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FLYING QUALITIES EVALUATION OF THE UK ATTACK HELICOPTER CONTENDERS USING THE ADS-33 METHODOLOGY - CLINICAL CRITERIA & PILOTED SIMULATION TRIALS

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Summary

Contenders for the UK Army's Attack Helicopter (AH) competition were subjected to a Technical Assessment during the period November 1993 to December 1994. The Defence Research Agency's Flight Dynamics and Simulation Department were Lead Assessors for the flight control system and handling qualities aspects of the assessments. FDS carried out a programme of off-line and piloted simulation activities in support of the handling qualities assessments, using the DRA's HELISIM simulation model. A piloted simulation evaluation was completed using the DRA's Advanced Flight Simulator, where the objective was to evaluate the contenders' handling qualities and agility in the context of the AH mission. The paper describes the test techniques and procedures used in the tests and discusses the background details of the handling qualities assessment methodology, presenting results in general terms.

1. Introduction

The UK MoD plans to procure a 'new' armed attack helicopter (the UKAH) for entry into Service with the Army Air Corps in the late 1990s. The approach taken to the selection of the UKAH has been to develop a set of Target Operational Characteristics (AHTOC) and to invite bids from potential suppliers. To aid in the assessment of the various contenders, a Technical Data Requirements List (TDRL) was developed and provided to each supplier with the AHTOC. The AHTOC covers a wide range of different characteristics relating to the airframe, weapon and mission equipment and support systems. A number of specialists groups were set up to conduct assessments of the responses to the AHTOC and TDRL, drawn largely from the UK Defence Research Agency (DRA). All worked to the same basic agenda. Combat Effectiveness and Survivability were identified as important attributes that related directly to flight performance. The chosen aircraft was to be capable of conducting aggressive all -weather, ultra low-level operations by day and night, with acceptable pilot workload. This requirement dictated that the UKAH should be agile with a wide manoeuvre envelope. For the pilot to be able to exploit fully the available performance with a tolerable workload, the airvehicle would need to exhibit good handling qualities. The flight handling qualities and control assessment was conducted by Flight Dynamics and Simulation Department at DRA Bedford and this paper reports on the methodology adopted to discern flying quality and presents results in general terms.

The assessment approach taken was based on the new handling qualities requirements - Aeronautical Design Standard 33 (ADS-33) - developed by the US Army in collaboration with Canada, Germany and UK. While the AHTOC did not specify compliance with ADS-33, the TDRL defined sufficient data to enable the DRA to create simulation models of the different contenders in order to perform assessments with respect to this standard.

Off-line analysis of the simulation models provided key information on agility characteristics, including attitude bandwidth, quickness and control power, stability and cross coupling dynamics. ADS-33 sets standards which, if not met, serve to highlight potential handling qualities deficiencies. The ADS-33 criteria were also developed from testing in mission task elements hence enabling judgements to be made on the role suitability of the competing aircraft. As a check on the results of the off-line analysis, piloted simulation tests were conducted on the DRA's Advanced Flight Simulator. The simulation trials were complementary to the analysis, with selected hover/low speed and forward flight clinical mission task elements flown at moderate levels of aggressiveness by three test pilots. Detailed questionnaires were completed by the pilots prior to awarding handling qualities ratings (HQR). Each flight sortie culminated in a simulated mini - mission, that included a number of contiguous MTEs and associated reconnaissance duties, providing the pilot with the opportunity to fly each aircraft more freely and to exercise the various strengths and weaknesses in earnest.

The paper outlines the key steps in the UKAH handling qualities assessment. As a general point, the significance of meeting Level 1 handling performance will be emphasised and some of the potential consequences of achieving only adequate, Level 2, standards will be addressed. It should be remembered that ADS-33 was developed for the RAH-66 rotorcraft which will feature an active flight control system, while all of the UKAH contenders that were fully evaluated, being 'off-the-shelf' feature only limited authority augmentation systems. The exposition on the evaluation methodology will be accompanied by some limited, and de-identified, results and video footage from the simulation trials. The successful completion of the UKAH handling qualities assessment reinforces the importance of a rational and systematic approach to the evaluation of flight performance, based firmly on the mature quality standard ADS-33.

At the time of writing, the UKAH assessments have been completed and reported in full to the UKAH Project Office. By the time of the 21st European Forum the result of the competition should be known. In view of the commercial sensitivity of the assessments, the paper and presentation will not include any identified data or results, but will concentrate on explaining the methodology adopted, emphasising the importance of fying qualities and highlighting the value of piloted simulation.

2. Background and Overview to UKAH Assessment

The UKAH Staff Target described the attributes of the weapon system that the Army required. This ST was translated into a set of AH Target Operational Characteristics (AHTOC), in effect a Cardinal Points Specification (CPS), which became the primary document in the Invitation to Tender (ITT) provided to the potential bidders. The AHTOC described the mission, armaments, performance and key equipment requirements which would be available in the UKAH. The UK MoD's Procurement Executive was tasked with identifying suitable aircraft and assessing these for cost effectiveness against the AHTOC. The technical aspects of the assessment were carried out with the assistance of almost 100 specialists drawn mainly from the Defence Research Agency.

In terms of timescale, it required eighteen months from the time of the formation of the Project Office to the issue of an Invitation To Tender (ITT) to the bidders. During this time, assessment teams were formed and briefed, who then assisted in compiling a Technical Data Requirements list (TDRL) as part of the ITT. The TDRL comprised nearly 700 target parameters required by the ST together with over 2000 back-up items of data. Bidders were required to return their proposals within nine months and assessors were subsequently allowed five months in which to complete an initial appraisal of the TDRL data. During this time, assessors raised any necessary points of clarification and requested any vital information which appeared to be missing.

In the flying qualities area of the AHTOC, it was relatively straightforward to specify manoeuvre envelope requirements; however, it was more difficult to define the agility and handling qualities which would be desirable in the UK AH. Whilst it was possible for each of the bidders to specify the manoeuvre and agility characteristics for their designs, it was not considered sufficient to rely on desk-top analysis of the written responses alone. Practical assessment opportunities were limited since not all of the candidate aircraft were available in a fully representative form, and although limited scope 'preview' flight assessments were undertaken, further, more objective evaluation of the handling qualities was essential. As the lead assessor for the flight control system and handling qualities, FDS was tasked with this undertaking.

As noted in the Introduction, the flying qualities of the contenders were evaluated through various simulation activities, of which the focal point was a piloted simulation evaluation using the AFS. Other elements included an off-line assessment of each contender against the flying qualities criteria specified in Aeronautical Design Standard ADS-33 (Ref 1), the latest US specification for handling qualities of military rotorcraft, using a specifically developed DRA software 'Toolbox' (Ref 2). The handling qualities Toolbox derives ADS-33 criteria based on inputs from test data or from the responses of the embedded DRA HELISIM simulation model. In another activity, inverse simulation techniques using the Glasgow University/DRA HELINV model (Ref 3), were used to predict the performance capabilities and control workload of each contender in AH-related mission tasks.

The viability of the evaluations was critically dependent on the quality of the data provided by the bidders through the TRDL. FDS had specified a number of TDRL requirements that were intended to elicit key data sets for building HELINV and HELISIM configurations, and appropriate flight or model data for calibrating the DRA model responses. In the event, the data provided were adequate on both counts and enabled satisfactory models to be constructed to meet the aims of the evaluation plan.

3. Flying Qualities Assessment Methodology

Good flying qualities underpin mission effectiveness and flight safety. Establishing flying quality requires a combination of quantitative criteria, that define the customer's best understanding at a given time, and subjective opinion of how well the aircraft is fit for purpose. At the time of writing, the available quality standards for helicopter flying qualities are reasonably comprehensive. However, existing criteria relate to single axis response characteristics and pilots rarely fly single axis tasks when conducting a nap-of-the-Earth mission. A thorough test of quality therefore requires evaluation in task; the interplay between quantitative criteria and pilot subjective opinion of task-worth characterises the DRA approach to flying qualities assessment, and its application to the UKAH, as outlined below.

3.1 Flying Qualities Synergy and the ADS-33 Standard - A Resume

The DRA approach to flying qualities evaluation is based on the concept that flying qualities are the synergy between the internal attributes of the vehicle - its stability and control characteristics, cockpit ergonomics etc., and the external factors that influence the piloting task - threat level, atmospheric disturbances, quality of visual cues etc. Implicit in this approach is the assumption that flying qualities are task-oriented as reflected in the new standard, ADS-33D (Ref 1), anchored in a unique test database derived from ground-based simulation and in-flight validation studies over the last 15 years. ADS-33 is formally a US Army standard for the RAH-66 helicopter, but has been developed out of International Collaboration and, in its structure and form, is applicable to all roles and types. The framework for using ADS-33 as a requirements capture, design and evaluation/qualification methodology is illustrated in Fig 1, developed from Key (Ref 4). The detailed response type requirements follow from the user-defined missions and operational environments, and hence the usable cue environment (UCE). Resultant handling qualities levels are judged on a combination of results from clinical open-loop and demonstration closed-loop test manoeuvres.

A helicopter designed to, and complying with, the ADS-33 standard should exhibit very good qualities in service. Formally, the ADS-33 standard states that a helicopter should exhibit level 1 qualities (desired performance consistently achievable at low pilot workload) throughout the operational flight envelope. In this sense the standard has to be seen in the context of high levels of flight control augmentation, that tame the natural tendencies typified by the lack of carefree handling, strong cross couplings and poor stability. The question then arises as to what value is ADS-33 in judging the capabilities of existing aircraft or, more generally, aircraft not designed to this Standard? This question is particularly relevant to the UKAH evaluation. Research experience to date suggests that most current operational helicopters exhibit a wide range of Level 2 characteristics combined with some Level 1 and even Level 3 characteristics. A Level 2 helicopter can still perform missions with adequate performance but the pilot is likely to have to work harder to compensate for deficiencies. The ADS-33 standard has been developed to discern flying quality across all three Levels, and hence is properly applicable to existing aircraft as well as super-augmented aircraft of the future, in both normal and failed conditions (where some degradation into Level 2 and 3 is allowed). Indeed, much of the database from current types used in the development of ADS-33 was used to substantiate the new criteria in the Level 2 region. One of the outstanding issues in all flying qualities work relates to the effects of a combination of several Level 2 characteristics on pilot workload and task performance and the uncertainty surrounding these effects is perhaps the single most important reason for the continued strong emphasis on the need for pilot subjective evaluation in mission tasks.

ADS-33 states that, "*Compliance with the requirements will be demonstrated using analysis, simulation and flight test...*" This places initial emphasis on capability demonstration during design through analysis and simulation. Confidence in the results of compliance demonstration in design is critically dependent on the simulation fidelity level, including the modelling and cueing environment. For the UKAH evaluations, it was important that any limitations caused by simulation infidelity were well understood. Aircraft modelling issues are discussed briefly in Section 4.2, but even with perfect aircraft modelling there is still a question over whether tests conducted in ground-based simulation can accurately predict flying qualities levels.

A review paper by Condon (Ref 5) presents data showing the extent to which ground-based simulation has improved during the 1980s. During the formative years of ADS-33, in the early 1980s, there was a clear disparity between ground-based simulation and flight test data (Ref 6). Pilots were not able to achieve Level 1 handling qualities with rate command response types in simulation, while flight data predicted a genuine Level 1/2 boundary. Problems were attributed to poor visual and motion cueing in the simulation and the ground-based data were discounted in the early developments of ADS-33. When the DRA's AFS became available with a large motion capability in the early 1990s, one of the first tasks was to establish the degree of conformity with the ADS-33 flight test data.

Fig 2 presents roll axis handling qualities results for rate command response type aircraft flown in a sidestep mission task element on the AFS (Ref 7). The key handling qualities parameter relating to closed-loop piloting is the attitude bandwidth, defined conceptually as the highest frequency that the pilot can close a task - loop without threatening stability (Ref 1). The AFS ground-based simulation data are shown compared with the ADS-33 flight test data, indicating very good correlation with the Level 1/2 boundary predicted at a roll axis bandwidth of about 2.5 rad/sec - about 25% higher than the, more conservatively set, ADS-33 boundary itself. The AFS data also confirmed the importance of motion cueing to pilot control strategy, acting as a realistic filter to 'high gain' activity on the one hand and suppressing the over-controlling typical without motion, especially in the vertical axis (Ref 7).

The substantiating evidence of good fidelity, coupled with the engineering experience with flight and simulation trials over many years, made the AFS an ideal tool for evaluating the UKAH contenders flying qualities, relative to the ADS-33 standard. Two general guidelines were established. First, in general, it would be expected that the simulated aircraft would be marginally more difficult to fly than the real aircraft. Second, that the quality of the phototextured visual scenes and motion cueing were expected to be sufficiently realistic to expose any potential pilot - induced - oscillations, which can threaten flight safety at the higher levels of task aggression.

3.2 The 3 - Stage Evaluation Methodology

The approach taken by DRA can be described under three headings as follows:

(i) clinical tests and the HQ toolbox analysis; The ADS-33 standard contains a set of criteria for different response types and different control axes (Fig 1). These response characteristics are further subdivided into criteria for different ranges of frequency and amplitude. For example, agility characteristics are represented by large amplitude (control power) and moderate amplitude (quickness) criteria, while stability characteristics are represented by long term open-loop (e.g. phugoid, Dutch roll damping) and short term closed-loop (bandwidth) criteria. Quality criteria for the different forms of cross-coupling are also defined. These criteria are typically formed into 2 - parameter diagrams with defined boundaries between Level 1, 2 and 3 quality standards. The DRA handling qualities toolbox (Ref 2) has been developed to derive these parameters from flight or simulation test data and to present results automatically on the HQ charts. The DRA Helisim model is an integral part of the Toolbox, and pre-defined or custom test control inputs can be applied to the simulation model to produce responses from which the HQ parameters can be derived. The HQ Toolbox is developed within the MATLAB/SIMULINK environment. Areas of particular interest in the UKAH evaluation were agility, stability and cross coupling. Evaluations were made with and without stability and control augmentation.

(ii) inverse simulation; The Glasgow University/DRA inverse simulation approach, integrated into the software package HELINV (Ref 3), was used to predict the limits to agility in mission task elements (MTEs). HELINV takes as input the MTE, defined in terms of flight path kinematics, along with aircraft limits, e.g. control margin, power. The HELINV algorithm effectively inverts the simulation model to compute the rotor loads and control movements required to fly the manoeuvre. Some validation of this approach has been conducted with Lynx flying slalom MTEs (Ref 8), where comparison between flight test and HELINV results indicated that control limits were reached at very similar levels of agility.

(iii) pilot in-the-loop simulation using the AFS; This element of the methodology forms the main topic of this paper and will be discussed in more detail in later Sections. Underpinning the piloted evaluation is a series of mission task elements or flight test manoeuvres with well defined desired and adequate performance levels. These need to be (clinically) representative of operational situations, reflecting in the present case the UKAH role. Pilots need to be able to perceive their achieved task performance, dictating careful design of the MTE visual cueing. Pilots also need to be familiar with the roles being considered and properly trained in the use of the Cooper-Harper Handling Qualities Rating (HQR) scale - Fig 3 (Ref 9). The latter is particularly important for achieving consistency between pilots regarding the interpretation of low, moderate and considerable levels of compensation and aggressiveness. Finally, HQRs need to be arrived at following structured dialogue between the trials engineer and test pilot, that serves to document the system characteristics that lead to a particular HQR.

The three - stage approach contains a number of synergistic features. The Toolbox analysis can draw attention to areas of apparent deficiency while the HELINV results can identify limiting conditions to support the design of the MTEs. In the next Section, the approach to and results from the AFS trials are described in more detail.

4. UKAH AFS simulations - the approach

4.1 AFS trial objectives

The overall objective of the FDS assessment strategy was to evaluate the contenders' flying qualities and to check that these would not unduly constrain the levels of 'useable' agility, in the context of the AH's primary mission. The AH will be required to operate in the battlefield environment, primarily flying anti-armour, ground suppression and anti-helicopter missions. For mission effectiveness, it was stipulated in the target operational characteristics that "...The AH should have handling and engine response qualities appropriate to accurate flight path control with low pilot workload in the NOE, battlefield environment. Suitable means should be provided to allow for exploitation of the full flight envelope when flying 'eyes out' without the risk of inadvertent and unacceptable excursions beyond it....". In addition, a number of key point performance characteristics for given flight states were also defined, which specified the desired acceleration and speed capabilities for the aircraft. Taking the two issues together, it is implicit that the aircraft should embody good agility and manoeuvrability coupled with handling qualities that allow the pilot to exploit the available performance, with confidence and safety.

The specific aim of the AFS trial was to check the pilot-in-the-loop flying qualities, levels of workload, task performance and agility for each of the contenders, and to provide important data for comparison with inputs from the off-line simulation predictions. Specifically, the objective of the trial was to conduct piloted evaluations of the contenders' handling qualities in mission-orientated tasks extracted from key flight phases of the AH's primary anti-armour role.

4.2 Simulation Models - Creation and Validation

Simulation models of the UKAH contenders were created based on the data provided in the TDRL responses from bidders. Currently there are three versions of the generic DRA HELISIM, distinguished largely by the complexity of rotor modelling. The hi-fidelity version employs an aeroelastic rotor model with non-linear unsteady aerodynamics and is currently undergoing integration into the real-time AFS environment. The Helisim version adopted for the HQ Toolbox and HELINV analysis employs a rigid-blade disc approximation, with dynamic multi-blade coordinate representations of blade coning and cyclic flapping motion; blade aerodynamics are linear (Ref 10). For the real-time simulation, the rotor blade degrees of freedom were further approximated by quasi-steady representations of flapping and coning. This level of approximation is known to give moderate levels of fidelity across a frequency range between zero and about 10 rad/sec, in terms of primary axis control response, in the absence of aerodynamic nonlinearities e.g. caused by interactional effects or rapid manoeuvring. Comparisons with the test data provided by the AH bidders confirmed this. The aerodynamic linearity assumptions also become increasingly fragile at higher speeds, but, since only low - mid speed MTEs were flown, this weakness was not considered to have a significant impact on the simulation results.

One of the known failings of a flap-only model with simple 3-component inflow modelling is the poor fidelity of cross coupled pitch/roll responses and the HELISIM versions of the UKAH contenders were no exception. Comparisons varied from poor to fair and the general approach taken during the off-line analysis and piloted simulations was to reduce the emphasis on the cross coupling quality criteria. As a general point, during the piloted trials, particular care was taken to identify any adverse comments relating to a characteristic that was known to be poorly modelled. In the event, none of these areas appeared to be critical to the test pilots, who were encouraged to give emphasis to the primary control response (agility) and stability characteristics.

Rotorspeed was assumed contant for all configurations. HELISIM does feature a generic powerplant/rotorspeed governor/fuel flow model, but insufficient data were provided to model the different configurations. Constant rotorspeed will, on the one hand, obscure any handling features relating to delayed engine response or torque overshoots. On the other hand, the instantaneous engine response is likely to result in less representative yaw coupling to rotor torque changes. Any pilot comments relating to these issues were noted, as with pitch to roll couplings, although, once again, they did not appear as a major driver to the HQRs.

Configurations were modelled together with the stabilisation components of the stability and control and autopilot augmentation systems, again using data supplied by the manufacturers. Autopilot modes were excluded since all the MTEs evaluated were essentially full-attention, active flying tasks.

Overall, correlation with the test data provided by the bidders showed adequate correlation for primary response characteristics in terms of control power and damping. This conclusion is supported by previous validation work conducted using HELISIM with Lynx, Bo105 and Puma flight data. As noted above, cross coupling was, in general, poorly modelled, although the levels were such that, in a broad sense, similar handling qualities would be expected between model and the real aircraft, e.g. Level 2 handling qualities for pitch/roll/pitch coupling described in terms of the ratio of off-axis to on-axis response span the wide range from 25 to 60 % in ADS-33.

4.3 Test and evaluation methods

The test and evaluation procedures used for the AFS assessments were based on well tried and robust techniques, developed during previous FDS handling qualities research (Refs 7,11,12,13) through the complementary use of the ground based AFS and Lynx/Puma airborne test facilities. From previous experience, notwithstanding the limits of simulation capability, it was considered that the results would provide a valuable insight into the contenders primary axis handling characteristics to complement the HELINV and Toolbox analyses. Moreover, given the importance of motion cueing for piloted handling qualities evaluations, the AFS with its Large Motion System (LMS) was considered to be well suited for the AH assessments.

4.3.1 Simulator Configuration

The available time and resources precluded a detailed representation of each aircraft's cockpit, controls, cockpit systems and displays. Each contender was evaluated in a 'standard' configuration, with the assumption that they would be equally affected by any attributes or deficiencies.

The simulator configuration used in each case featured a single-seat helicopter cockpit with a Lynx seat and controls and a 'standard' set of head-down flight instruments. Visual scene content was displayed via a Link-Miles Computer Generated Imagery (CGI) visual system and three cockpit mounted monitors, arranged to provide one centre and two side windows. 'Platform' motion cueing was provided by the LMS. Key features are presented in Fig 4 and summarised below.

General

Specific features include:

(i) Electric feel-system with Lynx mechanical controls (centre-stick, rudder pedals and collective)

(ii) Lynx seat featuring vibration cueing scheduled with airspeed and normal 'g'

(iii) Link Miles Image 600-PT visuals featuring 3 windows with maximum fields-of-view:

- Total azimuth: ± 63deg,
- Centre window vertical: ± 18deg
- Side windows vertical: ± 24deg

(iv.) LMS motion cueing with maximum accelerations:

- Vertical: ± 1g
- Lateral/Longitudinal: ± 0.5g
- Angular: ±2 rad/s^2 pitch, ± 3 rad/s^2 roll, ±1.5 rad/s^2 yaw

(v) Head down display of primary flight instruments, e.g. artificial horizon, airspeed indicator, normal 'g' meter, main rotor speed and engine torque indicator

(vi) Data logging facilities:

- automatic recording of pilots control activity, aircraft responses and flight-path coordinates via computer disk and pen chart recorders
- video records of pilot's eye-view of the centre window

Controls configuration

Where possible, the controls were configured as friction devices or with static force gradients and breakout characteristics using information supplied by the bidders. Alternatively, the controls were configured with Level 1 characteristics in accordance with Def Stan 00-970 (Ref 14) and ADS-33 criteria. Regarding dynamic characteristics (frequency, damping and inertia), for the centre-stick and rudder pedals data representing measurements from a Lynx were used. The rudder pedals and collective controls had trim force release buttons, positioned on the collective control grip, while the cyclic control had trim follow-up and trim release buttons, mounted on the hand grip. These functions were not considered to be part of the assessment and were generally only used when setting up trim conditions.

Simulation transport delays

With the CGI visual system, the total AFS system latency, ie. time between initiation of a control input and visual system response, has a value of 115ms +/- 10ms. The latency is an important factor in handling qualities evaluations because it directly influences the minimum achievable phase delay and maximum bandwidth that can be modelled. However, checks on attitude bandwidth using the handling qualities Tool-box indicate that, when compared to the predicted data for the contenders, the AFS latency would not have a significant impact on the validity of the evaluations.

4.3.2 Test procedures

To meet the assessment objectives, test pilots evaluated the contenders' handling qualities in a set of mission-related flight tasks, or 'mission task elements' (MTE). MTEs form the basis for 'stylised' tasks specifically designed to enable formal handling qualities evaluations using the Cooper-Harper rating scale (Ref 9), as shown in Fig 3. To support pilot impression and to enable them to review the handling qualities in a mission context, pilots were also required to fly a simulated AH mini-mission. In this task, pilots flew an NOE flying sequence, interspersed with discrete mission task elements, accomplishing a number of mission objectives, eg. target acquisition, reconnaissance. For the formal evaluations, the pilots were required to achieve the tasks within given accuracy constraints and special visual cue arrangements were used to assist the pilot in judging the level of task performance achieved. Pilots were also required to evaluate the tasks at different levels of aggression, where aggression refers to pilot control strategy and may be taken as an indication of how hard the pilot is 'driving' the aircraft, or the level of inherent aircraft performance that is exploited in the execution of the task. Experience has shown (Refs 11, 12, 13) that testing over an increasing range of aggression can expose potential handling qualities 'cliff-edges', which signify a rapid rise in workload as the pilot strives to maintain adequate task performance under increasing time pressures. Hence, the intention was that pilots should explore the effect of task aggression on task performance, workload and agility in their handling assessments.

In order to achieve a reasonable spread of opinion, evaluations were completed by three different pilots, who were each allowed three sorties in which to assess each contender. The first sortie was allocated to training and familiarisation and the following two for formal evaluations. Before assigning a rating, the evaluation pilot was allowed to practise the task until a consistent level of task performance had been attained; the on-line data logging was used to provide feedback information to the pilot on applied levels of task aggression and task performance achievement. Handling qualities ratings were recorded using the Cooper-Harper 'decision tree' and scale and, in addition, a special questionnaire was used to record supporting comment and opinion. Pilot's control demands, flight path coordinates and vehicle responses were also logged for all designated evaluation runs and subsequently used to confirm achieved levels of task aggression and task performance. At the end of each sortie, pilots completed a further questionnaire as a means of providing a more detailed debriefing on their ratings and assessments. They were also asked to complete a summary report on their overall impression of each configuration, based on their experience in flying the simulated mission.

4.3.3 Test Manoeuvres

From ADS-33, a mission task element or MTE, is defined as "...An element of a mission that can be treated as a handling qualities task...". For the AH evaluations, MTEs were selected on the basis of the primary mission profile and the piloting tasks associated with key phases of the mission. In its primary role, the AH will typically be expected to spend a high proportion of time in NOE flight, at speeds below 80kn, and in manoeuvring at low speed close to the hover. As an agile combat helicopter, it must be capable of delivering rapid and accurate control of flight path. To this end, the speed and precision with which the pilot can redirect the rotor thrust, through control of attitude, will be a major factor. Hence, the roll axis response characteristics, and to lesser extent those of the pitch axis, play a key role in determining the suitability of the aircraft's handling qualities for the role.

The MTEs chosen for the evaluations included two hover and low speed tasks, the lateral sidestep and the quickhop, and one forward flight task, referred to as 'lateral jinking'. These MTEs had been developed and tested in previous FDS research (Refs 11,12) and represent handling qualities evaluation tasks with well defined control strategies and manoeuvre objectives, and with clear performance goals and levels of task aggression. Handling qualities in the tasks are dominated by the primary roll or pitch axis response characteristics, where key parameters will be roll/pitch controllability (control power and sensitivity), roll/pitch attitude quickness and closed-loop stability (attitude bandwidth and phase delay).

The sidestep and quickhop are essentially hover re-positioning manoeuvres (see Figs 5 & 6), which could entail moving from one point of cover to another with minimum exposure time, or perhaps a move from cover to complete an observation task. Lateral jinking (see Fig 7) is essentially a roll axis slalom manoeuvre, combined with sequences of tracking elements, and is designed to test the capability for accurate control of flight path in low level NOE flight, in the presence of obstacles in the ground plane.

Task performance and aggression requirements for all three tasks are defined in Tables 1 & 2. Regarding task performance, different requirements are given for 'desired' and 'adequate' levels. The target levels of task aggression were specified through an appropriate parameter associated with the primary control axis; for a sidestep for example, aggression is specified in terms of the maximum roll attitudes to be achieved during the acceleration and deceleration phases of the manoeuvre. The three levels are also indicative of the maximum angular rates, attitudes and translational rates to be achieved during the manoeuvre. In relation to the AH mission, the intention was that 'low' aggression represents unhurried or cautious manoeuvring in the presence of threats, or perhaps manoeuvring in poor visibility or confined places etc. Similarly, 'moderate' represents manoeuvring with 'normal' levels of mission urgency where there may be no direct or imminent threats, while 'high' represents rapid weapon deployment, direct threat avoidance/evasion, or rapid withdrawal from danger zone.

The task handling qualities objectives are described in the following:

i. Sidestep

The sidestep task is dominated by the roll axis response, but at the same time a multi-axis control strategy is needed to coordinate the heading (rudder pedals), height (collective) and track over the ground (longitudinal and lateral cyclic). For the ADS-33 test manoeuvre, the task objectives are defined as follows:

(i) Check lateral/directional handling qualities for aggressive manoeuvring near the rotorcraft limits of performance.
(ii) Check for objectionable interaxis coupling.
(iii) Check ability to co-ordinate bank angle and collective to hold constant altitude.

The task designed for this assessment is similar to that in ADS-33 with the inclusion of markers with vertical extent to cover deficiencies in simulator field of view and CGI texture. ADS-33 defines this task by target speed achieved before deceleration and with start and end points as a function of aircraft performance following a number of test runs. The task used in the UKAH evaluations defined the same start and end points for all contenders thereby allowing a better comparison of the ability of the aircraft to re-position to a particular location.

ii. Quickhop

The quickhop is similar to the sidestep but in this case the primary control axis is in pitch. Again, however, a multi-axis control strategy is needed to coordinate the heading , height and track over the ground. The ADS-33 Objectives are as follows:

(i) Check the pitch axis and heave axis handling qualities for highly aggressive manoeuvring.
(ii) Check for undesirable coupling between the longitudinal and lateral/directional axes during highly aggressive manoeuvring in the longitudinal axis.
(iii) Check for harmony between the heave and pitch axes controllers.
(iv) Check for adequate rotor response to aggressive collective inputs.
(v) Check for overly complex power management requirements.

The task used is similar to the ADS-33 Acceleration-Deceleration with the inclusion of markers with vertical extent to cover deficiencies in simulator field of view and CGI texture. The acceleration is to a fixed speed but also to fixed markers, unlike the ADS-33 task which also accelerates to a fixed speed but defines the initial and final control strategies as a function of aircraft performance following a number of test runs. Airspeed targeting is not considered critical in a tactical manoeuvre whereas getting from hover point A to hover point B, as soon as possible, is. The task used therefore defined the same start and end points for all contenders. The quickhop is primarily a forward view task but lateral reference is necessary especially during the deceleration phase.

iii. Lateral jinking

The test objective is to check lateral/directional handling qualities in transient turning manoeuvres in the mid-speed range and in acquiring and maintaining a designated track. The manoeuvre is dominated by the primary axis roll response, but again a multi-axis control strategy is required for maintenance of height, speed and balance. Test objectives for the equivalent ADS-33 case, the 'rapid slalom', are defined as follows:

(i) Check ability to manoeuvre aggressively in forward flight and with respect to objects on the ground
(ii) Check turn co-ordination for aggressive forward flight manoeuvring
(iii) Check for objectionable inter-axis coupling during aggressive forward flight manoeuvring

Lateral jinking is similar to the ADS-33 slalom MTE but with level, straight sections connected by turns rather than continuous turns through gates. The target speed of 60kn is the same as ADS-33 and the course aspect ratio requires a similar level of aggressiveness to the ADS-33 slalom MTEs. However, the inclusion of the level, straight sections produces a high gain stabilising task within the slalom. The gates have much greater vertical extent and are narrower than in real flight trials in order to compensate for simulator field of view and CGI texture deficiencies. Lateral Jinking requires a combination of forward and lateral views.

iv. NOE course

As noted above, pilots were also required to fly a simulated AH mini-mission as part of the assessment using a designated NOE course. ADS-33 suggests such a combination course for final flight evaluations. The NOE course represented a contact flying task, which combined the spot turn, acceleration, deceleration, slalom, vertical unmask, vertical remask and sidestep manoeuvres. It was flown after the MTE tests and although not formally evaluated, it gave the pilots a final opportunity to review their impression of the handling qualities in a broader range of mission tasks. The general mission plan and sequence of events are summarised in Table 3. A representative view of the CGI scene detail for the NOE database is shown in Fig 8.

4.3.4 CGI Task cue arrangements

Referring to Fig 5, for the sidestep the principal cues are provided by a building-like structure and sighting arrangement. The near and far sights are designed to give height and plan position error feed-back relative to the 5/10ft (desired/adequate) requirement. The road in the foreground is intended to give additional longitudinal position cueing during the lateral translation. The posts provide additional height and longitudinal position cueing for precision hovering.

Task cues for the quickhop are shown in Fig 6. Height and position cueing are given by a road running between a building and a gantry-like structure. The building window line shows the target task height and its upper extremity delineates the desired task performance range. The initial and final hover positions are given by adjacent vertical black lines on the wall and the gantry, which for correct positioning should be aligned in the centre of the side windows. The road edges provide lateral positioning information. The vertical posts in the forward field-of-view are placed to give height and track cues during the final 'flare'.

For lateral jinking, see Fig 7, the task layout consists of a sequence of turning gates located on either side of a roadway. The gates are represented by sets of four posts, comprising a small inner pair, which represent adequate tracking performance (12m wide), and a larger outer pair which serve as a height reference. The direction of the roadway defines the tracking lines, while its width (6m) defines the desired tracking performance.

5. UKAH simulations - the results

The principal test objectives as discussed in the previous section were met. Sufficient information was provided by the bidders for building simulation model configurations and the calibration exercise gave confidence that the model responses were acceptable for the piloted simulation test objectives. Results achieved in the subsequent simulation evaluations were consistent with the findings of previous FDS flying qualities related research and were also in good agreement with the off-line assessments using the handling qualities Tool-box. In particular, pilots comments and ratings were well matched with predicted handling qualities levels for roll and pitch axis bandwidth, attitude quickness and control power criteria.

Handling qualities evaluations were carried out by three pilots at moderate levels of task aggression, where in all cases either desired or adequate task performance requirements were achieved. The tasks were also attempted at higher aggression levels and in nearly all cases, the pilots were able to achieve at least adequate performance levels. Most important, pilot comment showed that, at least up to the moderate aggression standards, simulation constraints did not unduly influence their perception of handling qualities. One formal set of evaluations at high aggression was carried out and the results are presented below, together with those for moderate aggression; some general comments on the overall results are also given. A summary of supporting pilot comments is also given, including more detailed reviews of flying each of the flight test manoeuvres.

5.1 Pilot handling qualities ratings

A summary of pilots ratings for handling qualities is shown in Fig 9. The plot shows the overall mean and spread of ratings for all configurations, for the three evaluation tasks. For moderate levels of aggression, the spread of ratings for each aircraft was generally within one scale point, indicating a good consensus of opinion between the pilots. In three instances scatter increased to 1.5 or 2 scale points, and in one of these cases, ratings also crossed the Level 1-2 rating boundary. The variation may be explained by differences in control strategy and task aggression. For example, even within the targeted task aggression level, pilots were able to select different roll rates to achieve the change in roll attitude, as indicated by different attitude quickness (Ref 7). This may reflect choice of a more relaxed control strategy, or may result from poor handling qualities, where the pilot is using a strategy that reduces the need for excessive compensation. Also, from observation, application of aggression tended to be a function of pilot background, eg. experienced 'attack' helicopter pilots tended to achieve higher attitude quickness values when compared with transport helicopter pilots. Ratings for the high aggression case show a clear increase in mean rating compared to the moderate aggression results.

Such results reflect the need for a sample of different subject pilots and to test across a range of task aggression. As aggression increases, the combination of task performance demand and increasing time pressures on the pilot, reduces the scope for 'backing-off' on control demand. As noted above, testing across a range of aggression can highlight the presence of any handling qualities 'cliff-edges'.

5.2 Overview of pilot comments and opinion

From pilot comment, for the tasks evaluated, simulation related limitations/deficiencies were not considered to be unduly intrusive, and were generally judged not to have had a significant impact on the results. A representative comment from one pilot was that:

"... The AFS provided a good method of comparison of the three aircraft. Some simulation limitations detracted from the overall realism but probably had little effect on the results achieved. The visual system was limited at high pitch up attitudes which precluded conducting truly representative tactical manoeuvres. However the required level of aggression was achieved in the assessments. The motion system gave good cues for most tasks, but when manoeuvring aggressively the lateral and yaw cues became unrepresentative..."

As commented, field-of-view limitations in the quickhop task were probably the most noteworthy limitation, and may have given rise to an estimated degradation in ratings of 1 scale point at the moderate level of aggression. At higher aggression, motion cueing was noticeably more intrusive, although pilots still preferred to fly with the motion system engaged. From past experience, tasks flown at high aggression in fixed-base simulations tend to give rise to pilot disorientation and even nausea. This is particularly true for NOE tasks, which involve dynamic roll axis manoeuvring, such as lateral jinking.

The head-down instrumentation was reported to be generally too distant from the pilots normal scan to provide more than minimal assistance, particularly in high aggression tasks. Regarding torque margins, at the target levels of task aggression, pilots were mostly able to achieve the task within the desired margin, particularly for the lateral jinking which was evaluated at a speed close to the minimum power case. However, for the low speed tasks at higher levels of aggression, when manoeuvre attitudes exceeded 25deg, there was a noted tendency to exceed the defined limit.

There were no adverse comments regarding the cockpit inceptors. Where used, the Lynx controls breakout forces and gradients were considered to be satisfactory, and there were no reported handling qualities deficiencies due to control characteristics.

5.3 Pilot assessment of the flight test manoeuvres

5.3.1 ADS-33 and the Selected MTEs

Tactically relevant manoeuvres have always been used in flight trials and the use of the ADS-33 MTEs or derivatives of them are now becoming more common in test and evaluation flight trials. All 3 UKAH evaluation test pilots had experience of flying MTEs in a number of aircraft and simulators in both research trials and test and evaluation flights, and found that the simulated and real aircraft results correlated well, with the obvious reliance on accurate mathematical modelling of the simulation. The relevance of ADS-33 MTEs to tactical manoeuvring varies and some merit further development into a number of variations or combinations. For instance the pirouette is not strictly a tactical manoeuvre in itself but yields relevant engineering data. The quickhop and sidestep are particularly relevant and merit an additional combined MTE of pitch acceleration with roll/yaw deceleration; this is a very common tactical manoeuvre which results in a deceleration without pitching the nose up to, thereby reducing exposure to the enemy. Certain ADS-33 MTEs are defined in very general terms leaving the pilot to develop a strategy to achieve the objective whilst others have control strategies embedded in the definition. Some tasks have very specific objectives defined in engineering terms, others in terms of time to complete the manoeuvre, some in aircraft performance attained and some in aircraft attitude. This can lead to different control strategies depending on pilot experience, perception of the task and aggressiveness. For the trial it was therefore necessary to be particularly selective when choosing tasks, in order that relatively consistent control strategies would emerge thus making the trial more of a comparison of the contenders than the pilots. Therefore tasks were chosen from ADS-33 which were the most tactically relevant and then modified or more closely defined such that a comparative trial of the contenders could be conducted.

5.3.2 Sidestep

The manoeuvre was initiated with a lateral cyclic input followed by inputs in the other axes/controls to compensate for cross coupling and power demands. The initial lateral input varied depending on the aggressiveness of the test manoeuvre according to the requirements of Table 2. The secondary inputs varied depending on the aircraft type. Once sufficient lateral speed had been attained the deceleration was initiated with opposite lateral cyclic and followed by compensating secondary inputs. The cross couplings and deceleration rate would often differ from that of the acceleration phase. As the target location was approached, a level attitude was adopted and the aircraft stabilised to within the desired parameters in heading and position. The vertical extent of the markings enabled the pilot to fly the task without significant reference to the lateral view thus removing some of the limitations of the simulator field of view.

The sidestep MTE was found to be very good for assessing the roll agility, stability and sensitivity and also showed up inter-axis coupling during the dynamic lateral manoeuvre. The need to acquire a target in the terminal hover meant that accurate positional control could be assessed whilst looking out. However, heading control was assessed from indicated aircraft heading which, being on the instrument panel, required the pilot to look into the cockpit. With no accurate head-up representation of heading, the high gain yaw task when stabilising in the hover may well not have been examined. Since the sidestep manoeuvre may well also be used to engage fixed forward firing guns or rockets, the MTE could be developed for future assessments by the addition of an on-board sight.

5.3.4 Quickhop

The manoeuvre was initiated by a forward cyclic input. Compensating inputs in the other axes were necessary but to a lesser extent than in the sidestep and varied according to the aggressiveness of the input. The initial pitch down was complicated by the lack of upper field of view and deficiencies in ground texturing which gave few cues to height change. This was partly compensated for by the inclusion of horizontal bars in the lateral structures which then gave adequate height cues. The distance between the start and finish points was such that no appreciable level attitude segment existed for any of the aircraft evaluated. The decelerating attitude revealed the lack of downward field of view; however, the horizontal markers in the lateral field of view continued to give adequate height cues. Due to the lack of lower field of view, the desired hover point was not in view during the deceleration. This required the pilot to utilise the lateral view to establish the required hover point. The addition of a radio mast in the distance, extending into the forward field of view at high nose attitudes, enabled the pilot to maintain heading during the deceleration. The workload during the deceleration was thus higher than may be expected in real flight. The deficiencies in sky texturing, although detracting from the realism of the manoeuvre, were compensated for by the additional lateral and forward cues. However, none of these deficiencies significantly affected the handling assessment.

The quickhop was found to be very good for evaluating handling qualities in the pitch axis and cross coupling during acceleration-deceleration. Having fixed start and finish points further constrained the task, making it more aggressive, and thereby further exposing deficiencies and highlighting differences between the contenders. Due to the layout of the simulator cockpit being unrepresentative, problems with rotor response and power management were more difficult to detect and, from a piloting viewpoint, were largely ignored in the assessments.

5.3.5 Lateral Jinking

The manoeuvre was initiated with lateral cyclic when passing through the first gate in straight and level flight at 60kn. Compensating inputs in the other control axes were then made as necessary. As the first level section was approached, opposite lateral input was applied and compensated for and then the pilot attempted to stabilise on the centreline of the level section. At the end gate of the level section a further lateral input was made to position for the next level section. This sequence was continued until the final gate was passed through at a target speed of 60kn in level flight. The deficiencies in CGI texturing were less evident in this task and had little effect on the assessment. The addition of gates with vertical extent compensated for the field of view deficiencies and the task had a high degree of realism throughout.

Lateral Jinking proved to be a good indicator of handling qualities relating to forward flight roll agility, stability, roll sensitivity and roll to pitch coupling/speed stability. The addition of level sections allowed assessment of the ability to stabilise on a high gain task in forward flight from an aggressive manoeuvre, such as would be required for fixed forward firing guns and rockets, and made any tendency to roll PIO evident.

5.3.6 NOE Course

The improved CGI texturing over the natural landscape were evident in this task. Field of view restrictions were more noticeable but, due to the well modelled scenery, an accurate flight path could be maintained and the field of view deficiencies were not felt to have had a noticeable effect on the assessment. Cockpit layout was not a factor in this task since no particular headings or heights had to be maintained.

The sequence began in the hover in a farmyard and was then followed by a spot turn before accelerating to 30-50kn towards a river valley approximately 100m away. A left turn into the valley was then followed by a right turn, left turn, straight section and left turn following the river before decelerating to the hover amongst buildings. A further hover spot turn was then followed by an acceleration to 30-50kn to rejoin the river valley. Flight under cables and a left turn were followed by a deceleration to the hover behind trees. A vertical unmask and remask manoeuvre to acquire a building target was followed by a left sidestep departure which was converted into an acceleration by yawing left into the direction of travel. A right turn and deceleration into cover was followed by a vertical unmask and remask to acquire the same building target.

Acceleration to the left was followed by a left and right turn and then a rapid deceleration to hover behind a building. Another vertical unmask to acquire and track a second target was then followed by a rapid remask, sidestep and acceleration to 70-80kn to follow the river valley out of the area.

Although not formally assessed, the NOE course was found to be excellent for identifying any handling qualities characteristics which could affect the attack mission. The stylised MTEs were flown first and these served to alert the pilot to any deficiencies. The subjective view of the handling qualities complemented the more clinical MTE results and generally confirmed in the pilots mind the impression which he had gained. The differences between contenders were more noticeable in this multi-axis, variable-speed task than in separate MTEs and proved to be a valuable contribution to the trial.

6 Conclusions

This paper has described the approach taken to the assessment of the flying qualities of the UKAH contenders, with particular emphasis on the piloted simulation element. The approach has demonstrated the complementary capabilities of off-line evaluations, using the ADS-33 Handling Qualities toolbox and inverse simulation, and piloted tests to establish flying quality. The background to the UKAH project and the overall evaluation programme have been summarised, followed by a resume of the DRA approach to flying qualities assessment. Simulation models of the contenders were assembled, within the DRA Helisim framework, from data provided by the bidders. The simulation facility used for the piloted evaluations, the Advanced Flight Simulator, and the associated experimental design have been described in some detail. Three test pilots conducted the evaluations in three mission related tasks - the sidestep, lateral jinking and quickhop - followed by a UKAH mini-mission, assembled as a series of contiguous tasks. Flying at moderate levels of aggressiveness, the pilots were able to complete all the tasks within adequate performance standards for all configurations flown. Confidence in the results was increased by the low spread of pilot handling qualities ratings and the overall pilot impressions that the simulation was representative for the tasks flown. Research also correlated well with off-line Toolbox and HELINV analyses.

Pilots' impression was that the MTEs used in the assessment were tactically relevant to the UKAH mission and, with the additional NOE course, gave a good feel for the capabilities of each contender. In comparison with flight in similar aircraft to those on offer, the simulations were considered to be accurate, giving the FDS evaluation team and MOD a high degree of confidence in the trial results. With the configurations under test not being available for flight, simulation was the only way that a comparative test could be conducted and the deficiencies in simulator field of view, cockpit layout, motion and CGI texturing were not sufficient to preclude a representative handling qualities evaluation to be conducted. Specific points relating to the piloted simulation are as follows;

(i) the combination of visual, motion, audio and tactile cues work synergistically to give the pilot a realistic impression of flying.

(ii) visual cues provide the most compelling inputs to pilots controlling a helicopter's flight path and attitude in the NoE. The field of view of the CGI display in the AFS helicopter cockpit was adequate for most of the MTE flying, giving strong periphal cueing laterally, but the range in the vertical FoV limited the level of aggressiveness possible in pitch manoeuvres. Textural detail, provided by the CGI photo-texturing, proved vital for good low speed velocity and attitude cues and was supplemented by a range of artificial objects to assist pilots in judging desired and adequate levels of task performance.

(iii) motion cues provide the pilot with important lead information, in general working to contain control aggressiveness to realistic levels and also proving vital to the correct prediction of PIO boundaries. In the UKAH trials, motion cues proved effective. At high levels of aggressiveness, control strategy became affected by spurious cueing, particularly in the roll/sway axes. Work is in hand to improve the motion drive laws in this area.

(iv) the design of a piloted simulation trial can be guided to great effect by off-line analysis as demonstrated in the DRA's approach to the UKAH assessment. Conducting analysis of a helicopter's response characteristics à la ADS-33 gives a clear indication of a helicopter's strengths and weaknesses. Effective use of the HQ Toolbox and HELINV inverse simulation has been made in this context to focus attention during the piloted evaluations.

The direct use of handling qualities simulations during an aircraft procurement has been a novel and successful experience. For a competitive selection process such as the UKAH, the AFS was demonstrated to be a valuable tool for assessment of handling qualities, whereby it allowed piloted evaluation of representative aircraft models in an even environment against predetermined objectives. The ability to compare results against other areas of the technical assessments increased confidence in the overall level of credibility. Although actual flight evaluation of current models of the contending aircraft was undertaken, these activities were regarded very much as complementary to the simulation activity, with different primary objectives for each. However, it is important to note that in common areas, the findings from the piloted simulation were consistent with those for the aircraft evaluations.

In this, first of a kind, exercise in the UK, much valuable information has been captured to assist in the overall assessment of the competing weapon systems and the DRA approach to flying qualities evaluation has proved successful in providing insight into the mission capability of the UKAH contenders. Piloted simulation has demonstrated its worth in highlighting handling characteristics relevant to the UKAH role. This assessment has also provided the opportunity to identify areas where simulation fidelity needs improvement to realise the full potential in supporting design, evaluation and, ultimately, airworthiness certification.

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Table 1: MTE task performance requirements

MTE	MTE Phase	Heading/ balance - deg -	Height - ft -	Ground track - m -	Over/ under shoot - m -	Plan position - m -	Speed - kn -
Sidestep	Transition	+/- 15 D +/- 25 A	± 5 D ±10 A	+/- 3 D +/- 6 A	+/- 3 D +/- 6 A	na	na
	Terminal hover	+/- 5 D +/- 10A	+/- 5 D +/- 10 A	na	na	+/- 1.5 D +/- 3 A	na
Quickhop	Transition	+/- 15 D +/- 20 A	< 58 D (17.5M) < 65 A (20M)	+/- 3 D +/- 6A	+/- 10 D +/- 15 A	na	na
	Terminal hover	+/- 3 D +/- 6 A	+/- 5 D +/- 10 A	na	na	+/- 3 D +/- 6 A	na
Lateral jinking	Overall	+/- 5 D +/-10 A	+/- 8.2 D (2.5M) +/- 16.4A (5M)	na	na	na	+/- 5 D +/- 7.5A
	Tracking	+/- 5 D +/-10 A	+/- 8.2 D (2.5M) +/- 16.4 A (5M)	+/- 3 D +/- 6 A	+/- 3 D +/- 6 A	na	+/- 5 D +/- 7.5A

Table 2: MTE task aggression requirements

MTE	Aggression parameter	Level of Aggression		
		Low	Moderate	High
Sidestep	Net roll attitude change during accel/decel	8-12 deg	18-22 deg	28-32 deg
Quickhop	Net pitch attitude change during accel/decel	8-12 deg	18-22 deg	28-32 deg
Lateral jinking	Maximum roll attitude during the 'jink'	10-20 deg	25-30 deg	40-50 deg

Table 3: AH Simulated mission sequence

Elem-ent	Location	Objective
1	Centre of farmyard	Hover at 25ft AGL, spot turn & transition to river bed
2	Northwards along river bed	Follow river bed maintaining height 25-30ft & speed 30-50kn
3	First village	Enter village, decelerate to hover and spot turn to reconnoitre buildings
4	First thicket on right bank of river	Return to NOE flight following river - Rapidly decelerate to hover within cover of trees
5	- ditto -	Execute bob-up to reconnoitre church, followed by bob-down to cover
6	- ditto -	Execute sidestep to right to reconnoitre surrounding terrain and return to cover
7	Northwards along river bed	Execute rapid sidestep to left from cover, turn rapidly & resume NOE flight following river
8	Second village	Rapidly decelerate to hover within cover of building
9	- ditto -	Execute bob-up to reconnoitre church & and bob-down to cover: bob-up to acquire & track building
10	- ditto -	Turn & make rapid withdrawal along the river bed (70-80kn).

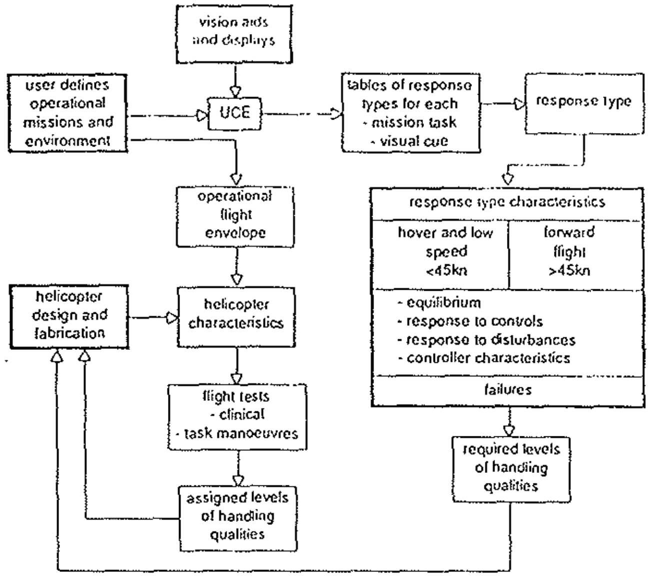


Fig 1 ADS-33 requirements capture, design & evaluation methodology

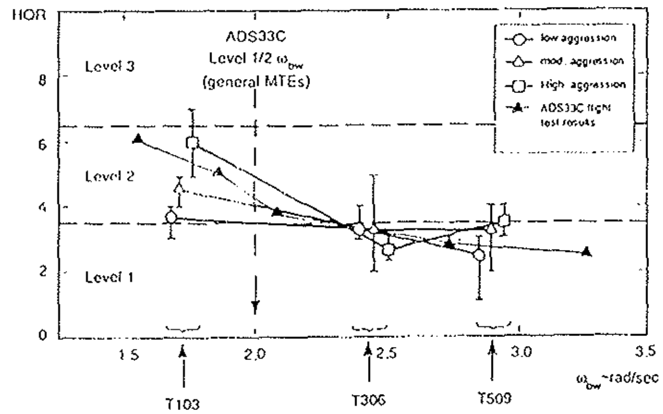


Fig 2 AFS Sidestep handling qualities results versus ADS-33 flight test data

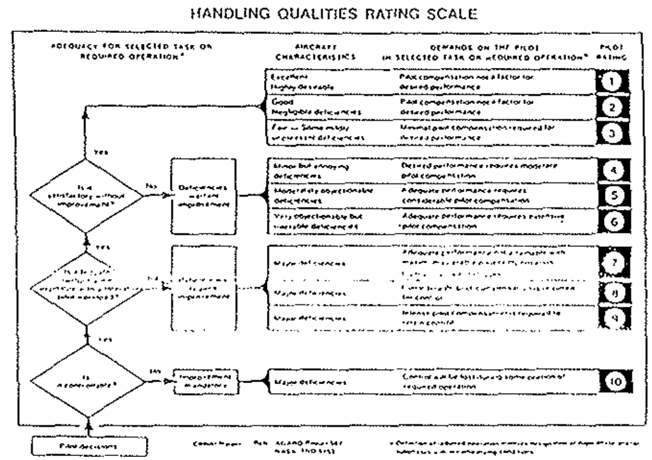
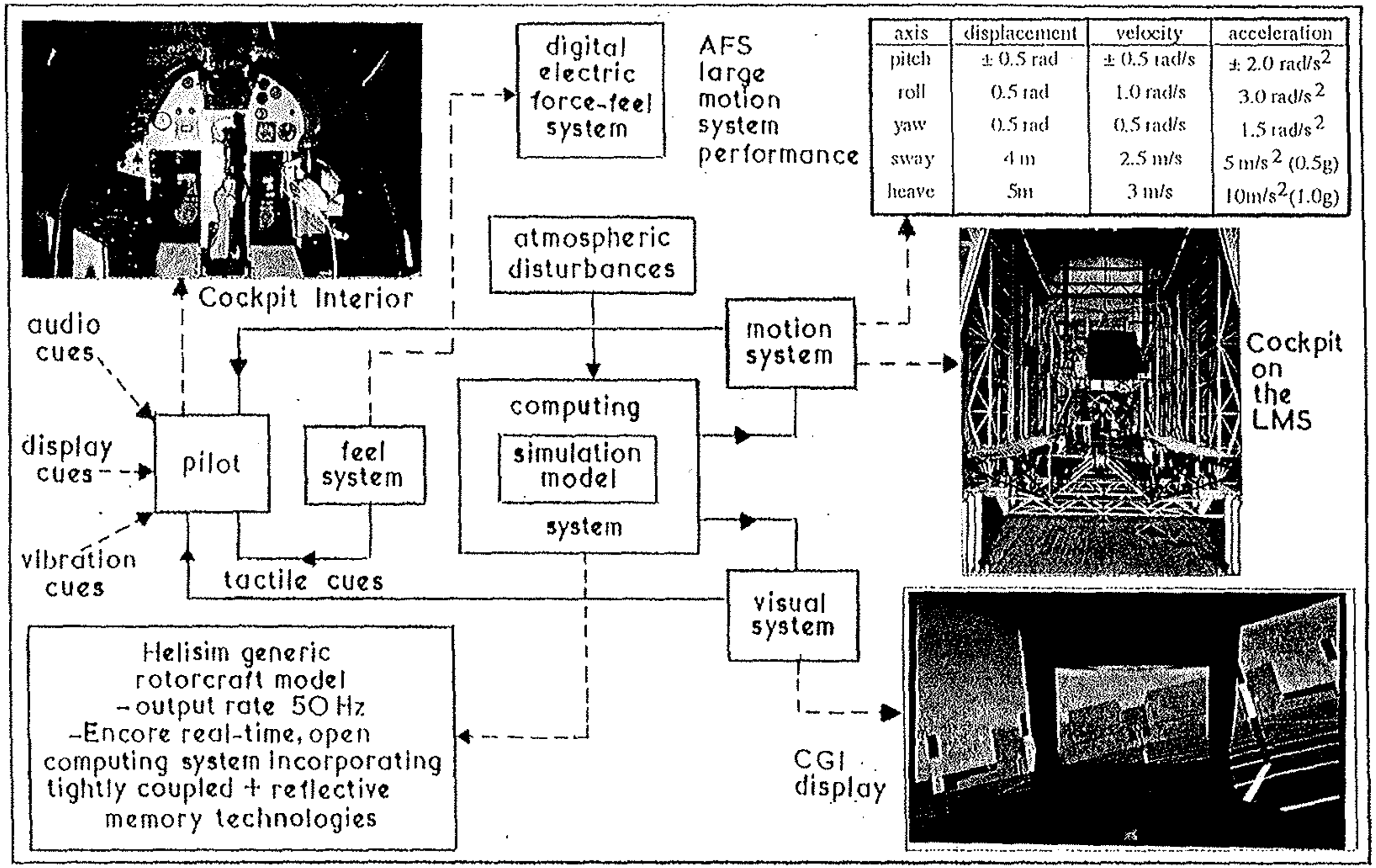


Fig 3 Cooper-Harper rating scale for handling qualities



axis	displacement	velocity	acceleration
pitch	± 0.5 rad	± 0.5 rad/s	± 2.0 rad/s^2
roll	0.5 rad	1.0 rad/s	3.0 rad/s^2
yaw	0.5 rad	0.5 rad/s	1.5 rad/s^2
sway	4 m	2.5 m/s	5 m/s^2 (0.5g)
heave	5m	3 m/s	10m/s^2(1.0g)

Fig 4 Key features of the DRA Advanced Flight Simulator

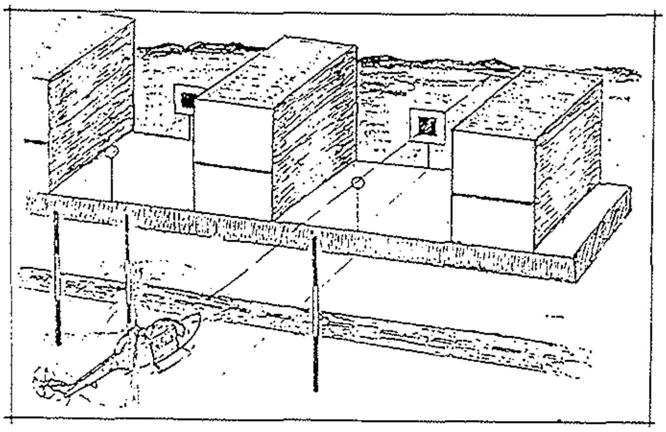


Fig 5 Sidetsep MTE

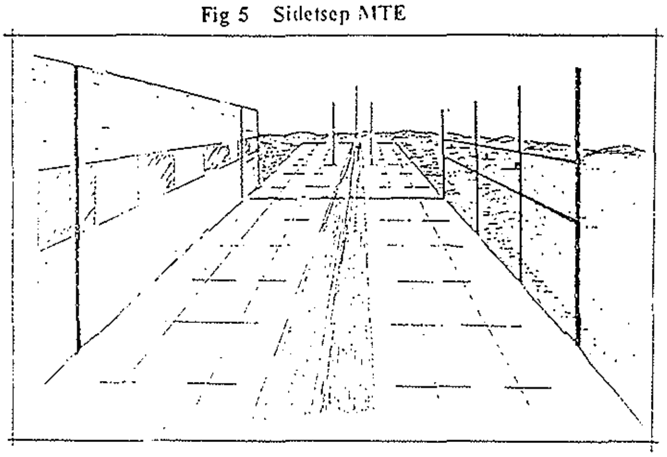


Fig 6 Quickhop MTE

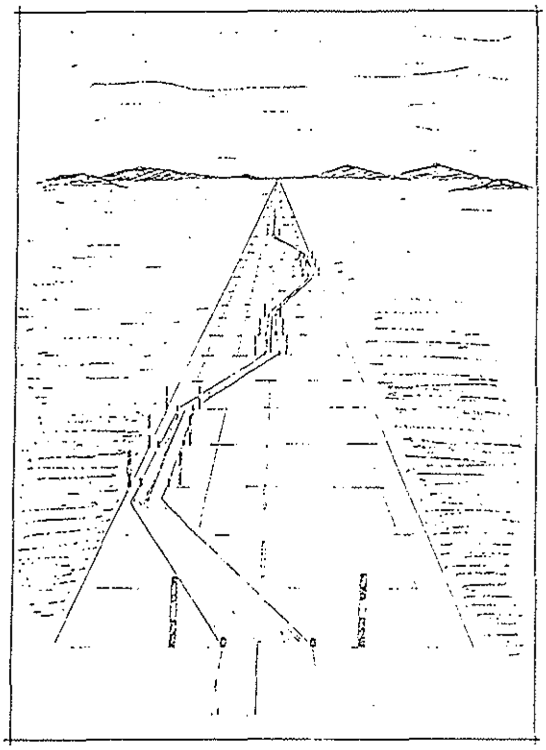


Fig 7 Lateral Jinking MTE

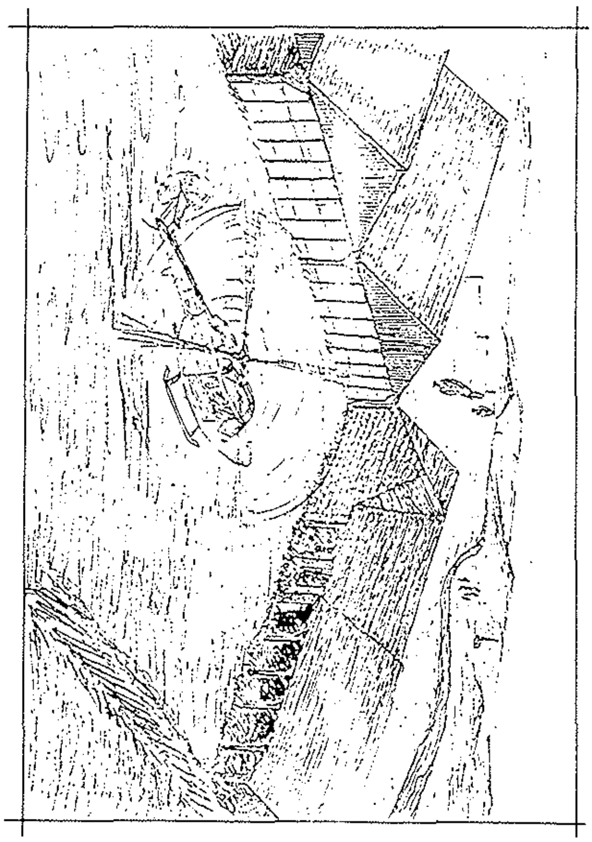


Fig 8 NOE scene detail

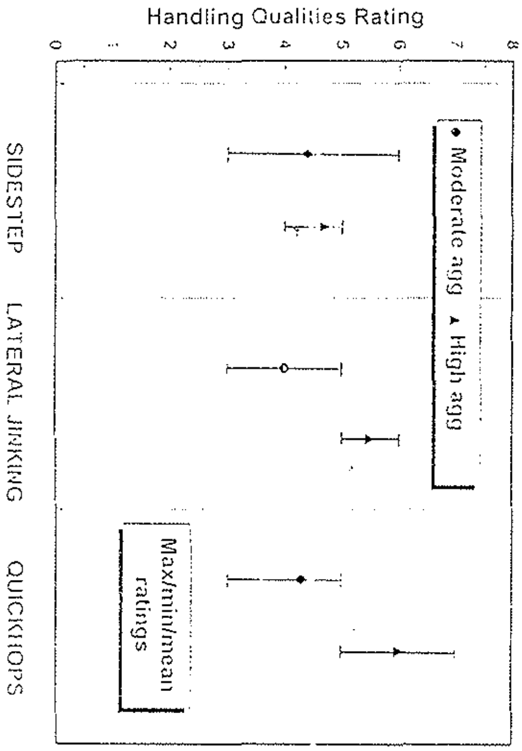


Fig 9 Pilot ratings for handling qualities - summary of all configurations