed 0.00
Landing Gear Nil Response
Low Level/Low Altitude Mode Not Selected
Next Entry 0

Figure 5.3 – Screenshot of the coding tool

The electronic form (see Figure 5.3) was designed to broadly mirror the layout and construction of the paper form with the aim of making coding more reliable. Creating the form in this way had the added benefit that, should a repeat of the survey be required, the form could be deployed electronically.

All forms were coded independently by two separate researchers. These databases were then compared for differences, with each difference being reviewed and an agreement being reached by the two researchers on how to resolve the difference. The researchers were aware of the general operation of helicopters and HTAWS but had no specialist knowledge or experience.

As well as transcribing the results, the researchers also put each form into one of the following categories:

No alert	The form indicated that no alerts sounded (e.g. “Nil”).
HTAWS alert sounded	Some form of HTAWS alert was generated during the flight.
HTAWS failure	A failure of the HTAWS system.
“Normal” HTAWS Alerts	An alert was generated but was considered normal. Some pilots used phrases like “no unusual alerts”.
Spurious HTAWS Alerts	Alerts which were considered erroneous or nuisance (i.e. an alert where the system worked correctly but the algorithm generating the alert was not relevant to that operational condition).

The transcribed and categorised forms were then passed to a subject matter expert for them to review and recode the forms.

5.3.2 - Results

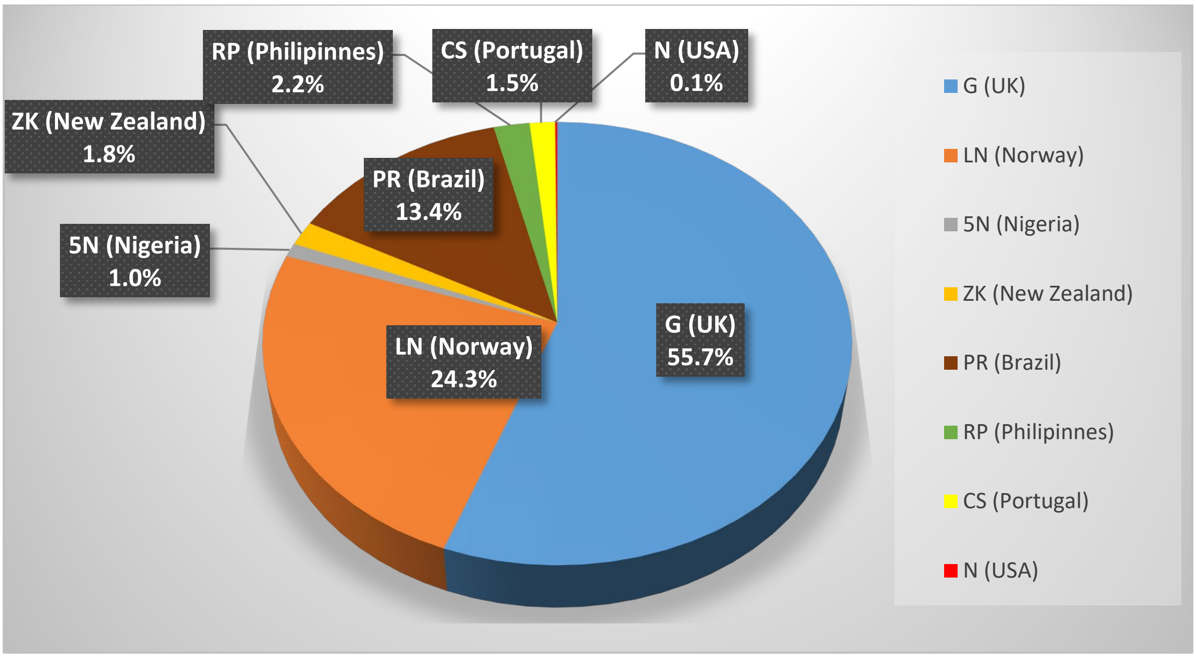


Figure 5.4 – Distribution of aircraft registrations on returned forms

Figure 5.4 shows the distribution of returned forms by aircraft registration. UK and Norway registrations make up 80% of the forms returned.

Table 5.2 shows the number of forms in each category and the change in coding from the initial “naïve” coding by the researchers. This highlights the importance of operational experience when interpreting HTAWS events.

Category	Number of forms	Change from initial coding
No alert	372	+2
“Normal” HTAWS alerts sounded	168	+132
HTAWS alert sounded	166	-164
HTAWS failure	67	+23
Spurious HTAWS alerts	13	+7

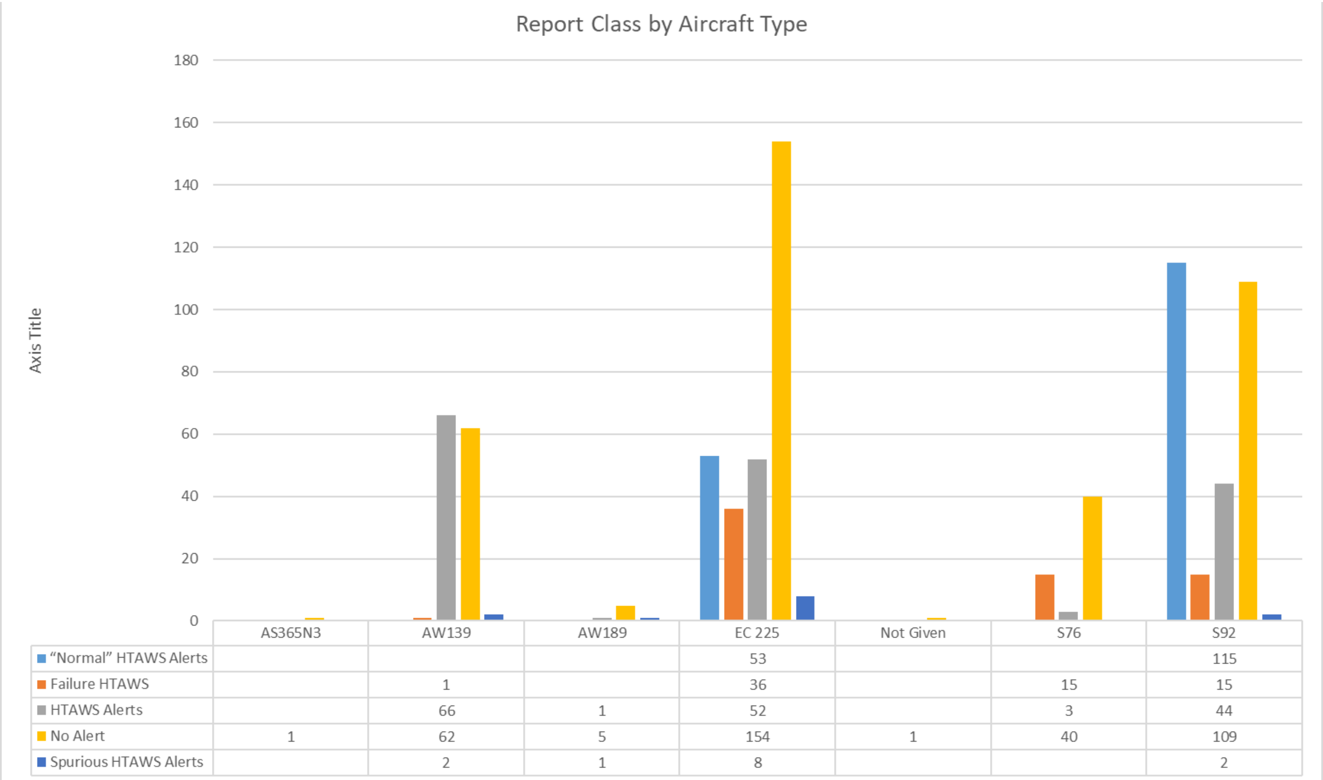
Table 5.2 – Number of forms categorised into each category and change from naïve coding

More than 90% of reports received concerned three aircraft types: EC225, S92 and AW139. Table 5.3 shows the distribution of aircraft types for which reports were received.

Type	Number of reports	Percentage	Cumulative
EC225	303	39%	39%
S92	285	36%	75%
AW139	131	17%	92%
S76	58	7%	99%
AW189	7	<1%	>99%
AS365N3	1	<1%	>99%
Not given	1	<1%	100%
TOTAL	**786**	**100%**	**100%**

Table 5.3 – Distribution of aircraft types in reports

Figure 5.5 shows the distribution of the different categories for the different aircraft types.



	AS365N3	AW139	AW189	EC 225	Not Given	S76	S92
“Normal” HTAWS Alerts				53			115
Failure HTAWS		1		36		15	15
HTAWS Alerts		66	1	52		3	44
No Alert	1	62	5	154	1	40	109
Spurious HTAWS Alerts		2	1	8			2

Figure 5.5 – Report categorisation for different aircraft types

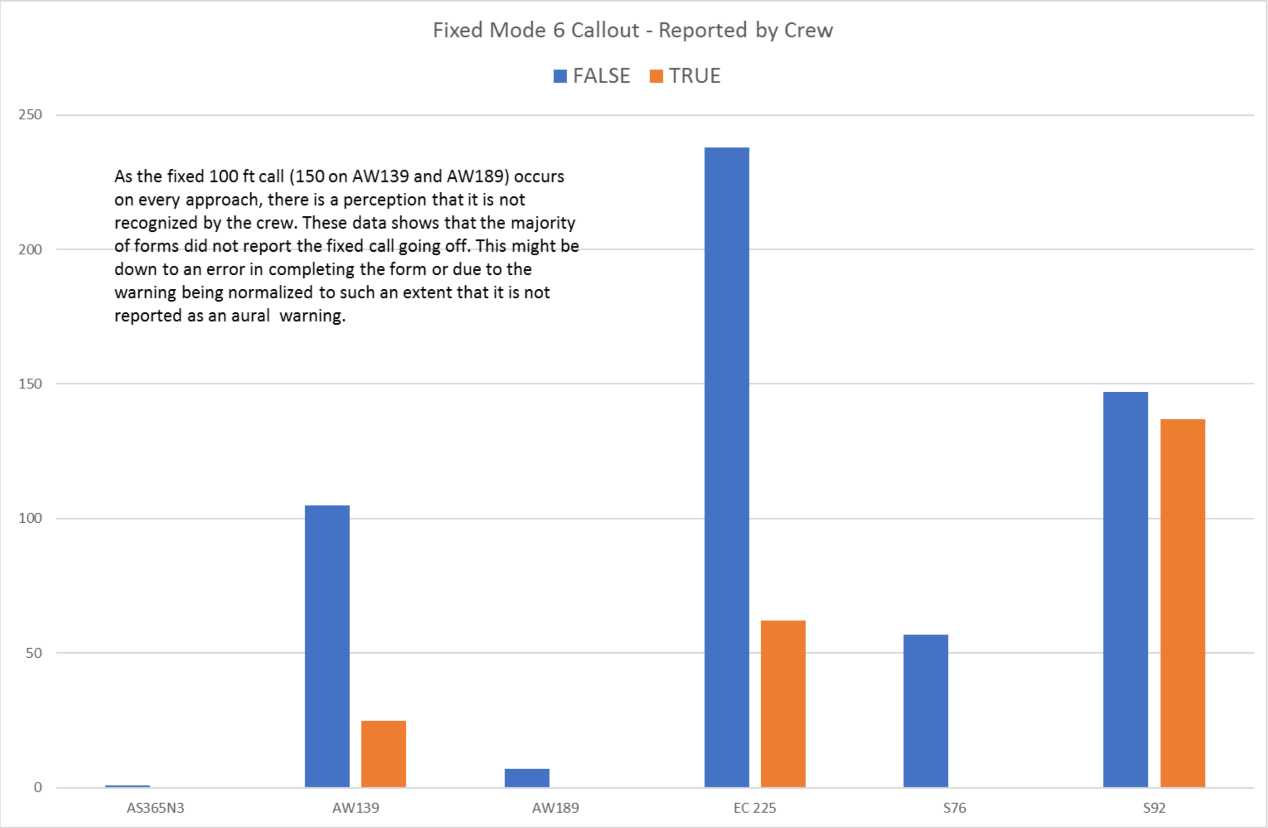
The “No alerts” category is of interest. In principle, the fixed height call (100/150ft) should be generated on every approach, and on the S92 additional calls will be generated based on other factors. Therefore, a crew may report no calls due to a number of possibilities or combinations thereof:

a. The call did not occur when it should have.

b. The call did occur but the crew didn’t ‘notice’ the call. This could be due to audibility or a failure to capture attention, possibly due to normalisation.

c. The call did occur and the crew heard it but didn’t report it on the form. This could possibly be due to the effort involved or perhaps due to a different perception of what constitutes an HTAWS alert (e.g. AVAD versus HTAWS).

Figure 5.6 shows whether the Mode 6 callouts were reported by crews or not, against aircraft type.



As the fixed 100 ft call (150 on AW139 and AW189) occurs on every approach, there is a perception that it is not recognized by the crew. These data shows that the majority of forms did not report the fixed call going off. This might be down to an error in completing the form or due to the warning being normalized to such an extent that it is not reported as an aural warning.

Figure 5.6 – Graph showing whether Mode 6 callouts were reported on form

It is not possible to understand from the forms alone why crews are completing the forms in this way. Therefore, it was considered appropriate to conduct interviews with crews to attempt to better understand their perception of HTAWS and the alerts it provides. This exercise is reported in section 5.4 below.

Six records showed the aircraft in ground taxi, which might be discounted since spurious cautions are often generated with high rates of turn while ground taxying.

Figure 5.7 shows the reporting of “check height” or “minimums” on approach.

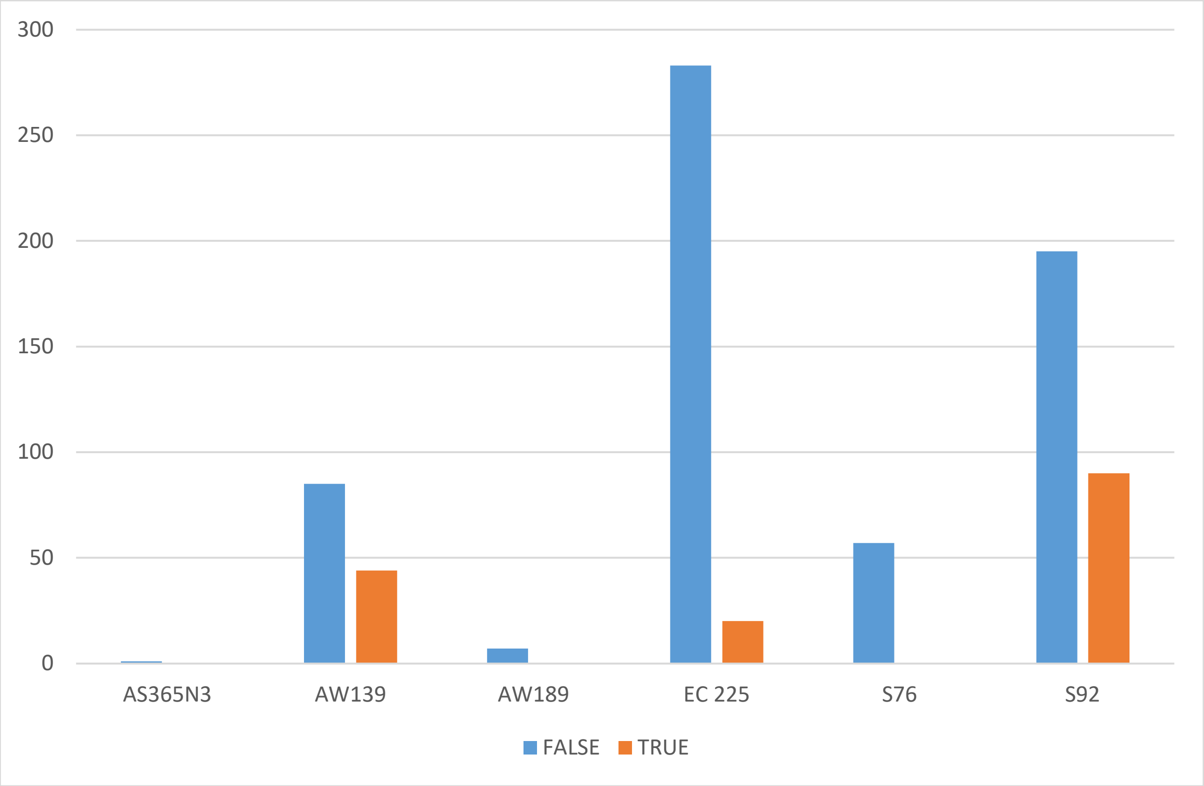


Figure 5.7 – Reporting of "check height" or "minimums" call on approach

If the SOPs are being followed, then a "Check Height" call on most types (S92 is the exception) should not occur. This high reported rate could be due to poor compliance with SOPs (this could be a KPI recorded in FDM).

On the S92, Bristow and CHC do not use the audio mute offshore. The audio mute will inhibit **all** HTAWS calls except for the mandated 100 ft call for 5 minutes. If the audio mute is not used, on every offshore approach the "Minimums" call will be heard when the barometric altitude bugged height is breached and the "Altitude" call when the RADALT bugged height is breached. The "100" call will also occur as it is mandatory. All of these calls are speech cautions without an attenson.

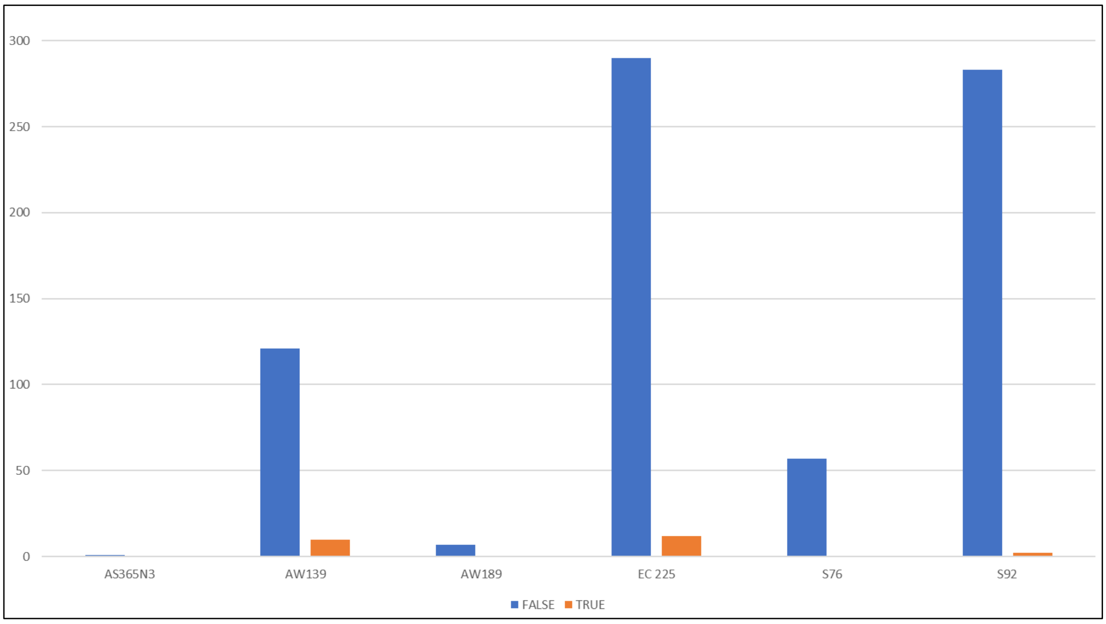


Figure 5.8 – "Caution Terrain" alerts

Figure 5.8 shows the occurrence of "Caution Terrain" alerts. There were 14 reports of a "Pull Up" warning being issued. 4 occurrences were from AW139s at Norwich, which has a known TAWS database issue. 7 out of 10 occurrences on the EC225 involved a SAR aircraft.

5.4 - Pilot Interviews

Summary

Semi-structured interviews were held in Aberdeen on Tuesday 13th November 2017. The interviews were unscheduled and opportunistic, taking place in a range of locations. Two interviewers were present, a Cranfield researcher and a SME.

The aim of the interviews was to explore attitudes to HTAWS, particularly in light of the survey responses that were received which, in many cases, seemed ambiguous or counter to what was expected.

Ethical approval was granted through the Cranfield CURES system. Participants were informed of the voluntary nature of their participation and their opportunity to withdraw.

Six pilots were interviewed from a range of companies and organisations with varying levels of experience and responsibility. The cohort included multiple roles including: simulator instructor, TRE/TRI, line pilot and chief pilot. All were current S92 pilots, with some having experience or ratings on other types.

Specific comments:

The understanding of HTAWS broadly fell into two different groups: those who might classed as 'users' having a more superficial understanding of behaviours and those with a deeper understanding of HTAWS.

The 'users' broadly understood the behaviour of the HTAWS/EGPWS, the types of alerts it might give etc.

Those with a deeper understanding were more able to talk in detail about the system, for example the distinction between Classic and Enhanced modes, 30s and 20s alerting times for Caution and Warning respectively or the pop-up behaviour of the NAV display.

However, none were completely familiar with all modes, algorithms, timings etc. which is not surprising considering the complexity of the system, the relatively infrequent exposure to alerts and the inadequacies of the documentation.

When asked about the types of alerts they would expect to receive in a normal flight, none of the participants offered all three of minimums, altitude and 100ft. Some offered "none" as their initial answer and needed heavy prompting to get to the result of all three. This might explain the questionnaire responses which were marked with comments such as "Nil alerts". It appears likely that crews did receive those calls but did not note them on the form.

When this was discussed with pilots, some could not recall hearing them on their last flight. However, none suggested that they hadn't sounded but instead felt that they had most likely sounded and been acknowledged. This suggests that a significant level of habituation has occurred with these alerts. Like, say, traffic lights on a frequently driven journey they may have been perceived and acted upon correctly but were such a common event that they were not available for recall.

On the subject of aural alerts, most felt that they were clear or very clear. Some suggested that a voice alert amongst cockpit discussion during a landing could be missed or could confuse. The information given by the voice alert was welcome but some liked the attenson used in other types such as Super Puma and felt the voice alone was less attention-getting. One was asked whether they felt a female voice provided better clarity and they agreed.

Responses regarding visual alerts were more mixed. Some described them as not very clear or attention-getting, whereas others said they hadn't seen them enough to judge. It seemed that the visual alerts were legible when pilots looked for them, but they did not attract attention. One participant seemed to consider the auditory alert as the main attention-getter.

Few of the participants had experienced a significant number of 'unusual' calls. Most described one or two calls such as a 'tail too low' or 'don't sink' when transitting a short distance from one rig to another. Most had experienced 'Terrain INOP' at some point.

Training around the use of the HTAWS system was considered by most to be satisfactory. One participant noted that pilots used to receive more detailed 'Mode by Mode' explanations, but that this had been replaced with a more general overview of the system. Another participant suggested that incorporating HTAWS training into Line-Oriented Flight Training (LOFT) might be useful.

When asked whether they trusted the HTAWS system, most responses could be described as "Yes, but…". All felt they would react to, say, terrain alerts but that if they felt their Situational Awareness was good and they felt in control of the situation, they might take a moment to assess whether the alert was reasonable. One described their view as "I don't distrust it…but I don't have blind faith in it either". This suggests that while trust in the system is high, it is not absolute, such as it might be with, say, TCAS.

One participant noted that, while the rotary wing world was not yet on par with fixed wing (where they felt a terrain warning would be acted upon directly), there had been significant changes in the industry since 2013 (Sumburgh accident and CAP 1145) and that behaviours were much more in keeping with those exhibited in an airline environment.

6 – Auditory Alert Development and Testing

6.1 – Introduction

This chapter describes work undertaken to develop and trial new auditory alerts. In order to inform this development process, frequency measurements were first performed in-flight in order to quantify the background noise.

6.2 - Cockpit measurements

Previous measurements have captured typical cockpit noise levels in-flight. However, these measurements typically recorded either a single overall value for sound pressure level (SPL) or a third-octave spectrum. Neither of these measurements provide enough spectral detail of the noise to understand the potential masking or interference it may cause. Therefore, a simple measurement exercise was conducted to establish the spectral content of the cockpit noise on a representative flight.

The aim of the exercise was to gather typical frequency spectra during an operational flight, quickly and with minimal effort, to allow the alerts being designed to be tailored around the existing noise spectrum.

Flight details

The exercise was performed on Monday 28th March 2016. The subject aircraft was G-CHYI, a Sikorsky S-92A built in 2013. The aircraft departed at 1130 local from Aberdeen for the Anasuria platform, a flight of around 45 minutes in each direction.

Microphone

A Behringer ECM8000 microphone was used for the recording. This is not a measurement grade microphone, but it is inexpensive with a reasonably flat frequency response extending as high as 20 kHz. It is a condenser microphone and is compatible with the power that the recorder unit can provide. It was connected using a balanced XLR connector at both ends.

A frequency response given in promotional material is shown in Figure 6.1. The dark black line shows that the relative response is very close to zero for most of the frequency range.

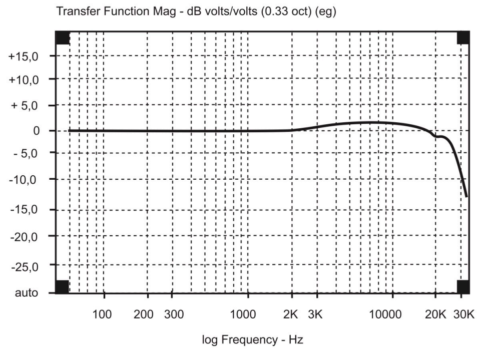


Figure 6.1 – Typical frequency response of ECM8000

Other measured data are given by independent laboratories:

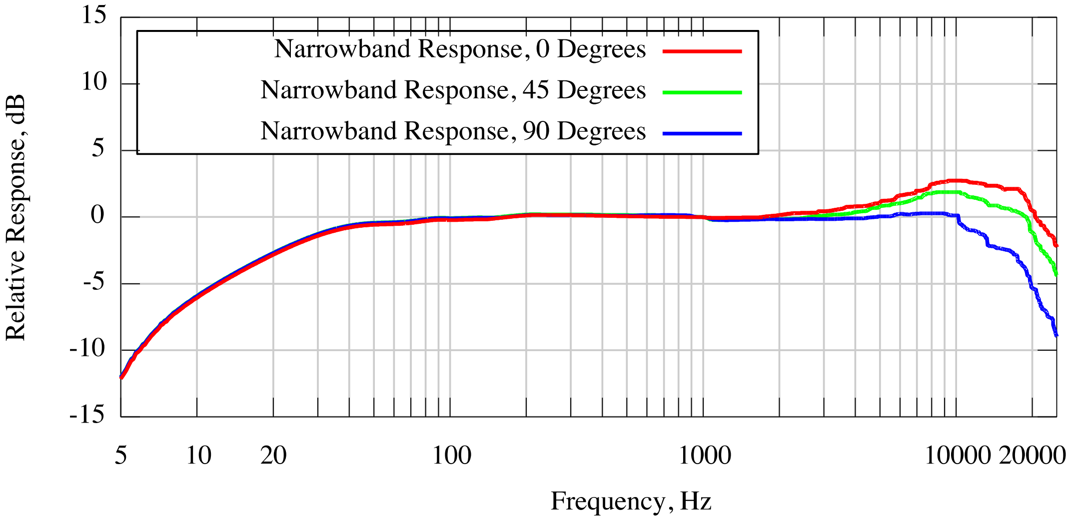


Figure 6.2 – Response of ECM8000 as measured by independent lab

The non-measurement grade status of the microphone means that a specific calibration is not supplied with it, and there will be variation from microphone to microphone.

Recorder

A TASCAM DR-60D MkII recorder was used. This is a small, lightweight, inexpensive, 4-channel digital recorder. At the recording resolution used, it has a frequency response of +0.5dB / -3dB from 20Hz -40kHz. As with the microphone, it is not classified as measurement-grade equipment.

Figure 6.3 – Tascam DR-60D MkII recorder

It was operated in ‘dual mono’ mode, meaning that a primary track was recorded (in this case Channel 1, the ECM8000 microphone) as well as a ‘security’ track at a lower level. In this case -12dB was selected. This track guards against excessive levels causing clipping on the primary track.

The recorder gains were only finally set after engine start when it became apparent that the noise levels might saturate the recording. It was fixed before taxiing to the passenger pickup point, so all measurements made after the doors were closed should be consistent.

A calibration tone from a B&K Type 4230 calibrator was applied. The calibrator is not specifically intended for this microphone, but will give an order of magnitude for the measurement although the main focus of the measurement was frequency rather than level.

The unit was powered by four AA alkaline batteries. An additional BP-6AA battery pack fitted with six AA alkaline batteries was used to power the Tascam recorder and increase the recording duration to around 5 hours.

The recorder was set to record in WAV format at 96 kHz, 24 bit. A file size (the point at which a new recording file was created) of 256MB was set to ensure that a power failure wouldn't jeopardise the entire recording. This gave an approximate recording duration for each file of about 15 minutes.

The microphone was attached to the centre grab handle of the LH seat. This may have introduced vibration noise onto the microphone signal, but complete vibration isolation is difficult to achieve. This position was chosen to give clear entry, egress, security of attachment and safety of operation rather than for any acoustic reasons. The recorder was housed in the 'blue bag' between the seats.

Figure 6.4 – Microphone (circled) location in flight

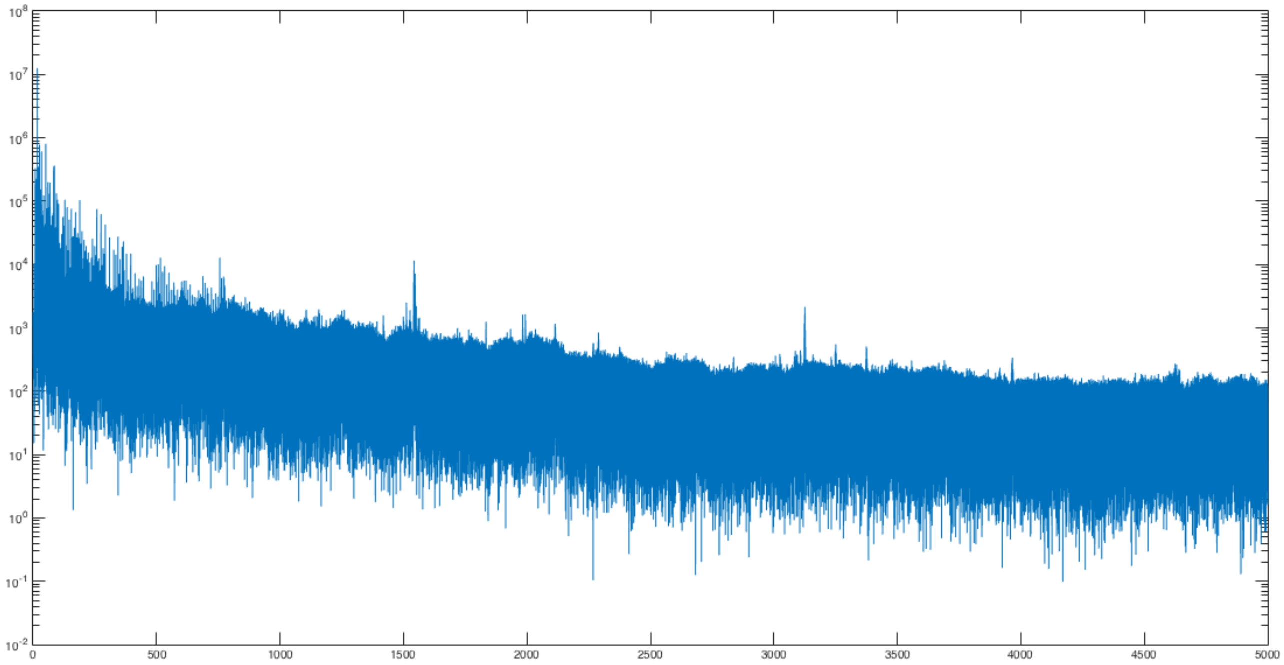


Figure 6.5 – Typical spectrum from measurement flight (to 5kHz)

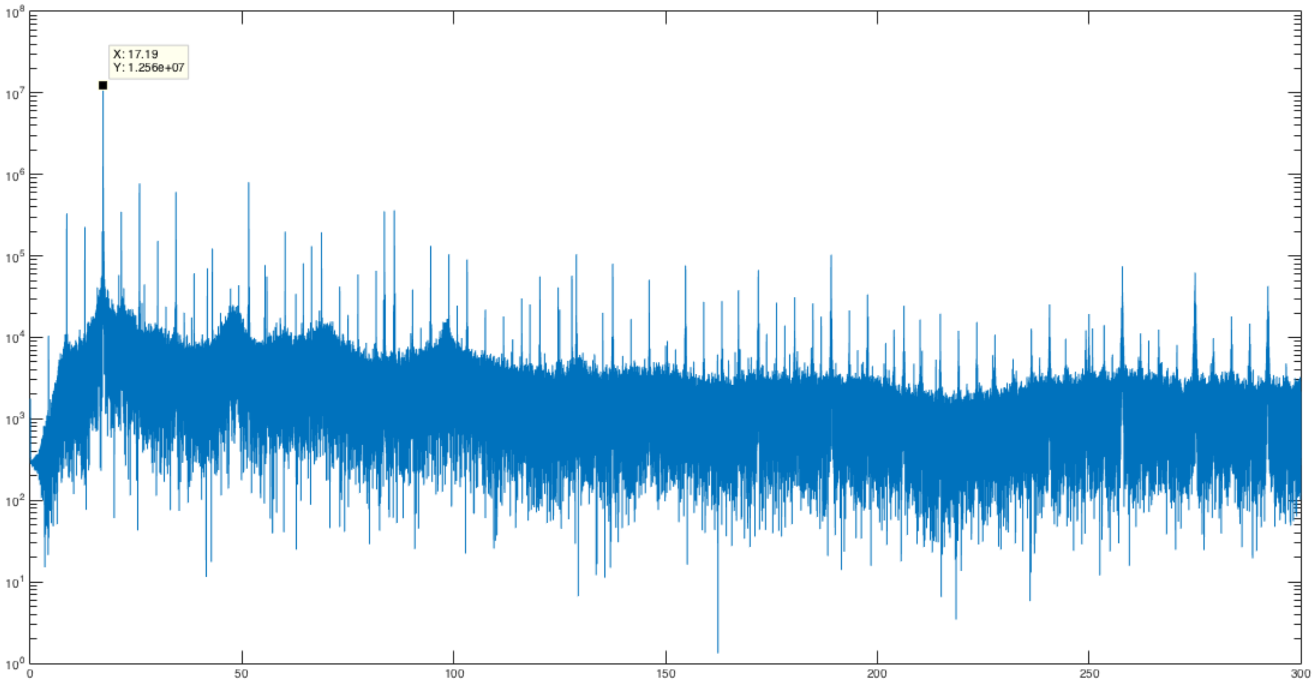


Figure 6.6 – Typical spectrum from measurement flight (to 300Hz)

Figure 6.5 shows a Fast Fourier Transform (FFT) of a typical signal measured in the cruise. The majority of the energy is contained below 500Hz, with values above 500Hz being more than three orders of magnitude lower.

Figure 6.6 shows the strong tonal component of the noise at lower frequencies. The peak value occurs at 17.19Hz, as highlighted. The output speed of the main rotor gearbox is quoted in the

Rotorcraft Flight Manual as being nominally 257.8rpm which for a 4-blade rotor gives a blade passing frequency of 17.186Hz.

These measurements show that there is no single, clear masking tone that needs to be avoided by an alert, but rather a large number of individual, narrow tones. The next section discusses the development of candidate alert tones.

6.3 - Development and Testing of Candidate Alerts

6.3.1 - Urgency and annoyance ratings

Motivation

The literature review identified the most promising auditory alerting approach as a combination of a brief tone, designed to be detectable against the cockpit background noise (sometimes referred to as an "attenson") and a brief spoken message indicating the nature of the issue. It seems reasonable to use the existing HTAWS messages for the spoken components of the alerts, because pilots have been extensively trained on these so there would need to be a very good reason to change them. However, the question of which tones to use is more complicated, because any number of different tones could be designed to fit the requirements identified:

- four or more components spread across the spectrum at levels that are appropriately high, in order to ensure that they are not susceptible to masking by the background noise;
- causes clear change in ongoing background sound;
- as brief a duration as possible;
- high perceived urgency for the hard alert (warning) tone, lower urgency for the soft alert (caution), ideally also with lower annoyance (particularly for soft alert);
- ability to capture attention under high workload.

It is relatively easy to modify any chosen tone in order to reduce its susceptibility to masking by the background noise by adding a range of additional harmonics across the spectrum. Attention was therefore focused on the other requirements listed above when selecting an initial set of sounds to develop into candidate alerts. In particular, sounds whose urgency, annoyance and/or attention-capturing properties had already been tested to some extent in the literature were chosen so that there was some expectation about how each alert would perform in these areas. However, each of the studies in this area used a range of very similar sounds in order to allow a systematic investigation of the impact on perceived urgency of variations along a single stimulus dimension (such as level, rate, pitch or harmonic regularity - see section 3.3.1 for a summary of the outcomes of this research). By contrast, the current project requires comparison of the urgency, annoyance and attention-capturing properties across a much wider range of different sound types taken from across the previous literature, as well as a new sound created specifically for this project and the existing HTAWS alerts. The current study therefore compared the candidate tones in terms of their perceived urgency and annoyance, in order to select a smaller subset for further testing of their attentional capture properties (described in the following section of this report).

Methods

Participants

The protocol was initially run with twelve experienced helicopter pilots, in order to take advantage of a unique opportunity to gather their input. However, due to a technical error in stimulus presentation on that run, the study was later repeated. For practical reasons, it was not possible to recruit another group of pilots at that stage, so the repeat test was run with 12 non-pilot participants recruited through the Department of Psychology at Royal Holloway, University of London via campus-based email lists and internet message boards. Although there is no a priori reason to assume that pilot and non-pilots would differ in their perception of the inherent urgency and annoyance of the sounds tested, the specific operational experience of the pilots could affect their judgements. For this reason, an informal comparison between the results of the two groups is provided in the discussion section (and note, to anticipate, that similar patterns were found in general between the two groups). However, the formal analyses and the final selection decisions concerning the candidate alerts were based upon the findings from the non-pilot participants. Of these 12 participants, eight were female. This relatively high proportion of female participants reduces the representativeness of the sample, given that the majority of helicopter pilots are male. However, there is little evidence that gender plays a significant role in the processing of alerts, and where gender differences have been observed they have tended to affect “higher level” behaviours, such as compliance and risk perception (e.g. Wogalter, Conzola, & Smith-Jackson, 2002). One (female) participant was left-handed. The mean age was 26 (SD=6). All participants reported normal hearing.

Stimuli

Seven candidate alerts were created: five possible hard alerts (predicted to have higher urgency and, in some cases, high annoyance) and two possible soft alerts (predicted to have lower urgency and annoyance).

- The first candidate hard alert (referred to as ‘Edworthy’) was made up of two 100ms complex tones with a fundamental frequency of 280Hz followed by four 100ms complex tones with a fundamental frequency of 390Hz. This was perceived as the most urgent of the range of tones tested by Hellier & Edworthy, 1999b.
- A second candidate hard alert (referred to as ‘Greaves’) was newly created for this project, based on principles derived from the literature. This consisted of four 50ms complex tones (made up of components at 500, 800, 1700, 2200, 2600, 4000 Hz presented with equal amplitude) separated by 30ms silences, followed by a silent interval of 100ms silence, after which the same four complex tones were repeated again. This alert was predicted to have high levels of perceived urgency and annoyance because of its fast rate and the irregularity of its harmonics.
- A third candidate hard alert (referred to as ‘Marshall’) was based on Marshall et al. (2007, pg. 152) who argued that:

  “it is possible to create alerts with high levels of perceived urgency and relatively low levels of perceived annoyance by using a high duty cycle, low interburst period frequency series”.

  Based on these findings, one such stimulus from their experiments was included, with an interburst period of 227ms and a duty cycle of 80%, in the expectation that this would produce a reasonably urgent alarm with relatively low perceived annoyance.
- A fourth candidate hard alert (referred to as ‘hard sawtooth’) was based on the most urgent of the tones tested by Haas & Casali (1995). This consisted of two 300ms sawtooth frequency-modulated pulses. Each pulse was created from a 500 Hz pure tone carrier, frequency modulated over the 300ms pulse duration by a positive sawtooth

function, producing a signal that travelled from 500 to 3000 Hz. Additional irregular harmonics were added to this sound, in order to increase its predicted urgency.

- The fifth candidate hard alert (referred to as 'hard-4') was based on an alert that was in fact found by Haas & Casali (1995) to have a relatively low level of perceived urgency. Their alert was made up of a sequence of four 75ms pure tones of increasing frequency (500, 1000, 2000, 3000 Hz) repeated twice over 600ms. However, their version was modified by introducing irregular harmonics, which were predicted to increase the urgency substantially, hence making this appropriate as a candidate hard alert.

The two soft alerts were created by making pure tone versions of 'hard sawtooth' (referred to as 'soft sawtooth') and 'hard-4' (referred to as 'soft-4'). The removal of the irregular harmonics from these alerts was predicted to reduce their urgency and annoyance substantially (recall that the pure tone version of 'soft-4' had in fact already been tested by Haas and Casali, 1995, who had found it to have the lowest urgency of the sounds that they used).

In order to benchmark the performance of the candidate alerts against those in use in the current HTAWS system, two existing alerts, consisting of the word "warning" and "caution" spoken in a male voice, were also included in the comparisons (referred to as 'warning' and 'caution'). These lasted 350ms and 450ms respectively, but their length was not edited to match the proposed candidate alerts because the intention was to evaluate the existing alerts in the format in which they occur in current usage. For the purposes of matching the overall stimulus presentation parameters, a 250ms silence was added to the end of the 'warning' alert and a 150ms silence was added to the end of the 'caution' alert, to ensure that both were presented in a 600ms window to match that of the new candidate alerts.

Each of the 600ms alerts was followed by a 100ms silence, then the word "terrain" spoken in a female voice lasting 500ms, followed by another 100ms silence. This 1300ms stimulus was then repeated again, followed by 500ms of silence, to give a total stimulus duration of 3100ms. Lastly, a recording of background noise from a helicopter cockpit was added to each stimulus, in order to give a more representative idea of the way in which the alerts would be perceived in operational conditions. This recording was transformed in frequency to mirror the attenuation that would be introduced by a typical headset.

Procedure

Perceived urgency and annoyance were measured separately, using subjective overall ratings and paired comparisons, in line with protocols previously established in the literature (e.g. Edworthy et al. (1991), Marshall et al., 2007). Each of the procedures described below was run separately for urgency judgements and for annoyance judgements, with half of the participants making urgency judgements first, and the other half making annoyance judgements first. Participants began by providing initial one-off subjective ratings. They heard each of the nine candidate alerts in a random order and assigned a value from 0 to 100 to indicate the urgency or annoyance that they perceived each sound to have (with 0 representing *low urgency* or *low annoyance* and 100 representing *very high urgency* or *very high annoyance*). Participants then completed paired comparisons. Each alert was paired with every other alert and presented in a random order, and participants chose the more urgent/annoying alert of each pair. Finally, the one-off subjective ratings were repeated.

Results

The paired comparison data were analysed by computing (separately for each participant) the frequency with which each alert was judged the most urgent/annoying of each pair. Because there were nine alerts, the maximum frequency was eight (in which case the alert in question was always judged the most urgent/annoying) and the minimum was zero (in which case the alert was never judged the most urgent/annoying). These frequencies were then transformed (again, separately for each participant) into z scores (whereby each data point is expressed in terms of its standard deviation from the mean) and overall means calculated across all participants.

Figure 6.7 below shows (using a different colour for each participant) the frequency with which each alert was judged the most urgent of the pair. Because only integer values are possible from this analysis, the scores are presented with a random jitter (plus or minus 0.33) so that scores from all participants are visible. The alerts are ordered (left to right) according to increasing overall mean urgency. Figure 6.8 shows the same data from the annoyance comparisons in increasing mean annoyance.

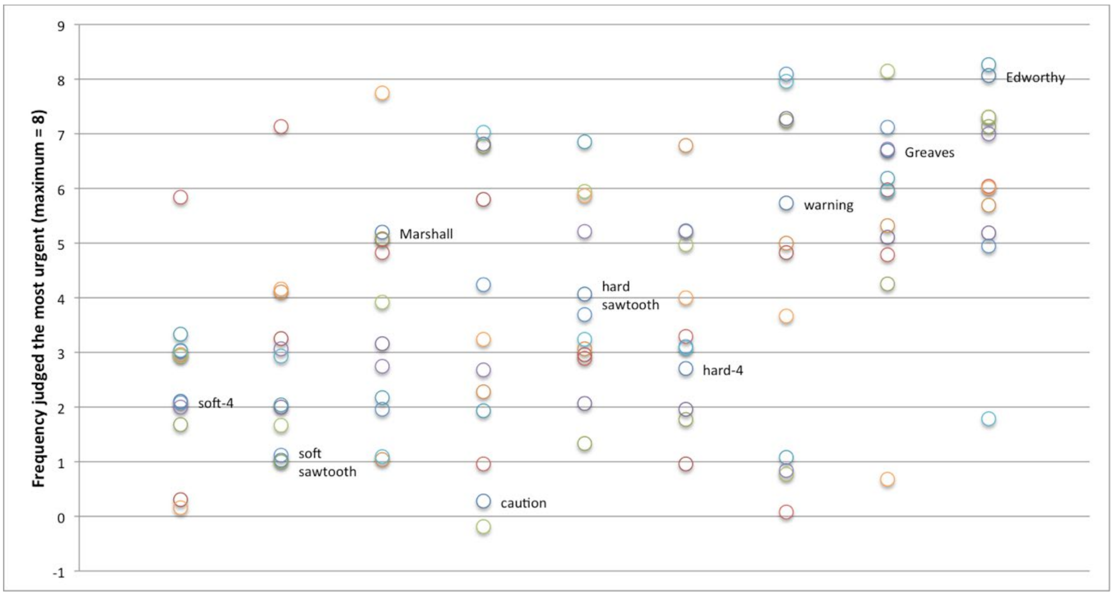


Figure 6.7: Urgency scores from paired comparison judgements (each point represents the score from a single participant)

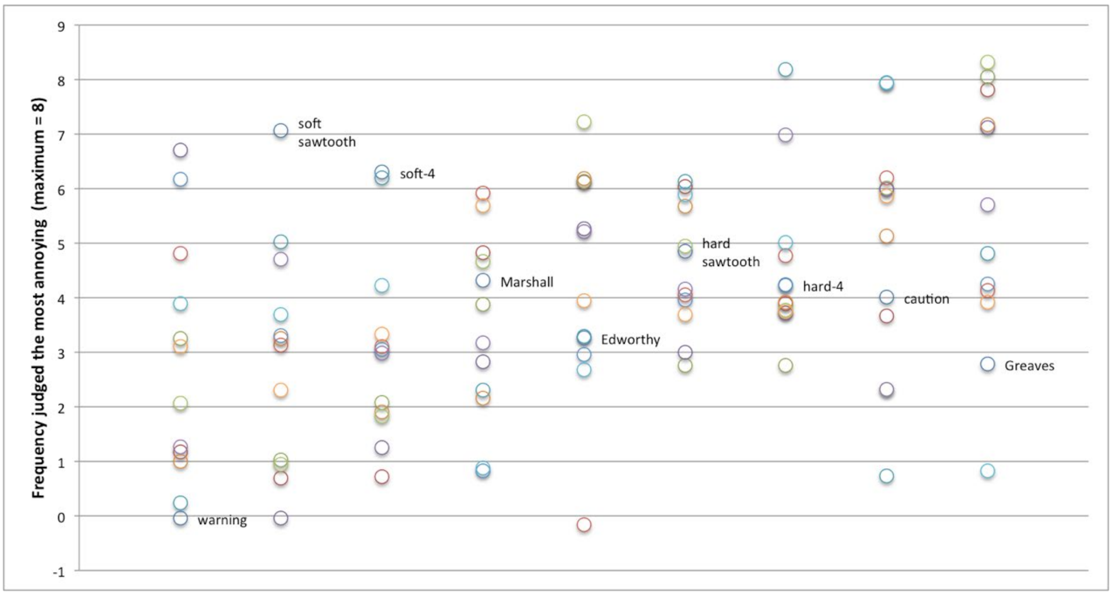


Figure 6.8: Annoyance scores from paired comparison analysis (each point represents the score from a single participant)

The one-off subjective ratings (provided by participants on a scale of 0 to 100) were averaged for each participant (recall that these were carried out twice, once at the start of the procedure and once at the end). Mean subjective ratings across all participants are presented in Table 6.1 (urgency) and Table 6.2 (annoyance).

Alert name	Mean urgency rating
Edworthy	61.0
Greaves	58.5
Warning	56.0
Caution	50.5
Marshall	48.0
Hard 4	44.5
Hard sawtooth	44.0
Soft sawtooth	39.0
Soft 4	34.5

Table 6.1: Mean subjective urgency ratings for each alert on a scale of 0 to 100

Alert name	Mean annoyance rating
Greaves	60.0
Edworthy	55.5
Warning	52.5
Hard sawtooth	51.0
Caution	48.5
Hard 4	48.0
Soft sawtooth	41.0
Soft 4	39.5
Marshall	37.5

Table 6.2: Mean subjective annoyance ratings for each alert on a scale of 0 to 100

Discussion

The aim of this study was to compare urgency and annoyance levels across a range of candidate alerts in order to select a smaller set for further testing. In this sense, the results for the existing ‘caution’ and ‘warning’ alerts are not of central interest, because they were planned for inclusion in further testing regardless of the outcomes of this study in order to provide a means of comparison between the current HTAWS system and the new alerts.

With regard to the other alerts, the paired comparisons and overall subjective ratings clearly agree that two – ‘Edworthy’ and ‘Greaves’– were consistently perceived as the most urgent of the candidates. This was also in line with the data from the initial testing with the experienced pilots. All these sources also agreed that ‘Greaves’ scored very highly in annoyance. By contrast, the ‘Edworthy’ alert scored lower in annoyance in the paired comparison data (although this was not mirrored in the overall ratings). Given that the highest priority alerts should only sound very rarely, annoyance is a less important consideration than urgency. For this reason, both of these alerts were selected for further testing.

Soft-4 scored lowest in urgency, in both the paired comparisons and the overall ratings (as well as in the testing with the pilots). It was therefore selected as the candidate soft alert in order to provide the maximum difference in inherent perceived urgency from the hard alerts.

Finally, hard-4 was selected for inclusion in further testing for comparison purposes, as an intermediate scorer on both urgency and annoyance. It also has the possible advantage of providing a clearly matchable pair with soft-4, one of which is clearly more urgent than the other but both of which are similar in structure. This could be useful in the sense that pilots would only need to become familiar with one ‘type’ of sound in relation to HTAWS alerts, and then urgency levels would be indicated by variations in the harmonic make-up of that sound.

Interestingly, in line with Marshall et al.'s (2007) findings, their alert was perceived as intermediate in urgency but low in annoyance when looking at the overall subjective ratings. However, this pattern did not hold in the paired comparisons data, where their alert scored at an intermediate level for both urgency and annoyance. It is likely that this discrepancy between their work and ours in the paired comparison findings stems from basic differences in the experimental design. For example, their study used a range of much more similar stimuli whereas ours involved comparisons across a wide range of very different stimuli. Thus, the cues that were associated with reduced annoyance in Marshall et al.’s work are likely to have been much less salient to participants in our study, because of the large baseline differences across the different stimuli. (Indeed, this suggestion would seem to be in line with the fact that the difference in the findings arises in the comparative judgements between stimuli and not in the overall subjective judgements for each stimulus, in which we replicated Marshall et al.’s results). In addition, it is worth noting that two out of the twelve experienced pilots spontaneously noted that the Marshall alert might risk confusability with existing cockpit alerts. This provides an additional strong justification for eliminating this alert from further testing.

6.3.2 - Attentional capture under workload

Motivation

Having developed a range of new candidate alerts based on the existing literature, and selected a subset of these based on their perceived urgency and annoyance, the next question was whether the new alerts were likely to capture attention more effectively than the existing alerts when participants were engaged in another task. In order to test this, the four alerts selected from the previous study (three of which are intended as high priority ‘hard alerts’ and one of which is envisaged as a ‘soft’ alert of lower priority) were presented alongside the existing ‘warning’ and ‘caution’ alerts as targets to which participants were required to respond as a high priority, while also carrying out a range of other simultaneous tasks.

Methods

Participants

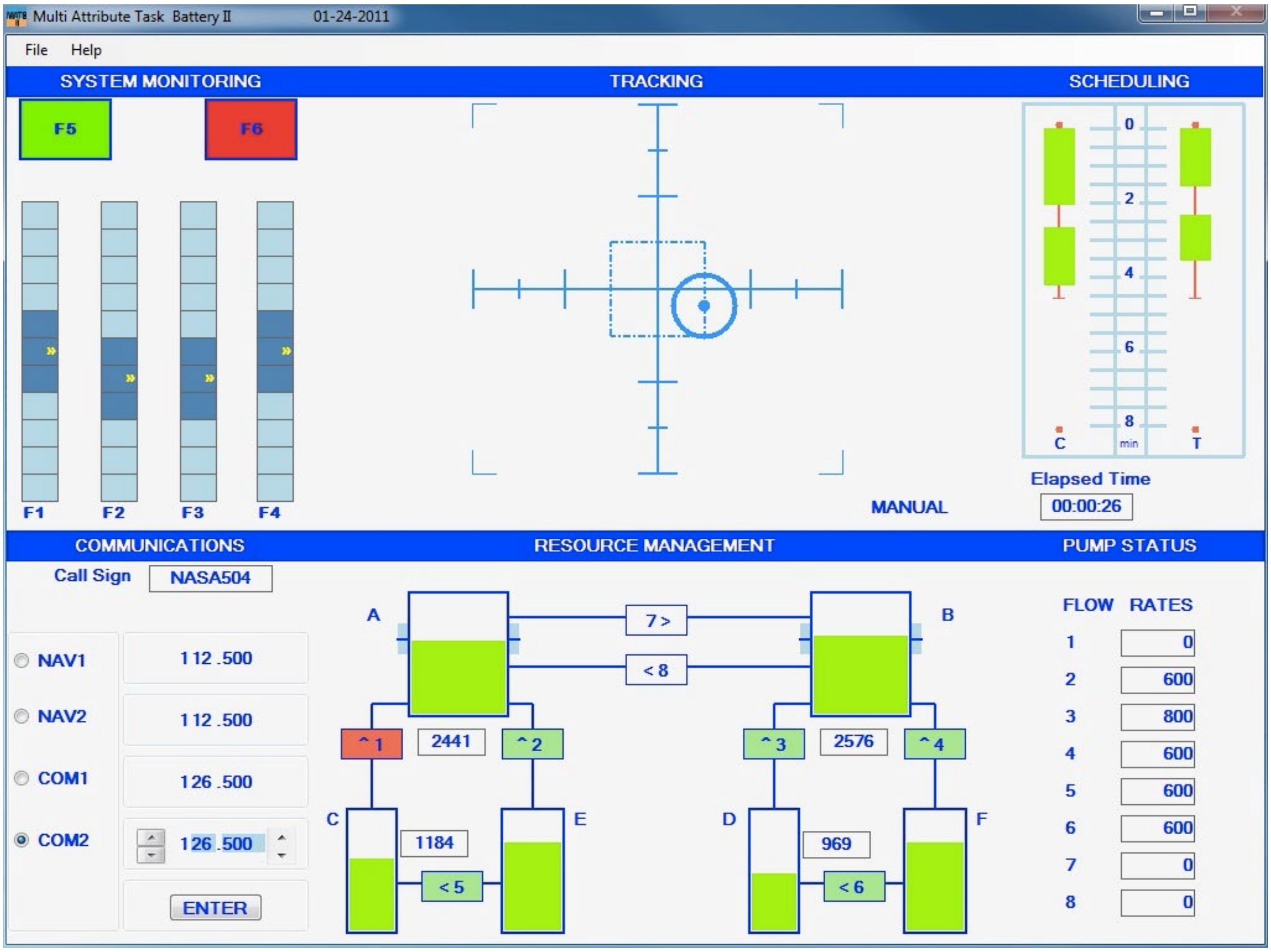
Twenty non-pilot participants were recruited at Royal Holloway, University of London via campus-based email lists and internet message boards. The data from one participant were excluded because of a technical problem during data collection. Of the remaining 19 participants, 16 were female, and two (both female) were left-handed. The mean age was 27 (SD=8). All participants reported normal or corrected-to-normal vision and hearing.

The participants tested here were not representative of the helicopter pilot population, being non-pilots and mainly female. For this reason, the study used a task battery that simulates pilot-like tasks in a way that is appropriate for testing with non-pilots. In addition, the central comparisons from the study are relative, such that the different alerts are compared at each participant’s individual performance level. Thus, even though experienced pilots would have been likely to perform better at the task overall, a more salient alert would be expected to improve performance for both pilots and non-pilots alike, and this is what the trial was designed to test.

MATB-II tasks

The experiment was run using NASA's Multi-Attribute Task Battery (MATB-II; Santiago-Espada, Myer, Latorella, & Comstock, 2011). This requires participants to monitor several ongoing tasks at the same time, using the computer mouse to click on items on the computer screen in response to visual events occurring on the screen and auditory events presented over headphones (Figure 6.9 shows an example display). The 'system monitoring' task (in the upper left corner of the display) requires participants to respond both to status changes in the colours of the 'F5' and 'F6' buttons and to deviations in the locations of the four nearby indicator pointers (labelled 'F1'-'F4'). The 'resource management' task (in the centre of the bottom portion of the screen) requires participants to maintain the levels in two simulated fuel tanks ('A' and 'B') by adjusting the operations of a number of simulated pumps (labelled 1-6). The 'communications' task (in the bottom left corner of the screen) involves responding to audio messages by clicking the appropriate radio buttons (labelled 'NAV1', 'NAV2', 'COM1' and 'COM2'). There is also a manual tracking component available within the MATB-II task set, however this was not used because it was important for participants to be able to use their dominant hand for responding to the alerts, rather than for manual tracking. The software can also interrupt the task at specified times to request participants' ratings of workload. Six onscreen sliding scales elicit ratings from 'low' to 'high' in the areas of 'mental demand', 'physical demand', 'temporal demand', 'performance', 'effort' and 'frustration'.

The settings for the MATB-II tasks can be adjusted in order to achieve the desired level of workload. Parameters were selected that had been found in previous studies to exert a relatively high workload, this being the situation of interest in terms of investigating the attention capturing properties of the alerts (which were presented as part of the communications task, see below). More specifically, five response-requiring events per minute were included in the system monitoring task (following the high load condition of Hsu, Wang, Chen, & Chen, 2015). For the resource management task, the requirement was to maintain tanks A and B at 2500 units, using the MATB-II default flow rates. One pump failure lasting 15s every minute was also introduced (following the high load conditions used by Fairclough, Venables, & Tattersall, 2005; and Hsu et al., 2015).



Elapsed Time 00:00:26

Call Sign NASA504

○ NAV1 112.500
○ NAV2 112.500
○ COM1 126.500
● COM2 126.500

FLOW	RATES
1	0
2	600
3	800
4	600
5	600
6	600
7	0
8	0

Figure 6.9: Example display from the MATB-II task

Auditory stimuli

The six alerts to be tested comprised the ‘Edworthy’, ‘Greaves’, ‘soft-4’, ‘hard-4’, ‘warning’ and ‘caution’ alerts described in the previous section of this report. These were edited such that each lasted around 450 ms. For the purposes of eliciting responses to the alerts, each one was followed by a spoken instruction, starting 500 ms after the onset of the alert, specifying a particular radio button to click. As described above, these radio buttons occur as part of the ‘communications’ task within the standard MATB-II environment, with the pre-existing labels: ‘NAV1’, ‘NAV2’, ‘COM1’ and ‘COM2’ (see Figure 6.9). Spoken instructions comprised the radio label followed by the word “radio” (e.g. “NAV 1 radio”) spoken in a female voice and lasting 900ms. Thus, in total each of these auditory target stimuli lasted 1400 ms.

Each alert was presented eight times throughout the experiment, paired twice with each radio name (so that the required response was unpredictable across the experiment). Thus, in total, participants had to respond to 48 alerts throughout the experiment, with the order of presentation randomised for each participant. In order to ensure that there was no strategic benefit to assuming that sounds would always be relevant, a range of 48 nontarget sounds was developed, consisting of brief air traffic control (ATC) exchanges, recorded during real operations and each lasting between 5 and 11 seconds. Thus, across the experiment, 50% of auditory events required a response and 50% did not. Unlike for the target sounds, the order of presentation of the nontargets remained fixed for all participants.

A recording of cockpit background noise (taken from a S92 helicopter) was played over loudspeakers in the testing room throughout the experiment at a level of approximately 63 dB(A), measured in the headphones. The alerts were presented over headphones, at approximately 15 dB(A) above this background noise level, in line with the recommendations derived from the alerting literature. The levels of both the alerts and the background noise were significantly lower than those that would be experienced during real helicopter operations, and were set in line with the health and safety requirements of Royal Holloway, University of London.

Procedure

Demographic information and confirmation of informed consent were collected via the computer at the start of the experimental run. Participants then heard examples of each of the six target alert sounds, as well as an example ATC event, and were briefed in detail on the MATB-II task requirements. Next there followed a demonstration block lasting 95 seconds, which provided an example of each of the MATB-II events in turn. The experimenter prompted participants to make the correct responses if necessary. This ended with presentation of the six workload rating scales (which always remained on screen for 30 seconds or until participants had finished their ratings). Next came a practice block of 70 seconds, consisting of a range of MATB-II events in an unpredictable order, again followed by the workload ratings scale. The experimenter then confirmed that the participant understood the task and had no further questions, before proceeding to the experimental blocks.

The experiment was divided into four blocks of 8 minutes duration. Each block included 24 communications events (of which 12 were targets requiring responses and 12 were ATC events to be ignored), 40 system monitoring events and eight pump failures in the resource management task. This equates to an overall rate of nine specific events per minute (or around one every seven seconds) on top of which the resource management task requires frequent attention and ongoing adjustments to the pump operations.

Results

Workload ratings

In order to ensure that the MATB-II tasks as implemented in the current study were imposing a high level of workload, participants' subjective workload ratings from the 'mental demand' category were examined. The overall mean rating across all four experimental blocks was 65 out of 100 (SD = 14), indicating a relatively high level of perceived workload, as predicted. Only one participant gave any rating of below 50 on the scale; the remaining 18 participants categorised the workload as 'high' rather than 'low' (by selecting a value that was above 50) at all stages of the experiment.

Detection rates and accuracy

Detection performance (in terms of making any response to the alert) and accuracy (in terms of selecting the correct radio button) were extremely high throughout the experiment. Only one alert did not elicit a response and only two incorrect radio button responses were selected (these errors were made by three different participants). Thus, these performance measures were not analysed further.

Reaction times

Reaction times (RTs) were measured in terms of the latency between the onset of the alerting stimulus and the time at which the participant clicked the specified radio button. Mean correct RTs for each alert type were calculated for each participant (see Figure 6.10).

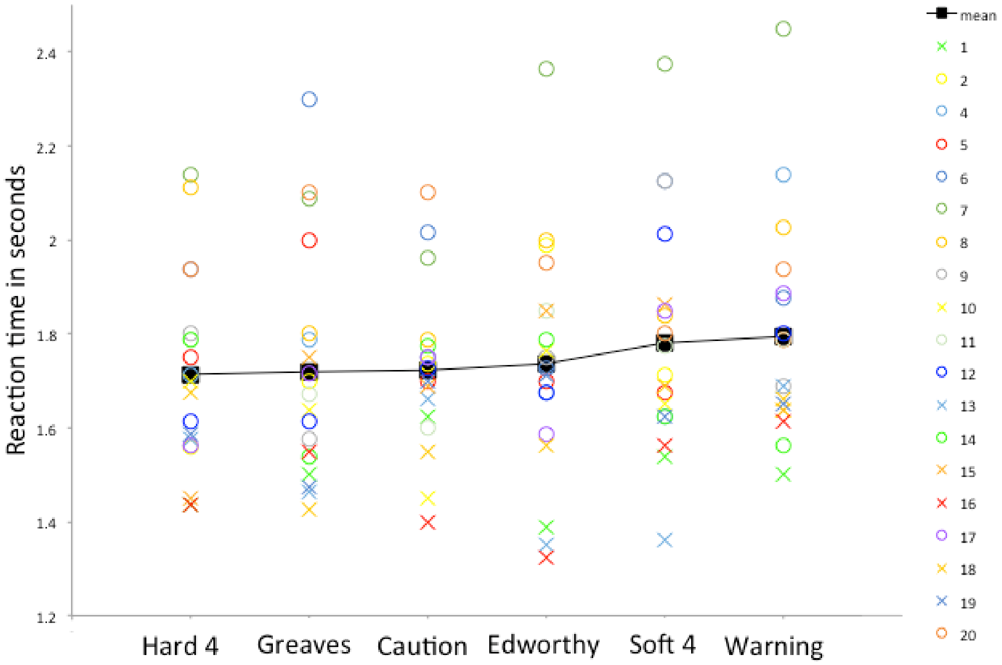


Figure 6.10: Mean reaction times to each alert for each participant (ordered left to right by increasing grand average RT, shown in black)

Two-tailed paired-samples t-tests were run to compare each new candidate alert with the relevant existing alert (i.e. candidate hard alerts were compared with the existing 'warning' alert, and the candidate soft alert was compared with the existing 'caution' alert). The results are summarised in Table 6.3.

Candidate	Reference	Mean RT difference (ms)	t value	*P* value
Edworthy	Warning	60	1.32	.205
Greaves	Warning	75	1.65	.115
Hard-4	Warning	80	2.12	.049
Soft-4	Caution	-60	1.25	.228

Table 6.3: Results of t-tests (df = 18 for all comparisons)

Although the ‘hard-4’ alert might appear to have elicited RTs that are significantly faster than those elicited by the existing ‘warning’ alert (uncorrected p<.05), this result does not survive Bonferroni correction (an adjustment which guards against false positives) for multiple comparisons. And in any case, the 80 ms advantage delivered by the ‘hard-4’ alert would be unlikely to lead to substantial safety improvements in operational situations. Thus, overall there are no significant differences between the RTs elicited by the new candidate alerts and the existing alerts.

Discussion

In the current experiment, the proposed candidate alerts did not demonstrate significant advantages compared with the existing HTAWS spoken alerts. Performance in response to all alerts was extremely good, with very few errors and little variation in RTs across the different alert types. It therefore seems likely that participants reached a performance ‘ceiling’ on the alert detection task. This would have masked any differences between the different alert types, because if performance were already at ceiling for the worst-performing alerts, there would have been little opportunity to observe performance increases for more effective alerts.

By comparison with real-world helicopter operations, the workload imposed by the MATB-II task in this experiment is relatively low. One possible explanation for the excellent performance on the alert detection task is therefore that, despite using high workload parameters in line with the existing literature, and eliciting a high level of perceived workload from participants, the MATB-II tasks implemented here imposed an insufficiently high level of workload. A future direction would be to increase the workload by increasing the frequency of events in the system monitoring and resource management tasks, as well as possibly introducing the manual tracking task.

Another important difference between the task used here and the real-world contexts in which the HTAWS alerts are experienced concerns the frequency of participants’ exposure to the alerts. In the present study, for practical reasons, all alerts sounded frequently and participants were explicitly instructed to respond to them every time. By contrast, in real-world operations many of the HTAWS alerts are much less frequent and are thus less-expected by the crew when they do sound. This reduced expectancy could in turn reduce detection performance in the real-world contexts by comparison with the present study. Interestingly, however, other HTAWS alerts in real-world contexts (in particular the mode 6 calls) are likely to be heard on every approach, and are thus likely to be expected by crew. However, although these alerts occur frequently, there is rarely any need for a response when they are heard, and thus it is possible that crews come to deprioritise them.

However, before examining this possibility it is important to address another potential explanation for the excellent alert detection performance. This relates to the high levels at which the alerts were presented in this experiment, relative to the background noise. In line with most recommendations for the design of auditory alerting systems, the alert levels were set at around

15dB(A) above the background cockpit noise. This made them extremely salient, to an extent that may well have masked any more subtle differences between the different alert types. If HTAWS alerts are presented at similar relative levels during real operations, then it may be the case that changes in the format of the alert will have little impact on their detectability above and beyond the high level of salience that is delivered by the sheer intensity of the alert. This makes it essential to determine whether HTAWS alerts are indeed presented at these levels – a question that is addressed in the following section of the report.

7 – Auditory Alert Presentation and Recorded Levels

7.1 - Introduction

The level above background noise at which an HTAWS auditory alert is presented is a function of many different factors. While it should perhaps be a trivial factor, the exact situation with presentation levels is, perhaps surprisingly, not clear.

7.2 - EGPWS Configuration

The HTAWS ‘box’, the line-replaceable unit (LRU), is the source of most HTAWS-type alerts.

Category 14 of the Type XXII EGPWS configuration sets the audio output level for alert menu callouts and Figure 7.1 presents Table 5.3.14 from the installation manual, detailing the available levels, with “Nominal” equal to the maximum level. The Nominal output is 4 watts rms into an 8- ohm load and 100 milliwatts rms into a 600-ohm load.

The two outputs from the LRU are for headsets (600 Ohm load) and cockpit loudspeakers (8 Ohm), however, because most helicopters use a full muff headset, cockpit speakers are not applicable.

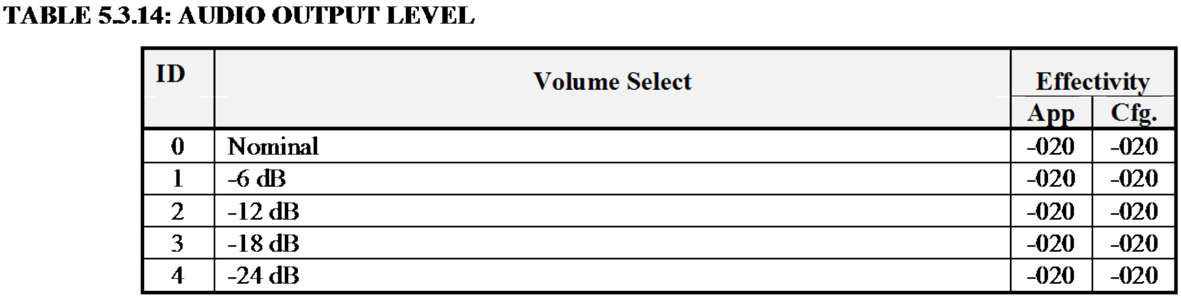


TABLE 5.3.14: AUDIO OUTPUT LEVEL

ID	Volume Select	Effectivity	
		App	Cfg.
0	Nominal	-020	-020
1	-6 dB	-020	-020
2	-12 dB	-020	-020
3	-18 dB	-020	-020
4	-24 dB	-020	-020

Figure 7.1 – Available audio output levels for Type XXII EGPWS

It is worth noting that only -6dB steps are available. This is a halving of voltage or a reduction to 66% of perceived loudness. This configuration setting is the only way to adjust the standard HTAWS alert levels on an aircraft as the level is independent of the intercommunication system (ICS) levels.

Bristow confirmed that their engineers do not change the level setting on their aircraft, nor do they have the facility to do so. However, talking to flight crew of other operators (onshore), it seems that requests are sometimes made to reduce the level of the alerts and this is done through a request in the aircraft’s technical log.

One pilot described the risk of an EGPWS call out masking an ATC clearance when landing at a location unrecognised by the EGPWS. This highlights the danger of spurious calls in distracting pilots or masking other important information, and reinforces the need for alerts to be reliable and relevant.

However, there is a significant risk that by judging the appropriateness of an alert level in a non-emergency or low-workload situation there may be a tendency to underestimate how loud the alert should be. This has been seen in numerous other areas – a visual or aural alert that is considered intrusive in normal operations is then not registered in an emergency or high workload situation.

The Type XXII also offers an option to enable a low volume for Mode 6 altitude and bank angle callouts through the use of a discrete. The audio output level for Mode 6 alerts can be reduced by an additional 6 dB by activating the Mode 6 Low Volume discrete of Category 13. Honeywell note that *"This discrete is typically connected to ground to lower the volume an additional 6dB. In some installations, it is connected to the windshield wiper control to decrease the Mode 6 Volume level under normal conditions and automatically increase Mode 6 volume 6dB when the cabin noise increases due to the windshield wipers being on."*

Some configurations use a 'soft' Glideslope alert which is issued at 6 dB below nominal alert volume level. Also, when activating the EGPWS self-test, alerts are given 6 dB below nominal alert volume level. Finally, some configurations are reported to issue a quieter Mode 6 call in low torque conditions.

7.3 - Pre-delivery checks

It has not been possible to establish from OEMs the level at which the alerts are set when they leave the factory beyond being checked as acceptable by the delivery test pilot. One OEM test pilot was unsure how the levels were set but surmised they must be, since they had never experienced a problem.

Given that some operators have described receiving aircraft with fixed height callout alerts being set to incorrect heights, it is possible that there exists some variability in HTAWS alert level. Also, one operator reported observing one OEM when they were testing cockpit noise as part of pre-delivery checks, and felt that the technique used could lead to large inaccuracies. Again, this suggests that noise level measurements may not be as thorough as they could be.

For fixed wing aircraft, one OEM reported setting the TAWS alerts so that they could be heard above the level of the Ram Air Turbine. Crews then complained that this was too high and the volume was reduced on later aircraft, which was signed off by the certification test pilot as being acceptable.

7.4 - Cockpit configuration

Clearly the background noise generated by the aircraft will directly affect the difference between background noise and alert level.

In fixed wing aircraft, Boeing use an automatic gain control (AGC) for TAWS depending upon phase of flight. This modulates the level of the alert to ensure there is sufficient difference between the alert and ambient in high noise phases of flight, but that it is not too loud in quieter phases. This approach may prove to be useful in helicopter applications, although the background noise may be sufficiently consistent with rotors running to make this approach unnecessary.

Anecdotal reports suggest that a significant number of pilots wear earplugs under their headsets to further reduce background noise and then, to compensate for the added attenuation, turn the ICS levels up significantly. While this may be understandable from a personal perspective it creates a very large safety issue since the HTAWS alert levels (and presumably other system alert levels) are intentionally independent of volume dials on the ICS panel. Therefore, a pilot wearing earplugs will experience the alert at a much lower level than intended; well-fitted ear plugs can provide as much as 35dB attenuation (HSL, 2009). This might allow the alert to be masked easily by higher level ICS noise or even be undetected in isolation. Operators should consider taking steps to understand the extent of this practice and alert flight crews to the risk it poses.

However, the issue of cockpit noise and hearing damage in pilots is also a significant one as highlighted by Rolfe (2016). Rolfe cited in-flight noise levels of the order of 101 dB LA_{eq} and other measurements by Bristow have shown levels of 95dB and 98 dB LA_{eq} in the cockpit as shown in Figure 7.2.

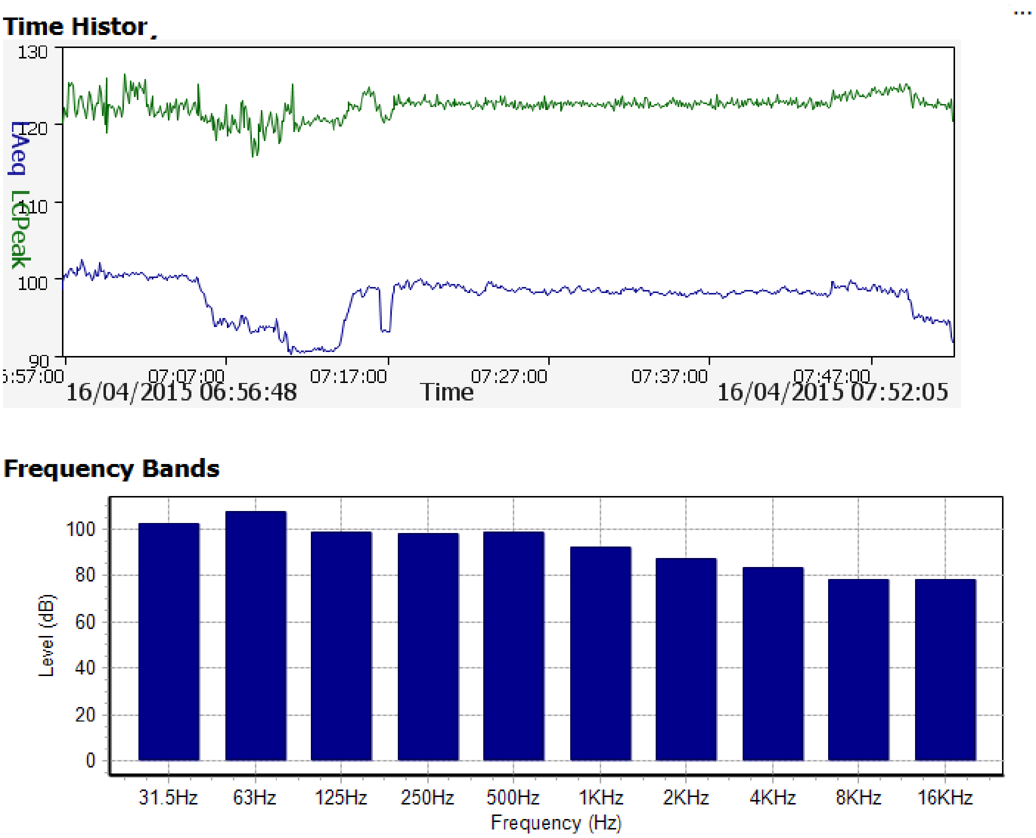


Figure 7.2 – Typical cockpit noise measurements

This same problem of alert level versus background noise level has been noted in other modes.

Rail Accident Investigation Branch (RAIB) report 08/2016 issued in May 2016 deals with a signal passed at danger on approach to Wootton Bassett Junction, Wiltshire in 2015. The report (Rail Accident Investigation Branch, 2016) notes that "*At the time that Tangmere's AWS* [Automatic Warning System] *system was installed, there was no requirement… for the sound level of AWS warnings to be above ambient noise levels by a specified amount. However, later standards require warnings to have a sound level of between 6 dB(A) and 10 dB(A) above the expected level of ambient noise and RSSB's Good Practice 'Guide for the design of alarms and alerts' states that audible alarms should generally be at least 15 to 25 dB(A) above ambient, in order to ensure that they are not missed*."

The RSSB have published an alarm toolkit and a Good Practice Guide (J Edworthy et al., 2008) which is co-authored by Edworthy and draws on her work.

A further complication regarding presentation level is that different headsets will provide different attenuation levels (which will also be a function of frequency). As a result, this will change the difference between background noise and alert level in the headset. Headset sensitivity will also affect the presentation levels. For a given power, different headsets will produce different SPLs in the cup.

CVR recording

Another issue that has arisen from the work into HTAWS alert levels is that there are questions about how representative the levels recorded on the CVR are of the alert levels presented to pilots. This potentially has a large impact on accident investigation since, for example, alerts which are clearly audible on the CVR may not have been similarly audible to the pilots. This is particularly important for rotary wing applications where cockpit speakers are not used and so the cockpit area mic (CAM) cannot give an indication of audibility.

Practical testing

For these reasons, a trial was conducted to establish the background noise levels and HTAWS presentation levels in an aircraft and to correlate those with CVR recording. This work is reported in the next chapter.

7.5 - Concluding remarks

The fact that the auditory environment of the helicopter cockpit is open to significant modification by individual pilots, both intentionally (e.g. through the use of earplugs and adjustments to ICS levels) and unintentionally (e.g. through the properties of the specific headset used) makes it very difficult to ensure that auditory HTAWS alerts will be presented at a level that complies with the guidance (at least 15 to 25 dB(A) above ambient) without presenting the alerts at dangerously high levels. This makes it important to increase the detectability of the auditory alerts in other ways (e.g. through the use of abstract tones that can be designed in such a way as to reduce their susceptibility to masking by the background noise, as proposed in Chapters 3 and 6) and also to give serious consideration to the use of a tactile component in the HTAWS alerting system.

An alternative approach would be to introduce controls, such as automatic gain control, to ensure that auditory alerts are not compromised. However, given the levels experienced in the cockpit (of the order of 90dB) it is probably not advisable to simply raise alert volumes to give a 15dB difference (i.e. around 105dB). That would be an extremely high level which, while possibly appropriate in instances of great risk, would be extremely intrusive and distracting in most circumstances. A better approach might therefore be to tie the HTAWS alert level to the ICS level such that it remains at a suitable level above the ICS level, and such that HTAWS alerts will still be audible with the ICS level is at its minimum setting. In this way, adjustment of the ICS level by the pilots to compensate for use of ear plugs or headset characteristics will automatically adjust the HTAWS alerts to an appropriate level.

8 – Alert Level Measurements

8.1 - Background

In order to establish the presentation levels of the alerts in practice, measurements were performed on an operational aircraft. The measurements consisted of two phases / configurations (a ground phase and a flight phase) which are described separately below.

An S-92A in a SAR configuration was used for the testing. Routine SAR operations were entirely unaffected by the testing as a spare aircraft was used. The aircraft was operated by a full flight crew, specifically rostered for the testing. The flight crew had volunteered for the testing and were briefed on the nature and the purpose of the measurements.

The flight crew had also been briefed on the range of possible alerts that could be triggered in flight and were happy that most could be triggered safely. The only exception was *Tail Too Low* and so this was removed from the test plan.

All aircrew wore ALPHA Eagle helmets for operations and none of the crew wore any type of earplugs for the tests.

8.2 - Measurement Equipment

A Brüel & Kjær (B&K) 4128-C Head and Torso Simulator (HATS) was used for in-cockpit measurements (see Figure 8.1). The HATS contains an ear simulator, which consists of a removable silicon-rubber pinna (the external part of the ear) joined to an ear canal. The ear canal ends in an occluded ear simulator that simulates the inner part of the ear canal according to the IEC60318-4 standard. The ear simulator contains a ½" microphone and is connected to a microphone preamplifier with an adaptor. The ear simulator complies with ITU-T Rec. P.57 and ANSI S3.25. The microphone was connected through a battery-powered preamp to a B&K Type 2250 battery-powered analyser (see Figure 8.2).

Figure 8.1 – B&K Type 4128-C Head and Torso Simulator (HATS)

Figure 8.2 – B&K Type 2250 Analyser

The S92 requires two flight crew for operation, which precludes the use of the HATS in-flight or whilst taxiing. It is permissible, however, to ground run the aircraft with the left-hand seat unoccupied.

In order to capture data in-flight, measurements were made inside the ear cup of the headset using an Etymotic Research ER-7C probe (see Figure 8.3). This microphone has a thin, flexible tube on the end allowing measurements in the ear. However, in this case, rather than being inserted into the ear, it was laid on the foam inside the ear cup of the headset and held with surgical tape (see Figure 8.4). This allowed a measurement to be made of the sound wave being presented to the ear of the flight crew member being monitored. Rolfe (Rolfe, 2016) outlined this protocol and equipment for performing in-ear tests.

Figure 8.3 – ER-7C measurement probe

Figure 8.4 – ER-7C in headset

There is potential in this configuration for compromising the noise reduction of the headset since a cable runs across the ear seal of the headset. However, after the flight, the pilot did not report a change in attenuation properties and reported no discomfort, despite this having been one of their concerns when they first saw the setup.

The ER-7C was connected to an NTi Audio XL2-TA analyser (Figure 8.5) which was set to log L_{Aeq} values (see 8.2.1) at 100ms intervals. A separate NTi Audio XL2 was used to take occasional ambient measurements in the cockpit during the flight.

All microphones and analysers were calibrated before being installed in the aircraft.

Figure 8.5 – NTi XL2 analyser

8.2.1 Equivalent Continuous Sound Level

Equivalent continuous sound level is a method of describing sound levels that vary over time. It results in a single decibel value for a given measurement time period and takes into account the total sound energy over that period of time. It is defined as the steady sound pressure level which, over a given period of time, has the same total energy as the actual fluctuating noise.

Equivalent continuous sound level is often abbreviated as L_{eq} with the A-weighted measurement indicated as L_{Aeq}. A-weighting is an adjustment applied to instrument-measured sound levels in an attempt to account for the relative loudness perceived by the human ear, as the sensitivity of the ear is frequency-dependent.

L_{eq} sound levels are dB values and cannot be added directly. A doubling of sound level results in a measured increase of 3dB. L_{eq} is also used in the assessment of noise dose or sound exposure in the workplace and the 3dB 'doubling rule' applies to time and/or level. For example an L_{eq} level of 85dBA over 8 hours is currently assessed as 100% dose in the UK. Using the doubling rule then 85dBA (8 hour) = 82dBA (16 hour) or 88dB is only acceptable for 4 hours a day.

8.3 - Ground Measurements - Configuration

The HATS device was installed into the left-hand seat of the aircraft and fitted with an ALPHA Eagle helmet (see Figures 8.7 and 8.8). The ER-7C was installed in the cup of the headset.

It is possible that the helmet headset was not in the ideal position since the fit around the ears of the head simulator can only be judged visually, with the view of the ear cups being restricted by the helmet structure. The HATS may sit lower in the cockpit than the pilot due to the short torso on the HATS but this is not expected to make a significant difference.

Figures 8.7 and 8.8 – HATS installed in cockpit with ALPHA Eagle helmet

There is a modification available (Sikorsky, 2013) to the ICS system on the S-92A which inserts a 4kHz low-pass filter before the headset. This was introduced to silence an unintended 4.8kHz tone being generated by the aircraft. The test aircraft was not fitted with this modification, but it may prove relevant when considering the spectrum or audibility of alerts in the future.

The analysers measuring the HATS and ER-7C microphones were set to log results and the aircraft engines were started with the commander in the right-hand seat of the aircraft, all other personnel in the rear of the aircraft and the door closed. Once both engines had stabilised, the EGPWS Initiated Built-In Test (IBIT) was triggered three times in succession, the fire alert was triggered and the autopilot disconnect alert was triggered.

The S-92A RFM states that "*The EGPWS test can only be conducted when on the ground with engines off*". However, this was not the situation in this case, which had been verified in advance.

8.4 - Ground Measurements - Results

For the ground run measurements, the Head and Torso Simulator was placed in the left-hand seat, and the probe was placed inside the ear cups of the helmet, which was then positioned on the HATS.

8.4.1 Ambient noise measurements

Comparison of the in-cup measurements (using the ER-7C probe) with the HATS measurements during the ground run (see section 8.4.2 and Figures 8.10 and 8.11) showed very similar levels, both of which appeared to represent high levels of ambient noise. This implies that the ear cups had not properly sealed around the HATS ear simulators and noise was leaking in. For this reason, it was not possible to assess the helmet attenuation due to the poor sealing, or measure the alert levels due to the excessive ambient noise.

Figure 8.9 shows the ambient spectrum for the ground run as measured in the cockpit between the pilots.

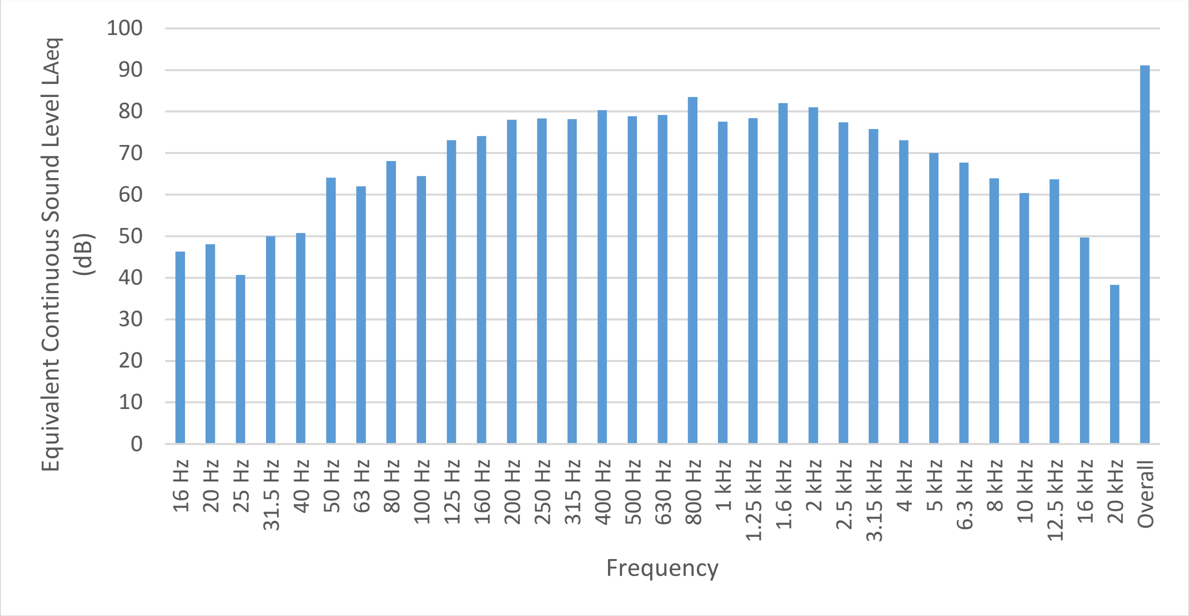


Figure 8.9 – Ambient measurement in cockpit during ground run

8.4.2 HATS and in-ear measurements

In order to reference and corroborate the measurements made by the ER-7C in-cup probe during the flight trials, duplicate measurements were made using the HATS and the probe. These measurements acted as an informal 'calibration' for the probe.

Figure 8.10 shows the third-octave spectra derived from each measurement. The overall L_{Aeq} levels were measured as 73.2dB for the HATS device and 73.6dB for the in-ear probe. Figure 8.11 shows the difference between the two measurements shown in Figure 8.10.

The results of the two measurements are broadly similar between about 100Hz and 4kHz where most measurement values are within about 2dB of each other (although 2.5kHz and 3.15kHz show larger variation of 9.6dB and 6.0dB). However, there are some large variations between the two measurements outside of this frequency range.

The specifications for the ER-7C probe are ± 1dB at 1kHz (the frequency of the calibrator) and ± 2dB in the range between 250Hz and 10kHz, and therefore it is unsurprising that measurements outside of this frequency range show significant disagreement.

The similarity of the overall levels (73.2dB versus 73.6dB) is explained by spectrum; the bulk of the energy is contained in the 125Hz to 4kHz region where the readings show good agreement. The effect of large measurements differences at frequencies where there is much less energy will be small. However, it is important to bear this in mind when using the probe measurements.

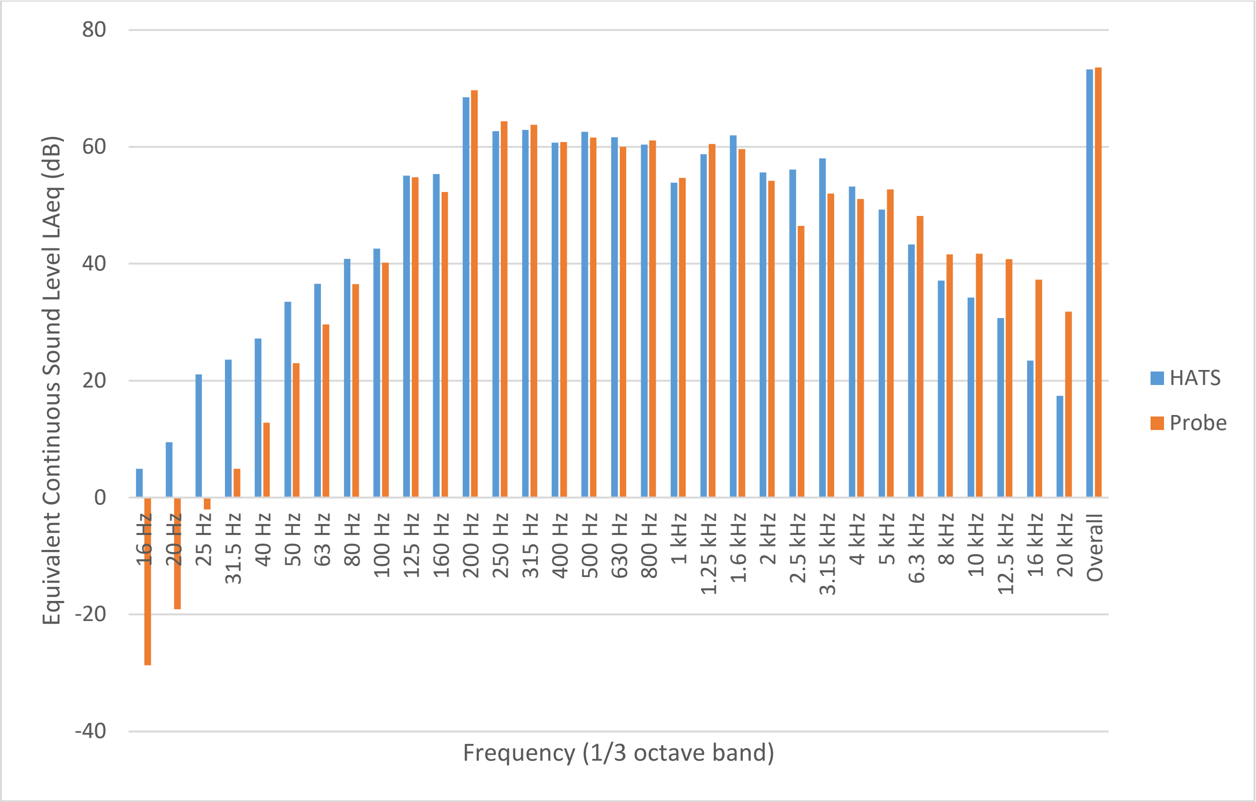


Figure 8.10 – Comparison of HATS and in-ear probe making simultaneous measurement

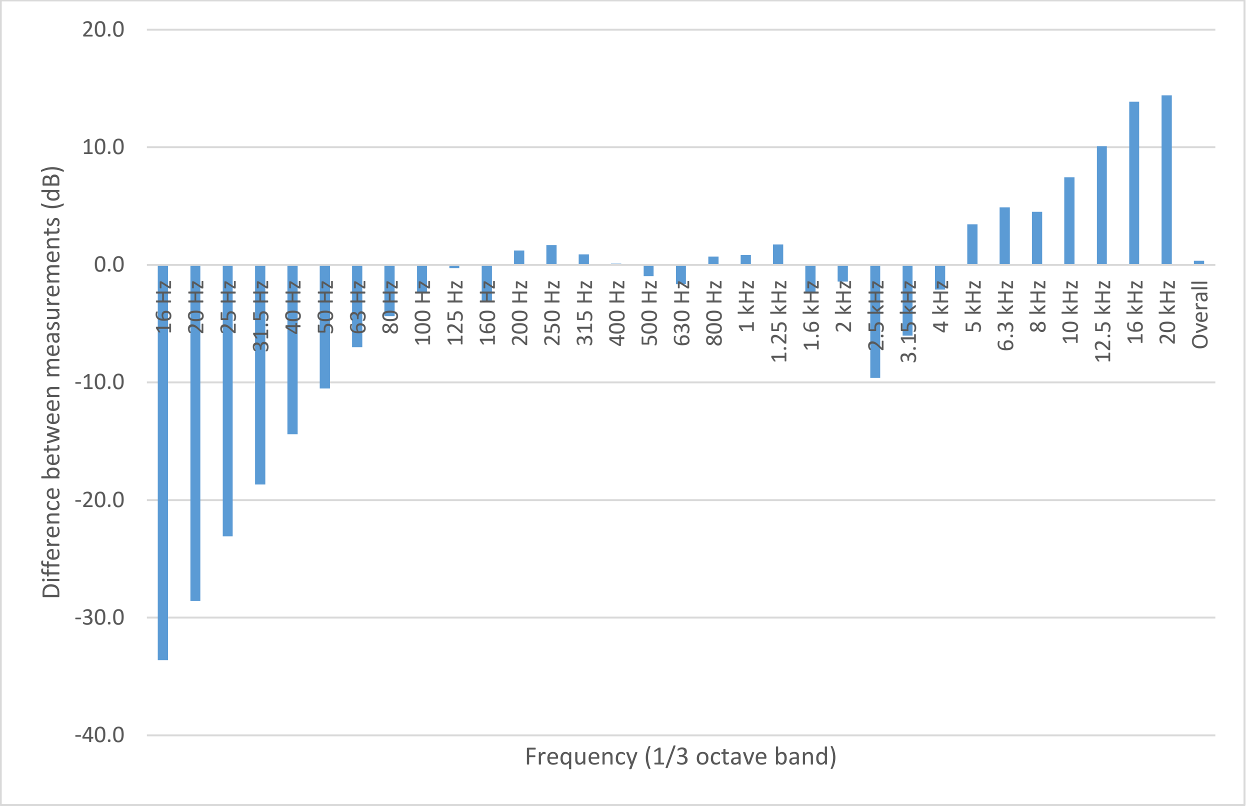


Figure 8.11 – Difference between the two measurements shown in Figure 8.10 (i.e. the difference between the HATS and in-cup probe measurement)

8.5 - Flight Test - Configuration

Following the ground measurements, the HATS device and helmet, probe and analysers were removed from the aircraft. The co-pilot had the probe fitted to their helmet and then occupied the left-hand seat. An ambient measurement was performed prior to taxying.

A flight trial was then conducted with three crew (commander, co-pilot and winchman) and one member of company staff as an observer.

The flight crew conducted a range of manoeuvres intended to trigger alerts including approaching known terrain, adopting a high bank angle and allowing a descent after take-off. It was not possible to trigger a *Glide Slope* alert due to a late change of landing runway and the limited time available before the CVFDR was over-written.

The following alerts were triggered, some more than once:

- *Caution Terrain*
- *Warning Terrain*
- *Too Low Terrain*
- *Too Low Gear*
- *Bank Angle*
- *One Hundred*
- *Altitude*
- *Don't Sink*
- *Minimums*
- *Hover Altitude*

(The *Hover Altitude* alert is part of the Auto-Hover functionality fitted to the test aircraft.)

8.6 - Flight Test - Results

8.6.1 Cockpit noise

A number of ambient readings were taken by the observer measuring between the pilots using the XL2 analyser. One of those measurements is shown below in Figure 8.12.

The measurement had a duration of 55s and resulted in an overall L_{Aeq} of 92.2dB. The highest third-octave value was 85.3dB at 800Hz. Summing only the values within 10dB of that peak (160Hz to 3.15kHz) gives a value of 92.04dB, showing that the bulk of the A-weighted energy is contained in that frequency band.

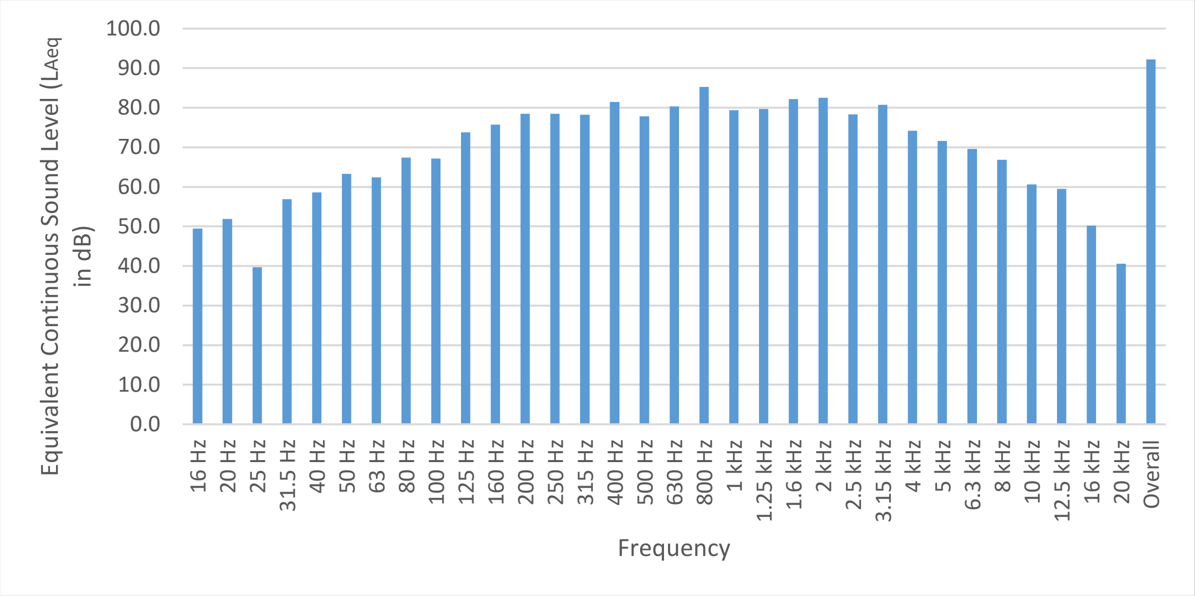


Figure 8.12 – Cockpit ambient noise measurement during flight trial

8.6.2 Helmet / headset attenuation

Five independent measurements of typical ‘ambient’ noise (i.e. during the flight but with no cockpit communication, radio traffic or alerts) were taken inside the earcup of the co-pilot to ensure consistency. The results are shown in Figure 8.13 below.

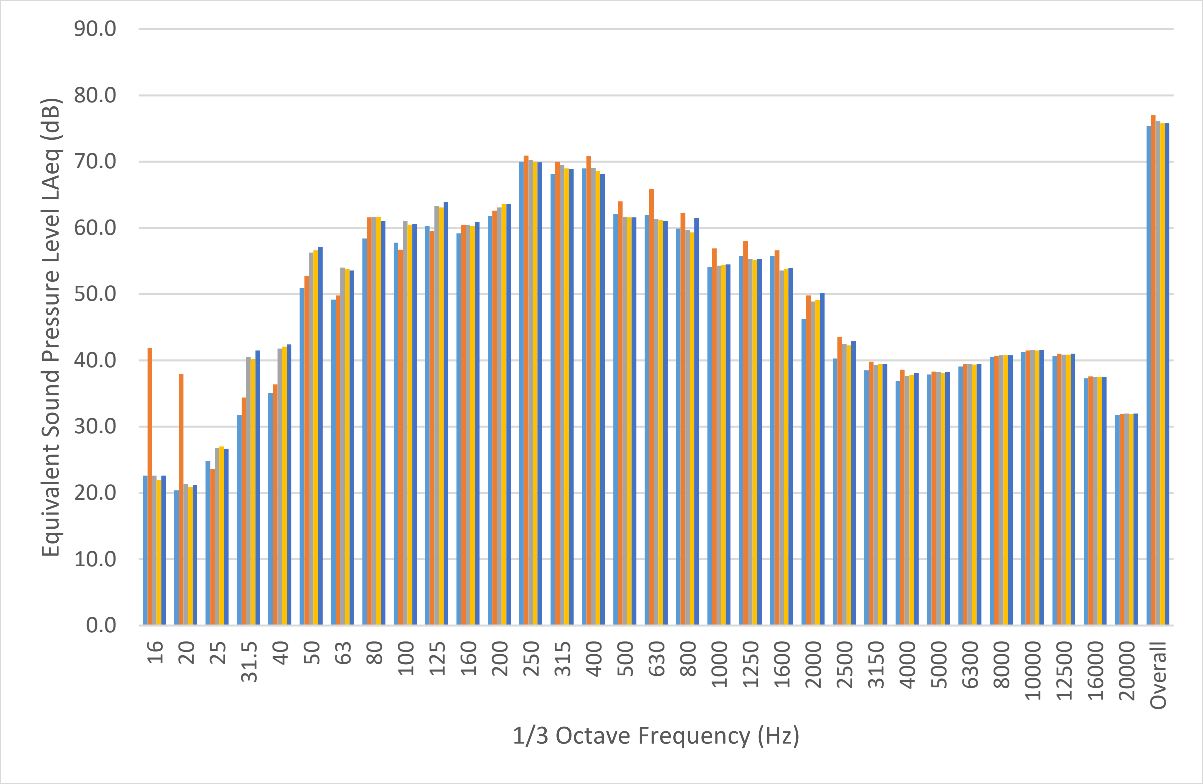


Figure 8.13 – Five independent measurements of ambient noise inside earcup during flight (i.e. no comms, RT or alerts)

Measurement	Duration (s)	L_{Aeq} (dB)
1	8.2	75.4
2	7.9	77.0
3	12.7	76.2
4	8.0	75.8
5	10.5	75.8
Average		76.1

Table 8.1 – Durations and L_{Aeq} values of 5 separate in-ear measurements

An average value of 76dB suggests that alerts should be presented to the pilot at a level of around 91dB to give the 15dB 'clearance' discussed in Chapter 3.

Figure 8.14 shows a comparison between the spectrum of measurement 1 from Table 8.1 (an 8.2s duration measurement of in-ear 'ambient' noise) with an ambient measurement in the cockpit. The two measurements were taken at different point times as the in-ear measurement was contaminated by radio traffic and internal communications at the point the cockpit measurement was taken.

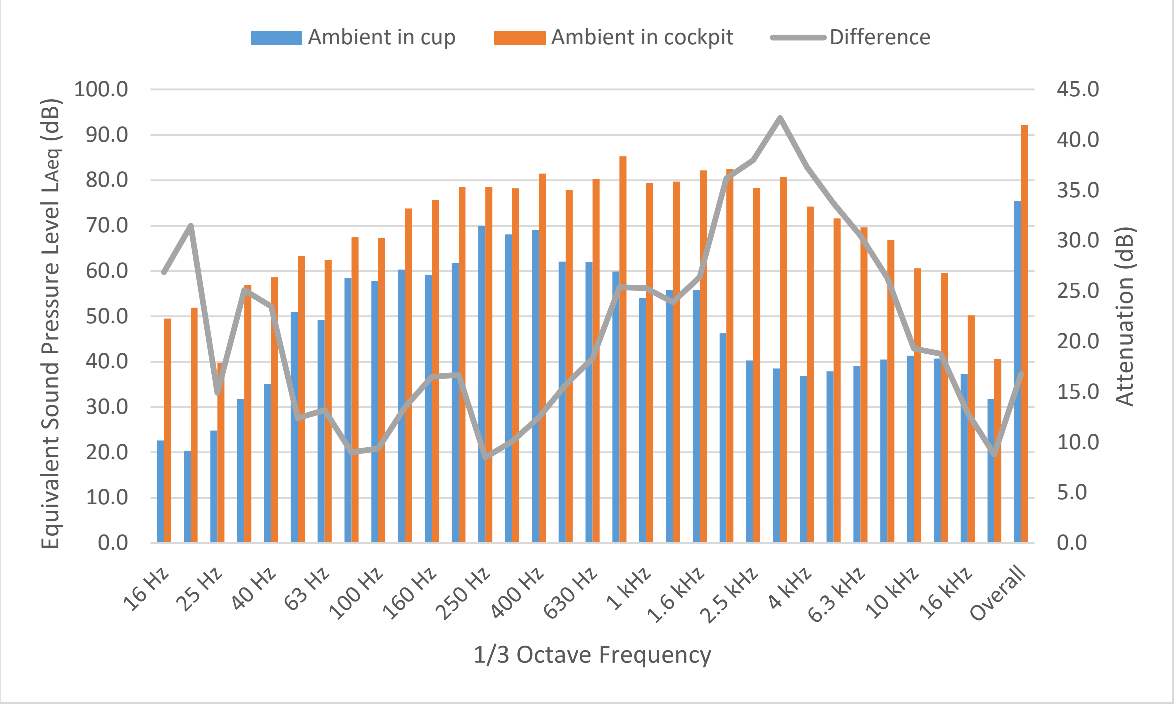


Figure 8.14 – Difference between ambient in-cockpit and in-ear measurements

Figure 8.14 also shows the difference between the two measurements which, assuming the noise in the cockpit was comparable at the two points, represents the attenuation provided by the helmet and ear cups. It is important to remember the limitations of the in-ear measurement described in Section 8.4.2.

James (James, 2005) presented the attenuation graphs shown in Figure 8.15 for three difference helmet types. These graphs show reasonable agreement with the data presented in Figure 8.14 within the bands of measurement accuracy.

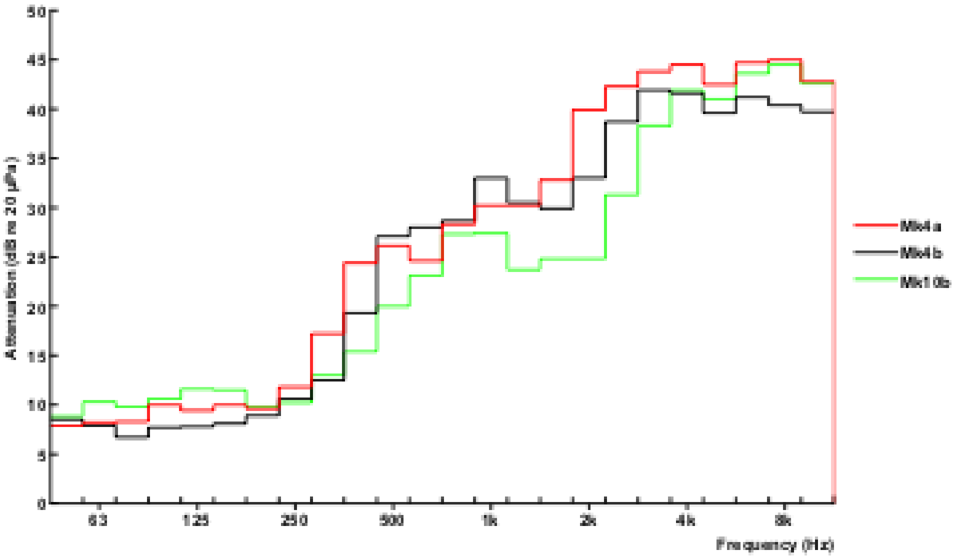


Figure 8.15 – Attenuation for three helmet designs from (James, 2005)

8.6.3 Total trip noise levels

In order to inform the Health and Safety process for assessing noise exposure, Figure 8.16 below presents spectra for the two recordings that were produced in the test flight. The first has a duration of 21min 28s and includes ground checks, taxi out and take-off. The second has a duration of 24min 54s and includes the alerts triggered in flight through to landing (but without shutdown and corresponding checks).

The graph shows that the total levels for the two measurements are 85.2 dBA and 85.6 dBA respectively. The spectra show good agreement between the two measurements, with the greatest energy contained in the 1kHz to 5kHz band. Again, the measurement limitations described in Section 8.4.2 should be noted.

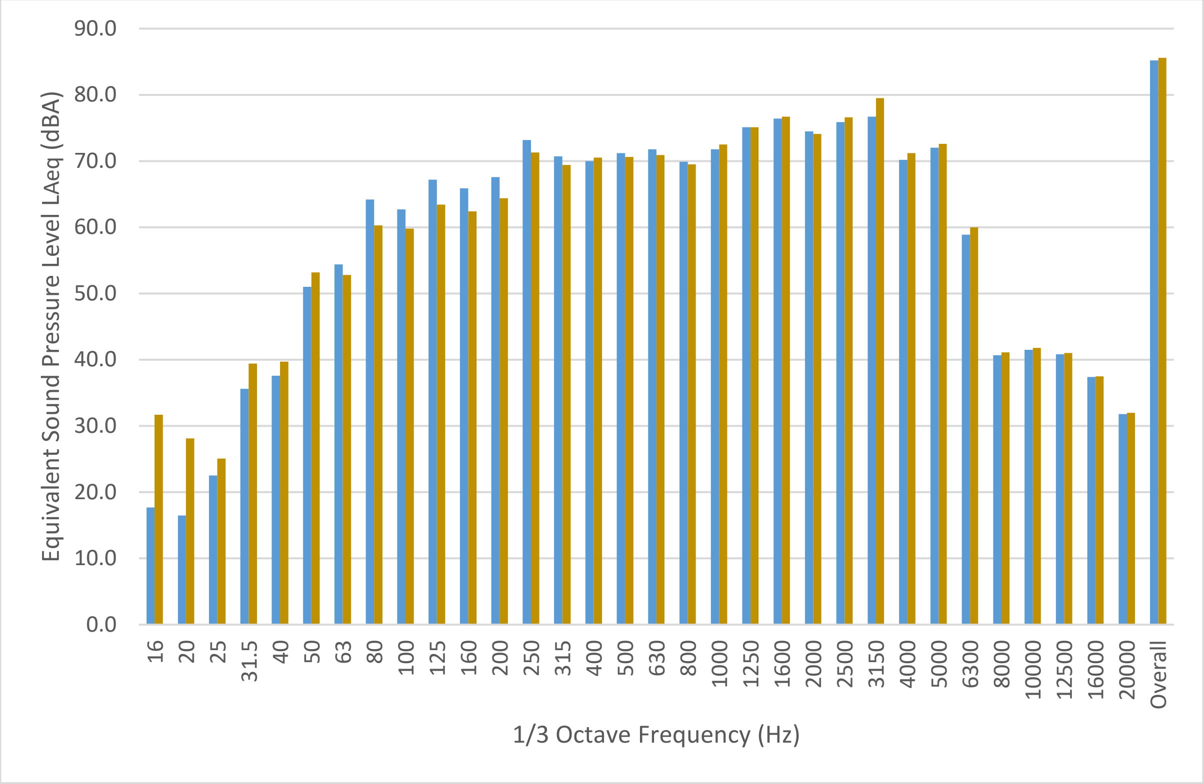


Figure 8.16 – Total spectra of the two recordings made during the flight

8.6.4 Alert presentation level

As described in Section 8.6.2, given an in-ear average value of 76dB suggests that alerts should be presented to the pilot at a level of around 91dB to give the 15dB 'delta' discussed in Chapter 3.

Table 8.2 shows a selection of alert levels as they were measured using the in-ear probe.

Alerts were only selected when they were predominantly free from other radio traffic or in-aircraft communication. The recorder was logging at 100ms intervals. The final sample of background noise before the alert and the first sample of background noise after the alert were included in the calculation.

Alert	L_{Aeq} (dB)
Don’t Sink	93.2
Bank Angle	91.7
Too Low Terrain	93.1 93.8
Too Low Gear	93.1
Caution Terrain	89.4 90.1 90.0 90.0
Warning Terrain	95.3 95.3 95.3 95.3 95.2
Altitude, Altitude	90.4
100	96.7

Table 8.2 – A selection of alert levels as measured using the in-ear probe

This suggests that, on this aircraft and with this helmet and headset, under normal operations, the presentation level of the EGPWS alerts was generally high enough for it to be 15dB over the ambient noise. (NB: This assessment disregards any Health and Safety issues around noise exposure.). “Caution Terrain” and “Altitude, Altitude” show the lowest levels among those alerts measured.

8.6.5 Communication levels and masking

The co-pilot set their ICS levels to the level at which they would normally have them and so can be considered to be typical for that pilot.

A number of L_{Aeq} calculations were made for various sections of speech during the flight. As might be expected, there was a considerable range of values varying from 77.9dB up to 91.1dB (and even higher with the door open – see below).

Recall that the measured alert levels ranged from 89.4dB to 96.7dB. This means that, when speech is present in the cockpit, the presentation levels of the alerts will often not be significantly higher than those of the speech (and will be very unlikely to achieve the recommended 15dB ‘delta’). This problem is compounded by the fact that all of the alerts themselves consist of speech signals because, as discussed in section 3.3.1.1, speech-based alerts are susceptible to informational masking by other speech sources in the cockpit (e.g. Brungart, 2001).

While making the measurements, a condition was captured which illustrates the potential issue this poses.

At one point during the recording, the crew elected to land at an off-airfield site. The Audio 8.1 below is an excerpt from the approach to that landing as recorded in the headset of the Pilot Flying (PF). The flight crew were consulted and gave their approval for this recording to be included. The recording was taken from the measurement analyser, not from the CVR recording.

Audio 8.1 – Approach to an off-airfield landing site captured in headset of PF

The microphones in this aircraft use a noise gate system in which they only ‘open’ when the crew are talking. In the clip, the winchman’s door is open and the elevated background noise can be heard when speaking.

Approximately 18 seconds into Audio 8.1, whilst approaching the landing area, the *Altitude, Altitude* alert sounds but it is partially masked by the communications within the aircraft.

Although the situation in the test aircraft did not present a safety risk, listening to the recording in isolation, it is extremely difficult to discern the *Altitude, Altitude* call against the other speech. As a result, it is not difficult, nor unreasonable, to extrapolate this to a situation with high noise, high workload, or poor situational awareness in which the alert could easily fail to capture attention.

Had any crew member been wearing earplugs and made a corresponding increase in their ICS level, this situation would have been exacerbated greatly.

Figure 8.17 shows the spectrogram for the winchman’s speech whilst counting down to touchdown (i.e. with the door open).

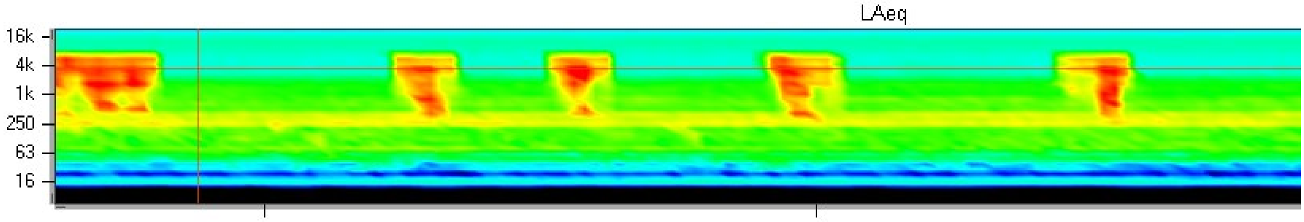


Figure 8.17 - Spectrogram of speech countdown with door open

Table 8.3 shows the typical L_{Aeq} levels for the background noise and the peak levels seen during the speech.

L_{Aeq} levels (dB)	
Background	**Peak during speech**
75.8	99.1
77.2	94.9
75.6	99.0
75.2	94.5

Table 8.3 – L_{Aeq} values during speech shown in Figure 8.17

A typical overall level (rather than peak level show in Table 8.3) for winchman speech with the door open was 96.6dB.

8.7 - CVFDR

Following the test, the permission of the pilots to replay the CVR was obtained. The recorder was then removed from the aircraft and transported to the AAIB where it was downloaded and decoded.

8.7.1 – Equipment and process

The recorder was connected to a computer via Ethernet and the files downloaded from the recorder using the web interface within the recorder.

The RFM describes 6 separate tracks on the CVR:

- 30 minutes pilot voice recorder
- 30 minutes co-pilot voice recorder
- 30 minutes cabin audio recorder
- 30 minutes, high quality cockpit audio
- 120 minutes, low quality cockpit audio
- 120 minutes of combined pilot, co-pilot, and cabin audio.

However, 4 tracks were available on the test flight recorded each of 120 minutes duration. The high quality channel had a sample rate of 16kHz with 16bit resolution. The other three channels had 8kHz sample rate with 16bit resolution.

Unfortunately, it became apparent from listening to the CVR recording that power had been applied to the aircraft shortly after the test but before the recorder had been removed. As a result, the ground run portion of the test had been overwritten. This confirms that it is only necessary for electrical power to be available for the recorder to operate, not oil pressure or some other trigger as is sometimes seen on other aircraft.

However, the overwriting highlighted a feature of the recorder. The level recorded by the cockpit area microphone (CAM) was very similar both from in-flight noise and also from speech and avionics fan noise in the aircraft. In practice there would have been a difference of at least 20dB between these two conditions, and since the recordings are of a similar level, this implies that some kind of automatic gain control was operating in the recorder and this was subsequently confirmed by the manufacturer. Figure 8.18 shows the amplitude of the .WAV file for the two conditions.

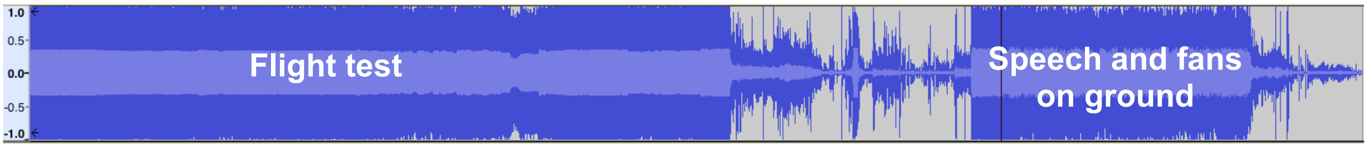


Figure 8.18 – Illustration of automatic gain control in CVR

This feature means that any sort of comparison with background noise is meaningless since a change in overall noise level results in a change in recording gain to maximise the recorded signal.

HTAWS alerts were recorded to all three (i.e. non-CAM) remaining channels but at different amplitudes.

A recent AAIB report (Air Accidents Investigation Branch, 2018) focussed on CVR recording quality. As part of the investigation, the AAIB performed a comparative review of the Boeing 787 EAFR CVR recordings against a range of other turbofan powered aircraft, which included the Boeing 747-400, 777, 767, 737-800, 737-300, Airbus A380, A340, A330, A320 and Embraer 190. These recordings were all from solid-state CVRs, meaning that the relative use of the dynamic recording ranges were directly comparable. Indicative results for the crew channel are shown in Figure 8.19.

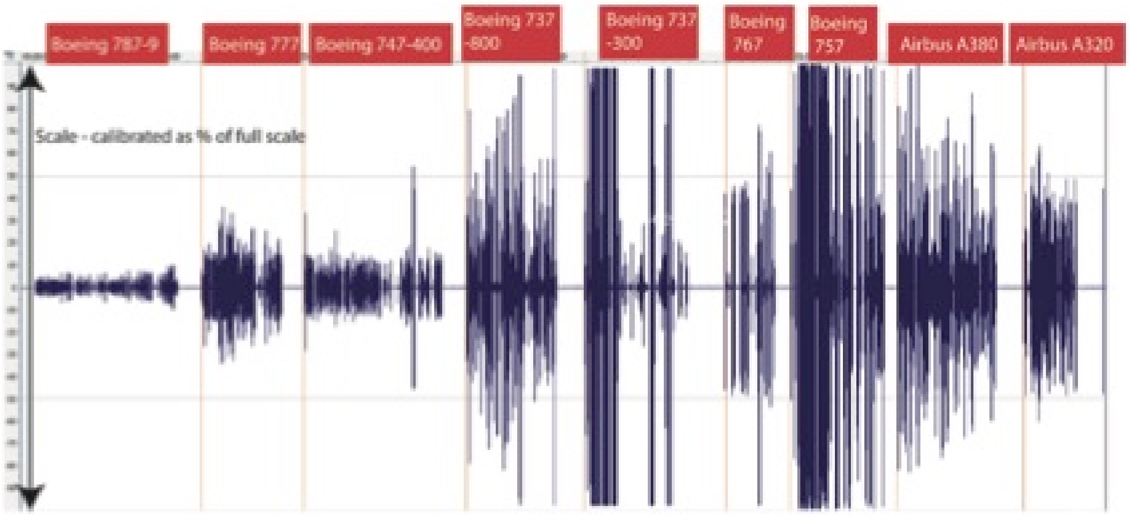


Figure 8.19 – Illustration of differences in CVR recording between types

The results of the review indicate significant variation between aircraft types of the 1) recorded dynamic range of the crew channels and 2) ambient background noise levels compared to crew speech recorded on the CAM channel. As a result, the AAIB issued the following recommendations:

> *"It is recommended that the European Aviation Safety Agency initiate a review to consider whether a repeatable and objective analysis technique can be applied to*

> *audio recordings to establish consistent installed performance of cockpit voice recorder systems."*

and

> *"It is recommended that the European Organization for Civil Aviation Equipment (EUROCAE) amend their document 'Mininimum Operational Performance specification for Crash Protected Airborne Recorder Systems' (currently ED-112A) to include a repeatable and objective analysis technique to establish consistent installed performance of cockpit voice recorder systems."*

Although these recommendations focus on performance, any review could also consider 'representativeness' of the recording.

Existing CVR systems record a maximum of four channels of audio, which consists of the crew channels and Cockpit Area Microphone (CAM). For each crew channel, the crew member's microphone and side-tone signal are combined before recording, with the side-tone amplitude reduced so as to ensure that masking of crew speech is kept to a minimum.

However, CVR system design is not limited to recording a maximum of four channels (EUROCAE, 2013), and therefore one option might be to record a separate channel dedicated to the pilots' headphone output. This may not totally address the issue of what either pilot heard (since headphone failure and sensitivity will affect the level presented to the pilot) but it would provide greater clarity for investigators.

8.8 - Discussion and Concluding Remarks

It is possible that this SAR aircraft, with three flight crew, may have exhibited an unusually high amount of in-aircraft communication compared to other flights, particular while making an off-airport landing. It is also possible that the ICS levels were set particularly high by the co-pilot.

From the measurements that were made, it is clear that the alert presentation levels typically meet the requirement of a 15dB difference, when compared with the typical background noise levels.

However, that is not the case when comparing with typical speech levels on the test flight. In some cases, the speech was presented at a higher level than the alert, as shown in the example given.

Clearly if it were possible to prioritise alerts over speech, or *vice versa*, then it would be possible to ensure that source were the louder. However, it is easy to conceive of situations where that priority may reverse, even during the same scenario.

One potential solution that has been raised during this project is the use of an automatic gain control such as that used by Boeing aircraft for the cockpit loudspeaker. Based on the phase of flight, the loudspeaker level is adjusted to account, say, for increased wind noise in cruise. However, in the case of helicopters, this will not work since the conflict is not with background noise *per se*, but rather appears to be with the speech levels in the ICS system. Also, the use of earplugs by flight crew will, in general, compound this problem since any change in ICS level to 'accommodate' the earplugs will not be applied to the fixed level of the alert. One possibility could therefore be to link the level of the HTAWS alerts with the ICS level, such that adjusting the ICS level would lead to an automatic adjustment in the level of the alerts. However, this approach could inadvertently deprioritise any auditory alerts that were not linked to the ICS level, so it may be appropriate to consider implementing this change for all high priority auditory alerts (rather than just HTAWS). Any such change would require careful review of the likely impact on all other auditory information presented to pilots.

A more radical solution to the problem of attenuation by earplugs could be to use bone-conducting technology to present alerts to pilots. Bone-conducting headsets use vibration to present signals directly to the inner ear and have been in use in the military for many years. Consumer headsets are now readily available from manufacturers such as ‘Aftershokz’. Such a system would allow alerts to be presented in a way that is largely unaffected by earplugs, although hearing damage is still possible by bone conduction.

One factor that could possibly be addressed is the masking of speech alerts by other in-aircraft speech. The fact that the EGPWS uses voice-only alerts means that the potential of masking by other speech is greatly increased. If those alerts were preceded by a tone, this would be likely to aid in distinguishing the alert, increasing the chances of it capturing the pilots’ attention.

These measurement results might suggest a possible reason for the high performance of candidates in the alert response test described in section 6.3.2. The alerts in that test were presented against representative helicopter background noise but in the absence of any speech. This set-up generated very good performance for all alerts tested. However, the current findings, along with the literature on informational masking, suggest that the proposed candidate alerts (which incorporate an ‘attenson’-type tone) are most likely to outperform the existing speech-based alerts in situations where other speech is present in the cockpit – a situation that was not addressed in section 6.3.2.

None of this is to discount the issue of inattentional deafness, which may still prevent an alert from being perceived, regardless of its presentation level or susceptibility to masking. However, increasing the overall detectability of the alert (e.g. by increasing its presentation level and/or reducing the extent to which it is likely to be masked) will increase the overall chances of it being noticed.

When considering the CVR, the automatic gain control and different recording levels between channels suggests that it may not possible for investigators to build an accurate picture of the relative audio levels as presented to flight crew, for this kind of configuration. This means that investigators cannot assume that an alert was audible to the flight crew despite being easily audible on the CVR recording.

9 – Concluding Remarks

Relative contributions of auditory and visual alerting

Aural alerting should remain the primary means of delivering HTAWS alerts. The effectiveness of a visual alert will depend on where the pilot is looking at the time it is generated, which cannot be reliably predicted. In addition, the capacity of pilots to assimilate visual information is limited by the high levels of critical visual information that pilots must continually process. Therefore, visual alerting should be seen as supplementary (e.g. providing a reminder of the situation after the auditory alert has sounded).

Masking and presentation levels

Based on the limited measurements made in this research, it seems that background noise does not present the greatest threat of masking alerts. The main challenge to the detectability of the alerts came from the volume set by the flight crew for in-cockpit communication, which was comparable with the alert volume. In situations such as this, the use of an attenson may help to improve the detectability of the alert against the other in-cockpit speech, as well as indicating that a spoken alert is coming and thus prompting a pause in speech in the cockpit.

Given the levels experienced in the cockpit (of the order of 90dB) it is probably not advisable to simply raise alert volumes to give a 15dB difference (i.e. around 105dB). That would be an extremely high level which, while possibly appropriate in instances of great risk, would be extremely intrusive and distracting in most circumstances.

One solution might be to increase alert levels, above some given minimum, in proportion to the ICS level as set by the pilot, although the issue of ‘absolute level’ described above still exists. The issue of potential masking also exists with other alerts that are not linked to the ICS level, and such a scheme should be applied to all auditory alerts of comparable or higher priority than HTAWS alerts in order to avoid inadvertently deprioritising any other alerts. In addition, this approach would require a careful review of the likely impact on the other auditory information presented within the cockpit.

Different headsets have different impedances and sensitivities and, as a result, will produce different volumes at the pilot’s ear. For communication this can be compensated by adjusting the volume level. However, this will not alter the alert volume.

As the headset is connected to the aircraft it should perhaps go through an approval process, possibly controlled by Part M. However, that was not the case for at least one large operator, where different headsets with and without active noise reduction were allowed alongside helmets.

The same is also true of earplugs which are routinely being used in operations. At present, the communication level can be compensated by adjusting the volume level, but this will not affect alert levels. In extreme cases this could mean alerts are being presented to pilots as much as 30dB below the intended level. This issue might be negated by linking alert level to ICS level as described above.

In short, it is not sufficient to consider alert level in isolation, but rather as a part of the complete operating environment.

Habituation

Habituation to alerts is an issue. Exposing pilots to an alert on every flight which, in a tiny proportion of cases, may prevent a catastrophic accident, is not sensible and expecting the situational dissonance of an alert triggered at an unusual time to provoke a response is not sufficient. This is currently the situation with the Mode 6 (100ft) call.

Mode 6 alerts are heard on virtually every approach and are not being recognised by crews; many do not even consider that alert to be part of the HTAWS protection. If an alert is triggered it should reflect the fact that a response is required, which is usually not the case for Mode 6.

Priming

Use of a Caution alert (where something is clearly wrong but is not yet catastrophic) before a Warning (where action must be taken immediately) is helpful. However, introducing an additional alert where no Caution currently exists would either reduce the warning time provided by the subsequent warning or, if the warning time were to be preserved, would increase the nuisance alert rate. There may be an overall benefit to adding a Caution alert, however, by sacrificing a small amount of warning time and accepting a slightly higher nuisance rate.

Visual alerting

The visual alerts in some HTAWS installations could be improved. Given the density of information presented in current glass cockpit designs, it is challenging to present additional visual elements in a way that renders them clear and easily-detectable without compromising the other information on the display. One possibility here might be to mirror the HTAWS alerts on the coaming, allowing them to appear in an area of greatly reduced visual clutter. Alternatively, it might be possible to employ the ‘de-clutter’ mode that some aircraft have (where information displayed on the PFD is reduced) while an HTAWS alert is active.

Tactile alerting

The literature around alerting using multiple modalities is clear that introducing a tactile element to the alert will improve its attention-getting qualities. This type of alerting should be developed and trialled to quantify the level of benefit that will be achieved.

CVR Recording

The present system of recording alerts on the CVR is aimed at ensuring investigators can tell whether an alert was generated or not. However, in a number of cases, the audibility of the alert has been called into question. On fixed wing aircraft, the audibility of the cockpit speaker can be confirmed using the cockpit area microphone, but this is not possible for helicopters. The alerts are delivered to the pilots’ ears via their headsets which the CVR does not sample, and as a result, accident investigators are unable to confirm what was presented to the pilots’ ears. A change to the recording system should be considered to address this issue.

One option might be to record a direct signal from the pilots’ headphone outputs. This will not totally address the issue of what either pilot heard (since headphone failure and sensitivity will affect the level presented to the pilot) but it may provide better information than that currently available.

Documentation

The documentation (RFM, operations manuals, training materials etc.) surrounding many HTAWS systems is inadequate, dispersed and, at times, contradictory. The new FCOMs (Flight Crew Operations Manuals) being delivered by manufacturers present a significant opportunity to address this shortfall.

Detailed understanding

Consideration should be given to the extent to which pilots need to understand the detail of the behaviour of the system. The underlying operation and algorithms of modern HTAWS systems is becoming increasingly complex, meaning that it will be increasingly difficult for pilots to understand every nuance of a system; the pilot interviews highlighted the limited understanding that already exists. There are dangers associated with pilots attempting to ‘troubleshoot’ a system while flying and with incomplete information.

Pilot response

The perception of HTAWS amongst the pilot community is generally positive with a reported tendency for pilots to believe the system unless there is strong contradictory evidence. However, trust in the system is not total and automatic response to an alert is not uniform. Pilots are still sometimes prone to ‘second guess’ the system, assuming they understand the reason for an alert rather than simply performing an evasive action. This is unsurprising since the performance of the system to date has been imperfect.

The ideal situation is a reliable system to which pilots react without question. However, total trust in HTAWS from pilots will require the system to perform with a high level of accuracy and reliability for a significant period of time.

Databases

Errors, inaccuracies and limitations in the HTAWS database led some operators to remove offshore installations from their databases in order to reduce nuisance alert rates. Although some aspects of the database such as the resolution could probably be improved, it is unrealistic to imagine that a database could ever be fully up to date for mobile installations and so it could never be fully relied upon. There are other, more robust means of detecting offshore obstacles.

Regulation

The lack of Human Factors guidance (i.e. CS 29 versions of CS 25.1302) is a significant shortcoming in the regulations. Action is underway to address this which should supported, pursued and enacted as a matter of priority.

It would be particularly beneficial if the regulation or supporting advisory material included references to indicate from where the advice was drawn. That way, any change in understanding by the academic community could be reflected in the regulations.

Reporting

There is a lack of reporting regarding HTAWS alerts, in part due to confusion over what constitutes an HTAWS alert. In addition, some operators are unable even to monitor an HTAWS alert discrete in their FDM data frame to identify when an alert has been generated let alone establish which mode was triggered.

It would be helpful if operators (with the support of the manufacturers) could add these parameters to their FDM programmes. This would allow operators to check that the HTAWS alerts are performing as expected and assure themselves that pilots are responding correctly to any alerts generated.

If adding HTAWS alert parameters to the data frame is impractical, operators could investigate the possibility of programming the HTAWS alert algorithms into the FDM analysis software to identify when HTAWS alerts should have been triggered.

10 – Further Work

Tactile alerting

A tactile alerting system for helicopters should be developed and trialled to quantify the benefit in terms of pilot response that adding this modality could achieve. One approach may be through the use of wearables or by incorporating tactile transducers into flight suits.

Visual response

It would be helpful to understand pilots' visual response to an aural HTAWS alert, possibly through flight simulator experiments employing eye-tracking. This could help to inform the design and location of visual alerts.

Simulator testing

A protocol should be established for testing the effectiveness of alerting strategies. Based on experience with this research, such a protocol should employ current flight crew, performing realistic tasks in a flight simulator with appropriate noise levels, cockpit communication etc. Ideally such a test would include artificially degrading the situational awareness of pilots without their knowledge.

Attention should be paid to the acoustic environment in the simulator. Accuracy and fidelity is not guaranteed, particularly with respect to discrete tones. Under Section 1.4.c.1 of CS-FSTD(H), only Level D Full Flight Simulators are required to demonstrate "*realistic amplitude and frequency of cockpit acoustic environment*".

Flight Data Monitoring

FDM should be used to measure the current rate of HTAWS alert activation prior to introducing the new algorithms. This may require coordination with the manufacturers to ensure that the appropriate data is available from the aircraft. HeliOffshore may be well-placed to assist with this task.

Recommendation Safety Recommendation 2011-062 from the accident to G-REDU stated that *"It is recommended that the European Aviation Safety Agency reviews the frequency of nuisance warnings generated by Terrain Awareness and Warning System equipment in offshore helicopter operations and takes appropriate action to improve the integrity of the system."* EASA's response to that recommendation pointed to the work of the HSRMC (the algorithm modifications and this study).

Once established, FDM could also be used to track the response of pilots to alerts to understand whether alerts are being perceived and acted upon.

Presentation levels

Further work to establish typical presentation levels, other alert levels, background noise levels and cockpit communication levels should be conducted to confirm or refute the measurements described in this report.

There may be a role for using bone conduction technology as an alternative to airborne transmission of auditory alerts and this should be investigated.

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12 – Appendices

Appendix 1 - Extracts from Appendix 1 of (E)TSO-C151c

Section 1.3. c.

An appropriate visual and aural discrete signal for both caution and warning alerts.

Section 3.3

c. Altitude Callouts. Class A equipment must provide a voice callout of ‘five hundred’ or equivalent when descending through 500 feet above terrain or 500 feet above the nearest runway elevation during nonprecision approaches, but are recommended for all approaches. Additional altitude callouts, such as ‘one hundred’ or ‘two hundred’ are acceptable, but not required. This voice callout will not be made at ascent, for example on a missed approach or departure.

d. Sweep Tones ‘Whoop-Whoop’. If a two-tone sweep is used to comply with RTCA/DO-161A, paragraph 2.3, the complete cycle of two-tone sweeps plus annunciation may be extended from ‘1.4’ to ‘2’ seconds.

Section 4.0 AURAL AND VISUAL ALERTS

4.1 The TAWS is required to provide aural and visual alerts for each of the functions described in section 3.0 of this Appendix.

4.2 The TAWS must provide the required aural and visual alerts in a manner that clearly indicates to the flight crew that they represent a single event. The TAWS may accomplish the entire alerting function, or provide alert inputs to an external aircraft alerting system. Exceptions to this requirement are allowed when suppression of aural alerts is necessary to protect pilots from nuisance aural alerting, but a visual alert is still appropriate.

4.3 Each aural alert must identify the reason for the alert, such as ‘too low terrain’,- ‘glideslope’, or another acceptable annunciation.

4.4 The system must remove the visual and aural alert once the situation has been resolved.

4.5 The system must be capable of accepting and processing aeroplane performance-related data or aeroplane dynamic data and providing the capability to update aural and visual alerts at least once per second.

4.6 The aural and visual outputs as defined in Table 4-1 must be compatible with the standard cockpit displays and auditory systems.

4.7 The aural and visual alerts should be selectable to accommodate operational commonality among aeroplane fleets.

4.8 The visual display of alerting information must be immediately and continuously displayed until the situation is resolved or no longer valid.

4.9 At a minimum, the TAWS must be capable of providing aural alert messages described in Table 4-1. In addition to this minimum set, other voice alerts may be provided.

Table 4-1

STANDARD SET OF VISUAL AND AURAL ALERTS		
Alert Condition	**Caution**	**Warning**
FLTA Functions Reduced Required Terrain Clearance and Imminent Impact with Terrain Class A & Class B	**Visual Alert** Amber text message that is obvious, concise, and must be consistent with the aural message. **Aural Alerts** Minimum selectable voice alerts: 'Caution, Terrain; Caution, Terrain' **and** 'Terrain Ahead; Terrain Ahead'	**Visual Alert** Red text message that is obvious, concise and must be consistent with the aural message. **Aural Alerts** Minimum selectable voice alerts: 'Terrain, Terrain; Pull-Up, Pull-Up' **and** 'Terrain Ahead, Pull-Up; Terrain Ahead, Pull-Up'
Premature Descent Alert (PDA) Class A & Class B	**Visual Alert** Amber text message that is obvious, concise, and must be consistent with the aural message. **Aural Alert** 'Too Low Terrain'	**Visual Alert** None Required **Aural Alert** None Required
Ground Proximity Envelope 1, 2, or 3 Excessive Descent Rate Mode 1 Class A & Class B	**Visual Alert** Amber text message that is obvious, concise, and must be consistent with the aural message. **Aural Alert** 'Sink Rate'	**Visual Alert** Red text message that is obvious, concise, and must be consistent with the Aural message. **Aural Alert** 'Pull-Up'
Ground Proximity Excessive Closure Rate (Flaps not in Landing Configuration) Mode 2A Class A	**Visual Alert** Amber text message that is obvious, concise, and must be consistent with the aural message. **Aural Alert** 'Terrain, Terrain'	**Visual Alert** Red text message that is obvious, concise, and must be consistent with the aural message. **Aural Alert** 'Pull-Up'

STANDARD SET OF VISUAL AND AURAL ALERTS		
Alert Condition	**Caution**	**Warning**
Ground Proximity Excessive Closure Rate (Landing Configuration) Mode 2B Class A	**Visual Alert** Amber text message that is obvious, concise, and must be consistent with the aural message. **Aural Alert** 'Terrain, Terrain'	**Visual Alert** Red text message that is obvious, concise, and must be consistent with the aural message for gear up. **Aural Alert** 'Pull-Up'—for gear up None Required—for gear down
Ground Proximity Altitude Loss after Takeoff Mode 3 Class A & Class B	**Visual Alert** Amber text message that is obvious, concise, and must be consistent with the aural message. **Aural Alerts** 'Don't Sink' and 'Too Low Terrain'	**Visual Alert** None Required **Aural Alert** None Required
Ground Proximity Envelope 1 (Gear and/or flaps other than landing configuration) Mode 4 Class A	**Visual Alert** Amber text message that is obvious, concise, and must be consistent with the aural message. **Aural Alerts** 'Too Low Terrain' **and** 'Too Low Gear'	**Visual Alert** None Required **Aural Alert** None Required
Ground Proximity Envelope 2 Insufficient Terrain Clearance (Gear and/or flaps other than landing configuration) Mode 4 Class A	**Visual Alert** Amber text message that is obvious, concise, and must be consistent with the aural message. **Aural Alerts** 'Too Low Terrain' **and** 'Too Low Flaps'	**Visual Alert** None Required **Aural Alert** None Required
Ground Proximity Envelope 3 Insufficient Terrain Clearance (Gear and/or flaps other than landing configuration) Mode 4 Class A	**Visual Alert** Amber text message that is obvious, concise, and must be consistent with the aural message. **Aural Alert** 'Too Low Terrain'	**Visual Alert** None Required **Aural Alert** None Required

STANDARD SET OF VISUAL AND AURAL ALERTS		
Alert Condition	**Caution**	**Warning**
Ground Proximity Excessive Glideslope or Glidepath Deviation Mode 5 Class A	**Visual Alert** Amber text message that is obvious, concise, and must be consistent with the aural message. **Aural Alert** 'Glideslope' or 'Glidepath'	**Visual Alert** None Required **Aural Alert** None Required
Ground Proximity Altitude Callout (See Note 1)	**Visual Alert** None Required	**Visual Alert** None Required
Class A & Class B (See Note 3)	**Aural Alert** 'Five Hundred'	**Aural Alert** None Required

Note 1: The call out for ground proximity altitude is considered advisory.

Note 2: Visual alerts may be put on the terrain situational awareness display, if doing so fits with the overall human factors alerting scheme for the flight deck. This does not eliminate the visual alert color requirements, even in the case of a monochromatic display. Typically in such a scenario, adjacent colored annunciator lamps meet the alerting color requirements.

Note 3: Additional callouts can be made by the system, but the system is required to make the 500 foot voice callout.

Table 4-2

Legend: W = Warning, C = Caution, I = Non-Alert Information

ALERT PRIORITISATION SCHEME			
Priority	**Description**	**Level**	**Comments**
1	Reactive Windshear Warning	W	
2	Sink Rate Pull-Up Warning	W	Continuous
3	Excessive Closure Pull-Up Warning	W	Continuous
4	RTC Terrain Warning	W	
5	V_1 Callout	I	
6	Engine Fail Callout	W	
7	FLTA Pull-up Warning	W	Continuous
8	PWS Warning	W	
9	RTC Terrain Caution	C	Continuous
10	Minimums	I	
11	FLTA Caution	C	7 s period
12	Too Low Terrain	C	
13	PDA (‘Too Low Terrain’) Caution	C	
14	Altitude Callouts	I	
15	Too Low Gear	C	
16	Too Low Flaps	C	
17	Sink Rate	C	
18	Don’t Sink	C	
19	“Glideslope” or “Glidepath”	C	3 s period
20	PWS Caution	C	
21	Approaching Minimums	I	
22	Bank Angle	C	
23	Reactive Windshear Caution	C	
Mode 6	TCAS RA *(‘Climb’, ‘Descend’, etc.*)	W	Continuous
Mode 6	TCAS TA (‘*Traffic, Traffic*’)	C	Continuous

Note: These alerts can occur simultaneously with TAWS voice callout alerts.

Appendix 2 – Review of Accidents

A2.1 G-BIJF - 12th August 1981

Location:	1.3 mi SE of the Dunlin Alpha Platform
Aircraft type:	Bell 212
Injuries:	1 crew (1 minor/none)
	13 pax (1 fatal, 2 serious, 10 minor/none)

The flight was being operated with a single pilot. During daytime flight, planned for Visual Meteorological Conditions (VMC), the helicopter encountered an area of reduced visibility, with the flight continuing at 200 feet until a decision was made to return. During the turn, control of the helicopter was lost and after pitching 20 deg nose up, it climbed to 300 feet with zero airspeed. It began yawing rapidly and descending, and struck the sea in an essentially level attitude. The aircraft was not fitted with a TAWS or AVAD system (Air Accidents Investigation Branch, 1982).

The history of flight in the accident report (Air Accidents Investigation Branch, 1982) notes that the pilot:

"…transmitted a distress message saying he was 'disorientated in cloud unsure of position'. During the interval (approximately 53 seconds) between the start of this call and the impact the commander was unable to control the aircraft with the exception of maintaining a level attitude on the attitude indicator."

It is possible that the availability of more modern autopilot systems might help to prevent this accident from happening in the current environment. However, as has been seen from recent accidents, increased automation is not a panacea and brings its own difficulties.

The use of two crew may also help mitigate against such loss of control accidents; the report states that:

"…if the aircraft had been operated with two pilots whose responsibilities were divided so that one was permanently 'on instruments' it is probable that the accident would have been prevented."

However, as with automation, two crew is not a panacea and loss of control accidents do still occur with two crew.

It is highly debatable whether any TAWS alert would have prevented this accident, although the new offshore Mode 7 would have alerted the pilot to the loss of airspeed. The pilot was aware of his disorientation and his difficulty in controlling the aircraft, as evidenced by the radio communications. Since it was broadcast 'in the open', it is possible to listen to the radio traffic from this accident. From this recording it is interesting to note the greatly increased ambient noise in this accident, seemingly from both mechanical and aerodynamic sources. There is also considerable fluctuation of rotor rpm and associated frequencies. Due to restrictions on access to CVR data, this represents one of the few publicly available data points concerning noise levels during accidents.

A2.2 G-BDIL - 14th Sept 1982

Location:	14 miles from the Murchison platform
Aircraft type:	Bell 212

Injuries: 6 crew (6 fatal)

The aircraft was being operated as a night search and rescue (SAR) flight. The report (Accidents Investigation Branch, 1984) concludes that "*there was insufficient evidence to enable the cause of the accident to be determined although there can be little doubt that the difficulty of the task, the adverse weather, the total darkness and the time of day were major contributory factors"*.

When considering the additional equipment fitted to the aircraft, the report notes that:

"The type of radio altimeter fitted to the accident aircraft can be modified to provide an audio warning when the aircraft descended below the decision height 'bug' setting although it was not so equipped at the time. Such an audio warning could have been vital in preventing this accident and it can in general only be beneficial. Consideration should be given to requiring helicopters operating offshore around the British Isles to be equipped with radio altimeters modified to give such audio warnings."

From this observation there stemmed a recommendation that *"Radio altimeters incorporating audio as well as visual decision height warning be fitted to all helicopters operating offshore around the British Isles."*

A2.3 G-BEON - 16th July 1983

Location: Near St Mary's aerodrome, Isles of Scilly

Aircraft type: Sikorsky S-61N

Injuries: 3 crew (1 fatal, 1 serious, 1 minor/none)
23 pax (19 fatal, 1 serious, 3 minor/none)

The aircraft was on a scheduled service under Visual Flight Rules (VFR). The report (Air Accidents Investigation Branch, 1984) notes that "*Whilst it was on the approach…the helicopter gradually descended from its intended height of 250 feet without either pilot being aware of this, and flew into the water*." The report cites one of the contributory factors as "*...the lack of an audio height warning equipment."*

As part of the approach the landing gear was down, thereby disabling the "gear up below 250 ft horn" which is described as a "*pulsating note*". As part of the flight the *"…co-pilot was entirely engaged in operating the radar set…and so he was no longer monitoring the flight instruments.*" The report notes indications of an "*unsatisfactory workload*", which can be inferred as being too high. In conditions that were described as "*poor and deceptive*", the aircraft struck the water because "*Neither the commander nor the co-pilot had been aware of any descent below 250 feet*".

The investigation report also comments on the differences at the time between the state of alerting for public transport aircraft and helicopters:

"It is surprising that following the action taken a decade ago to require the larger public transport aircraft to be equipped with a ground proximity warning system, no action had been taken to apply this important safety lesson to helicopters. Had even the simplest audio alert system, such as one operated simultaneously with a radio altimeter decision height warning light, been in use in [G-BE] ON it could have alerted the crew in ample time for them to arrest the helicopter's descent safely."

Furthermore, the report comments on the HARP review (Civil Aviation Authority, 1984):

"The report of the Helicopter Airworthiness Review Panel (HARP) of the Airworthiness Requirements Board, published in March 1984, stated that 'ground proximity warning systems

(GPWS) suitable for helicopters seem highly desirable and should be developed and used'. This view is supported"

G-BEON was fitted with an analogue RADALT which, below the set height, illuminates a "*small amber light*" with which there "*is no associated audio warning*". In addition, the "*Manual contained no instructions on the use of the decision height warning system and there was no standard practice in use by pilots."*

The report highlights the poor attention-getting qualities of the system as fitted to G-BEON, noting that:

"…the height alert system is unlikely to attract the attention of a pilot not looking at the instrument panel, because the radio altimeters are mounted low on the panel and the warning light is small."

This in turn leads to the observation that

"The lack of an audio height alert system capable of warning pilots even if they are not looking at their flight instruments is therefore judged to have been a contributory factor in this accident."

This comment highlights the need for warning modalities beyond only visual. At face value, this seems a trivial observation but it highlights the complex nature of helicopter operations; it is not possible to be certain, at any given time, where pilots' attention will be focussed (Jarvis Bagshaw Ltd., 2016).

In addition, when considering the location of the RADALT and any warning, the report notes that:

"Given the importance of the radio altimeter in offshore helicopter operations it is suggested that consideration be given to re-locating the S-61N's radio altimeter indicators to significantly reduce the head and eye movement needed to transfer the gaze between them and the outside world, and to ensure that they are fully visible to a pilot whatever his seat position."

The investigation into this accident gave rise to 8 recommendations including the following:

> *"It is recommended that:*
>
> *...*
>
> *4.2 Radio altimeters incorporating audio as well as visual decision height warning be fitted to all helicopters operating offshore as a matter of urgency.*
>
> *4.3 In the longer term, consideration be given to the development of a ground proximity warning system for helicopter use.*
>
> *4.4 The practicability of moving the S-61N's radio altimeter indicators to a position clear of the cyclic stick, and nearer the pilot's head-up field of vision, should be examined."*

The similarity of recommendation 4.2 to that issued in relation to the accident to G-BDIL is striking, with the only differences being a slight change of context ('*offshore*' versus '*around the British Isles')* and the addition of the phrase '*as a matter of urgency'*. It is the recommendations given in this accident that gave rise to the CAA mandating AVAD for offshore operations.

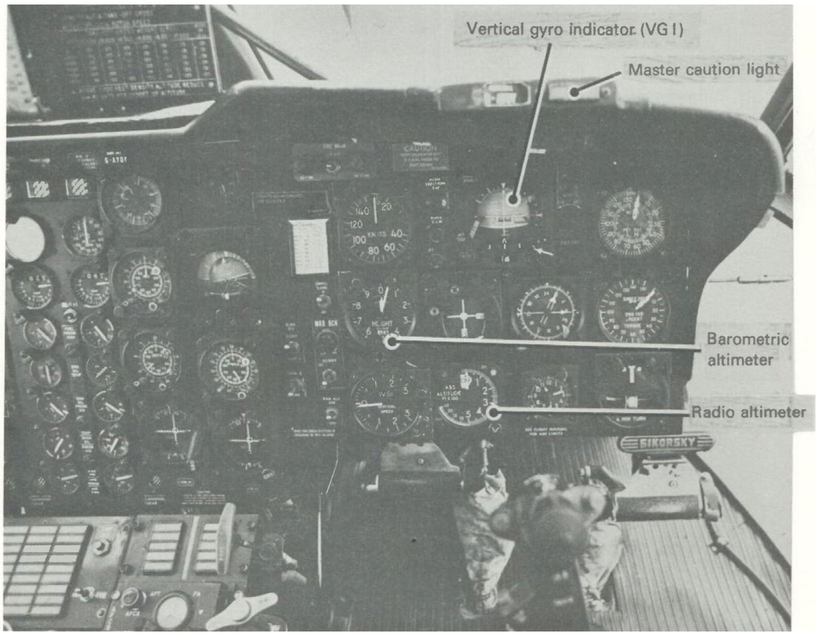

Figure A2.1 – Details of cockpit layout from (Air Accidents Investigation Branch, 1984)

A2.4 G-BHYB - 9th December 1987

Location: Near Fulmar A Oil Platform in the North Sea

Aircraft type: Sikorsky S-76A

Injuries: 2 crew (No injuries)
8 pax (No injuries)

The aircraft was conducting shuttle flights in the North Sea. On approach to the Fulmar platform from a height of about 500 feet, *"the aircraft lost all forward speed and entered a steep descent towards the sea. At a very late stage, the co-pilot managed to arrest the descent just as the aircraft touched the water."* (Air Accidents Investigation Branch, 1988)

The aircraft was fitted with AVAD alerting which provided two audio (spoken) warnings, preceded by chimes, of CHECK HEIGHT (activated by the aircraft when descending through a height selected by the pilot) and ONE HUNDRED FEET (activated automatically when passing through 100 feet). *"On this occasion, the relevant altimeter bug had been set at fractionally below 100 feet and so the '100 feet' preceded the 'Check Height' warning".*

"Replay of the cockpit voice recorder (CVR) showed that during this descent, the two automatic voice alerting device (AVAD) warnings sounded, activated by the radio altimeters, but the crew have stated that these were not heard." Based on the data presented in the report, the first chimes appear to have sounded around 2.5 seconds before the impact with the sea. The data also show that the rotor RPM started to decay, due to a large collective input, at around the same time as the chime, although the two may be unconnected; the flight crew statement suggests that it certainly was not a conscious response to the chime. Indeed, the "chimes occurred almost simultaneously with the start of the drop in rotor rpm that resulted from the rapid power demand" which, assuming a finite and not insignificant reaction time, suggests that the power application occurred before the chime sounded.

The reporting of the chimes as *"not heard"* is an extremely important finding since, in this incident, the aircraft was serviceable and although the commander suffered a temporary incapacitation, the co-pilot was still in a position to react if his attention had been captured with sufficient warning time available.

The report notes that

"The subject incident would, most likely, not have occurred had the co-pilot's altimeter bug, to which the AVAD was slaved, not been set at a height below that of the helideck. The declared reason for this usage was that the repetitive warnings, occasioned by 'bugging' a height greater than that of the helideck, were more of an irritation than a safeguard."

This is a clear reminder that any new alerting system must not be considered a nuisance by pilots if it is to avoid being defeated, worked-around or ignored.

In addition, the report concludes that one of the causes of the incident was that the *"company Operations Manual contained no procedures for the use of the Automatic Voice Alerting Device during visual approaches"*. This finding highlights the need not only to fit effective alerting devices, but also to ensure they are properly used.

The AVAD fitted to this aircraft was "capable of providing 14 different voice warnings" and the "operating company had chosen to include a "CHECK HEIGHT" warning as well as the "100 FEET" warning required by the CAA". The AVAD functionality was described in the report as follows:

"The 100 FEET message is not variable and occurs as the aircraft descends through that height, but the height at which CHECK HEIGHT occurs depends upon the height to which the relevant radio altimeter bug is selected. A switch in the cockpit allows the selection of either SINGLE PILOT or TWO PILOT operation; the former selection slaves the AVAD to only the commander's radio altimeter; the latter to both altimeters, choosing the lower of the two individual altimeter bug settings for the CHECK HEIGHT warning. At the time of the incident, TWO PILOT was selected. Finally the AVAD is fitted with an automatic inhibit facility which deactivates both warnings when the radio altimeter senses a descent rate of 5000 feet/minute or greater. This facility prevents the spurious warnings which would otherwise occur whenever the aircraft crosses the lip of the helideck.

The prime purpose of the altitude related warnings is to guard against the inadvertent 'drift down' when flying over a featureless surface, and to warn the crew of arrival at specific heights. During the very short sectors of Shuttle flights, the necessary bugging and re-bugging of the altimeters, together with the thus promoted audio warnings, was considered by the crews to be detrimental, rather than advantageous, to the safe conduct of the flight.

It was reported by several company pilots that, in order to avoid this during Shuttle flights, some co-pilots would select 100 feet on their altimeter bugs as, when landing on helidecks of greater height, the AVAD would not then function. This was the case on the incident flight. However, this is not the recognised method of avoiding such intrusive warnings: For this purpose, the equipment includes a button operated SUSPEND facility, whereby the CHECK HEIGHT message can be delayed by three minutes. The button, which is situated on the cyclic stick, may be operated repeatedly, each time restarting the 3 minute delay. Furthermore, if the selected check height is passed during the delay period, the warning will be cancelled; this facility does not apply to the 100 FEET warning. Finally, when two warnings overlap, one of the sets of chimes will not sound.

Since the incident, the company have issued a Flying Staff Instruction stating that, whilst on final approach, both altimeter bugs will be set at helideck height."

One of the report's conclusions is that *"The Automatic Voice Alerting Device was not being used in a manner advantageous to flight safety."*

The operational use of AVAD alerts is a recurring theme, with a number of accidents occurring while alerts were suspended.

A2.5 G-BDII - 17th Oct 1988

Location: Near Handa Island off the north-west coast of Scotland

Aircraft type: Sikorsky S61N

Injuries: 4 crew (2 minor, 2 none)

The Synopsis of the AAIB report (Air Accidents Investigation Branch, 1989) states that:

“Towards the end of the [SAR] search, whilst performing a hover manoeuvre, a crew member commented that the aircraft was travelling backwards very fast. The commander’s attempted recovery from this manoeuvre resulted in the aircraft striking the sea...”

While deciding where to continue their search, the commander climbed the aircraft to about 200 feet into wind. Although he later stated he only intended to slow his progress towards the cliffs ahead, he instead, unintentionally, climbed and brought it to a near hover.

As a result of the climb:

“he lost visual contact with the surface and was attempting to fly uncoupled by reference to the flight instruments only. A few seconds later, the winch operator announced “WE’RE GOING BACKWARDS VERY FAST”, to which the commander immediately replied that he was “PUTTING THE NOSE DOWN”. Less than one second later, the Automatic Voice Alerting Device (AVAD) announced that the aircraft was descending through 100 feet.”

The replay of the CVR showed that “*less than 3 seconds after the AVAD warning, the helicopter struck the water*.”

The report concluded that *“...once the descent rate and rearwards speed had been established, recovery to either level or climbing forward flight was almost certainly not possible within the 100 feet remaining.”*

The report identified three causal factors, one of which was that:

“Following the crewman’s warning, there was insufficient height remaining for the recovery to forward climbing flight which was attempted by the commander.”

In this accident, the AVAD did not provide sufficient warning time to allow the commander to recover the aircraft.

A2.6 G-TIGH - 14th March 1992

Location: Cormorant ‘A’ Platform

Aircraft type: AS 332L

Injuries: 2 crew (1 fatal, 1 minor/none)
15 pax (10 fatal, 1 serious, 4 minor/none)

The aircraft was being used in severe weather conditions (including gusts up to 55 kts, snow showers and rough seas), in place of two Bell 212 helicopters because of its higher wind limit. It was engaged in shuttling personnel from the platform to a nearby ‘flotel’, which was normally moored alongside the platform but had been moved away due to the poor weather. The AAIB synopsis in the report (Air Accidents Investigation Branch, 1993) states that:

“Climbing to a height of 250 feet and whilst turning downwind, the handling pilot, who was also the aircraft commander, reduced power and raised the nose of the helicopter such that the airspeed reduced to zero and a rate of descent built up. Once he was aware of the descent,

which was also advised by his co-pilot and the Automatic Voice Alerting Device (AVAD), he applied full power but the descent could not be arrested before the helicopter struck the sea. Down draughts and incipient Vortex Ring state may have exacerbated the situation."

This was the first accident investigation involving a civil helicopter fitted with an FDR.

After leaving the deck:

"The helicopter climbed slightly to just above 200 feet Radio Altitude at minus 29 seconds, before descending slightly to 185 feet. This activated the AVAD warning to sound chimes and then "CHECK HEIGHT", the bug had previously been set to 200 feet as indicated from the audio data. The audio data also indicated that the crew then reset the bug to 100 feet."

The helicopter then climbed to 250 ft and the airspeed began to decrease. The altitude then began to decrease and the airspeed had fallen to under 20 kts. "*The AVAD sounded chimes and a "ONE HUNDRED FEET" warning as the helicopter descended, three seconds before the end of the data; this occurred simultaneously with the warnings shouted by the co-pilot.*"

"The co-pilot's bug should, according to the OM, have been set to 300 feet and, had it been so, the 'CHECK HEIGHT' warning would have played no part in the sequence since the helicopter never achieved that height. However, the crew reaction to this warning was to reset the lower of the two Radalt bugs to 100 feet (co-incident with an already scheduled 'ONE HUNDRED FEET' warning), thereby removing the nuisance of what they believed to be an unnecessary 'CHECK HEIGHT' warning."

"The more significant warning of 'ONE HUNDRED FEET' occurred when the accident sequence was already established and the helicopter was descending through 100 feet, some four seconds before impact. Although not directly applicable to this accident, if this pre-scheduled warning height had been set at 150 feet, another four seconds would have been gained."

"The original reason for scheduling the fixed height warning at 100 feet no longer applies to UK offshore conditions. When AVAD was introduced, flights in Instrument Meteorological Conditions (IMC) permitted a minimum descent height for an offshore radar approach of 150 feet, and the AVAD warning was therefore set appropriately below this. However, as the daytime minimum for such approaches has now been elevated to 200 feet, a more appropriate scheduled warning would perhaps be set at 150 feet."

"It is therefore recommended that the CAA should discuss with helicopter operators the safety benefit of raising the AVAD fixed height warning to a more appropriate height for existing minimum descent heights."

Finding (xv) states that:

"The AVAD height warning at 100 feet occurred too late to alert the crew since by then the pilot had already made corrective control inputs in an effort to avoid the crash. A warning at 150 feet, which is more relevant to current operating limits, would have gained 4 seconds but still would not have averted the crash."

The nature of this shuttling task highlights a difficulty in the AVAD warning approach – the short distances and small heights connected with this operation meant that any alerting strategy based only on height is liable to a high nuisance rate.

A2.7 G-HAUG – 12th December 1996

Location:	Omeath, Co. Louth
Aircraft type:	Sikorsky S-76B
Injuries:	2 crew (2 fatal)

1 pax (1 fatal)

G-HAUG departed Belfast Airport to return to its home base at Ballyedmond, Co. Down. The approach to the home base was executed using a locally produced GPS-based approach procedure. Having commenced its descent, in preparation for landing at Ballyedmond, the helicopter struck mountains at 960 ft ASL. (Air Accident Investigation Unit, 1998)

The aircraft was equipped with one RADALT and this altimeter was equipped with an AVAD audio alarm that produced a triple chime, followed by a verbal warning of “ONE HUNDRED FEET”, when the aircraft descended to 100 feet above ground. This signal was fed directly into the pilots' headsets. This altimeter was also fitted with a pilot adjustable bug. When the bug was set to above 100 feet, and when the helicopter descended to the bug height, a yellow warning light in the top LH corner of the altimeter indicator was illuminated. The height output of the RADALT was also displayed on the HSI and the colour of this display changed when the aircraft descended below the set bug height.

In the accident flight:

“the radar altimeter bug, set at 160 ft, would have caused the alarm light on the indicator to illuminate less than 2 seconds before impact. The radar altimeter audio alarm sounded less than 1 second before impact. Neither of these final warnings gave enough time for terrain avoidance action.”

In addition, the report comments on the positioning of the RADALT:

“Due to the location of the radar altimeter in the lower right corner of the instrument panel in G-HAUG, the reduction in the radar altimeter indication would have been almost invisible to the PF.”

On the issue of GPWS, the report comments that:

“It was not a legal requirement to carry Ground Proximity Warning System (GPWS) on G-HAUG. Given the steepness of the terrain gradient, it is doubtful that such equipment could have given the crew a warning as they approached the mountain that would have resulted in successful avoiding action. However, Enhanced GPWS (EGPWS), if equipped with a suitable database, could possibly have given the crew sufficient warning of the terrain obstacle in front of the aircraft.”

A2.8 G-BLUN - 27th December 2006

Location:	Morecambe Bay
Aircraft type:	Aerospatiale SA365N
Injuries:	2 crew (2 fatal)
	4 pax (4 fatal)

The aircraft was flying the third of eight scheduled sectors in Morecambe Bay gas field. The routing up to the accident was Blackpool – AP1 – Millom West – North Morecambe. The report (Air Accidents Investigation Branch, 2008) notes that:

“The co-pilot was flying an approach to the North Morecambe platform at night, in poor weather conditions, when he lost control of the helicopter and requested assistance from the commander. The transfer of control was not precise and the commander did not take control until approximately four seconds after the initial request for help. The commander’s initial actions to recover the helicopter were correct but the helicopter subsequently descended into the sea.”

The aircraft was fitted with an AVAD system, routed through the radio boxes without adjustable volume. The system provides a “ONE HUNDRED FEET” aural warning when descending below 100 ft radio altitude (at a rate of less than 5,000 ft/min to avoid nuisance alerts due to helideck edge crossing ‘spikes’).

The helicopter was fitted with two radio altimeters, equipped with moveable height ‘bugs’. A single/dual selector switch was fitted. With the switch in the dual position, a “CHECK HEIGHT” aural warning would be triggered as the helicopter descended below the lowest height of the commander’s and co-pilot’s RADALT bug. In the single position, only the commander’s bug is used. The switch was found in the single position, the co-pilot’s bug was found set at 500 ft and it was not possible to determine the commander’s bug setting. On the approach to AP1 the commander stated he had set his bug at 200 ft.

SUSPEND buttons were fitted to each cyclic grip which will inhibit the “CHECK HEIGHT” warning only, for three minutes.

No AVAD calls were recorded on landing at AP1, although transition through 100 ft was rapid due to crossing onto the helideck. On the approach to Millom West, the “ONE HUNDRED FEET” call was heard on the CVR, but no “CHECK HEIGHT” call was recorded. During the approach to North Morecambe there were no AVAD-generated calls except “ONE HUNDRED FEET”.

The report notes that:

“During the three approaches, as recorded on the CVR, the commander said “JUST YOUR BUTTON TO DO” once visual with the platform. This is believed to have been a reminder to the co-pilot, to suspend the AVAD as no ‘CHECK HEIGHT’ was subsequently heard. The OM contains no guidance on the procedure and calls to be employed when suspending the AVAD warning.”

The final moments of the flight included the commander taking control of the aircraft from the co-pilot, and an exchange between them. The report states that *“Cockpit communications were calm and there were no indications of additional problems*”. The AVAD “ONE HUNDRED FEET” warning sounded 3 seconds before impact.

The report describes the difficult situation faced by the flight crew and notes of the commander that:

“It is clear that he was not expecting to take control of the helicopter; nevertheless, his initial actions in rolling the helicopter to a level attitude and reducing the pitch angle were correct. But he was now devoid of any external visual cues and became concerned for the well being of his co-pilot who appeared to be upset at being unable to control the helicopter. This distraction from his instrument scan, albeit brief, probably explains why he did not notice the increasing angle of bank to the right and the continuing descent into the sea and possibly why he did not hear the AVAD warning at 100 ft.”

The proposed, revised HTAWS alerting system would have given 35 seconds of warning under the EC225 envelope, triggering as part of the Mode 7 TT/IAS algorithm (Civil Aviation Authority, 2017a, 2017b).

One of the comments from a test flight that was conducted for comparison was that:

“Although positioned appropriately to assist the pilot with a visually conducted task such as a helipad landing or aborted take off the location did not lend itself well to be incorporated easily into a normal radial instrument flying scan.”

which led to a finding that

“The location of the radio altimeter, optimised for reference in the final stages of a visual landing on a helipad was difficult to include in the pilot’s instrument scan during a go-around.”

This conflicts directly with the recommendation made regarding RADALT position stemming from the accident to G-BEON. This is not to imply that either observation is incorrect, but rather to highlight the complex and competing demands that helicopter operations impose. In some conditions, flight with reference to the outside environment supplemented by instruments is appropriate whereas, at other times, predominantly instrument flying with some visual reference is more appropriate. Alternatively, a clear division of ‘head-up’ and ‘head-down’ flying between the flight crew may be preferred. Designing a cockpit which is ideal for all situations is extremely challenging, as the contradiction between these recommendations implies, or may even not be possible.

Figure A2.2 – RADALT position from (Air Accidents Investigation Branch, 2008)

In some ways, this accident represents a quintessential CFIT accident, albeit on recovery from a loss of control situation. This accident contains nothing exceptional with regard to the acoustic environment; conversation was described as calm, there were no alarms, and there was not a great deal of noise from the IAS. However, the descent rate was high at times, possibly nearing 4,000 ft/min, which may have induced some aerodynamic noise. Nonetheless, the final “ONE HUNDRED FEET” warning was audible on the recording. There is no evidence in the recorded flight data of a reaction to the alert by the commander.

This suggests that the alert was not detected, not perceived/ processed, or not reacted to. The benign cockpit environment suggests that the first is unlikely. Considerably more likely is that the commander’s attention was focussed elsewhere which either prevented him from perceiving, or slowed his reaction to, the aural alert. Alternatively, he may have detected and processed the alert but disregarded it. As a result, this accident strongly supports an approach of: increasing the attention-getting qualities of the alert; providing a longer warning time to allow a response; and increasing trust in the alerting system.

A2.9 G-REDU – 18th February 2009

Location: Eastern Trough Area Project (ETAP) Central Production Facility Platform

Aircraft type: Eurocopter EC225LP

Injuries: 2 crew (minor/none)

16 pax (minor/none)

The accident occurred on a scheduled flight from Aberdeen to the ETAP Central Production Facility Platform, the first of three planned sectors. The visibility was estimated as 0.5 NM and the cloud base as 500 ft. The flight crew made a visual approach to the platform *"during which the helicopter descended and impacted the surface of the sea"*.

On the accident aircraft, a Honeywell MK XXII EGPWS TAWS had been fitted to replace the AVAD system. At the time of the accident, a decision height of 150 ft had been selected by both pilots. The investigation report (Air Accidents Investigation Branch, 2011b) identified as one of the causal factors:

"The two radio altimeter-based audio-voice height alert warnings did not activate. The fixed 100 ft audio-voice alert failed to activate, due to a likely malfunction of the Terrain Awareness Warning System (TAWS), and the audio-voice element of the selectable 150 ft alert had been suspended by the crew. Had the latter not been suspended, it would also have failed to activate. The pilots were not aware of the inoperative state of the TAWS."

The operations manual of the operator of G-REDU contained an instruction that suspending the check height alert was a mandatory operation on short finals offshore.

In addition to the aural warnings, a DH visual caption is generated when the aircraft passes through the selected alert height. Because it is generated by an independent system, it would still have been presented to the flight crew despite the TAWS system failure. However, it did not prompt action to avoid the accident.

The FDR contained 25 hours of flight recordings from before the accident. It is interesting to note that the Mission Display screen (the screen on which terrain data is displayed] *"was not selected at any time during the 25 hours of data recording"*.

"The co-pilot identified the descent and announced it to the commander but no corrective action was taken" However, *"Both flight crew members were unaware of the helicopter's continued descent"*. This raises the question of whether a further alert would have helped avoid the accident. It may have prompted the commander to arrest the descent, or it may have had no effect.

Simulation of the accident suggests that the 100 ft callout would have allowed time for the helicopter to avoid the impact, albeit very narrowly. However, this assumes the warning was detected, perceived and acted upon promptly.

The investigation into this accident gave rise to 27 safety recommendations including:

"It is recommended that the Civil Aviation Authority reviews the guidance in Civil Aviation Publication (CAP) 562, Civil Aircraft Airworthiness Information and Procedures, Part 11, Leaflet 11-35, Radio Altimeters and AVADs for Helicopters, regarding the pre-set audio height warning that is triggered by the radio altimeter and may not be altered in flight, to ensure that crews are provided with adequate warning to take corrective action."

"It is recommended that the European Aviation Safety Agency reviews the frequency of nuisance warnings generated by Terrain Awareness and Warning System equipment in offshore helicopter operations and takes appropriate action to improve the integrity of the system."

"It is recommended that the Civil Aviation Authority reviews the procedures specified by commercial air transport helicopter operators as to when a crew may or should suspend a radio altimeter aural or visual height warning"

and

"It is recommended that the Civil Aviation Authority reviews commercial air transport offshore helicopter operators' procedures to ensure that an appropriate defined response is specified when a height warning is activated."

This accident prompted the work package to review HTAWS for North Sea operations, of which this report forms part.

A2.10 N2NR – 23rd October 2010

Location:	Shanlieve, Mourne Mountains, Northern Ireland
Aircraft type:	Agusta A109A II
Injuries:	1 crew (1 fatal)
	2 pax (2 fatal)

The helicopter was on a VFR flight from a private site near Londonderry, Northern Ireland, to Caernarfon Airport in Wales (Air Accidents Investigation Branch, 2011a). As the helicopter approached Newry it turned onto an easterly heading and climbed to about 2,000 ft. Some 6.5 nm later the helicopter turned onto a south-easterly track towards Caernarfon Airport, followed by small track changes to the left and right. The groundspeed throughout the flight was about 150 kt. The helicopter impacted the west face of Shanlieve.

The aircraft was fitted with a Honeywell Mk XXI unit. However, this had not been powered on in the previous year. The EGPWS AUD switch was found in the OFF position. Trial flights were conducted in a Sikorsky S-76C equipped with an EGPWS similar to that in N2NR. *"During the trial the EGPWS provided accurate and compelling warnings during the approach to Shanlieve."*

The report notes that:

"The helicopter was equipped with an EGPWS but it had not been in use at least since the replacement unit was fitted in 2009. An EGPWS has significant safety benefits when operating under Instrument Meteorological Conditions (IMC), particularly overland. However, the EGPWS is not a requirement for helicopter operation and the alerts it provides in VMC can become considered as 'nuisance' alerts, as the system will frequently initiate "TERRAIN" alerts due to the proximity of ground which is already visible to the pilot. For this reason the EGPWS may be selected off and examination of the data by the manufacturer showed that the system in N2NR had not been powered up since the particular unit had been installed in late 2009. Had the system been in use on the accident flight, the presence of the high ground ahead of the helicopter should have initiated a "TERRAIN" alert activated by the Shanlieve feature."

A2.11 C-GQCH – 23rd July 2011

Location:	St. John's, Newfoundland and Labrador, 200 nm E
Aircraft type:	Sikorsky S-92A
Injuries:	2 crew (No injuries)
	5 pax (No injuries)

The aircraft was conducting a flight from a floating production, storage and offloading vessel (FPSO). After engaging the go-around mode of the automatic flight control system during the departure, the helicopter's pitch attitude increased to approximately 23° nose-up while in IMC and a rapid loss of airspeed occurred. After reaching a maximum altitude of 541 feet above sea level the helicopter began descending towards the water in a nose-high attitude at low indicated airspeed. The descent was arrested 38 feet above the surface of the water (Transportation

Safety Board of Canada, 2013). The helicopter departed and flew to St. John's. The helicopter's transmission torque limits were exceeded during the recovery. The helicopter was fitted with a Honeywell Mk XXII EGPWS.

"As the aircraft began descending … the first officer recognized the deviation…and began making attitude and airspeed deviation calls. The captain, whose attention was focused on the attitude indicator, acknowledged these deviation calls and indicated that corrective action was being taken… as the helicopter descended through 454 feet asl (437 feet radar altitude), the helicopter's enhanced ground proximity warning system (EGPWS) began making an automated "Don't sink" aural alert to the pilots, and remained on for 11 seconds. The rate of descent at the time was 1375 fpm. While descending, the first officer made attitude and airspeed calls at least 2 more times and also advised the captain to lower the nose of the helicopter. The captain acknowledged these calls and advised that corrections were being made."

"the captain increased collective pitch; both engines increased power, reaching a maximum torque of 132% on engine No. 1 and 129% on engine No. 2. Despite the increased power outputs, the main rotor rpm (Nr) decreased"

"At the same time, the EGPWS aural alert changed from the "Don't sink" alert to the landing gear aural warning ("Too low gear"), due to the fact that the landing gear was in the up position at a radar altitude below 150 feet above ground level (agl)."

Finally, "*the descent was arrested 38 feet above the water*". A total of 32 seconds elapsed from the time the helicopter reached 541 feet asl until the time it was established in the hover over the sea.

"In this occurrence, Mode 3 of the EGPWS detected the inadvertent descent and issued the "Don't sink" aural alert and yellow caution on the PFD. The inadvertent descent commenced as the airspeed reached a maximum value of 67 KIAS, with the gear in the up position. In addition, Mode 4 issued the "Too low gear" aural alert, as well as the corresponding caution and warning indications on the ADI and the master warning panel, when the helicopter descended below 150 feet asl with the gear still in the up position."

Following this incident, two other similar incidents were found, which had not been reported, "In one instance, the helicopter descended to an altitude of 31 feet above sea level (asl) and in the other, there was a main rotor gearbox torque exceedance."

"As seen in this occurrence and in the 2 previous occurrences identified in this report, the transition to and from an offshore facility resulted in an inadvertent descent at low airspeed and a high rate of descent. Fortunately, in all 3 occurrences, the flight crew was able to arrest the descent prior to impact with the water. The S-92A's EGPWS provides no warning of an inadvertent descent at airspeeds below 40 KIAS when the landing gear is down. As a result, there is increased risk of CFIT during those phases of flight."

The report also notes that:

"…in order to realize the full benefit of an EGPWS, flight crews must be taught the appropriate CFIT avoidance procedure and have opportunities to practice this procedure. Despite the fact that Cougar Helicopters had established a CFIT avoidance procedure in its SOPs, the procedure was not carried out in response to the "Don't sink" aural alerts. In this occurrence, the collective was increased approximately 16 seconds after the aircraft began descending. As a result, the helicopter developed an excessive rate of descent and came within seconds of impacting the water. If there are delays initiating the CFIT avoidance procedure in response to an EGPWS alert, there is an increased risk of a CFIT."

The last sentence reinforces the need for immediate corrective action to be taken by flight crews. However, this also requires the flight crew to detect, perceive and believe the alerts being presented to them.

A2.12 G-WIWI – 3rd May 2012 (Incident)

Location:	Peasmarsh, East Sussex
Aircraft type:	Sikorsky S-76C
Injuries:	2 crew (none) 2 pax (none)

The report notes that on a flight from Battersea to Peasmarsh, the third of four planned legs:

"The helicopter descended towards the tops of trees following a discontinued night approach to a private landing site in conditions of reduced visibility and low cloud". (Air Accidents Investigation Branch, 2014a)

The incident aircraft was fitted with a Honeywell Mk XXII EGPWS.

On the approach the commander "assessed that the helicopter was too high and too fast to continue the approach straight in" and elected to conduct an orbit. As the turn progressed:

"The EGPWS recorded issuing 'CAUTION TERRAIN' then 'WARNING TERRAIN' alerts, as the helicopter's height reduced towards 100ft agl."

"Neither pilot recalled hearing the 'CAUTION TERRAIN' and then 'WARNING TERRAIN' alerts registered by the EGPWS computer, or seeing the accompanying visual indication".

The aircraft then began a further descent, and the commander recognised that the helicopter was approaching the treetops at which point he initiated an aggressive go-around. *"During the go-around, both pilots heard the EGPWS 'TAIL TOO LOW' warning. The minimum radio altitude recorded in this portion of the flight was 2 ft."* CVR data from the flight was not available and so it was not possible to establish whether the alerts sounded, or were detectible.

The report notes that:

"No technical reason was identified for EGPWS warnings to be recorded without being presented to the pilots. If the audio inhibit switch had been selected prior to the approach, the audible warnings would not have been announced to the pilots, but neither pilot recalled that the inhibit switch had been selected.

Both pilots recalled hearing the 'tail too low' warning, issued slightly more than 20 seconds after the 'warning terrain'. The earlier audible alerts may have also been announced, but not 'heard' by the pilots, because of inattentional deafness or the effects of overload on the pilots' capacity to process auditory cues."

"The 'WARNING TERRAIN' warning triggered when the helicopter was flying at slightly less than 80 KIAS and descending at approximately 500 fpm. The helicopter's descent ceased and it entered a climb over the eight seconds following the 'warning terrain'. It is possible either that the flight crew did assimilate and react to the EGPWS warnings, but later did not recall doing so, or that the commander became aware of the close approach to terrain and reacted to avoid it at the same time the warning was issued."

Test flights were conducted to observe the manner in which alerts were presented. The report notes that in G-WIWI:

"EGPWS visual cues appeared not to be especially attention-getting being small and presented only as illuminated script in small lit push-buttons"

Figure A2.3 – RH instrument panel of G-WIWI showing GPWS visual alert (amber – circled red) from (Air Accidents Investigation Branch, 2014a)

The operations manual of the operating company contained information about the response required from pilots on hearing an EGPWS alert. This differs from instructions given in the operations manual of an example offshore operator, possibly reflecting the difference in missions or a difference in philosophy.

The helicopter was fitted with an audio inhibit switch, which was described in the EGPWS manufacturer's pilot guide:

*"... an **"Audio Inhibit"** switch can be installed. This momentary activated switch allows the pilot to turn off all MK XXII audio warnings for 5 minutes. Resetting the switch will also restore the audio immediately. The Audio Inhibit switch is intended for EMS and SAR operations where the aircraft may be operating very close to terrain. Under normal operations this switch **should never be needed**. The visual warnings are not inhibited. If you find that you need to use this switch during your normal operations please contact [the manufacturer]"*

The report also notes that "The manufacturer had no record of a request from the operator to use the switch during normal operations."

As part of its final conclusions, the report notes that *"Although the EGPWS issued warnings that the helicopter was approaching contact with the ground, the flight crew were not aware of these warnings."*

A2.13 G-WNSB – 23rd August 2013

Location: Sumburgh

Aircraft type: AS332L2

Injuries: 2 crew (1 serious)

16 pax (4 fatal, 3 serious)

The aircraft was making a non-precision approach into Sumburgh airport. The Minimum Descent Altitude (MDA) for the approach was 300 ft and the AVAD bugs were set accordingly (Air Accidents Investigation Branch, 2013). The plan was for the commander to fly the approach while the co-pilot monitored the vertical descent profile.

“At 2.0 nm the co-pilot advised the commander that the height at 1 nm should be 390 ft. The co-pilot made a call at 100 ft above the MDA (300 ft); the commander acknowledged. There was then an automated audiocall of “CHECK HEIGHT” [at 300ft]*, an acknowledgement by the commander, and then a comment by the co-pilot to draw the commander’s attention to the airspeed. At this time the helicopter’s airspeed was 35 kt and reducing. Shortly thereafter, there was a second automated audio call of “CHECK HEIGHT”, followed by a “100 FEET” automated call two seconds before impact with the surface of the sea.*

At some point the commander saw the sea, but he was unable to arrest the helicopter’s descent and it struck the surface”

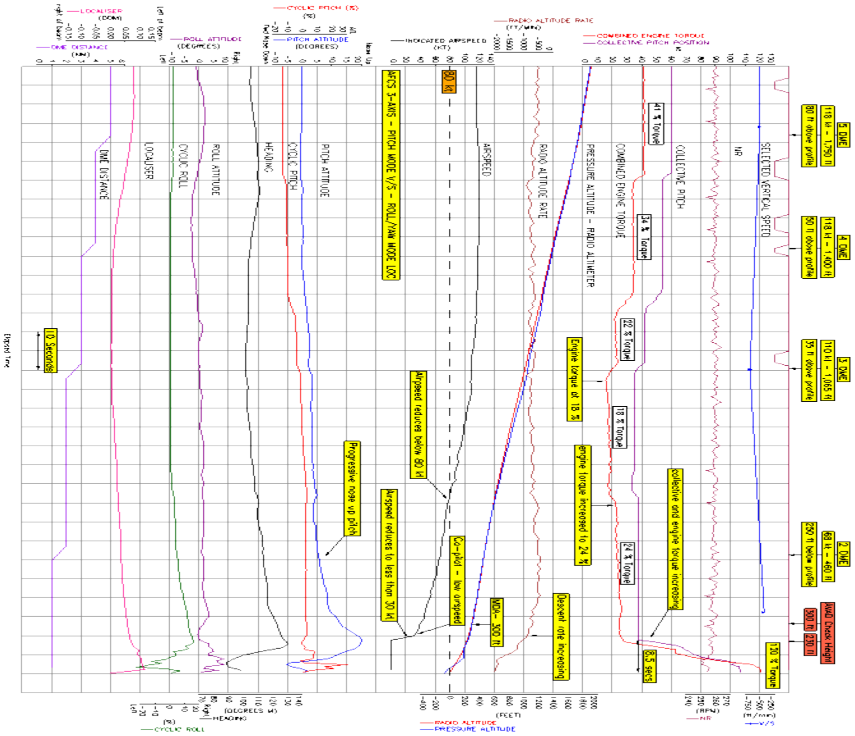

Figure A2..4 – G-WNSB Flight Data from (Air Accidents Investigation Branch, 2013)

The flight data shows that engine torque and collective pitch began to increase coincident with the second AVAD CHECK HEIGHT call at 230 ft. It is extremely unlikely that the response is due to the call at 230 ft. It is possible that the input was in response to the initial AVAD call at 300 ft, although it may also have been triggered by the co-pilot’s call or the sight of the sea after emerging from cloud.

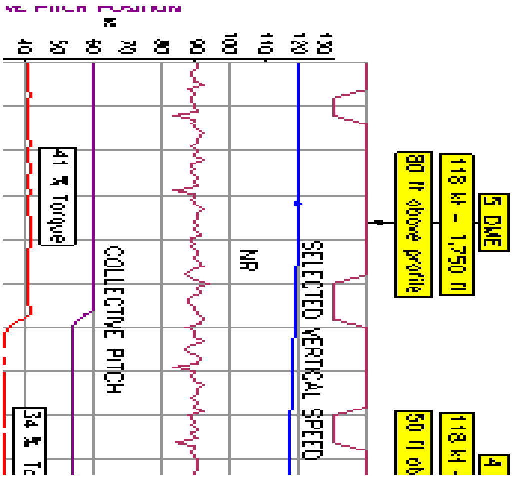

Figure A2..5 – Flight data from (Air Accidents Investigation Branch, 2013)

G-WNSB was not equipped with a TAWS, nor was there any requirement for it to be fitted. A laboratory simulation was performed by Honeywell to establish if a TAWS alert would have been generated. Figure A2.6 below, taken from the report, where the alerts would have sounded had a TAWS been fitted. The report concluded that "*at a height of 179 ft, about 5.7 seconds before G-WNSB struck the surface of the sea, a Mode 1 'sink rate sink rate' audio alert would have been generated".*

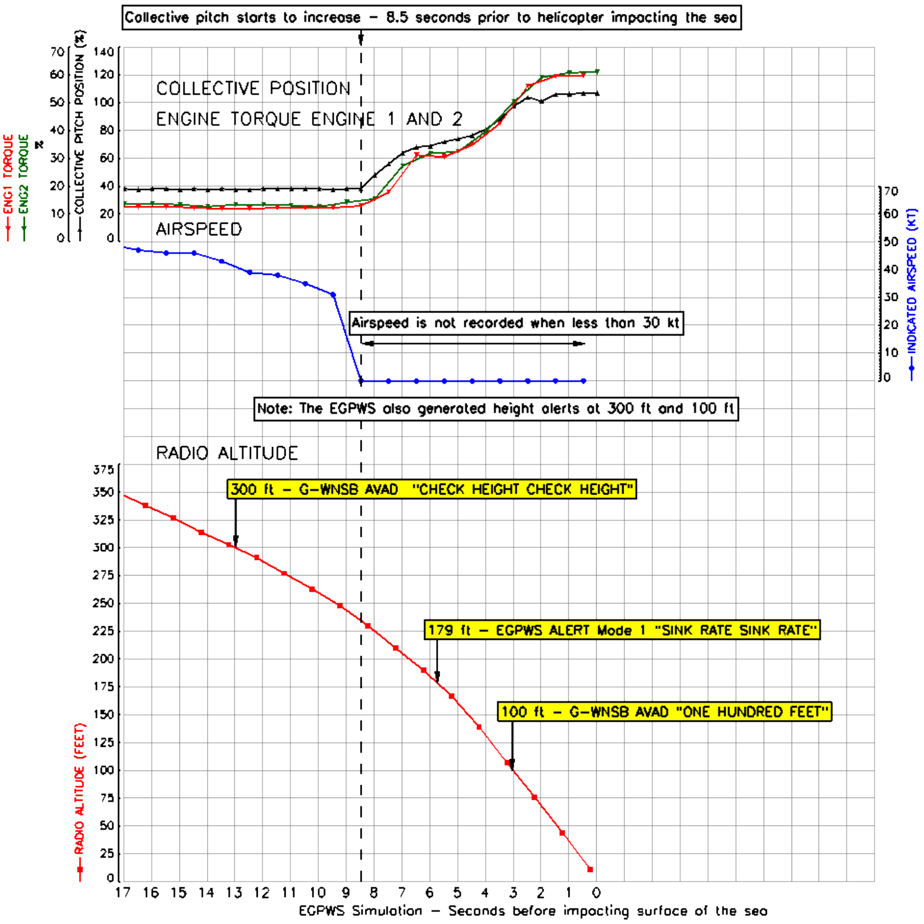

Figure A2.6 – EGPWS Simulation

The report also references the work on alert envelopes reported in CAP 1538 and includes analysis using the new envelopes described in Section 2.4, shown in Figure A2.7. Based on this simulation using the torque / airspeed mode, a warning time of 11.5 seconds was produced (1% line) or 10.5 seconds (0.1% line).

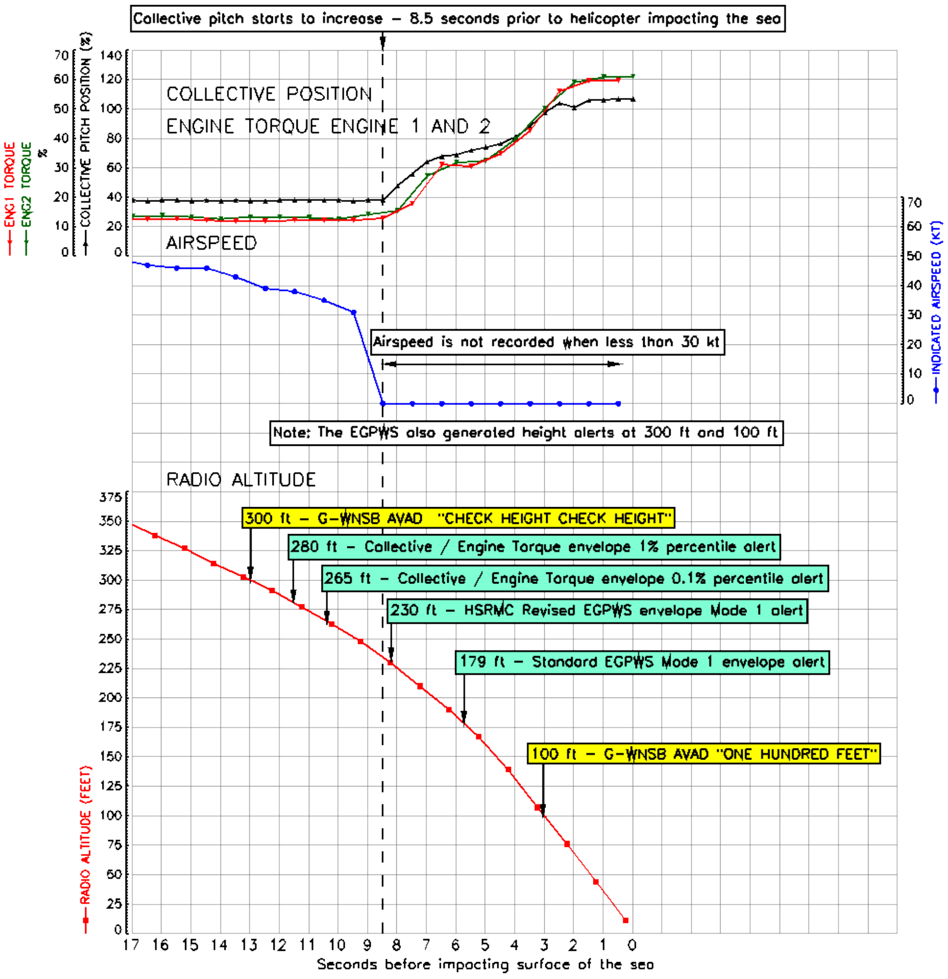

Figure A2.7 – Simulation of HTAWS alerts for the accident to G-WNSB

A2.14 OY-HJJ – 6th November 2013 (Incident)

Location:	Clipper South Gas Field, North Sea
Aircraft type:	Eurocopter EC155B1
Injuries:	2 crew (no injuries) 8 pax (no injuries)

The AAIB synopsis (Air Accidents Investigation Branch, 2014b) states that:

"Shortly after takeoff from an off-shore platform at night, the helicopter entered a series of extreme pitch excursions which resulted in the airspeed reducing below 20 kt, followed by a descent. The flight crew were eventually able to recover to normal flight. The helicopter had descended to within approximately 50 feet of the sea surface. It was found that the helicopter's flight path was consistent with inappropriate control inputs."

Following a pitch excursion and a loss of airspeed, the co-pilot twice warned the commander they were descending, although the commander did not acknowledge the calls. The aural voice alert "ONE HUNDRED FEET" sounded three seconds after, and the co-pilot said "CHECK HEIGHT". The commander later reported that he heard the automatic aural alert "ONE HUNDRED FEET". The report does not state whether any RADALT bugs were set.

It is arguable whether or not the alert saved this aircraft. It is certainly true that the aircraft was in a very serious situation in the period around the time of the alert; 36 degrees nose-down leading to a descent rate of 2,900 ft/min with an IAS of around 90 kts at a height of around 100 ft. However, it is not possible to say whether the alert brought about the corrective action or was merely coincident with it.

3.2.15 G-LBAL - 13th March 2014

Location:	Near Gillingham Hall, Norfolk
Aircraft type:	Agusta Westland AW139
Injuries:	2 crew (fatal) 2 pax (fatal)

The aircraft was planned to conduct a night departure from a private landing site. The AAIB synopsis (Air Accidents Investigation Branch, 2015) states that:

"The helicopter departed from a private site with little cultural lighting at night and in fog. Although the commander had briefed a vertical departure, the helicopter pitched progressively nose-down until impacting the ground."

In the poor weather conditions, the commander suffered a loss of situational awareness, possibly due to somatogravic illusion. The co-pilot twice issued an ambiguous prompt about the pitch attitude, "NOSE DOWN", to which the commander may have responded by applying more forward cyclic, but in any case the aircraft continued to descend.

Shortly before impact, a Mode 3 "Don't Sink" alert was issued but not completed. The report notes that:

"The helicopter's EGPWS provided a warning immediately before impact, but not in sufficient time for the pilots to react. The limitations of EGPWS in rotary wing operations are understood and work by the UK CAA and others is seeking to optimise the system's functionality. The rapid

onset of the abnormal flight profile, such as in this case, may mean that sufficiently prompt alerting is not achievable without unacceptable rates of nuisance alerting during safe flights."

A2.16 EI-ICR – 14th March 2017

Location:	Black Rock, Co. Mayo
Aircraft type:	Sikorsky S-92A
Injuries:	4 crew (fatal)

The aircraft was conducting a SAR mission when it impacted Black Rock. The aircraft was fitted with a Honeywell MK XXII EGPWS although the island and the lighthouse were not in the terrain database. The LOW ALTITUDE switch was engaged at the time of the accident. The Rad Alt provided a callout of "ALTITUDE, ALTITUDE" 26 seconds prior to the initial impact. The Commander identified the reason for the aural alert as a small island below the helicopter. The investigation continues, and EGPWS is part of ongoing activities.

A2.17 Summary of accidents

Table 2.1 overleaf gives a summary of the accidents reviewed. As with the description, the causation and description are considerably more complex than is represented in the table. The purpose is to summarise some of the salient detail around the AVAD and TAWS alerting.

Reg	Type	Alert sounded?	Alert detected?	Warning time	New algorithm	Notes
G-BIJF	B212	Not fitted	-	-	-	Disorientation and loss of control
G-BDIL	B212	Not fitted	-	-	-	Insufficient evidence
G-BEON	S61	Not fitted	-	15s* (100ft) 24s* (160 ft)	24s (4B)	Inadvertent drift down
G-BHYB	S76	Yes	No	2.5s	No data	Not heard, touched water
G-BDII	S61	Yes, but corrective action underway	Unknown	3s	No data	Too late to avoid
G-TIGH	AS332	Yes (100)	Unknown	3s	17s (3B)	Already made corrective action
G-HAUG	S76	Yes (100)	Unknown	<1s	n/a	Onshore accident
G-BLUN	SA365	Yes (100)	No response	3s	35s (TT/IAS)	Not heard?
G-REDU	EC225	No - TAWS u/s	-	4.5s* (100ft) 7s* (160 ft)	16s (1 & 2A)	Failed to sound
N2NR	A109	No (switched off)	-	-	-	Onshore accident
C-GQCH	S92	Yes (DON'T SINK and TOO LOW GEAR)	Unknown	11s	tbc	
G-WIWI	S76	Yes (TERRAIN and TAIL)	No Yes	- -	- -	Onshore incident – TERRAIN not heard
G-WNSB	AS332	YES (CHECK HEIGHT x2 and 100)	1st CH ack.	2s 3.5*/5*	13s (TT/IAS)	100 too late
OY-HJJ	EC155	Yes (100)	Yes	?	tbc	
G-LBAL	AW139	Started (DON'T SINK)	?	Immediately before impact	3s? (3B) 2s? (3A)	Too late