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Can ADS-33 meet the need?

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Can ADS-33 meet the need?

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Abstract

Although ADS-33 methodology is fast becoming the accepted standard by which to judge rotorcraft handling qualities, it is not yet a generic specification covering all helicopter types. Research work undertaken to define handling criteria for maritime helicopters at the Defence Research Agency on behalf of the UK Ministry of Defence has demonstrated that specific deck operation criteria would be required. The purpose of this paper is to examine the issues that would be involved in the extension of ADS-33 to cover maritime missions using a common methodology and with particular emphasis on the dynamic interface. Early work has indicated that extensions of the Specification in the areas of Mission Task Elements, response types and dynamic response criteria would be required. A TTCP international collaboration has recently endorsed a proposal to produce a draft supplement to ADS-33 for maritime missions. The paper approaches the issues through examining the needs of the customer and applying evidence from initial trial work using the Defence Research Agency Advanced Flight Simulator.

1 Introduction

The methodology associated with ADS-33 (Reference 1) is fast becoming the accepted standard by which the handling qualities of rotorcraft are judged. However, as a result of its origins in the LHX/Comanche programme, ADS-33 is optimized for the scout/attack mission (with read-across to utility/light support) and is not yet a generic specification which could be applied to all rotorcraft and missions. Work aimed at validating the Standard for the cargo/medium support helicopter mission is already being conducted (Reference 2) and indicates that, with the addition of a number of new dynamic response criteria (DRC) and related Mission Task Element (MTE) definitions, ADS-33 could be extended to cover this helicopter role. However, the extension of ADS-33 to cover maritime helicopter roles holds particular challenges such as deck motion, ship air wake and turbulence and positioning over the deck - all of which are beyond the present scope of ADS-33. Although some work has been carried out to investigate the application of ADS-33 to ship board operations, this has taken the form of attempting to apply the existing Standard rather than assessing its potential shortcomings (References 3 and 4).

The Defence Research Agency (DRA) at Bedford is tasked with developing handling qualities requirements for maritime helicopters on behalf of the UK Ministry of Defence (MoD). Work completed to date has demonstrated that, in some respects, compliance with 'battlefield' ADS-33 criteria does not necessarily assure adequate performance for maritime helicopter operations (Reference 5).

The need for common testing methodologies and pilot rating scales has been recognised by a UK/USA/Canada/Australia The Technical Collaboration Programme (TTCP) HTP-6 collaboration which covers helicopter/ship dynamic interface simulation technology. The Nations have recently agreed to investigate the provision of common criteria and a defined assessment and testing structure using ADS-33 methodology which will be presented for consideration as an addition or supplement to ADS-33.

The purpose of this paper is to examine the issues which would be involved in the extension of ADS-33 to cover maritime missions using a common test methodology and with particular emphasis on operations at the dynamic interface. Existing supporting evidence will be presented where possible and suggestions will be made as to the scope of other work that may be required in areas where

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ADS-33 may not meet the needs of the maritime environment. The needs of the customer and the manufacturers are considered along with identifying the reasons why an expanded Specification is required. The deck landing task is defined together with considerations for a maritime specific deck landing MTE. Discussions of the impact of the Useable Cue Environment (UCE), control response types and dynamic response criteria are used to support the determination that current battlefield criteria cannot cover the maritime environment.

2 The need for a comprehensive handling qualities specification

For helicopters involved in ship operations good handling qualities confer benefits in several significant areas. A primary concern for ship-borne helicopters is the ability to operate in severe environmental conditions to assure maximum aircraft availability. Current helicopters are unavailable for a significant proportion of the time in, say, the North Atlantic during winter, largely due to handling deficiencies. This is a critical limitation, particularly when modern Naval strategies often consider the embarked helicopter as the primary weapons system of a frigate or destroyer. The ability to operate in more severe conditions can also be translated into an increase in flexibility for the helicopter/ship team; the vessel has increased freedom to manoeuvre during launch and recovery operations. Good handling qualities could also lead to an aircraft of lower raw performance being needed for a particular task. Lower performance is likely to translate into a lighter and cheaper airframe. Benefits may also be apparent in reduced pilot training requirements. A trade-off could also be made by improving safety margins for the same or better task performance. The case for a comprehensive handling qualities specification is underpinned by the need for good handling qualities.

Requirements

The need for a comprehensive helicopter handling qualities specification can be approached from four different perspectives:

- *Customer Requirements*: Unlike the specification of mission-related performance requirements (eg how fast?, how much lift? etc), it is not nearly as straight forward for the military customer to draw up a meaningful yet concise helicopter handling qualities specification. Inevitably trite phrases appear such as 'must have good handling qualities' or, slightly better, 'must have handling qualities which allow satisfactory mission performance'. However, being entirely subjective, such statements are open to a considerable range of interpretation. Thus, unable to describe his specific needs in technical terms, the military customer is often forced to rely upon a generic handling qualities specification which, with the exception of ADS-33 and the Comanche programme, is unlikely to have been tailored to his requirements.

- *Assessment and Trade-off Requirements:* A military customer will be interested in the trade-off between capability and cost across a range of weapon system attributes. Good handling qualities are intuitively valuable to flight safety and operational effectiveness, but the benefits are difficult to quantify. Of equal importance is establishing the degree of compliance with a validated specification, which can contribute to candidate system assessment.

- *Manufacturer Requirements:* The designer may only know in general terms what the customer requires and yet he must produce a helicopter with satisfactory handling qualities for a wide range of specialised tasks. He must determine what aircraft physical characteristics will assure the desired attributes. Unfortunately, without a very large procurement programme, it is unlikely that a sufficiently robust research base from which to draw such decisions will be available and thus there will be design and development risk. The need for a systematic link between handling qualities and engineering parameters becomes obvious.

- *Qualification Requirements:* The customer has done his best to express his needs and the designer has produced an aircraft which he hopes will meet these needs. The qualification team must now determine if these two are coincident and, hence, whether or not the helicopter is suitable for its intended mission in the hands of the 'average squadron pilot'. Such a judgement is frequently derived from the operational experience of the test pilot. Let there be no doubt that such subjective assessment has its place, but it needs to be conducted within the framework of more quantitative criteria, exactly as ADS-33 envisages. As customers increasingly appreciate the importance of handling qualities to successful mission accomplishment, the contractual implications of poor judgement in this respect become profound.

The Need For A Specification

The common thread between all four of the above requirements is the need for a comprehensive handling qualities specification based upon validated criteria and optimised for the subject aircraft class and role. The customer can then call upon an 'off-the-shelf' handling qualities specification which the manufacturer can use as a basis for new or upgraded designs and against which the helicopter can be assessed in an objective manner. As mission requirements increase and greater demands are placed on handling qualities, so the specification must evolve to match them in order to assure a satisfactory development programme. The corollary of this is that specifications relying on outdated, unvalidated criteria now have only limited relevance to military applications. Global improvement is required to assure the effective specification, design and acceptance of advanced military rotorcraft for all roles. To date, ADS-33 is the only specification developed in this manner and it offers the 'vehicle' by which the handling criteria for all helicopter types and missions can be developed.

The Current Scope of ADS-33

ADS-33 is based around the scout/attack mission although application to the utility or light support helicopter role is possible. The current version (ADS-33D - Reference 1) does not contain the information necessary for most maritime missions or for the cargo/medium support helicopter roles. It is not yet the global helicopter handling qualities specification which is sought. Nevertheless, the comprehensive research and rigorous approach which created ADS-33 has endowed it with a robust foundation on which it should be possible to create a more broadly based specification by the addition of supplementary data derived from new research.

Extension of ADS-33 is required for all the same reasons that the original document was developed for battlefield helicopters and outlined above. Customers require a specification and assessment tool and manufacturers need a clear measure of what is required of them by the customer. Researchers, testers and evaluators would benefit from a common standard from which to work.

3 DRA research and trials work to date

Scope

A range of simulation experiments using the DRA Advanced Flight Simulator (AFS) at Bedford have been conducted aimed at improving operational limits for helicopters operating to ships of frigate and destroyer size, particularly in adverse weather. Various concepts have been examined including improvements to basic aircraft handling qualities through flight control enhancements, the provision of advanced automated flight path guidance (Reference 6) and the use of novel visual aids to assist in the final approach and positioning the aircraft over the deck (Reference 7). The thrust of the work has been to establish criteria which can be used to improve handling qualities for maritime helicopters.

Facilities

The AFS is a general purpose research tool that provides a high degree of flexibility to enable tailoring for a wide range of fixed and rotary wing applications. The high fidelity cueing environment, particularly the motion system, promotes confidence in the use of the facility for handling qualities work. A detailed description of the facilities is contained in Reference 8.

The vehicle model used in the simulation trials was the DRA Conceptual Simulation Model (CSM), described in References 8 and 9. The CSM comprises a flexible low order equivalent system representation whose characteristics can be altered to suit a range of aircraft control parameters and response types. The baseline CSM configuration used for dynamic interface trials had the characteristics of an aircraft in the EH101 class. This baseline was altered to provide a spread of attitude and heave control parameter configurations.

An important element in the trials work was accurate representation of ship motion. This was provided by time history data from a Type 23 ship motion computer model consisting of roll, pitch, yaw, heave and sway components. A range of sea states could be represented. This data provided a typical maximum vertical movement at the flight deck centre of ± 4 metres in sea state 5.

In this early trials work no ship air wake and turbulence model was used. However, an air wake model, based on wind tunnel data, is in development and initial trials have proved encouraging (Reference 10). A new turbulence model is also in development and flight trials to support this effort will take place in 1995 using the DRA's highly instrumented ALYCAT Lynx. These models will be introduced in the handling qualities work in due course.

Plans

The focal point for future research will be the provision of a requirements-capture manual for handling criteria for maritime helicopters. This document will use the ADS-33 methodology developed in the piloted simulation trials carried out using the AFS to identify a wide range of criteria for different aircraft and ship platforms. As currently envisaged the requirements-capture manual will cover the following issues:

- Closed-loop stability - attitude bandwidth
- Agility - attitude quickness and control power
- Heave damping and thrust margins
- Traditional and novel control response types including rate, attitude and translational rate command control types

- Use of integrated control and display systems through director symbology on a pilots helmet-mounted display - this work is being carried out in conjunction with visual aids research to provide additional cueing on the approach and during landing

Much of this work is aimed to produce contributions to a new international (TTCP) specification in conjunction with collaborative effort to broaden its scope and conduct validation work.

4 Proposed supplements to ADS-33 for maritime missions

The work to date has produced results which could form the basis for the development of ADS-33 supplements covering maritime missions. There are also preliminary indications that some of the existing ADS-33 methodologies are not directly applicable to operations at the dynamic interface and that further refinement may be necessary. Those elements of ADS-33 which may require enhancement are discussed in detail below and supporting data are presented where possible.

5 Operational Flight Envelope (OFE)/Service Flight Envelope (SFE) Definition

The OFE defines the boundaries within which the aircraft must be capable of operating in order to accomplish the operational mission. In comparison, the SFE is derived from aircraft limits. At the helicopter/ship dynamic interface there is a clear analogy between the ADS-33 OFE and the more traditional ship/helicopter operating limits (SHOL) both of which can define the acceptable envelope of relative winds and ship motion states. However, the philosophy involved in the creation of a SHOL is the inverse of the ADS-33 methodology in that the SHOL is not defined *a priori* for all conditions but varies according to aircraft weight, deck motion and visual conditions. For example, the SHOL (OFE equivalent) for a heavy Sea King at night with significant deck motion is considerably smaller than would be the case in more favourable conditions and, in practice, can only be determined by experiment. However, in the context of an idealised ADS-33 type evaluation, the OFE would be defined as a function of the desired ship manoeuvring envelope and the anticipated ambient winds; testing would then determine if the helicopter retained Level 1 handling qualities throughout this envelope without encroaching its own limitations (ie the SFE). Thus it is likely that a new ADS-33 OFE philosophy might need to be developed to cover operations at the dynamic interface allowing handling qualities to determine the OFE and not vice versa.

6 MTE development

The need for a deck landing MTE

An MTE is an element of a mission that can be treated as a handling qualities task. Although many of the existing ADS-33 MTEs are relevant to maritime aircraft (especially those undertaking the commando assault role) there are some obvious gaps which need to be filled. The 'deck landing' MTE is so fundamental to maritime operations that it will inevitably have a strong influence on handling qualities requirements and must, therefore, be carefully defined.

There are a number of characteristics of operations at the dynamic interface which preclude the use of current MTEs for battlefield operations:

- The ship itself is providing the primary visual cues because the sea surface generates limited height, position and rate cues, particularly in a Degraded Visual Environment (DVE).
- The ship is moving, perhaps at up to 30 knots.
- The ship will be reacting to the sea way with movements in roll, pitch, yaw, sway, heave and surge.
- There are control implications generated by the air wake and turbulence caused by airflow over and around the ship.

These factors mean that, particularly in relation to ship movement and in a DVE, it is inappropriate to apply handling qualities rating boundaries derived from battlefield MTEs. Unlike current ADS-33 methodology, it is also inappropriate to apply different (relaxed) MTE tolerances in DVE since the accuracy with which the aircraft must be positioned to assure a successful landing is fixed irrespective of the conditions. The significant ship motion often associated with a DVE may further increase task difficulty for the pilot but no relaxation in accuracy can be tolerated. The opportunities to utilise stylised land-based MTEs are limited by the need to include ship motion.

Thus it will be necessary to define 'deck landing' as a flight test manoeuvre for inclusion in Section 4 of ADS-33 and to set task tolerances which are appropriate to the deck itself and applied to all ambient conditions. The variable which then remains to be determined is the OFE within which these tolerances can be achieved. The manoeuvre is complex and will require careful definition to assure consistent results. DRA simulation may assist this process. Already, DRA trial work has indicated the possible structure and task performance parameters for a deck landing MTE.

Operational practice

Current Royal Navy operational practice calls for an approach to the stern of the vessel, generally from the port side, along a radial 165 degrees from the line of advance of the vessel (Figure 1). This approach is technically flown on a 3 degree glideslope following a decreasing speed profile. The aircraft is then brought to a hover alongside the flight deck in the correct fore/aft position for landing with the main rotor clear of the ship's side. For smaller aircraft the pilot then waits for a quiescent period in ship motion before side-stepping over the flight deck, positioning the aircraft and landing. Larger aircraft will tend to move over the deck in anticipation of a quiescent period and then land when the pilot is satisfied with both position and ship motion (see also Figure 1). In both cases the pilot must be able to judge the correct moment to land to achieve the necessary accuracy and touch down within the limits of the aircraft. As an example of accuracy, the pilot of a Merlin operating to a Type 23 frigate will be required to land such that the deck lock system can be engaged. The grid on the flight deck on which the aircraft must land is 1.8 by 2.2 metres in size. The pilot must consistently be able to land the aircraft such that the deck lock probe is in this area, even in the most demanding operational conditions.

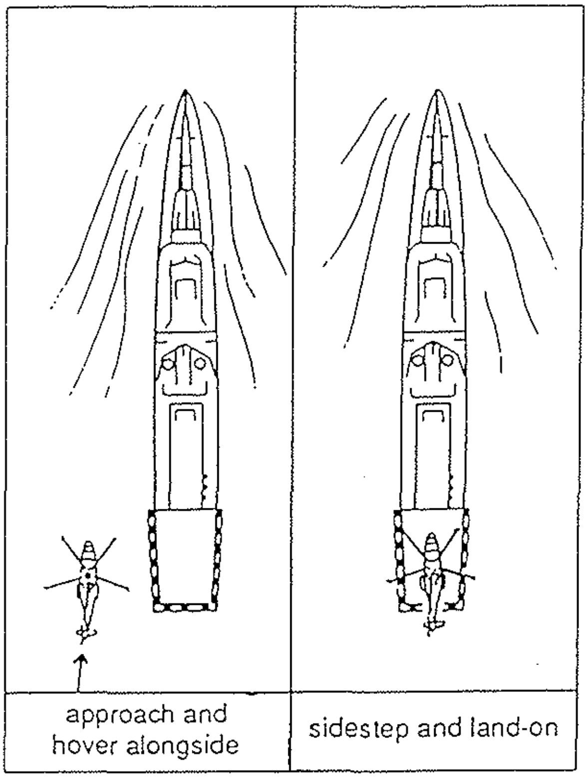

Figure 1 - Approach and deck landing task

Simulated task

DRA trial work required the development and definition of an MTE applicable to maritime operations from a small ship. This entailed consideration of the actual task at sea together with meeting the requirements and limitations of the simulator. The pilot was required to fly the final part of the approach task and conduct a landing using, as far as possible, standard Royal Navy techniques. All the runs were conducted in full daylight. To minimise run times the task was begun 150 metres aft of the ship at an airspeed of 15 knots. This low airspeed reduced the need for the pilot to raise the nose to decelerate and, in consequence, lose sight of the ship and the source of primary visual cues as a result of the restricted simulator field of view. Task difficulty was altered using varying degrees of sea state. The task was flown in reduced visibility to focus the pilot on the ship for visual cueing requirements.

The lack of a visual system dynamic sea surface model was a limitation as it reduced the cueing available from such features as moving waves and wind lanes. This made height and horizontal translational rate cueing more difficult. Pilots were also distracted by the fact that the ship appeared to be lifting out of the water in the higher sea states. The field of view in azimuth to the right of the pilot was also a limitation.

Task division

Ideally, the deck landing MTE would be broken down into a number of key sub-tasks with performance parameters that the pilot could easily assess and apply to ratings. In reality this is not practical, as the assessment of a large number of sub-tasks overload the pilot. Early DRA experiments evolved a deck landing MTE consisting of two sub-tasks, and this structure has remained for all subsequent simulator and flight trials:

a. Approach to and maintenance of a steady hover alongside the flight deck (at the 'port wait').

b. Manoeuvre to position over the landing point and landing.

Experience has shown that the most consistent results are obtained if the two MTEs are flown concurrently.

Task performance parameters and tolerances

Task performance parameters were defined for these sub-tasks. For the approach this included maintaining glideslope and localiser limits. At the hover alongside the flight deck the performance was measured as hover position accuracy within a given reference box and heading. The key parameters for the landing phase were landing accuracy, heading and vertical velocity at touchdown, as well as observing torque limits. Other parameters that were used to assess performance, but were not provided to pilots, were drift and the time spent over the flight deck before landing.

The precise choice of task performance parameters and their tolerances will be governed by a number of factors. The chief consideration will be the aircraft/ship combination involved. Generally, landing accuracy is just as important for large flight decks, but other parameters may not be so critical.

Both qualitative and quantitative methods of assessment were used during the trials, based largely on experience gained through simulation work on handling qualities requirements for battlefield helicopters (Reference 11). A key element in the evaluation methodology was the post-run questionnaire. This questionnaire, one of which was completed for each of the sub-tasks (approach phase and landing phase), uses in-house developed rating scales for elements such as aggression, workload and task performance to lead the pilot to giving a Cooper-Harper handling qualities rating (Reference 12).

Experience

The landing task and the associated MTEs were refined in preparation for initial trial work and have remained essentially unaltered through subsequent simulator and flight trials. Although pilots have generally been satisfied with the task and with the assessment methods, there were difficulties with the approach sub-task of the MTE in the simulator. This was due almost entirely to the deficiencies in the simulator visual system outlined above. Holding a hover in the designated box alongside the flight deck was difficult due to the restricted fields of view to the right. To overcome these deficiencies pilots hovered further aft than would normally be the case.

The deficiencies in the simulator were not considered to have significant influence on the MTE. The overall results were not considered to be seriously prejudiced as it was clear at an early stage in the experiments that the landing sub-task was dominant and considerably more critical than the approach sub-task. This implies that there may be no need to include the approach MTE in Section 4 since it may not be handling qualities critical. However, further work will be needed to confirm this for other aircraft and ship configurations and control response types.

Mission Manoeuvres

ADS-33 mentions, but does not define, 'sonar dunking' and 'mine sweeping' MTEs - work will be required to determine the precise requirements for such manoeuvres. In addition, the 'jump' between 'dips', which often has to be accomplished as quickly as possible to prosecute a submarine target, is demanding of a helicopter's handling qualities and might merit consideration as a distinct MTE for the ASW role.

It may be that tasks such as 'jumps' could be covered by existing ADS-33 tasks, such as the acceleration/deceleration task. However, these tasks generally become handling qualities critical if they are fully transient. Consequently, if the task were to include some cruise element aircraft performance would probably be the critical factor. Also, if these tasks were to be carried out in DVE it is likely that the aircraft would, for the critical elements of the task at least, be controlled by the autopilot.

Considerations

Although it is considered that a generic MTE could be developed for the approach and landing task, variations may be necessary to account for the differing operating techniques used by each nation. For example, the US Navy generally approach at a 45 degree angle to the stern and come to a hover over the flight deck. There would certainly be changes necessary in the MTE for the provision of any RAST-type haul-down device; indeed, separate MTEs may have to be defined according to the configuration of such aids. Variations in task tolerances will certainly be necessary to account for different aircraft/ship combinations both within and across different nations.

7 Determination of Useable Cue Environment (UCE)

Recognition of the trade-off between piloting cues and rotorcraft response characteristics is a cornerstone of ADS-33. The accurate determination of UCE ratings impinges upon virtually all other aspects of the Specification and there are a number of additional factors to consider in the context of a maritime mission.

Determination of UCE at the Dynamic Interface

The current ADS-33 UCE criteria mandate certain degrees of pilot situational awareness as a function of the ability to assess aircraft attitude and 3-dimensional translational rate. These parameters are adequate for operations over homogenous surfaces but additional situational information is required at the dynamic interface - namely a knowledge of actual position relative to the deck. In a manner analogous to the ADS-33 methodology, work at the DRA has already shown a strong linkage between the provision of artificial deck position cueing and aircraft handling qualities (Reference 6). These experiments, using a baseline rate command control system type in the aircraft model, were used to develop improved visual aids for pilots involved in operations to small ships. A clear link was established between the level of cueing and pilot ratings, as expected. The same experimental arrangements and assessment methods were used as in the handling qualities work. Various environmental conditions were covered from daylight with no ship motion to sea state 4 in 1 nm of visibility at night. Figure 2 shows the landing scatter plots for landings conducted in the simulator with and without the aid of a hover position cueing device mounted on the hangar in front of the pilot. As can be seen, the inclusion of this device causes an appreciable tightening of the landing scatter. In trials to date it has been shown that pilots are able to remain with task tolerances at higher sea states with the assistance of the device. This occurred without any increase in pilot ratings (see Reference 6).

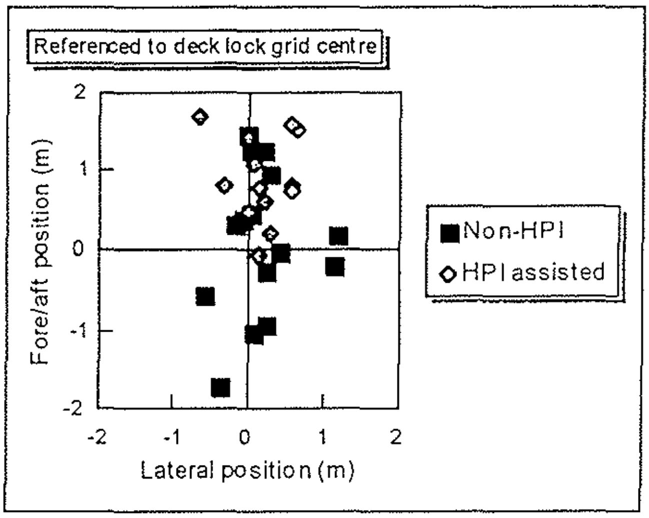

Figure 2 - Landing scatter showing the impact of using hover position indicator (HPI) for deck landings

In the context of deck operations, the current ADS-33 methodology for the definition of UCE would need to be expanded to account for the following factors:

- *Deck motion:* The baseline 'rate rotorcraft'/zero turbulence surrogate may have to be operated to a non-moving deck in order to assure consistency in UCE assessment. However, an additional complication in DVE would be the influence of ship motion on attitude cueing coupled with the presence or absence of a stabilised horizon bar. The apparent contradiction in these requirements would need to be resolved.

- *Deck characteristics:* Deck lighting (including reflections), deck markings and even the presence or absence of a marshaller would need to be allowed for and would, to a certain extent, render UCE deck-specific.

- *Position over the deck:* In addition to attitude and translational rate cues, position cues may need to be factored into the UCE calculation. Another visual cue rating scale may need to be created and given the appropriate weighting.

Determination of UCE During Over Water Operations

During 'blue water' operations, the only external visual reference for translation is derived from observing the sea surface. Unfortunately, a large expanse of water does not present a uniform or consistent reference plane and considerable skill and experience is required to interpret cueing information properly. The two primary factors which cause variation are sea state (waves and swell) and, independently, surface wind (the creation of white caps and wind lanes). A further complication during hover MTEs arises from the variation in the influence of rotor downwash with hover height. ADS-33 already suggests that the 'mine sweeping' and 'sonar dunking' MTEs are likely to be conducted in UCE>1 even in day/VMC conditions. Research would be required to determine whether or not the ADS-33 UCE methodology could be applied directly to over-water operations or whether new techniques would be required. No work has thus far been carried out on this subject either at DRA or in support of ADS-33, as far as can be determined.

No specific determination of the UCE in the AFS for the shipboard task has yet been carried out. Initial work has been with a three-monitor visual system, phototextured visual modelling and conditions intended to simulate degraded visual conditions. Subjective pilot assessment rated this configuration as UCE=2. It is unlikely that UCE=1 will be achievable in the AFS until a visual system upgrade is completed in the latter half of 1995. This will significantly increase the available field of view, particularly in the vital area downwards and to the right of the pilot. A new sea surface modelling package will also be available in this timescale that will provide a more realistic model. This should improve height and rate cueing over the sea surface. Trials in late 1995 will include a full UCE assessment using ADS-33 methodology.

8 Required Response Type

In the current version of ADS-33, the required control response type for 'shipboard landing including RAST recovery' MTE makes the normal progression from simple 'Rate' in UCE=1 to the highly augmented Translational Rate Command/Rate Command with Heading Hold (RCDH)/Vertical Rate Command with Altitude Hold (RCHH)/Position Hold in UCE=3. However, this is a generalised requirement which makes no distinction between, for example, the requirements of operations to a carrier in calm conditions and those to a frigate in sea state 6. Relatively little work has been accomplished to date to determine the optimum response type(s) for deck operations. Most of the ADS-33 background data are not specifically related to ship work or they were conducted to investigate V/STOL fixed wing aircraft operations. It may be that, even in UCE=1, a degree of additional control augmentation might be appropriate to more demanding situations. Conversely, one might discover that a high bandwidth rate response would be better than ACAH during compensation for deck motion even in UCE>1. Research is therefore required to determine the influence of ship characteristics on the optimum helicopter response type and to validate the response types which may be called up by an eventual specification. Similar treatment of 'Sonar Dunking' and other MTEs would be required, if it was determined that there were critical handling qualities issues to be addressed in these tasks.

DRA work to investigate control response types other than 'traditional' rate command is due to commence in 1995. Only rate command control types have thus far been evaluated (Reference 5). This work has, however, shown that Level 1 performance is achievable at lower sea states with moderate bandwidths (less than 2 rad/sec in the roll axis), even in the DVE (subjectively UCE=2) in the simulator (see Figure 3). These results contrast the findings in ADS-33, which suggest that in UCE=2 Attitude Command Attitude Hold+RCDH+RCHH is necessary to achieve Level 1 performance for the deck landing task. As stated earlier, supporting work for the ADS-33 recommendations has used data from various simulator and flight trials. The visual arrangements for the experiments were very different, and no specific determination of UCE was made. This may suggest that the experiments forming the basis for the conclusions drawn in ADS-33 concerning the required control system types may not be wholly applicable.

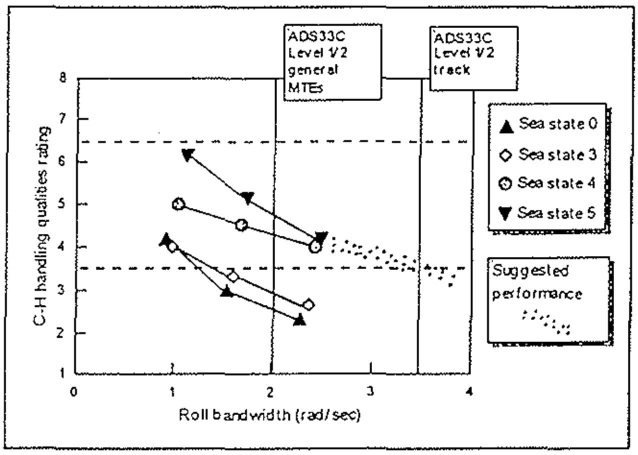

Figure 3 - HQRs for rate command control type achieved with varying roll bandwidths across several sea states

9 Dynamic response criteria

The quantitative elements of ADS-33 centre around dynamic response criteria (DRC) whose form varies according to the frequency and amplitude of the associated control input and/or disturbance. DRC are further sub-divided according to speed regime and axis. Unlike any other MTE, in any conditions other than very calm, deck landing requires continuous tracking of a moving target in both the cyclic and heave axes and thus places unique demands on aircraft response, particularly to collective inputs and on engine control systems and rotor governing. For example, during a deck landing pilot collective control activity has significant and continuous (relatively) high frequency/small amplitude content as shown in Figure 4. Here control activity for a bob-up (Reference 13) is compared with that generated over the flight deck of a frigate by a helicopter in the EH101 class in sea state 4 during simulation trials with a 6% thrust margin. It can be seen that there is significantly more collective activity for the deck landing task than for the bob-up.

Much of the following discussion of DRC will concentrate on assessing the suitability of the ADS-33 attitude and heave axis DRC for maritime MTEs with particular emphasis on deck landings.

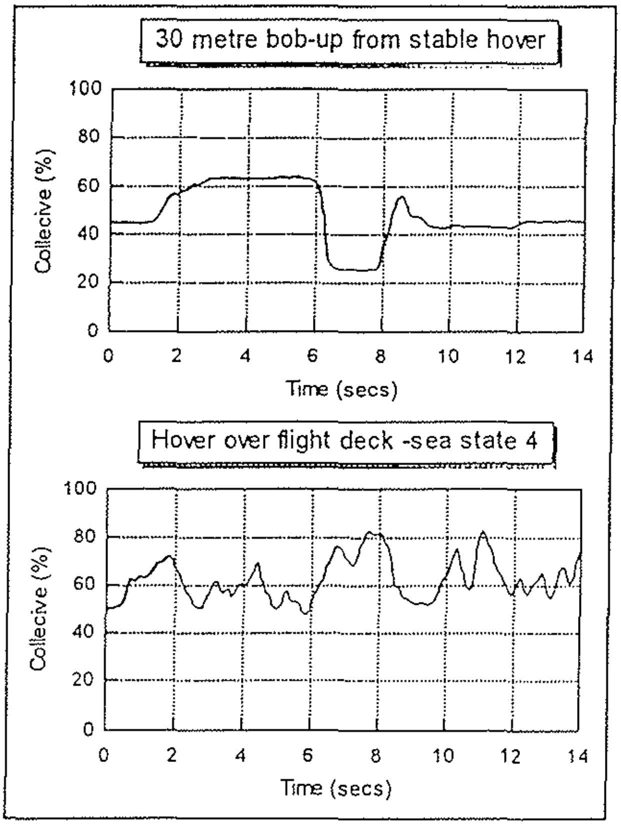

Figure 4 - Comparison of collective activity between bob-up and ship landing task

Hover and Low Speed Small Amplitude DRC (Pitch, Roll and Yaw)

It seems likely that small amplitude pitch, roll and yaw dynamic response would have a strong influence on the deck landing MTE in the same way as it affects other 'high gain' precision tasks. DRA research indicates that the small amplitude short-term (pitch, roll, yaw) requirements of the deck landing MTE seem to fit with existing bandwidth and phase delay boundaries, depending on the sea state. For the pitch and roll axes at low sea states the Level 1/2 boundaries derived from DRA work fit well with ADS-33 boundaries for 'other' MTEs (Figure 3 shows the results for the roll axis). In sea states over approximately 3, the boundaries indicated by DRA work for the shipboard landing task are similar to those in ADS-33 for MTEs containing a significant tracking element (Figure 3). More work is required to improve confidence in these results and to develop knowledge of the higher bandwidth configurations.

Hover and Low Speed Small Amplitude DRC (Heave)

In DRA heave axis work, vertical damping (Z_w) and thrust/weight (T/W) ratio were selected as the key vertical axis parameters for assessing their impact on handling qualities. Again sea state was used to vary task difficulty. The results gave a clear indication that the ADS-33 boundaries for these parameters are not applicable to small ship operations. A review of the initial results of DRA work is given below to illustrate the differences brought about by operating to a moving deck.

The aircraft model was configured such that a known vertical damping and thrust margin were available. For the heave axis evaluations the pilot was then told to attempt a landing without overtorquing. Desired performance required no overtorques above 100%. Adequate performance was achieved with transient overtorques above this maximum continuous limit up to the 'never exceed' limit of 110%. Above 110% torque performance was considered not to have been achieved and the task was considered not to have been completed successfully. Initially the pilot monitored torque on a standard gauge in the cockpit. Later trials provided the pilot with an audio torque warning to indicate to the pilot when desired and adequate performance boundaries were being breached.

Figure 5 summarises the handling qualities rating (HQR) data for varying T/W for a low heave damping of -0.40 sec^{-1}, without an audio torque warning system. The data shows that Level 1 handling qualities were achieved for a T/W of 1.09 across all sea states. At a T/W of 1.06 HQRs of 4 are still being achieved, even at sea state 5. However, when T/W reduces to 1.03 the HQR becomes Level 3 (adequate performance not attainable) when the sea state reaches 5. At T/W values of 1.03 frequent over-torquing occurred as pilots attempted to stay away from the deck as the ship rose to meet the aircraft, particularly at higher sea states.

The data for a high Z_w of -0.207 sec^{-1} are shown in Figure 6, again with no torque warning system. This shows the degradation in ratings expected for the higher damping case. Level 1 ratings were only achievable at the high T/W case (1.09) and at sea state 0. At sea state 5 performance was mid-Level 2, and at a T/W of 1.06 and sea state of 4 performance passed into Level 3. All cases beyond this (T/W 1.06 or less and sea state 4 or worse) remained firmly Level 3.

The inclusion of a torque warning system does not appear to offer the benefits in terms of improved performance that might be have been expected, particularly in the Level 2

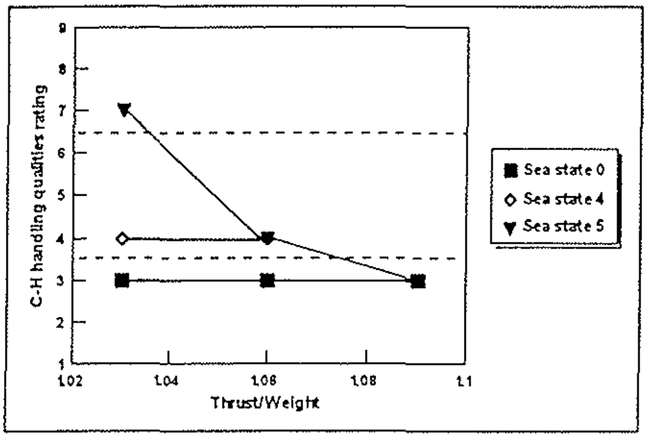

Figure 5 - HQRs against thrust/weight for a vertical damping of -0.4 /sec without audio torque warning

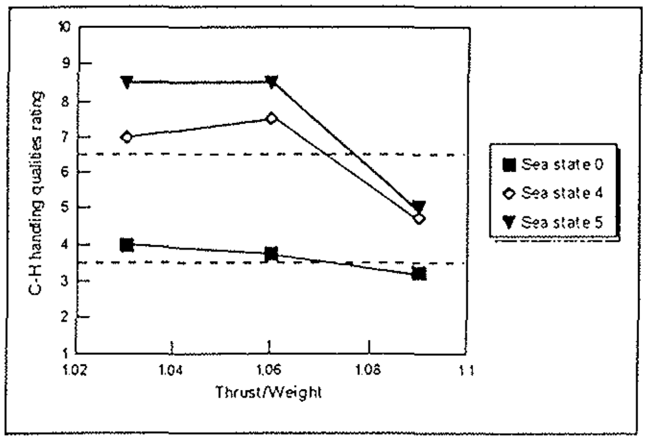

Figure 6 - HQRs against thrust/weight for vertical damping of -0.209 /sec without audio torque warning

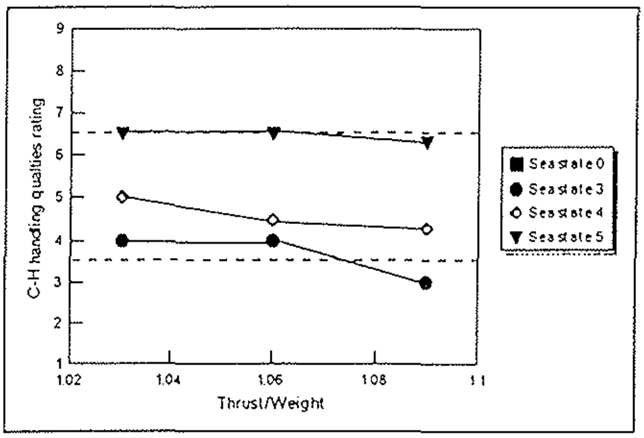

Figure 7 - HQRs against thrust/weight at a vertical damping of -0.4 /sec with audio torque warning

area. In cases where torque was not a major issue, unsurprisingly the system had little impact. Similarly, where performance was being rated at or near Level 3 the system had little influence. An example of these effects can be seen in Figure 7 which shows a good vertical damping of -0.40 sec^{-1} with the audio torque warning system. This is probably an indication that pilots were already at or near saturation and the addition of a warning provided no benefit. The cases that previously attracted Level 2 ratings were influenced the most, particularly those at the higher sea states. From pilot comments and by analysing collective control activity it may be postulated that the inclusion of audio torque warning raised pilot awareness of overtorquing. This had the following consequences:

- increased pilot mental workload in attempting to analyze and react to warnings
- caused pilots to react by reducing collective. This caused the aircraft to be in more marginal situation as the pilot 'backed away' from using overtorque regions
- increased collective control activity as pilots reacted to warnings
- distracted pilots from the task of positioning and maintaining clearance with the flight deck

Overall this resulted in higher workload having the effect of increasing ratings without a significant change in performance of the task. It is possible that pre-emptive audio torque warnings or tactile warnings through the collective channel would have a more beneficial impact on task performance. This is the subject of current work for battlefield helicopters where tactile cueing has produced significant improvements in task performance (Reference 14). This work will be applied to the maritime task in 1996.

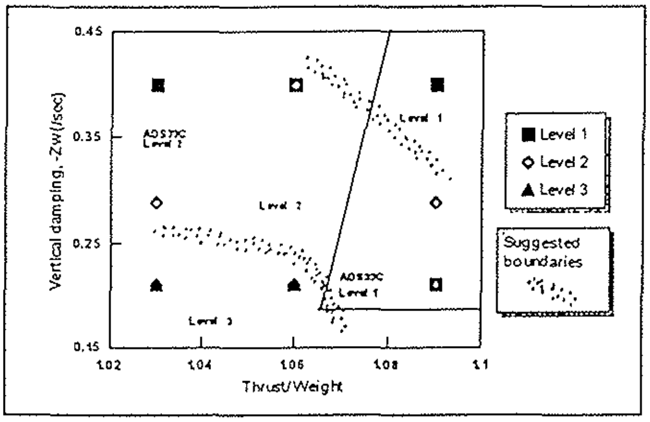

Figure 8 - Vertical damping against thrust/weight with no torque warning showing suggested boundaries

The handling qualities trend lines for the damping and T/W values were fairly well defined, particularly if considered for a particular sea state. Enough evidence exists to suggest tentative handling qualities boundaries (Figure 8). Also shown on the figure are the ADS-33 boundaries for the vertical axis derived from battlefield helicopter MTEs such as bob-up and hurdle hops. The helicopter/ship dynamic interface data shows a stronger relationship between damping and thrust margin than the ADS-33 boundaries suggest. At the lowest value of T/W the Level 2/3 boundary is crossed as damping is reduced for sea state 4, while at sea state 0 and 5 the sensitivity of handling with damping is less marked, being largely Level 1 at sea state 0 and Level 3 at sea state 5. The vertical movement of the ship clearly has a strong impact on the vertical handling qualities.

Damping is a measure of heave velocity bandwidth and it is well established that tasks requiring the pilot to increase velocity, to achieve task performance, will show improved ratings with higher bandwidth configurations. Increasing sea state has exactly this effect and is believed to be the primary reason for the differences between the battlefield and maritime MTEs.

These sample results from early DRA work demonstrate that, for hover and low speed small amplitude DRC, there is a requirement for maritime specific MTEs and boundaries. The audio torque warning work shows that piloting aids can significantly alter task performance and influence the position of boundaries. The use of warning and indications systems and pilot visual cues will need to be taken into account when drawing up a maritime specification.

It may be that other DRC will require similar treatment to that investigated here, although few others are likely to be as relevant to deck operations. However, it should be recognised that any detailed re-assessment of DRC for the dynamic interface environment would be a major undertaking, even given the relatively low cost of simulation compared to flight trial work. It may be that, practically, existing DRC would be utilised but with dynamic interface MTE-specific boundaries. The boundaries would be tailored to take account of deck motion and UCE issues.

10 Implementation

Achieving a maritime helicopter handling qualities specification

From the preceding discussion it seems likely that a concerted effort would be required to expand ADS-33 to cover the needs of maritime helicopters. It may well be that much of the existing specification is already adequate but, just as for battlefield helicopter roles, considerable experience, research and study would be needed to validate the requirements. If a new specification was to be universally applicable it would have to be capable of covering a wide variety of helicopter/ship combinations and allow for variations in operating procedures and equipment. The preceding sections of the paper have illustrated areas where work already conducted by the DRA might contribute to such a process.

Use of simulation

There is a high degree of confidence in the results obtained from piloted simulation using the AFS for handling qualities work. This has been demonstrated with the results from these trials as well as from the considerable tranche of work carried out in support of developing handling criteria for battlefield helicopters. Problems and deficiencies with simulation have been identified and these will have to be addressed if full benefit is to be drawn from future work. Key areas being currently addressed include the expansion of the available field of view, improvements to sea surface modelling and incorporation of ship air wake and turbulence modelling. It was considered, however, that within the scope of the trials carried out to date, these deficiencies did not impinge significantly on the quality and validity of the data gathered.

There is some evidence to suggest that pilots were less cautious in the simulator than they would have been in the real world. This underlines the importance of validation for calibrating work conducted in the simulator. Validation flight tests for this work would be difficult. A variable stability flight test helicopter would be required. Testing at sea would increase risk and be very expensive. Some ship simulation capability may be possible through the use of simulated flight decks, such as the DRAs 'rolling platform' facility. This can generate roll and pitch motions on a land-based installation with a large flight deck. However, there would be visual cueing considerations to be taken into account.

Collaboration

Helicopter/ship dynamic interface simulation is the subject of a TTCP collaboration involving the UK, USA, Canada and Australia. A working team was formed in 1991 with the objectives of developing, demonstrating and applying dynamic interface simulation capability sufficient to predict operating envelopes, carry out research, conduct pilot training and investigate safety issues. The vehicles for this collaboration have been the exploitation of existing models and capabilities, as well as defining common modelling structures and data formats.

The group has achieved notable success in transferring data and knowledge as well as sharing key modelling elements. Pilots and engineers from the UK, US and Canada frequently participate or observe relevant simulator and flight trials of other nations involved in the collaboration. This has allowed a valuable and positive exchange of ideas and knowledge.

Early in the collaboration it was realised that common testing methodologies and pilot rating scales may offer significant benefits in dynamic interface research and test and evaluation. The Cooper-Harper handling qualities rating scale does not pervade the naval aviation handing qualities community; in fact, there are a proliferation of different rating scales used in helicopter/ship interface testing and simulation making the process of sharing results and comparing data very difficult. Consequently, in 1994 a new proposal was accepted to develop and present a discussion document identifying possible common standards and methodologies. Obviously, one of the key challenges for this collaborative effort is to identify common MTEs that can be applied to the helicopter/ship operating techniques of several nations, together with applicable task performance parameters. The intention is that this work will evolve into a detailed draft of a 'Maritime Operations' appendix to ADS-33. Once detailed simulator evaluations have taken place it is proposed that some flight testing is carried out to verify MTE applicability and provide simulator validation data. Flight tests may, for example, utilise a highly agile variable stability helicopter.

The programme, as currently envisaged, calls for a discussion document detailing the research effort required to support the work to be available by mid-1996. This would be followed by a detailed draft of modifications to ADS-33 in mid-1997 and a final version to be completed by mid-1999 following flight testing. It is considered that general adoption of ADS-33 methodology, the UCE and the Cooper-Harper rating scale will permit standardisation within and between nations with the attendant cost and efficiency savings that this will bring.

11 Further applications

A further driving force behind the improvement in simulation capability is the ability to use piloted simulation for helicopter/ship compatibility testing. Currently, compatibility testing in the UK for one aircraft/ship combination requires an instrumented aircraft and ship for 3-5 weeks and 350 plus deck landings are carried out. This process is vulnerable to weather and serviceability. If the right weather conditions are not found then a restrictive set of operating limits can result. Simulation could be used to clear an initial operating envelope and determine possible critical areas which would then be investigated through flight trials. This would result in savings in resources and improve the chances of a good initial operating envelope. It has certainly been recognised by the US Navy that simulation has a key role to play in the development and testing of new rotorcraft. Considerable effort has been expended in developing a high fidelity simulation to support the development and testing of the V-22 Osprey (Reference 15). The UK is actively seeking to develop simulation capability in this area for future helicopter/ship compatibility testing, both to reduce risk and cost. The provision of a capability to assist in ship design work for aircraft operations is also of interest. This could be used to assess structural features of vessels, visual cueing, and assess predicted ship motion.

The incorporation of ADS-33 based testing and assessment would also benefit the comparison of simulated and flight test data and facilitate direct comparison of SHOLs for aircraft of different nations.

There are also significant operational and cost benefits to be gained form the use of simulators to train pilots for deck operations. Currently, there are very few simulators capable of achieving any significant training in this area. Requirements for upcoming Royal Navy helicopter simulators have highlighted the need for this capability and the DRA is carrying out research to support delivery of such capability.

12 Conclusions

DRA piloted simulation work to investigate handling criteria for maritime helicopters has produced clear evidence that, while the ADS-33 structure is suitable, MTEs and boundaries are not applicable for all key control system parameters. The need for additions to ADS-33 to fulfil the requirements of maritime helicopter operations has been demonstrated. Work to date has focused on attitude response and heave axis characteristics. Consideration has also been given to a deck approach and landing MTE.

There is a well-recognised requirement for handling criteria for all helicopter types and missions. This allows customers to specify effectively and evaluate new or upgraded aircraft. Similarly, it also provides manufacturers with the information necessary to make firm conclusions about the characteristics a particular aircraft should have, thus reducing design and development risk.

The results of this work have indicated the following conclusions:

a. ADS-33 provides a sound methodology and recognised structure on which to base handling criteria for maritime helicopter operations.

b. Maritime-specific MTEs are required for deck operations. It may also be necessary to develop MTEs for other maritime missions.

c. Sea state and ship motion are the key handling qualities drivers, together with visual cueing. The impact of ship air wake and turbulence has yet to be demonstrated.

d. Attitude bandwidth boundaries for deck operations show similar trends to ADS-33 boundaries for MTEs with a significant tracking element. This indicates that deck landing is primarily an acquisition and tracking task in higher sea states.

e. In the heave axis the boundaries for vertical damping and thrust margin are significantly different from those for ADS-33, with damping being the dominant factor.

f. A detailed UCE analysis of maritime tasks is required to support further work.

g. Although specific UCE work has yet to be conducted, early results indicate that the recommended control response types for battlefield missions in DVE may not be applicable to maritime operations.

There is already broad agreement on the need for the development of common standards across the TTCP nations. Further work, utilising the benefits of the collaboration, could allow the production of a detailed and validated supplement to ADS-33, approved and utilised by all TTCP nations. There is good reason to expect that a common standard can be developed to encompass the differences in national operating procedures and various ship and aircraft types.

The provision of handling criteria and a commonly recognised test methodology would provide significant benefits to naval helicopter procurers and operators.

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