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Some Lessons Learned in Three Years with ADS-33C

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ABSTRACT

Three years of using the U.S. Army's rotorcraft handling qualities specification, Aeronautical Design Standard – 33, has shown it to be surprisingly robust. It appears to provide an excellent basis for design and for assessment, however, as the subtleties become more well understood, several areas needing refinement became apparent. Three responses to these needs have been document in this paper: (a) The yaw-axis attitude quickness for hover target acquisition and tracking can be relaxed slightly. (b) Understanding and application of criteria for degraded visual environments needed elaboration. This and some guidelines for testing to obtain visual cue ratings have been documented. (c) The flight test maneuvers were an innovation that turned out to be very valuable. Their extensive use has made it necessary to tighten definitions and testing guidance. This was accomplished for a good visual environment and is underway for degraded visual environments.

INTRODUCTION

Aeronautical Design Standard – 33 (ADS-33C) (Ref. 1) was adopted in August 1989. Since that time, it has been used in several programs which cover the spectrum of possible applications. These include a full flight test evaluation of a current Army helicopter (Apache), full design application and simulator assessment of the competing designs for LHX, which later evolved into Comanche, analytical evaluations using high fidelity math models for the Black Hawk and Sea Hawk, and flight tests of several aircraft including the OH-58D and the BO-105. Such application early in its lifetime is a specification writer's dream. We can already see the influence modern handling qualities concepts are having on new design and assessment methods and we also get feedback on criteria which need more work, or topics which need more guidance to enable users to understand and apply the methodologies. This paper describes some of the results of efforts to resolve questions on three topics that have arisen during the last three years.

The first topic covered is attitude quickness. The evolution of this new requirement is outlined. Several experiments were performed to enhance the database, and a proposed revision to a yaw-axis boundary in hover has been developed.

The second topic treated is related to Degraded Visual Environment (DVE). To handle the Army's need to fight at night, as well as, or perhaps even more than during the day, a new concept was introduced into ADS-33C which relates the required helicopter flying qualities to degradations in the visual cuing. A definition of DVE is provided and the methodology of obtaining Visual Cue Ratings (VCR's) and relating these to required Response-Types through the concept of Usable Cue Environment (UCE) is described. Particular guidance is presented for pilot briefing notes and questionnaires to help in obtaining consistent VCR's.

Since degraded visual cuing is usually encountered on ground-based simulators even when trying to simulate day, the basic concept of UCE has been extrapo-

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lated to calibrate simulators; the methodology, called SIMulated Day UCE (SIMDUCE), is described.

The last topic described is refinement of the flight test maneuvers. These were introduced into the handling qualities specification to provide guidelines for an overall assessment of the design. They have turned out to be a major item used by the test and assessment community, and also as a primary goal for the designer. In applying these tests, it was realized that they needed to be defined more precisely for repeatability, and also the standards needed to be well-justified. In addition, guidance was clearly needed on how elaborate the test maneuver cuing and test performance documentation had to be. The progress made for both the day and the DVE maneuvers is described.

ATTITUDE QUICKNESS

The ADS-33C is a mission-oriented specification, based upon mission task elements (MTE's) and the cuing available to the pilot. Minimum requirements are established for control Response-Types and their characteristics. These requirements are categorized into terms of small, moderate, and large amplitude changes. The moderate amplitude requirements include the attitude quickness criteria, where attitude quickness is defined as the ratio of peak angular rate to the change in angular attitude. ADS-33C establishes minimum Levels of attitude quickness for pitch, roll, and yaw depending upon the speed range and MTE (see Fig. 1).

Criteria Development

Most of the background and the initial supporting data for the attitude quickness requirement came from a helicopter roll control study (Ref. 2). The basis for the requirement was extracted from "maneuver performance" diagrams that were constructed from a number of discrete lateral maneuvering tasks. For a maneuver that requires discrete control inputs, the ratio of peak angular rate to change in attitude for the entire maneuver describes a "task signature" related to the pilot's demands on the vehicle. For small attitude changes, the value of attitude quickness is dominated by the bandwidth criteria. For large attitude changes, the attitude quickness is dominated by the large amplitude requirements. The attitude quickness requirements effectively connect the frequency-domain bandwidth limits at small amplitudes with the time-domain peak angular rate limits at large amplitudes.

Since Reference 2 was specifically a roll control study, there was no information for setting the pitch limits, and therefore, some assumptions were made for the pitch requirements. The extrapolation to the pitch axis was fairly well justified given the well-substantiated small and large amplitude pitch requirements and the attitude quickness formulation technique based upon the roll axis.

Initially the yaw-axis attitude quickness boundaries were based upon the same procedure as pitch. Recently, an in-depth piloted simulation study was performed by the Aeroflightdynamics Directorate (AFDD) at Ames Research Center to provide an improved basis for the yaw-axis boundaries. The simulation, performed on the NASA-Ames Vertical Motion Simulator (VMS), examined the yaw attitude quickness in hover while performing a target acquisition task and a 180 degree turn task. Configuration bandwidth and attitude quickness were varied via the yaw damping derivative and the tail rotor collective pitch actuator rate limit.

The results from the target acquisition in hover task suggest that the current ADS-33C yaw-axis attitude quickness boundaries might be relaxed without sacrificing Level 1 handling qualities (see Fig. 2). The results from the 180 degree turn in hover task indicate that relaxation of the attitude quickness requirement indicated by the target acquisition in hover task would not adversely impact the pilot's ability to perform large, aggressive heading changes. These refined yaw attitude quickness boundaries will be included the new version of ADS-33C.

Compliance Testing

The attitude quickness requirement states that the attitude changes must be made as rapidly as possible from one steady attitude to another without significant reversals in the sign of the cockpit control input relative to the trim position. The initial attitudes and the attitude changes required for compliance shall be representative of those encountered while performing the required mission task elements. It should be noted that the attitude changes should be made "open-loop," i.e., without a specific target attitude and as rapidly as possible.

The recommended control input for a Rate command Response-Type is to utilize spike (or very short duration pulse-like) inputs of varying magnitude to produce the necessary range of attitude changes. For the larger attitude changes it is acceptable to initiate the changes from a non-level equilibrium, e.g., a large roll attitude change may be initiated from a positive or a negative bank angle.

The recommended control input for an Attitude command Response-Type is to initially overdrive the commanded attitude followed by an essentially steady value of the stick consistent with the commanded attitude. The purpose of this control strategy is not to provide lead equalization, but simply to overcome the inherent stability of the attitude command response. On the other hand misleading results can be obtained if significant control reversals from the trim position are allowed. This technique is not representative of rotorcraft alone dynamics and is more a measure of the pilot skill in timing the inputs. In fact, using significant control reversals to quicken the response and arrive at a steady attitude change is like having the pilot closing the angular rate and attitude loops just like a Stability Control Augmentation System (SCAS), and of course, paying the penalty in terms of workload. The purpose of this requirement is to specify the rotorcraft dynamics without pilot equalization, and hence, significant control reversals are not allowed during compliance demonstration. In general, control reversals are not considered significant if the control reversals are significantly less than the initial input.

DEGRADED VISUAL ENVIRONMENT (DVE)

Helicopters are inherently unstable. The flight control system can change this, but current-generation aircraft typically only enhance rate damping so the pilot is still left with the task of constant manipulation of the controls to maintain attitude. It must be realized that this is primarily a visual task. Unlike riding a bicycle, it is not possible to balance the helicopter solely using vestibular cues. This means that the pilot needs good visual cues, not only for guidance, that is, to see where he is going and avoid obstacles, but also for control and stabilization. It has been found that the stabilization needs can be reduced or almost eliminated if the appropriate stability is build into the helicopter. Such a flight control system is, of course, more elaborate and expensive than a simple rate damping system, and hence the handling qualities specification had to devise a scheme for informing the designer when he had to change to the more elaborate system. The process involves defining the Degraded Visual Environment (DVE), obtaining a Visual Cue Rating (VCR), and hence, defining the Usable Cue Environment (UCE), and this in turn is related to the flight control system Response-Type. Some of the questions that have arisen in applying this methodology will be addressed in this section.

DVE is an environment in which the pilot of a Level 1 Rate response helicopter cannot get adequate visual cues to perform maneuvers aggressively and precisely. This can occur because there are reduced or few cues for him to see, such as over desert, snow, or water, or because he cannot see the features that are there because of a lack of illumination, such as at night, or because of obscuration, such as in smoke, dust, fog, or restricted cockpit field of view. Vision aids such as night vision goggles (light intensification) or infrared devices such as the helmet mounted FLIR help compensate for some of these deficiencies, but can introduce deficiencies of their own such as reduced resolution, remotely located eye point, slow tracking dynamics, and vibration of the scene image.

Visual Cue Rating (VCR)

The VCR scale was developed as a basis for quantifying the UCE. It is a subjective pilot rating scale intended to quantify the usability of the visual cue environment for stabilization and control during low-speed and hover operations near the ground. The basis for this scale is discussed in detail in Reference 3. It has been in use for over six years, and experience has shown that certain procedures must be followed to achieve repeatable and valid pilot ratings. These procedures are still being developed and refined as the scale is used for new applications. This evolution is similar to the Cooper-Harper subjective pilot rating scale (Ref. 4). Early use of that scale resulted in significant pilot rating scatter because the importance of certain procedures were not understood. When the established procedures are carefully adhered to (see Ref. 5) this subjective rating scale is reliable and repeatable. This experience emphasizes the importance of identifying and implementing proper procedures in the use of subjective pilot rating scales.

The cues required for aggressive and precise low-speed and hover operations are not well understood by pilots or engineers. Therefore, it is not possible to assess them directly. The VCR scale is an attempt to circumvent this gap in the knowledge base by making an assessment of the cuing environment in terms of the pilot's ability to accomplish aggressive and precise maneuvers with an aircraft that would be Level 1 in a good visual environment (GVE). The scale is shown in Figure 3. Factors to be considered to ensure that the test aircraft is Level 1 are discussed under SIMDUCE in this paper.

The descriptions in Figure 3 have been slightly modified from those shown in the current version of ADS-33C to eliminate any reference to the word "cues." This is based on experience that has shown that pilots are tempted to evaluate their perception of the cues rather than their ability to achieve the noted aggressiveness and precision. That experience has shown that pilot perceptions of visual cues are usually excessively optimistic. For example, essentially all pilots feel that hovering will be no problem when sitting in the cockpit of a modern ground-based simulator and visual system before it is put into operate. They are surprised to find that a simple hover task requires extreme concentration, or may not even be possible without considerable practice. Experiments have resulted in evidence that pilots rely heavily on fine-grained texture to hover and maneuver in low-speed flight (Ref. 3). Such "micro-texture" is not available in most digital image generators, and in cockpit vision aids in marginal conditions (e.g., night vision goggles on a moonless night).

To get a measure of the UCE, ADS-33C specifies that the following Flight Test Maneuvers be performed, and VCR's be assigned: Hover (4.4.1), Vertical Landing (4.4.3), Pirouette (4.4.4), Acceleration and Deceleration (4.5.1), Sidestep (4.5.2), and Bob-up and Bob-down (4.5.3). The VCR's are to be assigned while attempting to achieve desirable performance in the DVE where the DVE is to be specified by the procuring activity. The following guidelines have been established for assigning the VCR's and should be a part of any pilot briefing where such ratings are to be given.

Pilot Briefing Notes

Assign the ratings based only on the ability to be precise and aggressive.

Use the precision hover and vertical landing tasks as primary measures of precision.

Aggressiveness should be considered in the context of mission performance and may not require large aircraft attitudes. Consider the ability to stabilize quickly at the end of the pirouette, sidestep, and acceleration/deceleration maneuvers as a good measure of aggressiveness. Any tendency to "back out of the loop" to avoid undesirable oscillations should be considered as in inability to be aggressive.

Do not try to make a distinction between the aircraft dynamics and the visual cuing environment that is being evaluated.

Try to meet the desired performance standards for most of the maneuver. Small deviations from the desired performance limits should not be a primary factor in the evaluation. However, an inability to aggressively correct back to the desired region without exciting undesirable aircraft excursions or oscillations should be cause to consider the fair-to-poor region of the scales.

If the evaluation is being made on a ground-based simulator, do not try to extrapolate to the "real world"; rate what you see.

It is a good idea to assign Cooper-Harper handling qualities ratings (HQR's) during the UCE testing. There should not be a significant discrepancy between the VCR's and the HQR's. For example, if the VCR's are between good and fair (1 to 3) it would be expected that the HQR's would be no worse than five. If the VCR's are in the fair-to-poor range (3 to 5), HQR's of five or worse would be expected.

The UCE testing should be accomplished in an environment where the cues for desired and adequate performance are reasonable and consistent with purpose of performing the task. For example, testing the precision hover task in a large field, with minimal cues for position, bears no relationship to the task that established the requirement in the first place. Such requirements are driven by mission-related tasks, such as hovering in confined areas where the cues representing obstructions are not subtle. This aspect is treated in more detail in the section discussing the flight test maneuvers. The purpose of the UCE testing is to establish the ability to be precise and aggressive with respect to realistically sized and located objects.

The inability to achieve good VCR's can usually be traced to a lack of visible details, and should not be related to the inability to see obstructions soon enough, such as when driving a car too fast in fog. Such issues cannot be resolved with improved handling qualities and should be evaluated separately.

A separate set of VCR's should be assigned for each task. It is recommended that the pilot practice the task at least twice before conducting the evaluation run. The VCR's may be averaged across pilots, but may not be averaged across tasks.

One final point, it has been observed that there are a very select group of pilots who can hover and precisely maneuver with poor visual cues when most pilots cannot. Ideally, they should be aware of their unusual capabilities and give ratings accordingly.

SIMULATED DAY UCE (SIMDUCE)

During the evolution of the design process and evaluation of new rotorcraft designed for compliance with ADS-33C, ground-based simulation will likely occur. Visual systems with computer generated imagery (CGI) and their associated presentation device(s) are typical for ground-based flight simulators. Initially, these visual systems lacked field of view, resolution, and detail, and their dynamic response was sometimes less than optimum. For example, the poor resolution in an early visual system is illustrated in Figure 4 from Reference 6. Although the quality of visual cues has improved as the technology has advanced, simulated day scenes still do not compare with the real-world day scene. This observation is illustrated by the fact that good Rate command Response-Types continue to receive Level 2 handling qualities on ground-based simulators whereas, in-flight they typically receive solid Level 1 ratings.

To quantify the quality of the simulated day visual cues for handling qualities work, a technique of using the VCR-UCE concept has been applied. We call this SIMulated Day UCE (SIMDUCE). With a Level 1 Rate response model, if the cues are as good as they would be during the daytime, SIMDUCE = 1. If the SIMDUCE = 2 or 3, it is roughly equivalent to having Level 2 or Level 3 handling qualities. The procedure for determining the SIMDUCE follows the same approach as the UCE evaluation with the exception that the day maneuvers and performance standards are used for the evaluation instead of the DVE maneuvers and standards. So to obtain an overall assessment of the simulator, the following Flight Test Maneuvers of ADS-33C should be flown: Hover (4.1.1), Vertical Landing (4.1.3), Pirouette (4.1.4), Rapid Acceleration and Deceleration (4.2.1), Rapid Sidestep (4.2.2), and Rapid Bob-up and Bob-down (4.2.3). While performing these maneuvers, VCR's are collected from which a SIMDUCE is determined. The VCR collection and consolidation procedures for SIMDUCE are the same as for the UCE determination.

Level 1 Rate Response Helicopter

In performing the UCE determination, the ADS-33C states that the test rotorcraft must meet the requirements for a Rate Response-Type and must have a Level 1 mean pilot rating by at least three pilots operating without any vision aids in good visual conditions (UCE=1) and negligible turbulence. This concept was established with the idea of performing this test in-flight and not necessarily on a ground-based simulator. The potential hitch in the process when using a ground-based simulator is the establishment and documentation of the Level 1 aircraft. Implementing a Rate Response-Type is not difficult, but even if all the ADS-33C requirements are met there are additional parameters which can result in poor handling qualities such as control sensitivity and inceptor force-displacement characteristics. The ADS-33C guidance for conventional controls force-displacement characteristics are quite comprehensive, and if met, the handling qualities are likely to be good if tests are conducted to optimize the sensitivity. Unfortunately, the same cannot be said of multi-axis side sticks where many unspecified characteristics could cause a degradation. This another topic which needs elaborating in ADS-33C.

FLIGHT TEST MANEUVERS

Motivation for Flight Test Maneuvers

A selection of maneuvers is specified to provide an overall assessment of the rotorcraft's ability to perform certain critical tasks. It is recognized that although quite comprehensive, the state of knowledge is such that the quantitative criteria in Section 3 are not sufficient to guarantee that the handling qualities will be Level 1. Some important characteristics, such as control sensitivity are not specified, and a poor choice could easily result in poor handling qualities. The requirements have been formulated with the philosophy that each one is necessary, and not meeting any one will be sufficient to result in a degradation in the handling qualities. Hence, it was decided that some overall "proof of the pudding" should be applied to ensure that the combination of characteristics result in good handling qualities for some tasks important to that aircraft's role.

The flight test maneuvers are not comprehensive in terms of tasks or flight conditions. However, they do include critical task elements which could be encountered in many applicable missions. They include single-axis and multi-axis tasks for each direction, and for different levels of aggression. In addition, sets of maneuvers are provided for Day and for DVE.

Experience in Application

Significant experience has now been gathered on the application of the maneuvers in ADS-33C. The two primary examples are the LHX assessments performed on each of the competing teams' simulators during the Demonstration Validation (Dem Val) program, and the flight test evaluation of the AH-64 Apache. References 7 and 8 describe these efforts in some detail, so only a few of the topics which influenced the evolution of the criteria will be mentioned here.

LHX Dem Val – As part of ADS-33C, the flight test maneuvers were included in the contract so they became benchmarks which had to be met. As such, they became design drivers, but for nearly all of the maneuvers the only way they could be assessed was subjectively in piloted simulation. This put considerable pressure on simulation fidelity/validity assessment. It also showed-up any ambiguities or vagueness in the criteria. Some of the reactions were as follows: Systematic application required specifying adequate standards, not just desired. The precision with which some of the maneuvers were defined allowed the pilots to adopt different levels of aggressiveness, thus resulting in different pilot ratings. With insufficient cuing, the pilots did not know if they had met the performance standards. Such a lack of cues was clearly unrealistic since the need for precision would usually mean that there were constraints nearby which would be providing the cues. The defined performance standards had a big effect on pilot rating, so the chosen standards must be meaningful. Accuracy of performance standards suggested that the eventual flight test program would involve some very expensive test equipment to demonstrate compliance.

Apache flight tests – Flight testing reinforced most of the overall impressions developed on the simulators during LHX Dem Val. However, the simulation related issues went away, and new issues related to flight testing became apparent. For example: Some of the aggressive maneuvers (Fig. 5), especially in DVE, were quite thrilling and resulted in much philosophical debate. Though perhaps not universally accepted yet, it is the authors' opinion that if these stylized maneuvers are representative of maneuvers which will be performed by the Army in operational use, then the flight test community must be willing to test them. Certainly, if they are too dangerous for a skilled test pilot to perform in a tightly controlled environment, it is unreasonable to expect the user to fly such maneuvers in an unfamiliar, unfriendly environment in the fog of war.

The need for simple solutions to cuing and compliance issues was re-emphasized. Some solutions were developed which served to achieve the desired intent, but clearly more work was required.

Overall, these results showed that the flight test maneuvers were important. Not only were they well accepted by the test community, but they were given even more influence than initially intended. In view of this, it was decided to make an effort to refine the maneuvers and resolve the questions that had been raised.

Objectives of Refinement

The objectives of the maneuver refinement effort were focused in the following four areas:

Maneuver Definition – To refine and standardize the definition of the maneuvers so that the written descriptions can be easily understood, and will be repeatable by different pilots in different organizations.

Performance Standards – To ensure that the level of precision and aggressiveness for Level 1 (desired performance) was appropriate, and to generate a valid set of standards for Level 2 (adequate performance).

Cuing Requirements – To define test courses and suitable cuing. The important characteristics here were that there should be sufficient cuing, but that it should be kept simple and therefore cheap and easy to reproduce. Also, to allow considerable flexibility for the flight test organization to make modifications as needed to accommodate their own particular capabilities or limitations.

Compliance Methods and Documentation – An additional constraint on the cuing was that it must be useful for showing compliance. In particular, to provide guidance on the type and scope of instrumentation to be used so that it was clear to the flight test organization that they did not need multi-million dollar laser tracking or GPS systems.

New Maneuvers- Good Visual Environment

This section describes the maneuver refinement effort approach, lists the new maneuvers, and describes one of them in detail.

Approach – Flight tests were performed by the Flight Research Laboratory of the Institute for Aerospace Research, National Research Council of Canada, using their variable-stability Bell 205 airborne simulator (Fig.

6). In addition, help and expertise was provided by engineers and test pilots from the U.S. Army's Airworthiness Qualification Test Directorate (AQTD). Each of these pilots and engineers had experience in the LHX or Apache tests so their inputs were extremely valuable.

The approach was to discuss the aim of each task and the possible approach for meeting it. The tasks were then flown and pilot comments and performance data reviewed. If necessary the tasks were revised and re-flown. Finally two pilots who had not been part of the task development were asked to perform the maneuvers working only from the written description.

The tasks were performed using three configurations: one which just met the Level 1 quantitative requirements of ADS-33C, one well within the Level 2 region, and one just inside the Level 3 boundary. The pilots gave Cooper-Harper HQR's and these were expected to correspond with the configuration "Levels" inferred from the quantitative standards. Further details are described in Reference 9.

Since the Bell 205 is limited in maneuverability, it was necessary to develop the aggressive and high speed maneuvers in a different aircraft. Such tests were performed using similar techniques, only without any changes to the basic flying qualities, by AQTD on a UH-60, and a T-34. The T-34, a fixed wing training aircraft was particularly useful for evolving the air-to-air maneuvers.

New Maneuvers – Table 1 summarizes the major revisions made to the maneuvers. In addition to refinements to the existing maneuvers, several new maneuvers were added. These primarily addressed aggressive maneuvering tasks, both in hover and forward flight.

The Precision Hover task illustrates many of the factors treated. The Appendix shows the current and revised versions of the maneuver, and Figure A-1 in the Appendix is a sketch of the suggested cuing devices in the test course.

In the original maneuver definition, it was found that although the task of achieving the desired hover point was quite likely to cause higher pilot workload than the actual hover, it was not part of the task that was evaluated. To rectify this, the maneuver was modified to start some distance from the desired hover point and a 45-degree crabbing translation made to the hover point.

To force some uniformity in the task aggressiveness, the time to reach hover, and the nature of the deceleration are defined.

Other details changed were: The maneuver is to be performed in calm (< 5 knots) and moderate (20 to 35 knots) winds; To change the hover target from a circle to a square since this would be easier to cue the pilot and for observers to check; The use of any available hover assists was allowed if they were available and consistent with operational use; Adequate standards were generated with looser tolerances and less aggressive time requirements; The simple cuing props, illustrated in Figure A-1 of the Appendix, gave sufficient guidance for the pilot to be able to tell if the required standards were being achieved. The same cues could be used by outside observers and onboard video recording to document the performance for compliance demonstration purposes.

New Maneuvers- Degraded Visual Environment (DVE)

The day maneuvers have now been reviewed and revised several times and are now considered to provide excellent benchmarks. The maneuvers for Degraded Visual Environment (DVE) are less refined, but two efforts are underway to refine them.

The first effort involves a simulation performed by AFDD on the NASA Ames Vertical Motion Simulator (VMS). The CGI representation of the proposed cuing for DVE was set up with a UCE=2. The various tasks were flown with a Level 1 and Level 2 Attitude Command Attitude Hold (ACAH) Response-Types, and also with a Level 1 Rate command. The pilot performance and pilot commentary was obtained in much the same way as done at the National Research Council of Canada for day. The results are still being analyzed, but Figures 7-10 shows some preliminary data for the Hover task.

As would be expected, the Level 1 rate configuration shows frequent excursions into the adequate region (Fig. 7) and the Cooper-Harper HQR was Level 2.

With a Level 1 ACAH response (Fig. 8), the pilots were essentially within desired standards and the rating was 2.8, clearly Level 1. Figure 9 shows all of the runs for pilot 6 whereas, the other figures only show the last three runs for each pilot. It is interesting to note that the pilot took several runs to achieve the desired performance. It appears as though he first increased the aggressiveness to achieve the desired time and then worked on maintaining his longitudinal precision.

Figure 10 shows what happens with a Level 2 ACAH response. Aggressiveness is only adequate, longitudinal precision frequently is worse than desired, and the spread for lateral error increases noticeably though it is generally in the desired range.

Overall it would appear that the standards chosen for this task are compatible with the Level achieved. The reduction in aggressiveness for night operations does not seem unwarranted; the precision standards were the same as day in the horizontal plane, but loosened very slightly for altitude ($\pm$ 2 ft became $\pm$ 3 for desired and $\pm$ 4 ft became $\pm$ 5 ft for adequate.)

The second effort at refinement is a joint Army/NASA project to actually fly the tasks in a real DVE, that is, at night. An Army AH-1G Cobra helicopter (Fig. 11) equipped with the Apache Integrated Helmet and Display Sight System (IHADSS) is operated at the NASA Ames Research Center in various joint Army/NASA research tasks. This is not a variable-stability helicopter so it will not be possible to assess the Level 1 standards in the DVE. The Cobra is a Rate Response-Type with essentially Level 1 ratings for day; it would be expected to be Level 2 in a UCE=2. The aircraft will be used to evaluate the other aspects of trying to perform these evaluations at night. Topics of concern are the details of cuing when using night vision goggles or FLIR, how to calibrate the degraded visual environment, and how to perform the necessary compliance assessment and documentation. These efforts are currently underway and the flight test program is expected to be performed by about March 1993.

CONCLUSIONS

Three years of using the U.S. Army's rotorcraft handling qualities specification, Aeronautical Design Standard – 33 (ADS-33C) has shown it to be surprisingly robust. It appears to provide an excellent basis for design and for assessment, however, as the subtleties become more well understood, several areas needing refinement became apparent. Three responses to these needs have been documented in this paper:

(a) the yaw-axis attitude quickness for hover target acquisition and tracking can be relaxed slightly.

(b) understanding and application of criteria for degraded visual environments needed elaboration. This and some guidelines for testing to obtain visual cue ratings have been documented.

(c) the flight test maneuvers were an innovation which turned out to be very valuable. Their extensive use has made it necessary to tighten definitions and testing guidance. This has been done for good visual environment and is underway for degraded visual environments.

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Table 1. Overview of Major Revisions to ADS-33C Section 4 Flight Test Maneuvers

ADS-33C	MAJOR REVISIONS
4.1 Precision Tasks 1. Hover 2. Hovering Turn 3. Vertical Landing 4. Pirouette 5. Slope Landing	Hovering Turn ~ changed to a precision maneuver tighter position stds and longer time to complete Vertical Ldg. ~ renamed Precision Landing ~ decreased position tolerance and vertical displacement ~ increased time to complete
4.2 Aggressive Tasks 1. Rapid Acceleration and Deceleration 2. Rapid Sidestep 3. Rapid Bob-up and Bob-down 4. Pull-up/Push-over 5. Rapid Slalom 6. Transient Turn 7. Roll Reversal at Reduced and Elevated Load Factor	Accel/Decel ~ relaxed pos'n and altitude tolerance Bob-up/dn ~ increase req'd height change and time to complete Pull-up/Push-over ~ increase req'd "g's" to OFE ADDED New Maneuvers: Vertical Remask Deceleration to Dash Aggressive Turn to Target (old HT) High and Low Yo-Yo
4.3 Decelerating Approach to Hover	
4.4 Precision Tasks in DVE 1. Hover 2. Hovering Turn 3. Vertical Landing 4. Pirouette	
4.5 Moderately Aggressive Task in the DVE 1. Acceleration and Deceleration 2. Sidestep 3. Bob-up and Bob-down 4. Slalom	Accel/Decel ~ relaxed pos'n and altitude tolerance Bob-up/dn ~ increase req'd height change and time to complete

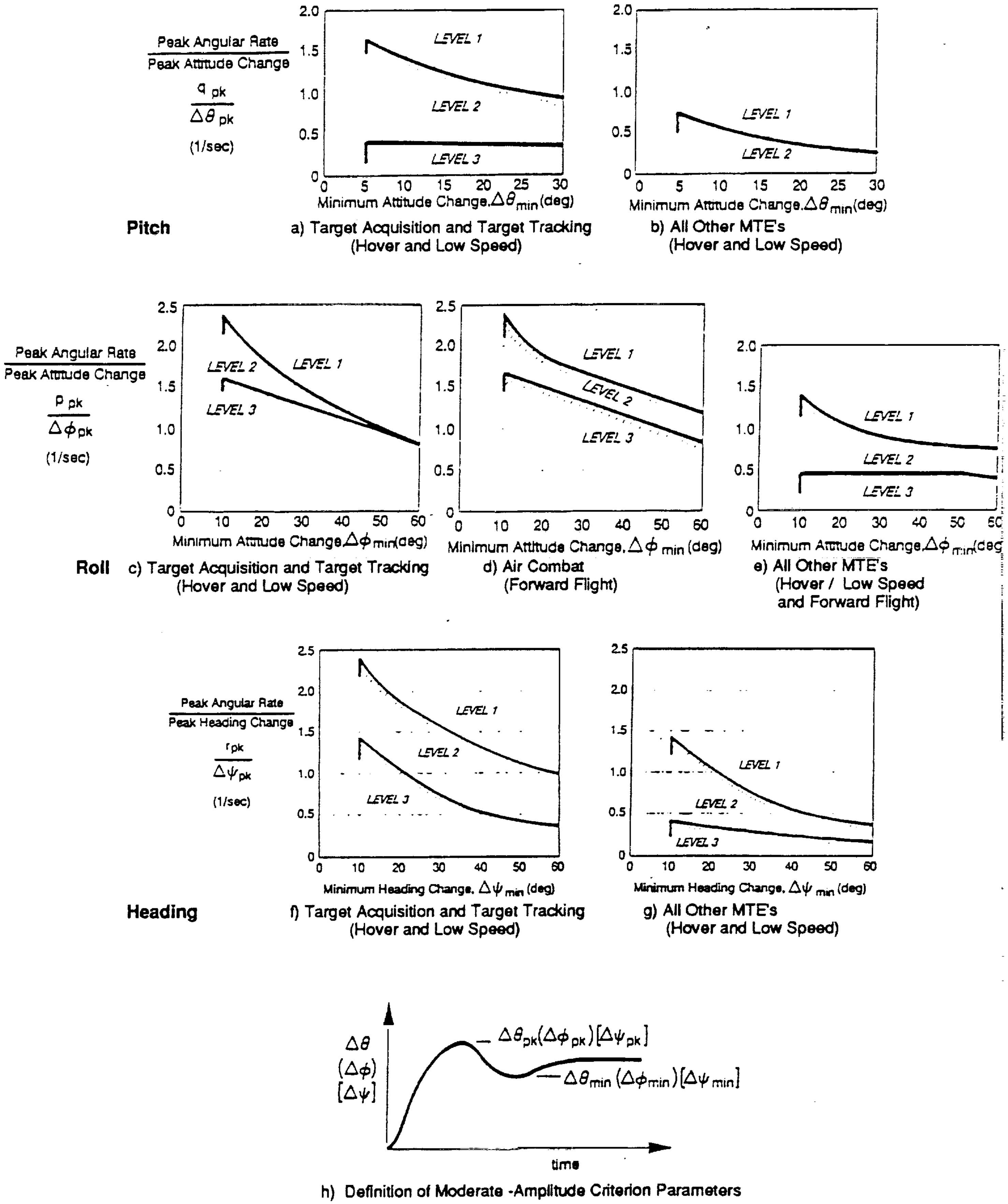


Figure 1. Requirements for Moderate Amplitude Attitude Changes (Attitude Quickness)

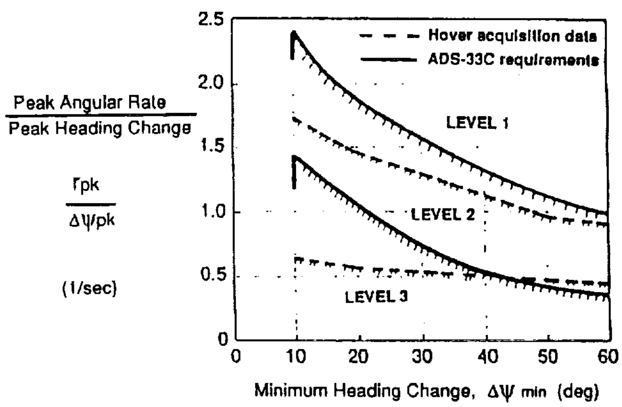


Figure 2. Refined Heading Attitude Quickness Boundaries for Target Acquisition and Tracking (hover/low speed).

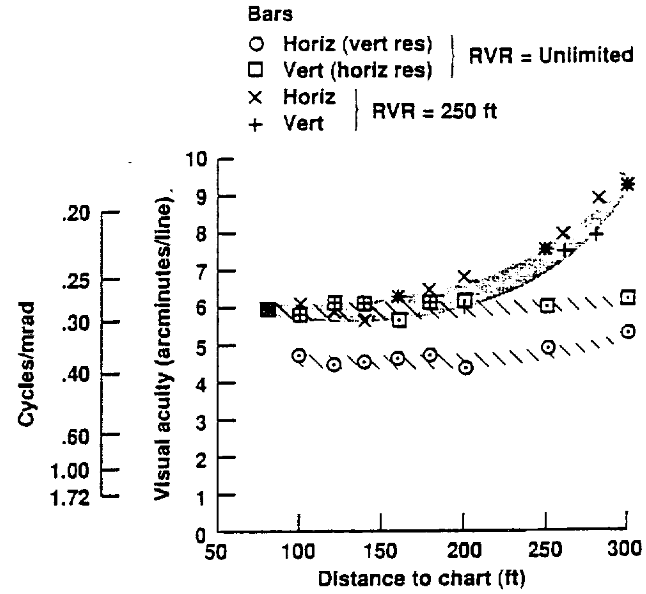
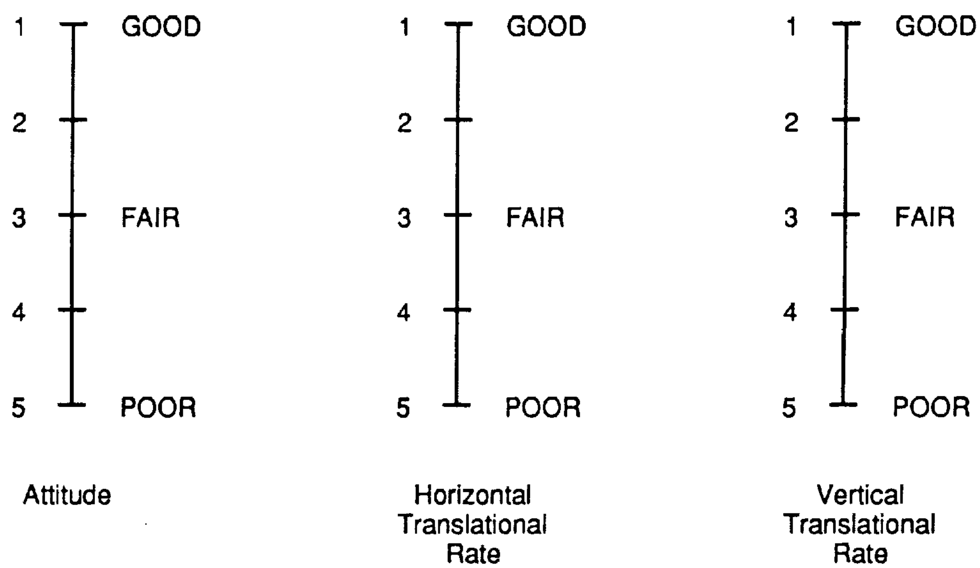


Figure 4. Resolution Results from the VMS Singer-Link DIG 1 (from Ref. 6).



Pitch, roll, and yaw attitudes, and lateral-longitudinal and vertical translational rate shall be evaluated for effectiveness for stabilization and control according to the following definitions:

GOOD: Can make aggressive and precise corrections with confidence and precision is good.

FAIR: Can make limited corrections with confidence and precision is only fair.

POOR: Only small and gentle corrections are possible and consistent precision is not attainable.

Figure 3. Modified Visual Cue Rating (VCR) Scale to be Used When Making UCE Determinations.

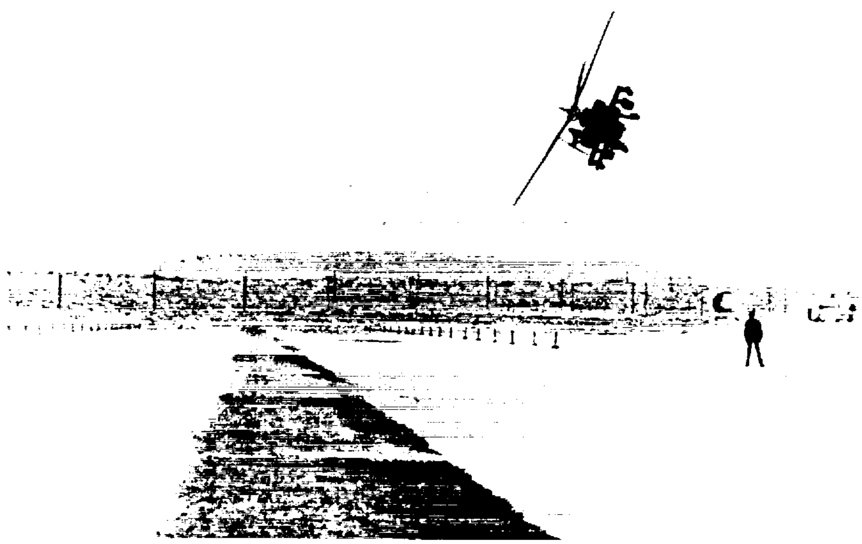


Figure 5. AH-64 Apache Performing ADS-33C Rapid Slalom.

Figure 6. IAR Variable-Stability Bell 205 Airborne Simulator

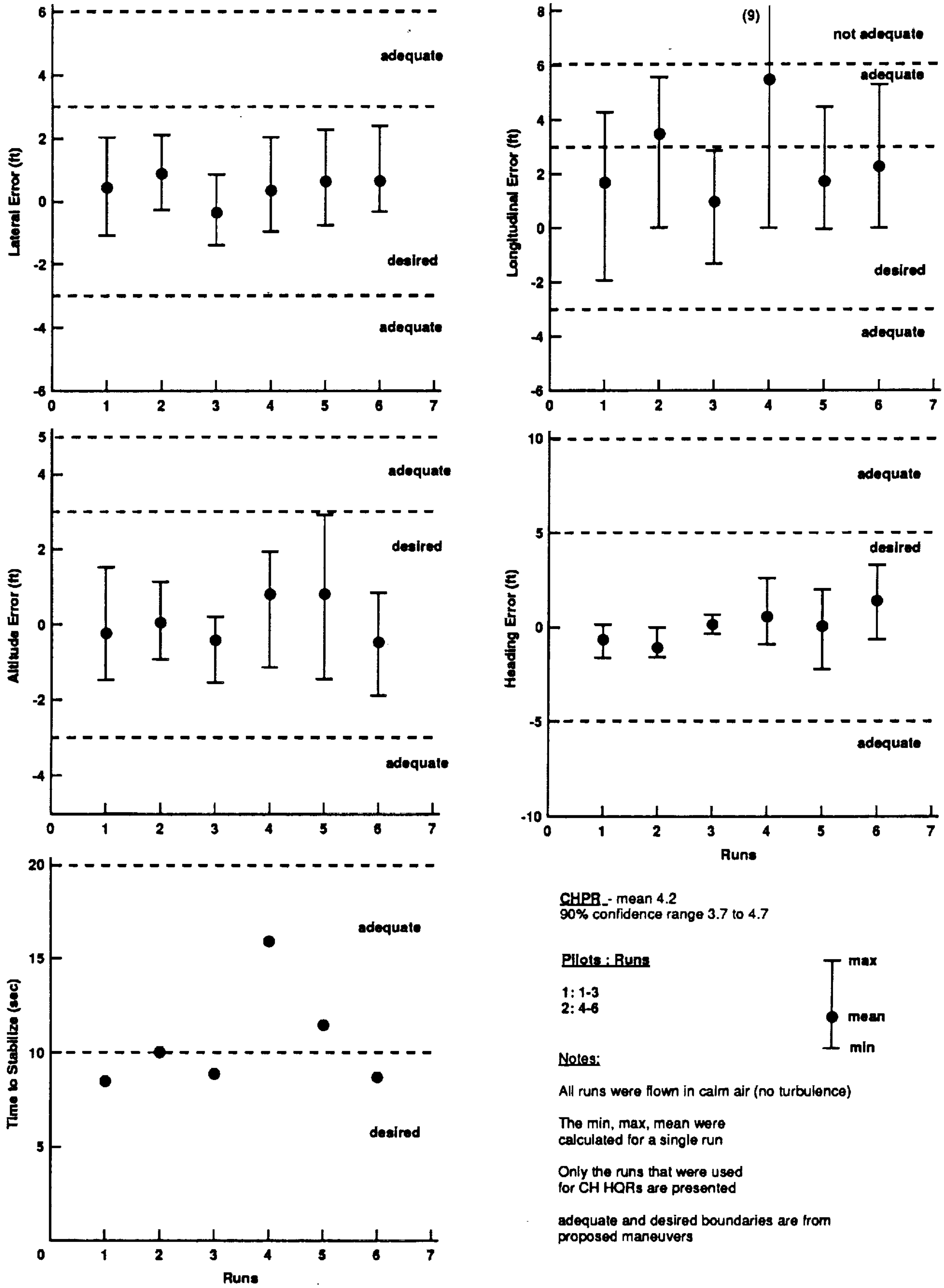


Figure 7. Hover task, Level 1 Rate Command Response-Type

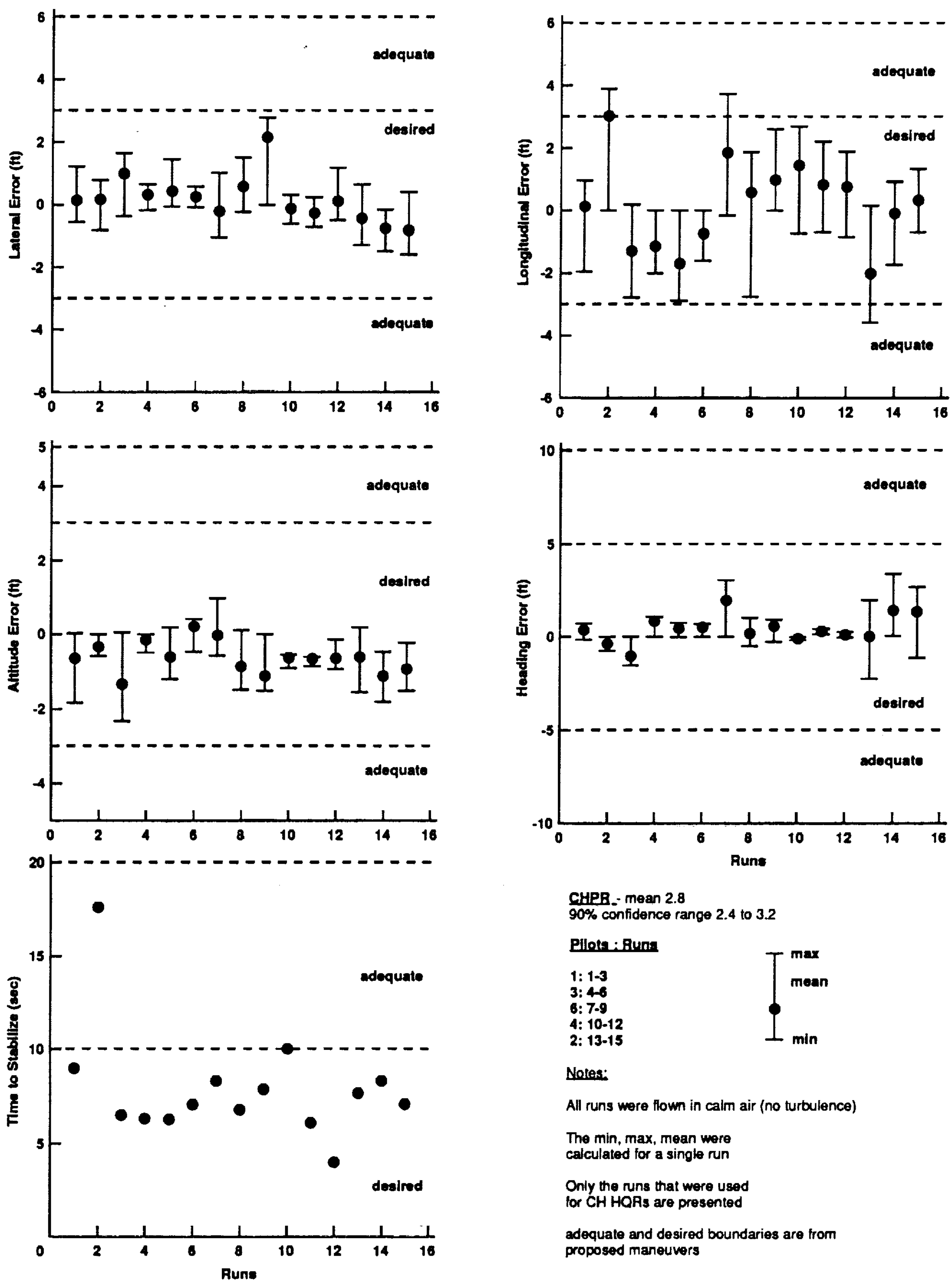


Figure 8. Hover task, Level 1 Attitude Command Attitude Hold (ACAH) Response-Type

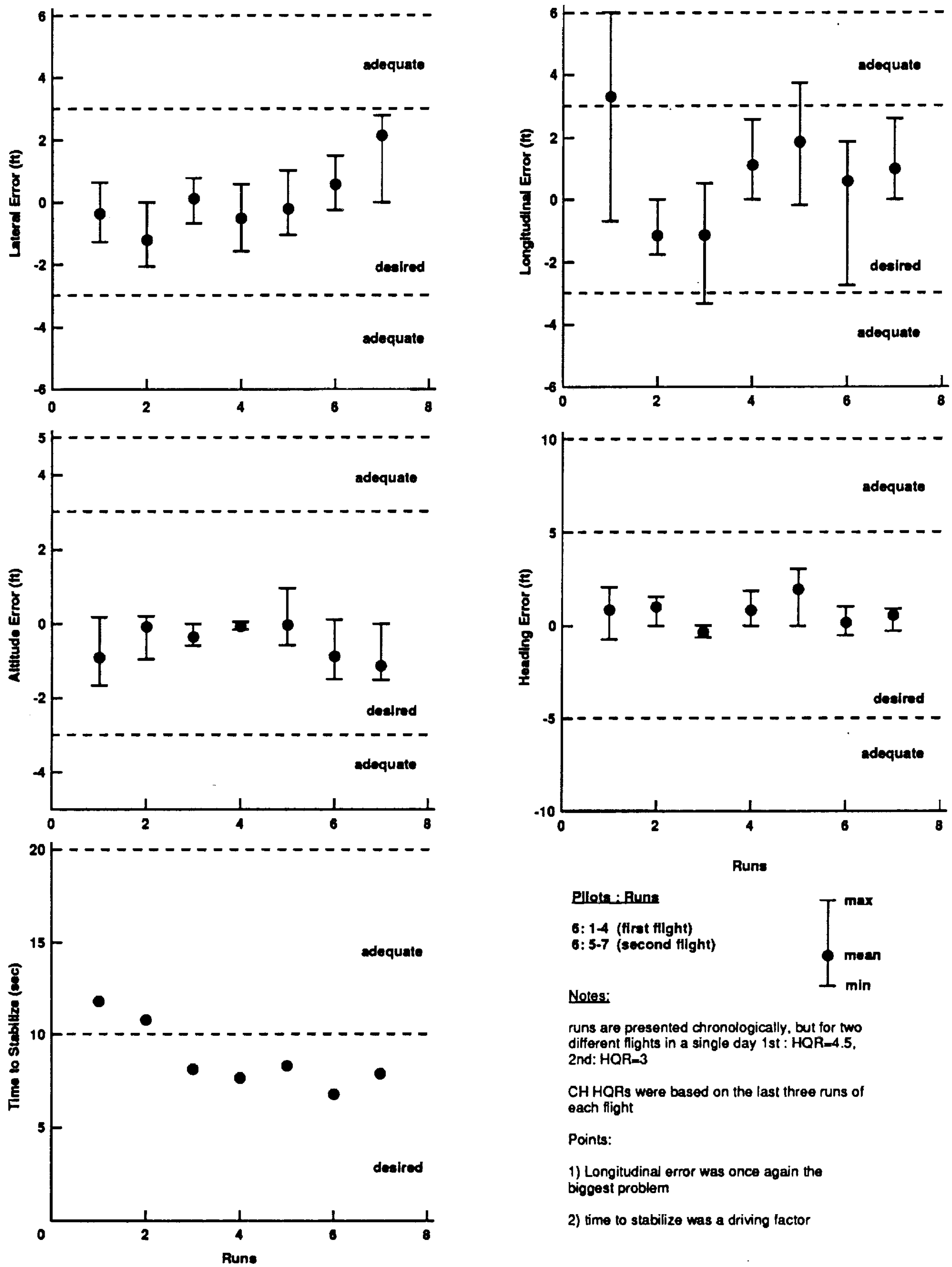


Figure 9. Hover task, Level 1 ACAH Response-Type – Effect of Training

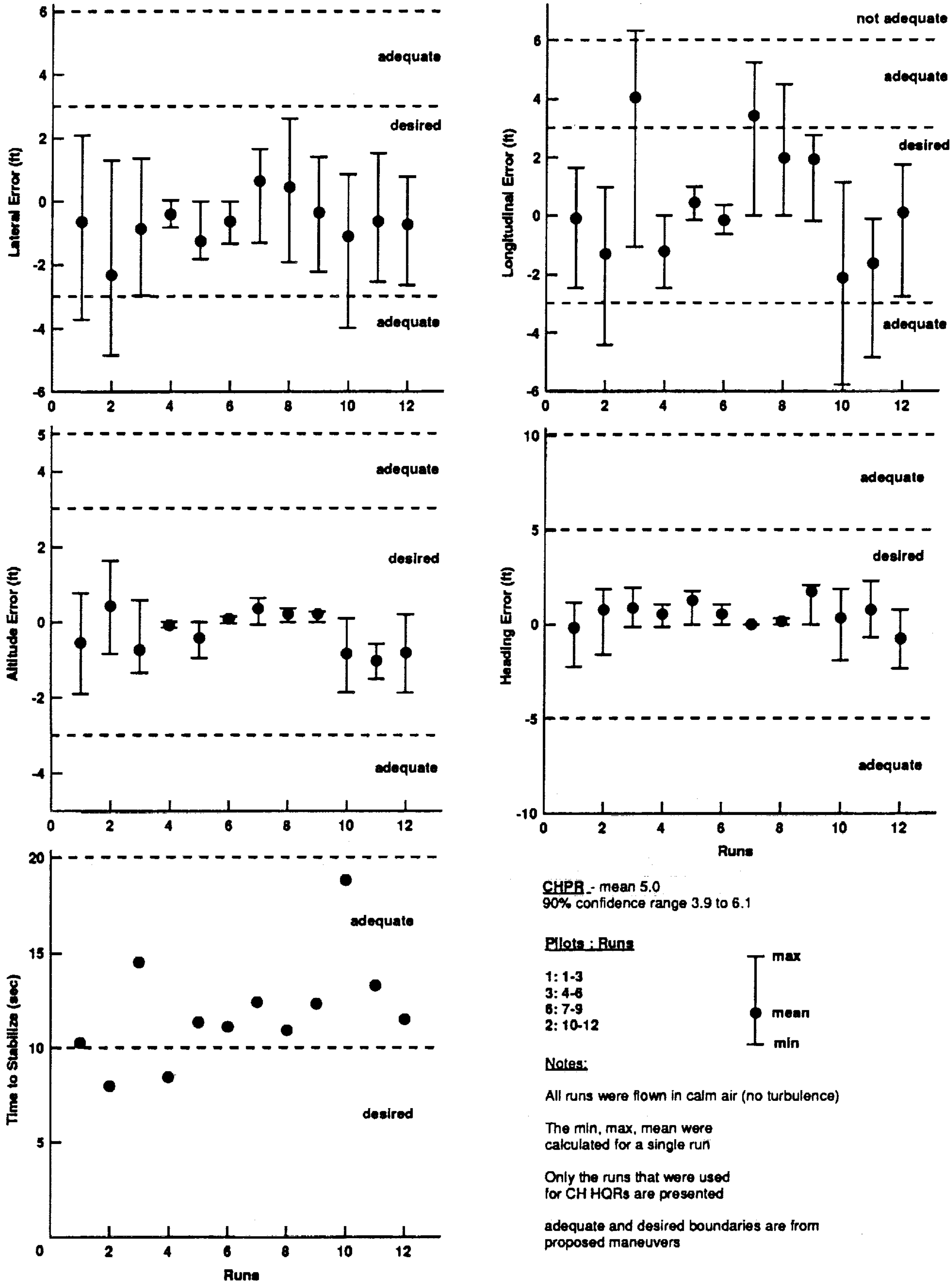


Figure 10. Hover task, Level 2 ACAH Response-Type

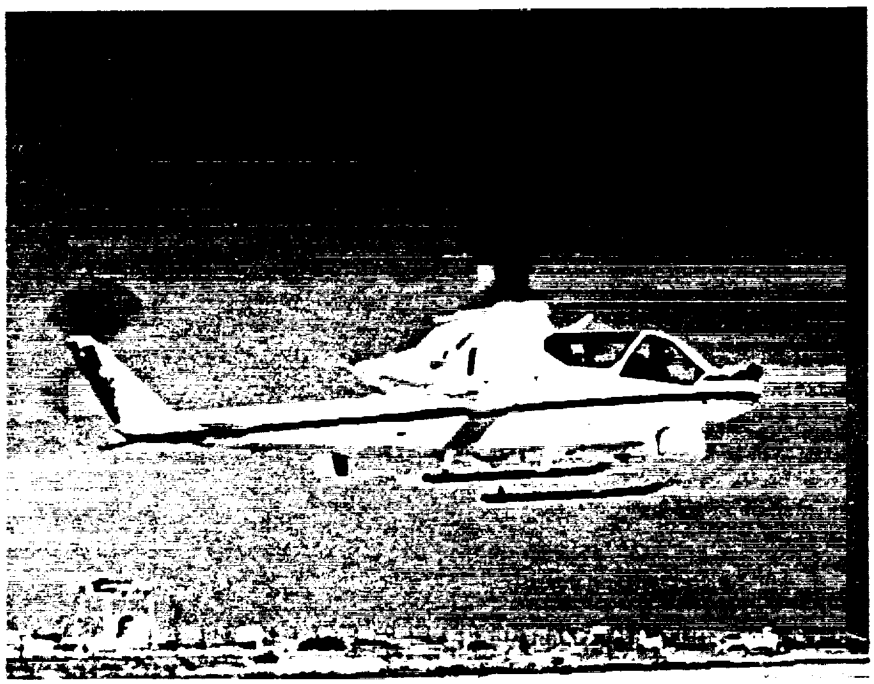


Figure 11. Army/NASA AH-1G Cobra Equipped with Apache IHADSS

APPENDIX

4.1 PRECISION TASKS (DAY)

ADS-33C TASK DEFINITION

4.1.1 Hover. Maintain a precision hover for at least 30 sec in winds of at least 20 knots from the most critical direction. If a critical direction has not been defined, the hover shall be accomplished with the wind blowing directly from the rear of the rotorcraft. The hover altitude shall be equal to or less than 6.1m (20 ft).

Desired Performance

- Maintain horizontal position of the pilot's station within 0.91m (3 ft) of a reference point on the ground.
- Maintain altitude within ± 0.61m (2 ft).
- Maintain heading within ± 5 degrees.
- There shall be no objectionable oscillations in any axis. In particular, oscillations which interfere with precision control, or with operation of controls or switches, would be deemed objectionable.

NEW PRECISION TASK DEFINITION

4.1.1 Hover.

Objectives

Check ability to transition from translating flight to a stabilized hover with precision and a reasonable amount of aggressiveness.

Check ability to maintain precise position, heading, and altitude in the presence of a moderate wind from the most critical direction.

Description of Maneuver

Initiate the maneuver at a ground speed of between 6 and 10 knots, at an altitude less than 6.1m (20 ft). The desired hover point shall be oriented approximately 45 degrees relative to the heading of the aircraft. The ground track should be such that the aircraft will arrive over the target hover point (see illustration in "description of test course"). The maneuver is to be accomplished in calm and moderate winds from the most critical direction. If a critical direction has not been defined, the hover shall be accomplished with the wind blowing directly from the rear of the rotorcraft. This maneuver is to be performed with any available hover or position hold functions turned on.

Description of Test Course

The suggested test course for this maneuver is shown in Figure A-1. Note that the hover altitude depends on the height of the reference symbol, and the distance between that symbol, the hover-board, and the helicopter. These dimensions may be adjusted to achieve a desired hover altitude.

Desired Performance

- -- The transition to hover should be accomplished in one smooth maneuver. It is not acceptable to accomplish most of the deceleration well before the hover point and then to creep up to the final position. The time from the initiation of deceleration to a stabilized hover must not exceed 3 seconds.
- -- Transition to the stabilized hover should be such that once the rotorcraft is within the hover box (see Fig. A-1), it should remain within that volume for at least 30 seconds.
- -- Maintain the longitudinal and lateral position within ± 0.91m (± 3 ft) of a point on the ground and altitude within ± 0.61m (± 2 ft). Keeping the hover reference symbol within the desired box on the hover board (Fig. A-1) will insure desired lateral and vertical performance.
- -- Maintain heading within ± 5 degrees.
- -- There shall be no objectionable oscillations in any axis either during the stabilized hover, or the transition to hover.

Adequate Performance

- -- The transition to the stabilized hover should be accomplished in one smooth maneuver. It is not acceptable to accomplish most of the deceleration well before the hover point and then to "creep up to" the final position. The time from the initiation of deceleration to a stabilized hover must not exceed 8 seconds.
- -- Transition to the stabilized hover should be such that once the rotorcraft is within the hover box (see Fig. A-1), it should remain within that volume for at least 30 seconds.
- -- Maintain longitudinal and lateral position within ± 1.83 m (± 6 ft); see test course description.
- -- Maintain altitude within ± 1.22 m (± 4 ft).
- -- Maintain heading within ± 10 degrees.

4.4 PRECISION TASKS IN THE DEGRADED VISUAL ENVIRONMENT

The following precision maneuvers shall be flown in the Degraded Visual Environment (DVE) specified in Paragraph 3.1.1, and using the displays and vision aids which will be available to the pilot. The wind conditions may be calm, but it would be desirable to demonstrate the maneuvers in stronger winds.

ADS-33C TASK DEFINITION (DVE)

4.4.1 Hover. Maintain a steady hover at an altitude of not more than 6.1 m (20 ft) above the ground.

Desired Performance

- -- Maintain horizontal position of the pilot station within 0.9 m (3 ft) of a reference point on the ground.
- -- Maintain altitude within ±0.91 m (3 ft).
- -- Maintain heading with ±5 degrees.
- -- There shall be no objectionable oscillation in attitude or position.

NEW TASK DEFINITION

4.4.1 Hover.

Objectives

Check ability to transition from translating flight to a stabilized hover with precision and a reasonable amount of aggressiveness in the DVE.

Check ability to maintain precise position, heading, and altitude in the DVE.

Description of Maneuver

Initiate the maneuver at a ground speed of between 6 and 10 knots with the desired hover point oriented approximately 45 degrees relative to the heading of the aircraft. The ground track should be such that the aircraft will arrive over the target hover point (see illustration in "description of test course").

Description of Test Course

The suggested test course for this maneuver is shown in Figure A-1. Note that the hover altitude depends on the height of the reference symbol, and the distance between that symbol, the hover-board, and the helicopter. These dimensions may be adjusted to achieve a desired hover altitude. The hover board will have to be modified from Figure 4.1 to reflect the increased altitude tolerances allowed for the DVE.

Desired Performance

-- The transition to hover should be accomplished in one smooth maneuver. It is not acceptable to accomplish most of the deceleration well before the hover point and then to creep up to the final position. The time from the initiation of deceleration to a stabilized hover must not exceed 10 seconds.

-- Transition to the stabilized hover should be such that once the rotorcraft is within the modified hover box (see Fig. A-1), it should remain within that volume for at least 30 seconds.

-- Maintain the longitudinal and lateral position within $\pm$ 0.9 m ($\pm$ 3 ft) of a point on the ground and altitude within $\pm$ 0.91 m ($\pm$ 3 ft). Keeping the hover reference symbol within the desired box on the modified hover board (Fig. A-1) will insure desired lateral and vertical performance.

-- Maintain heading with $\pm$ 5 degrees.

-- There shall be no objectionable oscillations in any axis either during the stabilized hover, or the transition to hover.

Adequate Performance

-- The transition to the stabilized hover should be accomplished in one smooth maneuver. It is not acceptable to accomplish most of the deceleration well before the hover point and then to "creep up to" the final position. The time from the initiation of deceleration to a stabilized hover must not exceed 20 seconds.

-- Transition to the stabilized hover should be such that once the rotorcraft is within the modified hover box, it should remain within that volume for at least 30 seconds.

-- Maintain longitudinal and lateral position within $\pm$ 1.83 m ($\pm$ 6 ft); see test course description.

-- Maintain altitude within $\pm$ 1.53 m ($\pm$ 5 ft).

-- Maintain heading within $\pm$ 10 degrees.

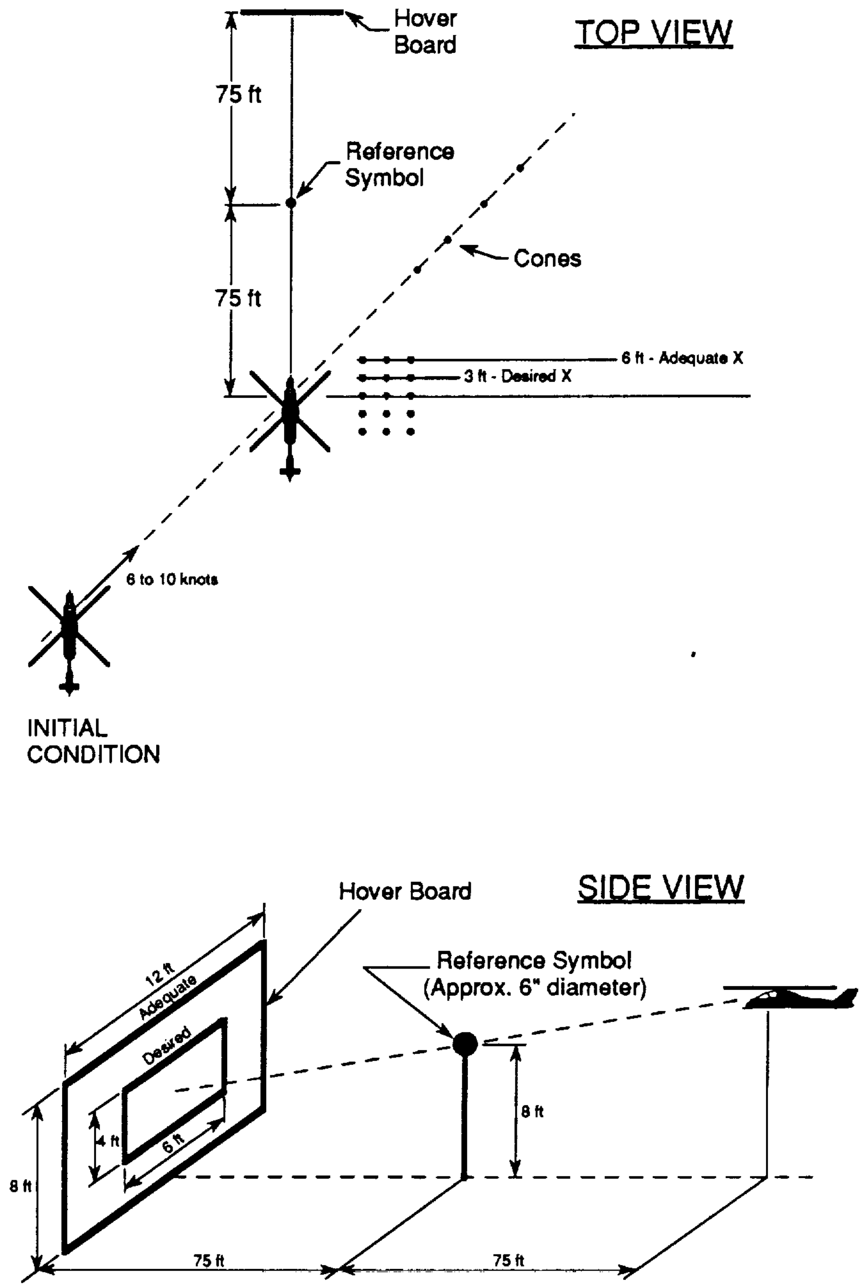


Figure A-1. Suggested Precision Hover Task Cuing and Standards.