THE USE OF HELMET-MOUNTED DISPLAYS IN RECOVERING STOVL AIRCRAFT TO SHIPS

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ABSTRACT

Using a helmet-mounted display to provide the pilot with short-range approach and landing information could help in recovering aircraft to a ship, where deck movement, wind and poor visibility can make the manoeuvre one of the trickiest in flying. Suitable symbology has been devised for displaying key information, and trials have been carried out using the Advanced Flight Simulator at QinetiQ Bedford. It was concluded that the benefits of better situational awareness out-weigh the penalty of greater pilot's workload. The work has also highlighted scope for improving the svmbologv.

Introduction

Landing an aircraft on a ship's flight deck is difficult: the pilot may have to contend with high levels of deck motion, adverse wind over the deck and poor visibility, as well as the normal aspects of flight-path control. The only aids currently available to the Royal Navy pilot are:

- Painted deck markings.
- Lighting patterns in the form of electroluminescent panels along the deck edges and superstructure.
- The Flight Deck Officer, who provides invaluable verbal positioning information via 'voice con'.

A roll-stabilized horizon bar, as used by the Canadian Navy for example, can help but such a device is large and unsuitable for multi-aircraft-capable ships. The current aids are likely to be unsuitable for future aircraft-ship operations where maximizing the 'operational day' will be important.

The help that might be provided by a Helmet-Mounted Display (HMD) has been under consideration for some time. This article gives an account of work carried out to provide symbology and of trials to test its suitability. These trials showed that the HMD aid is useful but that the symbology could be improved. Suggestions for improvements are made.

Background

The pilot's situational awareness during the critical deck transition, hover and landing phase could be improved by enabling the ship's visual cues to be kept in view, along with the symbolic overlay of critical information, on a HMD.

Early work on embarked helicopter all-weather operations concentrated on the hover and landing task. At first, symbology similar to that in the APACHE HMD hover display was used and displayed via a simple virtual reality headset. Subsequently, a BAE SYSTEMS binocular HMD having a field of view of 53° x 30° was tried. Both of these investigations suffered from limitations in the HMD used, mainly from weight, discomfort and visual obstruction. As a result, a more suitable HMD was sought, the system procured specifically for further investigations being the GUARDIAN, jointly developed by Cumulus SA and Pilkington Optronics. The Guardian (FIG.1) is a lightweight, monocular HMD with a 20° field of view where information generated by a miniature CRT is relayed to the pilot's eye via a reflective 'patch' coated on the clear visor.

FIG.1 – THE PILKINGTON GUARDIAN HMD

Simulator trials in 1997 and 1998 using the new system featured novel symbology specifically designed for the deck hover and landing task. This symbology is illustrated in (FIG.2).

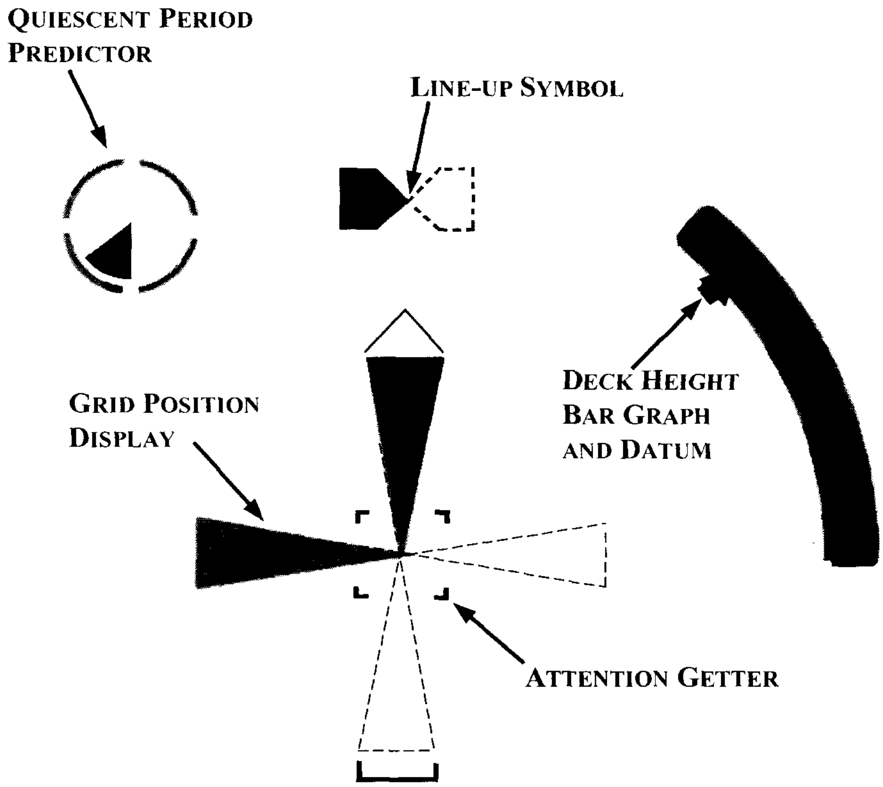


FIG.2 – DECK LANDING AID SYMBOL

The central display, the Grid Position Display (GPD), shows the position of the aircraft relative to the ideal landing spot and shows the direction to move the aircraft in ship axes. The Line-up symbol at the top shows the direction to move to reduce aircraft yaw error relative to the centre line of the ship. The 'Attention Getter' ticks light up when the pilot is over the landing grid. The height-above-deck bar-graph display has a re-datum facility: the action of the pilot in pushing a button on the cyclic resets the height of the bar-graph so that the symbol's maximum deflection represents the height at the instant the button is depressed. This enables the pilot to set the scaling of the display, a useful facility if descent rate is critical. The symbol in the top left-hand comer is the Quiescent Period Predictor, which has two parts:

> The outer ring indicates to the pilot the likelihood of deck movement going out of safe landing limits in the near future:
>
> > One segment being lit indicates a 'safe' deck, i.e. it is likely to remain within safe limits for up to 5 seconds. As the ring closes up, the deck becomes increasingly unsafe for landings. A full circle indicating an unsafe deck.
>
> The segment in the centre of the display is an estimate of an oncoming safe landing period, up to 30 seconds into the future.

The example shown is of a safe period some 15 seconds away lasting for about 4 seconds. Current technology only provides short-term predictions.

Background STOVL Control – Law research at QinetiQ Bedford

The Vectored-thrust Aircraft Advanced Control (VAAC) HARRIER research aircraft (FIG.3) is a highly modified HARRIER T Mk 4 two-seat trainer.

FIG.3 – QINETIQ BEDFORD VAAC HARRIER

An experimental digital Flight Control System (FCS) has been fitted to the aircraft alongside the existing mechanical control runs. The front cockpit retains the normal HARRIER control system while the rear cockpit controls interface only with the digital FCS and thus form an experimental station for FCS research, and can be fitted with a variety of flight controls (inceptors) including normal 'stick and throttle' or other more advanced concepts. Work has been carried out on reducing the pilot's workload by reducing the number of inceptors from three to two and using new control modes such as Translational Rate Control (TRC). This enables low workload hover manoeuvring by allowing the pilot to command his desired rate of movement over the ground directly. The FCS then interprets these commands and converts them into motivator commands to achieve it. To date, TRC guidance symbology has been presented on a Head Up Display (HUD), which requires that the pilot keeps his eyes in the cockpit. The FCS computer code can be used on both the Advanced Flight Simulator (AFS) (FIG.4) and the VAAC HARRIER.

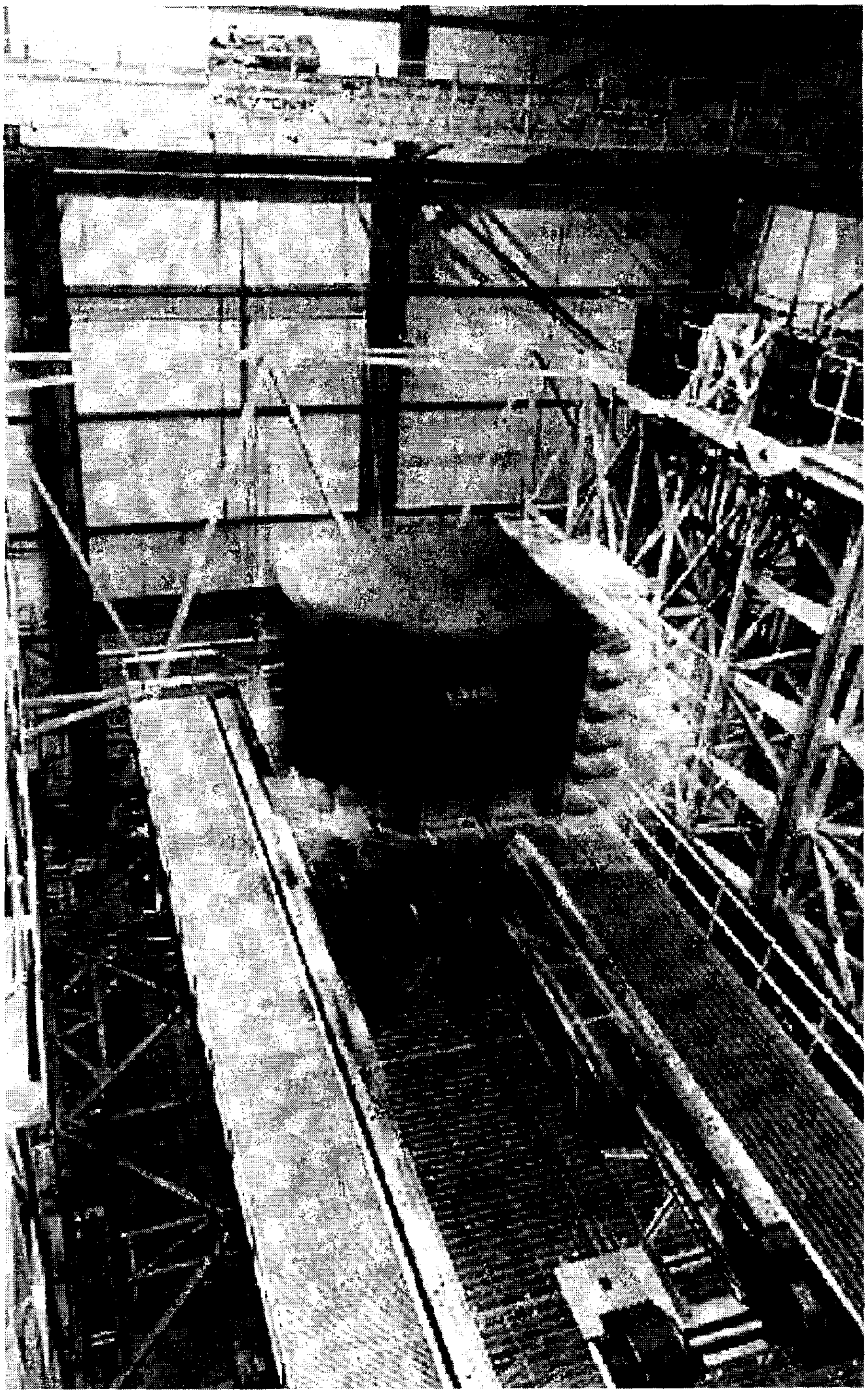


FIG.4 – QINETIQ BEDFORD ADVANCED FLIGHT SIMULATOR

Trial AQUILLA rationale and design

The work on using HMD in maritime helicopters is equally, if not more, suitable for maritime fixed-wing applications. For example, the future Joint Strike Fighter pilot is likely to rely greatly on head-mounted displays, so the deck recovery symbology could be added as another HMD mode.

Trial AQUILLA was designed to answer some of the initial questions on how pilots would use an HMD displaying TRC guidance information compared with a HUD. Using the VAAC project pilots attached to the programme, comprehensive task analyses covered deck positioning, visual cues and current operational procedures. Literature searches unearthed some interesting information going back as far as 1976. Some of the ideas were subsequently included in the latest symbology designs.

Fast-jet HMD trials were being undertaken, at the same time, by the Cockpit Displays Group at QinetiQ Farnborough. These trials, in TORNADO and JAGUAR aircraft, used both the 40° BAE SYSTEMS VIPER binocular HMD and the GUARDIAN HMD. Although the emphasis in these trials was on developing symbology for air-to-air combat, the lessons learnt on displaying information away from the normal longitudinal axis of the aircraft, or off-bore-sight, were complementary to the simulator programme. One observation made by the pilots concerned using the HMD as a monitor when performing off-axis visual scans - they reported being able to use it to increase their 'eyes-out' time.

The objective of trial AQUILLA was thus to compare and assess the merits of HMD, HUD and combined HUD/HMD operations. The aims of the trial were to evaluate:

- The use of HMD for the TRC phase.
- Using the GPD.
- concurrent usage of HMD/HUD.
- Alternative attitude displays.
- Use of stabilized horizon display.

Trials time was limited and only permitted looking at the 'big picture'.

To present symbology stabilized against the outside world scene, known as 'conformal' symbology, head tracking is required, to determine the head's pointing vector. Integrating the head tracker was the single most difficult problem faced. The presence of a metallic parachute head box on the Martin Baker ejection seat caused the biggest head-tracking error in the simulator trial. Substitution with a wooden version solved the problem!

Because the HMD and HUD were used simultaneously, a method was devised to switch off the HMD symbology when the head moved into the field of view of the HUD. This was termed 'Auto-Occult'.

The phosphor response and interaction with the HMD visor coating are important when looking at combined HUD/HMD operation. The visor coating is tuned to reflect green light from the HMD's CRT and hence would also reflect the green HUD emission. Fortunately, the phosphors used in the AFS HUD and the Pilkington HMD CRT had different spectra.

Symbology design

From the outset, it was realized that the primary role of the HMD was likely to be that of an enhanced weapon aiming aid, a 'super-sight'. It is thus important to leave the centre of the display as clear as possible for use in up and away flight. In the deck transition and landing phase, the TRC guidance symbology would become the dominant symbology and would be positioned in the centre of the display. This design tenet is known as the 'importance principle'.

The HUD symbology used in the VAAC HARRIER followed conventional design guidelines. Areas of the display are usually designated for specific functions, for example:

- Airspeed in the top LH comer,
- Heading at the top
- Height in the top RH comer.

The HMD symbology was also designed to display basic aircraft-state information conventionally. Helicopter pilots in the previous trials had said that a conformal horizon line would be very useful. However, generating stable conformal symbology, even in a simulation environment, is still a challenge and, because of this risk, only a conformal horizon was implemented. Experience of many methods used to display attitude information led to the Arc Segmented Attitude Reference (ASAR)[1] being chosen for the attitude reference. Provision was made for both large and small versions of this display.

(FIG.5) shows the up and away symbology and is similar to the VAAC HUD display. The attitude reference is a small ASAR near the centre of the display.

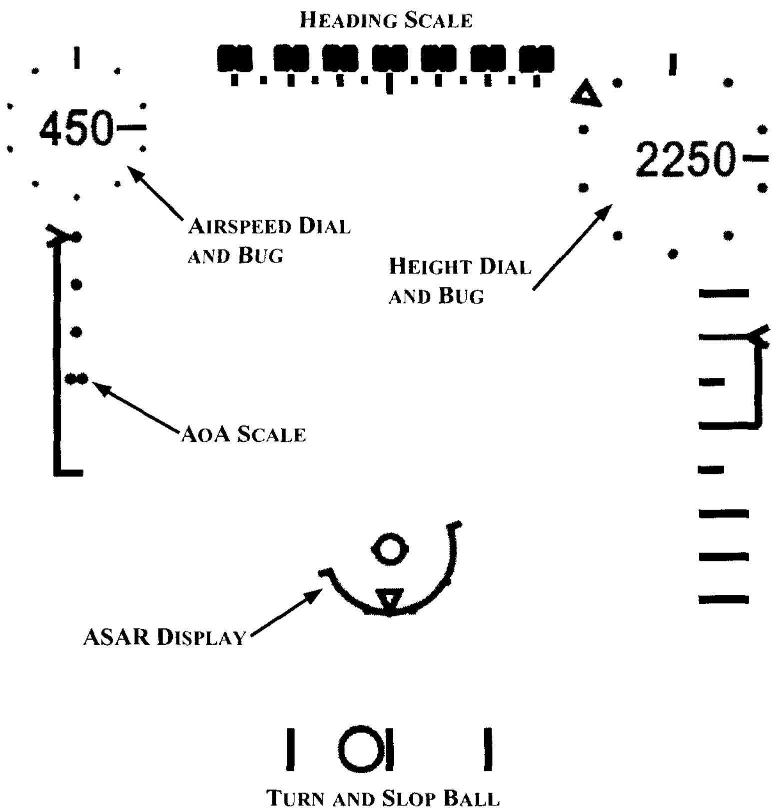


FIG.5 – UP AND AWAY SYMBOLOGY

The TRC mode symbology is shown in (Fig.6).

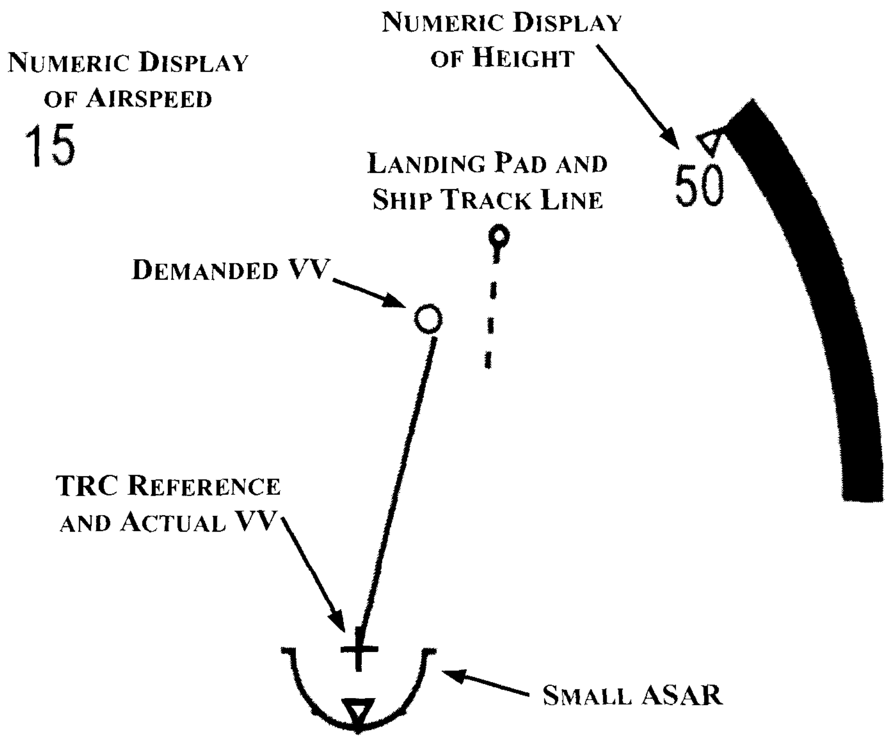


FIG.6 – TRC MODE

The main symbol is the small ASAR reference and TRC symbol. The actual Velocity Vector (VV) grows out from the centre of the reference. The demanded VV is shown as a small circle and is effectively the velocity demanded by the pilot via the position of a small thumb controller mounted on the stick. The pilot positions this circle over the landing-pad symbol. The subsequent motion of the aircraft brings the ship pad towards the centre of the display. The track of the ship is shown as a dotted line that trails the pad symbol. This helps the pilot in positioning relative to the longitudinal axis of the ship. The height bar graph has a re-datum facility similar to that used in the helicopter trials. The GPD mode display is similar to that used in the helicopter trials and is shown in (FIG.7).

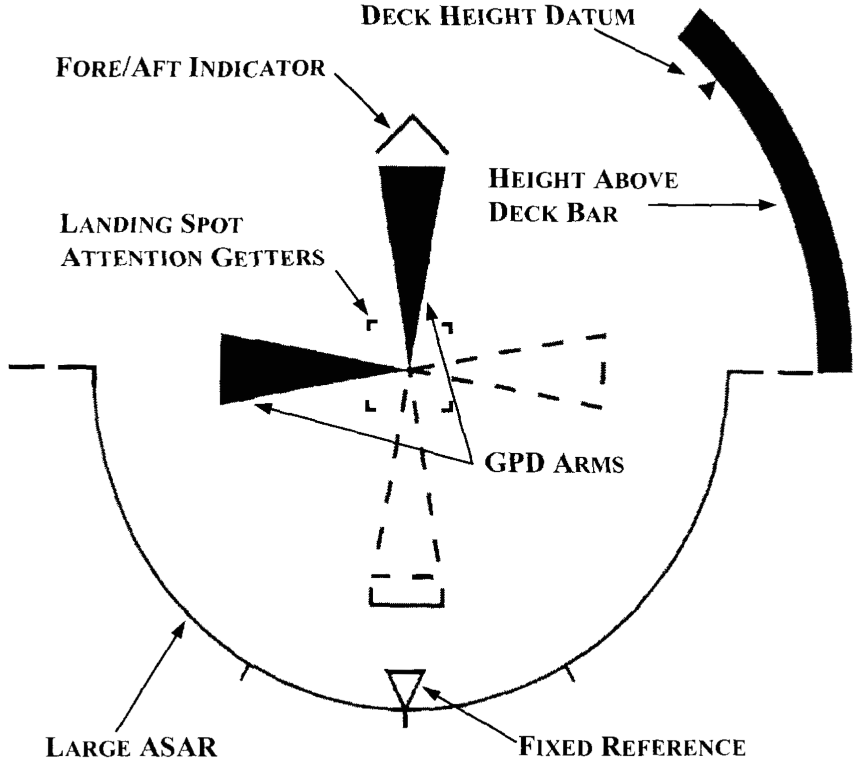


FIG.7 – GPD MODE

In this case a large ASAR display is used, which wraps around the outside edge of the display.

The only earth-referenced symbol type is the conformal horizon bar used in the TRC mode symbology.

(FIG.8) is a view from the AFS cockpit and shows the ship visuals used, the HUD, HMD and route gereration displayed on a Colour Head-Down Display (CHDD).

FIG.8 – SIMULATION ENVIRONMENT

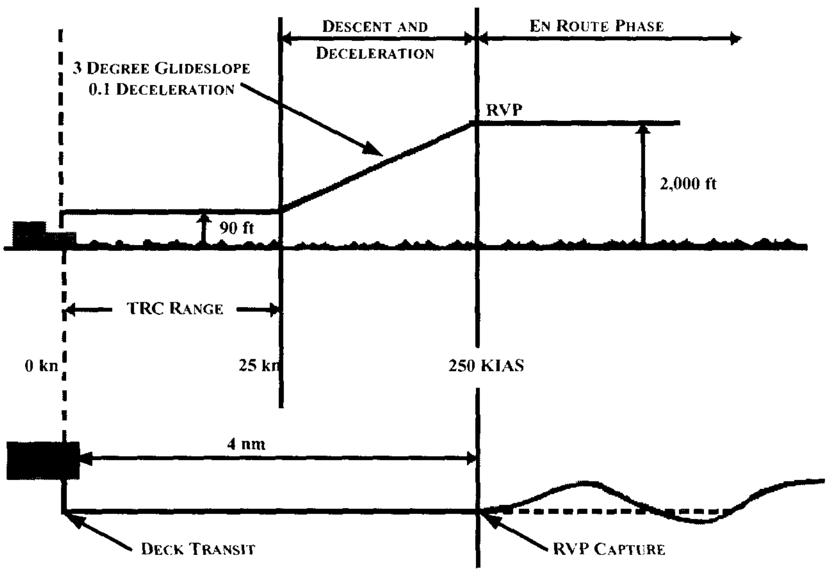


FIG.9 – TYPICAL VAAC APPROACH PROFILE

The approach profile used is shown in (FIG.9), and has three portions. The first is low workload flightpath guidance to a Rendezvous Point (RVP), which is displayed on HUD and CHDD. Once at the RVP, at a set height and speed, the symbology changes to a flight path director symbol. Because this is a higher workload task, and coding conformal flight path markers was not included in this trial, the guidance was displayed on the HUD. The pilot is guided down a descending, decelerating flight path that transitions to a level platform segment at a height of 90 ft, with the aircraft at a speed of approximately 25 kt.

TRC mode is engaged upon completion of the level platform segment of the profile. These changes in symbology throughout the profile are intentional and help to prevent 'attention tunnelling' or 'cognitive capture'.

The pilot's task is then to initiate a transit and landing as quickly as possible using either HMD, HUD or, in some cases, both. The HUD was physically turned off during the HMD only runs. The AUTO-OCCULT function ensured that the HMD and HUD did not conflict during the runs when both were used.

The simulation environment used:

- An HMS *Illustrious* Visual Database
- A simple sea state model approximating sea state 3 (6-8 feet wave height)and appropriate ship motion data,
- A range of wind conditions up to the control law limits, turbulence and air-wake models.
- For the night-time approaches, simulation of electroluminescent panels.

Trial results

The three assessing pilots made 54 approaches; more than 6 hours of data were logged. The most useful results were the pilot's comments, some of the key points raised being:

Pilot A

- Display was intuitive when used off-bore-sight, with no tendency to disorientation.
- HMD scaling seemed more sensitive than the HUD.
- Conformal horizon was useful but the small random motions were slightly distracting.
- Display was cluttered when over the spot.
  (*This was subsequently corrected on the remaining runs*)
- HMD was less clear than the HUD (owing to use of rastergenerated symbology).
- The large ASAR was useful as a horizon reference.
- The ability to re-datum height is of dubious value.
- Good comfort and fit were achieved with the HMD helmet.

Pilot B

- There was a perceived lack of stability using the HMD when compared with the HUD.
- The task of fusing the symbology without the window view became easier as the task progressed.
- The ability to re-datum the height was of dubious benefit.
- He was able to use the TRC symbology to move straight to the spot, which could not be done using the GPD.
- He was more aware of the ship's superstructure when using the HMD.
- Combination of display scaling and aircraft power in the hover made tight control difficult.

- Good comfort and fit were achieved.

Pilot C

- Rate information given by TRC was more useful than GPD.
- Control using TRC was overly sensitive when near to the landing spot.
- The ability to fuse symbology with the ship structure was useful.
- ASAR was of dubious benefit.
- HMD was less clear than the HUD (owing to use of rastergenerated symbology).
- Good comfort and fit were achieved.

To assess the workload, the time taken to complete the manoeuvre and the number of inceptor reversals used were measured. This inceptor activity was logged at 50 Hz. For convenience, the sorties were divided into low and high workload sections, as defined by the environmental conditions. (Fig.10) shows the plots of control reversals for pilots B and C.

Note:

Pilot A's performance is not shown as changes to the symbology were made as a result of this pilot's comments, particularly concerning the de-cluttering of the display when positioned over the landing spot.

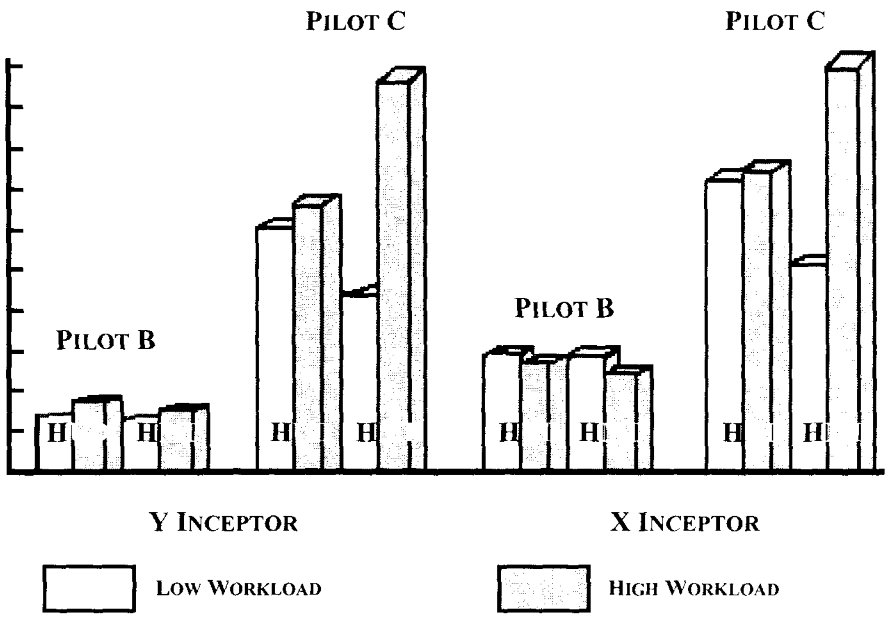


FIG.10 – CONTROL REVERSALSFOR PILOTS B AND C

There was very little change in the number of reversals made by pilot B when using HUD or HMD, indicating parity in terms of physical pilot workload. Pilot C, however, demonstrated better performance using the HMD in the low workload tasks. The higher workload tasks show a dramatic increase in the number of reversals and the time taken to perform the manoeuvre. It should be noted that pilot C was an experienced fast-jet pilot with but limited STOVL experience. In comparison, pilot B had extensive STOVL experience.

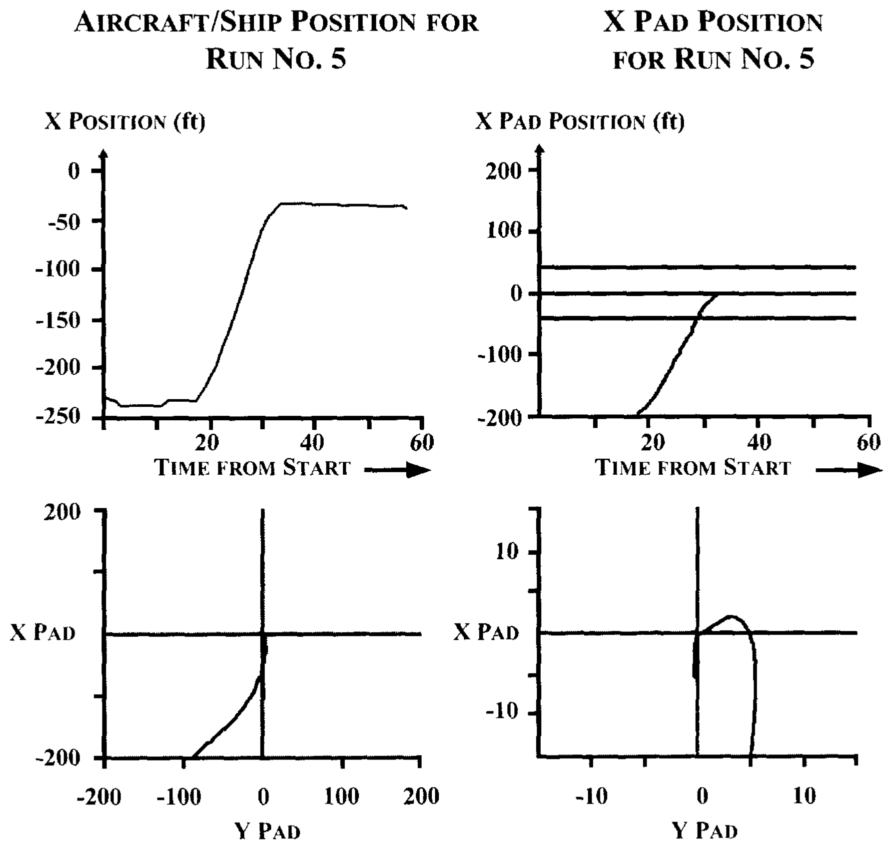
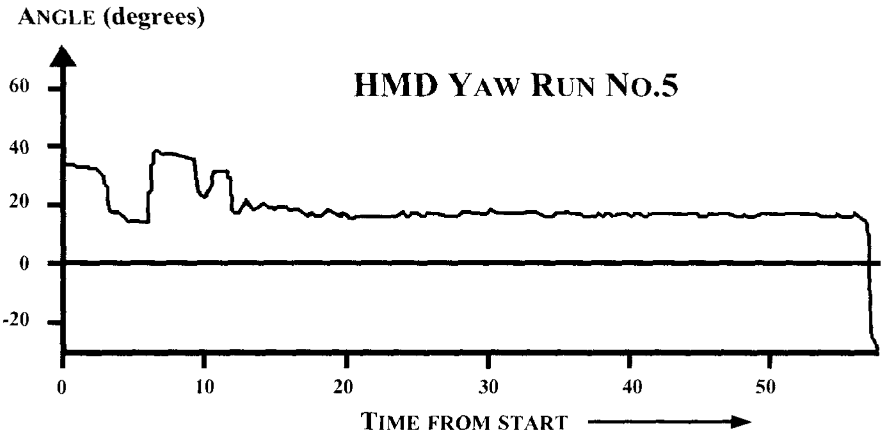


FIG.11 – POSITION PLOTS

(FIG.11) shows the aircraft's position with respect to the ship and to the landing spot as a function of time, and as X,Y cross plots.



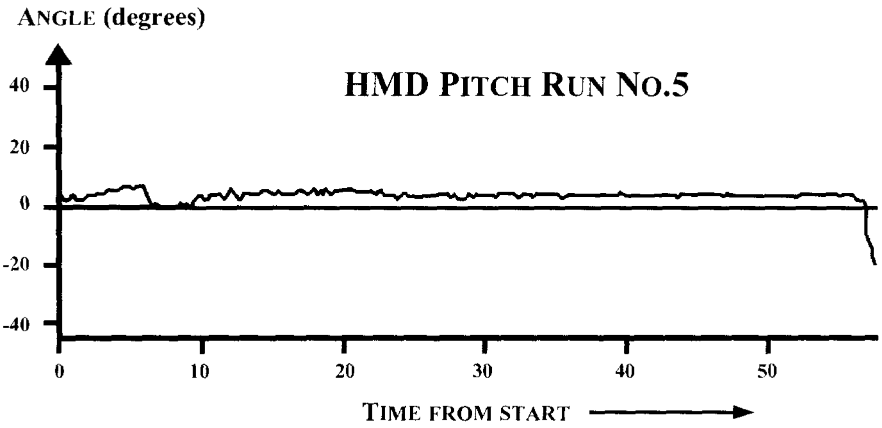


FIG.12 – HEAD TRACKER PLOTS

(FIG.12) shows the head-tracker plots for pilot B when performing a deck transit for the same approach and landing; the pilot first moves his head between about 20° and 40° off-axis. During debriefing, the pilot stated that this caused significant disorientation, which affected his flight-path performance and his subsequent positioning over the landing spot suffered.

In the subsequent run shown in (FIGs 13 and 14), he kept his head very still and this 'brought back the required level of stability to the display'. It can be clearly seen, from the plot of lateral position, that his performance over the landing spot is much improved. The plots of head yaw also show that, towards the end of the run, the pilot turns his head to straight ahead to check his line-up performance.

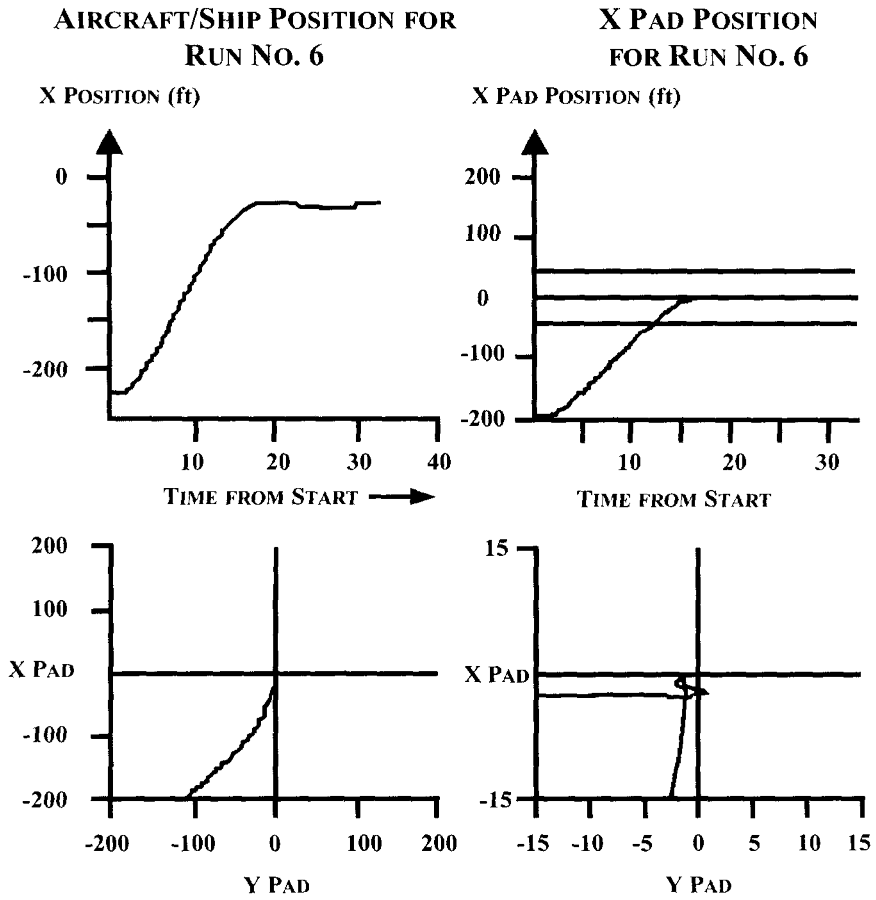


FIG. 13 – POSITION PLOTS

The pilot involved in the above runs noted that the workload was higher when looking off axis. He stated:

> "During training the pilot is taught to control the aircraft very carefully and prevent any unwanted excursions to the flight path. The HUD helps to increase the perceived stability by displaying the symbology in an aircraft stabilized position".

The other pilots did not, however, comment on a perceived increase in workload when performing the off-bore-sight TRC task, and Pilot A went as far as to say that the control-display action was natural. This could be attributed to the fact that the body axis set is 'aligned' to the aircraft's line-of-flight datum via the action of the pilot's being strapped into the seat. This appeared to hold true for values of head motion up to 90°.

The correct interpretation of information that follows one's gaze around is clearly a skill that has to be acquired. All the pilots noted that, as their experience grew, the ability to fuse the symbology with the view of the ship was 'useful'.

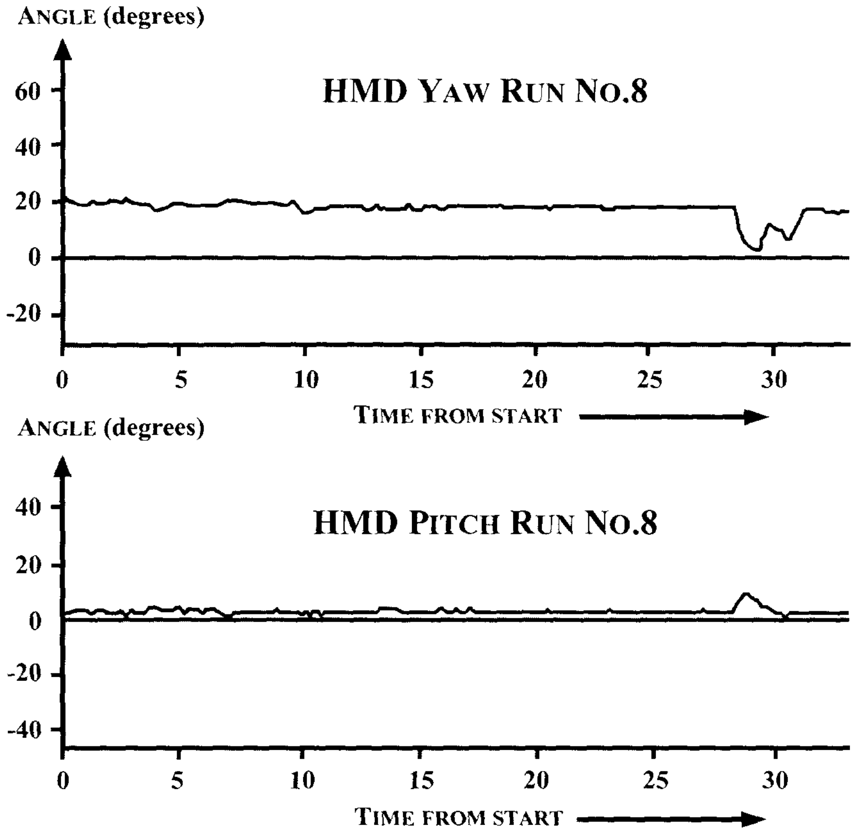


FIG.14 – HEAD TRACKER PLOTS

A tentative conclusion was drawn that the increase in workload from using the HMD is a small penalty and may be counterbalanced by benefits from being able to fuse the symbology with the ship's superstructure. It is important that sufficient time be allowed in such evaluations for the process of 'switching' between symbology and out-of-the-window view to be sufficiently assimilated by the user. This is clearly an area that needs further research.

Conclusions

The overall conclusions that were made from the trial were:

- The HMD can be used for the task, and axis translation was not a problem.
- Interpreting HMD information when presented off-axis requires significant training.
- HMD clarity was far worse than that of the HUD owing to the usage of raster symbology.
- Harmonization with the aircraft dynamics is essential.
- The large ASAR display is more useful than the small ASAR.

Recommended modifications to symbology

As a result of the trial, several improvements to the display were proposed. These are summarized in (FIGs 15 and 16).

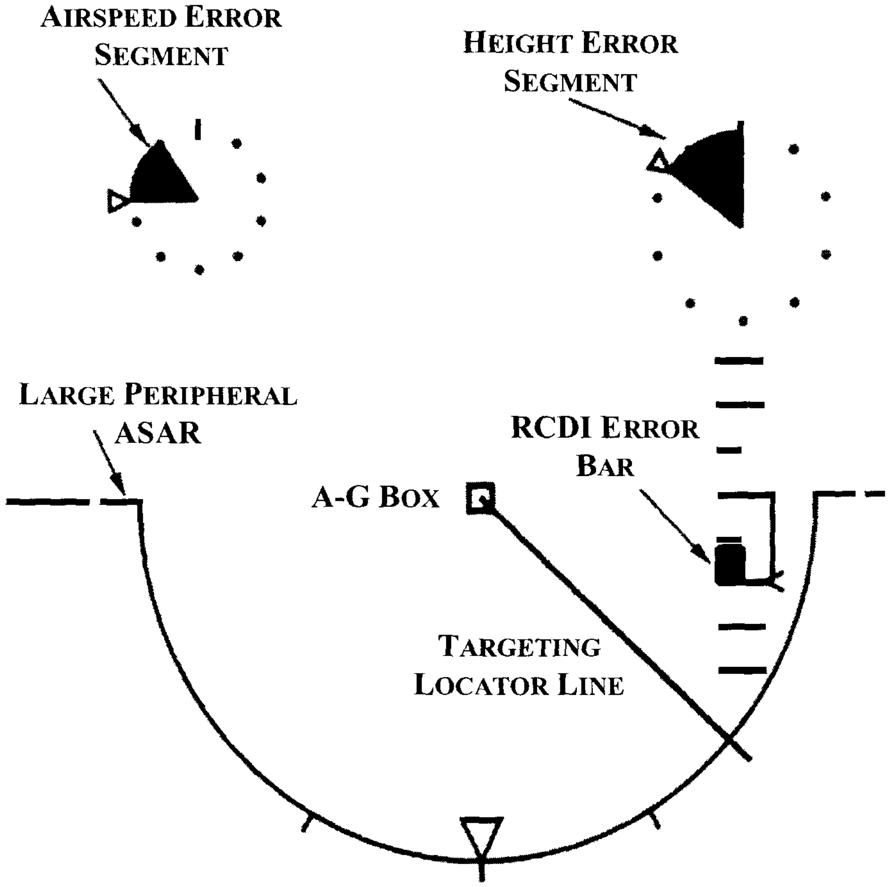


FIG.15 – HMD USED FOR FOR AIR TO GROUND WEAPON AIMING

FIG.15 shows an HMD used off bore-sight for air-to ground weapon aiming. The error segments show the difference that has accrued between the profile speed and height shown by the bugs on the outside of the display, and the actual speed and height over the time the pilot looks off axis. Any errors hence become increasingly apparent.

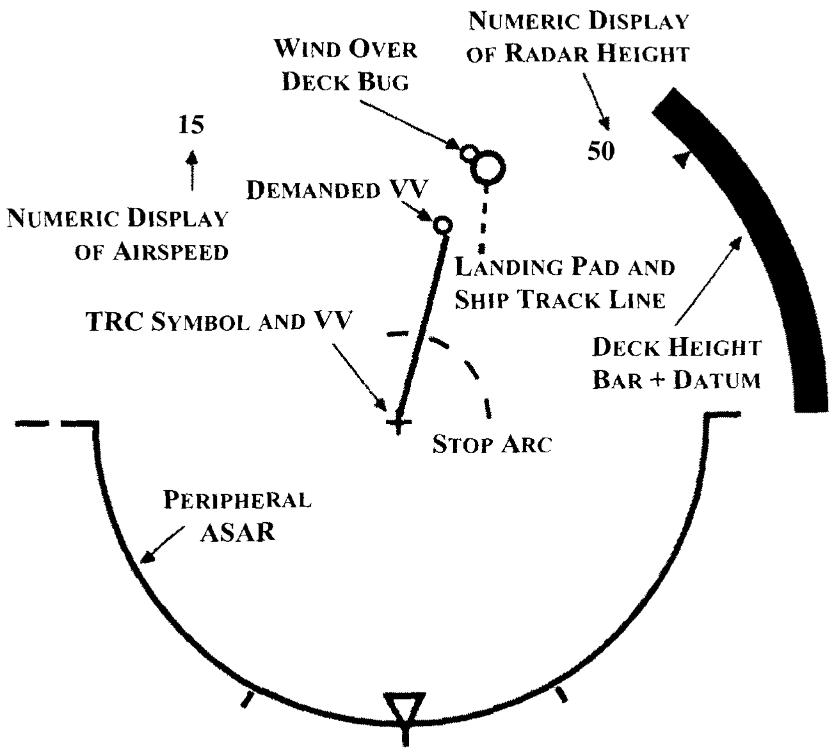


FIG.16 – PROPOSES CHANGES TO THE TRC MODE SYMBOLOGY

FIG.16 shows proposed changes to the TRC mode symbology. A bug has been added to the ship symbol to indicate the direction of the wind over the deck. (It would also be useful to indicate the magnitude of the wind over deck with a 10 kt ladder, for example.) In addition a 'stop' arc could be added. This would be continually computed from the actual aircraft velocity and would take the form of an arc drawn around the reference symbol. If the TRC thumb control is released at the instant the ship touches the arc, the vehicle dynamics would bring the aircraft to a halt either over, or on the 'safe side', of the spot. This would improve the pilot's confidence that he is not about to fly into the ship and would enable maximum-rate excursions to be made with confidence. The large ASAR has been retained as it appears to be the more acceptable of the attitude references studied in the QinetiQ fast jet HMD trials and in AQUILLA. Using a standard pitch ladder has not been considered for a small field of view HMD such as GUARDIAN as it generates a large amount of clutter in the central area.

Reference

1 FISCHER G; FUCHSW. 'Symbology for head-up and head down applications for highly agile fighter aircraft – to improve spatial awareness, trajectory control and unusual attitude recovery. *Paper 12 AGARD conference proceedings 520*, Edinburgh.