Abstract. The Royal Australian Navy (RAN) currently operates three types of helicopter. The roles of these helicopters can include anti-submarine warfare, anti-surface unit warfare, search and rescue, vertical replenishment, medical evacuation, training, and the transportation of troops and equipment. All of these aircraft can operate from a number of RAN vessels. An important factor determining the operational availability of these helicopters during embarked (at sea) operations is the requirement to safely launch (take-off) and recover (land) the aircraft. Whether this is possible to achieve or not is determined by empirical Ship Helicopter Operating Limits (SHOLs).

The limits that determine a safe launch and recovery are reduced at night, when compared to daytime conditions. The loss of visual cues at night results in a more restrictive SHOL. RAN have recognized the operational advantages that night vision goggles (NVGs) offer pilots flying at night and have began the process of introducing them into service. In 2000, RAN conducted a trial of NVGs for embarked (at sea) operations. As part of the trial report, several recommendations were made. Included in these recommendations was the combining of symbology with the view through the NVGs, so that the time the pilot spends looking outside the aircraft can be maximised. RAN tasked the Defence Science and Technology Organisation (DSTO) to examine the issue of symbology usage with NVGs for helicopter recovery (landing) and to develop prototype symbology sets. For the first phase of this project, the Aviator Night Vision Imaging System Head Up Display (ANVIS-HUD) symbology set, currently used by some Australian Army helicopter pilots, was evaluated for recovery in the Air Operations Simulation Centre (AOSC). This evaluation included minor modifications to the ANVIS-HUD set to make it more relevant to the recovery process. This paper reports the results of this simulation experiment and discusses potential future work.

1 INTRODUCTION

The Royal Australian Navy (RAN) currently operates three types of helicopter, the S-70B-2 Seahawk, the SK-50 Sea King, and the AS350BA Squirrel (primarily a training aircraft). The roles of these helicopters include anti-submarine warfare, anti-surface unit warfare, search and rescue, vertical replenishment, medical evacuation, training, and the transportation of troops and equipment. All of these aircraft can operate from a range of RAN vessels. RAN ships with an air capability include the Adelaide Class frigates (FFG), ANZAC Class frigates (FFH), Landing Platform Amphibious (LPA) vessels Manoora and Kanimbla, HMAS Tobruk, HMAS Success, and the Hydrographic ships Melville and Leeuwin. An important factor determining the operational availability of these helicopters during embarked (at sea) operations is the requirement to safely launch (take-off) and recover (land) the aircraft. The safe limits for launch and recovery are determined by the data gathered over many evolutions of launches and recoveries (flown by a test pilot) across a broad range of environmental conditions. The limits are defined in terms of wind speed and direction (relative to the ship), ship pitch and roll, and helicopter weight. These limits are formally referred to as Ship Helicopter Operating Limits (SHOLs).

When determining whether a safe launch and recovery is possible at night, the primary limiting factor is the loss of visual cues when compared to daytime conditions. This results in a more restrictive SHOL and hence reduced operational capability. RAN have recognized the operational advantages that night vision goggles (NVGs) offer pilots flying at night and have began the process of introducing them into service. NVGs are passive electro-optical sensors that amplify long-wavelength visible and near-infrared light present at night (there is relatively more infrared light at night compared to day). Most NVGs currently in use have a field of view of 40°, while the normal human field of view is approximately 200° in the horizontal and 130° in the vertical. Recently, panoramic NVGs with larger fields of view in the horizontal have become available.

In 2000, the RAN conducted a trial of NVGs for embarked operations [1]. Three test flights totalling 6.1 hours of flying time were undertaken to assess the value of NVGs for launch and recovery. All the trials were conducted within the night SHOL limits currently specified for the particular ship-helicopter combination. As part of the trial report, several recommendations were made. One recommendation was to combine symbology with the view through the NVGs, so that the time the pilot spends looking outside the aircraft can be maximised. Symbology is defined as any graphic element that can be displayed in a head-up format collimated with the view through the NVGs, including alphanumeric characters, icons, and
graphs. At a minimum, it was recommended that the following aircraft data be displayed in the symbology set: speed (ground and air), attitude (pitch and roll), engine torque and altitude. The RAN tasked the Defence Science and Technology Organisation (DSTO) to examine the issue of symbology usage with NVGs and to provide preliminary guidance on this issue. Initially, this project focussed on symbology for helicopter recovery because this is a high workload task where a reduction in the number and quality of visual cues is of concern. This paper reports the preliminary results of the first phase of this activity, that involved assessing currently available and prototype symbology sets using a research facility that can simulate the key attributes of night maritime operations.

1.1 Helicopter Symbology
Several symbology sets and different formats are currently in use in military helicopters. Symbolic information commonly included in these helicopter symbology sets includes speed, altitude, attitude (aircraft pitch and roll), engine data, and heading. The Integrated Helmet and Display Sighting System (IHADSS), which was developed for the AH-64A Apache [2], was one of the first Helmet Mounted Displays (HMDs) introduced into service. The Helmet Integrated Display Sighting System (HIDSS), which was developed for the RAH-66 Comanche [3], will enter service in the next few years. The Aviator Night Vision Imaging System Head Up Display (ANVIS-HUD) [4], shown in Figure 2, was developed in the early 1990s. Pilots flying at night with NVGs during the early 1990s were involved in several incidents when flying over low contrast, featureless terrain, where they were unable to detect a gradual loss of altitude. These incidents resulted in the requirement for flight information to be presented to the pilot collimated with the view through the NVGs to maximise the pilot’s head out time. This symbology set has been used for the last few years by some Australian Army pilots flying the S-70A-9 Black Hawk helicopter.

Although several helicopters now incorporate symbology in a helmet-mounted display, a number of flight and simulation studies have found that the performance of flight tasks is not necessarily enhanced by the addition of head-up symbology. In general, it is the flight tasks that require continual reference to the symbolic information that benefit from the head-up information, rather than the tasks that only require intermittent reference to the information [5].

1.2 ANVIS-HUD Evaluation
Initially, a questionnaire was developed for RAN and Australian Army pilots in order to determine the information requirements for the approach and landing phases of a recovery. The aim of this questionnaire was to determine the pilots requirements for the information to be displayed in the symbology set, including its format (numeric, for example), the displayed resolution of the data, and the frame of reference of the data (referred to the aircraft, or pilot’s head, for example). The questionnaire also sought any novel ideas the pilots may have had for symbology. Given that the pilots’ requirements were very similar to the ANVIS-HUD set, it was decided to evaluate this set for the recovery task. To examine more forward-looking symbology concepts, an ANVIS-HUD variant set was also evaluated, which included some minor changes to increase its value for recovery, specifically the addition of the following information: glideslope (angle of descent), glidepath (lateral deviation of the helicopter from the ship’s longitudinal axis), closure rate (difference between the helicopter and ship speeds), bearing to ship and distance to ship. The presentation of this information to the pilot in a symbology set implies some sort of telemetry system between the ship and the helicopter. This information can be easily transferred between the platforms in the simulation environment. How the data would be transferred in reality was not explored in this study.

2 METHOD

2.1 Subjects
Four Australian Defence Force (ADF) pilots participated in the study. Pilots 1 and 2 were based at the Aircraft Maintenance and Flight Trials Unit. Both
were test pilots, although pilot 2 had limited recent flying hours. Pilots 3 and 4 were Australian Army line pilots who flew the S-70A-9 Black Hawk. Their flight experience is summarised in Table 1.

Table 1: Pilot experience.

<table>
<thead>
<tr>
<th>Pilot</th>
<th>Helicopter experience (h)</th>
<th>NVG experience (h)</th>
<th>Symbology experience (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3200</td>
<td>30</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>3800</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>1200</td>
<td>160</td>
<td>60</td>
</tr>
<tr>
<td>4</td>
<td>1400</td>
<td>230</td>
<td>150</td>
</tr>
</tbody>
</table>

2.2 Experiment Conditions

Three display conditions were evaluated in this study. In all cases a simulated NVG view of the outside scene was used. In the first condition, the standard S-70B-2 Seahawk head down display (HDD) provided flight data to the pilot. In the second condition, the flight data was provided by the ANVIS-HUD symbology set overlaid on the outside scene. In the third condition, the flight data was provided by the ANVIS-HUD Variant symbology set superimposed on the outside scene.

2.3 Air Operations Simulation Centre

The experiment was conducted in Air Operations Division’s Air Operations Simulation Centre (AOSC) in Melbourne. The AOSC has a fixed based, partial dome simulator that also has a Kaiser HMD for the presentation of symbology. In this case, a mock up of a S-70B-2 Seahawk cockpit was used. This cockpit includes accurate representations of the cockpit windows, head-down instruments and controls.

The external scene was displayed on a dome extending 100° vertically and 200° horizontally. In this case only the green projector gun was used to simulate the view seen through NVGs. Field of view restrictors were attached to the pilot’s helmet to reduce the field of view to 40°, while at the same time allowing the pilot to look under the field of view restrictors at the head down displays in the same way the pilot does using NVGs. Flightlab (Advanced Rotorcraft Technology) software was used to model the dynamics and aerodynamics of the S-70B-2 Seahawk helicopter. The ship model used in the experiment was an accurate representation of an Adelaide-class frigate.

2.4 Helmet Mounted Symbology Sets

Two helmet-mounted symbology sets were evaluated in this study. The first was the ANVIS-HUD set, shown in Figure 2. The symbology set was composed of the following elements: heading scale; air and ground speed numerics; barometric altitude numeric; radar altitude bar and numeric; rate of climb scale; engine torque numerics; aircraft attitude (pitch and roll) indicator; bearing data, velocity vector (only displayed during the landing phase) and trim ball.

The ANVIS-HUD Variant added the following information to the ANVIS-HUD set: closure rate numeric; a glideslope scale; glidepath scale; bearing to ship and distance to ship. In addition, the velocity vector displayed was relative to the ship’s velocity.

2.5 Recovery Task

The experiment began with the helicopter 2.2 km directly astern of the ship at an altitude of 122 m. The helicopter then was flown to a point about 30 m behind the ship along an approximately three degree angle of descent (glideslope). The pilot decelerated to a relative hover at this point (the speed of the helicopter matching the speed of the ship), and then assessed ship motion and wind speed and direction. The pilot then moved the helicopter to a point over the deck, hovered, and waited for a suitable period to land. After the pilot had determined that the ship motion was suitable, the aircraft descended to the deck. The phase from the start of the recovery until 30 m behind the ship is referred to as the approach phase, and from 30 m until landing is referred to as the landing phase.

2.6 Procedure

The four pilots attended the AOSC for a period of three to four days (depending on pilot experience) during the first two weeks of December 2002. The first day was devoted to familiarisation with the simulator, the recovery task, experimental procedure and symbology sets. Following this, the pilots
completed 12 recoveries with each display, completing between three and six recoveries per session.

2.7 Data Recording

2.7.1 Simulation Data

Approximately 100 variables were logged during the experiment at a rate of 60 Hz. Data logged included aircraft and ship speed, altitude, closure rate and glideslope.

2.7.2 Display Rating

At the conclusion of the experiment the pilots completed a questionnaire for each display, rating various aspects of the display for both the approach and landing phases. Included were ratings for the display as a whole, such as the display’s effectiveness (on a seven point Likert scale). In addition, for the HMD cases, the subjects could provide a number of ratings for each individual display element.

2.7.3 Pilot Subjective Ratings

At the conclusion of the experiment each pilot completed the NASA Task Load Index (TLX) workload scale [6] for each display for the approach and landing phases. The resulting workload rating is on a 0 to 100 scale, the greater the number the higher the workload. The pilots gave ratings for six workload dimensions for both approach and landing phases. Each workload dimension was weighted according to each pilot’s rating of its significance for the task.

3 PRELIMINARY RESULTS

A broad range of information was gathered during this experiment, including both quantitative and qualitative data. The results reported here form only a preliminary analysis of some of this data.

3.1 Approach

3.1.1 Subjective Workload Ratings

Table 2 shows the subjective workload ratings for each subject for the three display conditions during the approach phase. Pilots 3 and 4, the Army pilots, both reported their highest workload for the HDD condition, and reported their workload reducing slightly for the ANVIS-HUD case and again for the Variant. Pilot 1 reported his lowest workload for the HDD case, his rating increasing for the two head-up cases. Pilot 2 gave the same workload rating for each of the three displays.

Table 2: Subjective workload ratings for approach.

<table>
<thead>
<tr>
<th>Pilot</th>
<th>HDD</th>
<th>ANVIS-HUD</th>
<th>Variant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>67</td>
<td>81</td>
<td>84</td>
</tr>
<tr>
<td>2</td>
<td>80</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>3</td>
<td>56</td>
<td>50</td>
<td>42</td>
</tr>
</tbody>
</table>

3.1.2 Glideslope Maintenance

As a measure of glideslope (angle of descent) maintenance, the percentage of time the pilot spent in the desired corridor (corresponding to a glideslope angle between 2.5° and 3.5°) was determined for each pilot and display. Table 3 shows the mean percentage of time spent in the desired corridor for each display. Three of the four pilots spent the greatest proportion of their time in the desired corridor for the Variant display, with pilots 3 and 4 (both Army pilots) spending virtually 100% of their time in the corridor. Pilot 2 showed essentially no performance difference across the three visual conditions. No pilot showed obvious performance differences between the HDD and ANVIS-HUD conditions.

Table 3: Glideslope maintenance.

<table>
<thead>
<tr>
<th>Pilot</th>
<th>HDD</th>
<th>ANVIS-HUD</th>
<th>Variant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>72%</td>
<td>72%</td>
<td>85%</td>
</tr>
<tr>
<td>2</td>
<td>82%</td>
<td>81%</td>
<td>84%</td>
</tr>
<tr>
<td>3</td>
<td>91%</td>
<td>86%</td>
<td>100%</td>
</tr>
<tr>
<td>4</td>
<td>89%</td>
<td>89%</td>
<td>99%</td>
</tr>
</tbody>
</table>

3.1.3 Display Ratings

Table 4 shows the ratings for the effectiveness of each display for approach on a one to seven scale, with seven corresponding to a rating of very effective for the approach task and one a rating of not at all effective. The ratings for the HDD condition are mixed, ranging from two to six. For the ANVIS-HUD case, pilots 1 and 2 (the RAN pilots) gave a rating of three and four, respectively, while the Army pilots gave ratings of five and six. For the Variant, pilots 2 and 3 gave a rating of six and pilot 4 gave a rating of seven. In contrast, pilot 1 gave a rating of three.

Table 4: Display ratings for approach.

<table>
<thead>
<tr>
<th>Pilot</th>
<th>HDD</th>
<th>ANVIS-HUD</th>
<th>Variant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>6</td>
<td>7</td>
</tr>
</tbody>
</table>

3.2 Landing

The pilots reported that rarely, if ever, did they use any of the three displays during the landing phase. As a result, the quantitative and qualitative measures were similar across the three display conditions.

3.2.1 Pilot Subjective Workload

Table 5 shows the subjective workload ratings for the three display conditions during the landing phase. The scores for pilots 3 and 4 (the Army pilots) were in the low sixties for each of the three experimental conditions. Pilot 1 reported workload ratings in the low to mid eighties, while pilot 2 gave ratings ranging from 84 for HDD condition to 75 for the two HMD conditions.

Table 5: Subjective workload ratings for landing.

<table>
<thead>
<tr>
<th>Pilot</th>
<th>HDD</th>
<th>ANVIS-HUD</th>
<th>Variant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>84</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>2</td>
<td>75</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>3</td>
<td>80</td>
<td>84</td>
<td>84</td>
</tr>
<tr>
<td>4</td>
<td>75</td>
<td>80</td>
<td>80</td>
</tr>
</tbody>
</table>
3.2.2 Display Ratings

The ratings for each of the displays (Table 6) were low, with the ratings ranging from one to three for the HMD conditions and one to two for the HDD condition.

Table 6: Display ratings for landing.

<table>
<thead>
<tr>
<th>Pilot</th>
<th>HDD</th>
<th>ANVIS-HUD</th>
<th>Variant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

4 DISCUSSION

The main goal of this experiment was to evaluate three different display conditions for the recovery of a S-70B-2 Seahawk helicopter to an Adelaide class frigate. The displays evaluated were the standard Seahawk head down instruments (Figure 1), along with the ANVIS-HUD set (Figure 2) and a variant of the ANVIS-HUD set (Figure 3).

The preliminary results of this study (although limited by the number of subjects and their experience with the displays or recovery task) indicate that, for the approach phase, pilots highly experienced with ANVIS-HUD have reduced workload for the HMD conditions. Furthermore, pilots with a range of ANVIS-HUD experience showed improved glideslope maintenance for the ANVIS-HUD Variant (no effect being observed for the pilot with no symbology experience). For the landing phase all the subjects reported that they rarely used the displays, relying on the visual cues from the ship instead. As a result, the task measures and ratings were similar across the three displays.

4.1 Approach Phase

4.1.1 Subjective Workload

Both the Army pilots gave their highest workload rating for the HDD condition, which decreased slightly for the ANVIS-HUD and further still with the addition of the extra information presented in the Variant. This is not surprising, since most of the pilot’s night flying would be done with the ANVIS-HUD as the primary flight reference. Feedback from the Army pilots indicated they could incorporate the additional recovery specific information in the Variant resulting in a reduced workload. The workload of pilot 1 increased with the HMD formats. This may be, in part, due to the level of experience of the subject (relative to the Army pilots) using the ANVIS-HUD set. It could also reflect the subject’s preference for the way the flight information was presented in the HDD condition. Pilot 2 gave the same high workload rating across the three displays, which given his lack of recent flying time and minimal symbology experience, may suggest a ceiling effect.

4.1.2 Glideslope Maintenance

As a measure of glideslope maintenance, the percentage of time the pilot spent in the desired corridor was determined for each pilot and display. Three of the four pilots spent the greatest proportion of their time in the desired corridor for the Variant display, with both Army pilots spending virtually 100% of their time in the corridor. Pilot 2 showed essentially no performance difference across the three visual conditions (most likely due to his lack of symbology experience and recent flying hours). No pilot showed obvious performance differences between the HDD and ANVIS-HUD conditions. This is to be expected, since the ANVIS-HUD provided the same information as the HDD (albeit in a different format) and the pilots reported only viewing the displays intermittently. Glideslope maintenance is one important quantitative measure of pilot performance during approach. In addition to this information, other factors need to be considered to fully evaluate pilot performance, such as the closure rate of the helicopter to the ship.

4.1.3 Display Ratings

The pilot’s ratings for the effectiveness of the three displays were mixed for the approach phase. One factor that may contribute to this is the familiarity of the subjects with a particular display. For example, the pilot with the most experience using ANVIS-HUD, gave this display a rating of six and the HDD display a rating of two. Another potential factor is the format of the displayed information. The head down displays in the S-70B-2 Seahawk are traditional analogue dials, while most of the information presented in the HMD conditions is in a digital format. Some of the subjects reported that it was easier to get rate of change information from the head down analogue displays and that they could quickly glance at the display and check that the needle was in the required position. The Variant, with its additional information unavailable in the two other conditions, received ratings of either six or seven for three of the pilots. In contrast, the other pilot gave a rating of three. This pilot reported the extra information was possibly excessive and reduced his overall situational awareness.

4.2 Landing Phase

The pilots reported that they rarely used any of the three displays during the landing phase. Once they were close to the ship, the pilot’s used the visual cues present on the ship, to provide information such as closure rate and altitude. Hence, the qualitative and
quantitative measures recorded for each pilot were similar across the three displays.

### 4.2.1 Subjective Workload Ratings

The subjective workload ratings for the Army pilots increased to the low sixties during the landing phase, reflecting the increasing demands of the task relative to the approach phase. Pilot 1 reported his workload stayed essentially constant over the approach and landing phases for the HMD conditions, but increased for the HDD condition to a similar level as the HMD conditions. Most likely for the reasons noted previously. In contrast, pilot 2 reported that his workload decreased for the HMD cases.

### 4.2.2 Display Ratings

The ratings for all three displays were low, ranging from one to three for the two HMD conditions and one to two for HDD condition. Feedback from the pilots suggest that positional information of the helicopter relative to the flight deck, rather than the standard flight information presented in the HMDs, could be of more value during the landing phase.

### 5 FOLLOW ON WORK

Following on from this study, symbology sets incorporating pilot feedback from this experiment, such as the display of some information in an analogue format, will be evaluated. In addition to this, more forward-looking symbology sets will be investigated for both the landing and approach phases. Concepts to be explored for the approach phase include the tunnel-in-the-sky perspective display, which is currently being evaluated by a number of research groups [7]. Also, during the landing phase, the presentation of helicopter position information relative to the ship’s flight deck, following on from recent work in the area [8].

### 6 CONCLUDING REMARKS

The preliminary results of this study, although limited by the number of subjects and their experience, indicate that pilots with sufficient NVG and symbology experience have reduced subjective workload using a HMD and improved glideslope maintenance during the approach phase of recovery using the ANVIS-HUD Variant. It was also found that during the landing phase, all four pilots rarely, if ever, referred to the displays. Hence, pilot performance and ratings were similar across the three display conditions. Further examination of the experiment data will include, for example, analysis of closure rate to the ship, and pilot eye and head movement behaviour. This further analysis will give a more accurate understanding of pilot performance using the three displays. Following this further analysis, a report will be issued to RAN to provide preliminary guidance for symbology set acquisition in both the short and long term.

### REFERENCES


