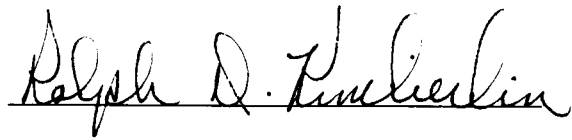


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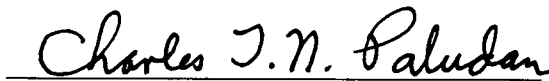
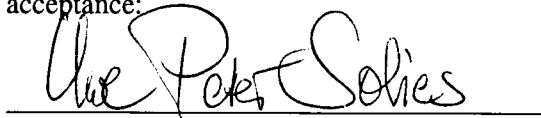
I am submitting herewith a thesis written by James Allen Holden entitled "A Comparison of the Human Machine Interface Aspects of Helicopter Deck Landings on Ships with Freedeck and Hauldown Deck Recovery Systems." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the Master of Science degree, with a major in Aviation Systems.



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A COMPARISON OF THE HUMAN MACHINE INTERFACE ASPECTS  
OF HELICOPTER DECK LANDINGS ON SHIPS WITH FREEDECK  
AND HAULDOWN DECK RECOVERY SYSTEMS

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee Space Institute, Tullahoma

James Allen Holden

May 1998

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## **ABSTRACT**

Helicopters have been operating off naval ships for decades. Their operational utility has been exploited exhaustively to carry out very diverse roles. The process of operating helicopters off ships, however, has been difficult at the best of times. Several factors have allowed for significantly improved operational ship-helicopter operating limitations (SHOL) or operating envelopes with today's navies. The use of helicopter deck recovery systems is one. Amongst other things, their use reduces pilot workload – the human factors aspect of the envelope. Two systems in common use today are the Recovery Assist, Secure and Traverse system (RAST) and the Helicopter Hauldown Rapid Securing Device (HHRSD). These systems both secure the aircraft to the deck immediately upon touchdown. The HHRSD, however, utilizes a wire attached from the ship to the helicopter to steady the aircraft. The RAST Mk III does not use a wire but employs a pilot visual cue display (PVCD) in an attempt to help the pilot steady the aircraft. This thesis makes a direct comparison of the human factors aspects of operating these systems in both benign and adverse environmental conditions in order to determine which could produce the largest SHOL for a given ship and aircraft type.

The results of the comparison were that the centering effect of the hauldown cable when using the HHRSD significantly decreased the pilot workload. The PVCD integral to the RAST Mk III was of limited operational utility, and in several cases, the human machine interface between the pilot and the PVCD increased pilot workload. The hauldown system was therefore the system of choice to ensure the largest possible SHOL and use of the RAST Mk III should only be used when space, weight or cost considerations preclude the use of a hauldown system.

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## LIST OF ABBREVIATIONS

|       |                                           |
|-------|-------------------------------------------|
| 6-DOF | Six Degree of Freedom                     |
| AESOP | Airborne Electric Sensor Operator         |
| AETE  | Aerospace Engineering Test Establishment  |
| AGL   | Above Ground Level                        |
| AOB   | Angle Of Bank                             |
| AOI   | Aircraft Operating Instructions           |
| ASE   | Automatic Stabilization Equipment         |
| AUW   | All Up Weight                             |
| CFB   | Canadian Forces Base                      |
| CG    | Center of Gravity                         |
| DDH   | Helicopter Carrying Destroyers            |
| DHA   | Delta Hover Astern                        |
| DLA   | Designated Landing Area                   |
| DOD   | United States Department of Defence       |
| DREA  | Defence Research Establishment - Atlantic |

|       |                                           |
|-------|-------------------------------------------|
| FOR   | Field Of Regard                           |
| FOV   | Field Of View                             |
| ft    | Feet                                      |
| ft/s  | Feet per Second                           |
| HHRSD | Helicopter Hauldown Rapid Securing Device |
| HPSE  | Helicopter Position Sensing Equipment     |
| HQR   | Cooper-Harper Handling Qualities Rating   |
| HUD   | Heads Up Display                          |
| Hz    | Hertz                                     |
| ILS   | Instrument Landing System                 |
| IR    | Infrared                                  |
| kts   | Knots (Nautical Miles per Hour)           |
| lbf   | Pounds (Force)                            |
| lbm   | Pounds (Mass)                             |
| LSO   | Landing Safety Officer                    |
| m     | Meter                                     |
| NETE  | Naval Engineering Test Establishment      |

|       |                                         |
|-------|-----------------------------------------|
| nm    | Nautical Mile                           |
| NVG   | Night Vision Goggles                    |
| PIO   | Pilot Induced Oscillations              |
| PVCD  | Pilot Visual Cues Display               |
| QFTE  | Qualified Flight Test Engineer          |
| QTP   | Qualified Test Pilot                    |
| RAST  | Recovery Assist, Secure and Traverse    |
| s     | Second                                  |
| SHRS  | Stabilized Horizon Reference System     |
| SMP   | Ship Motion Prediction                  |
| TWHPU | The Traverse Winch Hydraulic Power Unit |

# **1 INTRODUCTION**

## **1.1 BACKGROUND**

### **1.1.1 GENERAL**

The Aerospace Engineering Test Establishment (AETE) conducted a flight test of Indal Technologies Recovery Assist, Secure and Traverse (RAST) Mk III shipborne helicopter deck recovery system during the summer of 1992. The RAST system was being investigated as a potential replacement for the existing Helicopter Hauldown Rapid Securing Device (HHRSD) which was in use on all Canadian Navy helicopter carrying destroyers (DDH) at that time. The testing was broken down into two test phases, a shore- and a ship-based phase. The shore-based testing was carried out at Canadian Forces Base (CFB) Shearwater from the 6<sup>th</sup> to the 17<sup>th</sup> of April 1992. Its purpose was to determine if the RAST Mk III Helicopter Position Sensing Equipment (HPSE) and the Pilot Visual Cues Display (PVCD) were functional and operationally viable. The ship-based testing was carried out from the 15<sup>th</sup> of June to the 23<sup>rd</sup> of July 1992. It was carried out for two purposes: to determine if the equipment untested in the shore-based test phase was functional, and to determine the effectiveness of the system as a whole at sea. The untested equipment included the Landing Safety Officer (LSO) Console, the RAST Mk III Trap and the Ship Motion Prediction system.

### **1.1.2 HELICOPTERS OPERATING WITH SHIPS**

Helicopters have been operating off naval ships for nearly as long as helicopters have been around. Their operational utility has been exploited exhaustively to carry out such diverse roles as submarine hunting, surface surveillance, and mine hunting to intership mail delivery and search

and rescue. The process of operating a helicopter off a ship, however, has been difficult at the best of times, and is quite dangerous when the wind and sea conditions create pockets of turbulence around the landing area and cause the deck to move a great deal in an unpredictable way. This problem has plagued the designers of helicopters and ships as well as the crews operating them since the onset of ship-helicopter operations and has been tackled in many ways. Helicopters have been fitted with complicated flight control systems that help the pilot operate better in turbulence and decrease his workload in this demanding environment. Also, helicopters have been fitted with heavy-duty landing gear to allow the pilot plant the aircraft on deck very aggressively. Ships have been designed to minimize the turbulence over the flight deck and limit the deck motion in high sea states. Although these factors have allowed for significantly improved operational ship-helicopter envelopes, it wasn't until the advent of helicopter deck recovery systems that "all weather" operations could be considered.

### **1.1.3 SHIP-HELICOPTER DECK LANDING SYSTEMS**

Numerous deck landing systems have been experimented with, but few have been as successful as the RAST Mk III and HHRSD. They are described in detail at paragraph 1.4.1. These systems both secure the aircraft to the deck immediately upon touchdown even in conditions of high deck motion thus minimizing the problem of deck motion. The HHRSD addresses the problem of turbulence by using a wire attached from the ship to the helicopter to steady the aircraft. The RAST Mk III provides additional visual cues to the pilot in an attempt to do the same thing. The differences in these systems are the object of the investigation carried out in the thesis.

## **1.2 OBJECTIVE**

The objective of the thesis is to investigate the human factors aspects of operating the RAST Mk III deck recovery system by way of a comparison to the HHRSD deck recovery system and make recommendations for improvements to the systems.

## **1.3 SCOPE OF THE TESTS**

The scope of the tests investigated in the thesis is limited to the human factor aspects of operating the RAST Mk III and HHRSD deck recovery systems. The systems are shown at Figure A-1<sup>1</sup> through Figure A-5. It is from the pilot's perspective in the cockpit of the aircraft and investigates only the take-off and landing evolutions. The evolutions were investigated for system performance in both benign and adverse conditions. These terms are defined at paragraph 1.6.6. The comparisons were made under like conditions for all tests. The following technique was used to increase the severity of the conditions from benign to adverse:

- a) Lower light levels were used. Flying at night was more difficult than during the day.
- b) Relative winds were altered. The aircraft handling characteristics were significantly different with relative winds from abeam the aircraft rather than in front of it.
- c) Higher conditions of ship's pitch and roll were used. The pilot's workload increased as the ship's pitch and roll increased.

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<sup>1</sup> Figures and tables are contained in Appendix A and Appendix B respectively.

## **1.4 EQUIPMENT UNDER TEST AND TEST EQUIPMENT**

### **1.4.1 TEST SYSTEMS**

Two systems were under test: the RAST Mk III, and the HHRSD. The Ship/Helicopter Operating Limitations (SHOL), which consisted of relative wind speed and direction limitations as well as deck motion limitations, had been previously investigated for the HHRSD system but not the RAST Mk III. The HHRSD was considered the control system and a direct comparison was made between this and the RAST Mk III.

#### **1.4.1.1 RAST MK III**

The RAST Mk III is a freedeck recovery system (see paragraph 1.7.13). The general setup is shown at Figure A-3 and Figure A-6. Eight LASER beacons - four on each side of the aircraft, emitted low power infrared (IR) energy. The pattern was registered by two flight deck cameras and transferred to a Signal Processing Unit. The cameras and beacons comprised the HPSE. The processed signal was reduced using a six-degree of freedom (6-DOF) program to determine the position of the helicopter based on the light source geometry. The position of the helicopter with respect to the Designated Landing Area (DLA) was then determined and displayed to the pilot on the PVCD. This same information was also used to direct movement of the trap. The Traverse Winch Hydraulic Power Unit (TWHPU) moved the trap fore and aft beneath the aircraft. The trap was programmed to maintain a position 1.5 feet aft of a probe located on the underside of the aircraft until it was landed on the flight deck. When the aircraft was on deck, with the probe inside the DLA, the trap was fired by the LSO. The trap (see Figure A-7) then advanced to the main probe at a high rate until the probe broke a light beam on the trap. The speed of advance then reduced to a lower rate. A shock bar on the leading edge of the trap was then compressed as the

trap advanced towards the probe. A claw on the starboard side of the trap then slid across the front of the trap and secured the probe. The aircraft was then secured on deck.

#### **1.4.1.2 HHRSD**

The HHRSD is a tethered hover deck recovery system (see paragraph 1.7.14). The general setup is shown at Figure A-4. It is used as follows. The helicopter is initially brought into the high hover approximately 20 feet over the deck and slightly abeam the trap. A messenger cable is then lowered from the aircraft main probe. A member of the deck team then manually hooks up a ship's end fitting to the messenger cable. The ship's end fitting connected to the wire is routed through a bellmouth guide located on the deck in the center of the trap. The aircraft then reels in the messenger cable. The ship's end fitting is automatically hooked up to the aircraft creating a tethered connection between the ship and the aircraft. The LSO then reels in the cable at a rate of 3 ft/s. The aircraft is then tethered to the ship with only the residual tension of approximately 800 lbf on the cable. The tension is then increased to hover tension (1500 lbf), and subsequently to 4000 lbf once the landing is complete. If the trap is used -- it was not used for this trial -- the trap is then fired and the probe captured by the trap's two opposing beams. The aircraft was then secured on deck.

#### **1.4.1.3 DIFFERENCES BETWEEN THE RAST MK III AND THE HHRSD**

The major differences between the RAST Mk III and the HHRSD are itemized in Table B-1.

#### **1.4.2 CH 124A - SEA KING HELICOPTER**

A standard CH 124A Sea King helicopter was used as the aircraft for Shore-based testing. The aircraft was a dual-piloted, single main rotor, twin free turbine, all-weather anti-submarine

warfare helicopter with emergency amphibious capabilities. Twin General Electric T58-GE-8F turboshaft engines powered the aircraft. Each was rated at 1 250 shp at sea level ICAO standard day using maximum continuous power. The rotor system was comprised of a five bladed fully articulated 62-foot diameter main rotor and a five bladed antitorque tail rotor. The CH-124A was operated from either shore bases or ships. The left aft fuselage and tail boom section had a strake designed to promote flow separation on the left side of the tail boom section, thereby reducing the right yawing moment generated in the hover with right side winds. The side-by-side cockpit had a dual set of conventional irreversible flight controls which were hydraulically boosted by two (a primary and a secondary) independent hydraulic servo systems. Automatic Stabilization Equipment (ASE) was installed to improve the handling characteristics of the aircraft and was designed to induce static and dynamic stability to permit hands-off altitude, attitude and heading stabilization during pilot controlled flight. A more complete description is contained in the pilot's flight manual (AOI, 1991).

The following additions were made to the standard CH-124A in order to carry out the flight testing:

#### ***1.4.2.1 AETE INSTRUMENTATION PACKAGE***

The aircraft was fitted with an instrumentation package that recorded the parameters required to quantify the pilot workload, and the power and control margins. The instrumentation console displaying these data was located at the Airborne Electric Sensor Operator (AESOP) station. A Qualified Flight Test Engineer (QFTE) operated it.

#### ***1.4.2.2 IR BEACONS AND CAMERAS***

Four IR emitting LASER beacons were located on each side of the helicopter. The IR cameras on the flight deck recorded the location and orientation of these beacons.

#### ***1.4.2.3 RAST MK III MAIN PROBE***

The RAST Mk III system used a main probe similar to the main probe fitted on the standard CH-124A. The standard probe used for the HHRSD was located near the aircraft CG and was used as the guide and housing for the hauldown cable as well as to secure the aircraft on deck. The RAST Mk III probe was positioned 39.5 inches further aft than the standard probe and did not accommodate a hauldown cable. The probe was used to secure the aircraft to the trap with the RAST Mk III.

#### ***1.4.2.4 DESIGNATED LANDING AREA***

The DLA was the practical trappable area of the RAST Mk III. The DLA was limited fore and aft as well as laterally as shown in Figure A-8. Two DLA are described -- an inner and an outer.

##### ***1.4.2.4.1 OUTER DLA***

The front edge of the outer DLA was the furthest forward position of the probe that could still guarantee the required 5.8 m rotor clearance from the hangar (IAN HOSTAC, 1992). The aft edge of the outer DLA was the furthest position of the probe aft that could still guarantee the required 1.5 m tail wheel clearance from the aft edge of the flight deck on landing (IAN HOSTAC, 1992). The lateral limits of the outer DLA were derived from a statistical analysis that predicted with 99.7% certainty that the probe would be inside the lateral trappable area (Korwin-

Szymanowski, 1992). This resulted in an outer DLA 1.59 m wide by 1.71 m long. This was later modified to 1.59 m x 1.59 m for ease of testing - - a square DLA was easier to evaluate.

#### ***1.4.2.4.2 INNER DLA***

The inner DLA was the area described by 66% of the lateral and 66% longitudinal dimensions of the outer DLA. This resulted in an inner DLA 1.05m wide by 1.14m long. The inner DLA was used as the ideal landing area and was represented to the pilot on the PVCD. The dimensions were arbitrarily chosen and refined during flight test (see paragraph 3.3.5).

#### ***1.4.2.5 PVCD***

The pilot visual cues display located on top of the hangar, was integrated with the Stabilized Horizon Reference System (SHRS). It is shown at Figure A-9. The bar was a standard DDH roll bar with the addition of four amber, three green and one red directional chevron lights. It was stabilized in roll up to 45° and remained level with the horizon regardless of ship's movement. The bar was used to provide command, position and status information as defined in paragraphs 1.7.3, 1.7.18, and 1.7.22 respectively.

##### ***1.4.2.5.1 COMMAND INFORMATION***

The only command information provided to the pilot was the wave-off signal. This signal was used to indicate that the deck suddenly became unsafe and that the aircraft should abort the landing and circle. It was indicated by the simultaneous illumination of the three amber and the one red chevron.

#### *1.4.2.5.2 POSITION INFORMATION*

Position information was supplied to the pilot as indicated by the specific combination of chevrons that was illuminated.

##### *1.4.2.5.2.1 DISPLAY*

The PVCD display indicated the aircraft probe position relative to the DLA. To facilitate smooth transition of the display with respect to probe positions, an inner and an outer DLA was used, although the aircraft could be trapped anywhere inside the outer DLA. The PVCD indications for representative probe positions are shown in Figure A-10.

##### *1.4.2.5.2.2 POSITION ORIENTATION*

The position of the DLA was with respect to the ship's frame of reference. This is shown in Figure A-11.

#### *1.4.2.5.3 STATUS INFORMATION*

Deck status information was supplied to the pilot using the PVCD. The HHRSD system used a set of dedicated deck status lights similar in function to traffic lights and are shown in Figure A-12. They were mounted on the hangar face. A comparison of the status indications for the RAST Mk III and the HHRSD is shown at Table B-5.

### **1.4.3 DDH 205/265 CLASS SHIP**

The HMCS Ottawa, a standard DDH 205/265 class ship was used for the trial. It was fitted with the equipment shown at Figure A-13. The HHRSD trap shown as item ③ in this figure was stowed in the hangar for the trial due to incompatibilities with the RAST system. The hauldown

cable, however, was still operative and HHRSD landings were carried out using recoveries without the trap. These recoveries utilized a portable bellmouth that was fitted to the ship. This configuration allowed the direct comparison of RAST Mk III and HHRSD recoveries. Traversing for all evolutions was carried out with the RAST trap. Further details of the flight deck and landing area can be found in the IAN HOSTAC (1990).

#### ***1.4.3.1 SHIP'S MOTION RECORDER***

Defence Research Establishment - Atlantic (DREA) recorded the ship's motion parameters in pitch, roll, yaw and heave. This information was made compatible with the AETE data gathered on-board the aircraft via an IRIG B time synchronization.

#### ***1.4.3.2 SHIP VIDEO CAMERAS***

The Naval Engineering Test Establishment (NETE) mounted two video cameras on the port aft of the hangar top and the starboard aft of the flight deck. This information was used in conjunction with the DREA and AETE instrumentation to keep a video record of the flight testing. It was not in a format that could be incorporated into the data reduction of aircraft parameters and position information, but was used for photo documentation.

### **1.5 TRIALS TEAM**

#### **1.5.1 GENERAL**

The trial team was comprised of aircrew, engineers and support staff from HS 423 Squadron, AETE, NETE and DREA. HS 423 made up the ship's flight and organized the day to day operational aspects of having a helicopter at sea. The flight ensured the aircraft was serviceable for each flight of the trial as well as supplying the co-pilots and the Landing Safety Officers

(LSOs) for the trial. AETE supplied the Qualified Test Pilots (QTP), QFTEs, aircraft instrumentation engineers and technicians. NETE supplied engineers to oversee the integration of the RAST into the ship. DREA was responsible to record ship motion parameters and assist in the data reduction.

### **1.5.2 OPERATOR INFORMATION**

Table B-2 shows the experience level of the operators of the RAST Mk III System trial. Pilot B was the primary test subject, and where discrepancies existed, the data reported by pilot B was used.

## **1.6 METHOD**

### **1.6.1 GENERAL**

A direct comparison was made between the human machine interface aspects of deck operations with the RAST Mk III and the HHRSD. An effort was made to ascertain whether or not the systems could be employed safely and had operational potential while operating with a Sea King Helicopter. The testing was carried out using an incremental, phased approach. The system was tested during the day and at night in benign as well as adverse visual cues environments, wind conditions and sea states in a controlled manner. Definitions of benign and adverse visual cue environments are shown at paragraphs 1.6.6.1 and 1.6.6.2 respectively. The results of this testing of one system were compared directly with results of the other system under similar conditions. The RAST system was investigated during freedeck operations and the HHRSD was investigated using hauldown recoveries. The investigation included error susceptibility, field of view, human performance and usability.

## **1.6.2 TECHNIQUES USED**

The landing and take-off techniques varied between the RAST Mk III and the HHRSD. A description of each technique follows.

### **1.6.2.1 LANDING**

The landing evolution began with the helicopter in the Delta Hover Astern position and ended with the aircraft trapped on deck. These terms are defined at paragraphs 1.7.7 and 1.7.24.

#### **1.6.2.1.1 RAST Mk III**

The aircraft moved diagonally from the DHA to the high hover approximately 20 feet over the deck, directly over the trap. During a quiescent period and when the pilot was ready to descend, he lowered the aircraft to the low hover, approximately 5 ft over the deck. When the pilot was ready to land, he lowered the aircraft to the deck and it was trapped.

#### **1.6.2.1.2 HHRSD**

The aircraft moved diagonally from the DHA. The helicopter was initially brought into the high hover approximately 20 feet over the deck and slightly abeam the trap. This position was maintained until the ship's end fitting was locked in to the aircraft, and the residual tension (800 lbf) on the cable was taken in by the Landing Safety Officer (LSO). The pilot then assisted the aircraft in centering itself over the trap. Tension was then increased by the LSO to hover tension (1500 lbf). When a quiescent period arose, the pilot then lowered the aircraft to the low hover (approximately 5 ft above deck level). When he was ready to land, the tension was increased to 2000-4000 lbf, depending upon the all up weight (AUW) of the aircraft, and the aircraft was landed. The tension was then increased, if required, to 4000 lbf.

#### **1.6.2.2 TAKE-OFF**

The take-off evolution began with the aircraft trapped on deck and ended with the helicopter departing the ship, flying away at a 45° angle to the ship's path.

##### **1.6.2.2.1 RAST Mk III**

The probe was released and the aircraft ascended to the high hover. The aircraft then climbed left and aft maintaining heading to the 7 o'clock position with respect to the flight deck until approximately 40 ft above deck height. The aircraft was then yawed left and flown away at a 45° angle to the ship's path.

##### **1.6.2.2.2 HHRSD**

The trap was opened and the aircraft ascended to the high hover. The aircraft then climbed left and aft maintaining heading to the 7 o'clock position with respect to the flight deck until approximately 40 ft above deck height. The aircraft was then yawed left and flown away at a 45° angle to the ship's path.

#### **1.6.3 DATA MONITORING AND RECORDING**

The data appropriate to the test conducted was recorded by the aircraft and shipboard instrumentation systems as well as on hand-held data cards for all trial evolutions.

#### **1.6.4 TEST REJECTION CRITERIA**

In order to determine the human factor aspects of the deck operations, it was necessary to set boundary conditions and test rejection criteria. The following limitations were used:

- a) any limit from the Aircraft Operating Instructions (AOI) reached or exceeded;

- b) a torque or control margin rating that approached the useable limit; and
- c) a handling qualities rating (HQR) of 7 or above as described at Table B-7 was experienced.

#### **1.6.5 FLIGHT TEST ENVELOPE**

All flight testing was carried out within the following envelope:

- a) all aircraft/engine parameters were within their published limits (AOI, 1992);
- b) the relative wind and speed was within the aircraft's sideward and rearward limit (AOI, 1992);
- c) winds were forward of the beam (no relative winds from behind the helicopter);
- d) the ship motion was less than or equal to 9° pitch and 31° of roll; and
- e) the pilot visual cues, ship motion prediction system and trap of the deck recovery systems were working in a safe and predictable manner.

#### **1.6.6 TEST CONDITIONS**

Although a diverse range of deck motion and relative wind conditions as well as visual cue environments were seen during the trail, an effort was made to isolate two test conditions: benign and adverse. When these conditions were altered, they would elicit quantifiable measures of pilot workload. The amount of workload for each system would be the measure of its operational effectiveness.

##### **1.6.6.1 BENIGN**

Conditions were considered benign when pilot workload to achieve the desired performance was at a minimum (see Table B-3). These conditions optimized the pilot's ability to use the visual

cues available due to the low workload. Benign conditions allowed the pilot to use all cues available to the maximum extent possible resulting in the task being executed with the best possible precision.

#### **1.6.6.2 ADVERSE**

Conditions were considered adverse when the desired performance was progressively more difficult to achieve or not achievable due to the pilot workload (see Table B-3). These conditions limited the pilot's ability to use the visual cues available since a great deal of the pilot's processing power was used to "pilot" the aircraft and maintain controlled flight. Adverse conditions resulted in a focussing of the pilot's processing power on one or two of the available cues and degraded the precision with which the task was carried out.

#### **1.6.7 SHIP MOTION PREDICTION**

Though the initial design of the RAST Mk III incorporated a ship motion prediction (SMP) system, it was not ready to be evaluated at the time of testing.

#### **1.6.8 AIRCRAFT CONFIGURATION**

The aircraft test weight was monitored and flown at 18,000 lbm (referred) using the constant  $W/\sigma$  method (also known as corrected weight) as discussed in Findlay, 1991. The aircraft was maintained within 2% of the target  $W/\sigma$  using standard shipborne hot fuelling procedures. For the HHRSD recoveries, a cable hauldown tension of 1,500 lbf was used as hover tension in the high and low hover, and 2,000 lbf tension was used to haul the aircraft down to the deck when the aircraft was ready to land. 4,000 lbf tension was used to hold the aircraft on deck after landing.

## **1.7 CONVENTIONS AND DEFINITIONS**

The following conventions and definitions were used in this report:

### **1.7.1 CAUTION**

A caution condition indicated that there was potential for damage to materiel.

### **1.7.2 COLOR CONVENTIONS**

The convention for the color of advisory or caution capsules and lights varied depending upon the publication referenced. The color conventions adopted were consistent with the military standard and indicative of the severity or nature of the information provided to the operator. The convention described in MIL-STD 1472D (1992) best suited this application and was used. In summary, the convention adopted makes use of red to depict stop, no or a danger condition, yellow to depict a caution condition, green to depict yes or go and white or blue to depict an advisory condition. Blue was selected as preferable over white in order to minimize the effect of glare. In addition, modulating the lights at a set interval was adopted as a convention used to draw the operator's attention to a danger or caution condition if it was appropriate (Woodson, 1992).

### **1.7.3 COMMAND INDICATIONS**

Command indications were any indications displayed to an operator that required compliance or action. An example of this sort of information was the wave-off signal given to pilot to indicate that the deck suddenly became unsafe and that the aircraft should abort the landing and circle.

#### **1.7.4 DANGER**

A danger condition indicated that there was potential for injury to personnel.

#### **1.7.5 DEFICIENCY CATEGORIES**

The deficiency categories are taken from the US Navy TPS Test Report Format (USN, 1996).

##### ***1.7.5.1 CATEGORY I***

Indicates a deficiency, the correction of which is necessary because it adversely affects:

- a) Airworthiness of the aircraft or system.
- b) The capability of the aircraft or system to accomplish its primary or secondary mission.
- c) The safety of the crew or the integrity of an essential sub-system. In this regard, a real likelihood of injury or damage must exist. Remote possibilities or unlikely sequences of events shall not be used as a basis for safety items.

##### ***1.7.5.2 CATEGORY II***

Indicates a deficiency of a lesser severity than a Category 1 which does not substantially reduce the capability of the aircraft or system to accomplish its primary or secondary mission, but the correction of which will result in significant improvement in the effectiveness, reliability, maintainability, or safety of the aircraft or system, or requires significant operator compensation to achieve the desired level of performance; however the aircraft or system being tested is still capable of accomplishing its mission with a satisfactory degree of safety and effectiveness.

### **1.7.5.3 CATEGORY III**

Indicates a deficiency which is minor or that appears too impractical or costly to correct in this model but which should be avoided in future designs. Included are violations of specifications for use by the contract negotiator in final settlement of the contract.

### **1.7.6 DELTA**

The delta was the circling pattern the aircraft flew while waiting for clearance to recover to the ship. The aircraft was flown at 200 ft above ground level (AGL) in a counterclockwise racetrack pattern at a speed of 80 kts.

### **1.7.7 DELTA HOVER ASTERN**

The delta hover astern (DHA) position was the position the aircraft would assume while waiting for final landing clearance. The aircraft was in the hover at approximately 65 ft AGL, 50 ft abeam and slightly aft of the flight deck.

### **1.7.8 EVOLUTION**

Any individual aircraft maneuver carried out with the ship. Examples would include the take-off, landing, fuelling and passenger transfer.

### **1.7.9 FIELD OF VIEW**

The field of view was the angular visual range of perception. E.g.: The cockpit field of view from an aircraft would be the range of all things that the pilot could see from the cockpit.

#### **1.7.10 FIELD OF REGARD**

The field of regard was what appeared in a fixed field. E.g.: The aircraft was outside the field of regard of the camera until the main wheels were over the deck.

#### **1.7.11 FORE/AFT ALIGNMENT LINES**

The Fore/Aft alignment lines (or "Bum Lines" as they are better known) are lines on the edges of the flight deck used by the pilots to determine the correct fore/aft position of the helicopter for landing. They are shown in Figure A-13.

#### **1.7.12 FRAME OF REFERENCE**

A frame of reference is a system of geometrical axes for defining position. Two frames of reference were used in this report: ship and free space. The frames of reference used the coordinate system shown in Figure A-11.

##### ***1.7.12.1 FREE SPACE FRAME OF REFERENCE***

The free space frame of reference is the reference frame that moves at the ship's speed, in the same direction as the ship, but was stationary in all other parameters with respect to the position of the center of the DLA during a quiescent period. In other words, it is a frame of reference that moves along with the ship at the same speed and in the same direction, but does not move with respect to the earth in other axes when the ship pitches, rolls or yaws.

##### ***1.7.12.2 SHIP FRAME OF REFERENCE***

The ship frame of reference is the reference frame around the ship. All parameters of the reference frame move with the ship. In other words, it is a frame of reference that moves along

with the ship at the same speed and in the same direction, and pitches, rolls and yaws with the ship.

#### **1.7.13 FREEDOCK RECOVERY SYSTEM**

The freedock-type recovery system uses an on deck trap to secure the aircraft probe on landing. It does not use a wire connection between the aircraft and the ship as in the hauldown recovery system (paragraph 1.7.14).

#### **1.7.14 HAULDOWN RECOVERY SYSTEM**

The hauldown-type recovery system uses a wire connection between the aircraft and the ship to steady the aircraft in the hover over the deck. As with the freedock-type recovery system (paragraph 1.7.13) the system utilizes an on deck trap to secure the aircraft probe on landing.

#### **1.7.15 LINE-UP LINES**

The line-up lines are the alignment lines on the hangar face and deck that the pilot used to help determine helicopter position laterally. They are shown at Figure A-13. When the pilot was on the line-up line, the aircraft's lateral position was over the center of the landing spot.

#### **1.7.16 LOST ACQUISITION**

Three amber chevrons on the PVCD illuminated to indicate that the HPSE was not acquiring the beacons and that accurate position information could not be provided. The lost acquisition signal illuminated when the aircraft was outside of the cameras' field of regard

#### **1.7.17 MESSENGER CABLE**

The messenger cable was a cable fed out from the aircraft through the main probe. It was used to retrieve the ship's end fitting from the ship for the HHRSD recovery, thereby attaching the aircraft to the hauldown system.

#### **1.7.18 POSITION INDICATIONS**

Position indications were any indications displayed to an operator that provided position information. An example of position information was the directional chevrons on the PVCD that showed fore/aft and port/starboard information to the pilot. The position information matrix is shown at Figure A-10.

#### **1.7.19 QUIESCENT PERIOD**

The quiescent period was the time during which the ship had the least motion. It was the safest time to conduct a deck landing

#### **1.7.20 RELATIVE WINDS**

Relative winds were winds with their direction taken relative to the aircraft. Winds from the right of the aircraft were termed "Green" winds. Winds from the left of the aircraft were termed "Red" winds.

#### **1.7.21 SHIP'S END FITTING**

The ship's end fitting was attached to the ship's wire tether and was designed to lock into the aircraft's main probe. The tether was routed through the bellmouth located in the center of the trap as shown in Figure A-4.

#### **1.7.22 STATUS INDICATIONS**

Status indications were any indications displayed to an operator that provided information on the state of the system observed. The indications were provided as an advisory to the operator. An example of this sort of information was the green light displayed to the pilot to indicate that he was cleared to land the aircraft.

#### **1.7.23 SHIP'S PITCH AND ROLL**

Aircraft and ship pitch and roll were measured with respect to level with positive pitch and roll being nose up and right wing low respectively.

#### **1.7.24 TRAPPED**

The aircraft was said to be trapped, when: for the RAST Mk III, the claw had secured the aircraft main probe; and for the HHRSD, the trap's opposing beams were closed around the aircraft's main probe. When the aircraft was trapped, it was secured to the deck.

#### **1.7.25 UNITS**

The units used throughout this report were a mixture of SI and Standard units, but were consistent with the standards used in aviation. They were as per Table B-4.

## **2 THE HUMAN FACTORS ASPECTS**

This section will outline the aspects of the human-machine interface for helicopter flight during the conduct of deck evolutions. The scope will concentrate on the psychological cuing aspects, but will also mention the physiological cuing aspects when they affect the pilot's ability to conduct the tasks.

### **2.1 GENERAL**

The operational utility of a helicopter deck recovery system for use on ships is determined by the size of the Ship Helicopter Operating Limitations (SHOL). The SHOL can be defined by aircraft, ship or pilot limitations.

#### **2.1.1 THE MACHINE**

The aircraft is free to move in six degrees of freedom: pitch, roll, yaw, surge sway and heave. Man interacts with the machine directly through the aircraft flight controls (the collective, the cyclic and the pedals) to control the aircraft response. Inputs through the flight controls are translated to pitch changes of the main and tailrotor blades. In the process they are modified by: a trim system to give a "feel" to the controls; a hydraulic system to reduce the effort required to move the controls against the aerodynamic forces of the blades; and stabilization equipment that modifies the response to more easily attain stable and predictable flight. These movements cause lift and unbalance the forces about the CG of the aircraft. Altering these unbalanced forces adjusts the aircraft attitude. Adjusting the attitude as desired controls the aircraft position and rate

of movement. Therefore, the aircraft position can be altered in space by changing the aircraft attitude. The pilot therefore uses attitude to control the aircraft during the deck landing evolution.

### **2.1.2 THE MAN**

Even though advances have been made in helicopter and ship designs, the pilot, has changed little. As a result, the edges of the envelope are being defined increasingly by human rather than aircraft and ship limitations. Also, as the ships and aircraft evolve, the pilot's interactions with these systems change. Human machine interface therefore plays a significant part in deck recovery system envelope definition. The analysis of human machine interface with specific systems is further complicated by the fact that each human is different. There are a lot of problems that may not affect one pilot, but would another. Experience and education are means used to optimize man's ability to visualize and interpret cues.

#### **2.1.2.1 VESTIBULAR SYSTEM**

The vestibular system is a multisensoral system that provides the pilot with equilibrium and balance information. When on the ground and not in the moving helicopter, it gives attitude information, maintains balance when he moves, maintains images fixed on the retina and is constantly adjusting and rectifying signals from the environment so that interaction can take place. The vestibular system coordinates information received from the eyes, the muscles of the trunk and neck and also from the limbs and constantly adjusts the muscles, limbs, neck and the trunk in such a way that the eyes are able to maintain the image fixed in the retina. In this way, the movement of the body is coordinated to maintain position on or move about the CG. Of all the stimuli processed by the vestibular nucleus, probably the most important is the peripheral

information received from the ear. The semicircular canals in the inner ear (see Figure A-14) act as accelerometers detecting angular acceleration while other sensors detect linear acceleration (gravity). Connections between both sides of the brain stem maintain a symmetrical and rectified vestibular function.

### **2.1.3 OUTPUT CHARACTERISTICS**

Once information is sensed and processed, messages are sent to the muscles and a feedback system helps to control their actions. The effectiveness of the pilot's outputs depends on several factors, which include the quality of the feedback, the mechanical characteristics of the flight controls, the effectiveness of the aircraft stabilization equipment, the dynamics of the ship, and the environmental conditions. During the testing, there was no attempt made to change these factors. Instead, the effectiveness of the pilot output was quantified in the form of pilot workload to conduct a set tasks discussed in Section 3. Each task, such as the high hover position-keeping task, the transition to landing task, etc., had criteria against which they were tested and quantified using the Cooper Harper Rating Scale (Table B-7). The pilot workload was used as a measure of the output characteristics. Changes to human factors elements were based on these output characteristics.

## **2.2 DECK LANDING AND TAKE-OFF TASK ANALYSIS**

Although the task of positioning and landing an aircraft on a moving ship is rather complicated, it can be simplified by breaking it into two task elements: position keeping and transitioning from one position to another.

### **2.2.1 POSITION-KEEPING**

Position keeping involves maintaining the aircraft in the desired position for the task. The three positions identified for the purpose of the trial were the DHA position, the high hover, and the low hover. All position-keeping tasks rely on the pilot to be able to maintain position with respect to the ship, albeit with varying tolerances depending on the evolution. Tighter tolerances are required in the low hover than in the high hover. In the high hover, the aircraft need only maintain an approximate position from which it is suitable to descent to the low hover. In the low hover, however, the aircraft must be in the correct position and be stationary with respect to the ship to initiate the landing.

### **2.2.2 TRANSITION BETWEEN POSITIONS**

The transition between positions requires the pilot to assess position information and rates of closure. For the landing task, transitions are required between the DHA position to the high hover, from there to the low hover and from there to landing. For the take-off, transitions are required from the deck to the high hover and from there to departure. Tolerances for the transitions were, in general, looser than for the position keeping tasks.

### **2.2.3 FRAMES OF REFERENCE**

#### ***2.2.3.1 FRAMES OF REFERENCE IN THE DECK LANDING TASK***

Information on position and rates of closure gathered using the visual cues discussed in Section 2.3.2 must be further processed to correct for frame of reference. There are essentially two frames of reference used in the deck landing task. The ship frame of reference (see paragraph 1.7.12.2) is used for position cues. The aircraft must land on the ship, therefore, the position of the aircraft

with respect to the ship is important. The position of the aircraft, however, is controlled by the aircraft attitude, and this is altered with respect to the free space frame of reference (see paragraph 1.7.12.1). In other words, if the pilot wants to alter aircraft position with respect to the ship, he must consider the aircraft attitude in free space and not the aircraft attitude with respect to the ship. If the pilot used the ship as the aircraft attitude reference, and attempted to maintain a constant attitude with respect to the ship, small ship rolls would result in an equivalent aircraft roll. Unlike the ship, which alters position independent of roll angle, the aircraft alters position dependant on this angle. A ship roll would cause the aircraft to fly away from the ship. Essentially, this means that although it is important to position the aircraft with respect to the ship frame of reference, aircraft attitude with respect to the free space frame of reference must be used to correct or maintain aircraft position.

#### **2.2.3.2 CHOOSING CUES APPROPRIATE TO THE FRAME OF REFERENCE**

Choosing cues appropriate to the frame of reference is easy when considering the ship's frame of reference. Any part of the ship that can be seen by the pilot can be used as a visual cue. The pilot chooses the cue appropriate to the task to be carried out (see Section 2.3.2). The pilot, however, is provided with much less to choose from to determine the aircraft's orientation with respect to the free space frame of reference. The SHRS and the natural horizon (when visible) are the only cues available. Although they cue the pilot to the orientation of the reference frame, they do not supply any position information to help him determine the anticipated position of the DLA during the quiescent period. In the case of the SHRS, misleading position information is provided. Because the SHRS moves laterally in the ship's frame of reference as the ship rolls, the position of the SHRS cannot be used to determine position of the DLA in the free space frame of reference. The

pilot is therefore required to integrate the attitude information from a free space frame of reference with the position information from the ship frame of reference, causing confusion, especially with inexperienced pilots.

## **2.3 VISUAL PERCEPTION**

In order for the pilot to be able to accurately position the aircraft, or move between positions, he had to interpret the aircraft position from the limited cues available to him in the shipborne environment. Man possesses a vast system for collecting information to complete this task. He has means for sensing light, sound, smell, taste, movement, touch, heat and cold. All of man's senses are subject to degradation for one reason or another, and the helicopter cockpit is an environment which limits and alters almost all information that is characteristically provided to him. The moving glass and metal enclosure masks normal environmental auditory cues, modifies movement with vibration of varying amplitudes and frequencies, and limits the FOV. Parts of the environment are further distorted because the ship and the aircraft landing on it both operate in different mediums yet are required to interface to execute a deck landing. Man depends heavily on visual perception to execute deck operations. The means by which he processes the information provides useful insight into how the deck landing can best be carried out. It also determines what must be supplied to the pilot to allow him to do his task.

### **2.3.1 VISUAL INFORMATION PROCESSING**

#### **2.3.1.1 GENERAL**

Visual perception involves the eyes, the balancing mechanism of the ear (the vestibular apparatus) and the brain. Maintaining an aircraft stationary in space over a flight deck that is rolling beneath

him gives the pilot a strange sensation. This is because conflict has arisen between the visual message, which says that the aircraft is moving, and the vestibular apparatus and muscular reflexes, which say that no abnormal acceleration has been experienced and that no correction was required to maintain balance. The reason that the information can be processed despite the confusion is because perception is influenced by past experience as well as being forward looking and predictive (Hawkins, 1989). Deck landings would not be possible without this sort of visual information processing. When prediction is not possible, however, response suffers a delay. This is evident when deck landings are attempted in turbulent conditions. The aircraft reacts unpredictably and corrections that are applied can often be ineffectual or counterproductive, depending on the length of the delay. The pilot is out of phase with the aircraft and he can produce unwanted oscillations. These are commonly called Pilot Induced Oscillations (PIO). During PIO, the pilot's visual information processing power is often maximized and the physical output capabilities have been exceeded. This is a readily recognizable endpoint in flight testing and results in an endpoint due to pilot workload.

#### **2.3.1.2 OBJECT PROPERTIES**

Perception is greatly influenced by what we have come to believe about the properties of the object we are viewing and also by what we expect the properties to be by the time we have to respond to them. Different components of the body's sensing and processing systems are involved in this activity. The interaction is such that the eye has been described as an outgrowth of the brain (Hawkins, 1989). The retina contains typical brain cells between the light receptors and the optic nerve and these modify the electrical activity of the receptors themselves. Some of the processing of visual information, then, is occurring in the eye itself. It is as though a specialized

part of the brain surface has been transferred a short distance away to the rear of the eye. Objects themselves are not uncertain or ambiguous and the image of the objects is usually produced faithfully on the retina – inverted and reversed. Uncertainty and ambiguity only occur when the brain processes this correctly sensed information. The visual input is then combined with other information based, for example, on learning, experience and expectation. (Hawkins, 1989)

### **2.3.1.3 VISION AND VISUAL ILLUSIONS**

#### **2.3.1.3.1 FASCINATION**

A significant influence associated with the performance of visual tasks is called fascination. This refers to the failure to respond to a stimulus even though it is within the normal visual field. This phenomenon generally arises from one of two causes. Firstly, the observer may be concentrating so much on one part of the visual task that he fails to respond to another more important task or contradictory information. This could easily happen when the pilot uses the PVCD for position information and he ignores the aircraft attitude and compounds the difficulty involved with the position-keeping task (see paragraph 3.1.4.1.2). Secondly, the observer may adopt a trance-like concentration on a display, receive the message, but not respond to it. This phenomenon of fascination was evident when using the PVCD during high pilot workload tasks (see paragraph 3.1.4.1.1).

#### **2.3.1.3.2 SET**

When perception is influenced by expectation this is sometimes called set. In flying operations it can result in misinterpreting a display or other errors. This phenomenon was seen as a tendency to drift forward on take-off (see paragraph 3.2.1.1.1) and drift aft on landing (see paragraph

3.1.3.1.2). The common saying that one sees what one expects to see is a reflection of this phenomenon (Hawkins, 1989).

#### *2.3.1.3.3 DEPTH AND DISTANCE ASSESSMENT*

Judgement of depth and distance is an important perceptual ability that people possess. This ability is essential to the deck landing task. A number of cues are used to aid in accurate depth perception such as binocular vision, perspective, apparent movement of the object, superposition, relative object size, height of the object in a plane, and texture gradient (Hawkins, 1992). The flight deck environment provides these cues to varying degrees. The most effective of these are the SHRS, hangar top, hangar face and flight deck. Without conscious effort, the pilot is able to integrate and process the information provided by the above listed cues and makes an assessment of distance from the hangar and height. For instance, the pilot realizes that he is in the correct position in the high hover when: the hangar appears to have the appropriate shape; the SHRS obscures the appropriate part of the superstructure and hangar top; the objects appear where expected in the windscreen; and the texture is consistent with what is expected at that distance from the hangar. The line-up markings on the hangar face and the flight deck provide additional information that enhances perspective and make apparent movement more obvious. The effectiveness of these objects to enhance perception is demonstrated during night deck landings. Objects that are characteristically used to provide depth and distance information are either partially visible or have their perspective altered by shadows or unbalanced illumination. The pilot is easily confused and must select alternate visual cues and re-process the information provided by these cues to carry out effective deck operations.

#### **2.3.1.3.4 HEIGHT PERCEPTION**

The windshield location of an observed object, such as the PVCD, can lead to a misjudgment of height. The PVCD will appear at the same spot on the windscreen when the aircraft is high with a nose down attitude, as it will when the aircraft is low with a nose up attitude. This was particularly relevant when conducting deck landings involving high pilot control activity. This characteristically resulted in large attitude changes and degradation in height control (see paragraph 3.1.4.1.1).

#### **2.3.1.3.5 RELATIVE OBJECT SIZE**

The size that an object is perceived to be is dependent on its color and the color of the background. It is therefore best to be cautious when the size of an object is used to provide position cues. This phenomenon is a contributing factor to the misinterpretation of aircraft position when the aircraft is flown at night. Even though the same cues are used, the background is different. Pilot workload increases accordingly.

### **2.3.2 VISUAL CUES**

#### **2.3.2.1 GENERAL**

The specific attributes of a graphical object help make it distinct from other objects and help the brain to make assessments of the external environment. In normal circumstances, there are numerous clues to the size and the distance of objects. We learn to expect familiar objects at a certain distance to subtend a certain visual angle, and if the visual angle is less than expected, we will see the object as being further away (O'Hare, 1990). The object fill and the geometric outline of the object are characteristics that are processed easily. The properties of a fill that are readily

processed are things such as hue, saturation, brightness, contrast and texture. These cues help to identify the object and make it unique from others around it. Spatial cues are provided by the object's border. The characteristics most easily processed include length, size, shape, orientation, symmetry, foreground/background, angle and distance between objects. These cues, when combined with special 3 dimensional cues such as perspective, motion and occlusion, enable a pilot to orient himself to the environment and make such assessments as the position, rate of movement and attitude of the aircraft. It is for these reasons that the cues provided by the hangar face are unique to those that are provided by the flight deck or other objects.

#### **2.3.2.2 CHARACTERISTICS**

The utility of a visual cue is determined by the characteristics attributed to it. The visual cues discussed previously are ordered below. The higher the order, the more useful the information.

##### **2.3.2.2.1 NOMINAL**

Hue, texture, form, foreground, background, and distance are nominal cues. In other words, the cues name a characteristic that makes the object described unique, but attributes no value to it on a scale.

##### **2.3.2.2.2 ORDINAL**

Brightness, saturation, length, size, occlusion, contrast and hue (with a scale) are ordinal cues.

Each of these cues defines the characteristic's place in a series.

#### **2.3.2.2.3 QUANTITATIVE**

Position, orientation, angle, length (with a scale) and distance (with a scale) are quantitative cues.

These cues can be measured or are measurable by quantity.

## **2.4 DISPLAYS**

A display is any means of presenting information directly and it usually makes use of the visual, aural or tactual senses. The focus of this assessment is based on the visual cues, so the scope of the investigation will be limited to visual displays. The purpose of a display used by a pilot is to transfer information about some aspect of the task accurately and rapidly from its source to the brain of the pilot, where it is then processed. This introduces the first major human factors problem area. The human sensory capacity is enormous but the human information transmitting rate is very limited, as is man's short-term memory capacity. This imbalance results in a bottleneck arising when the information that is being fed to the brain is being filtered, stored and processed (Hawkins, 1989). This is of fundamental importance in the design of visual displays. The display must not only present information, but also present it in such a way as to help the brain in its processing task. Furthermore, it is of little use to display more information than the pilot will be able to use, or display the information in a location that would be difficult for the pilot to see.

### **2.4.1 TASK INFORMATION REQUIRED**

MIL-STD-1295A (AV), the standard for displays and display symbology used by the US DOD and other military organizations, outlines what visual information must be provided to the pilot to complete deck evolutions. Hovering, position keeping and transition from one point to another

are demanding tasks and the pilot relies almost exclusively on visual cues to orient himself and complete the assigned task within the required tolerances. To do this, the MIL-STD outlines what a display must have to allow the pilot to perform the task. The information required from a display is also required from the "real world." It is stipulated as follows:

#### **2.4.1.1 HOVER**

The hover requires the following:

##### **2.4.1.1.1 HELICOPTER LINE OF SIGHT REFERENCE**

A reference is required that indicates where the aircraft is pointing. Without this information, the pilot can easily yaw off the relative heading. The pilot used the perspective of the line-up lines and the deck and hangar geometry to align the aircraft.

##### **2.4.1.1.2 SENSOR LINE OF SIGHT REFERENCE**

The sensor line of sight is automatically determined in the case of the pilot by way of his vestibular apparatus. The pilot, for instance, can tell that when he is looking slightly off-axis with his eyes to view an object, where that object is in relation to him.

##### **2.4.1.1.3 HEADING INFORMATION**

Heading information, although vital to a display, is not required for the deck evolution.

##### **2.4.1.1.4 SPEED INFORMATION**

Speed can be determined by using the rate of change of perspective and the rate of movement of objects in the pilot's FOV.

#### **2.4.1.1.5 ALTITUDE INFORMATION**

Altitude information, or more appropriately height information, is determined from the deck and hangar geometry.

#### **2.4.1.1.6 VERTICAL VELOCITY INFORMATION**

Vertical velocity information is determined by the pilot from the rate of change of the altitude information.

#### **2.4.1.1.7 SIDESLIP INFORMATION**

Sideslip information is provided indirectly from the "seat of the pants" sideforce cues.

#### **2.4.1.1.8 PERFORMANCE MANAGEMENT INFORMATION**

It is difficult to manage performance information and maintain the aircraft in position simultaneously when in adverse conditions. For that reason, deck operations are designed to operate to a SHOL that ensures the performance margins required to complete the task are available.

#### **2.4.1.1.9 VELOCITY VECTOR**

The velocity vector has been implemented quite successfully on heads up displays (HUD) as well as night vision goggles (NVG). It provides aircraft velocity information that is easy to produce symbolically on a display. The pilot can formulate the same information provided by the velocity vector, but with much less accuracy. The accuracy of this information, however, is adequate for the pilot to perform the deck landing task.

#### ***2.4.1.1.10 ACCELERATION CURSOR***

An acceleration cursor provides information on the aircraft's normal acceleration. This is required for the initial development of the SHOL, but is not required by the pilot for the execution of the operational deck landing task. The pilot can formulate the same information provided by the acceleration cursor, but with much less accuracy. The accuracy of this information, however, is adequate for the pilot to perform the deck landing task.

#### ***2.4.1.2 POSITION-KEEPING***

Position-keeping requires the same parameters as the hover outlined in Section 2.4.1.1 with the addition of a position reference.

##### ***2.4.1.2.1 POSITION REFERENCE***

When the PVCD was used, the directional chevrons supplied position information. Without it, the pilot used the perspective of the line-up lines and the deck and hangar geometry to determine aircraft position.

#### ***2.4.1.3 TRANSITION BETWEEN POSITIONS***

In order to carry out a transition between positions at variable low speeds and altitudes, a horizon reference was required in addition to the information required for the hover as outlined in Section 2.4.1.1. Due to the unique environment experienced for the deck landing task it could quite easily be argued that the horizon reference was required for position-keeping as well as transition between positions.

#### **2.4.1.3.1 HORIZON REFERENCE**

The horizon reference was supplied by the SHRS.

#### **2.4.2 SITUATION DISPLAYS**

Situation displays such as the PVCD can be oriented in one of two ways. They can either display the position of the aircraft with respect to the desired position, or display the correction that the pilot has to apply to get to the desired position. The conceptual dilemma associated with the display orientation is usually solved during flight testing and it depends a lot on the way that the display is to be used. The PVCD displays the actual position with respect to the desired position, but also displays the correction required, by means of directional chevrons pointing in the intended direction of flight.

#### **2.4.3 MULTIFUNCTION DISPLAYS**

A multifunction display is one that is capable of displaying more than one menu of information. The PVCD would be classed as a multifunction display, although it is not necessarily operator selectable as is the norm. Instead, the display mode of operation was selected by the LSO, and the display would show information relevant to the mode selected. The PVCD was able to display command, position and status information, although it never displayed any combination of them simultaneously. The pilot was required to process the information provided by the display and interpret when the type of display information had changed. Design of displays providing such a wide variety of information must take into account the pilot's ability to process the information provided. The display must present information in such a way that confusion is avoided, especially while the pilot is carrying out critical or high gain tasks. Problems of this sort were

found with the PVCD when the command, position or status information being displayed was not easily interpreted or was confused with other information due to inappropriate cues or pilot expectation (see section 3.3.2).

#### **2.4.4 INCORPORATION OF ALERT AND WARNING SYSTEMS**

A useful function of a display is to provide alerts and warnings to the pilot. In grouping these signals in degrees of urgency, the highest priority reflects an emergency condition. The term 'warning' is used and the color coding is red. This implies that immediate action is required for the safety of the aircraft. This condition would exist if the aircraft were too close to the hangar and risked striking its blades. A second level of priority implies an abnormal condition that could become an emergency if neglected. Usually the term 'caution' is used here and the color code is amber. This coding was used to display aircraft position near the edge of the DLA. A third level of urgency involves a condition where some response is required. An example of this would be the "Charlie" signal which indicates that the deck is clear and that the aircraft can approach and land. A final and low urgency level is associated with alerts which provide information but where no special action is required. An example of this would be the trapped indication on landing. The colors displayed for these last two groups is not very specific but is often blue, white or green.

#### **2.4.5 BASIS FOR COLOR SELECTION**

It is important to note that tradition rather than research has established the colors used. The eye is most sensitive to light in the middle of the spectrum and least sensitive to light in the outer part of the spectrum. It would follow that the colors that could get the pilot's attention urgently would

be used to display the higher alert states and that colors that did not attract the pilot's attention as easily would be used to signify less urgent tasks. However, this was not the case as green is located in the middle of the spectrum and red is located in the outer part of the spectrum. The selection of color for the PVCD, therefore, was not straight forward especially considering the great variety of information provided.

## **2.5 GUIDANCE, CUING AND PROMPTING FEEDBACK MECHANISMS**

Displays provide valuable information that gives continual feedback of the pilot's performance. This is usually in the form of guidance, cuing and prompting (Hawkins, 1992).

### **2.5.1 GUIDANCE**

Guidance feed back involves physically controlling or guiding movement. This cannot be done visually and therefore cannot be used by the PVCD. The HHRSD, however, provides guidance in the form of the centering effect with the hauldown cable (see paragraph 3.1.2.3.1 for more detail). Guidance is often used in tasks where errors could have undesirable or dangerous consequences. This is one reason why the HHRSD is preferable to the RAST Mk III for the dangerous deck landing task.

### **2.5.2 CUING**

Cuing tends to be restricted to perceptual detection tasks and involves providing the pilot with information that gives him an increased situational awareness of the task or environment. Almost all information provided by the PVCD is cuing information.

### **2.5.3 PROMPTING**

Prompting usually involves having a response take place immediately after the stimulus. Again, a visual display cannot elicit this type of feedback.

### **3 RESULTS, DISCUSSION AND CONCLUSIONS**

In order to compare the systems, they were investigated during the landing and take-off tasks in sections 3.1 and 3.2 respectively. Section 3.3 discusses items that were found during a combination of several evolutions. General conclusions that could be gathered as a result of the testing are discussed in section 3.4.

#### **3.1 THE LANDING EVOLUTION**

The landing evolution is broken down into the individual phases of flight required to take the aircraft from the DHA position to the landing.

##### **3.1.1 LATERAL MOVEMENT FROM DHA TO THE HIGH HOVER**

The landing evolution began with the transition from the DHA to the high hover.

###### **3.1.1.1 RAST MK III**

###### **3.1.1.1.1 WITHOUT PVCD POSITION INFORMATION**

PVCD position information was not available to the pilot until the aircraft's main rotor was over the flight deck. The first part of the transition was done without the PVCD position cue information. Moving the aircraft laterally from the DHA to the high hover maintaining the desired height  $\pm 5$  ft, and the approach angle and heading  $\pm 5^\circ$  was easy in both benign (HQR 1-2) and adverse (HQR 3-4) conditions. Initially, the pilot used the ship's superstructure, the hangar face and the flight deck to determine position, height, approach path and closure rate. The provision of distinct cues outside of the pilot's primary field of view (FOV) such as the horizon and the water surface helped spatial orientation and simplified the task; the overall workload was

decreased by 1-2 on the HQR scale with these cues in adverse conditions. Lateral movement from DHA to the high hover without PVCD information was satisfactory.

#### ***3.1.1.1.2 WITH PVCD POSITION INFORMATION***

Once the aircraft was over the flight deck and in the field of regard (FOR) of the HPSE, the pilot transitioned to using the PVCD as the primary position cue. The transition was easy using the PVCD set for the DLA size outlined in paragraph 3.3.5. The display provided predictable information consistent with other position and rate visual cues provided by the hangar face and to a lesser extent the hangar top. For almost all approaches to the high hover position, the pilot established the aircraft laterally on centerline prior to easing the aircraft forward to the correct position. That way, the pilot was ensured of adequate rotor clearance from the hangar. Lateral movement from DHA to the high hover with PVCD information was satisfactory.

#### ***3.1.1.2 HHRSD***

Transition to the high hover with the HHRSD was carried out using the same tolerances as the RAST evolution at paragraph 3.1.1.1. Since the HHRSD did not have a visual cues display, the initial approach was the same as the RAST approach until the aircraft's main rotor was over the flight deck. From this position, the pilot then used the hangar face and top, and to a lesser extent the flight deck as the primary position cues. The transition was easy. The position and rate visual cues provided by the hangar top and hangar face (especially the line-up lines on the hangar face (see Figure A-13)) were adequate, and resulted in an approach similar to that flown for the RAST Mk III. The HHRSD system was satisfactory for this evolution.

### **3.1.2 POSITION-KEEPING IN THE HIGH HOVER**

Once established in the high hover, the pilot concerned himself mainly with the position-keeping task.

#### **3.1.2.1 RAST MK III**

In the high hover, the pilot used the PVCD and the aircraft's relative proximity to the hangar face and the hangar top to determine the aircraft's position over the flight deck. The pilot attempted to maintain the aircraft heading  $\pm 5^\circ$ , the position in the center of the inner DLA and the height  $16 \pm 4$  ft. This could be accomplished with ease in benign conditions (HQR 2-3). In adverse conditions, however, this task was difficult (HQR 5-7) and revealed problems associated with using the PVCD as the primary position reference as shown in the sub-paragraphs below.

##### **3.1.2.1.1 APPARENT DLA POSITION DURING SHIP'S ROLL**

During large ship rolls (greater than  $6^\circ$ ) it was apparent to the pilot that position cues from the PVCD were inconsistent with other position cues gained from using the hangar top, hangar face and superstructure. This was brought about because of the mode of operation of the position algorithm in the RAST Mk III. It depicted the DLA with respect to the ship's frame of reference instead of the free space frame of reference (see section 1.7.12). However to maintain aircraft control during ship's roll, the pilot was required to maintain the aircraft in approximately the same position in free space (see Figure A-15), causing a disparity in the visual cues gained from the ship when compared to the PVCD – a situation confusing to the pilot. Following the display could cause PIO (see paragraph 3.1.2.1.1.1) and would affect the pilot's ability to carry out an

effective deck landing. The apparent DLA position during ship's roll was a Part I deficiency and must be corrected. Some possible corrections are discussed in section 3.1.2.1.1.2.

#### *3.1.2.1.1.1 MAGNITUDE OF OVERCORRECTION*

In the case of an aircraft in a 16 ft hover in a 10° roll right, the PVCD will give the pilot an indication of being just under 1 m left of the desired position. If the pilot reacts to correct this, he must roll right. Because the aircraft rolls about its CG, a position near the center of the nose of the aircraft, this would result in a further displacement of the probe. In the case of an aircraft using 10° angle of bank (AOB) to correct for the indicated probe position, this would result in an additional display error of 0.3m, exacerbating the existing condition. As the ship roll changed from right to left, a pilot following the PVCD indications could enter PIO and would probably not be capable of carrying out an effective deck landing.

#### *3.1.2.1.1.2 CORRECTION FOR APPARENT DLA POSITION DURING SHIP'S ROLL*

Some possible corrections for the incorrect apparent DLA position during ship's roll are discussed below. The solutions that would be easiest to implement and most practical in their solution are as follows:

##### *3.1.2.1.1.2.1 Pilots Ignoring the Display*

The nature of the display and its prominent position in the field of view would make it difficult to ignore. Also, there is potential for an optimized display to decrease the pilot's workload in adverse conditions – especially conditions of high roll. This is not the preferred option, but was the option adopted by the test pilots during the trial. When the pilot had flown with the display in this configuration for approximately five to ten landings in adverse conditions, he was able to

process the information displayed and use it to aid in deck landing position cuing. Inexperienced pilots, however, would have to be warned of the condition. Flight test showed that this condition did not manifest itself in rolls less than  $5^{\circ}$ . The following caution must therefore be included in the pilot's flight manual.

Caution:

*When in the high hover, the PVCD displays misleading position information during ship's rolls. Pilot induced oscillations or in extreme cases, loss of control of the aircraft could occur if the position information from the PVCD is used in the high hover when the ship's roll is greater than  $5^{\circ}$ .*

#### 3.1.2.1.1.2.2 Disabling the Display

Disabling the display when high rolls are encountered should be considered when inexperienced pilots are to use the system in adverse conditions. As it is in these adverse conditions that the display would be most beneficial, this should only be considered a temporary measure and is not the preferred option.

#### 3.1.2.1.1.2.3 Modifying the Display

A solution that should be relatively easy to implement would be to modify the position sensing algorithm to account for the ship's roll – a parameter already recorded and used in the solution. The position algorithm could be adjusted to implement the simple trigonometric relationship that would correct the position of the DLA in the opposite direction of the roll by the sine of the roll angle times the aircraft height (a parameter already calculated). In other words, the displayed

DLA would be with respect to the free space frame of reference rather than the ship's frame of reference. This would be the preferred option.

### **3.1.2.2 HHRSD HOOK-UP SEQUENCE**

The hook-up sequence is described in paragraph 1.4.1.2. In the high hover, the pilot used the aircraft's relative proximity to the hangar face and the hangar top to determine the aircraft's position and orientation over the flight deck. The pilot attempted to maintain the aircraft heading  $\pm 5^\circ$ , the position approximately in the center of the DLA and the height  $16 \pm 4$  ft. This could be accomplished with ease in benign conditions (HQR 2-3). In adverse conditions, however, this task was more difficult (HQR 4-6) but easier than maintaining position with the RAST system (HQR 5-7 from paragraph 3.1.2.1) due in part to the absence of distracting display cues (paragraph 3.1.2.1.1) and the loose position keeping tolerances required for the sequence. The HHRSD hook-up sequence was satisfactory.

### **3.1.2.3 HHRSD POSITION KEEPING IN THE HIGH HOVER**

In the high hover, the pilot used the same cues as during the hook-up sequence. The pilot attempted to maintain the aircraft heading  $\pm 5^\circ$ , the position approximately in the center of the DLA and the height  $16 \pm 4$  ft. This could be accomplished with ease in benign conditions (HQR 1-2). In adverse conditions, however, this task was more difficult (HQR 3-5) but made easier than maintaining position with the RAST system due to the factors previously mentioned in the hook-up sequence (paragraph 3.1.2.2), as well as the centering effect provided by the tensioned cable. This is further investigated in paragraph 3.1.2.3.1 below. The HHRSD hook-up sequence was satisfactory.

#### 3.1.2.3.1 HHRSD CENTERING EFFECT IN THE HIGH HOVER

The centering effect of the HHRSD is a net effect causing the aircraft to center over the trap because of the forces imparted by the hauldown cable. It is shown in Figure A-17. Consider the aircraft in position ②, slightly right of the ideal landing position. Prior to the cable tension being applied it is level. Once tension is applied, several forces and moments are changed on the aircraft to modify its position and attitude. These elements (using the coordinate system in Figure A-16) include the cable longitudinal, lateral and normal forces ( $X_{\text{cable}}$ ,  $Y_{\text{cable}}$  and  $Z_{\text{cable}}$  respectively), the aircraft rolling moment  $L$  induced by  $Y_{\text{cable}}$ , and resisted by the ASE, and the displacement of the aircraft CG position induced by  $X_{\text{cable}}$ ,  $Y_{\text{cable}}$  and  $Z_{\text{cable}}$ . The net result is an initial unbalanced force down and to the left (increases the  $Z_{\text{CG}}$  and decreases  $Y_{\text{CG}}$ ) and induces a rolling moment (increases  $L_{\text{AIRCRAFT}}$ ). Left unchecked by the pilot, the aircraft would have a tendency to roll right and move left as well as descend. The pilot is, however, in the loop and corrects the descent rate and the roll to assume a normal hover attitude for the relative winds. This brings the aircraft over the trap. He does this instinctively due to the sudden attitude change seen as the change perspective of the visual cues as well as awkward sideforce cues felt in the seat of the pants<sup>2</sup>. It is also registered in the pilot's vestibular system. The pilot reacts instinctively to correct the linear and angular accelerations. This is an action natural to helicopter pilots. When an untethered aircraft is in the hover, the pilot counters any change in aircraft attitude since

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<sup>2</sup> When learning to fly, the pilot quickly discovers that in order to control position of the aircraft in the hover, he must control the aircraft attitude. The pilot is quick to correct small changes in aircraft attitude to maintain a steady hover.

experience tells him that attitude changes cause the aircraft to move in the direction of the attitude change. As discussed at Section 2, the pilot is quite sensitive to these changes. The overall effect of the cable tension is that it is relatively easy for the pilot to maintain aircraft position in the high hover. This is due to the proprioceptive cues given to the pilot and the increased aircraft static stability and decreased susceptibility to gust responses.

### **3.1.3 TRANSITION FROM THE HIGH TO THE LOW HOVER**

After establishing the aircraft in the high hover, it was necessary to lower the aircraft to the low hover. This broke up the landing task and allowed the pilot to establish the aircraft in a position from which a landing could be executed.

#### **3.1.3.1 RAST MK III**

Moving the aircraft from the high hover to the low hover maintaining the aircraft over the DLA at a descent rate not exceeding 5 ft/s and aircraft heading  $\pm 5^\circ$  was easy in both benign (HQR 1-2) and adverse (HQR 3-4) conditions since it was conducted during a quiescent period. The pilot was able to accurately determine the quiescent period using the SHRS and outside horizon, but was not always able to descend during this narrow window of opportunity in adverse conditions due to the workload associated with maintaining the aircraft in the high hover. The effect of the quiescent period on landing is further investigated at paragraph 3.1.3.1.1. Once the decision was made to land, attention was focussed on the PVCD, the hangar face and the flight deck to determine position, height, and aircraft relative heading. As the aircraft descended, the PVCD climbed in the windscreen. To arrest the rate of descent, his attention had to be focussed downwards. The PVCD was increasingly more difficult to use as the aircraft approached the low

hover. There were difficulties associated with using the PVCD as the major position cue (see paragraph 3.1.4.1.2), but these problems were only partially developed during the transition, and did not fully develop until the aircraft was in the low hover. His attention was redirected to the hangar face and the flight deck to determine position, height, rate of descent and aircraft relative heading. There were no problems associated with the transition from one set of visual cues to another in descent. Just prior to reaching the low hover height, the interface between the hangar face and the flight deck came into view in the main windscreen. This allowed the pilot to arrest the rate of descent predictably. Although the evolution was easy to do, there was a slight tendency to drift aft on descent. This was corrected by the pilot in the low hover and had no adverse affect on the transition. It is discussed in further detail at paragraph 3.1.3.1.2. Despite the slight tendency to drift aft on descent, the RAST Mk III system was satisfactory for this evolution.

#### *3.1.3.1.1 EFFECT OF THE QUIESCENT PERIOD ON LANDING*

Although numerous attempts have been made to predict ship motion electronically with the aim of providing the pilot advance warning of the approaching quiescent period and its anticipated duration, practically there has only been limited success. The problem lies in the fact that the ship motion is very difficult to predict until just before the event since it is the interaction between the ship and the water surface which can result in random ship motion. The system anticipated for use with the RAST Mk III used a sample of the ship's motion over time and determined deck motion from this pattern. The system, however, was not mature enough to trial. Other systems in use determined the dynamic energy the deck possessed and used this to determine when the motion would remain low for a given period. The Bombardier Landing Period Designated used

this concept. Although none of these systems was used for the trial, the pilot used the same principles of information processing to determine when the deck was steady and would remain so for a period required to complete the landing. Experience has shown that the steady period can be as long as 10 seconds but is frequently shorter, and that there is little warning to when the deck motion will be suitable for a deck landing. Since landings can only be carried out safely during a quiescent period, there is a direct relationship between the amount of time required by the pilot to attain the correct aircraft position in the high hover and his ability to land the aircraft. The HHRSD required less work from the pilot in the high hover than did the RAST (see paragraphs 3.1.2.1 and 3.1.2.3), making the landing sequence easier to execute with the HHRSD.

#### *3.1.3.1.2 TENDENCY TO DRIFT AFT ON DESCENT*

The slight tendency to drift aft on descent was likely attributable to two things: the aircraft mechanical characteristics and the PVCD layout. The pilot's collective and the cyclic controls were interlinked. When the pilot decreased the collective pitch, the rotor disk was cyclically pitched aft, causing the aircraft to drift aft if left unchecked. The tendency although slight, resulted in approximately 2 ft drift aft from the high hover to the low hover. The pilot allowed this to go unchecked due to his perception of the information displayed on the PVCD layout. Fore/aft position information was displayed by up/down indications on the display (see Figure A-9). In other words, the pilot was required to interpret the aircraft x-axis position in the real world from information displayed on the z-axis on the display. Although this is something that is commonly done for displays such as hover indicators, displaying height information in the z-axis is also commonly used for displays such as Instrument Landing System (ILS) glideslope indicators. The tendency to drift aft was not apparent when using the HHRSD (see paragraph

3.1.3.2). This would suggest that the pilot could readily interpret information in both ways. It was natural for him to assume that when the illuminated chevrons moved progressively down the display, it was indicating decreasing height. This tendency was slight and was easily corrected in the low hover. The tendency to drift aft on descent was satisfactory.

#### **3.1.3.2 HHRSD**

Moving the aircraft from the high hover to the low hover maintaining the aircraft over the DLA at a descent rate not exceeding 5 ft/s and aircraft heading  $\pm 5^\circ$  was easy in both benign (HQR 1-2) and adverse (HQR 2-3) conditions. This was due to both the centering effects of the HHRSD cable and the time at which it was carried out – the quiescent period. The pilot was able to accurately determine the quiescent period using the SHRS and the outside horizon (if visible). Also, because of the comparatively lower workload associated with the HHRSD, the pilot was more frequently in a position to descend in this narrow window of opportunity (see paragraph 3.1.3.1.1). Once the decision was made to land, attention was focussed on the hangar face and the flight deck to determine position, height, and aircraft relative heading. Just prior to reaching the low hover height, the interface between the hangar face and the flight deck came into view in the main windscreen. This allowed the pilot to arrest the rate of descent predictably. The evolution was easy to do, and there was no marked tendency to drift aft on descent as was seen with the RAST (see paragraph 3.1.3.1.2). The HHRSD system was satisfactory for this evolution.

#### **3.1.4 LOW HOVER**

The low hover was the final stage prior to the landing. The pilot used his time in the low hover to establish the aircraft in a position from which a landing could be executed.

#### **3.1.4.1 RAST MK III**

In the low hover, the pilot used the hangar face, the line-up lines, the fore/aft alignment lines, and to a limited extent the PVCD to determine the aircraft's position with respect to the DLA. The pilot attempted to maintain the aircraft heading  $\pm 5^\circ$ , the position in the DLA with no lateral drift and the height  $5 \pm 2$  ft. This could be accomplished with ease in benign conditions (HQR 2-3). In adverse conditions, however, this task was difficult (HQR 6-7) and often resulted in the tail wheel striking the deck (see paragraph 3.1.4.1.1). This condition was exacerbated further if the PVCD was used as a primary position cue (see paragraph 3.1.4.1.2). The position keeping in the low hover was often a limiting condition with the RAST, requiring pitch, roll, relative wind and ambient light condition limitations to be placed on operations to decrease the adversity of the conditions.

##### **3.1.4.1.1 EFFECT OF HIGH CONTROL ACTIVITY ON POSITION KEEPING IN THE LOW HOVER**

By positioning the aircraft in the low hover, the pilot was able to carry out a final check on aircraft position, relative heading, and lateral drift rate. The hover must be low enough to allow the pilot to see the interface between the hangar face and the flight deck but not so low as to have the wheels hit the deck. The aircraft must be in the DLA to ensure that the aircraft can be properly secured on landing. There are also limits on lateral drift rates. Although the main landing gear can withstand large normal loads (z-direction), the small lateral loads associated with even gentle lateral drift rates (y-direction) can cause damage to the main landing gear and tail wheel. When the pilot had difficulty controlling the heading, position or drift rates due to unpredictable,

destabilizing forces acting on the aircraft, the pilot used frequent high amplitude control inputs to maintain control of the aircraft. This resulted in large changes in aircraft attitude, which in turn effected the pilot's ability to correctly determine aircraft position in space. When in the hover, the CH 124A adopts a 2° nose up and 3° left wing low attitude. The tailwheel is approximately 2 ft below the main landing gear and is almost 30 ft behind the pilot, making it difficult for him to be aware of its exact position with respect to the flight deck. Even a small pitch up of the aircraft about its CG (aircraft attitude changes are about the aircraft CG) of 3° can cause the height of the tail wheel to drop by 1.5 ft. This leaves very little room for height error. In addition, the pilot's reference eye position is located forward, above and to the right of the aircraft CG. Even if the aircraft CG were to remain stationary and the aircraft were to change attitude in space, the pilot would perceive this as being an aircraft position change and would endeavor to correct accordingly. Since this characteristic is also true for changes in roll and yaw as well as attitude, it is easy to see how heavy control activity would affect the pilot's ability to keep position in the low hover, especially when his ability to process information is decreased. This could in turn preclude the pilot from landing during a quiescent period. This would likely cause the pilot to return to the high hover and require him to set the aircraft up again for landing.

#### ***3.1.4.1.2 EFFECT OF USING THE PVCD FOR POSITION INFORMATION IN THE LOW HOVER***

In the low hover, the pilot used the hangar face, the line-up lines, and the fore/aft alignment lines to determine position information. The PVCD/SHRS was used for attitude information and to determine if the ship was still in its quiescent period. In the low hover, the PVCD/SHRS appeared at the top of the windscreen outside the pilot's primary FOV. The hangar and deck position cues were in the primary FOV. When the pilot scanned from the deck position cues to

the PVCD/SHRS, 10-15° head movements up and down were required. There was an initial tendency to use the PVCD alone for position information, causing the pilot to stare up at the display. This affected his ability to maintain an accurate hover position, possibly by disorienting his vestibular apparatus, and caused him to overcorrect in pitch, roll and yaw. This caused the workload to increase by 1-2 on the HQR scale. Reversion to using the deck position references immediately returned the workload to its original difficulty level. Using the PVCD in the low hover for position information increased pilot workload. It was a Part II deficiency. It is recommended that further testing be carried out with the PVCD in a lower position. If it was moved down by approximately 1.5 m it could be seen in both the high and the low hover. In the interim, the following recommendation with respect to the position cues should be placed into the flight manual:

*Note:*

*If the PVCD is used as the primary position reference, erratic height and heading control and possible tail wheel strikes could result. Instead, the fore/aft alignment lines and the line-up lines should be used as the primary references with occasional cross-checking of the PVCD.*

#### **3.1.4.2 HHRSD**

In the low hover, the pilot used the hangar face, the line-up lines, and the fore/aft alignment lines to determine the aircraft's position with respect to the DLA. The pilot attempted to maintain the aircraft heading  $\pm 5^\circ$ , the position in the DLA with no lateral drift and the height  $5 \pm 2$  ft. This could be accomplished with ease in benign conditions (HQR 2-3). In adverse conditions,

although the task was more difficult (HQR 4-5), it was considerably easier than with the RAST. This was due to an even more pronounced centering effect than was seen in the high hover (see paragraph 3.1.2.3.1), making position keeping in the low hover (see paragraph 3.1.4.2.1) easier than the RAST. The system characteristics in the low hover were satisfactory.

#### ***3.1.4.2.1 HHRSD CENTERING EFFECT IN THE LOW HOVER***

The centering effect seen in the high hover (paragraph 3.1.4.1.1) was slightly different in the low hover due to the lateral or fore/aft centering force component provided by the hauldown cable. Although it reacted in the same way, the distance between the aircraft and the trap was so much smaller that minor deviations from the ideal position over the DLA in the x- or y-direction resulted in larger lateral or fore/aft centering force components. The centering effect was therefore much more pronounced.

### **3.1.5 TRANSITION FROM LOW HOVER TO THE LANDING**

The transition from the low hover to the landing was in effect the landing.

#### ***3.1.5.1 RAST MK III***

The landing was initiated during a quiescent period, when the aircraft was over the DLA with no lateral drift. The descent rate varied with the deck conditions but was not to exceed 8 ft/s and the aircraft heading was to remain  $\pm 5^\circ$  of desired. The evolution was easy in benign conditions (HQR 2-3) but could frequently not be done safely in adverse conditions (HQR 5-7). The cues outlined in paragraph 3.1.4.1 were used. Although the cues were satisfactory, and the trap size permitted a looser tolerance in position-keeping than the HHRSD, the imprecise aircraft control in the low hover required long time periods to position the aircraft for landing (see paragraph 3.1.4.1). This

frequently resulted in returning the aircraft to the high hover. The transition from the low hover to landing was often a limiting condition with the RAST, requiring pitch, roll, relative wind and ambient light condition limitations to be placed on operations to decrease the adversity of the conditions.

### **3.1.5.2 HHRSD**

The landing was initiated during a quiescent period, when the aircraft was over the DLA with no lateral drift. The descent rate varied with the deck conditions but was not to exceed 8 ft/s and the aircraft heading was to remain  $\pm 5^\circ$  of desired. The cues outlined in paragraph 3.1.4.2 were used. The landing could be accomplished with ease in benign conditions (HQR 2-3). In adverse conditions, the task was more difficult (HQR 4-5); however, it was considerably easier than with the RAST. This was due to the pronounced centering effect seen in the low hover (see paragraph 3.1.4.1.2), making position keeping in the low hover easier than the RAST. The system characteristics in transition from the low hover to landing were satisfactory.

## **3.2 THE TAKE-OFF EVOLUTION**

The take-off evolution is broken down into the individual phases of flight required to take the aircraft from the deck to a position clear of the ship.

### **3.2.1 TAKE-OFF TO THE HIGH HOVER**

This transition was an aggressive maneuver used to get the aircraft free of the deck.

### **3.2.1.1 RAST MK III**

The take-off was initiated during a quiescent period. The ascent rate varied with the deck conditions and aircraft AUV but was not to exceed 5 ft/s. The pilot attempted to maintain aircraft heading  $\pm 5^\circ$  of the ship's heading and keep the aircraft clear of the hangar face while maintaining a position approximately over the DLA. The looseness of the tolerances made the evolution easy in benign conditions (HQR 2-3) and only slightly more difficult in adverse conditions (HQR 3-4). Prior to the take-off, the pilot scanned the PVCD/SHRS to ensure that the deck motion had stopped. Although the PVCD/SHRS appeared at the top of the windscreen and outside of the pilot's primary FOV, it was easy to do and did not disrupt the pilot's orientation prior to take-off. Once ready to lift, the pilot used the hangar face and the line-up lines for orientation. Once the aircraft lifted off, the pilot transitioned to using the hangar face and hangar top for position cues. There was a tendency for the pilot to use the PVCD for position cues as well, but this exacerbated a tendency to drift forward on take-off and was later dropped from the initial scan (see paragraph 3.2.1.1.1). When the recommendations of paragraph 3.2.1.1.1 were observed, the take-off to the hover was satisfactory for the RAST Mk III system.

#### **3.2.1.1.1 TENDENCY TO DRIFT FORWARD ON TAKE-OFF**

There was a slight tendency to drift forward on take-off. As discussed at paragraph 3.1.3.1.2, it was likely attributed to the aircraft mechanical characteristics, which caused the aircraft to pitch down when power was applied, and the PVCD layout, which caused the pilot to misinterpret fore/aft position information with height information. Another contributing factor was the aircraft hover attitude. To alter the aircraft from the level attitude on the deck to the hover attitude, which was 2-3° nose high, required a significant application of aft cyclic (4-6 cm). The combination of

these three factors caused the pilot to allow the aircraft to drift forward, especially when unfamiliar with the problems associated with the PVCD. There was a risk of having the rotor strike the hangar. When the pilot was made aware of the drift tendency, he was able to overcome it. The tendency to drift forward on take-off was a Part II deficiency, but can be overcome if the pilots are properly educated. The following caution should be added to the pilot's flight manual:

Caution

*There is a tendency for the aircraft to drift forward on take-off. If the PVCD is used for aircraft position information on take-off, there is a possibility that the fore/aft position information displayed on the PVCD would be interpreted as height information and the aircraft would drift into the hangar. The pilot should use the fore/aft alignment lines and the hangar face and top for position information on lift-off.*

**3.2.1.2 HHRSD**

The take-off was initiated during a quiescent period. The ascent rate varied with the deck conditions and aircraft AUV but was not to exceed 5 ft/s. The pilot attempted to maintain aircraft heading  $\pm 5^\circ$  of the ship's heading and keep the aircraft clear of the hangar face while maintaining a position approximately over the DLA. The looseness of the tolerances made the evolution easy in benign conditions (HQR 2-3) and only slightly more difficult in adverse conditions (HQR 3-4). Prior to the take-off, the pilot scanned the SHRS to ensure that the deck motion had stopped. Although the SHRS appeared at the top of the windscreen and outside of the pilot's primary FOV, it was easy to do and did not disrupt the pilot's orientation prior to take-off. Once ready to lift, the pilot used the hangar face and the line-up lines for orientation. Once the aircraft lifted off, the

pilot transitioned to using the hangar face and hangar top for position cues. The take-off to the hover with the HHRSD system was satisfactory.

### **3.2.2 HIGH HOVER TO DEPARTURE**

This maneuver cleared the aircraft of the enclosed and confined area of the ship and cleared the aircraft of the ship's environment.

#### **3.2.2.1 RAST MK III**

Moving the aircraft aft from the high hover maintaining the flight deck environment in view, and the heading  $\pm 5^\circ$  to approximately 60 ft and then departing the ship was easy in both benign (HQR 1-2) and adverse (HQR 3-4) conditions. Initially, the pilot used the PVCD/SHRS, the hangar face and the hangar top to determine position, height, approach path and rate of departure. The provision of distinct cues outside of the pilot's primary field of view (FOV) such as the horizon and the water surface, which appeared as the aircraft climbed aft, provided useful spatial orientation cues in the benign visual environment. The departure with the RAST Mk III was satisfactory.

#### **3.2.2.2 HHRSD**

With the exception of the PVCD, which was not present with the HHRSD, the evolution was identical to the RAST Mk III departure. The lack of PVCD did not adversely affect the task. The departure with the HHRSD was satisfactory.

### **3.3 GENERAL DECK EVOLUTIONS**

The RAST Mk III was unique from the HHRSD in its display of visual cue information. It used the PVCD to present command, position and status information at varying times. This often lead to confusion during general deck evolutions. This section discusses the characteristics the RAST PVCD system since it was unique, and where applicable, makes comparisons to the visual cue information gathered using the HHRSD.

#### **3.3.1 EASE OF USE - GENERAL**

The PVCD is shown at Figure A-9.

##### **3.3.1.1 RED DIRECTIONAL CHEVRON LIGHT INTENSITY**

The PVCD lighting matrix is shown at Table B-5. The red directional chevron on the PVCD was used to display: signal delta; helicopter position when too close to the hangar; and the wave-off. All of these signals gave critical information to the pilot. They had to be readily noticeable. The red chevron light intensity was significantly less intense than the amber and green chevrons. The Delta signal could not be seen on a sunny day until 1/8 nm. This was much less than the trafficators, used with the HHRSD, which could be seen from over 2 nm behind the ship. The red chevron was not readily noticeable when displaying position too close to the hangar. Likewise, the wave-off was barely noticeable. Missing either of these two signals would put the aircraft in a dangerous position. The light intensity of the red directional chevron was a Part II deficiency. The light should be made more conspicuous when illuminated.

### **3.3.2 DISPLAY CONFLICTIONS**

Confusion reading the PVCD resulted when there was a requirement to display some combinations of command, position, or status information. The following points were noted:

#### ***3.3.2.1 SIMILARITY BETWEEN WAVE-OFF AND LOST ACQUISITION***

All amber and red chevrons illuminated to indicate the wave-off. It was used to order the pilot to position the aircraft in the high hover position when a caution or danger situation existed. The indication must therefore stand out and not be confused with other signals. The signal for beacon lost acquisition was all amber chevrons - very similar to the wave-off, especially when the low relative lighting intensity of the red chevron was considered (see paragraph 3.3.1.1). The display similarity was most critical when the HPSE had lost acquisition over the flight deck and the aircraft was directed to wave-off. The pilot seldom noticed the transition in signals from all amber chevrons to all amber and red chevrons, especially in adverse conditions because the pilot's scan only included the SHRS and not the PVCD (since position information was not displayed after acquisition was lost). The pilot would likely not notice the display for the wave-off and would have to count on hearing the wave-off call over the radio. The similarity between the wave-off and the lost acquisition signal was a Part I deficiency. The wave-off signal must be made more distinct and noticeable. It is suggested that all amber and red chevrons still illuminate to indicate the wave-off, but that the illuminated chevrons flash at 3 Hz with equal on and off times.

### ***3.3.2.2 SIMILARITY BETWEEN LOST ACQUISITION AND DELTA HOVER ASTERN***

All amber chevrons illuminated to indicate Lost Acquisition. This same symbol was used to depict the DHA command as well as indicating that the aircraft was trapped (see paragraph 3.3.2.3). If the aircraft was in the high hover, and all amber chevrons illuminated, then the pilot would be unsure whether to go to the DHA or wait in the high hover for re-acquisition. The similarity between the lost acquisition and DHA signals was a Part II deficiency and should be corrected. The Lost Acquisition and DHA displays should be made dissimilar. It is suggested that all amber chevrons still illuminate to indicate lost acquisition, but that the illuminated chevrons flash at 1 Hz with equal on and off times. This rate would be adequate to make it unique from both the DHA and the wave-off commands.

### ***3.3.2.3 SIMILARITY BETWEEN LOST ACQUISITION AND THE TRAPPED INDICATION***

All amber chevrons illuminated to indicate Lost Acquisition. This same symbol was used to indicate that the aircraft was trapped as well as depict the DHA command (see paragraph 3.3.2.2). If the pilot landed on the deck and all amber chevrons illuminated, the pilot would not know if he was trapped, or the HPSE had lost acquisition. This was especially dangerous if the pilot thought the aircraft was trapped, when in fact the beacons had Lost Acquisition. He would normally disengage the ASE, leaving the aircraft untrapped on deck without flight stabilization. This was a critical situation. A roll of the ship could cause the aircraft to slip off the deck or into the hangar. The similarity between lost acquisition and the trapped indication was a Part I deficiency. The indications must be made dissimilar. This could be accomplished if the trapped indication symbol remained the same and the lost acquisition symbol was modified as per paragraph 3.3.2.2.

### **3.3.3 EASE OF USE - COMMAND INFORMATION**

#### **3.3.3.1 TOO CLOSE TO HANGAR**

The red directional chevron indicated that the aircraft was forward of the DLA with the main rotor, at most, 5.8 m away from the hangar face. If the pilot was forward of the DLA and drifting forward the display did not change. A pilot who was transfixed on the horizon bar and forward of the DLA during high workload on a pitching deck might not notice that he was drifting continually forward while he thought that he was correcting aft. This would be hazardous and was therefore unsatisfactory. The indications to the pilot when the aircraft is approaching too close to hangar were a Part II deficiency and should be improved. It is suggested that the wave-off signal from paragraph 3.3.2.1 be given to the pilot, since this would be the desired response in this case.

### **3.3.4 EASE OF USE - POSITION INFORMATION**

Examples of position information are shown at Figure A-10.

#### **3.3.4.1 DISPLAY HARMONY**

The PVCD was 10 ft wide and 6 ft tall. It was used to graphically depict the position of the main probe with respect to the DLA. The trialed DLA size was approximately 1.59m wide by 1.59m long. This was not a proportional depiction of the actual landing area's geometry. This, however did not appear to affect the pilot's ability to determine his desired position despite the lack of display position harmony. This was satisfactory without improvement.

### **3.3.5 DESIGNATED LANDING AREA OPTIMAL SIZE**

The DLA was broken down into an outer and an inner DLA as defined at section 1.4.2.4 and shown in Figure A-8. The DLA boxes were varied to determine the optimal size to be used for the landing. Time constraints during testing limited the analysis to square shapes. The PVCD displayed the outer DLA as a square 1.59 m by 1.59 m. The trap, however, was capable of capturing the probe for a DLA 1.59 m wide by 1.71 m long. The best display harmony was found for an inner DLA  $1/9^{\text{th}}$  the area of the outer DLA and centered in it, resulting in the dimensions in Table B-1. As further testing is carried out, and the confidence in the accuracy of the landing system improves, the outer, and therefore the inner DLA size can be made larger. The size of the DLA was, however, satisfactory and could be considered an enhancing feature without improvement (see paragraph 3.4.2).

#### **3.3.5.1 POSITION DISPLAY CONFIGURATION**

The directional chevrons used to display position information to the pilot were located on top of the SHRS for lateral corrections and on the center of the horizon bar for fore/aft corrections. Although initially awkward to use, after approximately 15 minutes of experience flying using the PVCD, the pilot was able to accurately interpret position information. The position display configuration was satisfactory.

#### **3.3.5.2 EASE OF USE - STATUS INFORMATION**

The only identified problems with status information were discussed in the Display Conflicts paragraphs above (see section 3.3.2).

### **3.4 COMPARISON OF THE RAST MK III AND THE HHRSD WITH RESPECT TO THE SHOL**

In sections 3.1 and 3.2 a comparison was made of each system's performance in executing all phases of the deck landing task. Section 3.3 discussed the specifics of the RAST Mk III PVCD system and how confusion arose during general deck evolutions. The information gained by the investigations in these sections was sufficient enough to determine that the characteristics that made each system unique were what determined the suitability of that system for the task. For the RAST Mk III it was the PVCD and larger trap. For the HHRSD it was the hauldown cable. Each of these features contributed to the operational utility of that system since operational utility was measured by the size of the SHOL that could be produced with that system. In order to make an overall comparison of the systems, as this last section will do, the major characteristics of each system were investigated and assessed with respect to the SHOL.

#### **3.4.1 CHARACTERISTICS OF THE PVCD**

Although the PVCD provided position and rate information cues to the pilot, it added little to the overall system that could not be determined by using other cues available. In addition, the PVCD was often confusing: it caused the pilot to misinterpret height information with fore/aft position information (see paragraphs 3.1.3.1.2 and 3.2.1.1.1); it displayed misleading position information during ship's roll (paragraph 3.1.2.1.1); and it caused disorientation to the pilot in the low hover when it was used as the primary position source (paragraph 3.1.3.1.1). There was no real benefit experienced when using the PVCD for position information, although further testing with a DLA position re-oriented to the free space frame of reference may aid in carrying out landings during

high ship rolls. The cues provided by the PVCD were misleading and were considered a Part II deficiency for use in the take-off and landing task. The PVCD should not be incorporated on future designs and that it be removed from the RAST Mk III.

#### **3.4.2 CHARACTERISTICS OF THE LARGER TRAP**

The larger trap area of the RAST Mk III was beneficial, especially considering the difficulty in positioning the aircraft to land (see paragraph 3.1.5.1). For the trial, no wave-offs experienced when using the RAST Mk III system were due to the aircraft landing outside the DLA. Although no wave-offs were experienced with the HHRSD when the cable was used, trials involving freedeck (no cable) landings with the HHRSD system often (approximately 20-30% of the landings) results in wave-offs in adverse conditions. The large trap area was an enhancing feature that should be incorporated on future designs.

#### **3.4.3 CHARACTERISTICS OF THE HAULDOWN CABLE**

There were three distinct characteristics of the hauldown cable that differentiated it from the RAST system: the time required for recovery; the cable centering effect; and extra aircraft power required to offset the cable tension. The hook-up procedure with the hauldown cable required approximately one minute more in the high hover than the RAST Mk III. When the cable was attached, however, it virtually assured a safe and effective landing in adverse conditions and increased the severity of the conditions that could be encountered and still effect a landing, especially in terms of the pitch and roll limits. This was primarily due to the centering effect the cable had in the high and low hover (see paragraphs 3.1.2.3.1 and 3.1.4.2.1). Also the extra time spent in the high hover was almost made up for in the low hover because of the ease of

positioning the aircraft (see Table B-6). The extra aircraft power required was a potential problem, however, since it could limit the aircraft maximum AUW for recovery. Practically, this problem was overcome with an engineering solution. The aircraft was permitted to operate to an increased AUW for the duration of the landing sequence. Even this was seldom required since recoveries were almost always carried out at the end of the sortie. The aircraft AUW would normally have decreased to below the critical amount due to the fuel consumed during the sortie. When all points were considered and weighed against operational requirements, the advantages of the safety and larger operating envelope more than offset the disadvantages of the increased recovery time and the problem of the aircraft AUW. The hauldown cable should be incorporated on future designs.

#### **3.4.4 EFFECT OF SYSTEM CHARACTERISTICS ON THE WIND ENVELOPE**

The size of the wind envelope determines the operational effectiveness of the deck recovery system in the deck landing task for the aircraft and the ship investigated. The wind envelope is characteristically defined by pilot workload, aircraft limitations, ship limitations and system limitations, and was promulgated for the worst sea state and weather within which flight operations could be carried out. For aircraft with the American <sup>3</sup> and British standard main rotor blade rotating counterclockwise when viewed from the top, the edge of the 360° relative wind

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<sup>3</sup> For clockwise rotating rotor blades, this area was usually defined for relative winds from Red 60°, through ahead to Green 80°. The difference was attributed to the relative wind direction that required the most power from the anti-torque tail rotor. More power was required for American/British helicopters to fly with relative winds from the right, and vice versa for the other helicopters.

envelope was usually defined by pilot workload for relative winds from Green 60°, through ahead to Red 80°. The region from Red 80° to Red 180° was usually defined by engine or transmission torque available. The remaining region was usually defined by engine or transmission torque available and/or tail rotor margins. Because the HHRSD cable decreased pilot workload, the envelope was larger than the RAST Mk III in the order of 5-10 kts relative wind for a significant part of the envelope. Although the remainder of the envelope was defined by aircraft performance limitations, as discussed at paragraph 3.4.3, use of the hauldown cable very seldom restricted the size of the envelope for these regions. The characteristics that made the RAST Mk III unique, however, did little to enlarge the size of the SHOL, and in cases collapsed it (see paragraphs 3.4.1 and 3.4.2). When considering design of a new deck recovery system with respect to human machine interface considerations, the largest operational envelope can be gained using the HHRSD cable. Items such as the PVCD should not be incorporated to enhance visual cues unless significant improvement is made on the design.

## **4 RECOMMENDATIONS**

### **4.1 PART I DEFICIENCIES**

The following deficiencies required immediate rectification:

- a) The lost acquisition and the trapped indication must be made dissimilar. (paragraph 3.3.2.3)
- a) The apparent DLA position during ship's roll must be corrected. (paragraph 3.1.2.1.1)
- a) The wave-off signal must be made more distinct and noticeable. (paragraph 3.3.2.1)

### **4.2 PART II DEFICIENCIES**

The following deficiencies should be rectified:

- a) The PVCD should be improved for use in the take-off and landing task. (paragraph 3.4.1)
- a) Using the PVCD for position information in the low hover increased pilot workload. This characteristic should be rectified. (paragraph 3.1.4.1.2)
- a) The tendency to drift forward on take-off should be rectified. (paragraph 3.2.1.1.1)
- a) The light intensity of the red directional chevron should be increased. (paragraph 3.3.1.1)
- a) The similarity between the lost acquisition and DHA signals should be corrected. (paragraph 3.3.2.2)
- a) The indications to the pilot when the aircraft is approaching too close to hangar should be improved. (paragraph 3.3.3.1)

### 4.3 FURTHER TESTING

Further testing should be carried out with the PVCD in a lower position so that it could be used in both the high and low hover. (paragraph 3.1.4.1.2)

### 4.4 ENHANCING FEATURES

The following enhancing features were found:

- a) The hauldown cable should be incorporated on future designs. (paragraph 3.4.3)
- a) The large trap area should be incorporated on future designs. (paragraph 3.4.2)

### 4.5 CAUTIONS

The following cautions should be included in the pilots flight manual:

- a) *When in the high hover, the PVCD displays misleading position information during ship's rolls. Pilot induced oscillations or in extreme cases, loss of control of the aircraft could occur if the position information from the PVCD is used in the high hover when the ship's roll is greater than 5°. (paragraph 3.1.2.1.1.2.1)*
- b) *There is a tendency for the aircraft to drift forward on take-off. If the PVCD is used for aircraft position information on take-off, there is a possibility that the fore/aft position information displayed on the PVCD would be interpreted as height information and the aircraft would drift into the hangar. The pilot should use the fore/aft alignment lines and the hangar face and top for position information on lift-off. (paragraph 3.2.1.1.1)*

## **4.6 NOTE**

The following note should be included in the pilots flight manual:

- a) If the PVCD is used as the primary position reference, erratic height and heading control and possible tail wheel strikes could result. Instead, the fore/aft alignment lines and the line-up lines should be used as the primary references with occasional cross-checking with the PVCD. (paragraph 3.1.4.1.2)

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## REFERENCES

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## APPENDICES

## APPENDIX A

### FIGURES



**Figure A-1: DDH 265 Class Ship.**



**Figure A-2: RAST Mk III.**

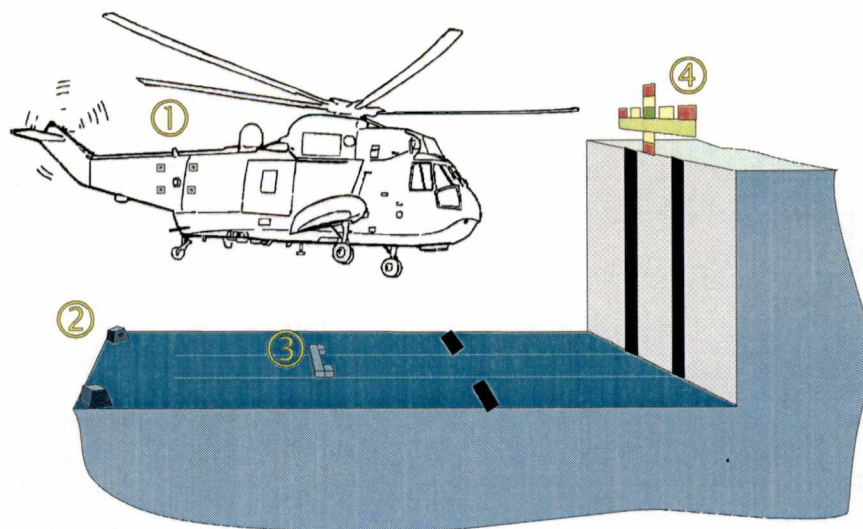


**Figure A-3: RAST Mk III.**

① Beacons; ② Cameras; ③ Trap; and ④ PVCD.

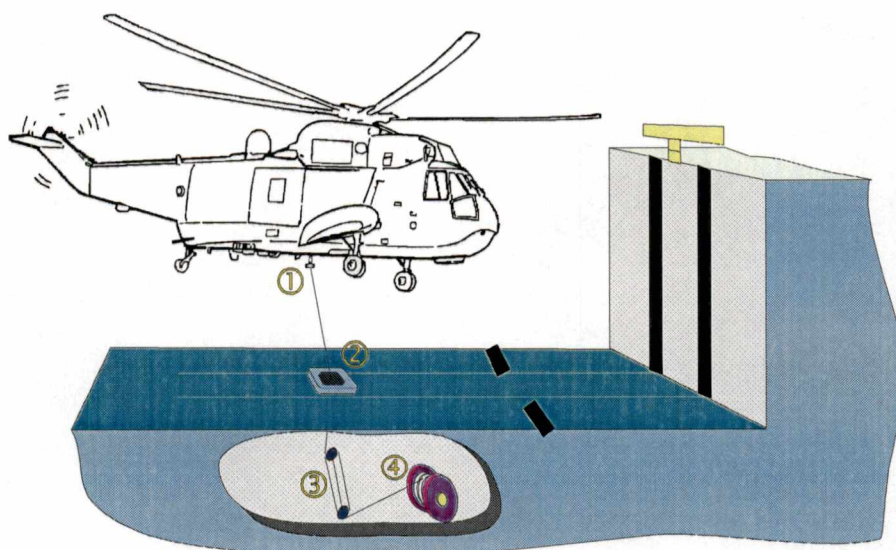


**Figure A-4: HHRSD.**

① Aircraft Main Probe; ② HHRSD Trap and Portable Bellmouth;  
③ Wire Accumulator – Constant Tension Device; and ④ Wire Reel



**Figure A-5: HHRSD Hauldown Cable.**

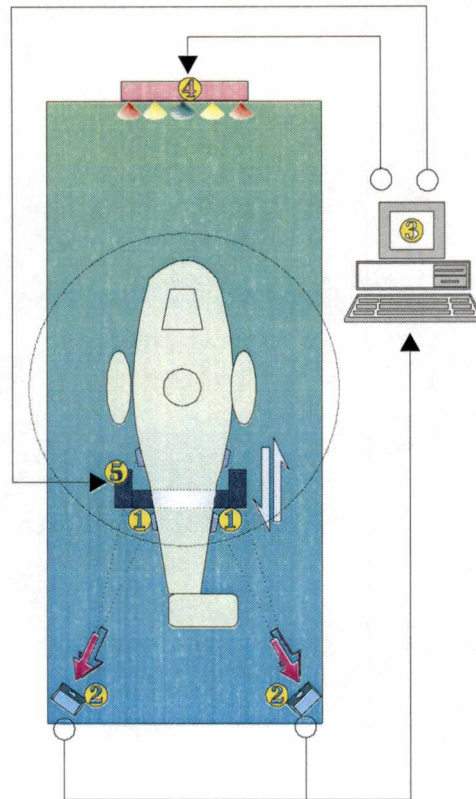


**Figure A-6: RAST Mk III Data Stream.**

- ① Aircraft LASER Beacons; ② Flight Deck Cameras; ③ Signal Processing Unit;  
④ Pilot Visual Cues Display; and ⑤ RAST Trap.

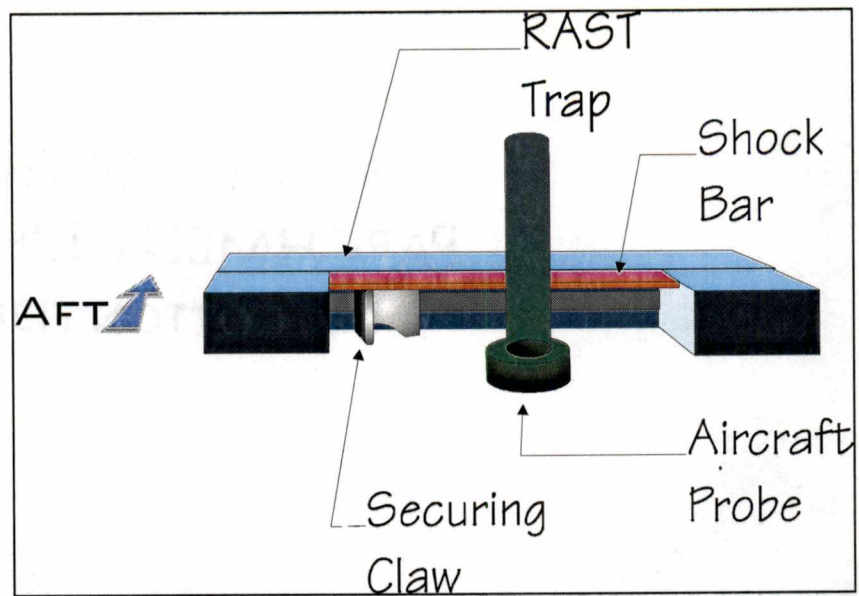


**Figure A-7: RAST Mk III Trap and Probe.**

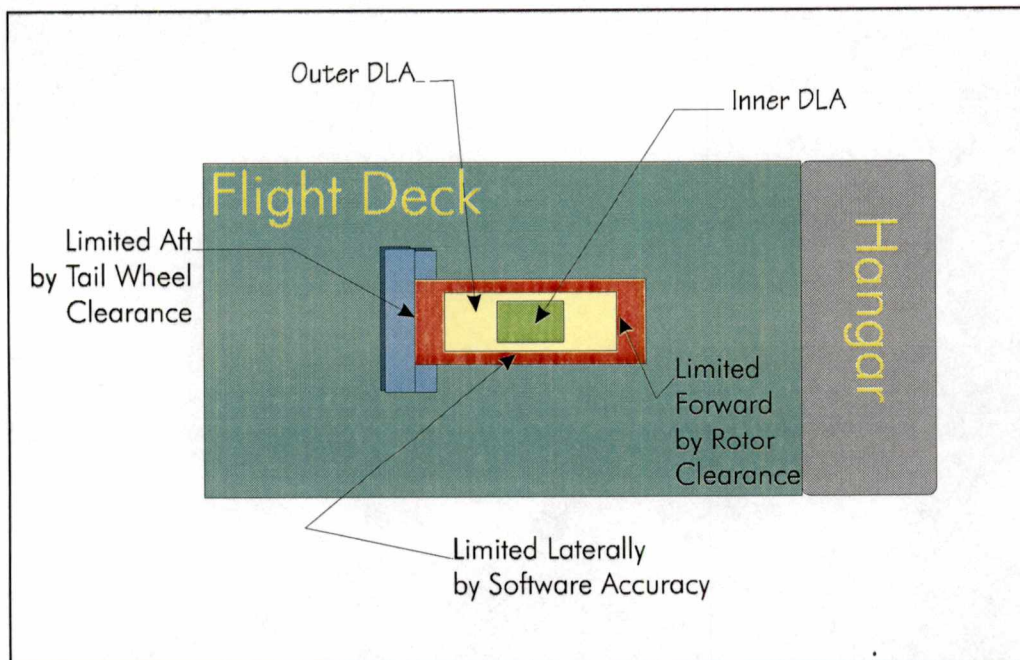


**Figure A-8: RAST Mk III Designated Landing Area.**

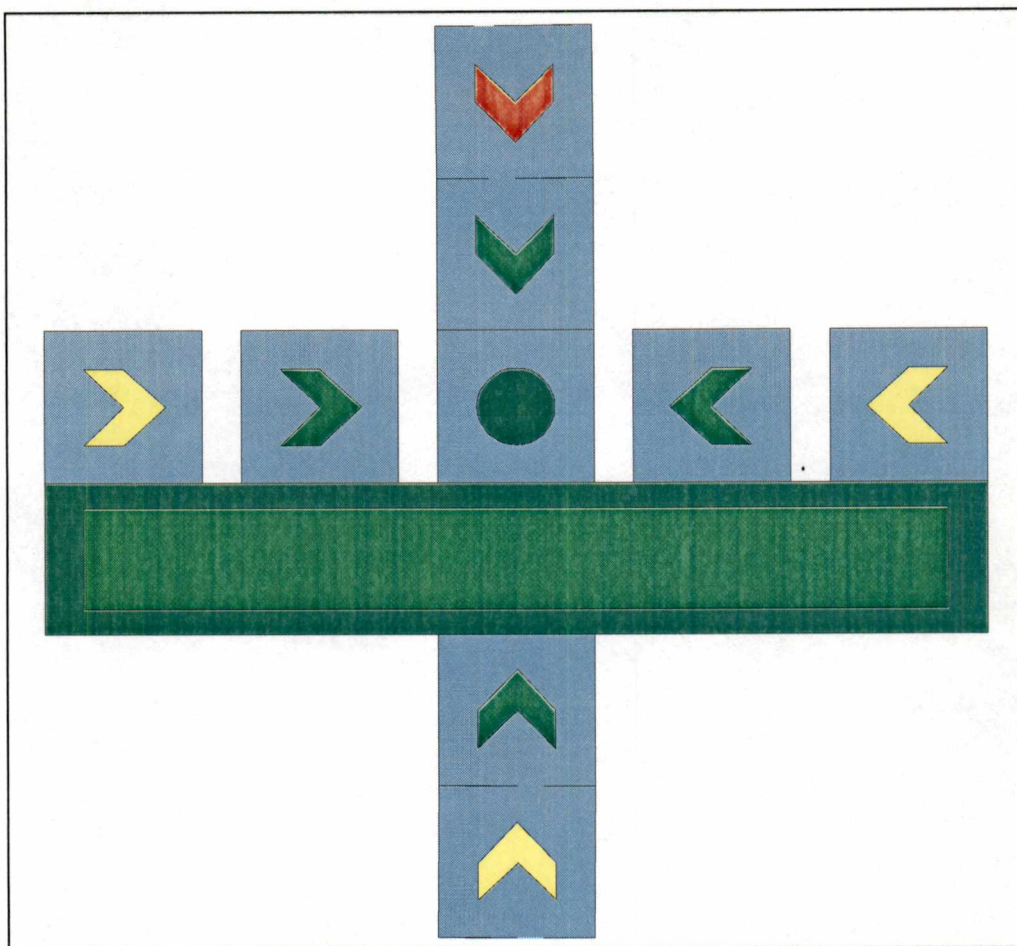


**Figure A-9: Pilot Visual Cues Display.**

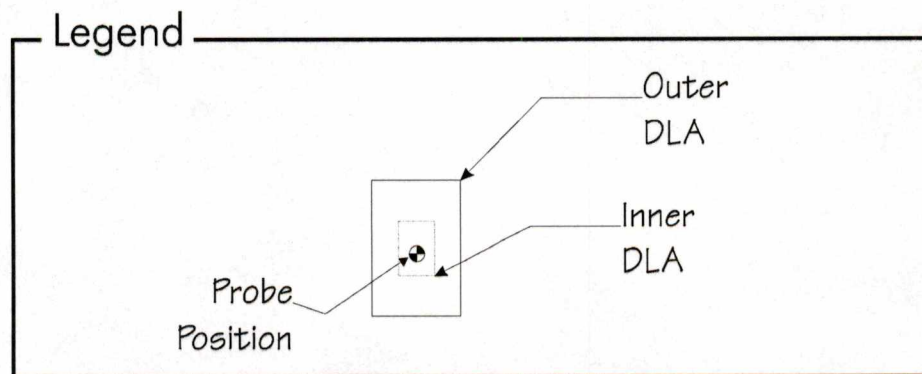
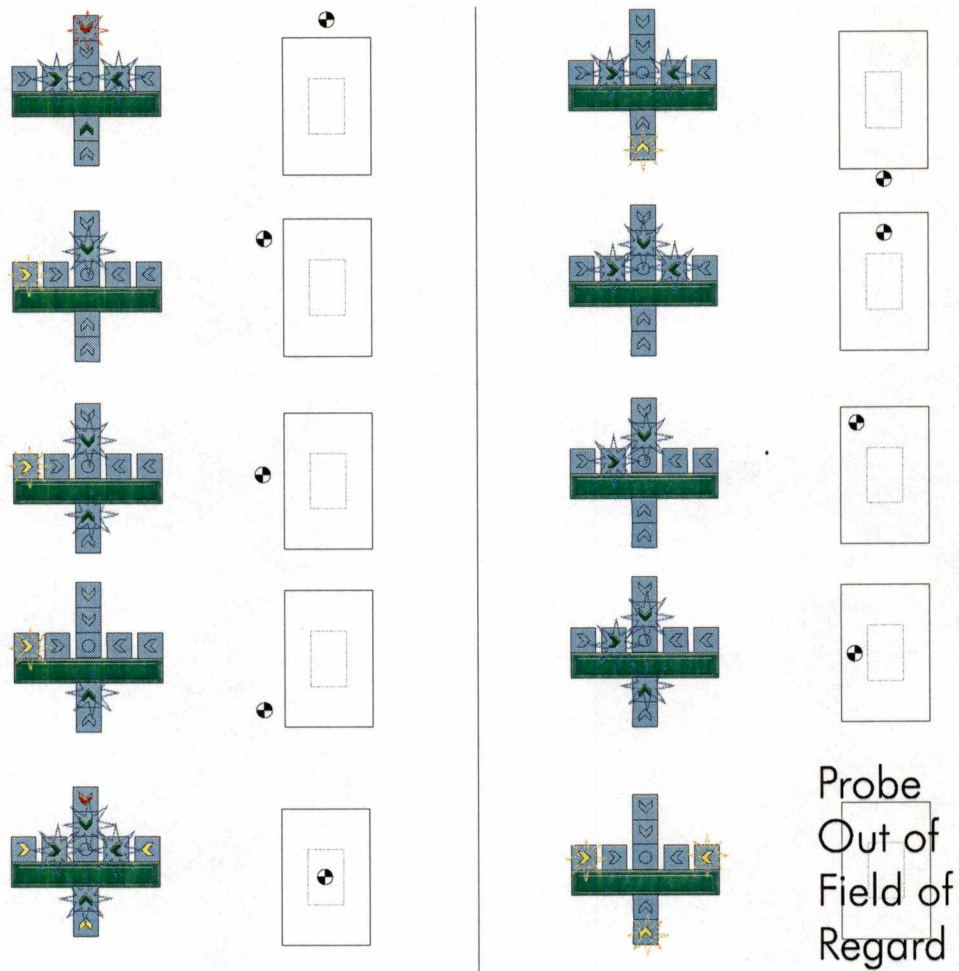
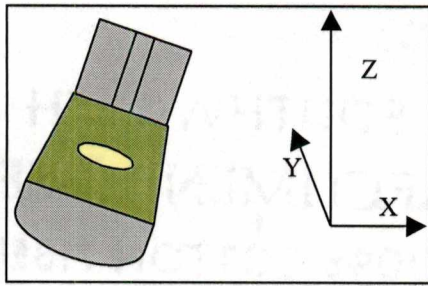
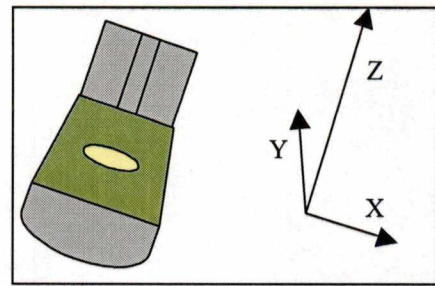


**Figure A-10: PVCD Display for Various Probe Positions.**



(a)



(b)

**Figure A-11: A Rolling Ship With Respect To Its Frames of Reference.**

(a) Free Space Frame of Reference; (b) Ship Frame of Reference

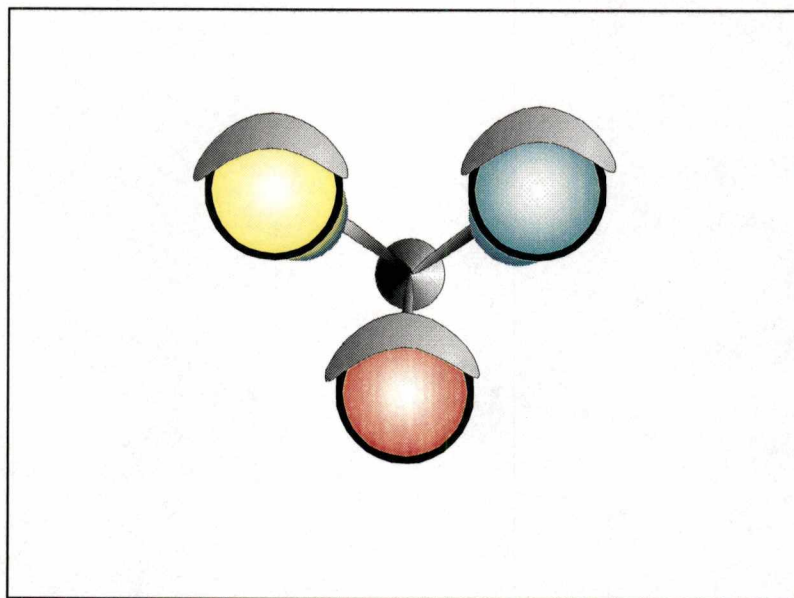


**Figure A-12: HHRSD Deck Status Indicators.**

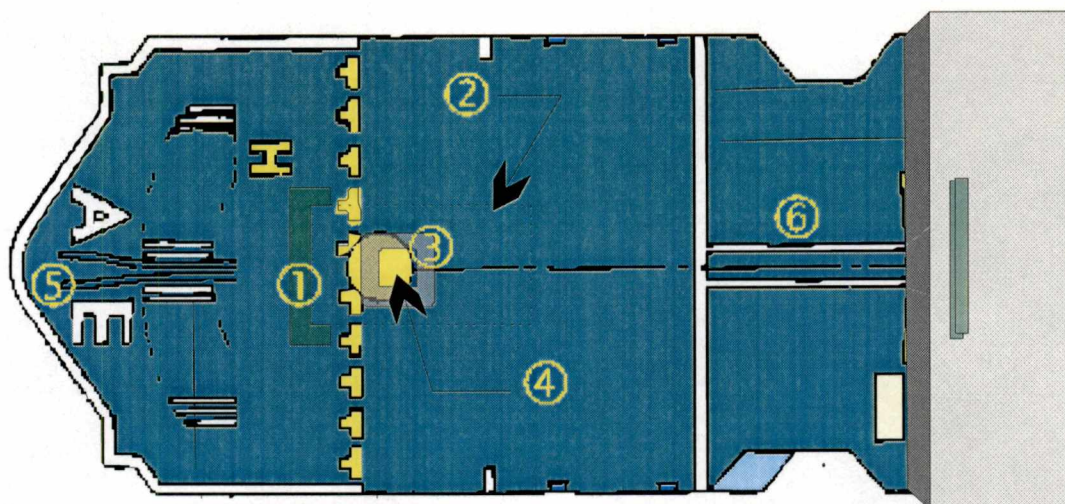


**Figure A-13: DDH 205/265 Class Flight Deck.**

① RAST Mk III Trap; ② RAST Mk III DLA; ③ HHRSD Trap; ④ HHRSD DLA;  
 ⑤ Fishtail Probe Guide; and ⑥ Line-up Lines. (IAN HOSTAC, 1990)

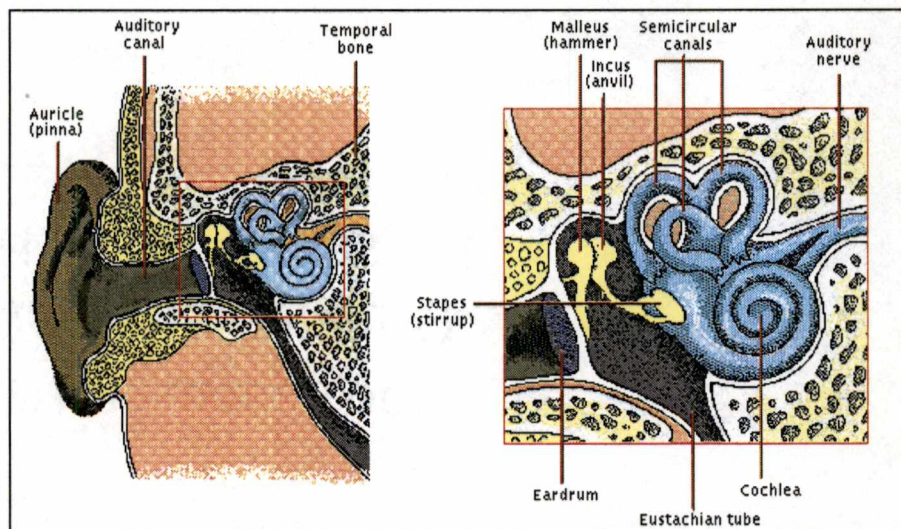


**Figure A-14: The Ear.**

(Microsoft Encarta, 1997)

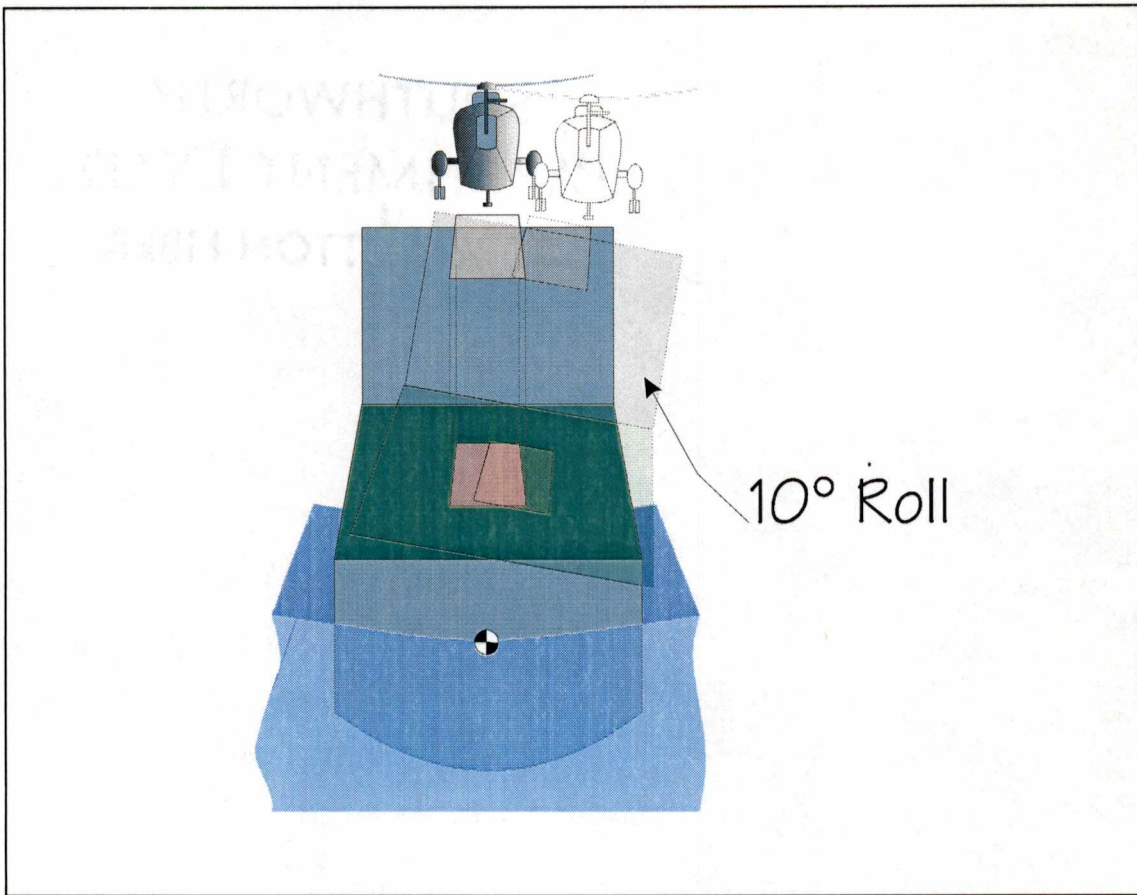
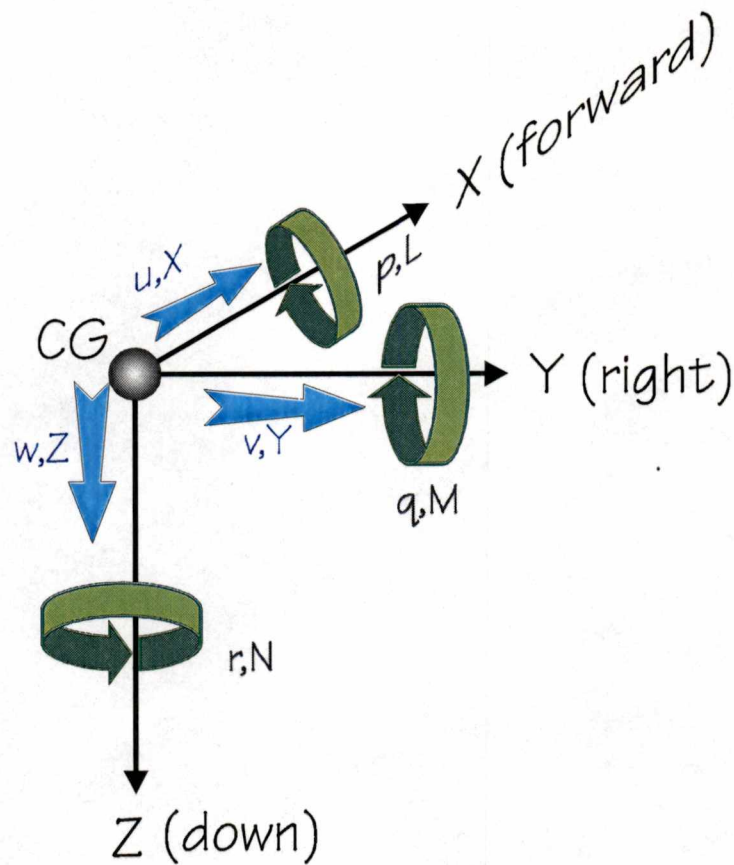


**Figure A-15: Relative DLA Position in Roll.**



| Axis | Velocity Along Axis | Angular Velocity | Force | Moment | Moment of Inertia | Angle of Rotation   | Control Deflection      |
|------|---------------------|------------------|-------|--------|-------------------|---------------------|-------------------------|
| 0x   | U, u                | p                | X     | L      | A                 | $\phi$<br>(roll)    | $B_{1s}$<br>(forward +) |
| 0y   | V, v                | q                | Y     | M      | B                 | $\theta$<br>(pitch) | $A_{1s}$<br>(right +)   |
| 0z   | W, w                | r                | Z     | N      | C                 | $\psi$<br>(yaw)     | $\theta_t$              |

**Figure A-16: Coordinate System.**

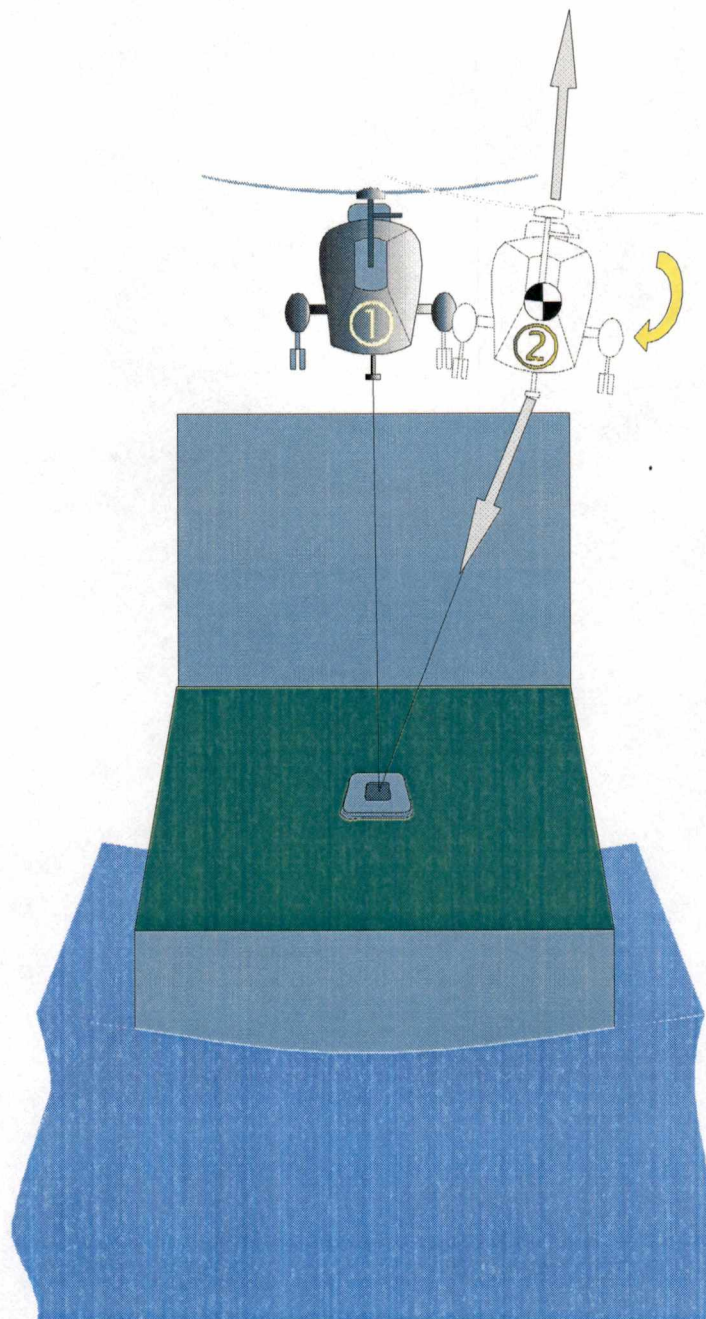


**Figure A-17: Centering Effect of HHRSD System.**

①Aircraft in a steady state; and ②Aircraft reacting to unbalanced forces.

## APPENDIX B

### TABLES

**Table B-1: RAST Mk III – HHRSD Comparison.**

| Item                                                                                                     | RAST Mk III                                                            | HHRSD                                                                                                     |
|----------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|
| <b>Designated Landing Area<br/>(width x length) (m)</b>                                                  | 1.59 x 1.59 (Outer DLA)<br>0.53 x 0.53 (Inner DLA)                     | 1.00 x 1.00                                                                                               |
| <b>Pilot Visual Cues Display</b>                                                                         | Yes (Integrated into<br>Stabilized Horizon Bar)                        | No<br>(Stabilized Horizon Bar Only)                                                                       |
| <b>Hauldown Facility</b>                                                                                 | No                                                                     | Yes                                                                                                       |
| <b>Moving Trap</b>                                                                                       | Yes                                                                    | No                                                                                                        |
| <b>Rapid Securing Device</b>                                                                             | Uses Claw to Capture Probe                                             | Uses Opposing Beams to<br>Capture Probe                                                                   |
| <b>Probe Position on Aircraft</b>                                                                        | 39.5 inches aft of CG                                                  | Approximately at CG                                                                                       |
| <b>Method for Traversing and<br/>Manoeuvring Aircraft<br/>(altering position port and<br/>starboard)</b> | Claw moves Main Probe left<br>and right, moving the whole<br>aircraft. | Main Probe is centered and<br>locked, then Tail Guide<br>Winches are used to move tail<br>left and right. |

**Table B-2: Operator Experience.**

|                         | Pilot A | Pilot B | Pilot C | Pilot D | Pilot E |
|-------------------------|---------|---------|---------|---------|---------|
| Flying Hours (Total)    | 1960    | 1980    | 4500    | 3200    | 2000    |
| Flying Hours (Sea King) | 1050    | 1145    | 2000    | 1200    | 300     |
| Qualified Test Pilot    | Yes     | Yes     | No      | No      | No      |

**Table B-3: Test Conditions.**

| Parameter                        | Conditions                                |                                           |                                            |                                            |
|----------------------------------|-------------------------------------------|-------------------------------------------|--------------------------------------------|--------------------------------------------|
|                                  | Benign                                    |                                           | Adverse                                    |                                            |
|                                  | Day                                       | Night                                     | Day                                        | Night                                      |
| Ship Pitch                       | <3°                                       | <2°                                       | >4°                                        | >2°                                        |
| Ship Roll                        | <5°                                       | <4°                                       | >6°                                        | >5°                                        |
| Aircraft Relative Wind Speed     | 15-25 kts                                 | 15-25 kts                                 | >35 kts                                    | >35 kts                                    |
| Aircraft Relative Wind Direction | 20 to 30°<br>from left of<br>the aircraft | 20 to 30°<br>from left of<br>the aircraft | 20 to 30°<br>from right of<br>the aircraft | 20 to 30°<br>from right of<br>the aircraft |

**Table B-4: Units for Various Parameters**

| Parameter               | Unit           |
|-------------------------|----------------|
| Attitude – aircraft     | Degrees        |
| Distance - aircraft     | Nautical Miles |
| Height – aircraft       | Feet           |
| Length – control throws | Centimetres    |
| Time                    | Seconds        |

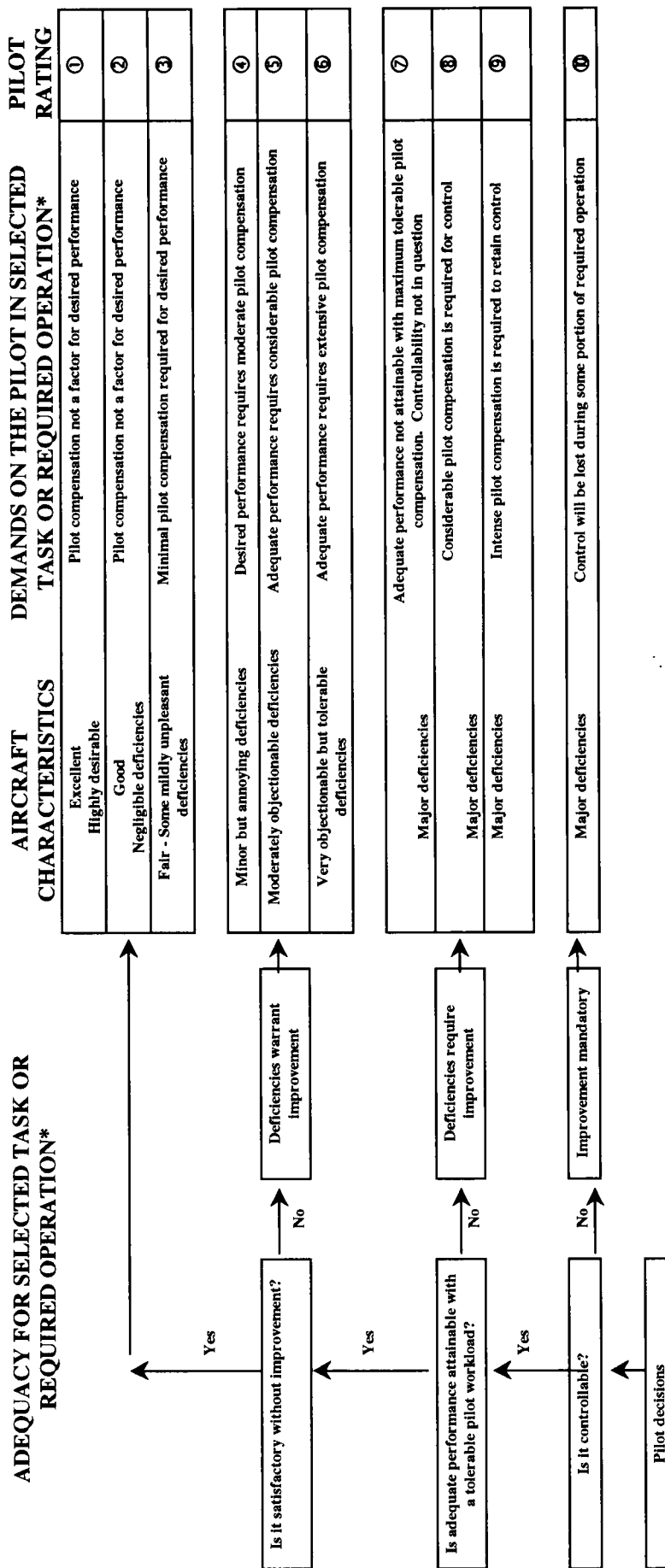
**Table B-5: HHRSD/RAST MK III Signals.**

| <b>SEQUENCE</b>                          | <b>HHRSD</b><br><i>(Action/Deck Status Indication)</i> | <b>RAST System</b><br><i>(Action/Deck Status Indication)</i>        |
|------------------------------------------|--------------------------------------------------------|---------------------------------------------------------------------|
| "Helicopter Cleared for Take-off"        | <u>Trap opened.</u><br>GREEN                           | <u>Trap opened, Tracking – Auto</u><br>Displays Helicopter Position |
| "All Clear"                              | AMBER                                                  | --                                                                  |
| Delta (Aircraft Circles Ship)            | RED                                                    | <u>Tracking – Manual</u><br>RED                                     |
| Delta Hover (Aircraft hovers abeam ship) | AMBER                                                  | <u>Tracking – Manual</u><br>AMBER                                   |
| Charlie                                  | GREEN                                                  | <u>Tracking - Manual</u><br>GREEN                                   |
| Aircraft is Ready to Land                | --                                                     | <u>Tracking - Auto</u><br>Displays Helicopter Position              |
| Trapped                                  | AMBER                                                  | Check - HELO LANDED<br>Indication                                   |
| Abort Landing                            | AMBER                                                  | AMBER                                                               |
| Wave-off Landing                         | RED                                                    | RED                                                                 |
| All Clear                                | Amber                                                  | GREEN                                                               |

**Table B-6: Helicopter Recovery Time.**

| <b>Evolution</b>                            | <b>Hauldown Recovery</b><br>Average Time (sec) |                              | <b>RAST Mk III Recovery</b><br>Average Time (sec) |                              |
|---------------------------------------------|------------------------------------------------|------------------------------|---------------------------------------------------|------------------------------|
|                                             | Benign<br>Conditions                           | Adverse<br>Conditions        | Benign<br>Conditions                              | Adverse<br>Conditions        |
| Delta Hover Astern to High Hover or Hook-up | 10                                             | 12                           | 10                                                | 12                           |
| Hook-up to High Hover                       | 90                                             | 90                           | N/A                                               | N/A                          |
| High Hover to Low Hover                     | 5                                              | 15 (when deck motion allows) | 5                                                 | 30 (when deck motion allows) |
| Low Hover to Land-on                        | 2                                              | 5                            | 2                                                 | 15                           |
| <b>Total</b>                                | <b>107</b>                                     | <b>122</b>                   | <b>17</b>                                         | <b>57</b>                    |

Table B-7: Handling Qualities Rating Scale.



\*Definition of required operation involves designation of flight phase and/or sub-phases with accompanying conditions. Cooper-Harper Reference NASA TND-5153

## VITA

Jim Holden was born in Ottawa, Canada on December 26, 1960. He joined the Canadian Forces as a pilot in 1980 and attended the Royal Military College of Canada. In 1984 received his Mechanical Engineering degree. He completed Air Force flying training then went on to fly Sea King helicopters off naval ships operating from the Atlantic and the Pacific coasts of Canada. He attended the Empire Test Pilot's School in the United Kingdom in 1989. He served for five years at the Aerospace Engineering Test Establishment, Cold Lake. Whilst there, he acted as the Project Officer and Test Pilot on over 20 projects including 5 projects that investigated ship helicopter operating limitations. He has presented two technical papers on the subject of ship/helicopter operations. These papers have won the Society for Flight Test Engineers' Technical Council Award in 1993 and the Canadian Aerospace Institute's Norm Ronaason award in both 1993 and 1994. In May 1995 he transferred to the Royal Australian Navy. He is currently serving there as the Navy's Chief Test Pilot.