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Distance Discrimination Thresholds During Flight Simulation in a Maritime Environment

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ABSTRACT

The *Aeronautical Design Standard 33* (ADS-33) prescribes a set of manoeuvres and limits for assessing the handling qualities of military rotorcraft. In developing an ADS-33 maritime addendum, the Aircraft Maintenance and Flight Trial Unit (AMAFTU) and Defence Science and Technology Organisation (DSTO) have collaboratively worked towards the definition for a maritime hover manoeuvre. Initial testing to validate this proposed manoeuvre in the DSTO Air Operations Simulation Centre (AOSC) flight simulator has proved problematic. Although pilots could successfully complete a land-based hover within performance limits in the flight simulator, they experienced difficulty in maritime conditions. Pilots were unable to perceive small distance changes in the AOSC simulated maritime environment in some conditions.

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Distance Discrimination Thresholds During Flight Simulation in a Maritime Environment

Executive Summary

The *Aeronautical Design Standard 33* (ADS-33) prescribes a set of manoeuvres and limits for assessing the handling qualities of military rotorcraft. In developing an ADS-33 maritime addendum, the Aircraft Maintenance and Flight Trial Unit (AMAFTU) and Defence Science and Technology Organisation (DSTO) have collaboratively worked towards the definition for a maritime hover manoeuvre.

Initial testing to validate this proposed maritime hover manoeuvre in the DSTO Air Operations Simulation Centre (AOSC) flight simulator has proved problematic. Although pilots could perform a land-based hover in the flight simulator, they experienced difficulty in maritime conditions, far exceeding the usual degradation in performance observed when shifting from actual flight trial to simulated flight trial. In accordance with the proposed Maritime Hover performance limits (Appendix A), pilots were expected to maintain plan position within 3 ft of the hover's origin, whilst also maintaining heading and altitude. This was to be done with reference to a buoy 50 m away. In the DSTO AOSC Maritime Hover trial, plan position could not be maintained under any conditions.

It was suggested that perceptual limitations were the reason for poor performance in the DSTO AOSC Maritime Hover trial. A short experiment was required to test whether or not a change of 3 ft between the aircraft and the buoy, at distance of 50 m and at a constant altitude, was large enough to be detected. The experiment described in this paper was conducted for this purpose. Its aim was to determine the minimum distance the aircraft must move from its original position for a change in position to be perceived. This minimum distance was defined as the distance discrimination threshold.

For both high and low sea states, the thresholds were found to be larger than the 3 ft 'desirable' performance limit. If a pilot is required to maintain plan position within a limit that is too small to be detected at a perceptual level, it will only be by chance than the hover is successfully completed. This is not adequate assurance for testing a potential manoeuvre in the simulator.

To rectify the problems pilots experience when performing the hover in the simulator, 3 solutions may be employed. These are as follows:

- Improve simulator technology to include more of the fine visual cues a pilot expects.

- Specify how far from the buoy the pilot should hover. A 3 ft movement backwards or forwards will change the image projected onto the screen by a larger proportion at closer distances, decreasing the threshold for discrimination.
- Review the maritime hover performance limits (for plan position in particular) and widen them to account for the degraded performance observed in the simulator.

A combination of these options may prove to be the most effective solution.

The results of this experiment suggest that the thresholds for distance discrimination are situated very close to or beyond the 3 ft 'desirable' limit of the maritime hover task. This is true in the absence of any task other than identifying distance. It is therefore unreasonable to expect pilots to maintain the current 'desirable' and sometimes 'adequate' distances within the AOSC simulator. While simulator improvement continues, a review of these limits, or alternatively a prescription for the precise distance to hover from the buoy, should be considered. This will ensure that limits for the maritime hover are a true reflection of the aircraft's ability to perform the manoeuvre and that such an ability is not impeded by a pilot's inability to perceive small distance changes in the AOSC simulated maritime environment.

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Plan position
A helicopter's position in the horizontal plane (See Appendix A).

Maritime Hover performance limits
The limits prescribed for the successful completion of the maritime hover manoeuvre. The limits are demarcated into limits for 'desirable', 'adequate' and 'inadequate' performance.

D_b (Baseline distance)
At baseline, the aircraft sits 50 m from the buoy. D_b represents this baseline or central distance. It does not represent an actual location or coordinate of the aircraft.

D_v (Variation distance)
D_v represents the distance between the aircraft and the buoy, when that distance varies from D_b. It does not represent an actual location or coordinate of the aircraft.

Distance discrimination threshold
The minimum distance the aircraft has to move towards or away from the buoy for that movement to be detected.

Rotor wash
The downwards blast of air from the turning blades of an operating rotor craft. Over water the rotor wash makes specific patterns that can be of use in judging altitude and plan position.

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1. Introduction

The *Aeronautical Design Standard 33* (ADS-33) (US Army Aviation and Missile Command, 2000) prescribes a set of manoeuvres and limits designed to assess the handling qualities of military rotorcraft, independent of their size or role. All current ADS-33 Mission Task Elements (MTE) were developed to be land-based. Examples of current ADS-33 MTEs include hover, pirouette and slalom manoeuvres. Although several maritime addendums have been proposed as ADS-33 MTEs, none at present has been included. Previous work completed by the Aircraft Maintenance and Flight Trials Unit (AMAFTU) and DSTO in development of a Maritime Hover MTE is provided in DSTO-TN-0936 (Manso & Arney, 2010). Continuing this effort, a DSTO Air Operations Simulation Centre (AOSC) trial was undertaken in December 2010 to further assess this proposed maritime hover manoeuvre. The AOSC simulator flight models are of a sufficient fidelity to allow for the development and assessment of MTEs such as the maritime hover. Testing manoeuvres in a flight simulator such as in the AOSC can reduce costly flight time and allow researchers to assess cognitive workload factors and their impact upon task performance.

During the development of the DSTO AOSC Maritime Hover trial, the maritime hover manoeuvre required altitude, heading and plan position (see glossary for definition) be maintained within certain prescribed performance limits (Appendix A; Table A1). Maintenance had to occur throughout a two minute low altitude hover over open water, at a distance of approximately 50 m (Figure A1), a distance which was estimated by test pilots as being approximately the distance used during actual flight trials. In particular, a pilot was required to maintain plan position within 3 ft of the hover's point of origin to achieve performance levels within the 'desirable' performance bracket. The manoeuvre therefore required, among other skills, an ability to interpret small movements, of a minimum of 3 ft, at a distance of 50 m.

The DSTO AOSC Maritime Hover trial was completed to confirm whether the maritime hover manoeuvre could be performed, and therefore tested, in the AOSC simulator. The cockpit setup for the DSTO AOSC Maritime Hover trial is shown in Figure 1. Pilots were required to execute the hover while maintaining a position 50 m from a buoy. Multiple sea states (see Appendix B, Table B1 for sea state information) were tested. In the lead-up to the trial, preliminary testing with a helicopter pilot was carried out in the AOSC flight simulator to validate the trial's experimental parameters, including the hover distance of 50 m and the hover performance limits. The preliminary testing was problematic. With the DSTO AOSC Maritime Hover trial experimental parameters, the pilot was unable to achieve 'desirable' or 'adequate' performance in the AOSC flight simulator, in any of altitude, heading or plan position. Plan position was particularly problematic. Helicopter plan position was lost within the first 30 seconds of the two minute interval. This was true for all sea states tested.

The DSTO AOSC Maritime Hover trial compared hover performance in simulated land-based and maritime environments. The ground-course hover was generally completed within 'adequate' performance limits. Although pilot performance is expected to degrade between a flight trial and its simulator equivalent, the discrepancy between performance degradation in the simulated ground-course and maritime hover manoeuvres was considerable. Performance in the simulated maritime hover was far worse than in its simulated ground-course equivalent. The maritime hover appeared to be far more difficult to complete than a land-based hover. Feedback obtained after the trial showed that the pilots experienced greater difficulty maintaining position in higher sea states, as reflected in their performance. The pilots also reported that it was more difficult to identify drift away from the buoy than towards it.

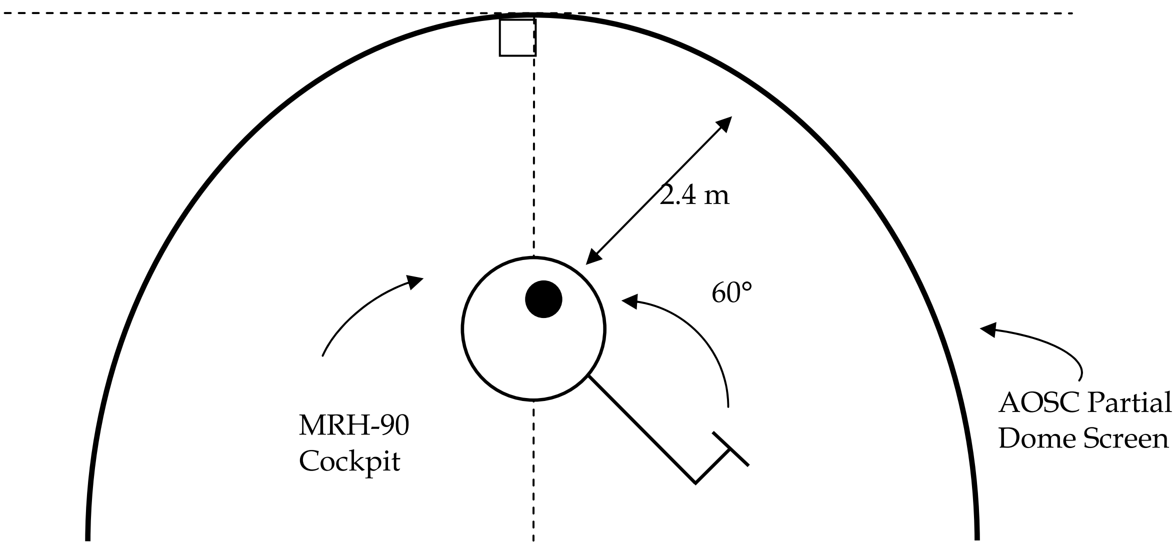

Figure 1 Cockpit position in AOSC partial dome flight simulator for the DSTO AOSC Maritime Hover trial

These problems and discrepancies presented a problem for the outcomes of the DSTO AOSC Maritime Hover trial. Although the recommendation could have simply declared that the task was unachievable in the AOSC simulator, more information about why this was the case was required. It was also necessary to determine if and how the task could be altered (for example with less stringent limits) so that it could be completed.

During an actual maritime hover flight trial, a pilot will rely on a host of feedback cues to determine and maintain their position over water. Some cues are motion based - the vestibular system detects self-movement through the rotations and accelerations of the head during flight, providing important motion feedback cues. Some cues are visual – the horizon, currents in the water, and in particular the aircraft's 'rotor wash' (see glossary) indicate change in position. Both types are important for adjusting and maintaining position during actual flight (Berger, Terzibas & Beykirch, 2007). Unfortunately, several of these cues cannot currently be replicated in the AOSC simulator. The AOSC flight simulator is not motion-based, and the image generator is in constant development. Therefore, only a subset of visual cues is available at any give time. At the time of the DSTO AOSC Maritime Hover trial work-up, the most pertinent and useful of the available cues were the line of the horizon and the position of the clouds in the sky and their reflections in the water.

Without familiar visual cues, changes in distance between the aircraft and the buoy may become difficult for a pilot to evaluate. This is particularly true if a pilot relies heavily on these cues. With only a subset of the usual cues available, the task of completing the maritime hover in the AOSC flight simulator becomes less focused on a pilot's skill and technique. Instead, it becomes focused on their ability to judge distance at a perceptual level.

At a distance of 50 m, a 3 ft movement backwards or forwards in the virtual environment changes the image of the buoy projected onto the simulator screen by approximately 3 mm top-to-bottom and 2 mm left-to-right. The buoy also moves in the visual field by a matter of millimetres. The magnitude of image size-change and movement may be too small to be perceived sitting 2.4 m from the screen (Figure 1). The cues mentioned earlier complement the perceptual systems in actual flight trials. They indicate to the pilot that they have drifted, even when the size of the image of the buoy has not changed. Without these cues, these additional indicators of movement are not at hand. The pilot's ability to perceive distance change could be compromised. This reduction in perceptual ability, resulting from the non-availability of expected visual cues in the AOSC flight simulator, could be part of the explanation for the degradation in performance observed in the simulated maritime environment.

Fine perception is important to the maritime hover, or indeed, any manoeuvre requiring continuous monitoring of slight movements. To maintain a fixed position while hovering, a pilot must continuously compensate for drift (Berger, Terzibas & Beykirch, 2007). If a pilot is unable to perceive small distance changes, he/she will be unable to perceive slight amounts of drift. If drift is not registered, the pilot may attempt to maintain a position that is offset by an error that compounds for the duration of the trial. An inability to perceive a 3 ft movement, caused by a lack of available cues in the simulator, will decrease the likelihood that the manoeuvre is successfully completed.

It was realised during the DSTO AOSC Maritime Hover trial that it would be beneficial to determine if perceptual limitations were the reason for poor performance. A short experiment was required to test whether or not a change of 3 ft between the aircraft and the buoy, at distance of 50 m and at a constant altitude, was large enough to be detected. If it was not large enough to be detected, some aspect of the maritime hover, the simulation environment or the DSTO AOSC Maritime Hover trial experimental design had to change. The experiment described in this paper was conducted for this purpose.

Determining thresholds for stimulus detection requires the application of classic psychophysical methods. A detection threshold refers to the minimum stimulus change required for that change to be detected. A great deal of research on detection thresholds has been performed for stimuli of varying type, quality and strength (Gescheider, 1997). Of interest for the DSTO AOSC Maritime Hover trial is the distance the aircraft has to move from its initial position, in the horizontal plane, for that movement to be identified.

As a stimulus moves towards or away from the eye, the size of its image projected onto the retina changes. As the stimulus moves closer, the image becomes larger. Similarly, as it moves away, the image becomes smaller. However, in a flight simulator, the image is always the same distance from the eye. Thus, for the DSTO AOSC Maritime Hover trial, the detection threshold for movement towards or away from the buoy concerns the detection threshold for changes in the size of the projected image of the buoy. In an environment where all simulated environmental stimuli are removed, it would be possible to determine if changes to the image of the buoy of a matter of millimetres are smaller than the threshold for size detection. If changes of this size are smaller than the threshold for image size change detection, they are beyond perceptual abilities. Elements of the environment that might affect perception would have to be removed. Results from such research would be useful to determine whether or not the difficulties with the DSTO AOSC Maritime Hover trial are purely perceptual.

During the DSTO AOSC Maritime Hover trial, there could have been factors other than perceptual limitations contributing to the degraded performance. Simulated flight trials are more complex than pure detection threshold test environments. Pilots could reliably complete a simulated hover over land within 'adequate' performance limits, with their performance showing the amount of degradation to be expected when shifting from actual flight trial to simulated flight trial. As stated earlier, a greater level of degradation was observed for the simulated maritime environment. Differentiating the simulated land environment from the simulated maritime environment is the availability and reliability of visual cues and the movement of the target with wave motion. Perceptual limitations might therefore be only one of several factors contributing to poor distance discrimination in the AOSC dynamic simulated maritime environment. Visual cue availability and target motion could also be contributing factors.

Consequently, the experiment described in this paper was not designed as a pure detection threshold experiment. Instead, the aim of the experiment was to determine how far an aircraft has to move from its initial position, in the presence of simulation environment cues, for a change in distance to be perceived. By establishing this threshold for distance discrimination in the AOSC simulator, it will be determined whether the current maritime hover limits are just very difficult to discern or are in fact unobservable. Furthermore, a recommendation may be made regarding the appropriateness of the 'desirable' and 'adequate' limits.

When estimating distance in a simulator or during actual flight trials, given adequate weather conditions, certain visual cues will always be useful (Berger, Terzibas & Beykirch, 2007). The horizon is such a cue. The position of a target relative to the horizon changes as the aircraft moves back and forth, and if maintaining a constant altitude, can indicate distance to the target. Similarly, the horizon indicates changes in pitch and roll as it moves in the pilot's visual field (Berger, Terzibas & Beykirch, 2007). Equally, visual elements of the environment such as wave movement can hinder distance perception. Yaw changes are difficult to gauge in the maritime environment due to the absence of distant objects (Berger, Terzibas & Beykirch, 2007). These cues and distractions in the AOSC simulator (horizon line, wave motion, clouds and cloud reflections, lack of distant objects) will always be present when flying the maritime hover manoeuvre. It is acknowledged that any threshold for distance detection that is determined while these cues are present will be contingent upon these cues remaining in the environment.

Based on observations from the DSTO AOSC Maritime Hover trial and associated pilot feedback, the hypotheses for the experiment were as follows:

1. Participants would be able to discriminate smaller distances in lower sea states due to the smaller wave movement and more static available visual cues.
2. Participants would be able to discriminate smaller distances for cases where the aircraft moved towards the buoy rather than when it moved away.
3. For both high and low sea states, and for both closer and farther distances, the 3 ft 'desirable' performance limit would be smaller than the distance discrimination threshold in the AOSC simulated maritime environment, for the DSTO AOSC Maritime Hover trial experimental parameters.

2. Method

2.1 Participants

The participants for this experiment were 10 male and 7 female DSTO employees ranging from 22 to 39 years of age. The participants were permitted to wear glasses if required.

2.2 Equipment

The DSTO AOSC flight simulator (predominantly the MRH-90 cockpit and partial dome) were the main components used for the experiment. The partial dome supports a 6-channel projector system, stitching 6 separate images to create a 200 degree horizontal field-of-view, 104 degree vertical field-of-view, 1200x1600 (per projector) resolution image. The AOSC comprises a fixed based simulator, including five degree-of-freedom medium fidelity avionics and flight model. The MRH-90 cockpit is a full-scale cockpit. The participants were seated in the right seat of the cockpit, facing the front window. The cockpit was angled at minus 60 degrees to the normal of the partial dome (Figure 1). The buoy was visible out the right-hand window, in accordance with the configuration of the DSTO AOSC Maritime Hover research. The experimenters were seated in the simulation control room with intercom communication to the participant in the cockpit.

2.3 Procedure

In accordance with the DSTO AOSC Maritime Hover trial, the buoy and aircraft were placed in open water with no landforms visible. The aircraft was initially placed 50 m south of the buoy. This 50 metre distance was defined as the baseline distance D_b. D_b was chosen in accordance with the DSTO AOSC Maritime Hover trial prescribed hover distance. Throughout the experiment, the aircraft was moved along the north-south axis, depicted in Figure 2 by the dotted line. The only object in the field of view of the participant was the buoy, which had actual dimensions of 3.05 m by 7.56 m. The simulated buoy was modelled from a real buoy, and had appearance and dimensions as shown in Figure 2. The blue wavy line depicts the water level.

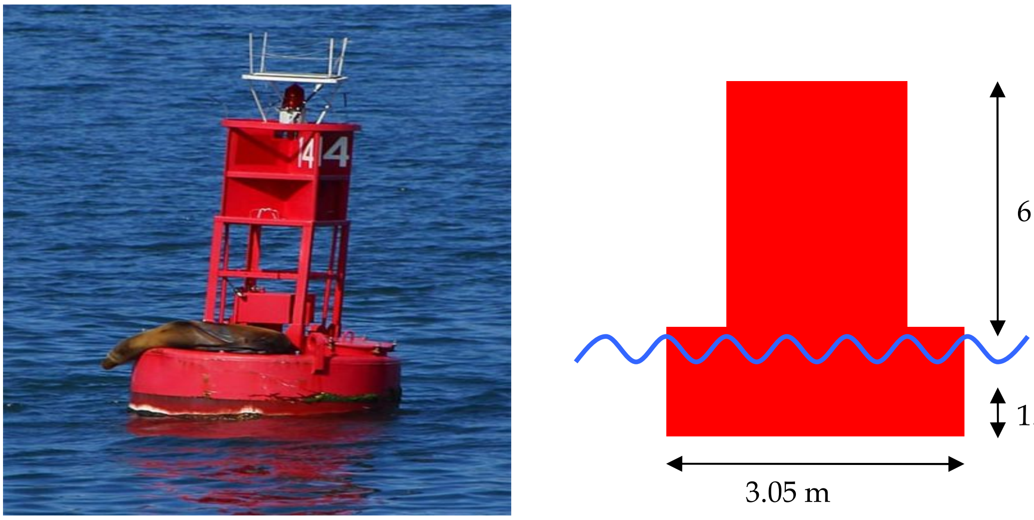

Figure 2 Buoy appearance and dimensions

While the buoy remained stationary, the position of the aircraft varied between 0 and 100 m south of the buoy. Any aircraft position, for which the distance between the aircraft and buoy varied from D_b, was denoted as D_v. The positions chosen for D_v are referred to as 'data points'. The differences between D_b and D_v ranged from 0 to 50 m. Table 1 and Figure 4 show the values for D_b and D_v at the chosen data points. Figures C1 and C2 in Appendix C show the same information. The values for D_v were to be compared to D_b and identified as 'closer' or 'farther'.

The values for D_v were determined using the equation given in Figure 3, for x values from 1 to 18. This method was chosen as it was assumed that the furthest distances from D_b would be easily identified as being closer or farther, and that the threshold would lie somewhere close to D_b. With this assumption, and by clustering data points around D_b, it was hoped that the interval the threshold lies within would be narrowed. The values determined using this equation are shown in Table 1. The distances of the aircraft from the origin and from the buoy are shown respectively in Figures C1 and C2.

$$y = \begin{cases} 50 + \dfrac{50}{2^{x-1}} & 1 \leq x < 10 \\ 50 + \dfrac{50}{2^{18-x}} & 10 \leq x \leq 18 \end{cases}$$

Figure 3 Equation for determining data points

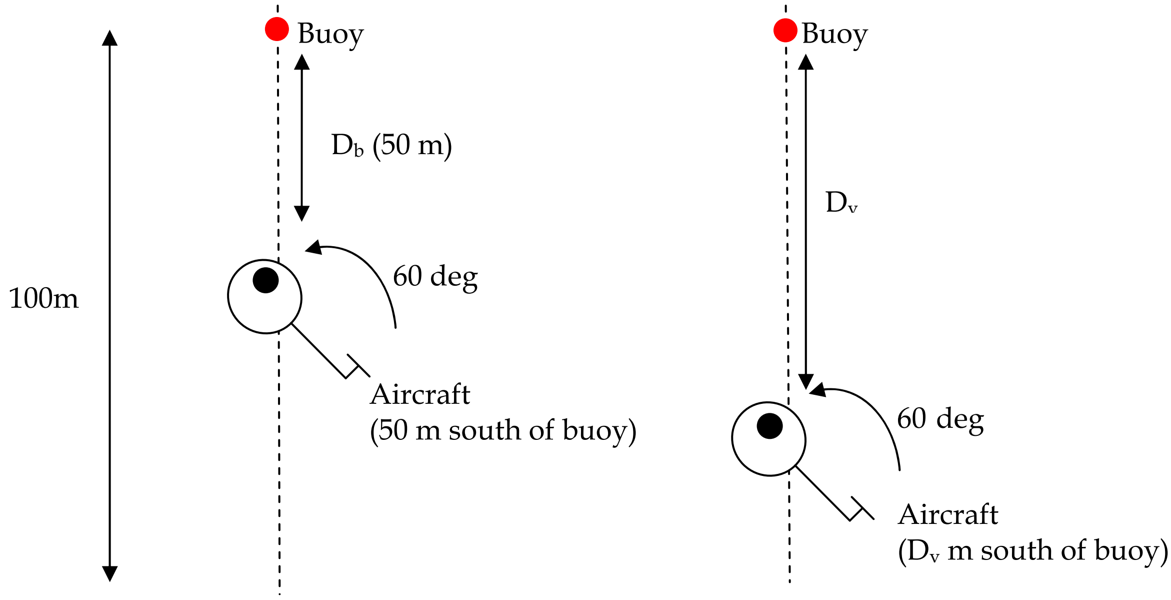

Figure 4 Birds eye view of buoy and aircraft positioning in D_b and D_v positions

Gescheider (2007) describes the classical psychophysical technique, the Method of Constant Stimuli, in which stimuli of varying strength or magnitude are evaluated against a single constant stimulus. A variation of the Method of Constant Stimuli was used for this experiment. The participants were seated in the aircraft as shown in Figure 1. An image of the buoy at D_b (50 m away) was projected onto the simulator screen for 10 seconds. The image was removed and replaced with a grey screen for two seconds, followed by a view of the first variation distance, D_{v1}, also shown for two seconds. The participant was required to identify whether D_{v1} was 'closer' or 'farther' than D_b. Refer to Figure 5 for sample images of 'farther', baseline and 'closer' buoy distances (though the experiment employed a realistic buoy, modelled on the buoy in Figure 2). Once they had responded, the grey screen was shown again, followed by D_b, then the grey screen, and finally D_{v2}, each for two seconds. Once again the participant was asked to identify whether D_{v2} was closer or farther away than D_b. This process was repeated until all variation distances had been presented. The variation distances were randomised for presentation for each participant. The participants were only permitted to respond with 'closer' or 'farther'.

The participants were presented with two sets of data points on different sea states. The first was Sea State 1, characterised by a smooth and glassy ocean with little or no wave movement. The second was Sea State 4, characterised by constant wave movement of 1.25 to 2.5 m. Further Sea State information is provided in Appendix B. The Sea State 1 condition was presented first, followed immediately by the Sea State 4 condition. In the AOSC, the centre of the buoy's base is fixed to a position just below the surface of the water. The rest of the buoy is free to move with wave movement. As such, the buoy tilted with the motion of the waves but did not move from its fixed position.

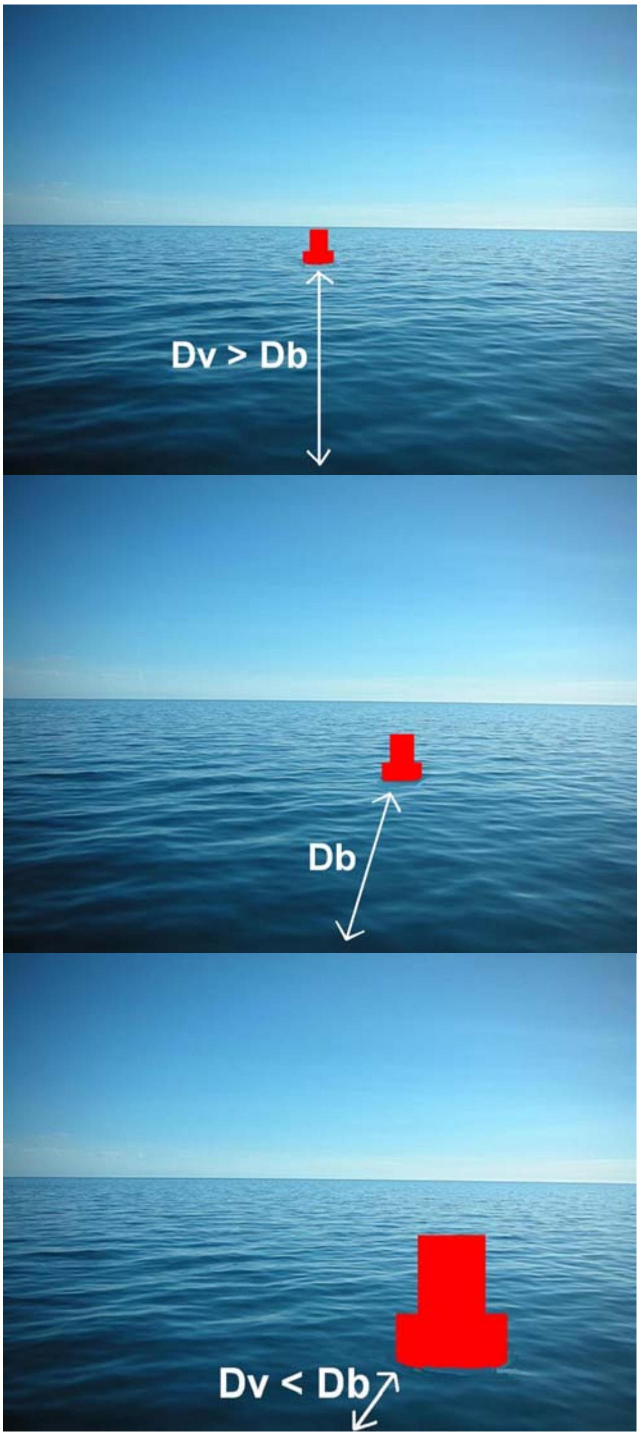

Figure 5 *Out-the-window views of buoys in $D_v > D_b$ ('farther'), D_b (baseline) and $D_v < D_b$ ('closer') positions respectively*

This methodology was chosen to replicate the cognitive processes of a pilot executing flight test trials in the simulator. The grey screen was presented between image presentations to replicate the break in visual perception experienced when a pilot glances away from the buoy to observe his/her instruments or other elements in the environment. It was also presented to prevent correct identification occurring simply because of the sudden movement of the buoy in the visual scene when different distances were presented.

Table 1 Data point information

Data Point	D_v (m)	D_b – D_v (m)	Correct Response
1	0	50	Closer
2	25	25	Closer
3	37.5	12.5	Closer
4	43.75	6.25	Closer
5	46.88	3.13	Closer
6	48.44	1.56	Closer
7	49.22	0.78	Closer
8	49.61	0.39	Closer
9	49.80	0.20	Closer
10	50.20	-0.20	Farther
11	50.39	-0.39	Farther
12	50.78	-0.78	Farther
13	51.56	-1.56	Farther
14	53.13	-3.13	Farther
15	56.25	-6.25	Farther
16	62.5	-12.5	Farther
17	75	-25	Farther
18	100	-50	Farther

3. Results

Paired sample t-tests[1] were conducted on the mean response for each data point paired with the 100% correct response, to determine whether the mean response for those data points was significantly different from the correct response. This was conducted for both sea

[1] The t-test is a statistical test used to identify how dissimilar two populations are. The t-score is the statistic calculated by performing a t-test. The p-value indicates how significant the results were, or how confident we can be that the two populations are different. The generally accepted cutoff for a p-value is 0.05 or less, or that we can be 95% confident that our populations are different. In this case, the populations were the participants' responses for each of the data points (each was a separate population), compared with two fictional populations - the first in which every person responded correctly (100% accuracy), and the second in which the participants responded with 50% accuracy (the level of accuracy we can assume if each person is randomly guessing). The standard deviation for a data point is represented by 'σ', and denotes how much the data tend to vary from the mean.

states. Paired sample t-tests were also conducted to compare the mean response for each data point with the 50% correct mark, to determine the data point at which the mean response was no longer correct more often than would be achieved from guessing. The proportions for each data point of participants giving 'farther' as their response are shown in Figure 6.

For Sea State 1, participants responded significantly worse than perfect for data points 9 ($t=-2.58$, $p<0.05$), 10 ($t=4.24$, $p<0.01$), 11 ($t=2.95$, $p<0.01$) and 12 ($t=2.95$, $p<0.01$) (see Table 2). For Sea State 1, none of these data points were significantly more accurate than the 50% mark - data points 9 ($t=1.81$, $p=.09$), 10 ($t=0.24$, $p=0.82$), 11 ($t=-1.23$, $p=0.24$), and 12 ($t=-1.23$, $p=0.48$) were all non-significant (see Table 3). Participants showed perfect discrimination for data points 1, 2, 3, 4, 5, 15, 16, 17 and 18 in Sea State 1.

For Sea State 4, participants responded significantly worse than perfect for data points 7 ($t=-2.95$, $p<0.01$), 8 ($t=-2.58$, $p<0.05$), 9 ($t=-3.35$, $p<0.01$), 10 ($t=5.42$, $p<0.01$), 11 ($t=7.21$, $p<0.01$), 12 (t=-, $p<0.05$) and 13 ($t=-2.58$, $p<0.05$) (see Table 4). For Sea State 4, the following data points were not significantly more accurate that the 50% mark - data point 7 ($t=1.23$, $p=0.24$), data point 8 ($t=1.81$, $p=0.09$), data point 9 ($t=0.72$, $p=0.45$), data point 10 ($t=1.23$, $p=0.24$), data point 12 ($t=-0.72$, $p=0.48$) and data point 13, ($t=-1.23$, $p=0.24$) (see Table 5). Data point 11 was significantly different from the 50% mark, $t=2.46$, $p<0.05$, but fell below the 50% line, that is, participants were responding worse than if they were merely guessing. Participants showed perfect discrimination for data points 1, 2, 3, 4, 16, 17 and 18 in Sea State 4.

Table 2 Paired t-tests comparing Sea State 1 data points against 100% correct mark. Perfectly discriminated data points are excluded.

	t	σ	p
Data Point 6	-1.85	0.39	0.83
Data Point 7	-1.85	0.39	0.83
Data Point 8	-1.46	0.33	0.16
Data Point 9	-2.58	0.47	<0.05
Data Point 10	5.41	0.49	<0.01
Data Point 11	2.95	0.49	<0.01
Data Point 12	2.95	0.49	<0.01
Data Point 13	1.46	0.33	0.16
Data Point 14	1.00	0.24	0.33

Table 3 Paired t-tests comparing Sea State 1 data points against 50% correct mark. Perfectly discriminated data points are excluded.

	t	σ	p
Data Point 6	3.40	0.39	<0.01
Data Point 7	3.40	0.39	<0.01
Data Point 8	4.74	0.33	<0.01
Data Point 9	1.81	0.47	0.09
Data Point 10	0.24	0.51	0.82
Data Point 11	-1.23	0.49	0.24
Data Point 12	-1.23	0.49	0.24
Data Point 13	-4.75	0.33	<0.01
Data Point 14	-7.5	0.24	<0.01

Table 4 Paired t-tests comparing Sea State 4 data points against 100% correct mark. Perfectly discriminated data points are excluded.

	t	σ	p
Data Point 5	-1.85	0.39	0.83
Data Point 6	-1.85	0.39	0.83
Data Point 7	-2.95	0.49	<0.01
Data Point 8	-2.58	0.47	<0.05
Data Point 9	-3.35	0.51	<0.01
Data Point 10	5.41	0.49	<0.01
Data Point 11	7.21	0.44	<0.01
Data Point 12	3.35	0.51	<0.01
Data Point 13	2.95	0.49	<0.01
Data Point 14	1.00	0.24	0.33
Data Point 15	1.00	0.24	0.33

Table 5 Paired t-tests comparing Sea State 4 data points against 50% correct mark. Perfectly discriminated data points are excluded.

	t	σ	p
Data Point 5	3.40	0.39	<0.01
Data Point 6	3.40	0.39	<0.01
Data Point 7	1.23	0.49	0.24
Data Point 8	1.81	0.47	0.09
Data Point 9	0.71	0.51	0.48
Data Point 10	1.23	0.49	0.24
Data Point 11	2.50	0.44	<0.05
Data Point 12	-0.71	0.51	0.48
Data Point 13	-1.23	0.49	0.24
Data Point 14	-7.5	0.24	<0.01
Data Point 15	-7.5	0.24	<0.01

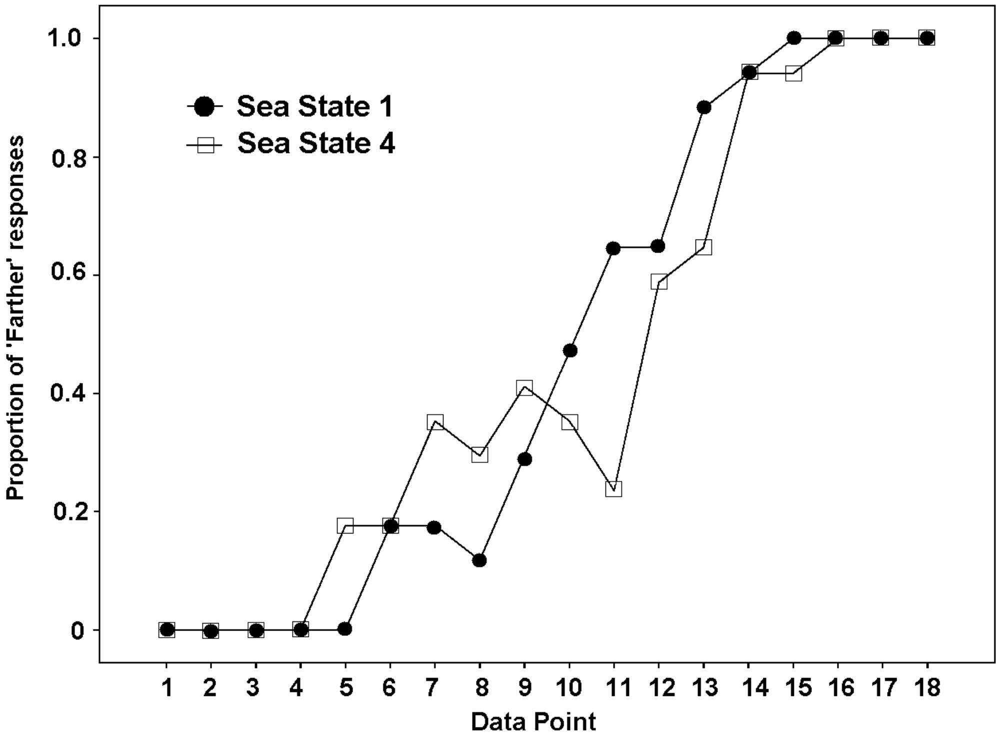

Figure 6 For each data point, proportion of participants giving 'Farther' as their response

Paired samples t-tests were performed for pairs of data points that were equidistant from D_b (for example, Data points 5 and 14 are both 3.125 m from baseline, but Data Point 5 is 3.125 m closer and Data Point 14 is 3.125 m farther). From the two sea states, only one data point was significantly different from its pair. Sea State 4 Data Point 11 was significantly less correctly responded to than Data Point 8, $t = 3.11$, $p<0.01$. The following pairs of data points were no different from one another: 1 and 18; 2 and 17; and 3 and 16. The results for the other pairs of data points are shown in Tables 6 and 7. Figure 7 shows the percentage of correct responses for data for Sea States 1 and 4.

Table 6 Paired t-tests comparing Sea State 1 data points equidistant from D_b

'Closer' Data Point	'Farther' Data Point	t	σ	p
Data Point 5	Data Point 14	1.00	0.24	0.33
Data Point 6	Data Point 13	-0.57	0.43	0.58
Data Point 7	Data Point 12	1.00	0.73	0.33
Data Point 8	Data Point 11	1.46	0.66	0.16
Data Point 9	Data Point 10	1.17	0.83	0.26

Table 7 Paired t-tests comparing Sea State 4 data points equidistant from D_b

'Closer' Data Point	'Farther' Data Point	t	σ	p
Data Point 4	Data Point 15	1.00	0.24	0.33
Data Point 5	Data Point 14	1.00	0.49	0.33
Data Point 6	Data Point 13	1.14	0.63	0.27
Data Point 7	Data Point 12	0.37	0.66	0.72
Data Point 8	Data Point 11	3.11	0.62	<0.01
Data Point 9	Data Point 10	1.73	0.56	0.10

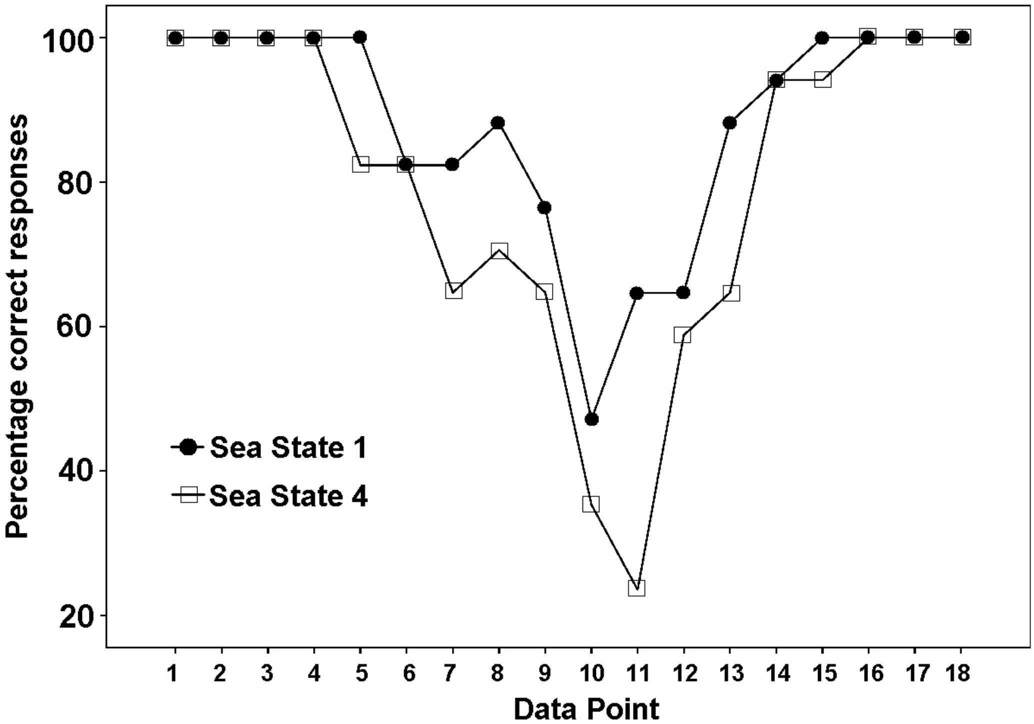

Figure 7 For each data point, percentage of correct responses

Paired sample t-tests for equivalent Data Points from the two different sea states were performed. The response for Data Point 11 was significantly worse in Sea State 4 than Sea State 1. No other data point pair was significantly different. The results from these t-tests are shown in Table 8. Data Points 1, 2, 3, 4, 6, 14, 16, 17 and 18 yielded the same results regardless of Sea State.

Table 8 Paired t-tests comparing equivalent Sea State 1 and Sea State 4 data points

Data Point	t	σ	p
Data Point 5	1.85	0.39	0.08
Data Point 7	1.38	0.53	0.19
Data Point 8	1.38	0.53	0.19
Data Point 9	0.70	0.70	0.50
Data Point 10	0.70	0.70	0.50
Data Point 11	2.75	0.62	<0.05
Data Point 12	0.37	0.66	0.72
Data Point 13	1.73	0.56	0.10
Data Point 15	1.00	0.24	0.33

Data fitting using the Weibull cumulative distribution function (Weibull, 1951) was applied to the means data plotted in Figure 6 to find the underlying psychometric function (s-curve) to fit the data. Data points 1 and 18 were excluded so the curve could be fitted. The equations for the curve fitted to the data are given in Figure 8. Figure 9 and 10 show the plots of these curves. For Sea State 1, the 25, 50 and 75% cumulative probabilities occur at x = 49.55, 50.34 and 50.97 m respectively. For Sea State 4, the 25, 50 and 75% cumulative probabilities occur at x = 49.05, 50.77 and 52.17 m respectively.

Sea State 1: $$y = 1 - e^{-(x/50.68)^{55.68}}$$

Sea State 4: $$y = 1 - e^{-(x/51.50)^{25.54}}$$

Figure 8 Fitted Weibull equations for Sea State 1 and Sea State 4 fitted curves

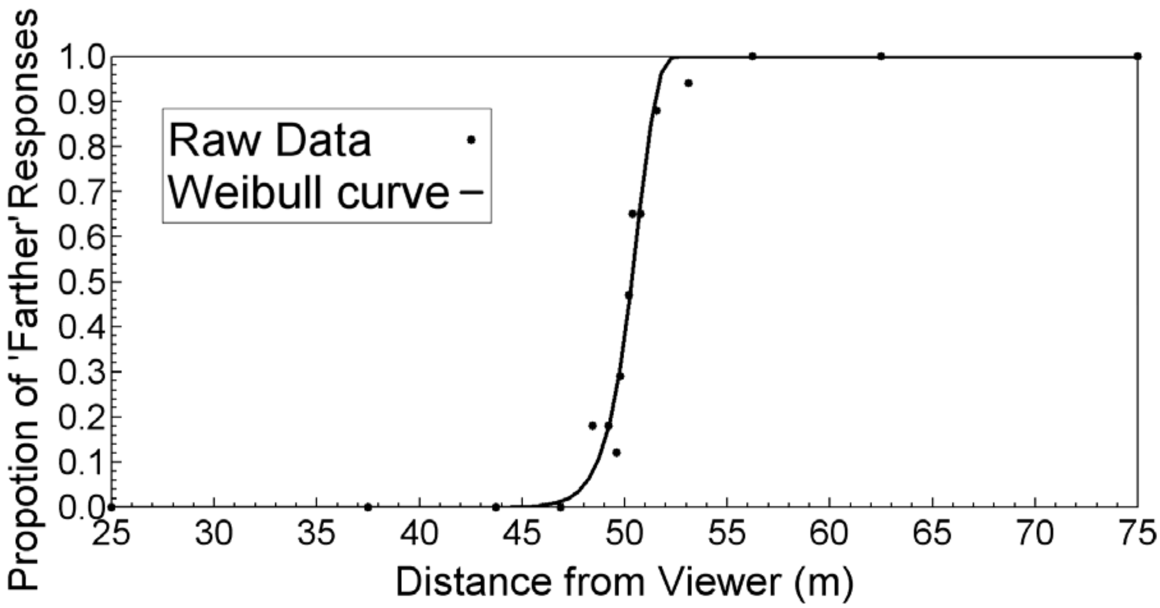

Figure 9 *Fitted Weibull curve for Sea State 1 responses*

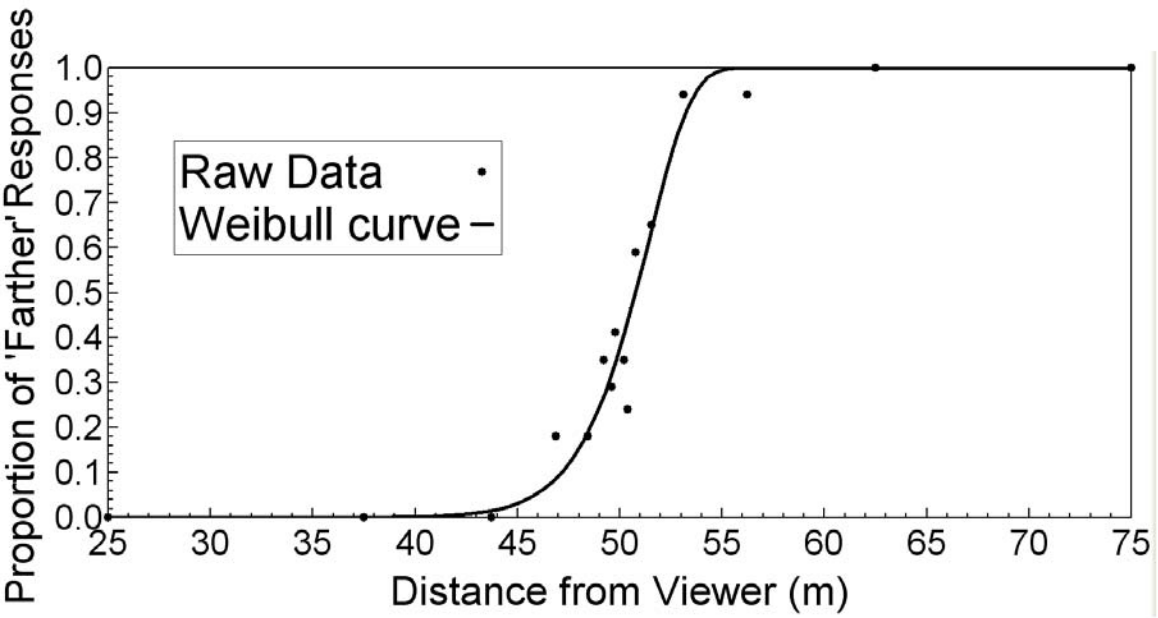

Figure 10 *Fitted Weibull curve for Sea State 4 responses*

4. Discussion

The results for this experiment indicate four intervals in which thresholds for distance discrimination lie in the AOSC flight simulator. For each sea state, there is one threshold for discriminating distances closer than the 50 m baseline distance, and one for distances farther than baseline. When determined for Sea States 1 and 4, these thresholds may be compared to the 'desirable' and 'adequate' performance limits of the maritime hover task. It may then be shown whether the distances the limits prescribe are, in fact, too small to be reliably perceived in the simulator.

4.1 Thresholds

4.1.1 Sea State 1

For Sea State 1, for conditions in which the aircraft is closer to the buoy than D_b, the threshold for distance discrimination in the AOSC flight simulator appears be 0.45 m. That is, the aircraft must move at least 0.45 m towards the buoy for that movement to be identified by the pilot. As 3 ft, the limit for 'desirable' amounts of aircraft movement, is equal to 0.91 m and is larger than this threshold, a pilot can be reasonably expected to perceive a movement of 3 ft towards the buoy in Sea State 1.

For distances farther from the buoy than D_b, the threshold for distance discrimination for movement away from the buoy in the AOSC flight simulator appears be 0.97 m. The aircraft must move a distance of at least 0.97 m away from the buoy for that change in distance to be correctly identified. The 3 ft 'desirable' performance limit is less than this threshold, hence it cannot be expected that a pilot identify a 3 ft movement away from the buoy. A pilot should be able to identify a movement of the 'adequate' distance of 6 ft (1.83 m) in Sea State 1.

4.1.2 Sea State 4

For Sea State 4, for conditions in which the aircraft is closer to the buoy than D_b, the threshold for distance discrimination in the AOSC flight simulator appears to be 0.95 m. The aircraft must move at least 0.95 m towards the buoy for that movement to be identified by the pilot. The 'desirable' performance limit of 3 ft (0.91 m) is less than this threshold, hence it cannot be expected that a pilot identify a 3 ft movement towards the buoy in the experimental conditions. A pilot should, however, be able to perceive a movement of 6 ft (1.83 m, the 'adequate' distance) towards the buoy.

For distances farther from the buoy than D_b in Sea State 4, the threshold for distance change identification in the AOSC flight simulator appears to be 2.17 m. The aircraft must move away from the buoy at least 2.17 for that change in distance to be correctly identified. The 3 ft 'desirable' performance limit is less than this threshold, hence it cannot be expected that a pilot identify a 3 ft movement away from the buoy. The 'adequate' performance requirement of 6 ft (1.83 m) is also smaller than the threshold, so we also cannot assume that someone will be able to correctly identify a movement of 6 ft away from the buoy.

During the experiment, it became apparent that the thresholds for distance discrimination were not mirrored about Data Points 9 and 10 (the centre data points). For Sea State 1, as stated above, for closer distances the threshold is 0.45 m. For farther distances, it is 0.97 m. A similar bias is apparent for Sea State 4. For closer distances, the threshold is 0.95 m and for farther distances it is 2.17 m. These results suggest that it is more difficult to discriminate distance when the distance between the participant and the target is increasing, and are in accordance with pilot feedback stating that it is easier to identify drift towards the buoy than away from it. However, comparing data points that were equidistant from D_b showed no significant difference, except for Sea State 4 data points 8 and 11. Thus, although the magnitudes of the thresholds appear to indicate a trend towards poorer performance when judging further distances, this is not explicitly shown by the data. Further testing with a larger sample size may reveal a significant difference in performance for 'closer' and 'farther' distances.

Pilots indicated after preliminary testing for the DSTO AOSC Maritime Hover trial that it was easier to maintain plan position in the lower sea state as they were able to use static environmental elements as cues to their position relative to the buoy. Examples of environmental elements that were mentioned included the reflection of the clouds on the water, and the position of the buoy relative to the line of the horizon. When there was considerable wave movement, the pilots found it very difficult to use these same cues to judge the distance. Pilots reported that the Sea State 1 condition presented, in essence, a static environment in which visual cues could be used to judge distance as they would in a static land environment. However, as above, the results of this experiment do not reinforce pilot feedback. No significant degradation in performance was found for any data point except Data Point 11. Nevertheless, observing Figure 6, the trend once again appears to be towards poorer performance judging distance in a higher sea state. Once again, testing a larger number of participants in future work may reveal a significant difference.

Pilot reports indicating greater ease in maintaining position in the AOSC Sea State 1 environment is contrary to feedback from actual flight trials, which suggests that that Sea State 1 actually provides the fewest visual cues and is the hardest sea state in which to maintain plan position. In higher Sea States, wave motion and visible currents can actually be of assistance when judging distance. In the simulator this outcome is not reproduced - Sea State 1 appeared to have smaller thresholds for distance discrimination, both for closer and farther distances, even if this difference was not significant. Examining the available cues may give some indication as to why this might be. Cloud reflections – though present in actual flight test environments – are not as reliably static in an actual maritime environment as in the simulated maritime environment. In the simulated environment they are a false cue, highlighting a problem with performing the task in the AOSC flight simulator – if cues that are readily used in actual flight trials (such as rotor downwash and spume patterns) are not present in the simulated environment, and other cues that do not exist in flight trials are used instead, pilots must be completing the task using some alternative method. The implications of this must be considered. The ecological validity of the maritime hover study – that is, the ability to compare the AOSC simulator findings to pilots completing the task in actual flight trials (Shadish, Cook & Campbell, 2002) - may be compromised if cues comparable to these flight trials are not provided.

4.2 Implications

In Sea State 1, for farther distances, and in Sea State 4, for both closer and farther distances, a pilot will not be able to perceive a movement of 3 ft. If a pilot is required to maintain plan position within a limit that is too small to be detected at a perceptual level, it will only be by chance than the hover is successfully completed. This is not adequate assurance for testing a potential manoeuvre in the simulator.

In those cases where the threshold is smaller than, but very close to, the 3 ft 'desirable' performance limit, other cognitive processes, active during aircraft operation, may interfere with perception. If the limit is only 0.46 m from the perceptual threshold, as is the case for Sea State 1 closer distances, any additional workload would only have to interfere with task performance to the extent that an additional 46 cm (0.92% of the total distance from the buoy) goes unnoticed for the 'desirable' limit to become undetectable. Performing a maritime hover, which requires aircraft operation whilst maintaining altitude and heading, could provide sufficient workload to degrade performance. Furthermore, task complexity for the maritime hover may be increased by the missing or false visual cues in a flight simulator. If a pilot is required to maintain plan position within a limit that is very close to the threshold for distance discrimination, the likelihood that the hover will be successfully completed will also be low, given the complexity of the full hover task.

4.3 Caveats and Future Work

Presenting the baseline distance only once, instead of between each data point, could extend the study to increase external validity. In actual flight trials, pilots will only view their initial distance momentarily before having to compare it to their subsequent two minutes of hover position. Slight amounts of drift that will inevitably occur may not be registered, and hence, for the remainder of the two minutes, the pilot may attempt to maintain a position that is offset by a significant error that compounds for the duration of the trial. It is suspected that this would increase task difficulty, and therefore increase the threshold for distance discrimination. Alternatively, the buoy could be presented continuously drifting, allowing the pilot utilise to the usual dynamic drift cues experienced when fixating on the buoy. It is suspected that this would also reveal a different threshold.

Unfortunately, it was not feasible to use only Navy pilots as participants for this experiment. Having had the training and experience of using subtle environmental cues to judge their position, it is expected that Navy pilots would have a greater ability to judge distance in a dynamic maritime environment. However, the cues in the AOSC dynamic simulated maritime environment are limited. The fine visual cues that might place a pilot at an advantage when judging distance are simply not present. Without these cues, the advantage a pilot should enjoy does not exist. Though a pilot may have a greater ability to judge distance in the presence of subtle environmental cues, without such cues, the task becomes merely perceptual instead of skill-based.

Ultimately, even in a task where workload is minimised, perceptual thresholds for distance discrimination lie close to performance limits. Allowing for some human error and accounting for switching attention as other aspects of the maritime hover are attended to, it becomes increasingly likely that the pilot will drift outside of the 3 or 6 ft radius they are required stay within. At its current stage, the simulator does not appear to be an appropriate environment in which to complete a low altitude maritime hover, with reference to a buoy 50 m away. If it is to be successfully completed in the AOSC simulator, some aspect of the simulator or the task must be altered.

4.4 Suggested Solutions

To rectify the problems pilots experience when performing the hover in the simulator, 3 solutions may be employed. These are as follows:

- The first is to improve simulator technology to include more of the fine visual cues a pilot expects, such as the rotor spray and spume patterns the aircraft makes in the water. Simulator improvement is a continuing and cumulative process, so this will not be the most rapid solution.
- The second is to specify how far from the buoy the pilot should hover. A 3 ft movement backwards or forwards will change the image projected onto the screen by a larger proportion at closer distances, decreasing the threshold for discrimination. Hence, a prescribed distance would have to be less than the 50 m used for this experiment. Further testing will have to be performed to find the optimal distance if this solution is to be employed.
- The third option is to review the maritime hover performance limits (for plan position in particular) and widen them to account for the degraded performance observed in the simulator.

Of course, a combination of these options may prove to be the most effective solution.

5. Conclusion

Although additional testing is required to narrow further the region in which the distance discrimination threshold lies, the results of this experiment suggest that the threshold is situated very close to or beyond the 3 ft 'desirable' limit of the maritime hover task, and in some cases, close to or beyond the 6 ft 'adequate' performance limit. This is true in the absence of any task other than identifying distance. It is therefore unreasonable to expect pilots to maintain the current 'desirable' and sometimes 'adequate' distances. While simulator improvement continues, a review of these limits, or alternatively a prescription for the precise distance to hover from the buoy, should be considered. This will ensure that limits for the maritime hover are a true reflection of the aircraft's capacity to perform the manoeuvre and that such a capacity is not impeded by a pilot's inability to perceive small distance changes in the AOSC simulated maritime environment.

6. References

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Appendix A: Maritime Hover Performance Criteria

Taken from DSTO-TN-0936

A.1. Proposed Maritime Hover Mission Task Elements

A.1.1 Objective

Check ability to maintain precise position, heading, and altitude in the presence of calm winds and moderate winds from the most critical direction.

A.1.2 Description of manoeuvre

Establish and maintain hover over the target point. For moderate wind, orient the aircraft with wind at the most critical azimuth.

A.1.3 Description of test course

Over water the manoeuvre should be flown to a fixed buoy with only open water visual references available. For baselining, the manoeuvre should be flown to an appropriate land-based target point.

A.2. Performance Criteria

Table A1 Maritime Hover performance criteria

Criteria	Desired	Adequate
Maintain plan position within _X ft of the target point	3 ft	6 ft
Maintain altitude within _X ft	4 ft	6 ft
Maintain heading within _X deg	5 deg	10 deg
Maintain hover for _X min	2	2

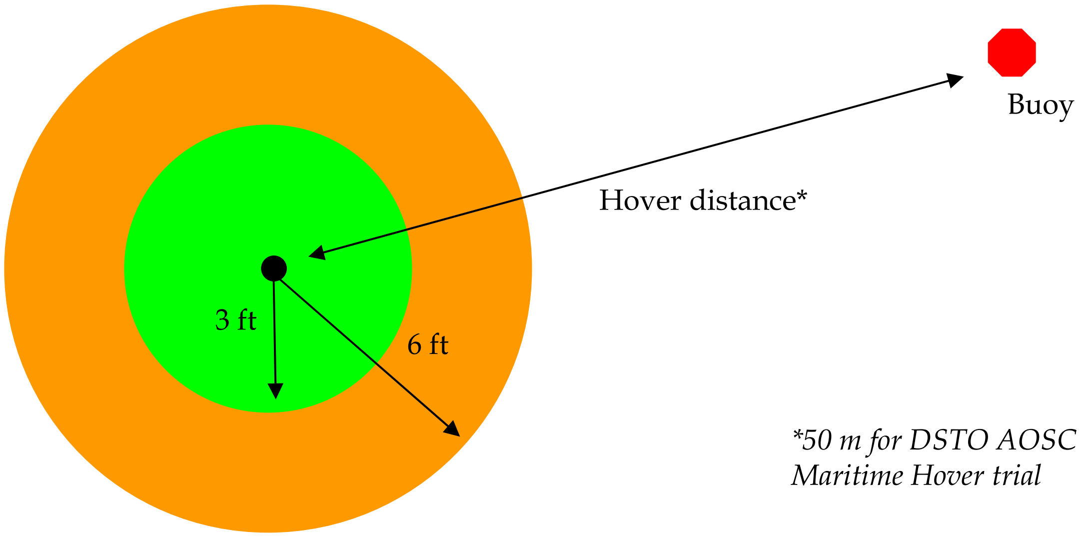

Figure A1 Plan position performance limits. The central black circle represents the 'target point' or point of origin of the hover. The inner circle represents the 'desirable' performance limit; the outer circle represents the 'adequate' performance limit. A pilot must stay within the inner circle to maintain 'desirable' performance for plan position. If they breach the inner circle but stay within the outer circle, they will perform within the 'adequate' limits for plan position.

Appendix B: Sea State Information

Table B1 Sea state information

Sea State Code	Wave Height (m)	Characteristics
0	0	Calm (glassy)
1	0 to 0.1	Calm (rippled)
2	0.1 to 0.5	Smooth (wavelets)
3	0.5 to 1.25	Slight
4	1.25 to 2.5	Moderate
5	2.5 to 4	Rough
6	4 to 6	Very rough
7	6 to 9	High
8	9 to 14	Very high
9	Over 14	Phenomenal

Appendix C: Aircraft and Buoy Placement

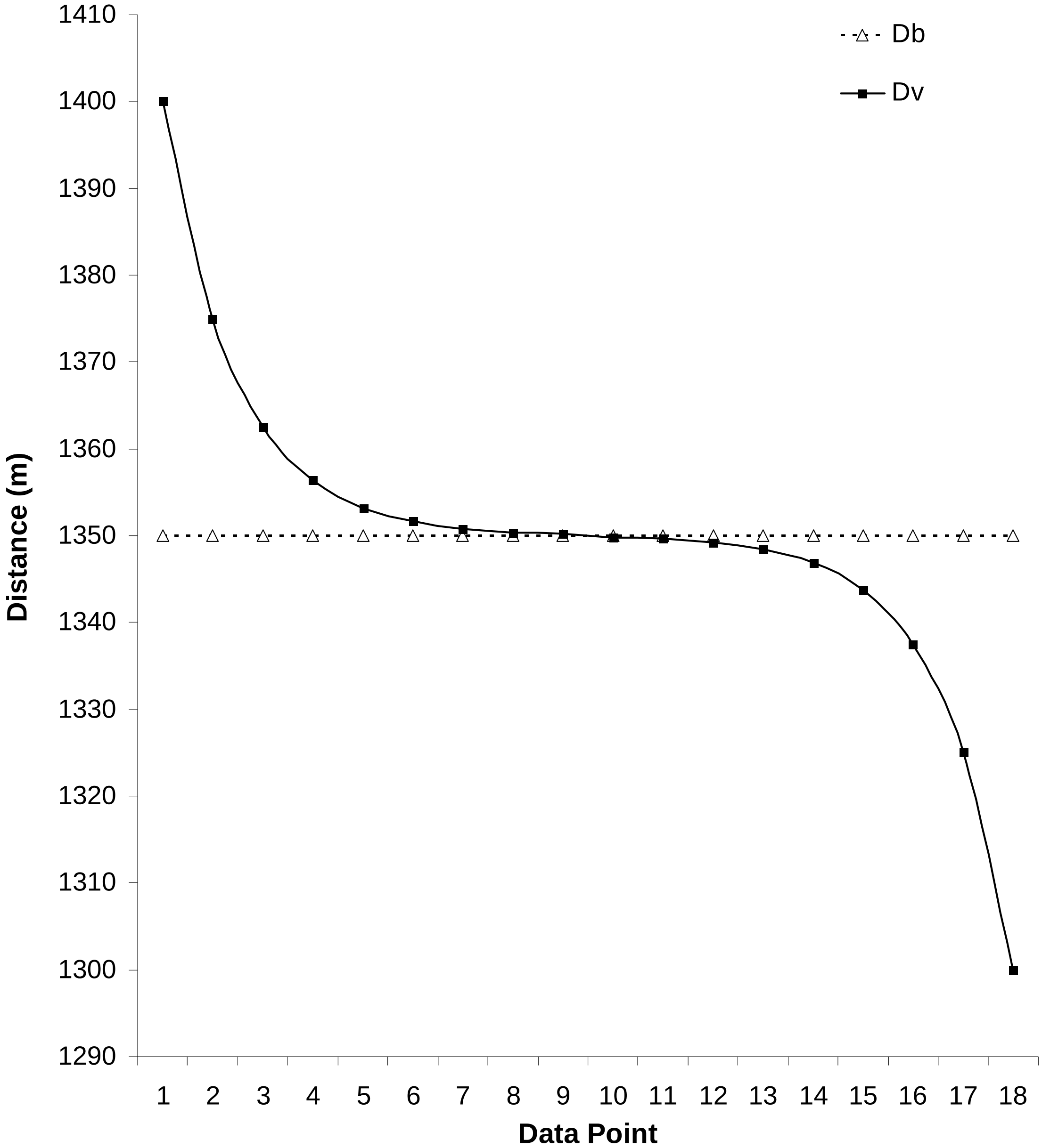

Figure C1 Distance of aircraft from origin for data points

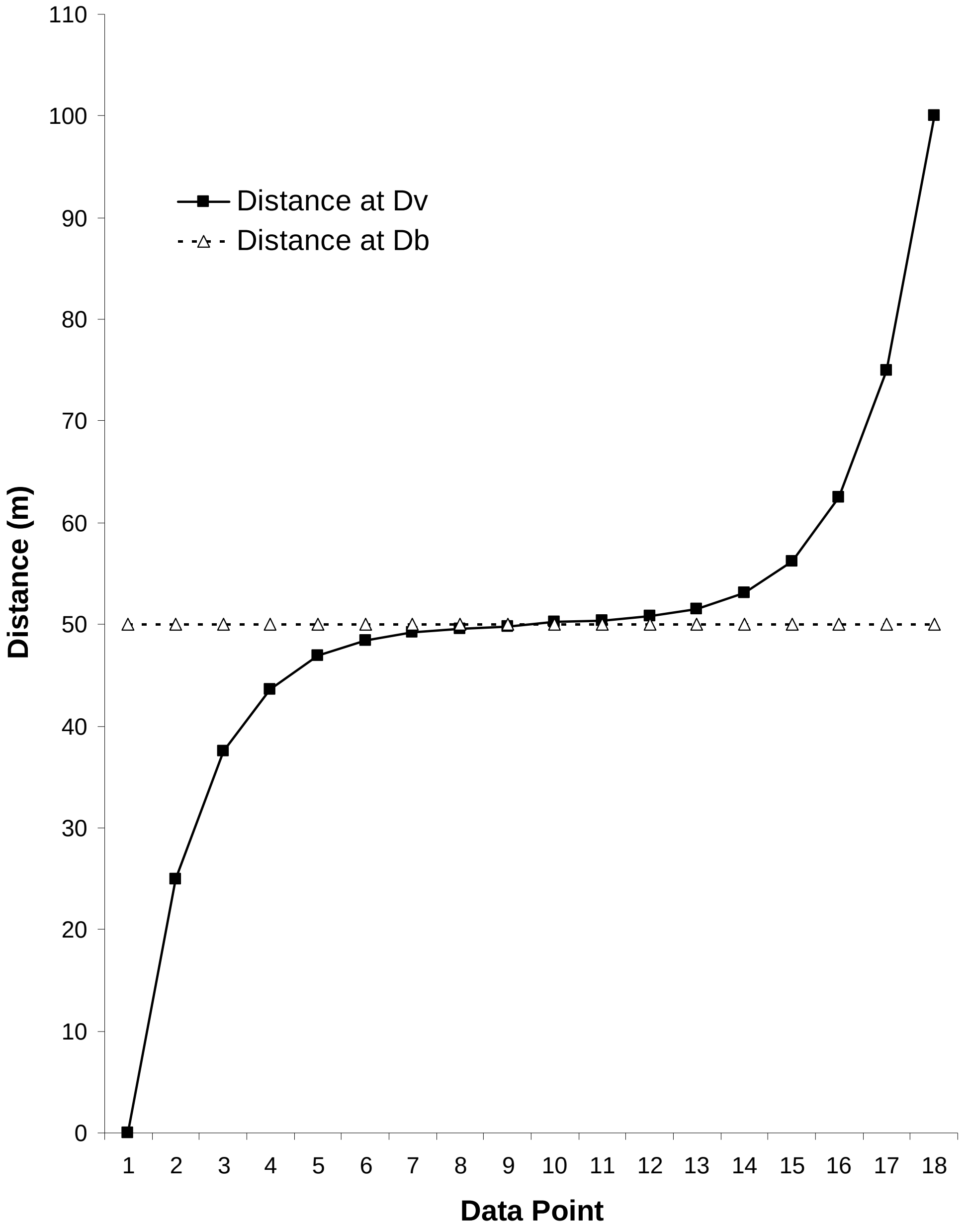

Figure C2 Distance of aircraft from buoy for data points

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19. ABSTRACT

The *Aeronautical Design Standard 33* (ADS-33) prescribes a set of manoeuvres and limits for assessing the handling qualities of military rotorcraft. In developing an ADS-33 maritime addendum, the Aircraft Maintenance and Flight Trial Unit (AMAFTU) and Defence Science and Technology Organisation (DSTO) have collaboratively worked towards the definition for a maritime hover manoeuvre. Initial testing to validate this proposed manoeuvre in the DSTO Air Operations Simulation Centre (AOSC) flight simulator has proved problematic. Although pilots could successfully complete a land-based hover within performance limits in the flight simulator, they experienced difficulty in maritime conditions. Pilots were unable to perceive small distance changes in the AOSC simulated maritime environment in some conditions.