OVERVIEW OF A PROGRAMME TO REVIEW CIVIL HELICOPTER HANDLING QUALITIES REQUIREMENTS*

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Summary

The UK's Defence, Evaluation & Research Agency (DERA) undertook a programme of work for the Civil Aviation Authority (CAA) to review the future needs for civil helicopter flight handling requirements. A comparison of existing requirements for both civil and military helicopters was carried out, and recommendations were made concerning the application of new criteria and procedures for civil qualification testing, based largely on the requirements specified in Aeronautical Design Standard 33. In a follow-on trials activity, an investigation of appropriate criteria boundaries for civil applications was carried out through piloted simulation tests using the DERA's Advanced Flight Simulator facility. The paper gives an overview of the documentation review and trials activities, and discusses the main findings.

Definitions:

P_{turb}	Model RMS roll rate response (rad/s)
Q_{turb}	Model RMS pitch rate response (rad/s)
R_{turb}	Model RMS yaw rate response (rad/s)
Lp_{turb}	Turbulence roll derivative coefficient
Mq_{turb}	Turbulence pitch derivative coefficient
Nr_{turb}	Turbulence yaw derivative coefficient
δ_{xx}	Control sensitivity (rad/s^2.%)
C_p	Control power (rad/s)
ω_{bw}	Attitude bandwidth (rad/s)
τ_p	Phase delay (s)
ω_m	Model first order damping (rad/s)
τ	Pure time delay (s)

Introduction

During 1990, the Flight Management and Control (FMC) Department of the DERA began a programme of work for the CAA to review the future needs for civil helicopter flight handling requirements. The motivation for the review stemmed partly from the CAA's participation in establishing Joint Airworthiness Requirements (JARs) for small and large rotorcraft, and partly from a recommendation in an earlier study of helicopter human factors issues (Ref 1). The CAA were interested in taking a longer term view to identify what changes or upgrades to JARs would be necessary to meet the needs of future rotary wing technology developments, such as fly-by-wire and digital flight control. There was concern that future innovative flight control systems would make application of the current requirements inappropriate. The CAA also had an ongoing collaboration with Industry involving research activities that were targeted at improving the safety record for civil rotorcraft operations. One of the concerns was that existing civil requirements were not sufficiently well defined to ensure flight characteristics consistent with high operational effectiveness and low levels of workload. Hence, the review was also intended to address the problem from a handling qualities versus flight safety standpoint.

The review was subsequently completed in two main phases. In Phase 1, a review of relevant documentation was carried out and, in Phase 2, a trials programme was implemented with the objective of providing substantiation data for the Phase 1 recommendations. The Phase 1 review took into account both civil and military requirements with a view to identifying any shortcomings and making recommendations for improvements to the former. Regarding the military requirements, a considerable volume of research into improved criteria for military helicopters had been carried out in both the US and Europe during the 1980's which had culminated in proposals for new quantitative mission oriented criteria. In the US, the proposals were formally adopted in Aeronautical Design Standard ADS-33, 'Handling Qualities requirements for Military Rotorcraft' (Ref 2). The CAA were aware of these developments and requested that DERA explore the possibility of exploiting them in support of civil requirements.

Civil requirements taken from BCAR Section G (Ref 3) and FAR 27/29 (Ref 4) were compared with ADS-33 and also the UK standard for military rotorcraft handling qualities, Def Stan 00970 (Ref 5). The main findings were that the civil requirements were overwhelmingly qualitative and open to subjective interpretation by the evaluation pilot, and that the requirements for compliance testing were poorly defined. In contrast, the new military requirements employed quantitative criteria whenever possible and specified comprehensive flight test procedures. A number of recommendations were made concerning the application of new criteria for civil qualification testing which were largely based on the requirements specified in ADS-33. A key recommendation was that the ADS-33 small, moderate and large amplitude handling qualities criteria be adopted for civil use, together with the complementary mission task element (MTE) approach to flight testing and evaluation.

In Phase 2, the aim was to develop the recommendations through the investigation of appropriate criteria boundaries for civil applications, and demonstrate the flight test procedures in a representative civil helicopter

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operational context. The investigation was carried out through piloted simulation tests using the DERA's Advanced Flight Simulator facility (AFS). The DERA's Conceptual Simulation Model (CSM) was used in the tests to represent helicopters with different handling characteristics. The general objective was to show how handling qualities predicted in accordance with ADS-33 criteria were correlated with levels of handling qualities assigned during piloted evaluations of typical civil helicopter manoeuvres and operating conditions. The tests involved an investigation of the applicability of the ADS-33 pitch and roll attitude bandwidth criteria in a small number of flight tasks which were based on what were considered to be demanding, but representative, civil helicopter flight tasks.

A preliminary appraisal of test techniques, test cases and MTEs was carried out by a CAA pilot in a preparatory trial at the AFS during March 1993. The objective was to establish the feasibility of the methodology and test cases, and to identify key handling qualities issues for further, more in-depth investigation. A follow-on trial was completed during 1996 in which two pilots, including a UK CAA qualification test pilot and a test pilot from the French DGA's 'Centre D'Essais en Vol', evaluated the CSM in a 6 degree decelerating approach to the hover test manoeuvre. The trial results enabled a number of significant conclusions and recommendations to be made regarding the applicability of the ADS-33 approach to civil handling qualities requirements.

The paper gives an overview of the programme's key activities and the main findings; the first part addresses the Phase 1 documentation review; this is followed by an account of the simulation trials activities and associated results, conclusions and recommendations; finally, the key issues that will have to be addressed in following up the recommendations are discussed.

Review of Documentation

General In recent years, the emphasis of research into future rotary wing technology developments, such as fly-by-wire and digital flight control applications, has been slanted towards military aircraft. However, it is inevitable and logical that the operational benefits that such systems potentially offer will eventually be exploited by civil helicopter programmes as witnessed by developments in the Eurocopter NH-90 programme. Thus, in common with military requirements, it will be important to specify suitable criteria which both guarantee safe handling characteristics and lead to increased operational effectiveness.

From a more general perspective, military handling qualities requirements have intentionally played a stronger role in providing design guidance. Hence, it is not surprising that, as commented in Ref 6, for want of better information they have served as a source of guidance for many civil projects too. Supporting research for updated requirements such as ADS-33 has endeavoured to identify handling qualities parameters that not only characterise the vehicle's stability and handling in flight, but also present basic quantitative information that enables desirable handling features to be built in and tested for throughout the whole design and development cycle. As the new criteria become more widely accepted and used, it is inevitable that they will exert an influence on civil designs.

Given this duality of purpose, it was considered appropriate to examine the latest developments in military handling qualities requirements to investigate the potential for read-across to civil counterparts. Accordingly, a comparative study of both civil and military handling qualities requirements was carried out which focused on the following elements:

i. A comparative review of the operational aspects and manoeuvre demands associated with both civil and military requirements.

ii. A review of existing civil requirements in BCAR Section G and FAR Part 29[1].

iii. A review of the military requirements contained in the UK's Def Stan-00970 and the USA's ADS-33.

iv. An investigation of the quantitative criteria contained in the military requirements that may be used in support of the qualitative civil requirements.

v. Identification of any gaps not covered by either requirements.

The review of operational aspects set out to establish the common ground, if any, between military and civil operations; this was regarded as an essential objective in justifying the case for adopting common requirements for civil and military types. Regarding military requirements, ADS-33 and Def Stan-00970 were initially selected because they represented the principal handling qualities requirements then in current use in the USA and the UK. At the same time, both documents provided comprehensive requirements that purport to address all aspects of handling and control that might be expected to impinge on flight safety and mission performance.

Civil requirements Key handling qualities topics addressed in both BCAR and FAR, and considered in the review include:

- Controllability and manoeuvrability
- Ability to trim
- Static and dynamic stability
- IFR operations

From critical observation, it was concluded that these requirements are inherently qualitative and subjective in nature. Their interpretation and assessment are normally carried out by only one pilot. Compliance demonstration is achieved through flight test evaluation, but while test conditions are referred to, guidelines for test procedures and specific test criteria are either not given or are poorly defined. In many cases, flight test definition is generally left to the discretion of the assessing pilot. Regarding handling criteria, typically adjectival descriptors and phrases are applied to what are essentially quantifiable dynamic performance parameters, e.g. 'satisfactory' roll control, or to describe

[1] JAR 27/29, published in 1993, did not exist at the time the review was carried out but are essentially similar to the FAR requirements

the nature of a given handling characteristic, e.g. 'dangerous behaviour', or level of pilot workload, e.g. 'undue pilot fatigue or strain'. Presumably, the use of such terminology is driven by the desire to produce generic requirements that are applicable to 'any' rotorcraft and operating circumstance. At the same time, qualitative statements are open to ambiguities through subjective interpretation and, in the interests of consistency and ultimately safety, it is highly desirable to present guidelines on what is meant by handling characteristics that are 'undesirable', 'dangerous' or 'unsafe', to identify the circumstances in which such behaviour is likely to occur, and to specify the appropriate test conditions.

A more detailed presentation of the main findings of the review is given in Ref 7; the main conclusions are summarised below:

- The requirements are predominantly qualitative and place the onus for compliance demonstration on the evaluation pilot. The nature, number and outcome of flight testing requirements are almost entirely subjective, and are generally reliant on a single pilot.

- While the requirements address controllability, manoeuvrability and stability, there is very little direction concerning the aircraft's short, mid and long term response characteristics to control inputs. Various requirements hint at a desired level of responsiveness, either through control in atmospheric disturbances, available control margins or manoeuvrability for recovery in emergencies, but they are entirely open to subjective definition.

- Very little direct information is given on acceptable levels of control cross -coupling.

- The stability characteristics are adequately addressed in a general qualitative sense but the requirements suffer from a lack of objectivity in the specification of more detailed testing and acceptability criteria.

- Response to atmospheric disturbances and control margins for flight in turbulence are addressed, but very little information is given on the gust conditions to be catered for in compliance demonstration.

- The FAR requirements provide an accompanying note (Ref 8) with supplementary guidance on specific issues of concern, containing detailed information on testing requirements and procedures. It is considered desirable that this type of information be provided for all test requirements, with definitions for all of the key descriptors and explanations of individual handling concerns and constraints, and a description of the flight tests and procedures needed for compliance demonstration.

Military requirements Broadly speaking, the Def Stan and ADS cover the same range of topics but differ considerably in their structure, layout, level of detail and criteria. Key handling qualities aspects addressed include the following:

- Dynamic performance and control response related issues
- Static and dynamic stability related aspects
- Control cross-coupling characteristics
- Disturbance rejection capabilities
- Flight testing and compliance demonstration aspects

ADS-33 embodies the latest results of an extensive programme of research and development over the last decade or so, which was aimed at a comprehensive overhaul of earlier requirements, i.e. MIL-H 8501A, to provide updated criteria of more general applicability. As such, it provides a radically new handling qualities methodology which incorporates the latest advances in rotorcraft handling qualities criteria and fills many of the gaps left by previous documentation. Def Stan 00970 has also been overhauled in recent years, although in many ways the document still represents a more conservative stance, particularly regarding the quantitative criteria that are specified. In many cases only provisional and largely unsubstantiated criteria are given. Ongoing research may eventually fill the gaps and it is implied that 'new' criteria will be adopted as and when substantiated results become available.

Both Def Stan 970 and ADS-33 specify minimum flight test requirements for qualitative assessment of an aircraft's handling and control in tasks that may be considered to be mission related. In the Def Stan, operations from ships are well covered and a procedure for setting Ship Helicopter Operating Limits, or SHOLS, is given. The ADS-33 MTEs, while intended to be broad based, are on the whole specific to the battlefield role. Tests for emergency situations are not well addressed in either document, although the Def Stan provides more detailed coverage of the control system and power failure cases than is given in ADS-33.

Discussion Notwithstanding the shortcomings discussed above, when applied correctly, existing civil airworthiness requirements are reasonably good at defining safe limiting operating conditions in steady state manoeuvres, for example, adequate control margins for sideways flight. In some areas, the requirements are very prescriptive, as for example the FAR 27/29 requirements for longitudinal static stability. In other areas however, there is very little of substance, where for example the dynamic stability for a VMC aircraft is covered by statements such as 'safely controllable in manoeuvres typical for the type'. Under these circumstances, situations can arise where a helicopter may be in strict compliance with say the longitudinal static stability requirements, but be very difficult to fly in turbulence because of very poor dynamic stability characteristics. On the other hand, the situation can also arise where the aircraft may not comply with the quantified criteria but still be agreeable to fly because of other good compensating features. During certification, a great deal of time, effort and money can be expended by the civil authority and the manufacturer in resolving these issues.

Regarding current trends in the development of civil requirements, there is understandable reluctance on the part of the authorities to relax those quantitative requirements that are now in use because they serve to ensure that a base level of certification will be carried out. There is also concern over the possibility of requirements based increasingly on vague 'she flew good' statements leading to an increase in lengthy certification issues between manufacturers and authorities. At the same time, it is also difficult for manufacturers to deal with imprecise requirements. During an aircraft's development there is often some doubt as to whether it is in compliance, which may result in certification difficulties or unnecessary effort being expended to achieve a higher standard than is required. The needs of both parties could be addressed by augmenting the civil requirements with the ADS-33 approach; it is conceivable that the resources needed for developing appropriate procedures would be compensated by the removal of uncertainty and corresponding improvements in safe operational use of future helicopters.

In light of the findings of the handling qualities review, a number of recommendations were made regarding the use of the ADS-33 criteria and test procedures in support of civil requirements. There were a number of reasons for adopting this approach, not least that it uses quantitative criteria that are supported by a substantial volume of flight research data. Although designed specifically as a specification for military helicopter requirements, its criteria and flight test procedures address handling qualities issues that are fundamental to rotorcraft flight control applications. Moreover, it is a mission orientated specification with criteria and flight test procedures centred on the demands of the intended roles. The relationship between handling qualities criteria and the operating environment is also established and documented in ADS-33 to a much greater extent than is the case for existing civil handling rules. The civil rules only differentiate between flight in VMC and IMC, resulting in the fundamental shortcoming that VMC in reality covers a very large range of visual cueing conditions, from good texture on a clear day to a few light points on a poor visibility night, without any change to the required handling qualities. From the standpoint of safety there is clearly a benefit to be gained from defining the required minimum handling qualities and response type in respect of a helicopters intended operational use. A review of civil helicopter loss of control accidents should be carried out, taking account of the prevailing operating conditions, with a view to establishing the likely effectiveness of the ADS-33 approach as a preventative measure.

<u>Recommendations from the review</u> The findings of the various components of the review were compared and a number of recommendations made which addressed potential improvements to civil requirements and test procedures. The key points offered to the CAA for consideration are summarised in the following:

- The ADS-33 MTE approach and handling qualities evaluation procedure should be considered for civil qualification testing purposes. The Cooper-Harper rating procedure (Ref 9) should be considered for application in subjective handling qualities evaluations; testing should be carried out by at least three different pilots.

- A basic set of civil MTEs could be defined as a basis for evaluation flight tasks; BCAR/FAR tests for 'Operating spaces and areas', 'Height-Velocity envelope' derivation, and SAS/AFCS failure should form an additional set of 'safety critical' test cases, specified in the form of MTEs. The Def Stan 00970 procedures for helicopter operations from ships' decks should be considered as an interim set of rules for clearance procedures for civil helicopter operations at sea.

- ADS-33 small, moderate and large amplitude criteria should be investigated for use in support of the civil controllability, manoeuvrability and control margin requirements.

- The ADS-33 criteria on cross-couplings should be investigated for adoption in civil requirements.

- Application of ADS-33 bandwidth criteria for specifying requirements for response to disturbance inputs should be investigated. The Def Stan criteria on turbulence characteristics should also be investigated as a source of guidance on test criteria for disturbance inputs.

- A dedicated flight test and procedures manual should be developed, which would include detailed evaluation objectives, task descriptions and task performance requirements. Guidance on subjective pilot assessments and rating scales, and any data recording requirements should be included.

<u>Trials activities</u>

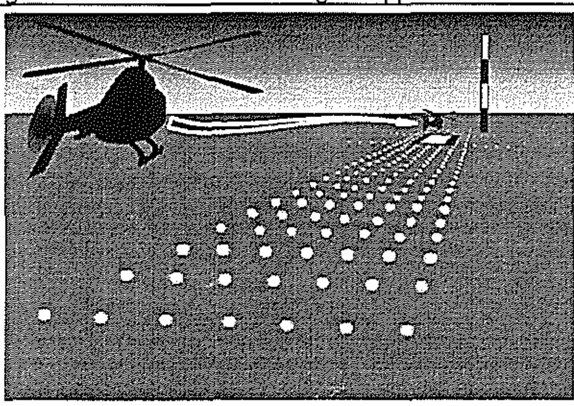
<u>Objectives</u> Following on from the documentation review and its findings, the objective of this exercise was to demonstrate the applicability of the ADS-33 methodology through a handling qualities investigation into the application of the proposed criteria and test techniques in a representative civil operational context. It was decided that the most effective way of carrying out an initial demonstration was through piloted simulation; it was recognised that actual flight tests would be needed to provide substantiation data for the simulation results in the longer term. The AFS had been established as a high fidelity facility for simulating helicopter handling qualities in previous FMC research programmes, when ADS-33 test techniques and procedures had been applied in the development of handling requirements for military rotorcraft. The conceptual simulation approach was adopted because the CSM could be used to provide a 'generic' helicopter representation, which allowed the handling characteristics to be modified in a controlled and systematic manner. In particular, the CSM could be tailored to represent specific Levels of handling qualities in terms of the ADS parameters and criteria.

The scope of the test objectives was limited to an investigation of the ADS-33 pitch and roll attitude bandwidth criteria in a small number of representative civil flight tasks. The traditional approach with the handling qualities methodology is to investigate the control axes separately, although the importance of harmony in pitch and roll makes it important that they be considered together. It was recognised that the heave and yaw axes were also important and that in some situations, e.g. engine failure cases, they would be the most important response axes. In the longer term, as in ADS-33, a more comprehensive range of tests would be needed to encompass the full range of handling requirements. Test conditions included both day VMC and night time scenarios, and cross-wind conditions with low to moderate levels of atmospheric turbulence.

In initial testing, it was established that the 6 deg approach MTE was a suitable civil flight task that could be used to meet the experimental objectives. For the night time case, an array of lights was implemented to provide representative ground-based cues for guidance to the landing point. Regarding atmospheric conditions, two datum cases were tested; zero wind and a steady crosswind of 15kn bearing from red 90deg relative to the initial aircraft track over the ground. A key issue that emerged from the trial was the degree of freedom the pilot had to adapt control strategy to accommodate poor handling qualities and/or operating conditions to achieve the task. Potentially dangerous handling situations, caused by over-controlling or incipient pilot induced oscillations (PIO), could be avoided by correcting flight path errors in a relatively discrete fashion, and/or slowing down the rate of progress of the task.

Consequently, there was a need to establish if there was a combination of handling qualities characteristics and likely operational circumstances that would ultimately defeat this strategy. It was considered that a further degradation in the operational conditions through the introduction of atmospheric turbulence would most likely prove to be the limiting case. This hypothesis was tested in a subsequent trial where the CSM was modified to respond to turbulence (Ref 10) and the tests repeated. At the same time, the aim was to achieve a more definitive piloted simulation evaluation of the ADS-33 criteria and investigate their applicability to the chosen category of civil flight test manoeuvre.

Fig 1 Schematic of the 6 degree approach task



Start positions:
1. 650m from pad centre line
2. 46m left of centre line
3. 15° Heading offset

Standard light Matrix:
1200m x 60m
7 x 41 Lights

Wind conditions:
15kn, red 90°

The evaluation test matrix is summarised in Table 1. The intention was to conduct comparative evaluations of a number of Level 1, 2 and 3 configurations, with both rate command (RC) and attitude command-attitude hold (ACAH) response types. The degraded handling qualities cases were achieved by reducing the roll and pitch attitude bandwidth and/or increasing the phase delay, through implementing an additional time delay over and above the AFS system latency, i.e. total computation time from pilot control demand to visual and motion system response. The target test condition was the 'Night with turbulence' case, although a small number of less severe conditions, including 'Day with zero wind', 'Day with turbulence' and 'Night with zero wind', were also tested to provide datums for comparison. A single standard flight task was evaluated which comprised a 6 deg approach; a schematic of the task is given in Fig 1. It was initiated from level flight at 60kn (on a compass heading of 0deg), 650m from the landing point at 240ft AGL with a 46m lateral offset (to the left of the approach line) and a 15deg heading offset to port. The wind condition was set to a mean of 15kn from port, with light to moderate levels of turbulence.

Table 1 Test Matrix

Aircraft Configuration:	• Medium sized aircraft, 5800-6000kg • Twin engines, Gem characteristics
Model Configuration	1. Rate command response type i. Level 1 - baseline case ii. Level 2 - bandwidth driven iii. Level 3 - bandwidth/time delay driven 2. Attitude command - attitude hold response type i. Level 1 - datum + reduced bandwidth cases ii. Level 2 - bandwidth/time delay driven
Visual Configuration:	1. Day time, Dusk/Standard lighting matrix + landing site 2. Night time, Dusk/Standard lighting matrix + landing site
Atmospheric Conditions	1. Zero wind - datum case 2. Steady wind at 15 kn + turbulence
Flight Task:	6deg approach - descending approach to hover from level flight at 60kn and 240ft AGL, with initial 46m lateral offset and 15deg heading offset

Test facility Principal features of the AFS simulation facility configuration included Large Motion System (LMS) platform motion cueing, Link-Miles Image 600PT Computer Generated Image (CGI) visual system, and a cockpit with a single pilot station featuring conventional helicopter cyclic, collective & yaw pedal controls. Sound & vibration cueing were also provided, modulated at 4R in frequency and amplitude. The controls were configured with Lynx static and dynamic force, and displacement characteristics. Primary flight information was displayed via a head-down CRT instrument display, which featured an artificial horizon and attitude indicator, airspeed indicator, rad-alt, baro-alt and a torque meter. The visual system incorporated a five window display including a 'chin' window.

Simulation model The CSM is a generic helicopter model that was designed to allow handling qualities concepts to be investigated without the constraints normally associated with a full engineering solution. The model can be configured with static and dynamic data sets specific to a given aircraft so as to generate primary responses characteristic of that type. It was configured with a Lynx data set for the trials, scaled to an AUM of around 5900Kg, providing a take-off safety speed, Vtoss, of about 60kn, i.e. at this speed a small rate of climb is available with one engine operative. Primary control axes were configured as follows:

- Fully de-coupled responses (apart from a turn co-ordination feature).
- Pitch and roll - RC and ACAH implemented with a first order transfer function.

- Yaw - first order RC response below 45kn, blending to a first order sideslip demand/sideslip suppression at higher speeds.
- Heave - thrust response modelled by simple momentum/blade element theory giving essentially an acceleration response to collective demand in the short term. Rotor thrust also responds realistically to changes in inflow and disc incidence.
- Turn co-ordination - at speeds above a blend region of 40-50kn and up to 70deg of bank.

Key handling qualities parameters that can be set for the roll, pitch & yaw axes include the following:

- control power, damping and sensitivity
- attitude bandwidth & phase delay
- time delay (minimum 115ms)

Heave axis characteristics conform with ADS-33 Level 1 criteria and, as the model is fully de-coupled (apart from the turn co-ordination feature), it also complies with the ADS-33 Level 1 coupling criteria. In addition, the model responses comply with the mid to long term static and dynamic stability requirements of both ADS-33 and BCAR Section G.

The CSM incorporated response to turbulence using an 'atmospheric turbulence generator' (ATG), which is based on a statistical discrete gust model that represents turbulence by an aggregation of discrete gusts (Ref 10).

Table 2a CSM Configuration data - RC types

HQ level	Case/Axis		ω_m (rad/s)	ω_{bw} (rad/s)	τ_p (ms)	δ_m (rad/s^2.%)	Control power (rad/s)	τ (ms)
1	RC/L1	R	6.0	2.392	0.114	0.180	1.500	120
	Case 1	P	4.5	2.078	0.117	0.100	1.111	120
		Y	3.0	1.656	0.120	0.045	0.750	120
2	RC/L2	R	6.0	2.392	0.114	0.180	1.500	120
	Case 1	P	3.0	1.656	0.120	0.045	0.750	120
		Y	3.0	1.656	0.120	0.045	0.750	120
2	RC/L2	R	6.0	2.392	0.114	0.180	1.500	120
	Case 2	P	3.0	1.656	0.120	0.067	1.111	120
		Y	3.0	1.656	0.120	0.045	0.750	120
2	RC/L2	R	3.0	1.656	0.120	0.090	1.500	120
	Case 3	P	1.5	1.044	0.124	0.033	1.111	120
		Y	3.0	1.656	0.120	0.045	0.750	120
2	RC/L2	R	6.0	1.853	0.172	0.180	1.500	210
	Case 4	P	3.0	1.378	0.181	0.067	1.111	210
		Y	3.0	1.378	0.181	0.045	1.000	210
3	RC/L3	R	6.0	1.527	0.226	0.180	1.500	300
	Case 1	P	3.0	1.176	0.242	0.045	0.750	300
		Y	3.0	1.176	0.242	0.045	0.750	300
3	RC/L3	R	6.0	1.527	0.226	0.180	1.500	300
	Case 2	P	3.0	1.176	0.242	0.067	1.111	300
		Y	3.0	1.176	0.242	0.045	0.750	300
3	RC/L3	R	1.5	0.816	0.251	0.045	1.500	300
	Case 4	P	1.5	0.816	0.251	0.033	1.111	300
		Y	3.0	1.176	0.242	0.045	0.750	300

The ATG had been used successfully in earlier DERA simulation research, where it had been configured to

Table 2b CSM Configuration data - ACAH types

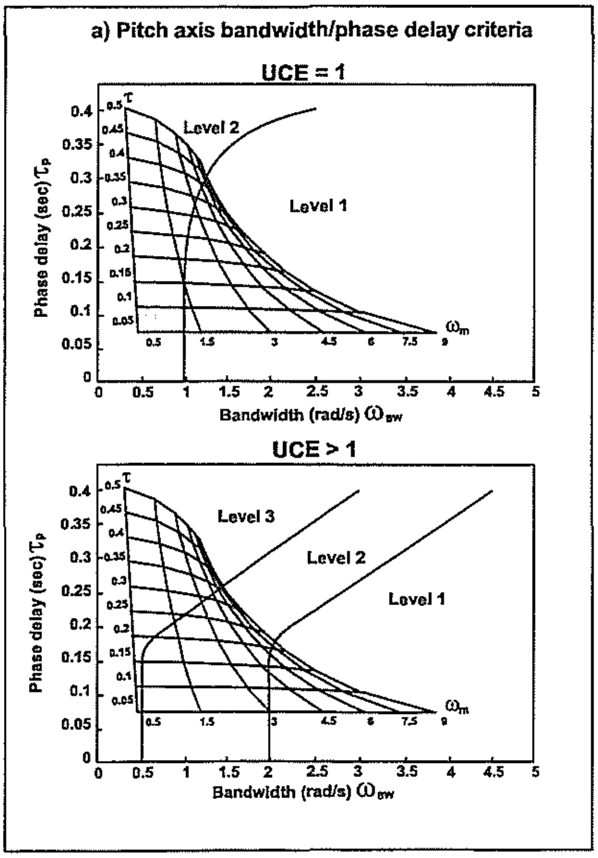
HQ level	Case/Axis		ω_m (rad/s)	ω_{bw} (rad/s)	τ_p (ms)	Control power (rad)	τ (ms)
1	AC/L1	R	6.0	5.6300	0.0997	1.000	120
	Case 1	P	4.5	4.6570	0.1091	1.000	120
		Y	3.0	1.6555	0.1202	1.000	120
1	AC/L1	R	6.0	5.6300	0.0997	1.000	120
	Case 2	P	4.5	4.6570	0.1091	0.500	120
		Y	3.0	1.6555	0.1202	1.000	120
2	AC/L1	R	6.0	5.6300	0.0997	0.750	120
	Case 3	P	3.0	3.3740	0.1174	0.375	120
		Y	3.0	1.6555	0.1202	0.750	120
2	AC/L1	R	6.0	5.6300	0.0997	1.000	120
	Case 4	P	3.0	3.3740	0.1174	0.500	120
		Y	3.0	1.6555	0.1202	1.000	120
2	AC/L1	R	6.0	5.6300	0.0997	1.000	120
	Case 5	P	3.0	3.3740	0.1174	1.000	120
		Y	3.0	1.6555	0.1202	1.000	120
2	AC/L1	R	3.0	3.3740	0.1174	1.000	120
	Case 6	P	1.5	2.0520	0.1234	0.500	120
		Y	3.0	1.6555	0.1202	1.000	120
2	AC/L1	R	3.0	3.3740	0.1174	1.000	120
	Case 7	P	1.5	2.0520	0.1234	1.000	120
		Y	3.0	1.6555	0.1202	1.000	120
3	AC/L2	R	6.0	3.1030	0.2124	1.000	300
	Case 1	P	3.0	2.0020	0.2326	1.000	300
		Y	3.0	1.1760	0.2420	1.000	300
3	AC/L2	R	6.0	3.1030	0.2124	1.000	300
	Case 2	P	3.0	2.0020	0.2326	0.500	300
		Y	3.0	1.176	0.242	1.000	300

represent low to severe levels of turbulence in a task involving an approach and landing on a ship's deck. The version representing a moderate level of turbulence was used as the baseline configuration for the trial. A set of scaling factors representing light, moderate and high levels of turbulence was determined using the baseline model configuration, and were subsequently assessed through piloted evaluation in the AFS during the trial workup. These tests confirmed that, subjectively, not only were the responses to turbulence realistic, but they also produced the desired effect of increasing the level of task difficulty. With turbulence, the pilot was forced to attend to flight path disturbances more or less continuously which had the effect of making handling qualities deficiencies, such as tendency for PIO, more apparent and intrusive. Workload also increased because turbulence had the effect of making the aircraft's roll, pitch and yaw attitudes less stable, increasing difficulty in monitoring the progress of a manoeuvre and in keeping the landing point in view.

Regarding response types, because of the lack of an attitude hold function the effect of turbulence on the model's responses was more noted for the RC configurations. In order to explore the limiting handling qualities cases for both response types, the RC configurations were tested at low levels of turbulence while most of the ACAH cases were tested at moderate levels.

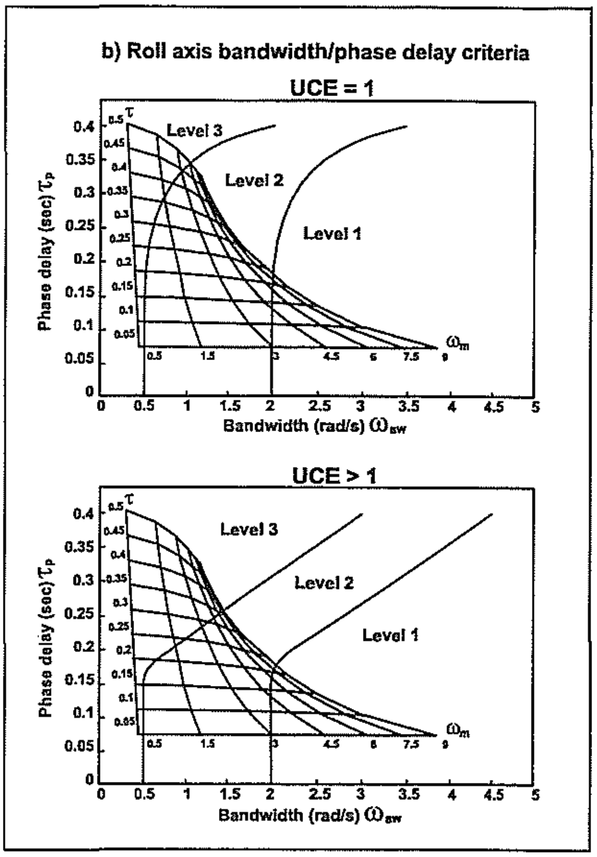
Handling qualities configurations Fig 2 shows the ADS-33 small amplitude attitude bandwidth criteria for pitch and roll axis responses that were used to determine handling qualities configurations for the trial. Note that ADS-33 defines visual conditions in terms of 'useable cue environment' (UCE). The 'good visual environment' (GVE) in ADS-33 terminology, UCE = 1, is equivalent to VMC, and the 'degraded visual environment' (DVE), UCEs of 2 & 3, represent conditions between VMC and IMC. Hence, the ADS-33 requirements for operations in UCEs of 1 (day time case) and >1 (night time case) were used to determine test configurations for the trials; Fig 2 shows the respective requirements, and also shows the relationship between the CSM first order damping parameter ω_m and system time delay τ, and the ADS ω_{bw} and τ_p parameters. Taking the roll axis response for an RC case as an example, the overlaid mesh shows the range of achievable ω_{bw} and τ_p values for different CSM ω_m and τ settings; the lines of the mesh represent the loci of constant ω_m and τ values. The RC and ACAH roll, pitch, and yaw axis cases that were evaluated are shown in Figs 3 and 4 respectively, and associated parameter values are given in Table 2. Control sensitivity and control power values for roll, pitch and yaw were selected both to match ADS-33 criteria, and to provide good control harmony as assessed in previous AFS research.

Fig 2a ADS-33C attitude bandwidth criteria versus CSM configuration



A further point to note is that test cases are only nominally labelled as either Level 1, 2 or 3, which signifies that the individual criteria for the roll and pitch axes were set at that level. This is because the ADS criteria only purport to predict that a configuration will have overall Level 1 handling qualities if all of the Level 1 criteria and conditions are met; failure to meet one or more of these can have a synergistic effect that may cause handling qualities to degrade even further, e.g. two Level 2 qualities may give rise to an overall Level 3.

Fig 2b ADS-33C attitude bandwidth criteria versus CSM configuration



The yaw axis was set at a nominal baseline configuration using values considered to be representative for a typical in-service helicopter. It is also important to note that, as mentioned above, the model configurations conformed with Level 1 criteria for cross-coupling, heave axis characteristics and to those for mid to long term static and dynamic stability requirements.

Test manoeuvres & task cues Following discussions with the CAA, four MTEs were identified as priority cases for investigation:

i. Final stage of descending, decelerating approach to hover with 3deg & 6deg glide slopes.

ii. Group/Cat A rejected take-off.

iii. Flight path corrections for lateral and/or heading offsets prior to an approach to the hover.

iv. Towering take-off from a raised platform.

Each of these MTEs was used as the basis for defining a suitable flight task for handling qualities evaluation purposes. In accordance with the ADS-33 methodology, the tasks were defined in terms of the handling qualities objectives, control strategy and initial conditions, flight path precision requirements, test conditions (time of day, wind & turbulence conditions etc.) and the principal task cues. For reasons of convenience, and because it was considered to be operationally relevant, tasks (i) and (iii) were merged into a single evaluation task which required correction of offsets prior to entering the final approach to the hover. The tasks were evaluated in a number of visual cue configurations including day VMC (estimated UCE = 1) and night time (UCE > 1) cases.

The task definition is summarised in Table 3. Referring to Fig 1, note that the same cues were used for both day and night time cases. The task performance requirements were based on what was considered to be a 'safe' approach to the platform.

Fig 3 RC configurations versus attitude bandwidth criteria for UCE>1

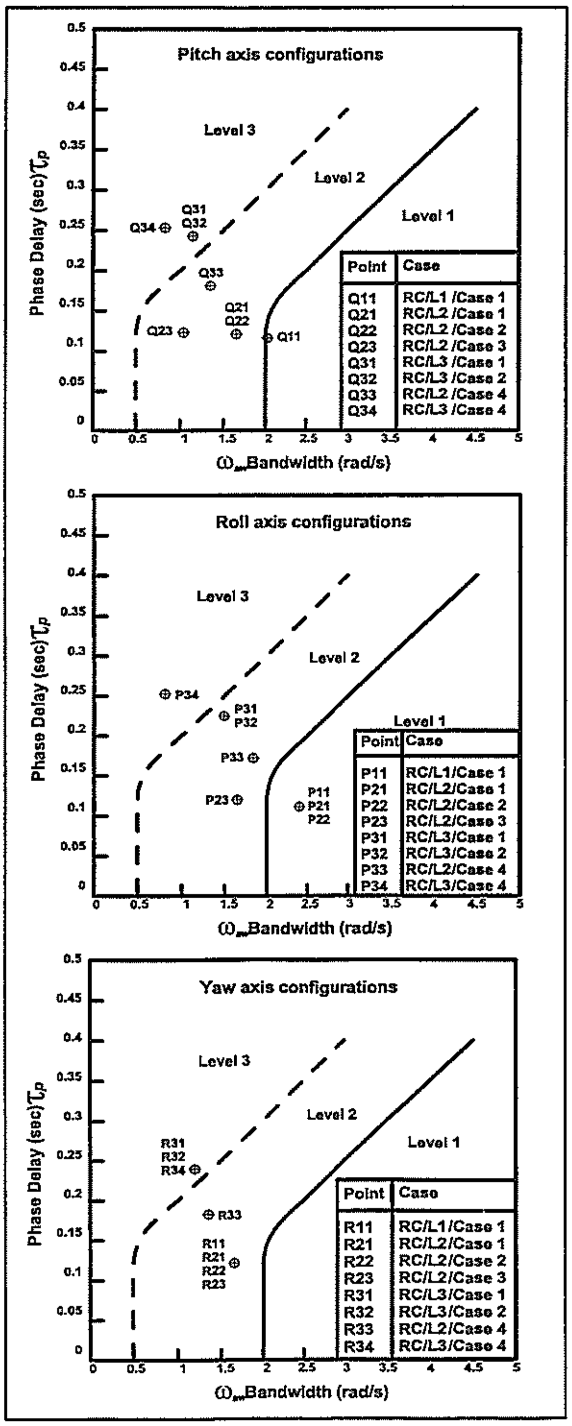
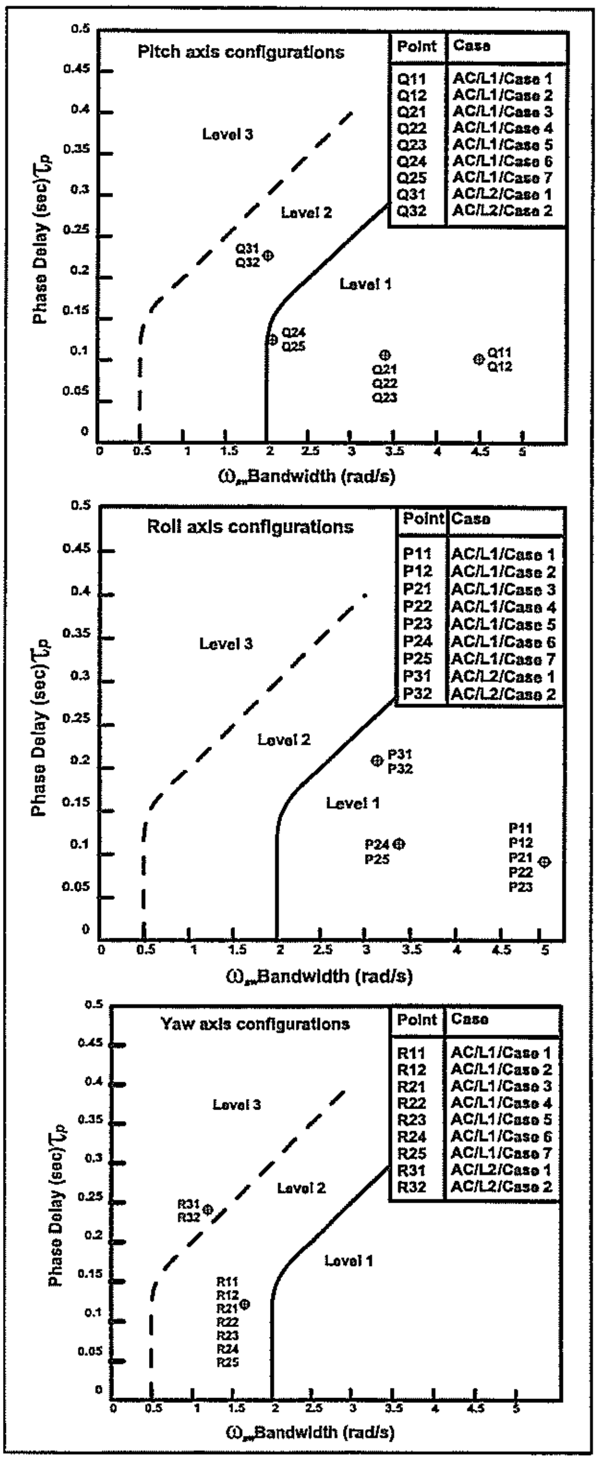


Fig 4 ACAH configurations versus attitude bandwidth criteria for UCE>1



In practice, flight path regulation and associated level of performance attainment relied largely on pilot impression.

More direct flight path guidance cues could have been added, either in the form of head-up type projected flight path way-points, or a head-down flight path director display for example, but this would have changed the nature of the task to something more akin to an IMC approach. The lighting matrix was intended to provide basic guidance for a manually piloted approach under conditions of darkness. The additional lights and the tower were added to provide peripheral height and position cueing to compensate for restricted forward view during the final phase of the approach, when the aircraft's pitch attitude increases. Such cues were considered to be representative of those in the vicinity of an offshore platform, for example.

Table 3 6deg Approach MTE Task Definition

Task description	• Final stages of a manually piloted visual approach to the hover Control strategy - from an initial entry point, correct for lateral position and heading offsets before initiating a 6deg, decelerating approach to the landing platform; establish a hover at 15ft AGL over the centre of a designated landing site. Maintain lateral flight path within given limits relative to the approach centre-line.
Objective	• To check the lateral, longitudinal, heave and heading control characteristics in a manually controlled visual approach to the hover in good visual environment (GVE) and degraded visual environment (DVE) conditions. Specifically, to check the ability to co-ordinate height, speed and directional control during correction of a lateral flight path offset, and in descending decelerating flight to acquire and hold a hover.
Initial conditions	• Straight and level flight at 60kn, 240ft AGL • 46m lateral position offset to left of approach line • 15deg heading offset to port Range at 650m from the landing point
Task performance requirements	• Acquire & maintain flight path within ± 5m of approach centreline • Maintain a steady deceleration and rate of descent to the point of hover • Maintain final hover position within the designated landing area constraints (plan position within ±5m from platform centre) Maintain final hover height 15ft ±5ft, and heading within ± 10deg
Task conditions	• Daylight VMC • Night, with visual range at 800m (0.5miles), with perceptible visual horizon 15kn crosswind (from Red 090) with light-moderate levels of atmospheric turbulence
Task cues	• Lighting matrix - 7 rows of 41 lights over an area of 60m x 1200m • Illuminated landing pad 20m x 20m with designated landing area of 10mx10m • Additional rows of lights extending out 100m on either side of the platform • A 200ft tower adjacent to the platform with illuminated sections at height levels of 50-100ft and 150-200ft

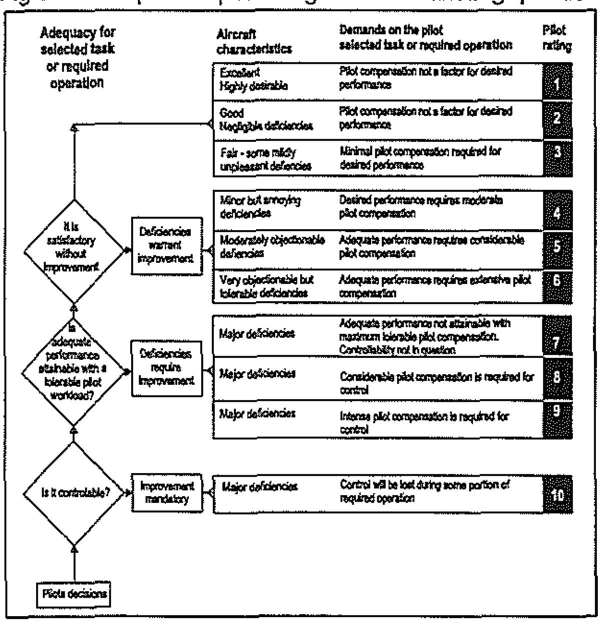
Trials conduct and procedures Evaluations were carried out in accordance with the ADS-33 approach using the Cooper-Harper handling qualities rating (HQR) procedure (Fig 5). The recording of supporting pilot comments is an integral part of the HQR procedure, and a special handling qualities in-cockpit questionnaire (ICQ) was used for this purpose. Flight mechanics data were logged during evaluation runs, including pilot control activity, aircraft angular rate and attitude responses, and flight path co-ordinates. Subsequent to the trials, the data were analysed to check the task performance achievement. The ICQ was used to capture immediate pilot impressions of the assessment and to provide supporting comments and opinions for the HQRs. A second questionnaire was completed at the end of each sortie, which contained detailed follow-up questions on handling qualities and simulation issues, e.g. motion cues.

Trials results

General The trial conduct and results are reported in detail in Ref 11. Initial tests established that the most limiting case tested, in terms of the handling difficulties experienced, turned out to be the 6deg approach at night time with lateral offsets of 46m, crosswind of 15kn and heading offsets of 15deg. Regarding the rejected take-off, for the poorest handling qualities case it was found that the level of task difficulty was particularly influenced by the distance available in which to recover and come to a hover following an engine failure. Ratings improved from Level 3 (task not achievable) to good Level 2 (desired task performance achieved) depending on the distance allowed for the recovery. Hence, for this task, it would seem that the handling characteristics combined with the available vehicle performance determine the safe operating limits for the landing site. The freedom to extend the landing distance in this way tended to negate the rejected take-off case as a generic handling qualities task.

Pilots were able to evaluate the CSM in the 6deg approach in all specified test conditions. Pilots generally reacted favourably to the tests, finding the test manoeuvre to be realistic within the limitations of the simulation. They were able to return Level 1 ratings under the best test conditions, indicating that the simulation limitations were not unduly intrusive. From pilot comment, the task was most difficult to achieve at night as would be expected in a similar real world task. The workload and piloting strategy were driven by the need to decelerate while keeping the landing point in view as much as possible. The strategy required considerable head movement and control inputs in pitch, roll and yaw to maximise the view; continuous control inputs were also needed to counteract the effects of turbulence.

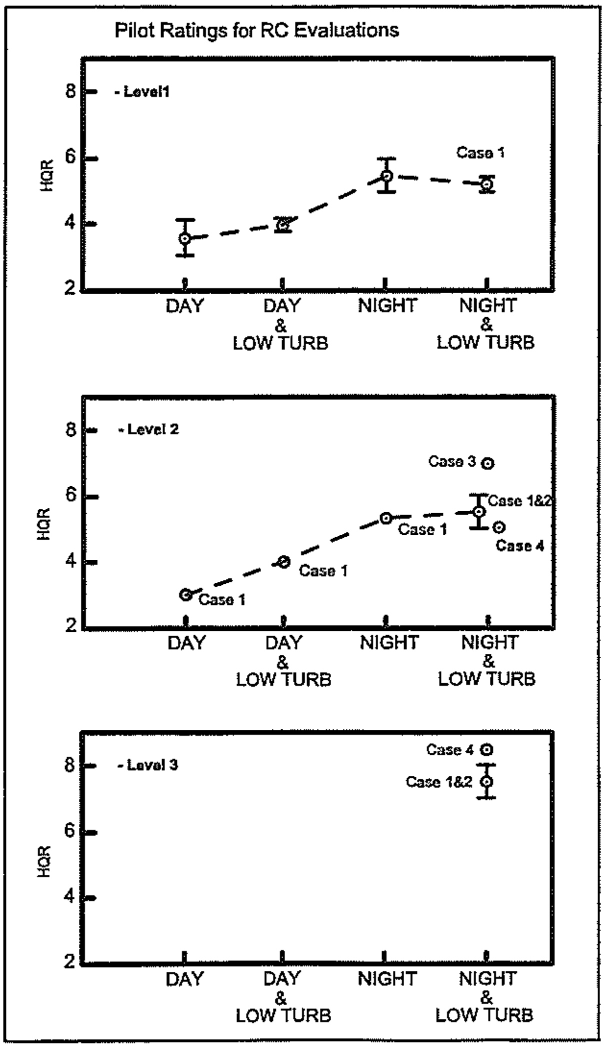
Fig 5 Cooper-Harper rating scale for handling qualities



A summary of pilot ratings for the cases evaluated (see Table 2 & Figs 3 & 4) is given in Fig 6. The spread of ratings between pilots was generally within one rating point, indicating a good consensus. The trend of ratings was as expected and largely in agreement with the ADS criteria. Scatter or discontinuity in the rating trends is judged to be attributable to learning effects and the order in which test cases were evaluated. More detailed observations are summarised in the following:

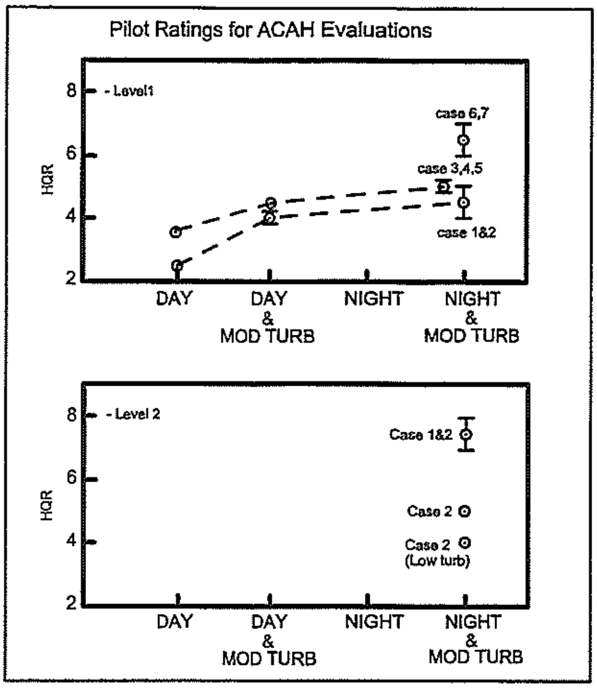
Pilot ratings for RC cases Level 1 RC cases achieved marginally Level 1 ratings under the best test conditions, degrading to poor Level 2 (HQR 5-6) under the more severe conditions, i.e. night and night with low turbulence. The degradation was the result of poorer task performance and increased workload in keeping the landing point in view. Pilot comments showed that the task cues were the main difficulty, although these were considered to be representative of the real world. RC Level 2 cases were awarded similar ratings to those for Level 1, although the poorest case achieved a Level 3 rating. For the higher time delay RC Level 3 cases (300ms total delay), the task was unachievable with very high workload, attracting ratings from 7 to 9. Reducing the time delay by about 100ms (total delay of 210ms) produced a significant improvement in both task performance and the level of workload, resulting in a rating of 5.

Fig 6a Handling qualities ratings for the 6 degree approach task



Pilot ratings for ACAH cases The highest bandwidth cases achieved the best overall Level 1 rating (HQR 2-3) under the most benign test conditions, i.e. day/no turbulence, although the HQR degraded to Level 2 (HQR 4-5) under the most severe condition, i.e. night plus moderate turbulence. From pilot comment, the degradation was again the result of a reduction in task performance and an increase in workload, the latter being attributed to the effects of turbulence and the poor, albeit representative, visual cues

Fig 6b Handling qualities ratings for the 6 degree approach task



For the cases with borderline Level 1 pitch bandwidth the task was only marginally achievable with moderate turbulence, resulting in Level 2-3 ratings. For the Level 2 cases, Level 3 ratings were awarded at moderate turbulence, again due to poor task performance and high workload. From pilot comment, there was a noticeable tendency to PIO in roll and pitch, and encroachment of torque and control margins was also a problem. These problems were not so noted with low turbulence, resulting in a Level 2 HQR of 5.

Comparison of RC versus ACAH cases The configurations tested are representative of an aircraft with a relatively sophisticated flight control system, having some of the attributes of a full authority Active Control Technology (ACT) design. The two levels of flight control system implemented represent a basic unaugmented RC response type and an augmented ACAH type. The results for the best ACAH Level 1 configuration show a 1-1.5 rating improvement over the best RC case, and pilot comment suggests that the ACAH configuration was preferred for the task because of its enhanced stability. Results for the borderline Level 1 configurations show that the advantage of ACAH was lost when the level of turbulence was increased to moderate.

A similar comparison can be made for the Level 2 cases. At low levels of turbulence the ACAH Case 2 configuration was awarded a low Level 2 rating but, as the level of turbulence increased the tendency for PIO became more noted, workload increased and task performance deteriorated to the point where the task was only marginally achievable. The best RC Level 2 cases (Cases 1, 2 & 4), achieved similar ratings to ACAH Case 2 at low turbulence, i.e. HQR 5-6 versus HQR 5. The difference in time delay for these cases appears to be a significant factor in this result, i.e. 120ms and 210ms for the RC cases as opposed to 300ms for the ACAH cases.

The RC Level 3 configurations attracted solid Level 3 ratings with low turbulence implemented as compared to the poorest ACAH cases (ACAH Level 2 cases 1 & 2), which also achieved Level 3 ratings but with moderate turbulence implemented. Without an attitude hold function, the RC configurations suffered from poor gust rejection characteristics. They were found to be increasingly unacceptable with increasing reduction in bandwidth and/or increase in phase delay. Both response types showed a marked degradation when added time delays were implemented. Such delays are representative of poorly implemented flight control and processor configurations and, as a point to note, the baseline AFS latency (mean of 114ms) is fairly representative of the equivalent lags found in current in-service types. In comparison, the maximum time delay case of 300ms represents a fairly extreme value, but it served the purpose of demonstrating effects in the limiting case.

Comparison with ADS-33 criteria   Caution is needed in the interpretation of the results because of the limited sample of pilots. More detailed tests would be needed to determine actual criteria for civil requirements. It is also emphasised that other handling qualities issues such as coupling and stability also need to be addressed. However, the results highlight issues that merit further investigation and it is of interest to compare them against two different sets of ADS-33 roll and pitch bandwidth criteria, those for 'All other MTEs, UCE =1', i.e. Day/Level 1 cases, and those for 'All other MTEs, UCE > 1', i.e. Night/Level 1/2/3 cases. Regarding turbulence criteria, ADS-33 actually uses the handling qualities bandwidth criteria as a basis for specifying gust rejection requirements where compliance is demonstrated through assessment of the actuator to rotor blade frequency response, either measured directly or through model prediction data. The trial results show that pilot compensation for gust disturbance effects increased with reducing bandwidth, indicating that similar criteria would be appropriate to this type of civil operational requirement.

In general, the results confirm the trend of the ADS criteria in that pilot ratings were in accordance with the predicted trend for reduced bandwidth and increased phase delay. Also, for operations in the DVE, ADS-33 requires that for Level 1 handling qualities the response type is attitude command-attitude hold for UCE = 2, and translational rate command-position hold for UCE = 3. Hence, not surprisingly, the ratings for the RC configurations tested were awarded Level 2-3 ratings for the night time condition (UCE > 1). The picture is less clear regarding the ACAH cases. For the day case (UCE = 1), without turbulence ACAH Level 1 configurations were awarded marginally Level 1 ratings, but Level 2 ratings with turbulence applied. There are several possibilities to consider here; simulation effects were too unrepresentative, notably, that the level of turbulence was too severe, or that the visual cues may have been too constraining; the boundaries for the ADS-33 bandwidth criteria for gust rejection are too low; and/or the boundaries for the ADS-33 bandwidth criteria for UCE > 1 are too low. Further, more detailed investigation would be needed to address these issues.

Regarding the ADS-33 criteria boundaries for UCE > 1, the results for RC configurations suggest that phase delay should be capped to around 200-250ms. From the results, there was a reduction from a Level 3 to a Level 2 rating (HQR 7 to HQR 5) as time delay was reduced from 300 to 210ms, suggesting that there may be a handling qualities 'break point' or 'cliff edge' associated with increasing phase delay in that region. The limited results for the day/turbulence configurations suggest that a higher pitch bandwidth is needed for operations in turbulence, and that the ADS-33 Level 1 criteria for UCE > 1 MTEs might be more appropriate, i.e. an increase in bandwidth from 1.0 to 2.0 rad/s.

Discussion   It is considered that the trial results support the case for adopting the ADS-33 handling qualities methodology for civil certification purposes. There was good correlation between assigned pilot ratings for the 6 deg approach task and expected handling qualities in accordance with the ADS-33 criteria. The task itself would be difficult to establish as a consistent evaluation flight task, but the results have demonstrated that the existing ADS-33 MTE-based procedures provide a suitable basis for establishing an aircraft's suitability for operations under the conditions tested.

On a general note, from comparison with the ADS requirements, it is expected that the AFS trial configurations, including the nominally Level 2 & 3 cases, would meet the coupling and stability requirements of BCAR Section G and FAR 27/29. In addition, although not formally evaluated, it is also considered likely that they would meet the general handling requirements. Some configurations performed poorly in the tests, however, and were unacceptable under the operating conditions tested. This is further underlined by the fact that the handling characteristics could have been degraded still further, through the yaw and/or heave characteristics or introduction of inter-axis cross-coupling terms for example. It is unlikely that aircraft with these handling qualities characteristics would have been prohibited from operating in the conditions of the simulator tests by operational, as opposed to airworthiness, regulations. This highlights the need for more objective criteria and again, the trials results have shown clear evidence of the benefits of the ADS criteria in meeting this need.

Trials conclusions & recommendations From the results it was concluded that a successful demonstration of certain aspects of ADS-33 handling qualities criteria and flight test procedures, and their application to a civil helicopter flight operation, had been accomplished. Key conclusions are summarised below:

- Pilots considered that the test manoeuvre and visual cues were sufficiently representative of operational flight conditions, and that the model responses to turbulence were also representative. They were able to award Level 1 ratings for the best configurations, and overall there was a low spread of results between pilot ratings, i.e. ≤ 1 rating point.

- For the poorest cases and test conditions, pilots experienced high control workload and adequate task performance could not be achieved; poor, albeit representative, visual cues and responses to turbulence were significant factors. Pilots expressed a preference for the ACAH response type because of the enhanced stability that it offered.

- Caution should be applied to interpretation of the results against the ADS-33 criteria because of the limited pilot sample and test matrix. However, the results conform to the trend of the ADS-33 criteria for 'All other MTEs, UCE = 1' and for 'All other MTEs, UCE > 1', and suggest that the criteria are appropriate for the type of civil flight operations considered.

- It is expected that the AFS trial configurations, including the nominally Level 2 & 3 cases, would meet the coupling and stability requirements of BCAR Section G and FAR 27/29. In addition, although not formally evaluated, it is also considered likely that they would meet the general handling requirements. It is unlikely that aircraft with these handling qualities characteristics would have been prohibited from operating in the conditions of the simulator tests by operational, as opposed to airworthiness, regulations. This highlights the need for more objective criteria, and the trial results have shown clear evidence of the benefits of the ADS criteria in meeting this need.

It was recommended that the ADS-33 small amplitude criteria for roll, pitch and yaw bandwidth should be considered for application as advisory data to support civil handling qualities requirements. Specifically, the criteria for 'All other MTEs, UCE =1' and 'All other MTEs, UCE > 1' and gust rejection criteria should be used for preliminary guidance on advisory limits for civil criteria. A further recommendation was that the ADS-33 flight test procedures, including use of the Cooper-Harper rating process, should be considered for adoption as a standard for civil qualification testing.

Overview of the findings and recommendations

It is considered that the review of handling qualities has, for the most part, met the original programme objectives. The review of documentation highlighted deficiencies in current civil requirements and the potential for these to be addressed through the adoption of ADS-33 handling qualities criteria and test procedures. The subsequent AFS simulation trials provided a successful demonstration of the ADS handling qualities methodology in a representative civil operational environment. The two exercises have enabled conclusions and recommendations to be made regarding specific application of the methodology to civil requirements, as presented in this paper. A number of important issues will have to be addressed, however, if these are to be pursued, namely.

- A primary issue regarding the application of ADS criteria in civil requirements concerns the appropriateness of the existing boundaries. It is clear that an extensive flight test database would be needed to establish substantiated values specific to civil applications. However, the existing ADS criteria for the so-called 'All other MTEs' would appear to be a sensible starting point for normal civil GVE operations. The trial results indicate that the requirements for higher bandwidth tasks, i.e. those with a high gain tracking element, or for operation in the DVE, and response to disturbance inputs also provide an appropriate starting point for equivalent civil requirements, but that further investigations are needed for confirmation.

- The time and costs associated with application of ADS style open-loop test requirements in civil helicopter testing need careful consideration. Instrumentation requirements for monitoring aircraft response and performance data and, possibly, the loads in flight-critical components, also need to be considered (Ref 12); this might have a considerable impact on the trial resources needed.

- Civil MTEs need to be developed, which include appropriate levels of task aggression and desired and adequate task performance requirements, taking account of civil operational requirements and safety constraints. The standard set of ADS-33 MTEs for GVE operations would be an appropriate starting point. Tests for operations in degraded visual conditions also need to be taken into account and again, the ADS-33 test procedures for DVE operations should be considered and developed for civil applications.

- Flight data is needed to confirm the findings of the AFS trial, and also to further investigate the role of MTE-based flight testing procedures in civil qualification testing. Flight trials should be considered with an existing civil helicopter type to investigate the application of the handling qualities methodology, testing to different levels of task aggression and the measurement of aircraft handling and task performance data. A back-to-back demonstration and comparison with the current civil procedures should be considered. Existing flight results from trials completed by other agencies should also be reviewed and taken into consideration.

- Use of the Cooper-Harper procedure has a clear implication on evaluation pilot training needs (Ref 13), and the additional time and cost penalties associated with more extensive testing. However, these should be weighed against the benefits to be gained in terms of consistency of application of the requirements and enhancements to flight safety.

- Recommendations from the review focused on areas where the main deficiencies were perceived to exist. Some of the more traditional handling qualities topics, such as static and dynamic stability, are addressed by both civil and military requirements and given similar treatment. These aspects are clearly relevant and fundamental to safe operational use and will continue to play an important role in the requirements.

- For the future, there is a need to address the implications of the application of full authority active control technology (ACT). Current requirements are expressly concerned with limited authority SAS and AFCS functions and failure states, but future requirements will also need to address issues such as controller physical and functional characteristics, control response types and blending between response types, failure states and pilot intervention times.

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