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OP 02
Challenges at the Helicopter-Ship Dynamic Interface

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ABSTRACT

The paper takes a total systems approach to the challenges at the helicopter-ship dynamic interface. It examines the problems of operating large helicopters from small ships in all weather conditions from the start of the mission to completion with due emphasis on the launch and recovery phases. Research taking place at DERA Bedford in support of current and future naval operations is outlined. Although the prime focus is Royal Navy Anti-submarine Warfare operations, the paper also considers present and future maritime and marinised helicopter types.

The paper is written from the perspective of developing requirements and reducing risk by demonstrating technical solutions. The main focus of the paper is the recovery from completion of task to securing in the ship's hangar. It addresses the aspects of automatic flight path management and flight control systems and the role of automation during the recovery process, particularly in the case of the single pilot aircraft. The performance advantages for the landing task at night and in poor visibility provided by ship mounted visual aids, both passive and active/sensor-based, are reviewed as is the use of Helmet Mounted Displays and modified aircraft head down cockpit displays.

The paper reviews the requirements, use of and the potential benefits of high fidelity simulation of all the elements of the helicopter-ship interface - the helicopter, the ship and the effects of the environment, including ship motion, airwake and reduced visual cues due to fog, spray and snow, for example. It also considers the role of piloted flight simulation in establishing the optimum handling requirements for maritime helicopters, supporting military aircraft release and predicting likely ship helicopter operating limits, the procurement specification of new types, practising new roles and procedures and continuation training.

Problems associated with securing the helicopter on deck before launch and after recovery, rearming and refuelling and manoeuvring on deck are also discussed.

1 INTRODUCTION

The operation of large helicopters from small frigates presents a demanding task for both the aircraft and the crew. The introduction of the 15T Merlin to the Royal Navy (RN) represents a significant advance compared with the 5T Lynx, not only in size and weight but also in terms of sortie endurance and complexity. These factors will have a major impact on the workload of the single pilot, especially during the recovery to the ship in adverse weather conditions at the end of a long mission. Research is taking place at the Defence Evaluation and Research Agency (DERA) at Bedford, (UK) in support of naval helicopter operations to ensure that the overall availability and operational effectiveness of large helicopters such as the Merlin, operating from small ships, will be maintained at a high level, without reducing safety margins throughout the life of the operational system. The research seeks to achieve this by providing methods of increasing the operational limits in respect of more severe sea states (ship motion conditions), relative wind and visibility conditions which will, in turn, increase the potential time on task and provide the capability to launch and recover at any time and in any conditions.

The paper draws on the work of the UK Ministry of Defence (MOD) Applied Research Programmes (ARPs). These programmes are linked to the Corporate Research Programmes (CRPs) which undertake fundamental and technically high risk research and which provide the scientific platform for many of the ARP activities. In their turn, the ARPs provide the mechanisms and techniques for solving the problems of existing procurement programmes (Project Support).

The paper is organised as follows. Section 2 provides an overview of the technical/operational problems associated with maritime helicopter operations with particular reference to the helicopter-ship dynamic interface. Section 3 discusses navigation and guidance aspects, followed by a description of the DERA Integrated Recovery Mode in Section 4. Section 5 discusses the problem of the airwake over the ship's flight deck, referring to wind tunnel/full scale testing and Computational Fluid Dynamics (CFD) calculations. Section 6 addresses requirements and technologies associated with manual approaches and landings, including visual and control augmentation aspects. Section 7 is concerned with deck operations and particularly deck securing systems. Section 8 considers the prospect of the virtual dynamic interface and the role of modelling and simulation in supporting procurement and qualification. Section 9 draws the paper to a close with some concluding remarks.

2 OVER VIEW OF THE OPERATIONAL/TECHNICAL PROBLEMS

2.1 Task area to ship location

The first problem that the pilot faces is to locate the ship without the use of conventional communications and radar. It is necessary to have a process that converts the estimated ship position leaving the task area (extrapolating the situation at launch) into a known location during the transit to the ship. Even knowing the approximate location of the ship, visual detection can be extremely difficult even in daylight hours; poor visibility caused by fog, mist, snow and rain and night only exacerbate the situation.

2.2 Approach to the ship

The second problem is that the recovery process adds to the workload of the crew, and particularly the single pilot, at the end of a long mission where fatigue is likely to play a significant role. Recoveries are normally flown manually along straight-line paths using radar steering directions provided by the radar operator. This process lacks accurate information such as the deviation from the required recovery profile and the rate of closure; it also lacks ship information such as speed, track and the conditions on the ship such as the wind over deck and the ship motion. In poor visibility, visual acquisition of the ship can be difficult without aiding (Figure 1) and the deceleration to the hover, when the aircraft is flown manually, can only take place when the pilot is visual with the ship. This factor alone determines the achievable weather minima. Figure 2 shows the visual range required to decelerate at 0.1g as a function of the closing speed. At a minimum Instrument Flight Rules (IFR) speed of 60kn, the range required to decelerate at 0.1g, assuming a 5s visual acquisition time, is 1250m. To achieve a minimum visual range of 400m requires a closing speed of 45kn (or 25kn Indicated Airspeed (IAS) at visual acquisition for a 20kn tail wind). To operate in these conditions therefore requires an IFR deceleration capability. Visual acquisition of the ship is also made more difficult with beam wind components which affect the field of regard from the cockpit and the control of the helicopter.

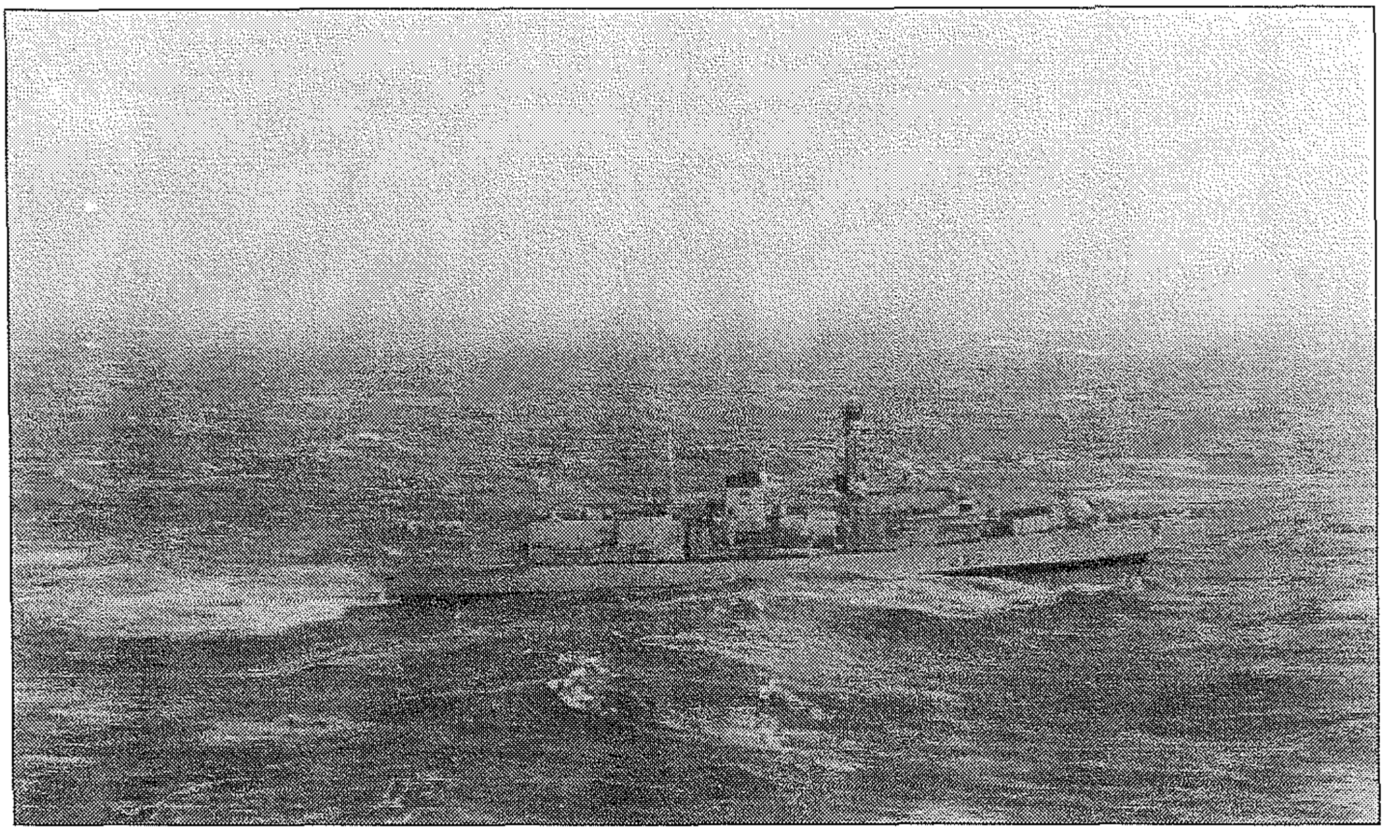


Fig 1. Locating the Ship

The standard RN 165° approach, at an angle of 15° to the ship's track, to the side of the ship provides good visual closing cues compared to the over stern approach favoured by the United States Navy (USN). Having achieved the hover alongside the ship, the pilot continues to formate with the ship and, in high sea states, awaits a period of low ship motion (quiescent period) before commencing the landing process.

2.3 Deck Landing and the Adverse Environment

2.3.1 The Ship and Deck Environment

Having achieved a successful formation with the ship, the final stages of the recovery, the transition over the deck and the land on, are affected by the pilot's Usable Cue Environment (see Section 6.1) in poor weather and at night when there is no external horizon reference. Added to this are the control difficulties caused by flying close to the hangar face and through the wind shear, wake and turbulence effects created by the air flowing over the superstructure onto the flight deck. The flight deck itself is subject to high pitching, rolling, yawing and heaving motion. These constitute the adverse environment in which operations take place. The poor visibility can be

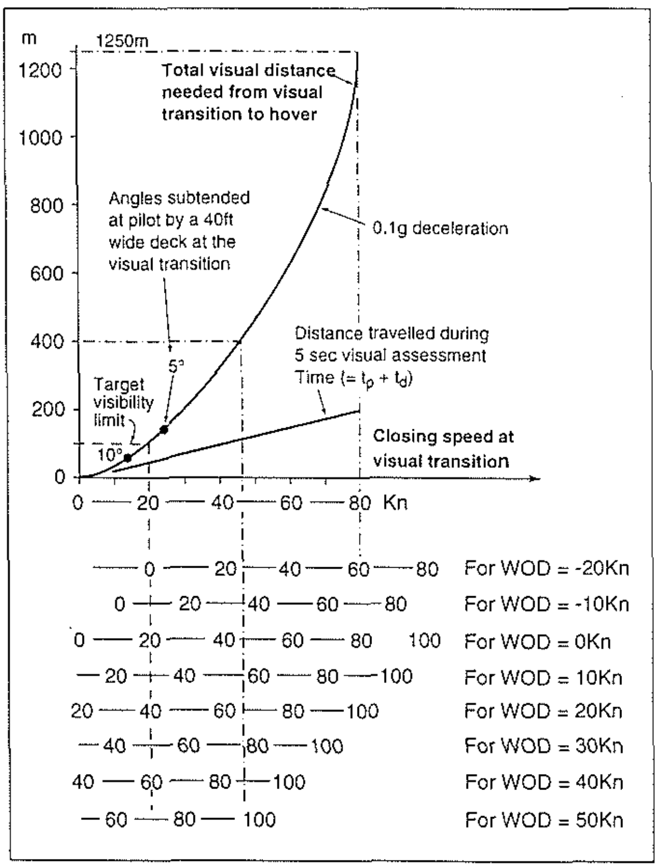


Fig 2. Visual Range Required

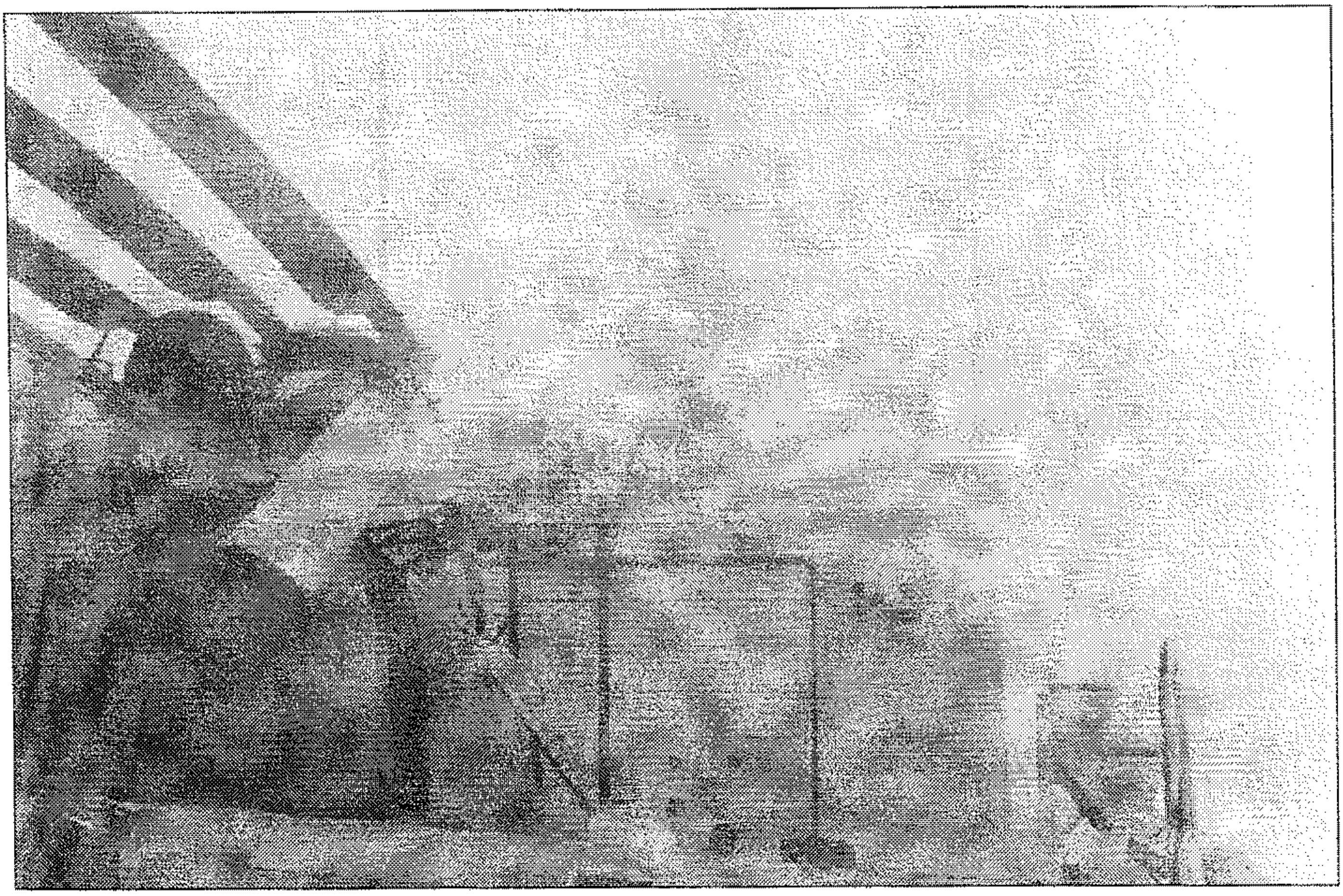


Fig 3. Poor Visibility at the Ship

caused by fog, mist, snow, rain and also spray (Figure 3) while the helicopter is operating close to the sea with breaking waves. Any visual cueing aids on the ship also have to be sited to ensure that, with high nose-up pitch attitudes and relatively high hover heights, they will not be obscured from view (see Section 6.2). The control characteristics of current helicopters are not well tuned to these tasks, and hangar downdraught effects are the cause of reduced helicopter thrust and manoeuvring margins experienced on certain ships and landing spots. In such conditions, controlling the position of the helicopter over the deck sufficiently well to ensure a landing within the required area (for example to engage a deck lock) can be extremely difficult.

2.3.2 Ship Helicopter Operating Limits

The limits imposed on deck landings and take-offs by wind condition and ship motion are expressed in terms of Ship Helicopter Operating Limits, or SHOLs. These are usually represented in diagrammatic form, an example of which is at Figure 4. The wind speed and direction must be within the safe operating envelope shown on the diagram for the helicopter to land or take-off safely; if they are not, the ship may be forced to change course and speed to achieve a safe wind

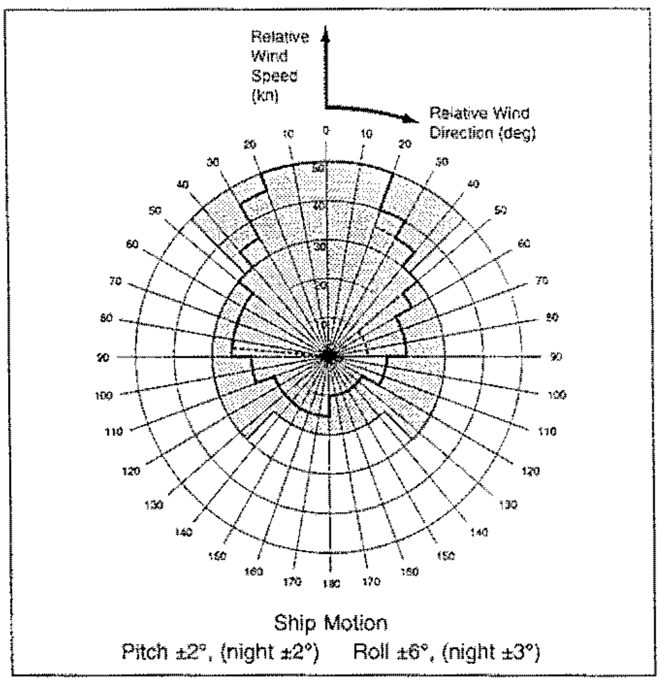


Fig 4. A Typical SHOL

condition. Boundaries of operation are reached when the pilot's workload becomes too high to safely achieve consistently accurate landings. A boundary can also be defined by aircraft limits. For example, a helicopter with a low thrust margin or inadequate vertical agility is in danger of unintentional contact with the deck in high sea states. Alternatively, in strong cross-winds, the limit of tail rotor authority can be reached such that the pilot cannot maintain heading relative to the ship.

SHOLs are derived during First of Class Flying Trials (FOCFT) for every helicopter/ship/landing spot combination and are consequently very expensive in terms of ship and aircraft time. Test pilots repeatedly land and take-off in progressively more severe wind conditions until a boundary is reached. Read-across between similar ships and aircraft is applied in certain circumstances, for example when a helicopter is required to operate to a foreign deck, but the safety factors applied result in a very restricted SHOL.

2.4 Deck Operations

Once the helicopter has landed on the ship, it has to be secured to ensure that it does not slide on the deck, with the potential of causing injury to the crew or the maintainers. The recent loss of a Lynx helicopter has highlighted concerns with current methods of securing helicopters on deck. In addition, to be effective, a securing system must also allow manoeuvring in and out of the hangar and support the process of re-arming and re-fuelling the helicopter, preferably without the aid of unsecured personnel. On deck, limitations are imposed on the spreading, folding, engaging and disengaging of the rotor blades which are currently based on experience and specific flight clearance tests. The process is not well researched or understood and a scientific basis for the area of operations is being established in the ARP, building on the original work of Newman (Ref 1).

In the following Sections, the various phases of the recovery process will be discussed in more detail, with emphasis on contributions made by past and ongoing DERA research into refining requirements and developing and demonstrating technology.

3 ENHANCED NAVIGATION AND SHIP RECOVERY GUIDANCE

3.1 Guidance - a Key Technology

The key technology for the recovery of both rotary wing and fixed wing aircraft to ships at sea is that which defines the position of the recovering aircraft relative to the parent ship. With that information available, the aircraft can be guided to the ship along pre-defined trajectories manually using information properly displayed in the cockpit, or using flight director information presented on the primary flight display or automatically through the autopilot. In the civil aviation world, aircraft use the ILS (Instrument Landing System), which has been developed for over 50 years, for approach and landing guidance and all major airports are equipped. This will be replaced by MLS (Microwave Landing System), in Europe at least, while the US Federal Aviation Authority have opted for a Global Positioning System (GPS) based solution. The military also still use another 'war-time' system called PAR, or Precision Approach Radar, which has the advantage of not requiring an aircraft installation (but the disadvantage of requiring skilled ground controllers).

3.2 RN Recovery Systems

For the recovery of the Sea Harrier aircraft to ships, the RN relies on Microwave Aircraft Digital Guidance Equipment (MADGE), an interferometric system operating in the microwave band which is fitted to the Illustrious-Class Carriers. MADGE, which operates in azimuth mode only on these ships, was developed in the early 70s and won a NATO tactical guidance competition, but only the RN systems were manufactured. Apart from MADGE, naval aircraft can use ship based radars and controllers (Ship Controlled Approach) or their own radar (Helicopter Controlled Approach). Like the PAR, these systems rely on skilled operators and impose high workload on the pilots.

3.3 US Navy Recovery Systems

The USN uses a range of lock-follow radar systems for the air traffic management and recovery of fixed wing aircraft, such as the F14 Tomcat and the F18 Hornet, to carriers. These systems are largely mechanical scanning systems, which have high capital costs and maintenance costs as a result of their age and operating in the severe maritime environment, and the USN are investigating replacement systems such as SMATCALS (Signature Managed Air Traffic Control, Approach and Landing System) based on GPS and JPALS (Joint (US Service) Precision Approach and Landing System).

3.4 Recovery Guidance System Proposed by DERA

3.4.1 HIGGER I

The DERA proposal for a covert aircraft/ship recovery guidance system is based on Relative GPS and the development of the Raytheon STR 2515 GPS receiver into a HIGGER (High Integrity GPS Guidance Enhanced Receiver). The HIGGER 1 receiver is currently being flight tested at DERA (Ref 2). HIGGER I is form, fit and function back compatible with the existing equipment, offers increased availability through an 'All Satellites in View' architecture (12 parallel channels), higher integrity through the use of Receiver Autonomous Integrity Monitoring (RAIM) and provides improved absolute accuracy through the inclusion of Wide Area GPS Enhancement (WAGE). HIGGER I also provides tightly coupled integration of GPS and Inertial Navigation System (INS) through an 18 state Kalman filter which supports both an efficient and accurate in-air and on-deck alignment of the INS. The output solution is robust and is protected against spurious data and satellite outages. Finally, to support guidance functions operating through autopilots, the output is increased from 1Hz to 10Hz.

HIGGER I can also support a number of advanced modes which require a datalink capability, including:

- Relative navigation based on pseudo-range pairs
- Differential navigation based on pseudo-range corrections
- Differential navigation with INS aiding

The relative navigation provides a 10Hz solution independent of an INS, with ±3m (R95) relative position accuracy. The system latency (largely that of the datalink) is reduced through forward propagation. An example of this relative navigation accuracy is shown in Figure 5 by a 100s sample which was obtained from two HIGGER I's fed by independent antennas, 6.25m apart, on the top of the test HS748 aircraft during a flight trial.

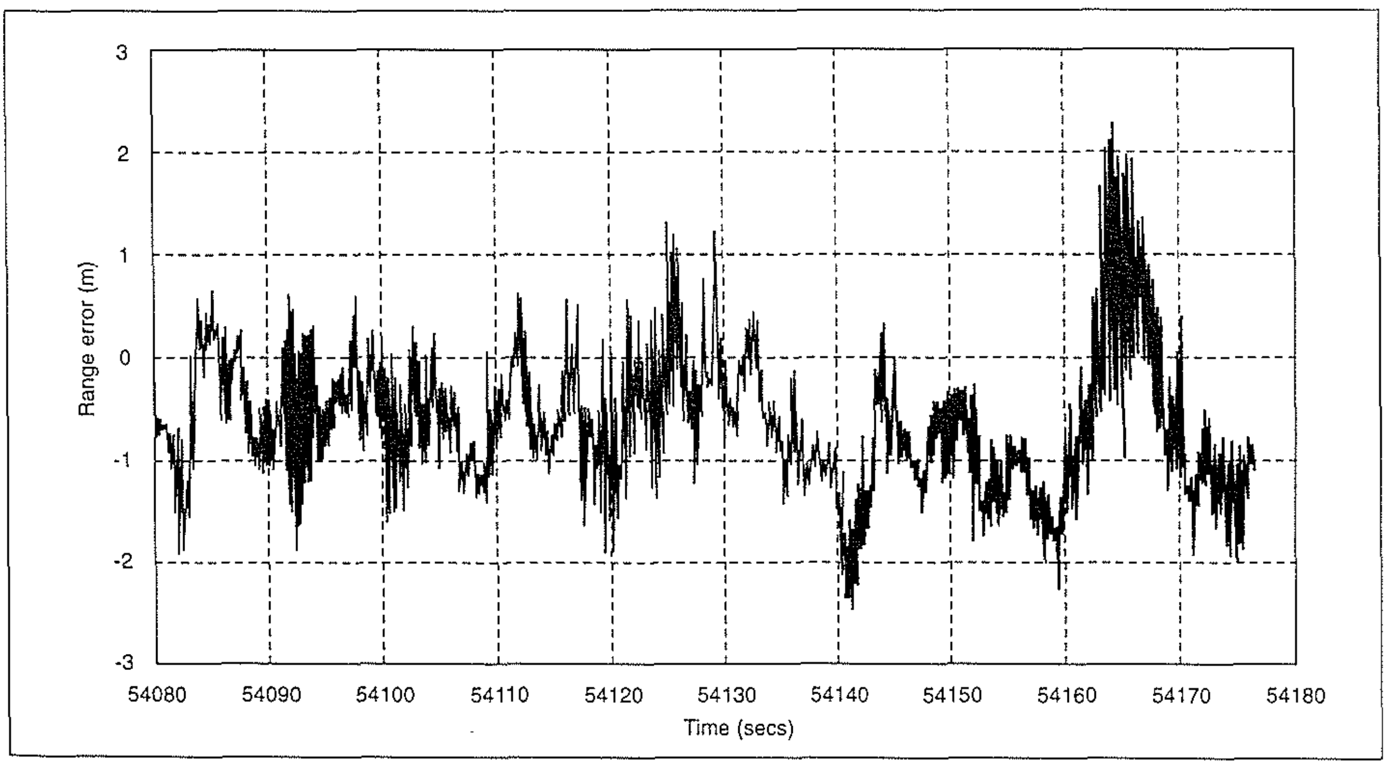


Fig 5. HIGGER Relative Navigational Accuracy

3.4.2 HIGGER II

A HIGGER II system is in development with the following features:

(i) 12 parallel dual frequency channel architecture

(ii) Kinematic Carrier Phase Tracking (KCPT)

(iii) Centimetric positioning accuracy (<30cm)

(iv) Backward compatibility with HIGGER I operation

Figure 6 shows a schematic of the HIGGER II Relative Guidance system integration which is scheduled to be evaluated during a helicopter-ship trial at the end of 1998. The schematic shows the datalink communication system between the helicopter and the ship and the use of the Military Standard (MS) 1553 bus on both the helicopter and ship.

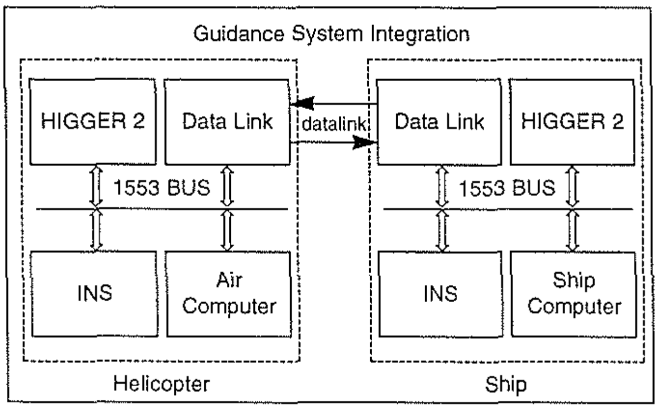


Fig 6. HIGGER 2 Schematic

4 RECOVERY TO THE SHIP: INTEGRATED RECOVERY MODE

With the availability of precision guidance, automating the recovery process can be seriously considered. At DERA, the first phases of the recovery, from the leaving of the task area to the arrival alongside the ship, were swept up into what is essentially a Flight Path Management function referred to as the Integrated Recovery Mode. This allows the pilot to select "Mother" and the autopilot will fly the helicopter from that point using either a minimum IFR speed or maximum range fuel strategy to the estimated location of the ship, converting that to an accurate knowledge of the ship, when within covert datalink range. An approach path to the ship is then set up, taking into account the prevailing wind and weather conditions and the speed and track of the parent ship. This proposed mode is based on research conducted at DERA on a research Wessex helicopter during the period 1993 - 1996 (Ref 3). The elements of the recovery are presented in Figures 7 - 9. The method of generating the guidance is depicted in Figure 7 which shows the same 4 satellites used at the ship and the helicopter to compute an accurate relative solution. Four satellites are required to generate a solution independent of other sources. With the HIGGER, the maximum number of satellites available from the STR 2515 has been increased to 12. Figure 8 shows the Wessex cockpit display which provides the pilot with improved situation awareness; the helicopter is at the centre of the display, the ship towards the top and the selected plan recovery profile joins the two. Figure 9 presents actual elevation profiles generated under automatic control in position and speed by the Wessex; they show the two level approach, which was originally selected to partition the phases of the recovery, such as the capture of the final track, the descent to recovery height and the deceleration to the ship, particularly in the worst tail winds to be expected. The recovery profile is adaptive to prevailing conditions (wind speed and direction and ship's speed) which modifies the profile shape in range as shown for head, tail and beam winds, according to the closure rate. The plots are shown in range which distorts the situation in the hover. It is clear, however, that some of the plots show the aircraft descending; this resulted, on occasions, from the inability of the autopilot, even using maximum collective demand, to prevent the helicopter from descending in the final stages of deceleration.

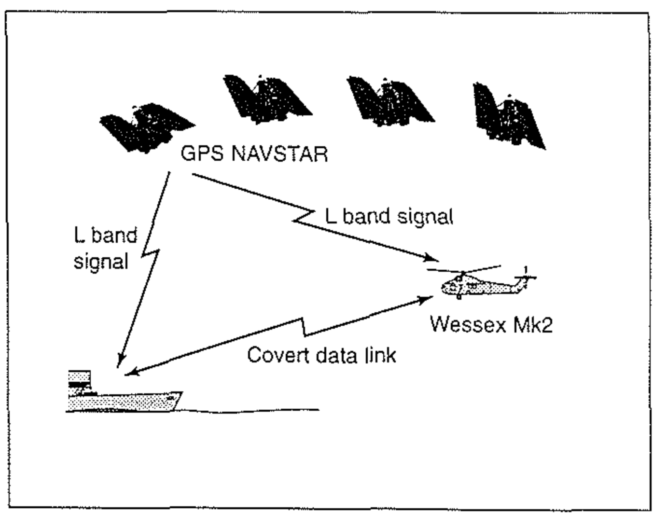


Fig 7. Relative GPS Guidance

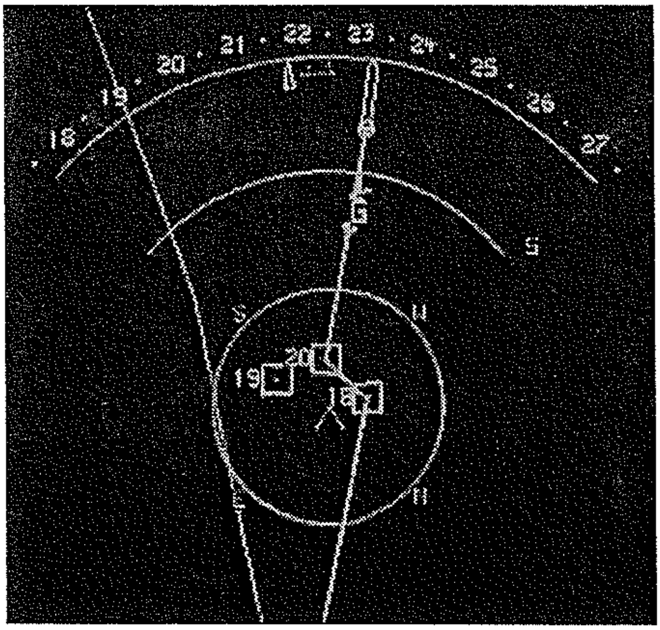


Fig 8. Wessex Cockpit Display

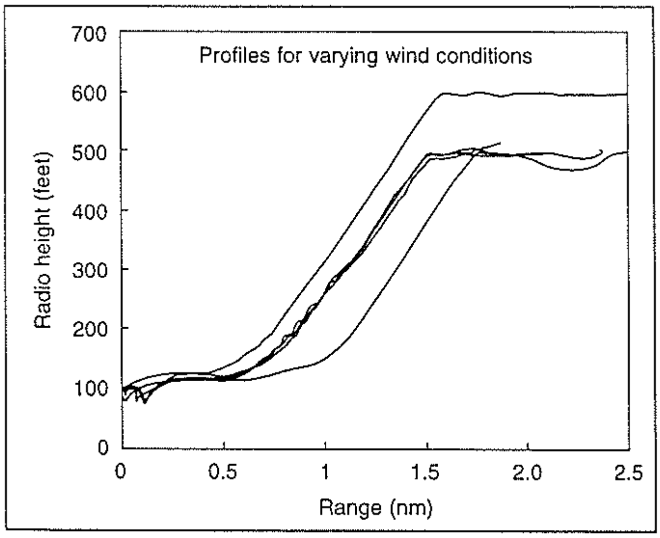


Fig 9. Recovery Profiles

Although, the work has concentrated on automating the recovery, an integrated flight director presented on the primary flight display also provides a pilot-in-the-loop capability and it has been shown (Ref 4) that recoveries can be successfully made using the map display, although the weather minima (decision height/range, visibility) to which these systems could be cleared will be higher than the automatic system.

Before discussing requirements and technologies to support landings and deck operations, it is appropriate to examine in more detail one of the most degrading influences - the airwake generated by the airflow over the deck, aircraft hangar and ship superstructure.

5 AIRWAKE - THE INVISIBLE ENEMY

5.1 Impact on SHOLs

The air flowing over the superstructure of a ship and then over the flight deck has always been a problem for helicopter-ship operations and the SHOLs reflect the difficulties that pilots face in particular wind conditions. A specific example is that of a helicopter in service for many years flying to a Royal Fleet Auxiliary (RFA) which has two landing spots, no 1 on the port side close to the hangar and no 2 on the starboard side to the aft of the flight deck. The difference in the SHOLs for spots 1 and 2 is compared with the original requirement during procurement in Figure 10. Although both are restricted, the SHOL for spot 1 makes it almost unusable in most wind over deck conditions. The problem is caused by the combination of the helicopter operating close to the hangar face at low heights, and the airwake created by the geometry of the ship, the hangar and the flight deck; we return to this close-in operational problem in Section 5.4 below.

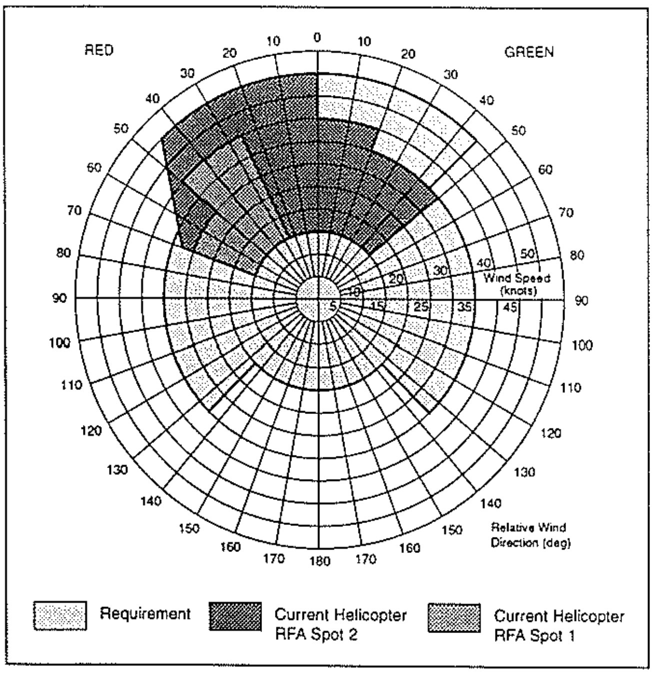


Fig 10. Comparison of SHOLs for Front and Aft Spots on RFA

5.2 Wind tunnel investigations

Although wind tunnel testing has traditionally been used to assess the flight deck environment for helicopter operations, the helicopter is typically not modelled in the tests, and the twin-wire anemometers conventionally used do not accurately measure the airflow direction due to recirculation effects, e.g. in the lee of the ship's hangars, as shown in Figure 11. For accurate measurements in such circumstances, however, other techniques can be employed, such as the use of three wire anemometers or single-wire anemometers carefully aligned to provide the resultant flow speed, and supported by observations of the flow direction (Ref 5). Also, wind tunnel testing cannot easily be integrated into the ship design process to allow the superstructure to be modified to optimise the flight deck environment.

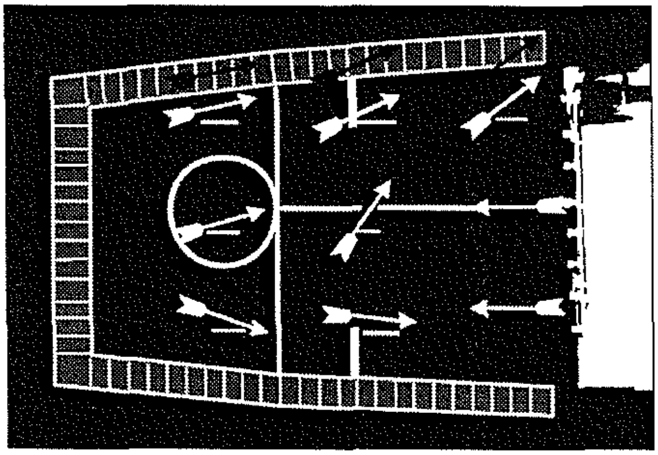


Fig 11. Horizontal Velocity Vectors over the Flight Deck of a T23 derived from Wind Tunnel Tests

5.3 The role of CFD in airwake investigations

To overcome the shortcomings of wind tunnel testing, a programme was initiated to provide a design tool based on Computational Fluid Dynamics (CFD) techniques which could be used in association with a Computer Aided Design (CAD) system. An early example of a CFD solution is provided in fig 12, which shows the w (vertical) component of the air flow above the helicopter flight deck of a generic naval ship at a point 16m aft of the hangar for a 20° port wind. The numerical velocity data is given as a percentage of the free stream wind. The work is currently in its third year and the results to date have been encouraging. Throughout the programme, use has been made of both wind tunnel results and full scale measurements to provide validation data for the CFD results. Full scale measurements were

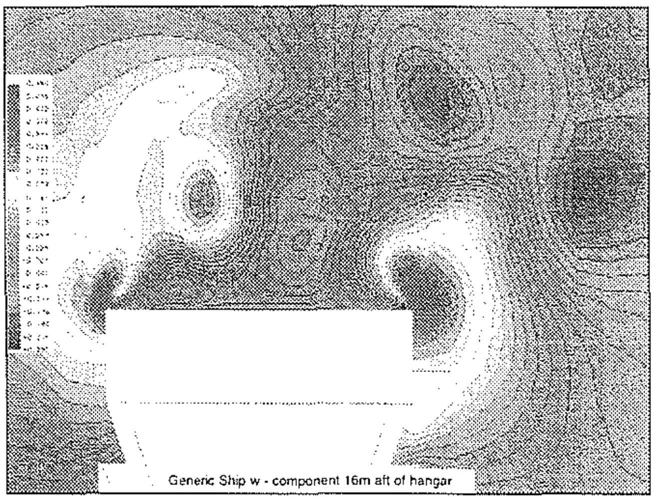


Fig 12. Results from CFD Analysis of Flow over Simple Frigate Shape

undertaken on a Type 23 Frigate and RFA ships using a Light Detection and Ranging (LIDAR) system from DERA Malvern (Figure 13). The plot shows the results of a conical scan of the laser beam in polar

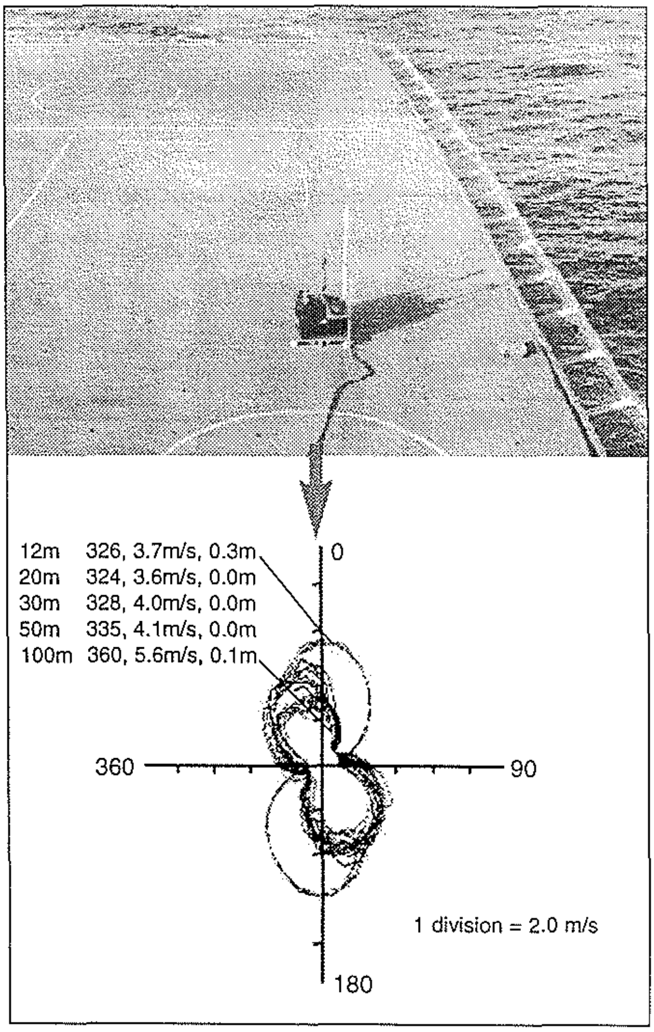


Fig 13. a) LIDAR System on the RFA b) Airwake Results from LIDAR Scan

form at a range of heights. The orientation of the two circular lobes gives the wind direction and the difference in the size of the lobes gives the wind speed. Variations from the circle indicate unsteady fluctuations in the air flow. Also, through The Technical Cooperation Programme (TTCP), a comparison of the output of various CFD codes, mostly commercial and implementing Navier Stokes solvers, has been conducted against test data on a simple frigate shape in the wind tunnel at the National Research Council (NRC) of Canada using oil mapping of the flight deck (Figure 14). Comparison of results from the different approaches has highlighted the features of the different codes, and the difficulty of achieving "absolute accuracy" when all the different approaches have specific features and/or limitations.

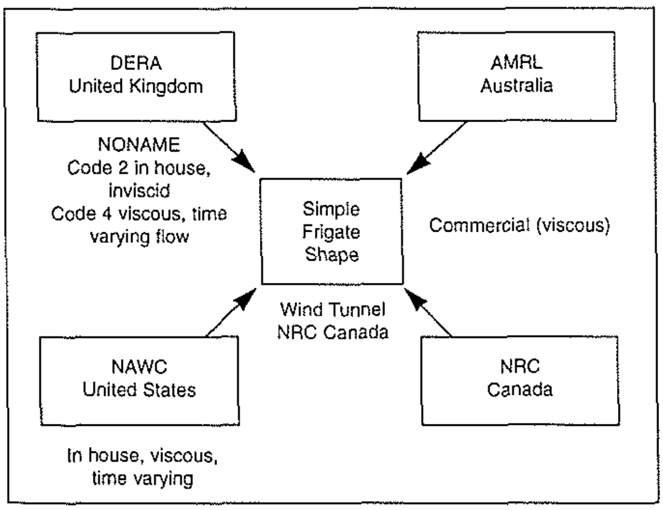


Fig 14. TTCP Airwake Collaboration

5.4 Helicopters operating in confined spaces

The problem of the helicopter flying in confined spaces has also been addressed during trials in which a Sea King helicopter was hovered close to a hangar and the air flows measured using a DERA Malvern LIDAR system. These results were compared to the CFD solution incorporating a rudimentary model of the helicopter; the results again were quite encouraging. The experimental set-up is shown in Figure 15 and a sample comparison of the full scale measurements and the CFD solution is shown in Figure 16; the chart shows 2-D flow vectors in a vertical plane across the face of the hangar in front of the rotor. In spite of the rudimentary model of the aircraft, both geometrically and aeromechanically (no tail rotor and a fixed pressure jump across the main rotor), the mean flows are in reasonable agreement and this has encouraged further CFD investigations. Figure 17 illustrates the predicted

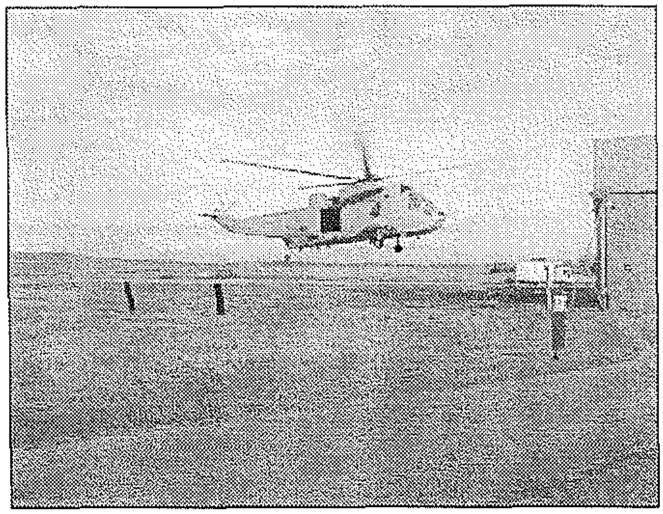


Fig 15. Sea King Test Aircraft Hovering Close to Vertical Surface

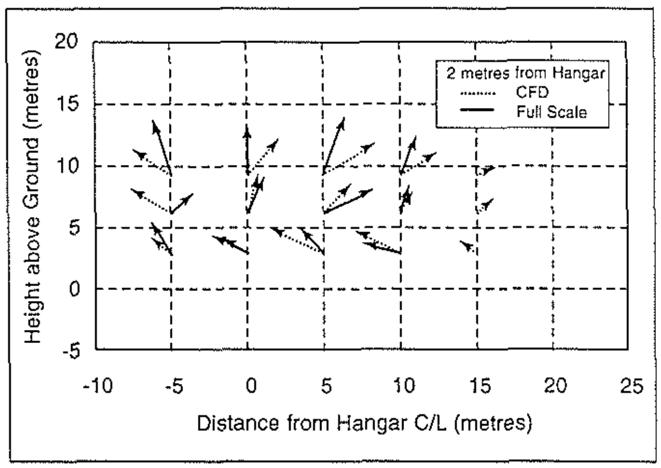


Fig 16. Comparison of Flow Vectors from Test and CFD

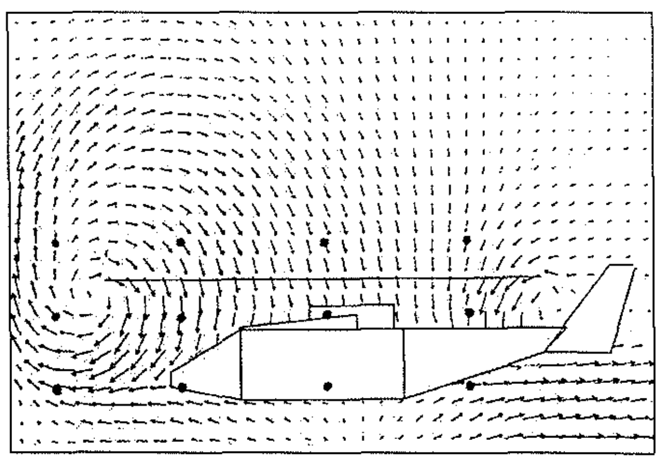


Fig 17. CFD Results for Flowfield around Helicopter when operating Close to a Vertical Surface

flow topology showing the recirculation of flow through the rotor in the presence of the vertical surface. The left hand edge of the diagram coincides with the hangar face and the measurement points are clearly indicated. The flight trial was deliberately conducted in the early morning in very light winds to minimise the hangar airwake effects and the pilots reported high workload during the task of maintaining a precise hover close to the hangar face (4m separation of the rotor), compared with the control task in open ground. This indicates that the helicopter - vertical wall interaction at low heights is a significant factor on the performance and handling of helicopters operating to ships; the effects are dependent on the distance of the rotor from the hangar and almost certainly dependent on both the height and width of hangars. It is planned to undertake a more fundamental investigation of this phenomenon.

6 AUGMENTATION FOR MANUAL RECOVERIES

In this section we examine some of the key requirements and technologies for providing the pilot with augmentation for performing manual deck landings in degraded environmental conditions, including poor visibility and high sea states.

6.1 General

Requirements criteria and system evaluation for piloting aids to support manual recoveries can be expressed within the framework of the handling qualities methodology. Handling qualities are influenced by the aircraft and its systems, the task and the environment and one of the current thrusts of DERA research concerns the development of handling requirements for maritime helicopters, based on the Aeronautical Design Standard (ADS)-33 requirements for battlefield missions (Ref 6). Three concepts from Ref 6 form the starting point in the constructive development of technical flying qualities requirements from operational requirements - the mission task element (MTE), the usable cue environment (UCE) and the aircraft response type. They are closely coupled, with the MTE/UCE combinations defining the required response type. Missions can be considered to be constructed of a contiguous sequence of MTEs, each with defined goals in terms of flight and mission performance. For example, the recovery phase of the maritime mission completes with the helicopter approaching the ship, manoeuvring over the deck and touching down on the landing spot, finally to be secured to the deck. Figure 18 illustrates a typical visual, unguided approach by an RN Anti-submarine Warfare aircraft to a single spot frigate.

The aircraft decelerates along a 3 degree descent flight path and is brought to the hover on the port side of the ship. The pilot then manoeuvres sideways over the deck, waits for a quiescent period in the ship motion, descends, lands on and engages a harpoon in the deck lock grid. Two important MTEs can be distinguished in the final phase - the decelerating approach and hover alongside, and the sidestep and landing (Ref 7). Variations in recovery techniques for different helicopter-ship combinations or by different navies require alternative division of the flight phase into MTEs (e.g. USN technique described in Ref 8). High sea states can result in the landing spot moving vertically and horizontally with amplitudes of several metres and frequencies as high as 1 rad/sec (0.16Hz). The disturbed air flow over the flight deck can contain vertical and horizontal shear flows that present significant demands on power management and yaw control. The nature of the landing task, particularly for large helicopters onto the stern of small ships, means that even in good visual environment (GVE) the cues available to the pilot are sparse.

The UCE concept was developed to aid the specification of the level of control augmentation required when a pilot can no longer make aggressive and precise manoeuvres due to the inadequacies of the visual cueing (Ref 6, 7). The UCE is a measure of the degraded visual environment (DVE) when flying close to obstacles and surfaces, and encompasses all the visual cues available to the pilot, both inside and outside the cockpit, both natural and synthetic. Recognition of the interaction between the sufficiency of piloting cues and rotorcraft response characteristics is a cornerstone of the systems approach to flying qualities. In ADS-33, the UCE is employed to define the required control response type to provide acceptable handling qualities for different MTEs in a DVE; the UCE degrades from 1 to 3, the former corresponding to good daylight conditions, the latter to poor visibility or night. For example, in a precision vertical landing flown in a UCE1, satisfactory handling can be achieved with a rate command (RC) response type. If the UCE degrades to 2, attitude command with attitude hold (ACAH) is required for satisfactory handling. The highly augmented translational rate command with position hold (TRCPH) is required in UCE3. A detailed methodology has been created to support the UCE concept, substantiated by flight and simulation tests; details are given in Ref 9. The

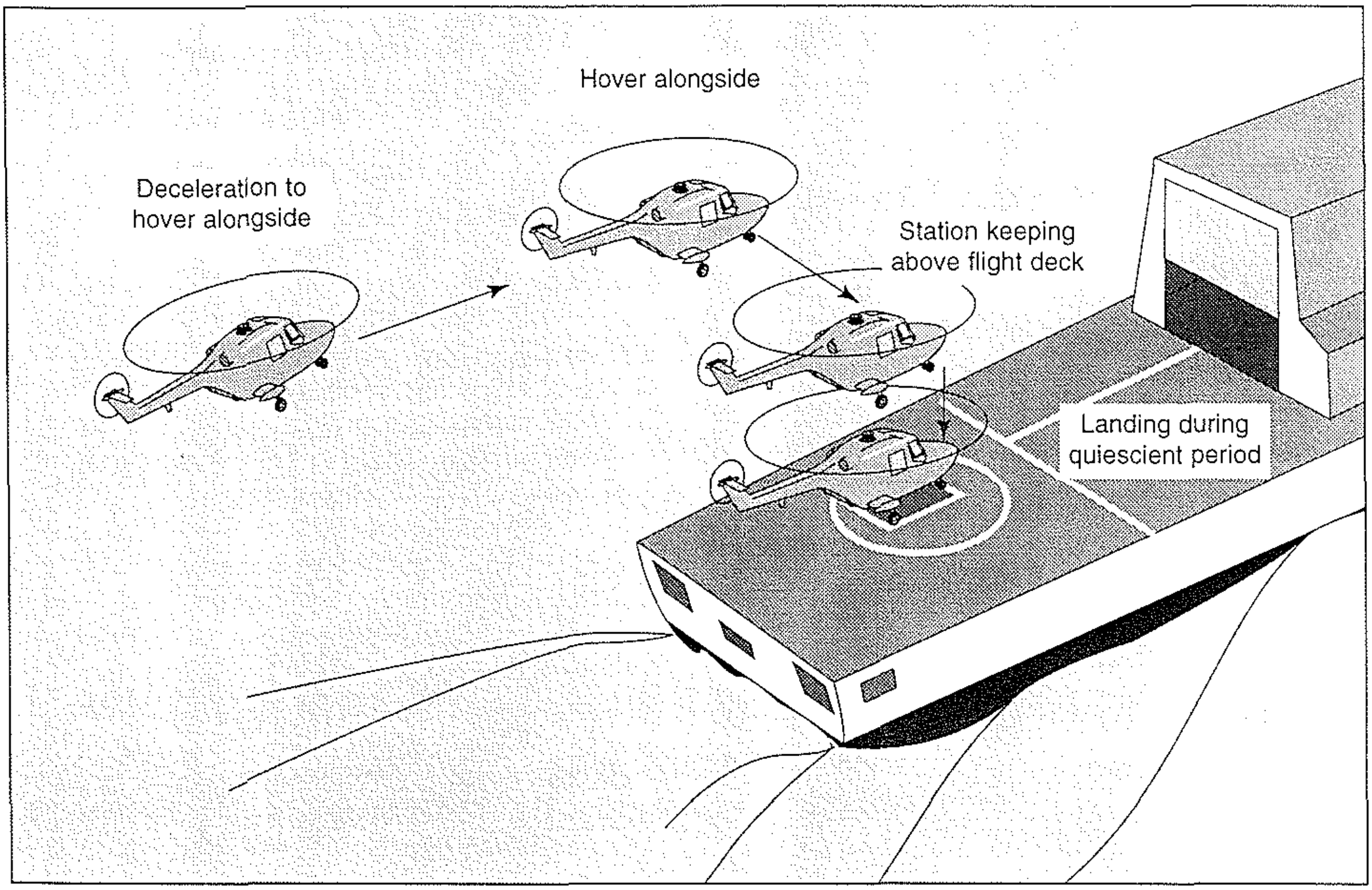


Fig 18. Final Stages of the Recovery Flight Phase of a RN Helicopter to a Single Spot Ship

UCE is determined for a given MTE in the DVE from a subjective evaluation of the cueing environment in terms of the pilot's ability to accomplish aggressive and precise manoeuvres.

Determining the UCE for the user-defined missions and environments is important for establishing the level of control augmentation and hence the required response types. The maritime helicopter recovery MTEs bring out the point that good handling qualities can be achieved by either providing greater vision augmentation, hence upgrading the UCE, or providing enhanced control augmentation at the degraded UCE. In the DERA ARP, this trade off is central to establishing guidance on flying qualities requirements for future maritime helicopters. To illustrate the kind of effects that might be expected in this trade-off, Figure 19 shows results from DERA simulation trials to explore the potential improvements conferred by increased control augmentation on handling qualities in the deck landing task. Results are shown for sea state 3, a relatively calm condition, in different visual conditions all of which were rated as UCE 2 by the 3 participating pilots. Pilot handling qualities ratings (HQRs - see section 6.3) for rate command (RC), attitude command (AC) and translational rate command (TRC) response types are shown (Ref 7). For the conditions shown, the TRC control system delivered the best performance, with largely Level 1 ratings. The RC system was solid Level 2, and the pilots found it more difficult when the UCE was degraded by darkness, compared with reduced visibility.

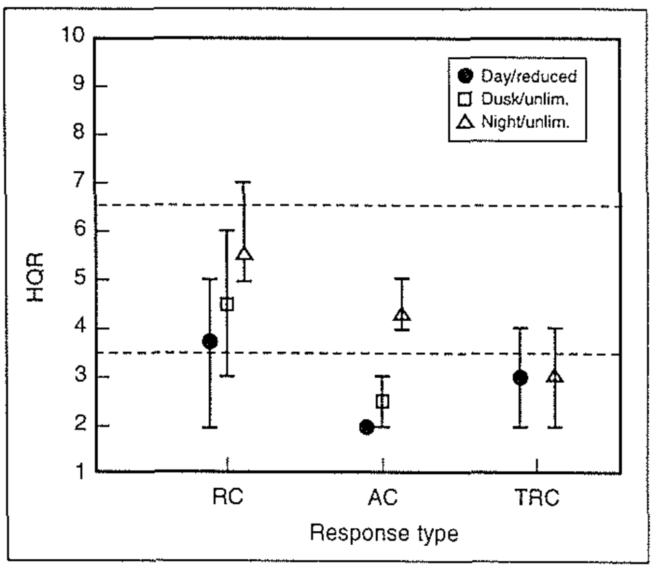


Fig 19. HQRs as a Function of Response Type; UCE = 2, Sea State = 3

If the goal were to upgrade the poorest required DVE to a UCE 2, then some form of vision augmentation is required, a topic that has received considerable attention in the DERA research programme.

6.2 Visual Aids for Manual Recoveries

We have already described how the helicopter-ship dynamic interface is characterised by a paucity of visual cues resulting in a degraded UCE and poor situational awareness. The pilot may be able to see very little of the ship when hovering over the flight deck and there are few fixed references on which to concentrate due to the constantly shifting sea surface. The difficulties are frequently compounded by low visibility obscuring the horizon and high sea states resulting in severe ship motion. At night the UCE degrades further as the visual cues available to the pilot are reduced or lost altogether and ship lighting is often limited due to tactical considerations. Despite these problems, the pilot is expected to achieve consistently safe and accurate landings on a 2m square grid whilst respecting undercarriage limits.

Enrichment of the cueing environment through ship-mounted visual aids provides the pilot with greater information of his movement and attitude relative to the deck and his position relative to the landing spot. It is important, however, that such aids do not interfere with the requirement for covert operations and are compatible with Night Vision Goggles (NVG). In ADS-33 terms, visual aids improve the UCE by increasing the pilot's confidence to manoeuvre aggressively and with greater precision. However, improvements in the UCE will be offset against increasing cost for diminishing returns. The efficient route to an aircraft with good handling qualities in all environmental conditions is through an appropriate balance of visual augmentation and flight control augmentation.

The current fit of visual aids for UK RN ships has several shortcomings regarding future operational potential, as discussed by Taylor (Ref 10). Figure 20 shows the minimal visual references afforded at night by the existing floodlighting, fixed horizon bar and Glidepath indicator (GPI). Floodlighting of the flight deck is tactically poor, causes reflections and glare from wet surfaces and provides poor definition of the ship and deck markings. The deck markings, usually consisting of fore-and-aft and lateral lines running through the pilot's position on the landing spot (Figure 21), require the pilot to rapidly scan his eyes through 90 degrees to gain sufficient cues to achieve an accurate touchdown. The problem is exacerbated if the pilot is wearing NVG, which are heavy and severely curtail peripheral vision. The fixed horizon bar provides no information on the relative attitude of the ship to the horizon when the horizon is obscured, making it difficult to distinguish movement of the ship from movement of the aircraft. The GPI, which is also non-stabilised, provides a single point of light as a visual recovery reference and use of this approach aid in isolation can lead to pilot disorientation with the attendant risk of aircraft loss.

A range of enhanced visual aids has been considered in recent years with the aim of improving the operational availability of maritime helicopters in all environmental conditions. Whilst some of these aids have been adopted by the RN for retro-fit to existing ships and installation in future types, others are still being assessed or are at an early stage of development. The work is summarised below and

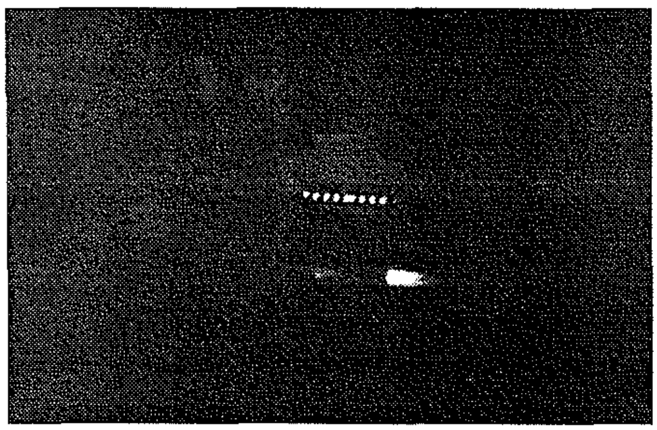


Fig 20. RN Frigate at Night with Current Visual Aids Fit

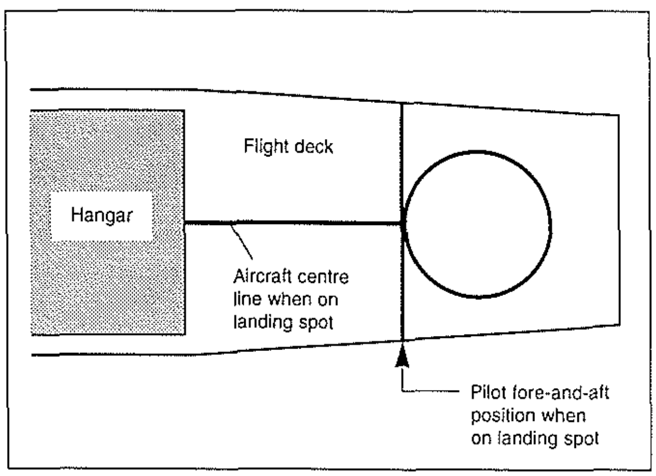


Fig 21. Current Layout of Deck Markings on a RN Frigate

discussed in more detail by Smith (Ref 11) and Tate (Ref 12).

One of the most successful yet simple of visual enhancements studied is the use of Electro-luminescent Panels (ELPs) to replace or augment floodlighting. The advantages of a typical ELP lighting system are clear from Figure 22. They can be used to define deck markings and the general outline of structures with which the pilot is familiar and provide strong cues relating to the position and orientation of the ship. More tactically sound than floodlighting, ELPs are less susceptible to rain and spray and are compatible with NVGs. Appropriate ELP patterns for small and large ships have been proven in the Advanced Flight Simulator (AFS) at DERA Bedford prior to sea trials and are expected to be fitted to RN ships in the near future. The ability to select individual ELPs is a particular advantage for multi-spot ships, enabling specific landing areas to be highlighted.

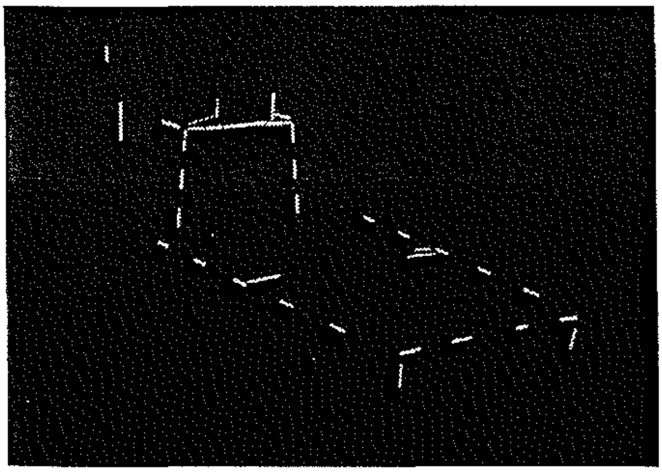


Fig 22. ELP Lighting Applied to the Flight Deck of a Type 23 Frigate

Roll stabilisation of the horizon bar and GPI has been investigated to improve cueing of ship motion and reduce the potential for confusion during the approach and landing phases for night recoveries. Both devices have been warmly received by pilots, although there was some evidence during trials that the additional information provided by the stabilised horizon bar can cause extra workload for pilots who are unaccustomed to its use.

The requirement to achieve and maintain an accurate position over the flight deck prior to landing has been approached in a variety of ways. Two suggestions for improved deck markings are shown in Figure 23. The diagonal line in the upper figure is aimed at reducing the amount of head movement required by the pilot and is particularly useful for NVG operations. By concentrating on the diagonal line, with occasional glances at the fore-and-aft and lateral cues, a relatively accurate hover can be maintained. The lower figure shows an extension of the diagonal line concept but the concentric squares provide vertical rate as well as position information as the aircraft descends to the deck.

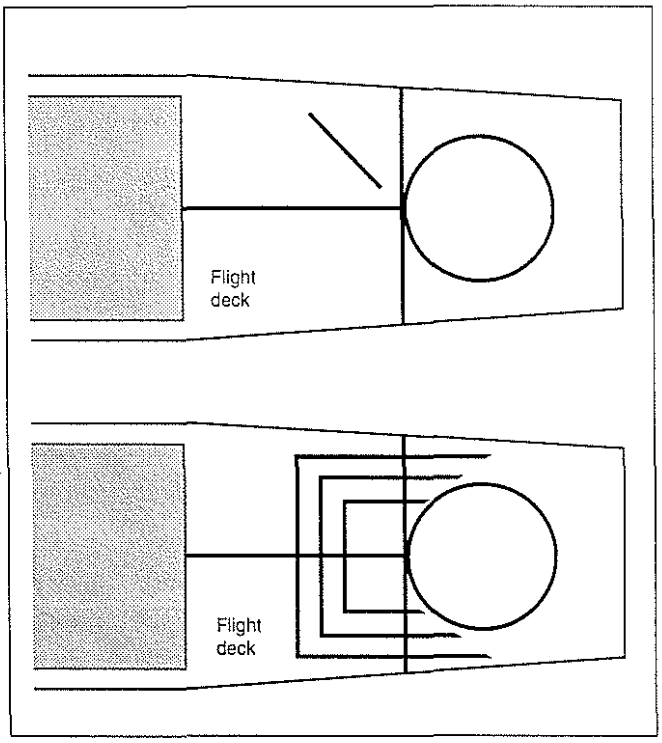


Fig 23. Suggestions for Improved Deck Markings

A more novel approach has been taken by fitting vertical poles to either side of the hangar to provide the pilot with a triangulation of the aircraft's position over the flight deck. A plan view showing the principle of the poles is shown in Figure 24. When the aircraft is directly over the landing spot, these poles line up with the sides of the hangar. Offset of the aircraft in any direction can be deduced by the relative position of the poles and hangar sides. If both poles disappear behind the hangar, the pilot is given a very strong cue that he is hovering too close to the hangar face. These poles form part of the ELP fit recommended to the RN for small ships.

An alternative solution is to use a sensor to provide the pilot with a picture of the aircraft's position relative to the flight deck. The Hover and Approach Positioning System (HAPS), under development at DERA, employs an infra-red camera to discriminate the size and shape of the helicopter

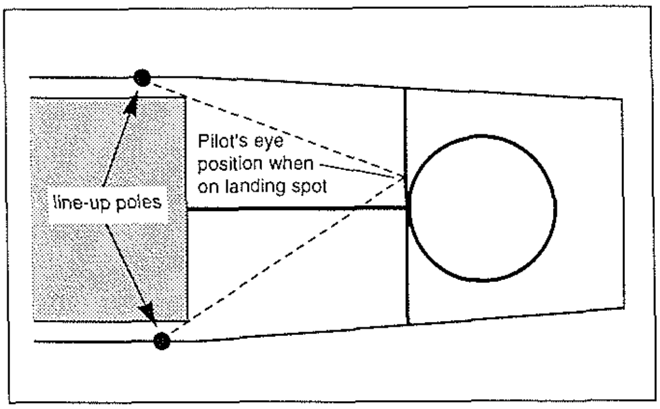


Fig 24. Plan View of a Frigate Flight Deck showing the Positioning of the Line-up Poles

rotor as it hovers over the deck. Processing the image allows the aircraft's position to be calculated to an accuracy of approximately 0.3m and displayed on a cruciform fitted to the hangar face, as shown in Figure 25. Although a simpler solution may be to use relative GPS to measure the position of ship and aircraft, the HAPS has the advantage that it is completely autonomous. The potential benefit of the system is that it relieves the pilot of the requirement to divide his attention between fore-and-aft and lateral deck markings. However, there is a danger that the pilot will fixate on the display, attempt to drive the aircraft to the centre of the cruciform and ignore other important cues around the ship. From a study of trials in the AFS and at sea, Maycroft (Ref 13) states that a ship-mounted display of this type should be used in conjunction with the other visual aids discussed above.

When operating to the flight deck of a moving ship, pilots will usually identify a quiescent period of ship motion before attempting to land. The process of assessing windows of opportunity is based purely on pilot experience and the penalty of an incorrect judgement is, at best, a heavy landing. DERA is currently exploring methods of ship motion prediction to assist the pilot as described by Lumsden (Ref 14). Two systems under investigation are the Landing Period Designator (LPD) and the Quiescent Period Predictor (QPP).

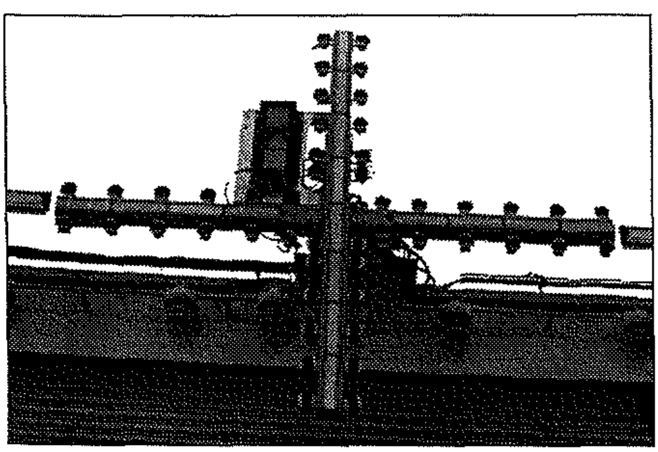


Fig 25. HAPS Display

The LPD identifies the onset of quiescent periods by calculating an empirical Energy Index (EI) which reflects the combined level of kinetic and potential energy in the ship. When the EI is low, the ship is stable and ship motion is low but when it rises above a specific threshold for each helicopter/ship combination, the deck motion exceeds the helicopter landing limits. Based on the premise that when a ship encounters a sea state, the resulting ship motion is limited by its own inertia, the time taken for motion to increase from a stable to a high risk condition can be determined both analytically (Ref 15) and experimentally. The process results in a minimum rise time for each sea state; for a Type 23 frigate in sea state 6, the minimum rise time is approximately 4 seconds. The LPD has been tested at sea on a Type 23 frigate in a trial reported by Manning (Ref 16). The LPD information was transmitted to the pilot via a ship-mounted 'traffic light' display using a green light to indicate that at least 5 seconds of safe deck were available and a red light to denote a dangerous deck. An amber light was used to show that the deck was still safe but that a period of 4 seconds was no longer guaranteed. In general, the LPD reduced the pilot's workload and improved his confidence of completing the landing successfully. Although a number of deficiencies were identified, it was concluded that the LPD has the potential to expand SHOLs in high ship motion conditions, especially at night and for large helicopters.

The QPP is a longer term prediction system that analyses the sea surface ahead of the ship, possibly using a laser, to forecast the occurrence and duration of the next quiescent period. This is a complex approach that requires a thorough understanding of the chaotic nature of wave dynamics as well as the interaction of the ship with the sea surface. Although the system is still in the research phase, the concept has been tested in the AFS resulting in clear indications of the substantial dividends offered by such a system.

The deck landing is essentially an eyes-out-of-the-cockpit task. The pilot needs to maintain visual references with the ship at all times, particularly in a DVE, and will rarely have time to look inside the cockpit at the instrument panel. Consequently the co-pilot, if there is one, may be asked to monitor the flight instruments, particularly the torque gauge and altimeter. Projecting primary flight information on to a Helmet Mounted Display (HMD), such that the pilot can remain 'eyes-out' and yet retain visibility of important aircraft parameters, would appear to present a solution to the problem. Furthermore, the use of an HMD would enable some of the visual aids described above to be incorporated in the display symbology. The concept has been tested in the AFS in a series of trials conducted by Thorndycraft (Refs 17, 18), aimed at evaluating the benefits of HMDs for the approach and landing phases of the recovery task. The optimum symbology set for the deck landing phase was assessed by evaluating combinations of LPD, QPP, HAPS, heading, aircraft attitude and torque information in the formats shown in Figure 26. Although it proved possible to overload the pilot with information, the advantages of presenting essential parameters in the pilot's foveal vision were clearly identified.

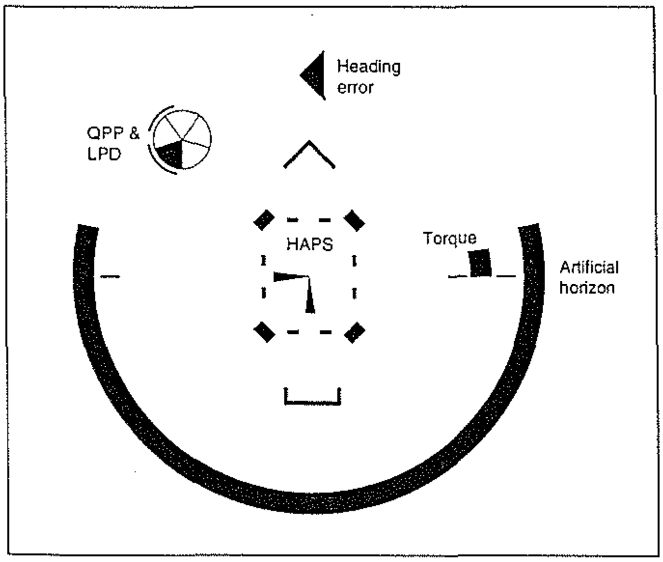


Fig 26. HMD Symbology Format for the Deck Landing Task

Visual aids are designed to provide the pilot with adequate situational awareness for flight control. This adequacy is part of a larger topic of handling qualities and aircraft response characteristics.

6.3 Handling Qualities Criteria

In handling qualities terms there is a need for good agility during the station keeping hover in the airwake over the deck lock grid (to reduce airborne scatter), good stability during the precision landing (to reduce landing scatter) and sufficient visual cues in both good and degraded visual conditions that the pilot can manoeuvre with confidence. The acceptability of rotorcraft handling qualities for mission tasks is quantified in terms of three levels;

Level 1 corresponds to good handling qualities that enable the pilot to achieve a desired level of performance, well within the margins of error for the mission task, and at a low workload, corresponding to minimal control compensation.

Level 2 corresponds to handling qualities with tolerable deficiencies that enable the pilot to achieve an adequate performance standard, just within the margins of mission task error, but possibly requiring extensive pilot compensation, hence high workload.

Level 3 corresponds to handling qualities with major deficiencies that intrude significantly on the pilot's ability to achieve even the adequate performance standard in a mission task, with maximum tolerable compensation.

These levels are linked to the Cooper-Harper HQR scale (Ref 19). Section 6.1 has already discussed the requirements on response type. For the different response types, dynamic response criteria (DRC) are defined to establish the most refined handling qualities (Ref 6). DRC address requirements for aircraft stability, agility and cross coupling across wide frequency and amplitude ranges. One of the most important of the DRC relate to the requirements on response bandwidth. Response bandwidth (ω_{bw}) defines the upper end of the frequency range where the pilot can close the loop on a particular motion without having to apply significant lead to avoid closed-loop instability. In this context, helicopters are particularly susceptible to so-called pilot-induced oscillations (PIO) in high gain tracking tasks, because of the dynamic coupling between the fuselage and the rotor system.

The deck landing is actually a pursuit task and places significant demands on both roll and pitch attitude bandwidth. Within the DERA research programme, piloted simulations on the AFS have been conducted to establish minimum values for attitude bandwidth that will confer Level 1 handling for the deck landing task. Figure 27 illustrates the pitch attitude bandwidth data. HQRs are shown for the deck landing task in sea states from zero to 5. A generic large helicopter was simulated, with parameters tailored to model the characteristics of a conventional rate command response type. According to ADS-33, the bandwidth requirements for ACAH systems are the same as for RC - the requirements driving the inner-loop control augmentation. The control architecture

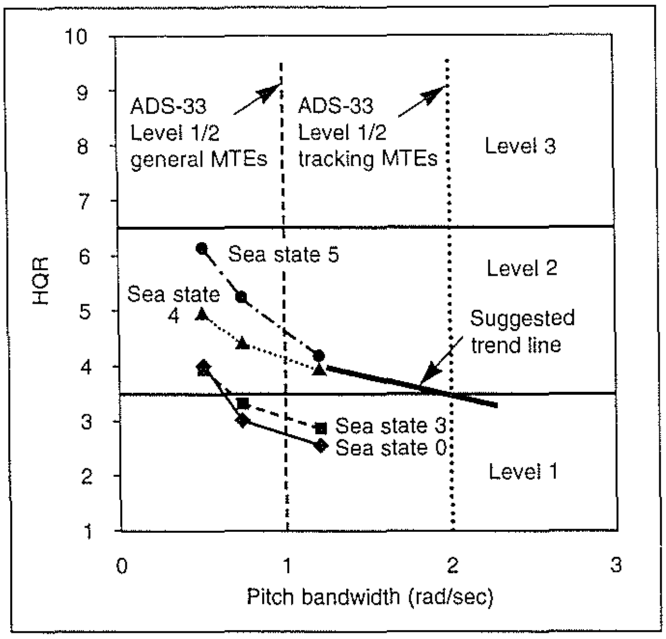


Fig 27. HQRs for the Deck Landing Task in Different Sea States

deliberately excluded high order configurations, where bandwidth is artificially augmented with feedforward/feedback, and the highest bandwidth tested was about 1.3 rad/sec. The suggested trend line on Figure 27 indicates the level of augmentation likely to be required to satisfy the Level 1 requirements for the deck landing of a large helicopter in moderate sea states. These requirements are likely to be significant in the design case for the control augmentation.

Increased attitude bandwidth confers a precision capability to the deck landing task. Of equal, and perhaps greater, importance is the agility conferred in the vertical axis by the thrust/power margin and the related heave motion time constant. Performance criteria for these handling qualities parameters is the subject of current simulation and flight research.

6.4 Control Augmentation; Automatic deck landings, a bridge too far or the Holy Grail?

Handling qualities criteria are developed to ensure that task performance is matched with the capability of the pilot. Increasing the levels of automation reduces pilot workload and aims to increase the operational performance and/or increase task safety margins. In the DERA research, the scope for fully automating the recovery, including the landing, is being investigated. In examining automatic deck landings, there are three main factors that need to be addressed. These are:

(i) the capabilities of the automatic flight control system

(ii) the safety issues

(iii) the pilot views on levels of automation

Automatic Flight Control Systems (AFCS) combine the stabilisation and command augmentation functions applied through series actuators, with the autopilot or flight path control functions applied through parallel actuators. In the first instance, it is assumed that AFCS technology will continue to involve limited (or partial) authority systems where the series actuator authority is limited to up to about 20% of full control magnitude. To avoid actuator saturation in manoeuvres, both the inner loop stability augmentation system (SAS) and command augmentation systems (CAS) are typically "washed out" over a period of time to permit the actuator to re-centre, where it again has maximum travel available to compensate for gusts or for manoeuvring. The autopilot control inputs are typically applied in parallel. In the limit, increasing the authority of the augmentation system leads to full authority active control technology (ACT) where the pilot's or autopilot's control inputs are combined with multiple sensor data in a digital computer to provide tailored response characteristics for the many different tasks the aircraft is required to perform.

6.4.1 Automatic deck landing investigation

To establish the capability of partial authority AFCSs, an investigation was undertaken of the capability of a large helicopter, landing on the deck of a frigate in a range of wind, weather and flight deck motion conditions, and using the guidance system with representative characteristics of performance (azimuth, elevation and range errors and latency).

Figure 28 indicates that the maximum frequency (with a peak to peak amplitude of 6m) that the helicopter can respond to, before the transient torque limit of 117% is exceeded, is 0.7Hz for vertical deck tracking. The torque peak of 117% corresponds to a maximum demanded climb rate of 1.4 m/s and the maximum deck motion possible, before the deck tracking degrades almost completely, is ±2.5m at 0.2Hz. The range of maximum amplitudes and rates of motion expected in both Sea State (SS) 5 and 6 are also provided in Figure 28. This shows that the automatic deck landing system can only cope with the lower end of SS5 without waiting for a quiescent period. This is an important limit on the performance of the automatic landing system and indicates the need

			SS5	SS6
Max Frequency	0.7 Hz			
Max Vertical Tracking Rate	1.4 m/s		1.0 - 3.0 m/s	1.6 - 3.8 m/s
Max Amplitude at 0.2 Hz	±2.5m		2.5 - 4.0 m	4.0 - 6.0 m

Fig 28. Deck Motion Limits for Vertical Deck tracking

for a ship motion predictor or designator system to warn the pilot/system of start and end of any quiescent period. It should also be borne in mind, however, that the deck motion limits (roll, pitch and accelerations) which are placed on the helicopter for both safety and structural reasons, and the associated vertical motion are likely to be much lower than the maximum values quoted in Figure 28. A possible method of reducing the required authority might be to reduce the rate of descent, preventing the large power increase just before touchdown. Another is to choose the trim point continually to make better use of the available blade angle range, although this effectively gives the control system a larger authority, which may not be acceptable from a certification point of view, and, in any case, the results indicate that the low authority cases saturate both above and below the trim point.

In terms of the wind envelope for automatic deck landing, Figure 29 presents the percentage authority required for the wind conditions in which it is expected that a large helicopter will be able to recover to the ship. Ship motion is included in this part of the study. In general, the authority required is less than 40% (±20%). There are, however, two particularly difficult wind conditions. With 30kn of wind from either aft quarter (Red/Green 120 deg), the helicopter is in a high power condition and is easily destabilised in yaw. A re-design of the inner loop controller is probably required to improve the stability in these areas.

The results indicate that it is unlikely that a fully automatic deck landing system will be possible using a conventional limited authority control system. Automatic deck landing appear to be achievable in all the test conditions using a control authority of about 50% (±25%) which could perhaps be reduced, with careful redesign, to 40%. The technical and safety issues involved in constructing a flight control system with greater than 40% authority are considered to be similar to that required for a full authority fly-by-wire system.

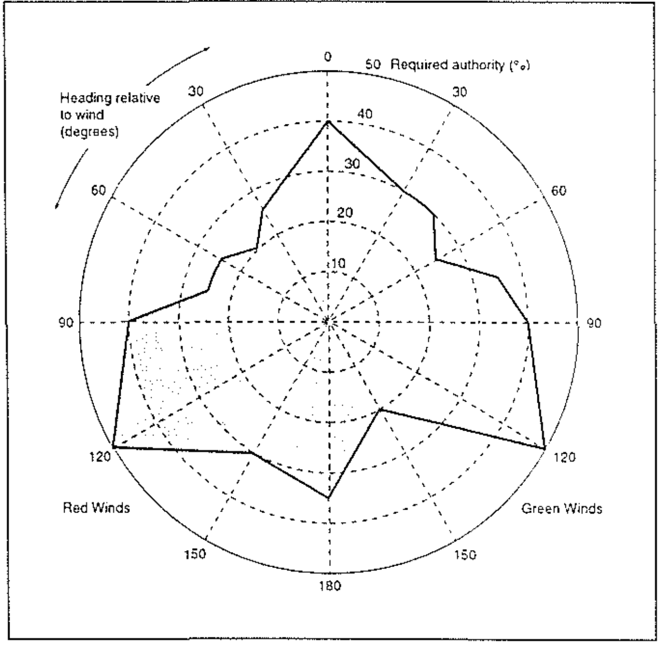


Fig 29. AFCS Authority for Deck Autoland

6.4.2 Pilot views on levels of automation

As a prelude to the study on automatic deck landing, a series of interviews were conducted with RN DERA test pilots and with RN line pilots. The strong opinion was that the pilot must be able to safely take command of the helicopter at any time during the automatic landings sequence, in case of a system failure in terms of proper function or expected performance. The pilots also felt that this manual reversion had to be designed and managed carefully to avoid large transient effects. In addition, the pilot had to know the accurate status of the equipment at any time. Many of the pilots commented that the most beneficial contribution would be a system which reduced the workload involved in the deck landing task. Such an alternative to the fully automatic system is the proposed Pilot Assisted Landing System (PALS) based on a capture and hold control system which could perform the functions illustrated in Figure 30 in the various phases of the landing process. The PALS removes much of the decision making from the automatic system but takes the majority of the workload away from the pilot. The pilot remains very much in the control loop and this is expected to make any reversion to full manual control an easier process. In the final stage of the landing, the pilot is only responsible for the primary task, the heave axis, and yet he is still completely in control of decision making and the landing. Pilot acceptance of a system of this kind should not be difficult as many navy pilots are already accustomed to similar systems such as heading and height holds and sonar dunking hover controllers.

	Hover Alongside	Transition Over Deck	High Hover Over Deck	Land On
Height Hold above 'Deck'	✓	✓	✓ ?	
Heading Hold	✓	✓	✓	✓
Longitudinal Position Hold	✓	✓	✓	✓
Lateral Position Hold	✓		✓	✓

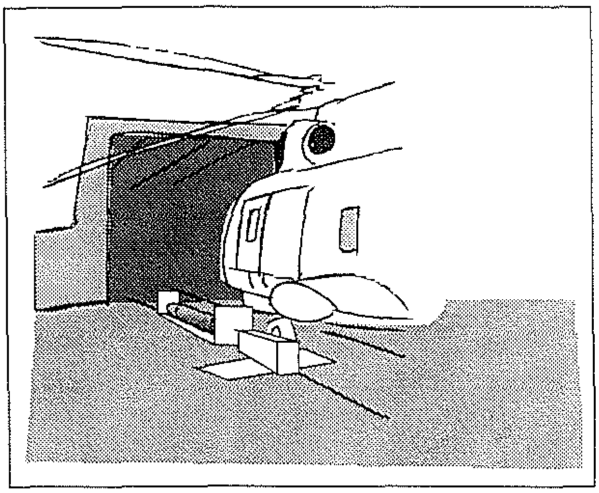
Fig 30. Pilot Assisted Landing System Concept

7 DECK OPERATIONS

Once the pilot has accomplished the deck landing, it is essential that it is secured against sliding off the deck or even toppling. The recent loss of a Lynx helicopter has highlighted this difficult area of operations. Studies using dynamic modelling techniques over recent years have established that securing needs to take place within 2s of the helicopter landing on the deck. The performance of current securing systems such as the deck lock, the probe and a generic main landing gear securing system (MLGSS), have been examined for a number of aircraft types on current and future ships.

Worst case ship motions of roll, pitch, lateral and vertical accelerations, and combinations of these parameters in sea states 5 and 6, were identified and the securing systems tested against these motions. For the deck lock study, the scenario was securing after landing with the rotor turning. For both the probe and MLGSS, the scenario was manoeuvring the aircraft on deck with the rotor stopped. The results of the studies in worst case conditions are summarised in Table 1.

This and other investigations have established that a system operating on the main landing gear (MLG) which can provide continuous securing and, at the same time, can also manoeuvre the helicopter on the deck and support re-arming and re-fuelling, is the preferred way ahead. To this end, a feasibility study has been launched based on the "beam concept" shown in Figure 31, which provides the high level of securing from hangar to take-off and landing and back to the hangar, which enables re-arming and re-fuelling without unsecured men on deck and which is applicable to both rotary and fixed wing aircraft. The system should be able to accommodate any helicopter, allowing cross decking and inter-operability to some degree. Inter-operability need not require the same system but the basis should be that the method of attachment is through the MLG spur.



Beam Concept

- High level of securing (from touchdown to hangar to launch)
- Enable re-arming and re-fuelling without unsecured men on deck
- Concept applicable to fixed wing aircraft

Fig 31. Main Landing Gear Concept of Securing

Helicopter	Ship	Stabilised	Unstabilised	Deck securing/ handling system type	Result
Large A	Frigate A		✓	Deck Lock	Not secure
Large B	Frigate B		✓	Deck Lock Probe MLG Spur	Not secure Not secure Secure
Large B	Frigate B	✓		Deck Lock MLG Spur	No slide but MLG Overload Secure

Table 1 Results from Deck Securing and Handling Study

Securing the aircraft on deck and manoeuvring safely into the hanger are the final phases of the recovery process. As noted previously, the capability to recover safely is often the deciding factor for the mission launch and hence has a significant impact on weapon system availability. The recent activities discussed have examined how requirements are established and quantified and technology options demonstrated to reduce the risk in the requirements-capture process. Simulation is used extensively in this process but there is a growing application of simulation in a broader context, best described as the 'virtual dynamic interface'.

8 VIRTUAL DYNAMIC INTERFACE

Modelling and simulation of the dynamic interface is particularly challenging due to the complexity of the helicopter-ship system with all the associated effects of airwake, ship motion, weather and sea surface. However, technology has reached a point where a high fidelity representation of the maritime environment is now possible, opening a wide range of simulation opportunities, from aircrew training to helicopter-ship qualification. The potential dividends are immense but stringent requirements ensure that the route to exploitation of a virtual dynamic interface will not be straightforward.

Simulation of a new ship or aircraft enables the helicopter-ship system to be assessed before either are built or their drawings finalised. As described earlier, DERA is currently developing a CFD tool to predict the airwake generated by a ship with the aim of helping ship designers to avoid airwake 'trouble spots'. Potential designs for new aircraft can be assessed and compared in a virtual environment to aid the selection process and novel ideas for visual aids or flight control systems can be explored through simulation with minimum risk and cost.

Perhaps the most beneficial use of a dynamic interface simulation is in the development of SHOLs when used in support of FOCFT. Recognising the scale of the task, the TTCP sub-group on 'Helicopter-ship dynamic interface simulation' has engaged on a new collaborative topic entitled 'Simulation in dynamic interface test and evaluation' with the aim of facilitating the development of individual nations' capabilities. The RN has tasked DERA with an aggressive programme to support FOCFT through simulation over the next decade and a similar programme is in development in the US. Initial trials at DERA, reported at this Forum (Ref 20) have demonstrated the feasibility of the concept and have indicated where effort needs to be concentrated to achieve the goal.

Until recently, deck landing training has not been considered possible in a simulator due to inadequate fidelity, both visual and environmental, in the region of the flight deck. However, research at DERA, reported by Wilkinson (Ref 21) has shown that comprehensive aircrew training through simulation is now considered to be possible. Indeed, the most modern training systems, for example the device for the RN's Merlin helicopter, include a high fidelity dynamic interface scenario which it is anticipated will form an important part of the syllabus.

The increasing role of simulation throughout the life of a ship or aircraft brings with it the necessity for careful and efficient management of models and databases. Furthermore, the growth of synthetic environments and the ability to link up simulations at remote sites, using common environmental and vehicle models, necessitates the use of standard protocols and formats. It is expected that future vehicle procurements will be accompanied by a virtual model which grows with the vehicle and is modified as the vehicle is modified. The same model will be used throughout the design and development process, aid the qualification process, form the basis for the training simulation and serve as a test-bed for in-service updates.

For maritime applications, ship and aircraft models should be compatible such that the interface can be tested in a virtual environment. Ideally the virtual ship will contain an airwake model as well as all appropriate visual aids, sensors and deck handling equipment. Similarly, the virtual helicopter will have the ability to interact with the virtual ship, including the airwake and communication systems, such that all aspects of the interface can be tested in simulated FOCFT. Whilst this scenario may still be some years away, it is important that the goal is defined such that the required co-operation between Users and Manufacturers can be fostered now.

9 CONCLUDING REMARKS

This paper has provided a review of the technical and operational challenges at the helicopter-ship dynamic interface and current DERA applied research aimed at developing increasing capability for future types. The post-mission 'problem' has been segmented into sub-problems of finding the mother ship, conducting covert approaches in degraded visibility, executing a successful recovery and landing, again in degraded conditions, and finally securing the helicopter and manoeuvring to the safety of the ship's hangar. Although this segmentation is helpful in describing the problem, DERA has taken a 'total system' approach to the solution, utilising navigation/guidance/control and a range of other augmentation technologies integrated into the recovery package. From the discussions on these aspects within the paper, the following observations and conclusions are drawn.

(i) High integrity datalinks are required to ensure a navigation solution to the problem of finding the ship, integrating inertial navigation and relative GPS systems on the ship and aircraft. Flight testing of the capabilities of such systems is a vital link in the demonstration of technical feasibility.

(ii) The dynamic interface is an unforgiving environment for helicopters and pilots need all the assistance possible to minimise the risk of task failure/loss of control. Developing concepts requires a good understanding of ship motion, the invisible airwake and the interactions with the helicopter. Ship-helicopter operating limits are still far too sensitive to the adverse nature of these effects. Research into airwakes in particular needs to continue to establish a more fundamental understanding of flow topologies and the impact of ship deck/superstructure design parameters. CFD analysis is showing significant promise as a supporting tool.

(iii) At the DI, the pilot needs a balanced mix of vision and control augmentation to support manual landings. A number of different forms of ship-based and aircraft-based visual aids has been described, some of which are being developed for entry to service. Control augmentation needs to be properly guided by handling qualities requirements and the DERA research to supplement the Army standard ADS-33 has been discussed. High fidelity simulation is an important capability for conducting this kind of requirements-capture work.

(iv) The potential benefits and feasibility of fully automatic landings have also been studied in design and simulation. Current limited authority automatic flight control systems are unlikely to provide the performance to enable this final touch to the automatic recovery. Authority levels of up to 50% appear to be required. However, partial authority augmentation in a 'pilot assisted landing system' (PALS), whereby different compensatory axes are automatically controlled during different phases of the landing, offers significant promise and presents the basis of a realisable solution in very high sea states and ship motion.

(v) Deck operations are a neglected area and research has identified the need for developing improved solutions for increasing capability; techniques based on securing the main landing gear appear to offer the greatest promise.

(vi) The paper has touched on the topic of the Virtual Dynamic Interface - a concept that embraces the use of simulation, modelling and analysis throughout the procurement cycle, but with an increased impetus for cost effective use of high fidelity simulation in design and qualification. Current DERA work with MOD is focused on using simulation to support First of Class Flying Trials; this will continue and the plan is to extend the methodologies more substantially into the requirements capture, competitive assessment and design processes.

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LIST OF ACRONYMS

AC	Attitude Command
ACAH	Attitude Command with Attitude Hold
ACT	Active Control Technology
ADS	Aeronautical Design Standard
AFCS	Automatic Flight Control System
AFS	Advanced Flight Simulator
ARP	Applied Research Programme
CAD	Computer Aided Design
CAS	Command Augmentation System
CFD	Computational Fluid Dynamics
CRP	Corporate Research Programme
DERA	Defence Evaluation and Research Agency
DRC	Dynamic Response Criteria
DVE	Degraded Visual Environment
EI	Energy Index
ELP	Electro-luminescent Panel
FOCFT	First of Class Flying Trial
GPI	Glidepath Indicator
GPS	Global Positioning System
GVE	Good Visual Environment
HAPS	Hover and Approach Positioning System
HIGGER	High Integrity GPS Guidance Enhanced Receiver
HMD	Helmet Mounted Display
HQR	Handling Qualities Rating
IAS	Indicated Airspeed
IFR	Instrument Flight Rules
ILS	Instrument Landing System
INS	Inertial Navigation System
JPALS	Joint (US Service) Precision Approach and Landing System
LIDAR	Light Detection and Ranging
LPD	Landing Period Designator
KCPT	Kinematic Carrier Phase Tracking
MADGE	Microwave Aircraft Digital Guidance Equipment
MLG	Main Landing Gear
MLGSS	Main Landing Gear Securing System
MLS	Microwave Landing System
MOD	Ministry of Defence
MS	Military Standard
MTE	Mission Task Element
NRC	National Research Council
NVG	Night Vision Goggles
PALS	Pilot Assisted Landing System
PAR	Precision Approach Radar
PIO	Pilot-induced Oscillations
QPP	Quiescent Period Predictor
RAIM	Receiver Autonomous Integrity Monitoring
RC	Rate Command
RFA	Royal Fleet Auxiliary
RN	Royal Navy
SAS	Stability Augmentation System
SHOLs	Ship Helicopter Operating Limits
SMATCALS	Signature Managed Air Traffic Control, Approach and Landing System
SS	Sea State
TRC	Translational Rate Command
TRCPH	Translational Rate Command with Position Hold
TTCP	The Technical Cooperation Programme
UCE	Usable Cue Environment
USN	United States Navy
WAGE	Wide Area GPS Enhancement
ω_{bw}	Response bandwidth