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ADS-33C Related Handling Qualities Research Performed Using the NRC Bell 205 Airborne Simulator

J.Murray Morgan
Stewart W.Baillie

Flight Research Laboratory
Institute for Aerospace Research
National Research Council
Canada

ABSTRACT

Over 10 years ago a project was initiated by the US Army AVSCOM to update the military helicopter flying qualities specification MIL-8501-A. While not yet complete, the project reached a major milestone in 1989 with the publication of an Airworthiness Design Standard, ADS-33C. The 8501 update project initially set out to identify critical gaps in the requisite data base and then proceeded to fill them using a variety of directed research studies. The magnitude of the task required that it become an international effort: appropriate research studies were conducted in Germany, the UK and Canada as well as in the USA. Canadian participation was supported by the Department of National Defence (DND) through the Chief of Research and Development.

Both ground based and in-flight simulation were used to study the defined areas and the Canadian Bell 205-A1 variable stability helicopter was used extensively as one of the primary research tools available for this effort. This paper reviews the involvement of the Flight Research Laboratory of the National Research Council of Canada in the update project, it describes the various experiments conducted on the Airborne Simulator, it notes significant results obtained and describes ongoing research associated with the project.

INTRODUCTION

For over 20 years, the Flight Research Laboratory (FRL) of the NRC has operated a Bell 205-A1 helicopter as a full authority fly-by-wire research aircraft. This aircraft has been used as a fundamental research tool for flight mechanics research at the laboratory, simulating a wide range of vehicle types (including fixed wing and lighter than air aircraft) but specialising in advanced rotorcraft topics. This long interest and the resulting expertise in the area of helicopter flight mechanics led to a natural symbiosis between the FRL and the US Army AVSCOM when it was required to update the US Military helicopter handling qualities specification, MIL-8501-A. The 8501 update program was announced by Key [1] in 1982 and while it has followed the general outline presented at that time, it has been affected by various changes in military emphasis and funding in the intervening years. A milestone in the process, but by no means the final one, was the publication of ADS-33C in 1989.

In cooperation with the US Army AVSCOM and NASA(Ames) the FRL, under the auspices of TTCP and with support and funding from DND, has been involved in the 8501 update process from the first. Not only have piloted experiments using the Bell 205 developed a considerable rotorcraft handling qualities data base, they have also served a significant role in 'ground truthing' the results obtained from experiments performed in the NASA(Ames) Vertical Motion Simulator (VMS). In addition to the independent experiments flown at the FRL, pilots from the laboratory participated as subjects in vari-

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ous VMS experiments, thus ensuring a measure of continuity and direct comparison between the two facilities. This was felt to be such an important factor that, to the extent possible, US military and NASA pilots who had participated in the VMS experiments were also invited to fly in the FRL studies.

While the activity spawned by the 8501 update project provided new direction, purpose and thrust to the FRL research program on rotorcraft handling qualities, it was not the beginning of such studies at this laboratory. Prior to the start of the 8501 update project, the most recent area of research had concentrated on the use of integrated side-stick controllers of various types and in various configurations (References [2] to [4]). Reference [4] also reports some initial work on yaw axis response types.

It is important to note the contribution made to this work by Systems Technology Inc (STI). This company, as the prime contractor to AVSCOM for 8501 update activities was responsible for the initial VMS experiments, the philosophical approach to the structure of the ADS-33C objective criteria and the introduction of the concept of a Useable Cue Environment (UCE), a metric used to describe, numerically and objectively, flight in Degraded Visual Environments. The STI principal investigator, Mr.R.H.Hoh took a full and active part in the design and execution of the initial bandwidth experiments at the FRL and cooperated frequently in most of the remaining studies.

This paper will provide a thorough review of those portions of the ADS-33C data base generated using the FRL Airborne Simulator. It will highlight the relationships between in-flight research and research conducted using ground based facilities. The specific studies to be discussed include:

- Control system bandwidth and sensitivity
- Vertical axis dynamics and installed thrust requirements
- Control system disturbance rejection requirements
- The effects of stick dynamics
- Useable Cue Environment (UCE) studies and flight in a Degraded Visual Environment
- The development of Part 4 flight test manoeuvres for use in a normal visual environment

Ongoing experiments concerning Part 4 manoeuvres in DVE and the potential of limited authority attitude SCAS in DVE will also be discussed.

The prime purpose of this paper is to provide a single reference point for the considerable Canadian contribution to the ADS-33C data base.

THE NRC AIRBORNE SIMULATOR

The Airborne Simulator operated by the FRL (Figure 1) is an extensively modified Bell 205-A1 single engine teetering rotor helicopter. It was acquired by the laboratory in 1969 and had been converted to the research configuration by early 1972. The modifications to enable this machine to operate in a fly-by-wire mode were extensive, the most significant being:

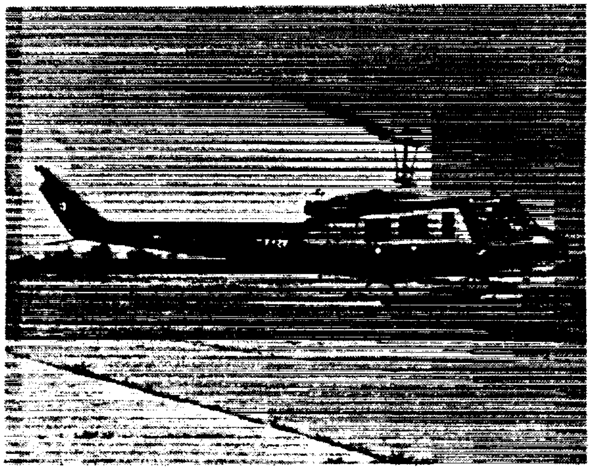

Figure 1: The IAR Airborne Simulator

- The normal 205 actuators were replaced by full authority dual mode (electrical or mechanically signalled) HR Textron HYDOMAT units. These actuators have approximately a 10 Hz bandwidth to small signals and a maximum rate of 100% per second under ground static conditions.
- The main rotor stabiliser bar was removed to improve dynamic response.
- The swash-plate to horizontal stabiliser linkage was removed and the stabiliser provided with

its own electrically signalled actuator. The stabiliser effectiveness was increased by sealing the fuselage/stabiliser gap with a faired-in plane surface.

- The pilot in command station was moved to the left side of the cockpit and the right station provided with a force feed-back control loading system with which to signal the flight computers. This system was provided with its own hydraulic system independent of the primary aircraft controls.
- A nose boom was added to carry airflow direction vanes and a swivelling static pressure sensor.

Fly-by-Wire System. The fly-by-wire (FBW) system in this aircraft is controlled by a hybrid digital/analogue general purpose computing system. This has been updated over the years to reflect changing computing technologies: it has changed in nature from a primarily analogue system to one in which all control functions are performed digitally, the analogue section being relegated to one or two display filtering or general purpose signal scaling functions.

The computer system reads a comprehensive suite of aircraft state sensors, the evaluation pilots control inputs (both primary inceptors and ancillary controls as required) and directly controls actuator commands and cockpit displays. Since very few constraints are placed on the control system logic and architecture, the project engineer has complete freedom in the design of feed-forward and feedback loops to attain the vehicle dynamics desired for a particular program

Safety of Flight Issues. The Bell 205 FBW system is both single string and experimental and therefore does not have adequate reliability to be permitted full time control of the aircraft. For safety of flight reasons, the aircraft operation revolves around a safety pilot. The safety pilot always remains in contact with all flight controls, even when an evaluator is in control of the vehicle. In the event of a system malfunction, the safety pilot has several methods available to him of disengaging the FBW system and reasserting full control of the aircraft. To assist the safety pilot there is a hardware monitoring system which will trip the FBW system in the event of power supply or hydraulic pressure failures and software monitoring of sensor consistency is also employed. The inherent 150 to 180 ms lags in the Bell 205 teetering rotor response coupled with over twenty years of experience in the aircraft make this approach to safety satisfactory for operations throughout the flight envelope and into the NOE environment. The experience of the laboratory in this aircraft indicates that there is greater danger from an evaluation pilot attempting to fly a poor model close to the ground than from any hardware or software errors that have ever been seen.

Performance and Limitations. The simulation flight performance envelope of an in-flight simulator is obviously subject to the performance limitations of the host aircraft, but the quality of the FBW system will determine the proportion of the overall flight envelope which is available to the experimenter. The FRL Bell 205 is routinely flown in the FBW mode throughout the entire envelope. Within the normal regime, the performance of the flight control systems depends primarily on available control power and inherent lags. By using fairly simple techniques to produce a compound feed-back signal comprising the aircraft's response at low frequency and that of a lag free model at high frequency, the effects of the natural aircraft lags can be nullified (See Figure 2), leaving the ultimate limitations on the dynamics available for a given experiment to those of control power versus the excitation of undesirable structural modes. The limited control power of a teetering rotor system plus the potential excitation of a fuselage/transmission oscillation (the Bell 205 mast rocking mode) limit the achievable

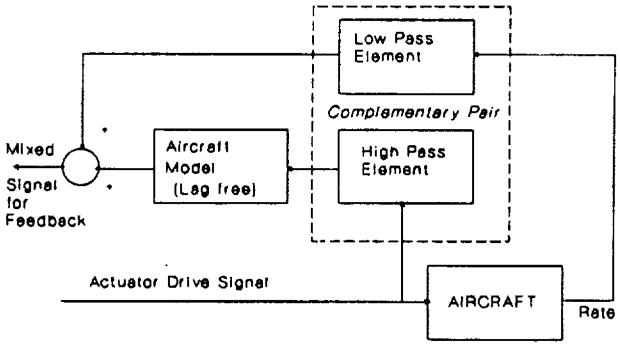

Figure 2: Compound Feedback Signal Arrangement

control bandwidths of the Airborne simulator to about 3.5 rad/sec laterally and 2.4 rad/sec in pitch. Yaw bandwidths of just over 2.5 rad/sec are also achievable.

A more complete, though somewhat dated in detail, description of the Airborne Simulator may be found at Reference [5].

RELATIONSHIPS BETWEEN IN-FLIGHT AND GROUND BASED SIMULATION

By its very nature, in-flight simulation is a difficult, costly and (compared to ground based simulation) of limited scope. The principle limitations to in-flight simulation arise from the nature of the task itself.

Without installing additional force and moment generators, the implementation of simulator models is restricted to those degrees of freedom over which the host aircraft offers direct control. The experimenter has to accept the aircraft's natural responses in the remaining freedoms. In the case of the FRL Airborne Simulator, it is impossible to modify the linear X and Y characteristics of the raw 205.

Secondly, since the evaluation is conducted in the real atmosphere, it is necessary to accept whatever disturbances exist at the time of flight. To an extent this problem can be overcome by choosing to fly only in very calm conditions and applying a known disturbing signal. While this is done for specific experiments which demand either no disturbances or a well understood disturbance pattern, it is far too restrictive a procedure for common use. The available research time would be very seriously depleted.

The final major limitation to in-flight simulation is the uncertainty which always exists regarding the nature of the plant under control and the current state of the host vehicle. What this means in practice is that, although quite precise design methods may be used to develop gain matrices for candidate control systems, the final outcome has to be identified by analysis of the vehicles's responses to a known exciting function. This is often an iterative process during the development stage of any study, consisting of control system design, measurement, adjustment and re-measurement.

The experimenter using ground based machines, on the other hand, has complete control over his model systems and the computed environment. However, he faces severe limitations on pilot cuing due to imperfect visual and motion systems, computer throughput times and other artifacts of the full simulation process. These deficiencies are very pronounced in the case of the helicopter simulations. It is generally accepted that helicopter pilots use very fine visual cues when operating at low speed near the surface, but whether these cues are primarily textural or kinematic is not well understood, nor are the mechanisms the brain uses to interpret them. To date it has not been possible to produce adequate visual cues for high precision tasks on any computer generated imaging system that this author has seen.

It is worth also considering another factor, the psychology of the pilot. In ground based simulation the pilot knows, albeit subconsciously, that he is ultimately not at risk whereas in the air that is not true: this may well have an effect on both the level of aggressiveness he is prepared to use in flying the tasks and the quality of control system he is prepared to accept.

By and large, experience has shown that handling qualities trends taken from ground based simulation are valid, but that the absolute values of the ratings achieved are *sometimes* not. Results from ground based simulation *often* tend to be conservative and this point will be emphasised later.

The remarks above suggest a natural complementary relationship between data from ground based and in-flight research. Although large matrix experiments can be conducted with relative ease in a ground based simulator, the results need to be examined closely for their validity due to lack of fidelity in the pilot's environment. In contrast, the smaller matrix experiments which lend themselves to in-flight testing have the advantage that the visual and motion cues are full scale and coherent, yet suffer from a range of uncertainties in implementation which are not a factor in ground based studies. It also follows that the in-flight simulator has a significant role in fundamental handling qualities research both in its own right and in the important task of anchoring data from ground based experiments into the actual flight regime. It is in this role that the FRL Airborne Simulator was first employed in support of the ADS-33C data base generation.

BANDWIDTH AND RESPONSE TYPE EXPERIMENT

This was the first formal experiment designed to generate a data base for ADS-33C performed on the Airborne Simulator; it was also the largest single study carried out in this program.

A 1984 experiment conducted in VMS (Reference [6]) used bandwidth and response type as major variables, and it was desired to validate these studies in actual flight. A total of 14 control systems were programmed into the Airborne Simulator, representing Rate, Rate Command/Attitude Hold and Attitude Command response types. The responses with respect to attitude were tailored to provide bandwidths over the ranges 0.85 to 2.7 rad/sec in pitch and 1.0 to 3.1 rad/sec in roll. It has been argued that these bandwidths are inadequate to represent modern rotor systems, however during the development of ADS-33C criteria the critical *minimum* bandwidths for the vast majority of tasks were determined to be within these ranges. The control system architecture was identical to that used in VMS and a similar set of tasks was used.

Since this study followed recent FRL work in the area of integrated side-stick control, the opportunity was taken to fly the experiment using both conventional controllers (cyclic and collective levers with yaw pedals) and a four function integrated side-stick. The experiment was initially reported in Reference [7], while the same data with a rather deeper analysis is to be found at Reference [8].

This experiment served as the foundation for the small amplitude manoeuvre bandwidth criteria to be found in ADS-33C and served in measure to define the response type requirements in the same document, at least for operations in normal visual conditions. It also emphasised the relationship between ground based and in-flight simulation regarding the need to relate data from ground based experiments to those conducted in actual flight. Figures (3 and 4), which have appeared in several publications, show that in flight, not only were the spreads of pilot ratings less than in VMS, indicating greater pilot confidence in their ability to evaluate the systems, but that the bandwidth requirements to obtain Level 1 handling qualities were lower by up to 3 rad/sec. This is most noticeable in the plot relating to the evaluation of attitude response types. The implications of the significantly lower bandwidth requirements are very far reaching. Bandwidth costs money, weight, structural stiffness and control system complexity.

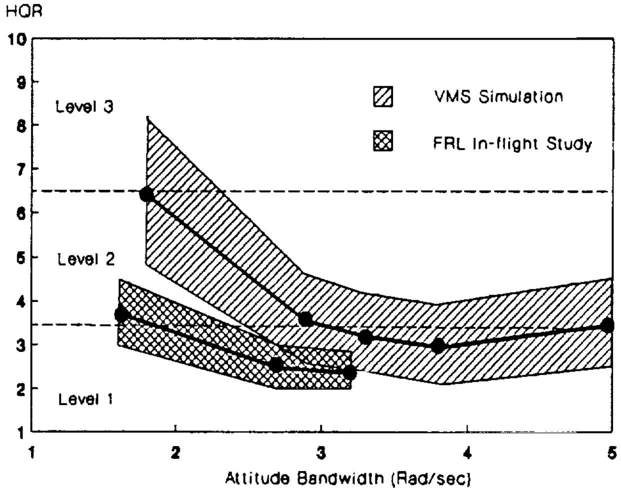

Figure 3: Flight/Ground Comparison, Attitude Command .

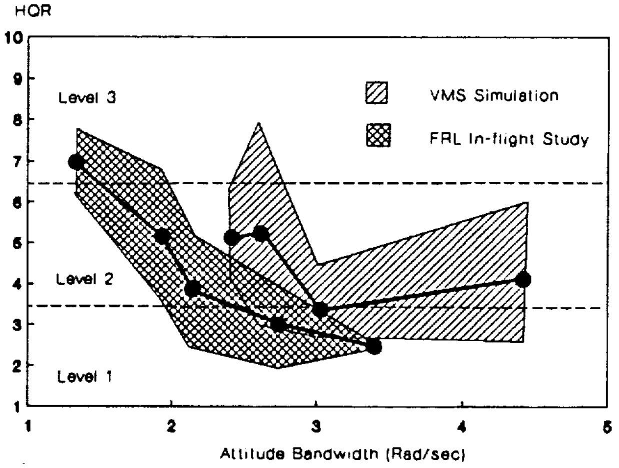

Figure 4: Flight/Ground Comparison, Rate Command

VERTICAL AXIS REQUIREMENTS

Two experiments in the 8501 update project concentrated on vertical axis requirements. The initial study concentrated on variations in heave damping and collective sensitivity (Reference [9]) while the second also considered the effects of thrust to weight ratio and the effects of engine/governor dynamics (Reference [10]). A more detailed analysis of data from these experiments can be found in Reference [11].

Again; following work already performed in VMS, these experiments were concerned with a topic already examined on the ground. The aircraft was configured with nominal pitch, roll and yaw control and airframe dynamics while the effective heave damping (Z_w), maximum thrust to weight ratio (T/W) and engine/governor/rotor dynamics parameters were varied.

Handling qualities ratings (HQR) of models which varied in Z_w and T/W showed that, in the airborne experiment, pilots were once again more tolerant of values which tended to degrade handling qualities than they were in VMS, however, the trends were the same. Figure (5), taken from Reference (10) demonstrates this point.

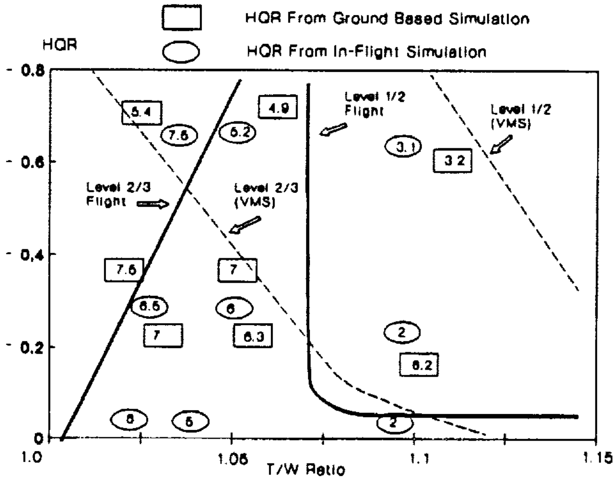

Figure 5: Suggested T/W v Zw Boundaries Ground and Flight

Led by the work of Corliss[12] and Hindson[13], typical engine/governor/rotor dynamic models were also evaluated on the Airborne Simulator. The sensitivity of HQR to torque monitoring workload became quite clear in this experiment. Analysis of the engine/governor/rotor models using the same criteria as those used by previous experimenters showed a significant discrepancy in predicted versus actual HQRs. Our own attempts to quantify a handling qualities boundary based on parameters related to the engine governor/rotor system dynamics was able to describe our observed trends in handling qualities ratings but overall the criterion was less than satisfactory. The authors of ADS-33C were able to coalesce handling qualities data from a variety of sources to develop an equivalent systems approach to defining the a more "satisfying" torque dynamics boundary. Each set of data, from VMS, the NASA CH-47 and the FRL 205 highlighted different areas of concern regarding the dynamics of torque in rotorcraft operations and all were reflected in the final specification.

FLIGHT IN DEGRADED VISUAL ENVIRONMENTS

It has long been recognised, if informally, that the helicopter pilot, unlike his fixed wing counterpart, has to operate for prolonged periods in visual conditions that are neither of the two traditional designations VMC or IMC. Whether it be night, fog, precipitation, dust, sand or snow, his problems are compounded in several ways, particularly in NOE flight. The task of stabilising today's helicopters when visual references are poor is known to be both difficult and dangerous. Every year the flight safety publications contain several reports of loss of control or inadvertent ground strike accidents caused by prolonged or inadvertent operations in such conditions. It has become important to the military philosophy that NOE operations should be possible under almost all conditions and within an acceptable risk envelope.

To facilitate the design of helicopters for which protracted operations in a degraded visual environment is a practical reality, it was necessary to examine the requirements for such flight. Following early work by Hoh [14], which resulted in the postulation of a system to quantify the level of visual cuing that the pilot had at his disposal from all sources, termed a useable cue environment rating

(UCE), experiments were performed in the Airborne Simulator to continue the research and further refine the concept. Since the primary concept of the UCE work was that the pilot stabilises the rotorcraft based on the full set of cues available to him, it was predicated that a degradation in the UCE was similar to a reduction in gains in or the order of a closed loop stabilisation system. To maintain overall system stability as the cue environment degrades, the obvious step is to augment the stability of the plant which the pilot is required to stabilise, in this case the uncommanded rotorcraft.

With this concept in mind a variety of configurations were developed for the Bell 205 ranging from the raw vehicle to a highly augmented vehicle possessing Translational Rate Command/Position Hold with Yaw Rate Command and Height Hold control systems (TRC/PH/HH). Night Vision Goggles, used in conjunction with day training filters and focus adjustments, were used to degrade the visual environment in which the pilot had to operate as were goggles with liquid crystal foggable lenses.

The handling qualities evaluations of a variety of low level tasks (Summarised in Figures 6 and 7) confirmed the tradeoff between uncommanded vehicle stabilisation and UCE. While rate response models were able to provide Level 1 handling qualities in good visual conditions (UCE = 1), only highly augmented configurations such as ACAH or TRC/PH/HH were able to produce the same results in degraded visual environments (UCE 2 or 3). A description of this study may be found at Reference [15].

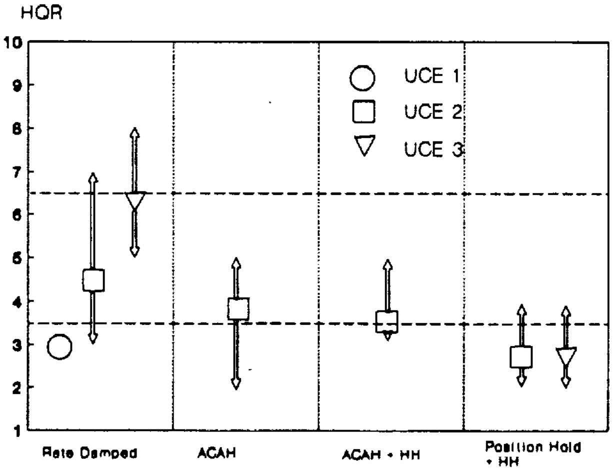

Figure 6: HQR v Augmentation, Stationary Tasks

Unlike previous examples mentioned in this paper, ground based simulation followed rather than led in-flight experimentation in this area. The associated VMS experiment (Reference [16]) corroborated the basic findings of the FRL study and was able to confirm some conclusions drawn from, but not fully justified by, the in-flight work. ADS-33C incorporates the UCE - augmentation tradeoff as the cornerstone for the entire handling qualities specification.

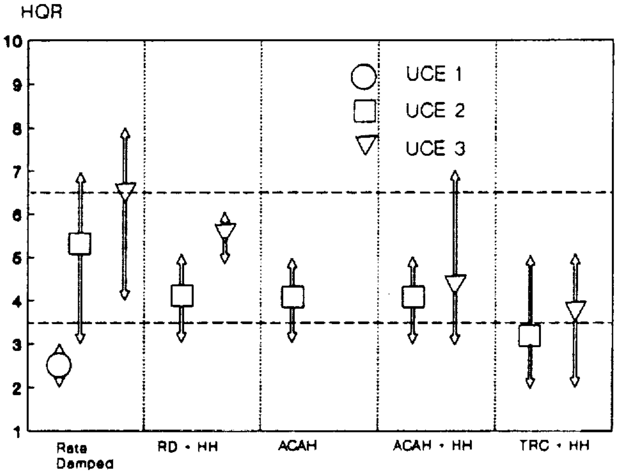

Figure 7: HQR v Augmentation, Manoeuvring Tasks

CONTROL SYSTEM DISTURBANCE REJECTION QUALITIES

In 1989 it became apparent that further in-flight data were required to confirm the bandwidth and, more importantly, the phase delay (τ_p) boundaries postulated after our previous experiments. There was a particular concern that the values of τ_p permitted for both Level 1 and level 2 boundaries were too high. Therefore, a second control bandwidth experiment was performed using the Airborne Simulator (References [17] and [18]). This differed from the first studies in that the elements of pilot selectable "optimum" sensitivity and the disturbance rejection characteristics of the control systems were considered in the evaluation matrix.

The previously determined bandwidth and phase delay handling qualities boundaries were confirmed by the evaluation data gathered during this study and so this area will not be discussed further. On the other hand, the novel feature of considering disturbance rejection capability as a rotorcraft handling qualities determinant should receive further attention.

It is clear that a closed loop control system with specific bandwidth and phase delay characteristics can be produced by numerous combinations of forward path shaping and state error feedback, but that only the state error feedback loops will augment the vehicles disturbance rejection capability. The tradeoff between forward path manipulation and feedback can make a considerable difference to the control system design, especially when failure tolerance is considered, therefore the definition of a minimum level of disturbance rejection (conversely, a maximum response to defined disturbances) is desirable.

The handling qualities evaluations of disturbance rejection capability were conducted using a matrix of 24 control systems using different levels of feed forward and feedback to accomplish specific bandwidth and phase delay design constraints. To ensure that all systems were subjected to the same disturbance environment, the evaluations were performed in calm ambient conditions, the disturbances being provided by the superimposition of a time series of actuator commands on the control system control path.

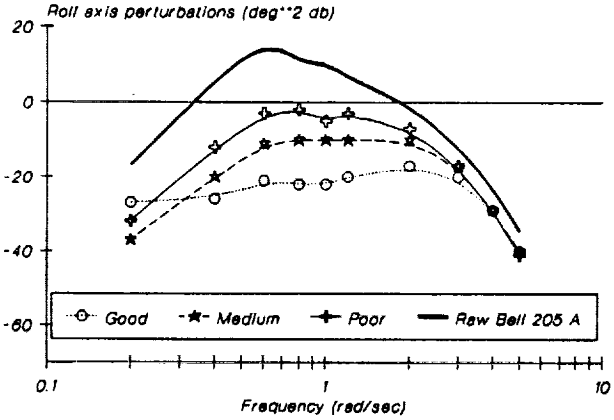

Figure 8: Model Responses to Disturbing Signal

The disturbance signal used had been developed by recording the motions of the unaugmented Bell 205 in a steady hover in very heavy turbulence - the lee side of a large obstruction in a strong wind. The aircraft response traces were processed through an inverse mathematical model of the Bell 205 to yield actuator commands which would produce similar motions. When empirically scaled and filtered, the data trace produced a 'turbulence model' considered to be the most realistic ever flown at the NRC.The responses of the subject models as well as the raw 205 to this disturbing signal is shown at Figure 8.

The result of this preliminary study was an envelope of attitude perturbations against frequency (Figure 9) which, for an otherwise Level 1 aircraft, seemed to cause degradation of its handling qualities to the Level 2 area. It is felt that further work in this area could be fruitful. A detailed documentation of this study can be found at Reference [19].

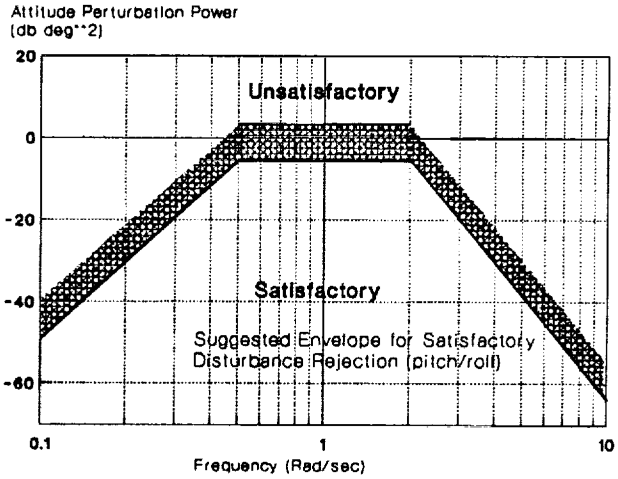

Figure 9: Suggested Disturbance Rejection Boundary

STICK DYNAMICS STUDIES

The ADS-33C bandwidth criteria section states that bandwidth should be measured from the transfer function relating the force applied to a given control to the aircraft attitude, but there have been suggestions that this is not necessarily correct for large displacement controls. In particular, research in the fixed wing world (Reference [20]) has suggested that a pilot can compensate more readily for control response lags due to the dynamics of a particular controller than he can for those due to forward path signal manipulation. This particular result might be expected since the pilot can form a neuro-muscular closed loop control system around the parameters of stick force and position, thus reducing their overall effect while the pilot has no feedback parameter available regarding forward path computational lags except for the final aircraft response.

The experiment performed at FRL on this subject revolved around the evaluation of helicopter handling qualities when the aircraft was controlled through a cyclic controller which had a variety of dynamic characteristics. The cyclic dynamics evaluated could be grouped into two types, one in which frequency domain characteristics were varied by the choice of physical model parameters, and one having different physical characteristics while maintaining constant natural frequencies and damping. Unfortunately, the evaluations of the latter group were less than satisfactory due to deficiencies in the Airborne Simulator control loading system.

Results from this study confirmed that pilots are very tolerant of low bandwidth displacement controllers; the results also permitted boundaries for controller design to be postulated based on natural frequency and damping (Figure 9). The evaluation data gathered during this experiment also suggests that the control bandwidth criteria in ADS-33C should be measured from stick displacement rather than applied force, *especially* if the cyclic stick is of rather low natural frequency. A full description of the experiment can be found at Reference [21]. Numerous other studies on rotorcraft handling qualities variations due to control feel system dynamics have taken place in the last few years and a good survey of recent work can be found in Reference [22].

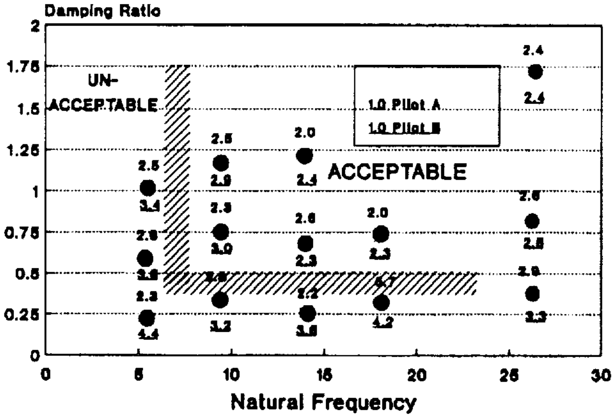

Figure 10: Suggest Cyclic Stick Dynamics Boundary

It is clear that the subject of how a pilot interacts with his vehicles control feel system dynamics has yet to be fully understood. With this in mind, work is currently in progress at FRL to replace the analogue control loading system in the Bell 205 with a more consistently repeatable digitally based system. When this system becomes operational, further studies in this area will be undertaken.

ADS-33C MANOEUVRES FOR PART 4

Although it was intended that the use of ADS-33C should rely heavily on the objective open loop criteria to be found in Part 3 of the document, specific flight test manoeuvres were written into Part 4 to supplement the objective criteria. These manoeuvres were designed to reveal handling qualities deficiencies that might be otherwise missed but were intended to be used for piloted checks of a candidate aircraft in a 'quick look' form of evaluation. When exercises were undertaken to evaluate the use of ADS-33C by flying existing aircraft against the criteria, the manoeuvres assumed a greater importance than was the original intention with evaluators wishing to apply them as aircraft acceptance criteria in their own right. This use of the manoeuvres required a further project at the FRL, to define the manoeuvres in a sufficiently rigorous way so that they could be used to evaluate handling qualities almost in lieu of the Part 3 criteria.

There were several significant constraints imposed on the manoeuvre designs by the US Army authorities, particularly:

- ▫ flight test costs should be kept as low as possible which implies very little special equipment could be required;
- ▫ performance limits should be such that achievement of them, or otherwise, should be readily obvious to the pilot or an external observer and;
- ▫ the manoeuvres should be applicable to any type of helicopter without significant changes.

While these constraints may seem trivial, in many ways they are not: the last constraint in particular legislates against using, for example, marked ground courses with target speed gates for the acceleration/stop manoeuvre as has been the standard practice at FRL for many years.

To insure that the intent of the Part 3 criteria would be met by the piloted evaluation of Part 4 manoeuvres only (that is, the manoeuvres should enable a pilot to distinguish between Levels 1,2 and 3 systems as defined in Part 3), the process of designing the manoeuvres had to include the evaluation of control systems which would pass and fail the criteria of Part 3. For this purpose, three control system models were incorporated in the Airborne Simulator. One of these was on the putative Level 1/Level 2 boundary, one well into the Level 2 region and the third just inside the Level 3 boundary. The evaluation pilots were asked to produce handling qualities ratings for each vehicle/manoeuvre combination and manoeuvres were varied to obtain a good correlation between pilot ratings and the system design handling qualities predictions. The necessity of producing models which would offer a range of handling qualities and the ability to record pilot performance numerically were the factors that legislated the use of the Airborne Simulator for this exercise, rather than an aircraft with greater performance capabilities.

The most difficult types of manoeuvre to design were those for which the aim was to determine handling qualities, but in which aircraft performance was a significant factor. An excellent example of this is the accelerate/stop manoeuvre. Traditionally the task has been defined at FRL by setting out a ground course marked by a start point, a 'gate' and an end zone and defining the task thus:

Establish a 10 foot hover at the start point, accelerate to achieve 40 kt groundspeed at the gate and return to the hover inside the end zone markers. Desired performance shall be ±10 feet laterally, ±10 feet vertically, ±10 degrees in heading and 2 knots at the gate. Adequate.....

For the evaluation of the Bell 205 models this defined manoeuvre was quite acceptable and the combination of speed and distance targets ensured that the pilot had to fly in a very aggressive manner. If, however, the test vehicle were not a Bell 205 but, say an Apache, these limits would not represent the same proportion of the aircraft's capability as they do with the Bell 205. The task would become too easy because of the performance margins the pilot had available to him. To make the task aircraft independent clearly requires a different approach to the manoeuvre. The final definition of this example task became, *somewhat abbreviated*:

Starting from a stabilised hover, rapidly increase power to approximately maximum and maintain altitude constant with pitch attitude. Hold collective constant during acceleration to an airspeed of 50 knots. Upon reaching the target airspeed, initiate a deceleration by aggressively reducing power and holding altitude constant with pitch attitude. The peak pitch attitude should occur just before reaching the final stabilised hover.

Desired Performance

Complete the manoeuvre over the reference point at the end of the course. The longitudinal tolerance is plus zero, minus a distance equal to one half the overall length of the helicopter (positive forward)

Maintain altitude below 50 feet.

Maintain lateral track within ±10 feet.

Maintain heading within ±10 degrees.

Achieve at least 95% of either maximum continuous power or the maximum transient limit, whichever is greater, within 1.5 seconds from initiation of the manoeuvre. If 95% power results in pitch attitudes that are deemed to be objectionable, use the maximum nose down pitch attitude that is felt to be acceptable. This pitch attitude will be considered as a limit of the operational flight envelope.

The power should be decreased to full down collective within 3 seconds to initiate the deceleration. Significant increases in power are not allowed until just before the stabilised hover.

The pitch attitude during the deceleration should be at least 30 degrees nose-up above the hover attitude, and should occur shortly before hover.

The rotor RPM shall remain within the limits of the Operational Flight Envelope without undue pilot compensation.

The greatly increased complexity in the second definition serves to produce a script which is easily interpreted by the pilot and gives him, or his observer, clear guidance as to whether the desired performance limits have been met. It meets the constraints on the manoeuvres mentioned initially, requiring no specific flight test instrumentation and being aircraft type independent. However, such a complex description of what is essentially a very simple piloting task raises questions as to the understandability of the definition and whether it would be interpreted by the pilot in such a way as to meet the intentions of the guide. This was checked by asking pilots who had not been party to the development process to fly the tasks, using only the draft definitions as a brief. This final stage in task development resulted in only minor changes in wording or emphasis.

This kind of re-working of task descriptions was necessary for most of the manoeuvres in ADS-33C Part 4 requiring large changes in attitude and power since these are the areas where individual aircraft capabilities are the most predominant.

The manoeuvre re-definition exercise was completed at FRL in two sessions in 1991, with the participation of US Army pilots from AQTD and was reported in Reference [23].

ONGOING RELATED STUDIES

The cooperative studies in support of ADS-33C at the FRL are continuing. Currently the laboratory is in the preparatory stage of a study on the potential benefits of modifying the typical rate feedback SAS found in current helicopters (eg, Bell 412,Blackhawk) to provide a limited authority attitude command mode to assist the pilot during operations in degraded visual environments. Again, this is a study which will complement a VMS experiment by repeating the evaluations of selected configurations in the cue rich environment of actual flight. The software development stage of this project is currently nearing completion and it is anticipated that piloted evaluations will commence early in February 1993.

In the longer term, the NRC is in the process of purchasing a replacement airframe to carry on the process of in-flight simulation. The decision to make this major capital investment was driven primarily by our acknowledgement that the agility of a teetering rotor helicopter will always be limited to levels far below those obtainable in most current helicopters and that it will be necessary to address that factor if the laboratory is to maintain the ability to conduct world class research in the area of helicopter flight dynamics.

The new aircraft, a Bell 412, is expected to be received at the laboratory in the late spring of 1993 and will be designated the Advanced Systems Research Aircraft (ASRA). It is anticipated that some 18 months will be required to convert the aircraft to a fly-by-wire capability, a process that will be primarily conducted in-house with the use of outside contractor assistance where necessary. The ASRA will be the fourth generation FBW helicopter at the FRL and will continue a nearly thirty year tradition of in-flight simulation activity with a machine capable of carrying out manoeuvres more appropriate to helicopters of the next decade.

CONCLUSIONS

The National Research Council's Airborne Simulator has played a large role in developing the data base against which the frequency domain criteria and the flight test manoeuvres incorporated in ADS-33C have been written. It has, as a part of this project, again highlighted the complementary nature of ground based and in-flight simulation, indicating that there would be quite severe cost and technological risk in specifying or designing radically new helicopters using data acquired purely from either source, ground-based simulation or in-flight simulation. As shown in this report, there have been occasions during the production of ADS-33C when data from several sources was necessary to formulate a given criterion.

The FRL, through its connection with TTCP, has renewed its intentions to continue its participation in the international effort in support of handling qualities criteria development and update.

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