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CIVIL HELICOPTER HANDLING QUALITIES REQUIREMENTS: REVIEW AND INVESTIGATION OF APPLICABILITY OF THE ADS-33 CRITERIA AND TEST PROCEDURES

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Foreword

The research reported in this paper was jointly funded by the Safety Regulation Group of the UK Civil Aviation Authority, the UK Department of Transport and the UK Health and Safety Executive. The work was instigated at the DERA Flight Management and Control Department to support CAA's participation in the development of Joint Aviation Requirements (JARs) for small and large rotorcraft, and in response to the findings of the Helicopter Human Factors Working Group reported in CAA Paper 87007 (Recommendation 4.1.2). The Helicopter Human Factors Working Group was formed in response to Recommendation 1 of the Report of the Helicopter Airworthiness Review Panel (CAP 491). A paper on the work was presented at the 23rd European Rotorcraft Forum, Dresden, Germany, in September 1997.

The CAA concurs fully with the conclusions of the research. The purpose of this limited study was essentially to establish and demonstrate the applicability of current military quantitative handling qualities requirements and test procedures for the certification of civil helicopters. It is recognised that significant resources would be required to progress the work to a stage where a proposal to the Joint Aviation Authorities (JAA) for adoption could be made. This activity will therefore need to be supported and funded by a number of JAA states and the Industry itself, and is anticipated to proceed with the development and introduction of fly-by-wire systems for civil helicopters.

Safety Regulation Group

25 March 1998

Abstract

The UK's Defence, Evaluation and 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 report gives an overview of the documentation review and trials activities, and discusses the main findings.

Executive summary

The Flight Management and Control Department of the Defence Evaluation and Research Agency (DERA) undertook a programme of work for the UK's Civil Aviation Authority (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 Aviation Requirements (JARs) for small and large rotorcraft, and partly from a recommendation in an earlier study of helicopter human factors issues (CAA Paper 87007). The CAA were interested in taking a longer term view to identify what changes or upgrades to the JARs would be necessary to meet the needs of future rotary wing technology developments, such as fly-by-wire and digital flight control. At the same time, the CAA 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.

In Phase 1 of the review, a comparison of existing requirements for both civil and military helicopters was carried out with a view to identifying any shortcomings and making recommendations for improvements to the former. Civil requirements were taken from BCAR Section G and FAR 27/29 and compared with the UK standard for military rotorcraft handling qualities, Def Stan 00970, and the USA's Aeronautical Design Standard ADS-33. The main findings of the review were that current civil handling requirements are overwhelmingly qualitative and open to the subjective interpretation of the evaluation pilot, and that requirements for compliance testing are poorly defined. In contrast, the military requirements employ quantitative criteria whenever possible and specify comprehensive flight tests for compliance demonstration purposes, based on formal evaluations using several pilots and a handling qualities rating scale. The ADS-33 handling qualities methodology in particular presents new, quantitative mission orientated handling qualities criteria which had been developed in an extensive programme of research into improved criteria for military helicopters. Three fundamental concepts are used as the basis for a reference framework around which the handling requirements are defined; operational requirements in the form of 'mission task elements' (MTEs); the nature of the vehicle response to control inputs, or control response type; and the level of degraded visual environment (DVE) or 'usable cue environment' (UCE). These are combined to form a set of requirements which specify the dynamic response criteria and level of control augmentation required for specific operations in given levels of UCE.

It was concluded that existing mandatory civil requirements would be better defined if supported by advisory, quantitative handling criteria and testing procedures similar to those for military use. Uncertainty regarding the interpretation of the current civil requirements can often result in certification difficulties between manufacturers and authorities. It was considered that the needs of both parties would be addressed by augmenting the civil requirements with ADS-33 type criteria and introducing a formalised method of pilot evaluation using MTEs that had been optimised for civil use. The resources needed for developing appropriate civil procedures would be compensated by the removal of uncertainty and corresponding improvements in safe operational use of future helicopters. A number of recommendations were made, largely based on the application of the ADS-33 handling qualities methodology and MTE-based assessment procedures for civil qualification testing. Specific criteria recommended for consideration include requirements governing the vehicle's short, mid and long term responses to control inputs, inter-axis couplings and responses to disturbance inputs.

In Phase 2, the general aim was to develop the recommendations through the investigation of the application of the ADS-33 methodology in a representative civil helicopter operational context. The investigation was carried out through piloted simulation using the DERA's Advanced Flight Simulator facility (AFS) and a Conceptual Simulation Model (CSM) which incorporated response to turbulence. A number of different aircraft model configurations were evaluated, which conformed to different levels of

handling qualities in accordance with ADS-33 small amplitude response, roll, pitch and yaw bandwidth criteria. The model's coupling, stability and control force and displacement characteristics also conformed to Level 1 criteria (satisfactory). Both rate command (RC) and attitude command – attitude hold (ACAH) control response types were evaluated. Evaluation pilots included a UK CAA qualification test pilot, and a test pilot from the French DGA's 'Centre D'Essais en Vol'. Handling qualities were evaluated using the Cooper Harper rating procedure and a flight task that was based on what was considered to be a representative but demanding civil MTE – a 6 degree, decelerating approach to the hover task. Evaluation conditions included both day/VMC and night time scenarios, and cross-wind conditions with atmospheric turbulence.

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 in question.

- 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 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. The earlier recommendation from the documentation review that ADS-33 flight test procedures, including use of the Cooper-Harper rating procedures, should be considered for adoption as a standard for civil qualification testing was reaffirmed. As a starting point, it was recommended that a review of civil helicopter loss of control accidents be carried out to investigate the effectiveness of the ADS-33 criteria for response type, UCE and handling qualities in preventing such accidents.

The report discusses the implications of taking up the recommendations and aspects of civil requirements where future development will be needed. Key issues highlighted are summarised below:

- Use of the Cooper-Harper procedure has a clear implication on pilot training needs, 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.

- Civil MTEs need to be developed, including appropriate levels of task aggression, desired and adequate task performance requirements, taking account of civil operational requirements and safety constraints. Tests for operations in degraded visual conditions also need to be taken into account, and the ADS-33 test procedures for DVE operations should be considered and developed for civil applications.

- 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; this might have a considerable impact on the trial resources needed.

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

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1 INTRODUCTION

1.1 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 Aviation 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. At the same time, the CAA 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.

1.2 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.

1.3 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.

1.4 In Phase 2, the aim was to develop the recommendations through the investigation of appropriate criteria boundaries for civil applications, and to demonstrate the flight test procedures in a representative civil helicopter 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 <u>predicted</u> in accordance with ADS-33 criteria were correlated with levels of handling qualities <u>assigned</u> 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.

1.5 A preliminary appraisal of test techniques, test cases and MTEs was carried out by a CAA pilot in a preparatory trial, HELCARS1, 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, HELCARS2, 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.

1.6 This report gives an overview of the programme's key activities and summarises the main findings and recommendations. More detailed reporting is provided in Ref 6, which covers the Phase 1 documentation review, and in Ref 7, which gives an account of the Phase 2 simulation trials. In this report, Section 2 gives a summary of key technical descriptions; Section 3 addresses the Phase 1 documentation review; Section 4 provides an account of the conduct and outcome of the simulation trials. These sections are self contained and provide a summary of the main conclusions and recommendations for each activity. Key issues that will have to be addressed in following up the recommendations are discussed in Section 5 and, finally a set of proposals for the way ahead is given in Section 6.

2 TECHNICAL DEFINITIONS

2.1 A number of key descriptors are used throughout this report and before entering the detailed technical discussion, the following descriptions are given for reference:

2.1.1 *Dynamic performance, task performance and task aggression*

In the civil world, performance normally relates to matters of engine power available and power required for a given flight phase. In discussions on military handling criteria, the expressions 'dynamic performance', 'task performance' and 'task aggression' are introduced. Dynamic performance is intended to refer to the vehicle's dynamic responses to control inputs in relation to its angular acceleration, rate and attitude or linear acceleration and rate capabilities. This includes the responses to collective, hence subsuming all the traditional civil performance issues related to engines and flight path response. Task performance refers to the desired or achieved precision error margins in parameters that the pilot is endeavouring to control in the execution of a given flight task, e.g. height, speed, heading, track over the ground. Task aggression relates to pilot control strategy and the level of dynamic performance that is demanded in the execution of a given manoeuvre.

2.1.2 *Handling qualities levels*

In military requirements, including ADS-33 and Def Stan-00970, the Cooper-Harper rating scale (see Fig 1 and Ref 8), is often used as the basis for defining levels of 'acceptability' regarding levels of pilot workload and handling qualities. In ADS-33, the following levels are defined:

Level 1: Ratings 1-3 Aircraft characteristics satisfactory; desired performance achieved with minimal pilot compensation & low workload.

Level 2: Ratings 4-6 Aircraft characteristics unsatisfactory; desired performance requires moderate pilot compensation (Rating of 4), or adequate performance requires considerable to extensive compensation (Ratings of 5-6).

Level 3: Ratings 7-9 Aircraft characteristics unacceptable; adequate performance unattainable with tolerable pilot workload. For ratings 8-9, loss of control is threatened.

2.1.3 *Mission task elements*

In ADS-33, an MTE is defined as 'an element of a mission that can be treated as a handling qualities task'. For a given operational role, a typical flight or mission comprises a contiguous sequence of events which may be broken down into component flight and task phases and their characteristic manoeuvres, or MTEs. In this way, the MTEs provide a basis for categorising the manoeuvre demands throughout the operational flight envelope in relation to piloting control strategy and demand on vehicle dynamic performance for the different primary control axes. For completeness, the MTEs can also be categorised according to specific operating conditions such as wind and visual cueing environment. The MTEs act as a basis for defining flight test manoeuvres for compliance testing, but beyond this they also play a more fundamental role in the definition of ADS-33 handling criteria as discussed in 3.4 below.

2.1.4 *Usable cue environment*

In order to allow for the use of pilot vision aids, rather than specify requirements just on the basis of VMC or IMC operation, ADS-33 applies a sophisticated technique for rating visual conditions, or 'usable cue environment' (UCE) as it is referred to. UCE provides a qualitative measure of the degraded visual environments (DVE) and is derived through subjective pilot assessment using 'visual cue ratings' (VCRs). The VCRs are awarded using 5 point rating scales that describe the quality of the visual cues used by the pilot to support control of aircraft attitude, and vertical and horizontal translational rates and displacements. The final UCE is derived using a weighted average of the individual VCRs, where UCE = 1 is equivalent to VMC and UCEs of 2 & 3 represent relatively degraded conditions between VMC and IMC.

3 PHASE 1 – REVIEW OF DOCUMENTATION

3.1 General

3.1.1 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.

3.1.2 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 9, 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.

3.1.3 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 requirements. 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 CAA and FAA requirements i.e. 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.

3.1.4 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.

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

3.1.5 Note that Ref 6 gives a detailed account of all of the topics covered in the documentation review. This paper focuses on those aspects that formed the basis for the main recommendations, and which are summarised in the following sections.

3.2 Operational aspects

3.2.1 From the documentation, it was clear that operational considerations played a key role in establishing handling requirements for both civil and military types. Taking the military perspective, helicopters are designed to work in a hostile environment where high agility and manoeuvrability are required. To allow the pilot to safely exploit the available dynamic performance without high levels of workload, these attributes must be combined with good handling qualities. Civil helicopters may also be required to operate in difficult and demanding conditions which may, as in the case of civil offshore operations in conditions of icing, turbulence or poor visibility, pose similar demands on pilot and vehicle performance.

3.2.2 Hence, from either the viewpoint of mission effectiveness or airworthiness considerations, in order to establish effective requirements it is essential that they adequately reflect the demands of the intended role. A necessary corollary is that, for compliance demonstration purposes, it is essential that the vehicle is at some stage evaluated in tasks and conditions that are representative of its expected operational environment. It was apparent that both civil and military requirements employed this philosophy to a greater or lesser extent. This was particularly the case for ADS-33, which makes extensive use of mission related flight tasks as a basis for both specifying requirements and for compliance testing purposes. Key questions that the review set out to answer included – how representative were such tasks? -were they sufficient to cover all the necessary conditions? – how appropriate were they for evaluating handling qualities?

3.2.3 The ensuing review set out to shape answers through examination of the existing philosophy of the subject documentation, and comparison of their test procedures against the likely mission task or manoeuvre demands. The following points summarise the main findings:

(i) Both Def Stan 970 and ADS33C 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, such tasks represent a broad spectrum of different roles for general application to all rotorcraft types; 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; particular roles not well represented include those associated with shipboard operations, or those that require operation from raised platforms. Tests for emergency situations are not well addressed in either.

(ii) ADS-33 places great emphasis on the definition of 'clinical' tasks for the purpose of achieving consistent and repeatable subjective handling qualities assessments. Carefully selected task performance requirements, based on mission considerations, are also specified. Special task cueing arrangements are suggested, again in the interests of consistency and repeatability, regardless of the test site.

(iii) Def Stan flight tests serve the dual purpose of demonstrating flight envelope limitations and assessing handling qualities. More detailed coverage of the control system and power failure cases is given than in ADS-33. A dedicated flight test chapter is provided but this does not include precise task descriptions, and it is left to the assessing pilot to determine suitable test procedures. Task performance aspects are only addressed in a general way by stipulating that testing should encompass the limiting case for attitudes, rates, load factors etc, while factors such as flight path accuracy are not given direct consideration.

(iv) Regarding civil requirements, only a limited set of flight tasks are specified expressly for the purpose of assessing handling and control, and these are completely open to definition by the assessing pilot. The greatest emphasis is placed on performance testing for the purpose of obtaining operating data and establishing safe operating techniques within the certificated flight envelope. The underslung load case in BCAR is the one exception of a specific role-related test. The lack of guidance concerning operations from ships or rigs out at sea is particularly noticeable, given the potential harshness of the operating environment and the impact on handling and control.

(v) From comparison of typical civil flight profiles and role related flying, it was evident that many common MTEs could be identified, particularly those that related to general handling, such as landing, take-off, hover turn, sidestep etc. Hence it was concluded that the ADS-33 approach for defining MTEs and flight test manoeuvres for handling evaluations should be considered for application to civil operations and requirements.

3.2.4 An essential feature common to all the documentation is that qualitative assessments of handling should be made in some form of flight test manoeuvres. Given the lack of definition of such tests in existing civil documentation, even in the supporting advisory information, there is clearly scope for defining more formal testing requirements, which would encompass a broader range of role related tests and achieve a more consistent approach. The ADS-33 approach would satisfy this need and its set of MTEs provide a suitable starting point for the definition of equivalent civil MTEs and flight tasks. The definition of suitable task performance requirements appropriate to civil operations would be fundamental to the success of this process.

3.3 Civil handling qualities requirements

3.3.1 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

3.3.2 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.

3.3.3 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 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.

3.3.4 Regarding the FAR requirements, an accompanying note (Ref 10) provides supplementary guidance on specific issues of concern, together with detailed information on testing requirements and procedures. Ref 10 has also been adopted for the JARs and it is considered desirable that this type of information be given for all test requirements, again in the form of a supplementary volume to the mandatory requirements. The volume could be used to supply definitions for all of the key descriptors applied in the requirements, to explain individual handling concerns and constraints and to outline all flight tests and procedures that are needed for compliance demonstration.

3.3.5 To conclude this section on the review of civil airworthiness requirements, the main findings are summarised in the following points:

(i) The requirements are predominantly qualitative and place the onus for compliance demonstration on the evaluation pilot. The nature, number and outcome of testing requirements is almost entirely subjective, and is generally reliant on a single pilot. Research experience has shown that pilot opinion can vary considerably, especially when tests are not based on well defined tasks and task performance requirements, emphasising the need for a broader consensus backed up, where possible, by quantitative and measurable criteria.

(ii) 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. The nature of a vehicle's response to control inputs has a major influence on pilot control strategy and levels of workload, and this aspect deserves more detailed discussion and definition within the requirements, for both the general VFR requirements and those given for IFR operations.

(iii) Very little direct information is given on acceptable levels of control cross-coupling. FAR does not address the issue at all while BCAR only has a general requirement that there should be a 'minimum' of coupling between the longitudinal and other control axes.

(iv) 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.

(v) While both BCAR and FAR refer to responses to atmospheric disturbances and control margins for flight in turbulence, very little information is given on the gust conditions to be catered for in compliance demonstration. There is a need for supporting data on gust criteria with regard to both practical and theoretical test considerations.

(vi) The current documentation is expressly concerned with limited authority SAS and AFCS functions and failure states and, moreover, the requirements on control characteristics only take into account conventional centre-stick plus pedals and collective control configurations. In the future, however, civil airworthiness regulations will need to address the implications of the application of full authority active control technology (ACT) to rotorcraft handling and control. There is a 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 etc.

3.4 Military handling qualities requirements

3.4.1 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

3.4.2 ADS-33 was adopted for specific use for the US Comanche attack helicopter project. However, it 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. It should be noted that over the duration of the programme, two versions of ADS-33 have been issued, ADS-33C and ADS-33D. The earlier version was used as the basis for the documentation review whereas ADS-33D was used subsequently. The two versions vary only in the detail of the requirements, and their respective use will not have had a significant impact on the outcome.

3.4.3 Def Stan 00970 had 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.

3.4.4 ADS represents a radically new handling qualities methodology, and key innovations include the introduction of new quantitative criteria, UCE and MTE-based specification formats, and detailed mission-related flight test procedures. In some areas, because of the lack of an adequate data base, the criteria are incomplete and still need refining and extending. By and large, the main debate centres on values or levels set, rather than the appropriateness of the criteria or the specification formats. Nonetheless, even in its incomplete form, ADS-33 represents the most comprehensive advance in rotorcraft handling qualities criteria and fills many of the gaps left by previous documentation. Its principal criteria and tests formed the basis for key recommendations in the handling qualities review, hence they are given more detailed explanation in the following sections.

3.4.5 *Overview of ADS-33 handling requirements*

ADS-33 uses three fundamental components as the basis for a reference framework around which the handling requirements are defined; operational requirements in the form of MTEs; the nature of the vehicle response to control inputs, or control response type (see Ref 6 Section 5); and, finally, the level of degraded visual environment or UCE. These are combined to form a set of requirements which specify the dynamic response criteria and level of control augmentation required for specific operations in given levels of UCE. The requirements are further classified depending on the degree of 'pilot-attention' associated with given tasks, i.e. 'fully attended' or 'divided attention' operations, depending on the level of pilot attention allocated to non-control related tasks.

3.4.6 Handling criteria have been developed and classified for the hover, low speed and forward speed flight regimes, i.e. from 0-15kn, 16-45kn and >45kn respectively. In each case, whenever possible a handling qualities parameter is defined and specification formats are given that define boundary values for Level 1, 2 and 3 'acceptability'. These criteria provide the basis for prediction of an aircraft's overall handling qualities, and the premise is that all of the specified requirements must be met to achieve Level 1. In addition, a further set of flight test procedures are specified for the purpose of awarding assigned handling qualities. In this case, compliance is demonstrated through subjective assessments of the aircraft's handling qualities in specified MTE-based flight test manoeuvres where it is stated that the aircraft must be evaluated by at least three different pilots using the Cooper-Harper rating scale. This dual approach has been adopted so as to ensure the achievement of an accurate assessment.

3.4.7 For a given response type, the individual handling criteria stem from consideration of the piloting tasks associated with the MTEs. Throughout the speed range, flight path control is achieved by way of the redirection of main and tail rotor thrust through attitude control. Hence the vehicle's suitability for a given role is significantly affected by its behaviour in response to attitude control demands. The likely variation of pilot control strategy with increasing manoeuvre amplitude forms the basis of a 3-level classification of the demanded roll, pitch and yaw attitude responses to control inputs. Taking roll control as an example, ADS-33 defines small amplitude responses as attitude changes of 10 degrees or less, and the background research (Refs 11, 12 & 13) suggests that these are normally associated with continuous 'closed-loop' attitude stabilisation tasks. Moderate amplitude responses, defined as ranging between 10 and 40 degrees, relate to control demands associated with open-loop type control strategies required for terrain avoidance, re-positioning or target acquisition manoeuvres. Large amplitude criteria apply above 40 degrees and represent the maximum manoeuvre and control demands.

3.4.8 To complete the picture, Fig 2 (from Ref 13) illustrates the different aspects of the dynamic responses of attitude control that form the basis of the various criteria. Small attitude changes are mostly concerned with the character of the vehicle's short and mid term responses and research has shown that frequency domain criteria are the most appropriate for specifying handling qualities (Refs 12 & 14); specification formats based on attitude bandwidth, phase delay, damping and natural frequency have been developed and incorporated into the requirements. Moderate amplitude responses are associated with lower frequency tasks, where it has been found that time domain criteria, expressed in terms of the demanded change in attitude and the associated peak angular rate, adequately represent the nature of the piloting task demand. Large amplitude responses are largely a function of the available control power governed by system limitations imposed by actuator or rotor blade authority limits, and is expressed in terms of a peak angular rate requirement.

3.4.9 The means of compliance testing is either stated explicitly in the requirements or detailed in the Ref 14 'Background and User Information Guide' (BUIG). This generally involves some form of 'open loop' testing whereby the aircraft responses are measured following a prescribed input through the pilot's controls. The BUIG also supplies 'user' guidance on the scope and applicability of the requirements and presents comprehensive information on the development of the criteria. The procedure for an aircraft to achieve acceptance involves the following steps: the MTEs appropriate to its role are selected; its predicted handling qualities are assessed through open-loop testing against the appropriate criteria for MTE, response type and UCE rating; finally, assigned handling qualities are awarded through qualitative assessment in the designated flight test manoeuvres.

3.4.10 *ADS-33 small amplitude criteria*

Specification formats for short term criteria for small amplitude changes in pitch, roll or yaw are given in Fig 3, which shows examples of requirements for 'Air combat MTEs', 'All other MTEs, UCE =1 and fully attended operations' and 'All other MTEs, UCE>1 and/or divided attention operations'. The criteria are expressed in terms of frequency domain parameters, attitude bandwidth and phase delay; they are derived from the open-loop frequency response gain and phase functions relating aircraft attitude response with pilot control displacement. The boundaries shown delineate the Level 1, 2 and 3 requirements. Similar formats are also specified for hover and low speed cases.

3.4.11 Fig 4, taken from Ref 2 outlines the procedure for obtaining the bandwidth and phase delay. The bandwidth is defined as the frequency at which the phase lag is 45 degrees less than the 180 degree 'crossover frequency', or the gain has decreased by a margin of 6dB above the crossover value, whichever is the lower. The phase delay is derived from the mean phase slope (derived from a least squares fit) over frequencies above the bandwidth frequency. Defined in this way, the parameters give an indication of the 'stability' of the closed-loop pilot/vehicle system (Ref 15). At control input frequencies approaching the 180 degree crossover frequency and beyond it, there is increasing likelihood that the pilot-vehicle system can become 'unstable'. The significance of the bandwidth is that it specifies the task related closed-loop performance capability, while at the same time providing a built-in stability margin that protects against potential pilot induced oscillation (PIO) problems. The phase delay provides an indication of the 'rapidity' with which the stability margin may be encroached, and can be used to guard against a 'cliff-edge' transition into the region of potential PIO (Ref 15).

3.4.12 Ref 14 proposes a 'frequency sweep' flight test technique as a means of obtaining suitable frequency response data for compliance demonstration purposes. The objective of such tests is to measure the vehicle open-loop frequency response for a swept sinewave excitation signal, introduced via the pilot's controls. Time series analysis techniques are applied to the recorded control inputs and response data to obtain the appropriate gain and phase functions.

3.4.13 *ADS-33 moderate amplitude criteria*

Moderate amplitude requirements for rate response types are specified through a parameter called 'attitude quickness'. Quickness is derived from the aircraft's angular responses and is defined as the ratio of the peak rate to net change in attitude displacement following a discrete pulse control demand. It provides an approximate measure of the response bandwidth for moderate amplitude attitude demands and is used as a means of specifying manoeuvre performance boundaries for Level 1/2/3 handling qualities. Requirements for pitch, roll and yaw for low speed and forward flight cases (defined in ADS-33 as 0-45kn and >45kn respectively) are specified, a sample of which is shown in Fig 5. Compliance with the requirements is demonstrated by means of measuring the appropriate responses to pulse type inputs; the step changes in attitude response should be representative of those that would be achieved in the execution of standard MTE based flight tasks.

3.4.14 *ADS-33 large amplitude criteria*

Large amplitude criteria specify minimum requirements for achievable steady state rate or attitude change, for rate and attitude response types respectively. Specified values are summarised in Table 1; they are divided into 'limited', 'moderate' and 'aggressive' manoeuvring categories, depending on the level of task aggression associated with the given MTEs. For the least aggressive case, the values are matched to the upper amplitude range point for the moderate amplitude criteria (see Fig 5). In this case, the values given are not intended to represent maximum limits for control power but, from Ref 14, in practical terms they serve to set reduced performance levels for redundancy cases for a limited authority SAS. The moderate manoeuvre category corresponds to more aggressive MTEs and applies in the case of transport or utility type aircraft that need some evasive manoeuvring capability for battlefield operations (Ref 14). The aggressive MTEs represent the maximum manoeuvre demands for attack helicopters, and the values set represent the maximum control power requirements. Defined in this way, these criteria, together with the moderate amplitude criteria described in the previous section, are particularly pertinent to emergency manoeuvres for civil operations.

3.5 Phase 1 recommendations

3.5.1 Following the documentation review, the findings of the various components 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:

(i) *Operational aspects*

- The ADS-33 MTE approach and handling qualities evaluation procedure should be considered for civil qualification testing purposes. 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.

- Task performance requirements relating to both operational safety and efficiency would be needed for each of the flight tasks.

- 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. A study should be conducted to provide a revised set of rules for future requirements; the study should consider the Def Stan SHOL concept as a means for setting operating/clearance procedures at sites other than ships e.g. rigs, raised platforms etc, where factors such as the relative wind conditions, turbulence from structures or exhaust gas ingestion also present significant operational constraints.

(ii) *Handling aspects*

- The set of civil MTEs could be used as a basis for general handling evaluations.

- The Def Stan 00970 criteria for short term, transient responses and ADS-33 small, moderate and large amplitude criteria should be investigated for use in support of the civil controllability and manoeuvrability requirements.

- For small amplitude criteria, Levels 1, 2, and 3 boundaries should be defined based on the following minimum set of MTEs:

  ⇒ VMC/IMC decelerating/constant approaches.
  ⇒ Sloping ground landings.
  ⇒ Precision hover/precision load positioning.

- For moderate amplitude criteria, Level 1, 2 and 3 boundaries for the attitude quickness parameter should be determined for the following minimum set of tasks:

  ⇒ Sidestep, forward step, spot turn, bob-up.
  ⇒ Transient banked turns at up to 60 degrees angle of bank.
  ⇒ Forward acceleration/deceleration at up to a maximum 30 degrees pitch attitude.
  ⇒ Balked landing.
  ⇒ Entry into autorotational flight/partially powered flight.
  ⇒ Flare and landing following autorotational flight/partially powered flight.

- The moderate amplitude criteria and MTEs should also be investigated as a means for specifying control margin requirements.

- For large amplitude criteria, appropriate maximum rates should be determined as deemed to be appropriate for the specified civil MTEs.

- An investigation of the application of ADS-33 small amplitude criteria to support BCAR and FAR requirements for IFR operations should be carried out. Consideration should also be given to the application of bandwidth criteria in support of the BCAR requirement that there is a low probability for the occurrence of PIOs.

- 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 to provide guidance on test criteria for disturbance inputs.

(iii) *Compliance testing aspects*

- All flight test procedures necessary for compliance demonstration should be clearly identified and documented, including tests associated with general handling evaluations, or for compliance against specific handling or stability requirements.

- The Cooper-Harper rating procedure should be considered for application in subjective handling qualities evaluations; testing should be carried out by at least three different pilots.

(iv) *Documentation issues*

- 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.

- All handling qualities issues should be clearly identified and documented within the main body of the requirements; any additional guidance should be clearly referenced and the flight test manual should also be referenced for any specific testing requirements.

4 PHASE 2 – SIMULATION TRIALS

4.1 General

4.1.1 As noted in Section 1, the broad objective in Phase 2 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.

4.1.2 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. A 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 DVE scenarios, and cross-wind conditions with low to moderate levels of atmospheric turbulence (see Section 4.4 below).

4.1.3 In the HELCARS1 tests, it was established that the 6 degree approach MTE was a suitable civil flight task that could be used to meet the experimental objectives. For the night time DVE 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 90 degrees 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.

4.1.4 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 HELCARS2 where the CSM was modified to respond to turbulence (Ref 16) and the tests repeated. At the same time, the aim of HELCARS2 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.

4.1.5 The test matrix for HELCARS2 is summarised in Table 2. The intention was to conduct comparative evaluations of a number of Level 1, 2 and 3 configurations, with both RC and 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 the 6 degree approach, as described in Section 4.6 below. It was initiated from level flight at 60kn (on a compass heading of 0 degrees), 650m from the landing point at 240ft AGL with a 46m lateral offset (to the left of the approach line) and a 15 degree heading offset to port. The wind condition was set to a mean of 15 kn from port, with light to moderate levels of turbulence (see Fig 9).

4.2 Test facility

4.2.1 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. It should be noted that, because of the exploratory nature of the tests, HELCARS1 was carried out in limited fixed-base simulation configuration. Also, primary flight information was displayed via head-down analogue instruments and a head-up display (HUD) in the forward field-of-view, which displayed an artificial horizon and attitude indicator, airspeed indicator, rad-alt, baro-alt and a torque meter. For HELCARS2, these displays were replaced by a head-down CRT instrument display. The same visual system was used for both trials, although a considerably enhanced FOV was used for HELCARS2, i.e. a five window display including a 'chin' window as opposed to a limited 3 window display for HELCARS1.

4.3 Simulation model

4.3.1 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 70 degrees of bank.

4.3.2 Key handling qualities parameters (see Fig 2) that can be set for the roll, pitch and yaw axes include the following:

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

4.3.3 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.

4.4 CSM turbulence implementation

4.4.1 The CSM upgrade to include response to turbulence was achieved through incorporation of an 'atmospheric turbulence generator' (ATG), which is based on a statistical discrete gust model that represents turbulence by an aggregation of discrete gusts (Ref 16). The ATG had been used successfully in earlier DERA simulation research, including where it had been configured to 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 HELCARS2. It was considered that, although this configuration had been set up to represent a specific operational condition, the nature of its turbulence characteristics was sufficiently generic to meet the broader aims of the demonstration trial.

4.4.2 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 PIOs, 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.

4.4.3 The effect of turbulence on the model's responses was more noted for the RC configurations because of the lack of an attitude hold function. 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.

4.5 Handling qualities configurations

4.5.1 Fig 6 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. Requirements for operations in UCEs of 1 and >1 are given, and the figures also show 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 7 and 8 respectively. 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.

4.5.2 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. 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 in 4.2.1 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.

4.6 Test manoeuvres and task cues

4.6.1 Following discussions with the CAA, four MTEs were identified as priority cases for investigation in HELCARS1:

(i) Final stage of descending, decelerating approach to hover with 3 degree and 6 degree 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.

4.6.2 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.

4.6.3 A schematic of the 6 degree approach task and task cues is given in Fig 9; note that the same cues were used for both day and night time cases. The task definition is summarised in Table 3. The task performance requirements were based on what was considered to be a 'safe' approach to the platform. 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.

4.7 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 1). 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 follow up post-sortie questionnaire (PSQ) was completed at the end of the sortie and contained detailed follow-up questions on handling qualities and simulation issues, e.g. motion cues.

4.8 Trials results

4.8.1 In HELCARS1, only the 6 degree approach task and rejected take-off tasks were formally evaluated. The most limiting case tested, in terms of the handling difficulties experienced, turned out to be the 6 degree approach at night time with lateral offsets of 46m, crosswind of 15kn and heading offsets of 15 degrees. 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.

4.8.2 In HELCARS2, pilots were able to evaluate the CSM in the 6 degree 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.

4.8.3 A summary of pilot ratings is given in Fig 10; 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 below:

(i) *Pilot ratings for RC cases (Fig 10a)*

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.

(ii) *Pilot ratings for ACAH cases (Fig 10b)*

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. 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 less noted with low turbulence, resulting in a Level 2 HQR of 5.

(iii) *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 case (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.

(iv) *Comparison against 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. HELCARS2 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 may have been too unrepresentative, notably, that the level of turbulence was too severe, or that the visual cues were 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 HELCARS2 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.

4.9 Discussion

4.9.1 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 degree 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.

4.9.2 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.

4.10 Conclusions

Key conclusions regarding specific aspects of the trial and its results are summarised as follows:

(i) *Test method*

Pilots considered that the test manoeuvre and visual cues were sufficiently representative of operational flight conditions. They were able to award Level 1 ratings for the best configurations and were able to discriminate handling qualities deficiencies of degraded cases. Hence, the evaluation task was considered to provide a suitable basis for testing requirements and for developing definitive civil handling qualities criteria.

(ii) *Handling qualities rating procedures*

Pilots were able to return Cooper-Harper ratings for all evaluations with a low spread of results between pilots, i.e. ≤ 1 rating point. A checking procedure was used which showed that pilots returned consistent ratings in accordance with the Cooper-Harper procedure.

(iii) *Turbulence implementation*

A turbulence upgrade was successfully implemented in the CSM and pilots considered that the model responses to turbulence were representative. The model upgrade was deemed to be suitable for the purpose of the trial, although further validation would be needed before it could be used to generate definitive results.

(iv) *Facility configuration*

Pilots reported that the simulation was representative compared to real operational flight. Although some deficiencies were noticeable, these were not judged to have had a significant impact on the results.

(v) *Simulation model*

The CSM provided a satisfactory means of implementing ADS-33 based handling qualities configurations. It was found to be acceptable in all aspects except for the yaw blend characteristics. Although improvements had been made prior to the trial, pilots still found this to be intrusive and considered that it needed further improvement.

(vi) *Test configurations*

Regarding response types, both RC and ACAH types were tested, and pilots expressed a preference for the ACAH type because of the enhanced stability that it offered. A number of Level 1, 2 and 3 configurations were evaluated and, for the poorest cases and test conditions for both response types, pilots experienced high control workload and adequate task performance could not be achieved. 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.

(vii) *ADS criteria*

Caution should be applied to interpretation of the results against the ADS-33 criteria because of the limited pilot sample and combinations of roll, pitch and yaw axis test cases. 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. The results also suggest that the UCE > 1 criteria should also be applied to the UCE = 1 case, and that phase delay should be capped at about 200-250ms.

4.11 Recommendations

(i) *Test manoeuvre*

Experience with the 6 degree approach task has confirmed the recommendation of the DERA's review of civil flight handling requirements that ADS-33 flight test procedures should be considered for adoption as a standard for civil qualification testing. An ADS-33 style set of civil MTEs and flight test manoeuvres should be developed to provide a comprehensive set of cases that encompasses the full spectrum of civil helicopter operational requirements.

(ii) *Test procedures*

The Cooper-Harper rating procedures and associated test techniques should be considered for application to civil qualification testing. To this end, further investigations should be conducted to establish the relationship between the Level 1, 2 and 3 ratings and the level of acceptability against specific civil handling requirements. Consideration should also be given to the creation of a flight test manual to document the procedures, acceptance criteria, and the desired and adequate performance standards.

(iii) *ADS-33 criteria*

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 civil criteria. ADS-33 also uses the bandwidth criteria to specify requirements for short-term pitch, roll and yaw responses to disturbances, which may be interpreted as effective gust rejection criteria. It is further recommended that this approach be adopted for equivalent civil criteria. However, further investigations should be carried out to confirm an advisory limit on phase delay and limits on bandwidth for gust rejection criteria. Initially, off-line studies with an improved CSM turbulence representation could be carried out to quantify the impact on vehicle response at given trim states with a view to developing gust rejection criteria. Validated data could then be generated using the Helisim Lynx model and in-flight data using the DERA's research Lynx.

5 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 new 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 report. A number of important issues will have to be addressed, however, if these are to be pursued, as discussed below.

5.1 Review of documentation

5.1.1 Regarding the completeness of the review, attention has been focused mainly on specific topics covered in the current requirements material. Its scope did not allow an in-depth coverage of all the pertinent topics; areas not addressed, and which will need to be addressed in the future, include:

(i) Handling criteria for civil ACT helicopters.

(ii) Sidestick criteria for civil helicopters.

(iii) Handling problems associated with flight at steep descent angles and vortex ring.

(iv) Handling problems associated with emergency conditions e.g. loss of tail rotor or engine.

(v) Agility requirements for emergency manoeuvres, including ADS-33 attitude quickness criteria.

(vi) Optimum response types for civil mission phases and flight in the DVE.

(vii) The use of the UCE concept in civil helicopter applications and associated handling qualities requirements.

(viii) Augmentation requirements for civil helicopters.

(ix) Display requirements to supplement augmentation and enable flight in poor UCEs.

5.1.2 Further research effort will inevitably be required to address these issues, and flight trials and simulation activities will be needed to provide a substantiated data base from which to derive validated criteria.

5.1.3 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 still considered to be relevant and fundamental to safe operational use and will continue to play an important role in the requirements. A further recommendation was that a dedicated flight test and procedures manual should be developed, which would include detailed evaluation objectives, task descriptions and task performance requirements etc. Such a document could be further developed in the form of a user guide, which would provide guidance on handling qualities issues and associated acceptance criteria.

5.2 Mission task elements and flight tasks

5.2.1 A key recommendation was that the ADS-33 MTE approach and procedure for awarding assigned handling qualities should be considered for civil qualification testing purposes, and that a basic set of civil MTEs be defined for this purpose. The intention was that the MTEs could be used as a basis for assessing overall handling qualities which would be evaluated using the Cooper-Harper rating procedure. They would also be used as a basis for classifying civil requirements as in ADS-33. A number of issues need to be addressed in order to progress this recommendation, as discussed below:

(i) The selection and definition of suitable civil MTEs. The recommendations proposed two sets of tasks; civil helicopter tasks where the ADS small amplitude criteria were considered to be appropriate, i.e. tasks which had recognisable high gain 'tracking' elements and, secondly, general handling and performance tasks, including emergency manoeuvres, where moderate and large amplitude criteria would be more appropriate.

(ii) Use of the Cooper-Harper procedure requires that pilots are familiar with its application; it was also recommended that evaluations be carried out by at least three pilots. There is a clear implication on evaluation pilot training needs, and the additional time and cost penalties associated with more extensive testing. However, these have to be weighed against the benefits to be gained in terms of consistency of application of the requirements and enhancements to flight safety.

(iii) For flight testing purposes, desired and adequate task performance requirements need to be defined, taking account of civil operational requirements and safety constraints. There is also a need to establish the relationship between Level 1, 2 and 3 ratings and performance attainment, the level of acceptability against specific civil handling requirements and criteria, and the award of operational clearance. This is particularly the case at the split between Levels 2 and 3, the boundary between achieving adequate performance and task failure.

(iv) Task cue requirements also need to be addressed. ADS-33 proposes task cues on the basis that it is the vehicle's handling qualities that are the subject of the tests and not the quality of the available visual cues. Hence, sufficient cues should be provided to ensure that visual cueing is not an issue in the tests and to enable the pilot to judge task performance attainment.

(v) There is also the question of the appropriate level of task aggression to be applied in civil helicopter tests. Time pressures that are a key driver of handling requirements for military style operations do not necessarily feature so strongly in relation to civil operations, except perhaps those associated with policing or search and rescue activities. The trials evaluations demonstrated the degree of freedom that the pilot had to adapt control strategy to accommodate poor handling qualities and/or operating conditions, and achieve the task. However, the results also showed that circumstances can combine to defeat this strategy; there is a need to identify such potentially limiting cases to ensure that these are adequately covered by flight test requirements. Testing at sufficient levels of aggression is an important factor here.

(vi) Tests for operations in degraded visual conditions also need to be taken into account. In ADS-33, a specific set of flight tasks is defined for DVE operations, which is in effect a sub-set of the GVE tasks with relaxed performance and precision requirements. The tasks are intended to be evaluated in the appropriate DVE conditions using the displays and vision aids that would normally be available to the pilot. An equivalent approach needs to be considered and developed for civil applications.

5.3 Handling qualities aspects

5.3.1 As noted above, it is expected that the test configurations would meet the requirements of BCAR Section G and FAR 27/29, even though some configurations performed poorly in the tests and were unacceptable under the operating conditions tested. To address the problem, the principal recommendation was that the ADS-33 small, moderate and large amplitude criteria should be investigated for use in support of the civil controllability and manoeuvrability requirements. Some of the main issues associated with this recommendation are discussed below:

(i) 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 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.

(ii) A second issue relates to the nature of the flight testing requirements for compliance demonstration purposes; the time and costs associated with application of ADS style open-loop test requirements in civil helicopter testing would need careful consideration. There is also a need to consider instrumentation requirements for monitoring aircraft response and performance data and, possibly, the loads in flight-critical components. A simple, portable instrumentation and data logging pack could be used to capture relevant response and performance data. Regarding flight loads, Ref 15 details DERA experience in frequency sweep testing for bandwidth criteria, which resulted in a recommendation that comprehensive flight loads monitoring should be undertaken for such tests. This requirement would have a much greater impact on the trial resources needed.

(iii) A further recommendation was that bandwidth criteria should be used for specifying requirements for response to disturbance inputs, and also that the Def Stan criteria on turbulence characteristics be used to provide guidance on test criteria for disturbance inputs. Again, the trial results indicate that the ADS boundaries are an appropriate starting point for a civil requirement but that further investigations are needed for confirmation.

5.3.2 It is considered that there is a strong case for taking the standard set of ADS task definitions for GVE and DVE flight test manoeuvres as a starting point for supporting civil flight test requirements. For the most part, the tasks represent general handling manoeuvres that can be applied to any helicopter, and would suit the needs of a general handling appraisal. The task set should of course be expanded to include the standard civil performance assessment and emergency situation test cases. If tested at appropriate levels of task aggression, they would serve as a basis for identifying potential handling qualities problems. To this end, it is considered that there is need to investigate handling characteristics close to the limits of an aircraft's dynamic performance capability in order to establish the likelihood of a 'cliff-edge' deterioration in handling qualities. Hence tasks would be evaluated using the ADS precision requirements, but flown at increasing levels of aggression so that handling is assessed up to and beyond the normal range of dynamic performance in operational use. In the event that specific problems were identified which gave cause for concern over an aircraft's operational clearance, further role related testing would be specified.

5.3.3 Regarding the recommended handling qualities criteria, it is considered that these would be most effectively introduced for use as supporting advisory material for existing mandatory requirements in the first instance. Used in this way, they could be used to provide guidance on specific handling qualities issues through the identification of the handling qualities parameters that are fundamental to the problem, and the provision of numerical criteria for design guidance.

5.4 Operational aspects

The relationship between handling qualities criteria and the operating environment is 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. This has 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. There have been a considerable number of civil helicopter accidents in which loss of control in flight has occurred which may have been due to the combination of aircraft handling characteristics and the prevailing UCE. It is considered that the ADS-33 UCE-based criteria would provide a clear indication of the likelihood of such an event occurring. Hence, 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 helicopter's intended operational use. For example, the task of high altitude hovering for surveillance purposes at night, with poor external visual cues, may require an ACAH response type, whereas the current civil rules would allow this to be carried out with a simple unstabilised helicopter with an RC response type. To address the problem, it is considered that a review of loss of control accidents should be carried out to establish the likely effectiveness of the ADS-33 approach in preventing such accidents.

5.5 Future civil requirements

5.5.1 Existing civil airworthiness requirements for handling qualities provide an established basis for possible future developments. Notwithstanding the shortcomings discussed previously, when applied correctly using the appropriate advisory material they are reasonably good at defining safe limiting operating conditions in steady state manoeuvres, adequate control margins for sideways flight for example. 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 compensating features. During certification, a great deal of time, effort and money can be expended by the civil authority and the manufacturer in resolving such issues.

5.5.2 There is understandable reluctance on the part of the authorities to relax those quantitative requirements that are in current 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 ADS-33 type criteria and introducing a formalised method of pilot evaluation using MTEs that had been optimised for civil use. 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.

6 FUTURE WORK

6.1 To address the issues and concerns raised above, and to fill the gaps identified in the current review, the following activities are proposed:

(i) A more detailed review of specific handling qualities requirements for helicopters with full authority ACT systems should be implemented; this should take into account factors such as response type, and operations in the DVE and requirements for active and sidestick inceptors.

(ii) An investigation of handling qualities and agility criteria for emergency manoeuvres should be initiated, focusing on ADS-33 moderate and large amplitude and vertical rate response considerations.

(iii) The role of MTE-based flight testing procedures in civil qualification testing should be further investigated and reported. 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.

(iv) A review of open-loop testing requirements should be carried out, leading to a practical flight test demonstration of the ADS procedures. Data measurement and recording aspects should be investigated, including the need for critical flight loads monitoring.

(v) ADS-33 bandwidth criteria for pitch, roll and yaw responses to disturbances should be further reviewed and developed for application to civil requirements for gust rejection. Specifically, further investigations should be carried out to confirm an advisory limit on phase delay and limits on bandwidth for gust rejection criteria. Initially, off-line studies with an improved CSM turbulence representation could be carried out to quantify the impact on vehicle response at given trim states with a view to developing gust rejection criteria. Validation data could then be generated using the Helisim Lynx model and in-flight data using the DERA's research Lynx.

(vi) A review should be undertaken of the content and structure of a flight test manual for civil qualification testing. The review would serve as a basis for the development of a practical guide to implementation of flight test procedures, and flight data recording and analysis requirements.

(vii) A review of loss of control accidents involving civil helicopters should be carried out to investigate the effectiveness of the ADS-33 criteria for response type, UCE and handling qualities in preventing such accidents.

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8 ABBREVIATIONS

ACAH	Attitude command attitude hold
ADS	Aeronautical Design Standard
AFS	Advanced Flight Simulator
ATG	Atmospheric turbulence generator
AUM	All up mass
BCAR	British Civil Airworthiness Requirements
CSM	Conceptual Simulation Model
CGI	Computer generated imagery
DERA	Defence Evaluation & Research Agency
DVE	Degraded visual environment
FAR	Federal Aviation Regulations
FMC	Fight Management & Control Department
FOV	Field of view
GVE	Good visual environment
HDD	Head down display
HQR	Handling qualities rating
HUD	Head up display
ICQ	In-cockpit questionnaire
IMC	Instrument meteorological conditions
LMS	Large Motion Simulator
MTE	Mission task element
IO	Pilot induced oscillation
SQ	Post-sortie questionnaire
RC	Rate command
RMS	Root mean square
UCE	Usable cue environment
VMC	Visual meteorological conditions

9 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.%)
Cp	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)

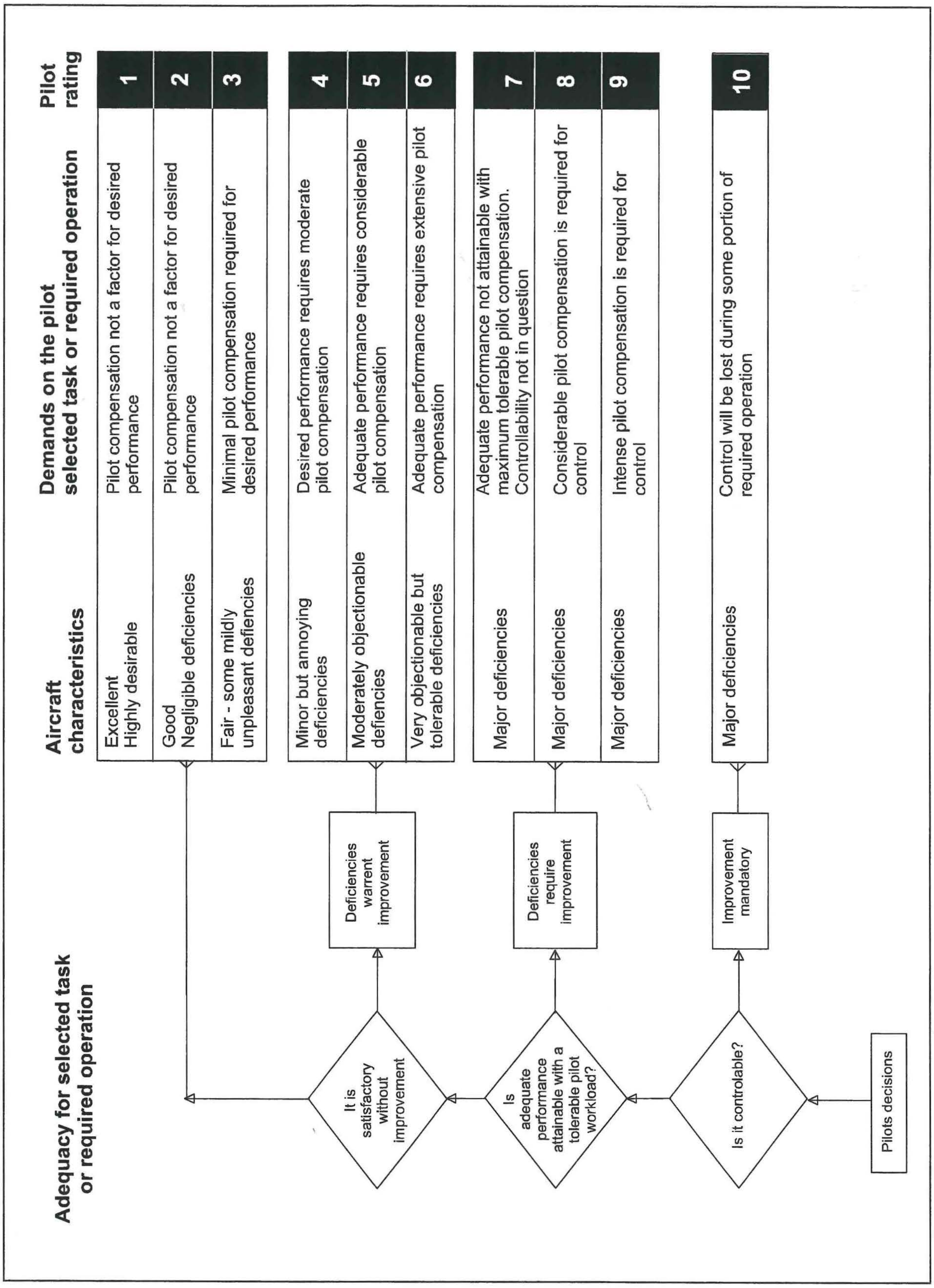


Figure 1 Cooper-Harper rating scale for handling qualities

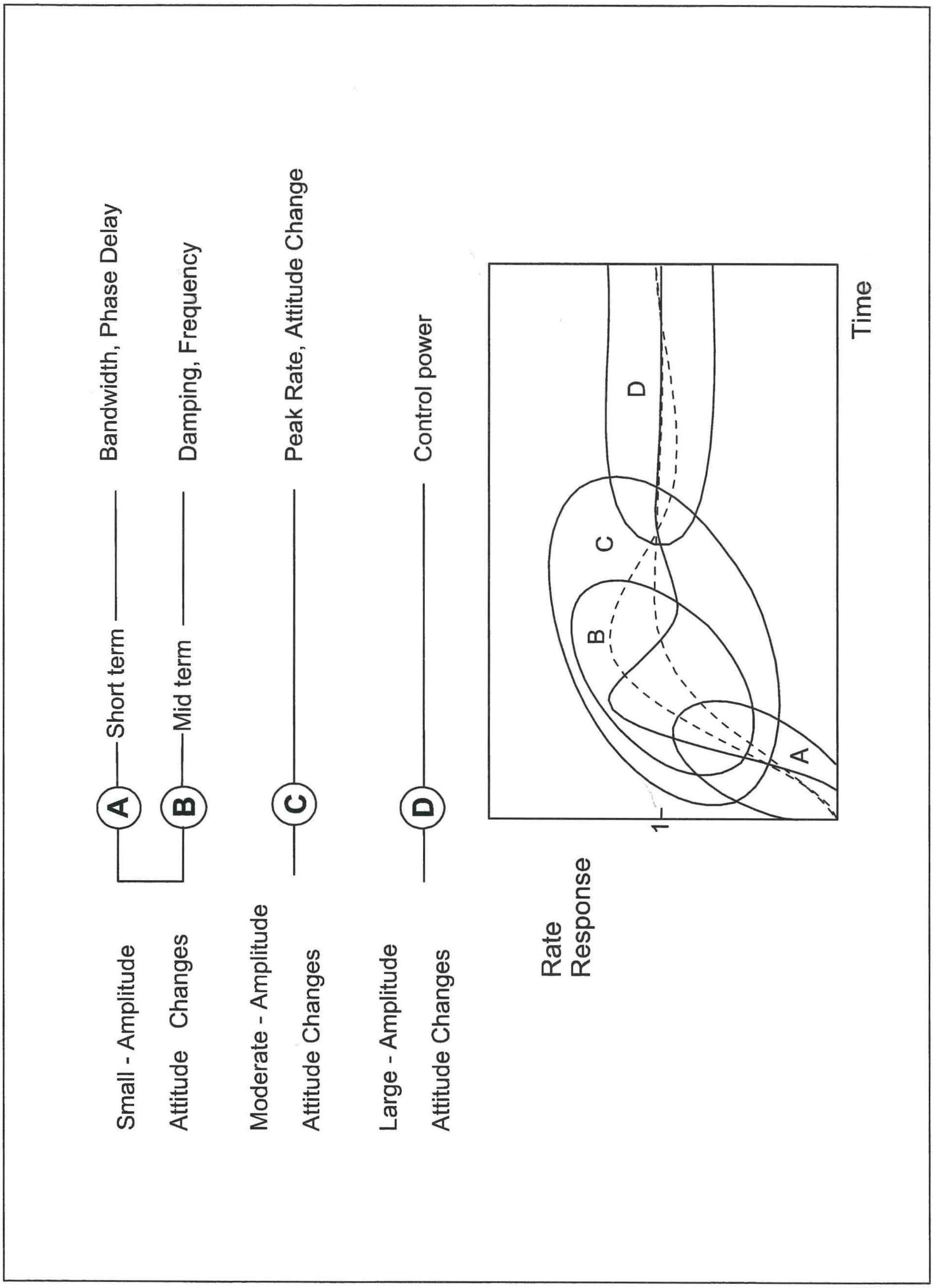


Figure 2 **Dynamic response criteria**

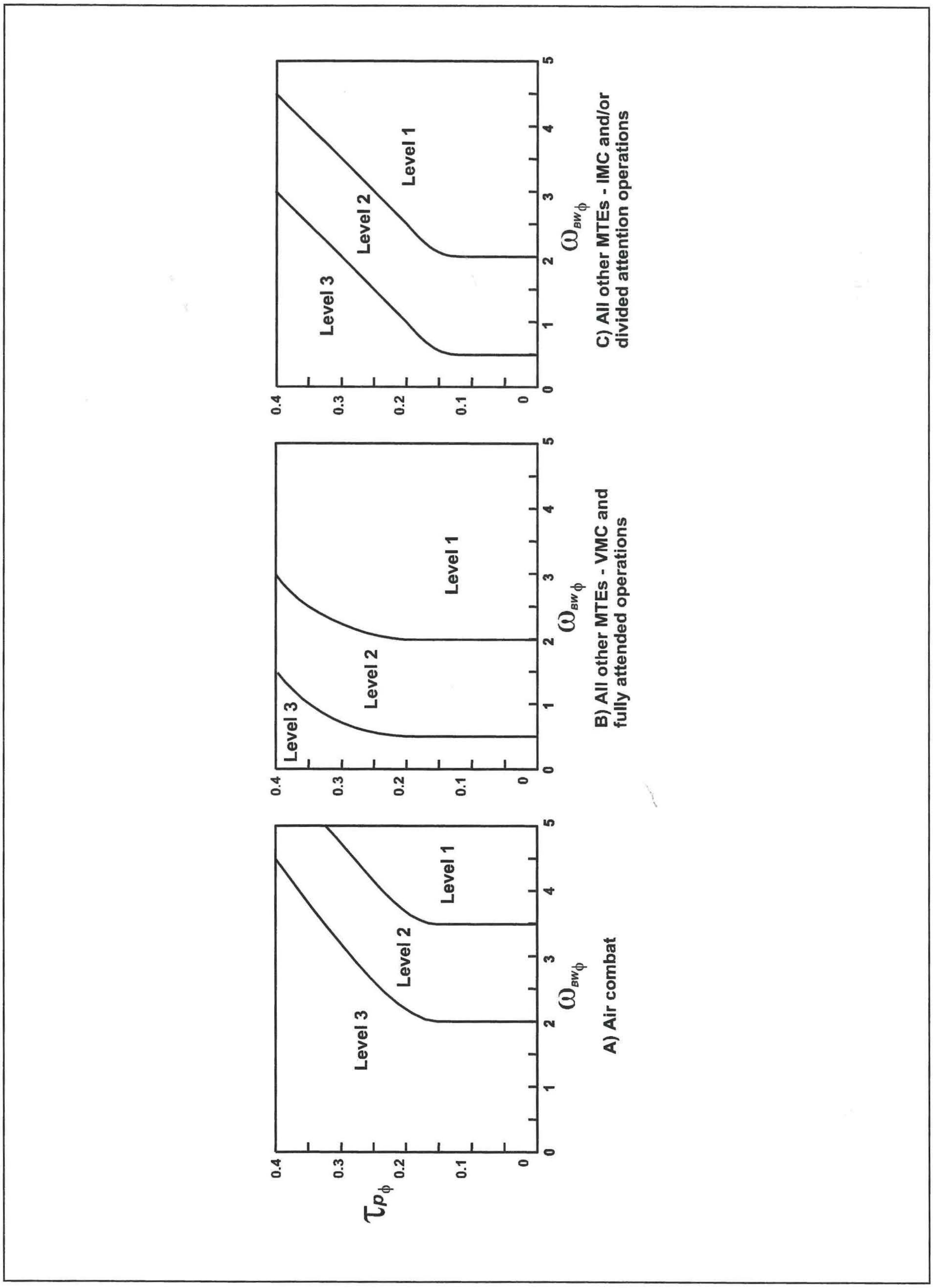


Figure 3 ADS-33 small amplitude criteria

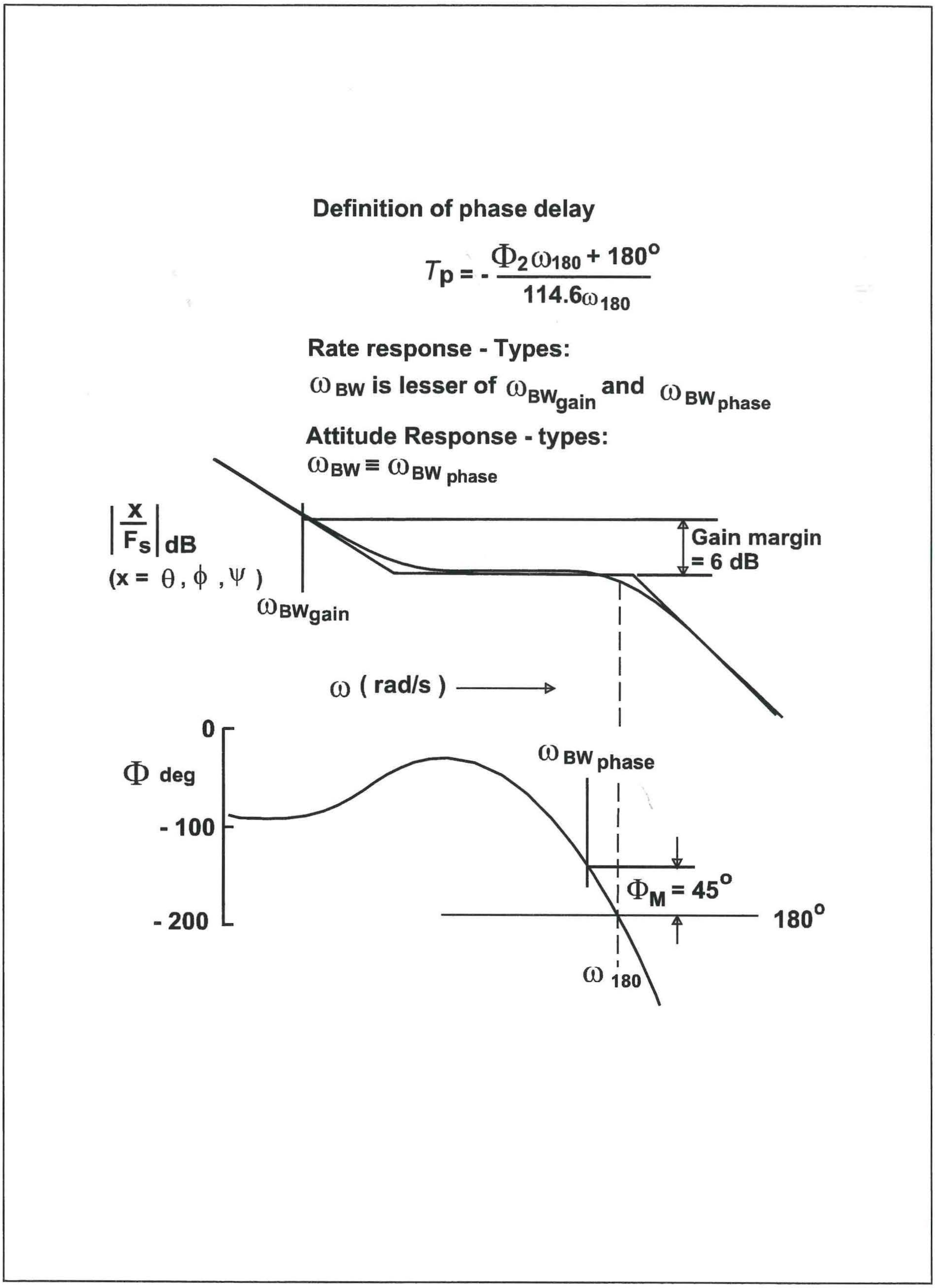


Figure 4 Derivation of small amplitude criteria

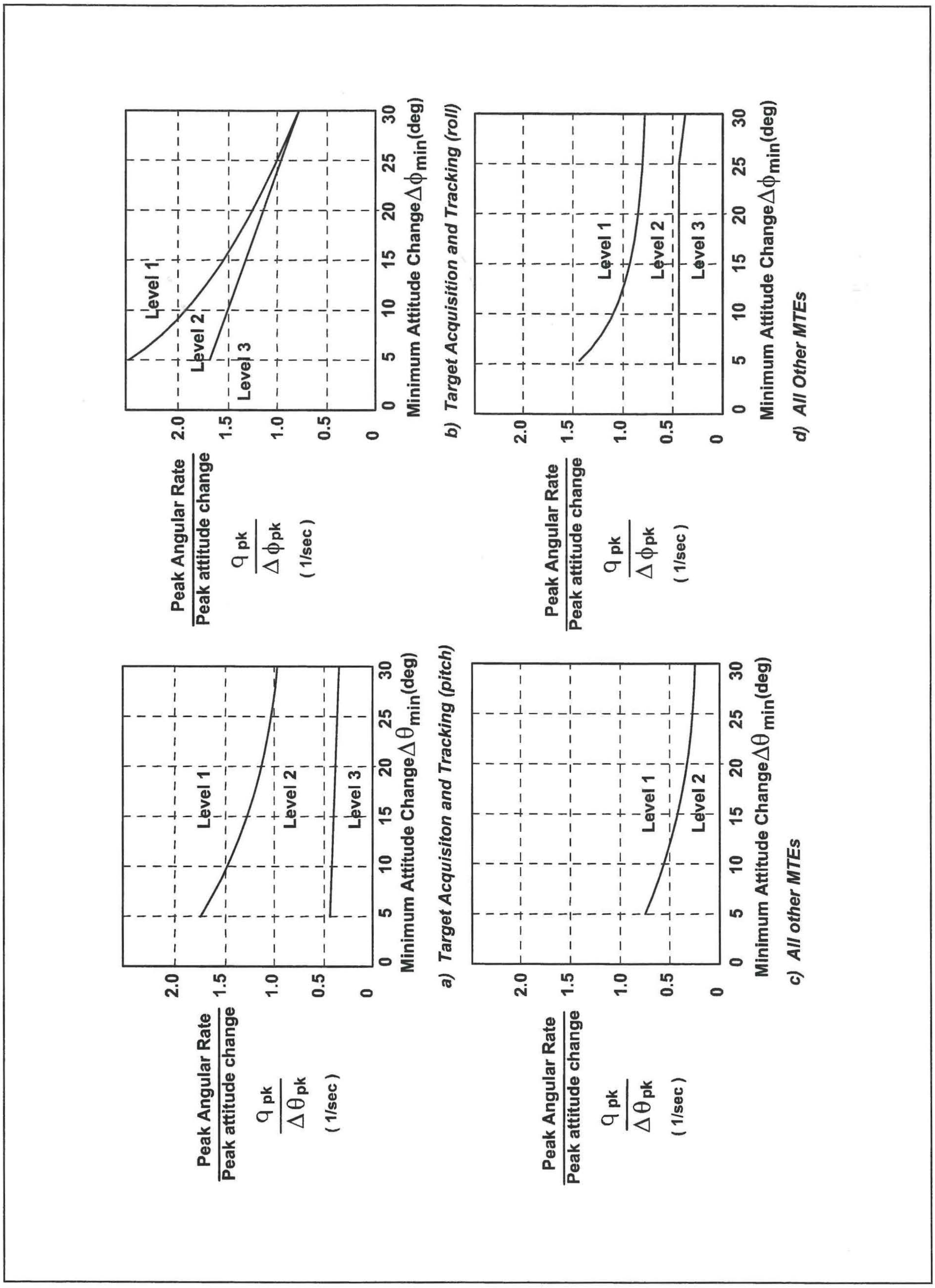


Figure 5 ADS-33 moderate amplitude criteria

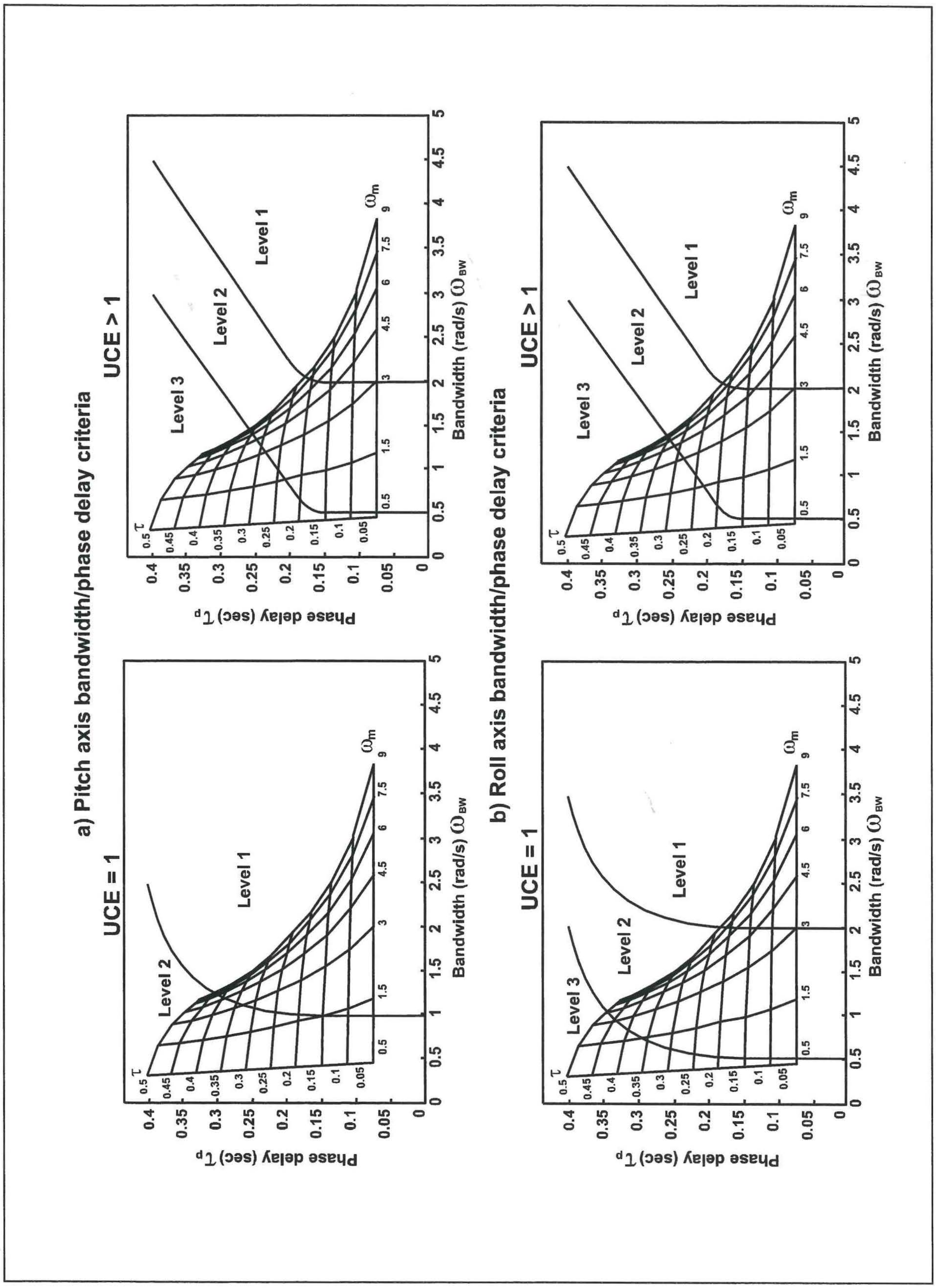


Figure 6 ADS-33D attitude bandwidth criteria versus CSM configuration

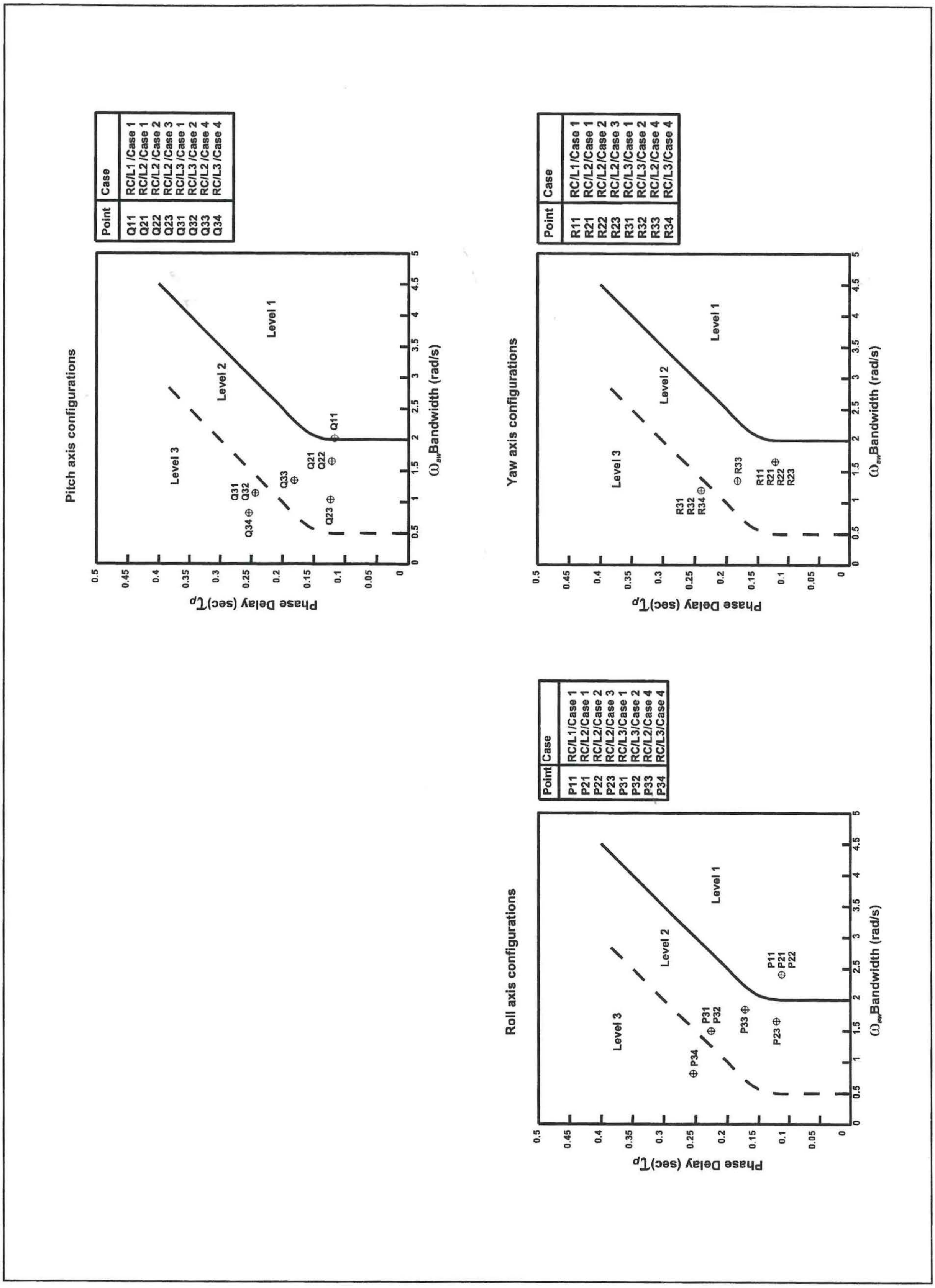


Figure 7 RC configurations versus attitude bandwidth criteria for UCE>1

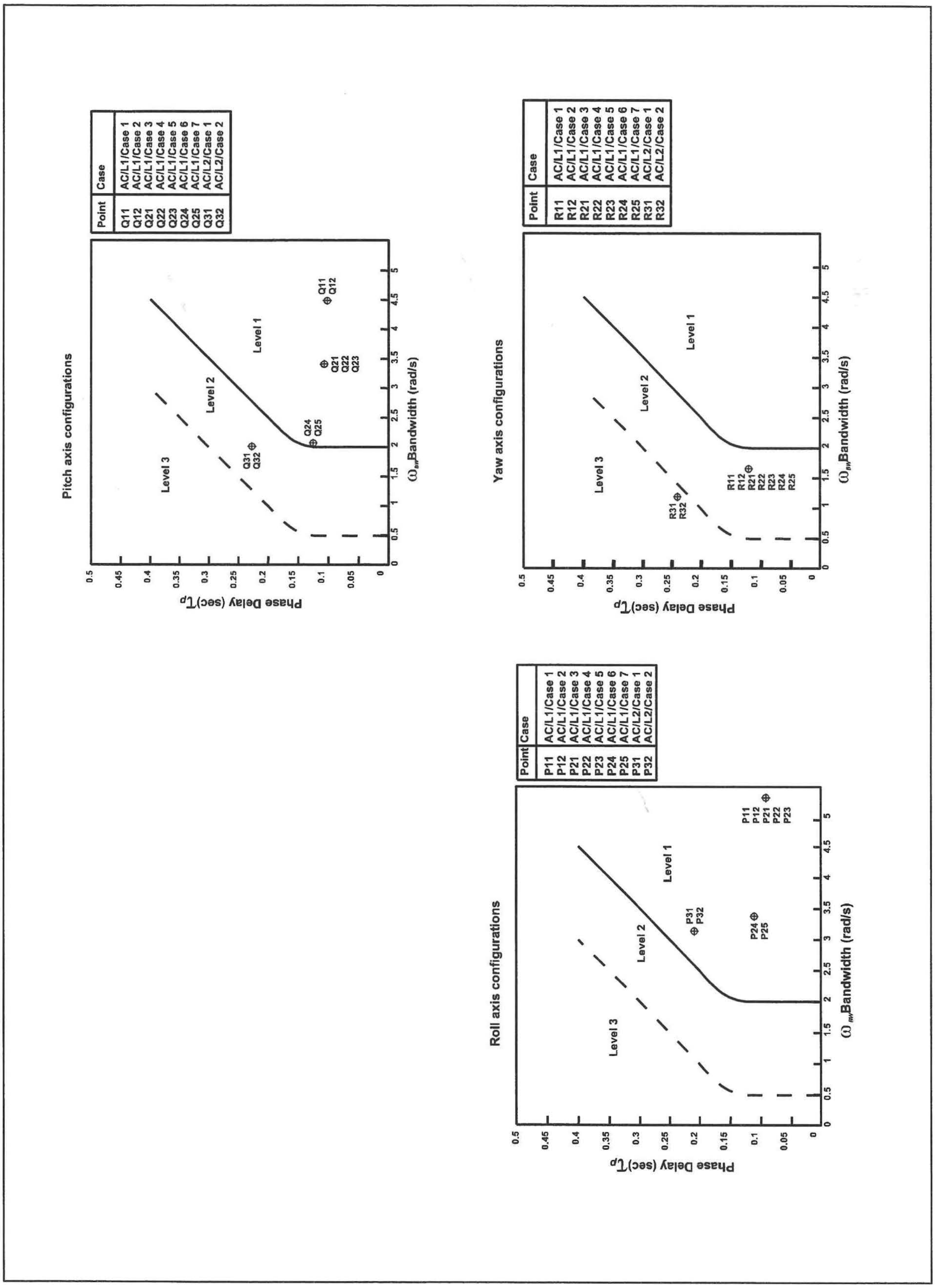
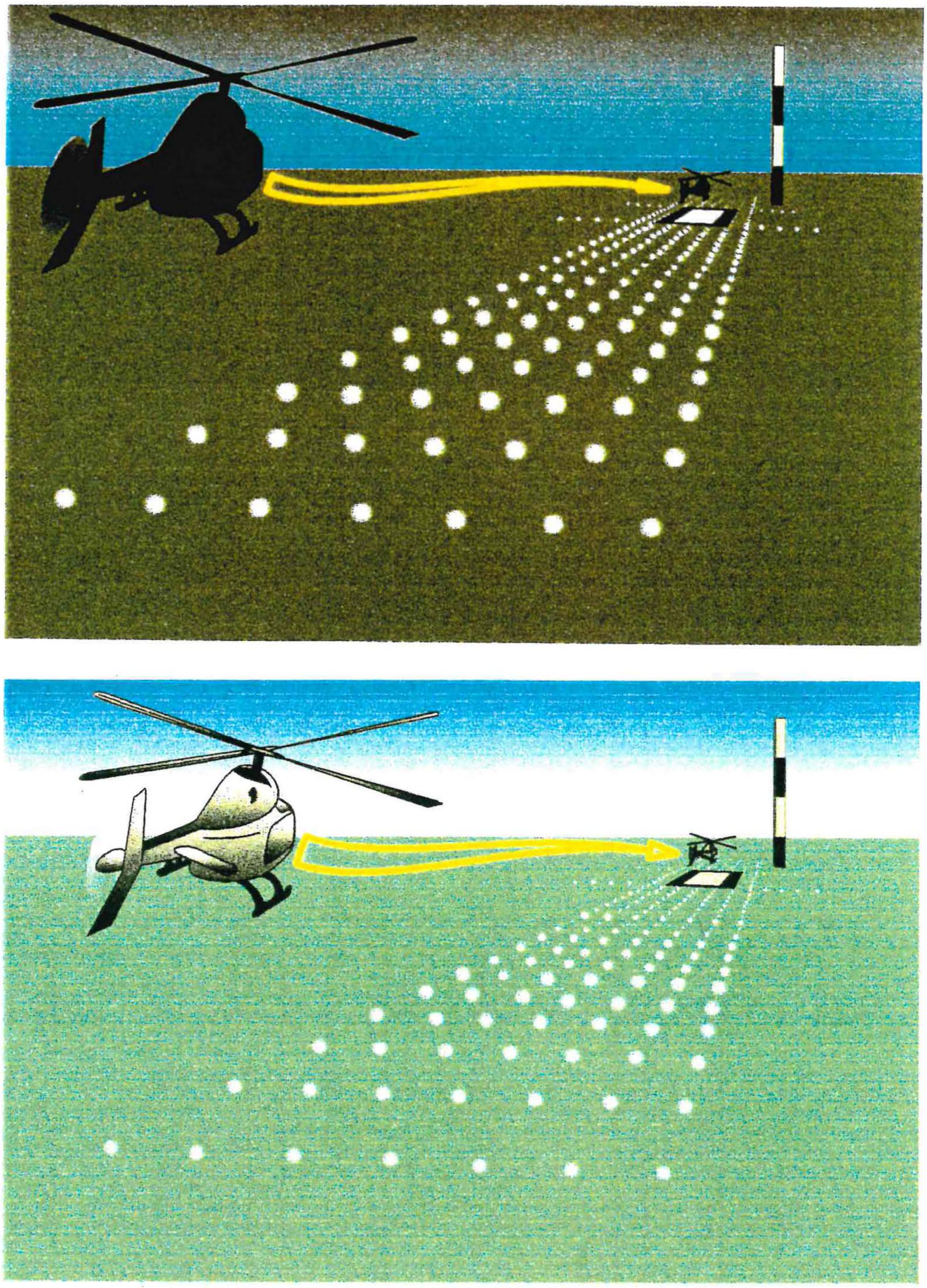


Figure 8 ACAH configurations versus attitude bandwidth criteria for UCE>1



Start positions:

1. 650m from pad centre line
2. 46m left of centre line
3. 15° Heading offset
4. Height 240ft AGL

Standard light Matrix:
1200m x 60m
7 x 41 Lights
Wind conditions:
15kn, red 90°

Figure 9 Schematic of the 6 degree approach task

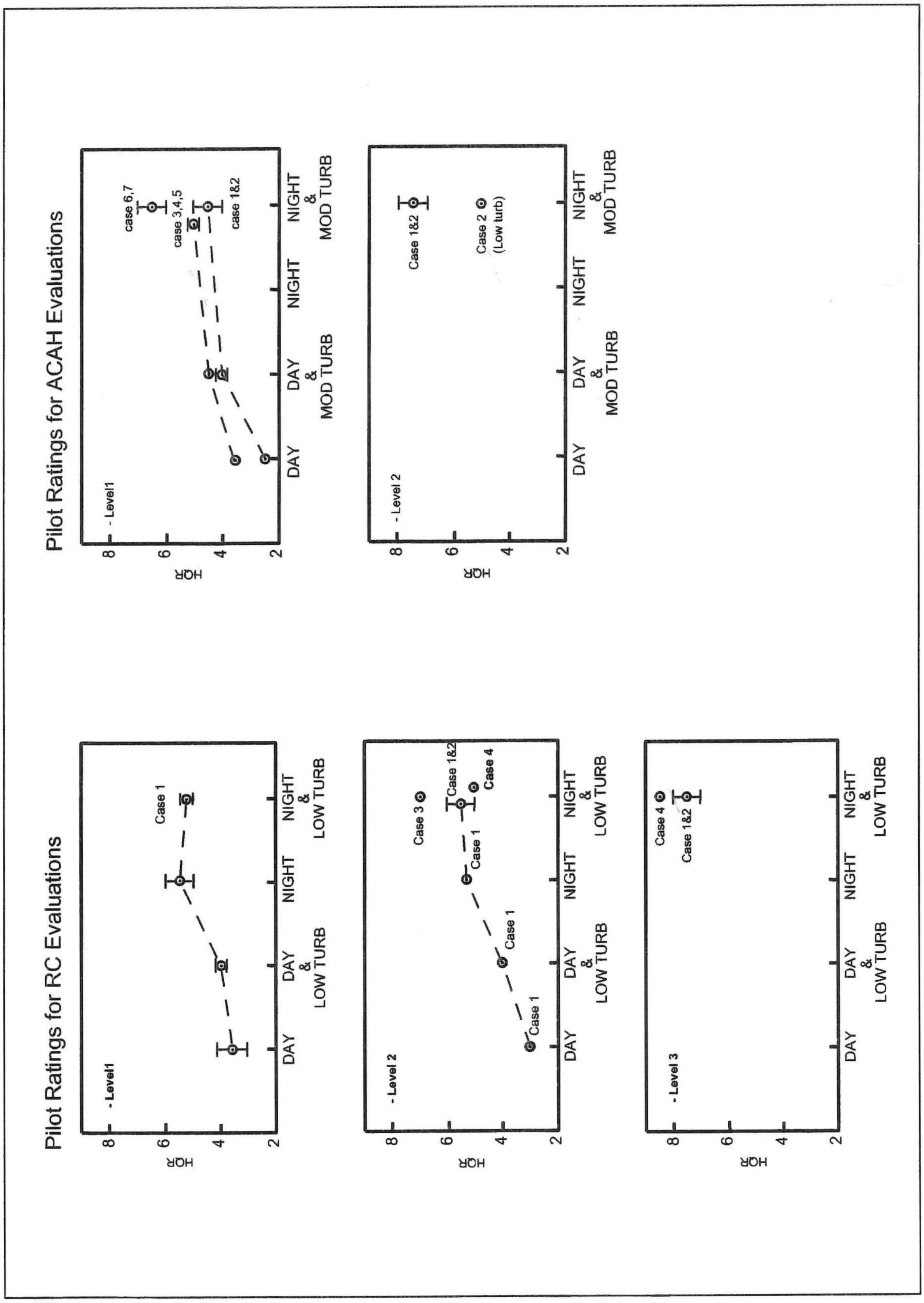


Figure 10 Handling qualities ratings for the 6 degree approach task

Table 1 ADS-33 large amplitude criteria

MISSION TASK ELEMENT	RATE RESPONSE -TYPES						ATTITUDE RESPONSE -TYPES			
	MINIMUM ACHIEVABLE ANGULAR RATE (deg/sec)						MINIMUM ACHIEVABLE ANGLE (deg)			
	LEVEL 1			LEVELS 2 AND 3			LEVEL 1		LEVELS 2 AND 3	
	q	p	r	q	p	r	θ	ϕ	θ	ϕ
Limited Manoeuvring All MTEs not otherwise specified	±6	±21	±9.5	±3	±15	±15	±15	±15	±7	±10
Moderate Manoeuvring Rapid transition to precision hover; Slope landing; Shipboard landing;	±13	±50	±22	±6	±21	±9.5	+20 -30	±60	±13	±30
Aggressive Manoeuvring Rapid accel and decel; Rapid sidestep; Rapid hovering turn; Rapid slalom; Target acquisition and tracking; Pullup / pushover; Rapid bobup-bobdown.	±30	±50	±60	±13	±50	±22	±30	±60	+20 -30	±30

Table 2 Simulation trial test matrix

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

Table 3 6 degree approach MTE task definition

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.
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.
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 centre-line - Maintain a steady deceleration and rate of decent 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 10m x 10m - 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