NASA Technical Memorandum 81217

A Pilot's Assessment of Helicopter Handling-Quality Factors Common to Both Agility and Instrument Flying Tasks

Ronald M. Gerdes

July 1980

NASA
National Aeronautics and
Space Administration

NASA Technical Memorandum 81217

A Pilot's Assessment of Helicopter Handling-Quality Factors Common to Both Agility and Instrument Flying Tasks

Ronald M. Gerdes, Ames Research Center, Moffett Field, California

NASA
National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035

A PILOT'S ASSESSMENT OF HELICOPTER HANDLING-QUALITY FACTORS COMMON TO BOTH AGILITY AND INSTRUMENT FLYING TASKS

Ronald M. Gerdes
Ames Research Center, NASA
Moffett Field, California, U.S.A.

ABSTRACT

Results from a series of simulation and flight investigations undertaken to evaluate helicopter flying qualities and the effects of control system augmentation for nap-of-the-Earth (NOE) agility and instrument flying tasks were analyzed to assess handling-quality factors common to both tasks. Precise attitude control was determined to be a key requirement for successful accomplishment of both tasks. Factors that degraded attitude controllability were improper levels of control sensitivity and damping and rotor-system cross-coupling due to helicopter angular rate and collective pitch input. Application of rate-command, attitude-command, and control-input decouple augmentation schemes enhanced attitude control and significantly improved handling qualities for both tasks. NOE agility and instrument flying handling-quality considerations, pilot rating philosophy, and supplemental flight evaluations are also discussed.

1 INTRODUCTION

Helicopter pilots must be assured of satisfactory handling qualities for a variety of flying tasks — hovering with a sling load as a crane, conducting a precision instrument approach to an offshore oil rig, or maneuvering rapidly at various speeds along the nap-of-the-Earth (NOE). Mission success, measured in terms of either profit or military tactical advantage, depends to a great extent on the ease and precision with which the pilot is able to accomplish these demanding tasks. To this end, piloting aids, such as stability and control augmentation systems (SCAS) and advanced displays, are being developed to help him compensate for basic helicopter handling-quality deficiencies.

Ames Research Center was designated as NASA's lead center for helicopter research and development in mid-1976. Since then, a major effort has been under way to assess and improve helicopter handling qualities through the use of research simulators and variable-stability helicopters. Two helicopter missions have received particular attention in these investigations — instrument flight operations and nap-of-the-Earth flight.

Cooperative programs have been established with other governmental agencies, such as the U.S. Army, the U.S. Federal Aviation Administration, and the British Royal Aircraft Establishment. Specifically, the main thrust of these investigations has been to identify the effects of various rotor-system characteristics on helicopter handling qualities and to define potential improvements of various SCAS and display applications. This paper presents some of the major findings from six of these investigations from the viewpoint of a research pilot who participated in them.

The primary purpose of this paper is to discuss specific handling-quality factors that were found to be common to these two helicopter flying tasks, the maneuverability requirements for which are quite different. Emphasis has been placed on the pilot's point of view, and quantitative results are presented in terms of pilot opinion rating numbers.

Two ground-based simulators and a variable-stability helicopter at Ames Research Center and a ground-based simulator at RAE-Bedford were used during these investigations. Actual NOE indoctrination flights were performed with the U.S. Army and the British Army Air Corps to gain operational experience and to help correlate and validate simulator results.

Handling-quality considerations for both the NOE agility and instrument flying missions are briefly discussed with respect to (1) the demands they place on the pilot and (2) desired aircraft response. This is followed by brief descriptions of the various simulation and flight investigations along with the associated piloting tasks. Results are then presented by relating handling-quality factors to basic rotor and SCAS configurations.

2 HANDLING-QUALITY CONSIDERATIONS

For a clearer understanding of the discussions of handling-quality factors to follow, one should first consider the NOE-agility and instrument flying tasks in terms of the demands they place on the pilot and the associated responses he expects from the helicopter. These considerations, which play a major role in the formulation of pilot opinion, are briefly discussed in the paragraphs below.

2.1 NOE-Agility Tasks

Helicopter handling-quality requirements encompass a maneuverability regime extending from the steady hover of a helicopter serving as a crane to the agility demands of scout, attack, and "fighter" helicopters. Thus, the term "agile" could also be defined as "being highly maneuverable." NOE missions are flown over many kinds of terrain where the pilot must fly within a narrow corridor that is bounded by two hazards — enemy fire and ground obstacles. Agility, indeed, is a key factor in the determination of a successful mission. Listed below are some typical maneuvers or desired flying qualities that the helicopter designer must consider in providing adequate NOE agility:

- Precise hover in turbulent air
- Bob up and down and move sideways in hover
- Rapid accelerations and decelerations within the full speed envelope
- Mild and rapid maneuvering near obstructions at varying speeds
- Requirement for relatively large and rapid attitude changes
- Stable gun platform at all speeds
- Day and night operations

In summation, the NOE pilot is frequently called upon to fly complicated, unpredictable, and rapidly changing flightpath trajectories. The precision with which he is able to control those trajectories is a direct measure of the helicopter's agility. For conventional helicopters, flightpath trajectory is controlled through attitude (pitch, roll, and yaw) and power (collective) controls. It is thus evident that precise attitude control is a major handling-quality consideration when assessing agility. Most of the handling-quality assessments described in this paper were based on helicopter or simulator attitude response to control inputs made while the pilot was performing the evaluation tasks.

2.2 Instrument Flight Tasks

Unlike NOE agility, instrument flight capability is a handling-quality consideration that is applicable to almost every class of helicopter operation. Even tactical helicopters, which primarily operate in visual meteorological conditions, must possess full instrument flying capabilities to meet "all weather" battlefield commitments. The sudden surge in business and offshore helicopter operations has increased demands that pilots operate in adverse weather. Certification of helicopters for instrument flight includes the installation of flight director displays and flight control system augmentation devices. Although a trade-off between control and display sophistication for instrument flight has been demonstrated, there exists a minimum level of stability and control that must be present to give the pilot the control response he requires for this high workload task. Listed below are some typical maneuvers or desired flying qualities that the helicopter designer must consider in providing adequate instrument flight capability:

- Basic requirement for "attitude flying"
- Precise control of airspeed and vertical velocity
- Mild accelerations and decelerations well within the full speed envelope
- Requirement for relatively small and slow attitude changes
- Precise adherence to published instrument flight procedures
- Day and night operations

When flying on instruments, the pilot must guide his helicopter along a carefully prescribed flightpath trajectory in accordance with standardized instrument flight procedures and in response to air traffic control instructions. It follows again that precise attitude control is a major handling-quality consideration with respect to the assessment of instrument flight capability.

It can be concluded from the foregoing discussions that handling-quality factors that directly influence the pilot's ability to maintain precise attitude control would be common to both NOE agility and instrument flying tasks. The primary objective of the series of handling-quality experiments described in this paper was to assess the controllability of various rotor configurations, and the primary assessment method was to consider handling-quality factors that influenced the pilot's control of helicopter attitude.

3 DESCRIPTION OF HANDLING-QUALITY EXPERIMENTS

The six experiments (Table 1) in which the writer participated as an evaluation pilot were conducted during a 3-year period. The descriptions that follow are necessarily brief, and references (1-6) are listed for readers who desire more detailed information on other aspects of the individual studies. Each experiment has been assigned an alpha-numeric designator for ease of reference.

3.1 NOE Agility Tasks

3.1.1 Agility Simulation: No. 1 (AS-1)

The objective of this simulation was to explore the effects of large variations in rotor-system dynamics on NOE handling qualities. Forty-four combinations of rotor-design parameters — such as flapping-hinge restraint, flapping-hinge offset, blade Lock number, and pitch-flap coupling — were applied to teetering, articulated, and hingeless rotor systems using a nine-degree-of-freedom mathematical model. The S.19 fixed-base simulator at Ames Research Center was used with a colored visual scene generated from a 400:1 scale terrain board. Evaluation pilots were asked to fly as fast as possible and as low or close to obstacles as possible while negotiating the NOE course. Pilot performance and opinion data were gathered for the report.

3.1.2 Agility Simulation: No. 2 (AS-2)

The objective of this simulation was to investigate the use of various levels of control augmentation to improve terrain flight handling qualities. Teetering-, articulated-, and hingeless-rotor configurations, selected from AS-1, were used as baseline cases for the application of augmentation schemes. These consisted of simple control augmentation systems to decouple pitch and yaw due to collective input; SCAS of the rate-command type designed to optimize sensitivity and damping and to decouple the pitch-roll due to aircraft angular rate; and attitude-command type SCAS. The moving-base Flight Simulator for Advanced Aircraft (FSAA) at Ames was used with the same visual display as AS-1. The evaluation pilots were asked to fly a task similar to that for AS-1. Both performance and pilot opinion data were gathered for this experiment.

3.1.3 Agility Simulation: No. 3 (AS-3)

The objective of this study was to investigate the effects of variations in two hingeless-rotor design parameters: blade-flapping stiffness and inertia. Twelve rotor variations were tested with other parameters at values appropriate to a Lynx. Autostabilizer effectiveness (pitch and yaw damping) was also studied. The RAE-Bedford moving-base simulator was used with a black and white visual scene generated from a 700:1 terrain model. The piloting task was to fly a serpentine course at prescribed airspeeds and as low as possible. Pilot ratings and performance data were also gathered.

3.1.4 Agility Flight Investigation: No. 1 (AF-1)

The objectives of this flight experiment were to investigate control augmentation and decoupling requirements for NOE flight (teetering-rotor case) and to correlate the results with simulation. Eleven combinations of roll and pitch damping and pitch-roll cross-coupling were evaluated, using Ames Research Center's UH-1H (V/STOLAND) variable-stability and control research helicopter.

The task was to fly a prescribed slalom course over a runway while holding speed and altitude constant (60 knots and 100 ft). Pilot opinion, performance, and flightpath trajectory tracking data were recorded.

3.2 Instrument Flying Tasks

3.2.1 Instrument Simulation: No. 1 (IS-1)

The purpose of this simulation was to explore the broad effects of flight control system design parameters on instrument handling qualities as a step toward a clearer definition of helicopter instrument airworthiness standards. Teetering-, articulated-, and hingeless-rotor mathematical models, similar to those used in AS-2, were evaluated with three levels of control system augmentation:

1. Three-axis rate-command

2. Three-axis rate-command plus decoupled collective control

3. Attitude-command in pitch and roll, rate-command in yaw and decoupled collective control.

The FSAA simulator, with visual attachment, arranged to simulate transition back and forth between visual and instrument conditions, was used. The evaluation task consisted of a six-segment nonprecision (VOR) instrument approach, including a missed approach procedure. Pilot opinion and performance data were gathered.

3.2.2 Instrument Simulation: No. 2 (IS-2)

The objective of this simulation, a follow-on of IS-1, was to investigate the effects of static stability gradients and control augmentation schemes on handling qualities during the instrument approach task. The same three rotor-system mathematical models (AS-2) were investigated with varying three-axis stability gradients. Three baseline rotor-system cases with neutral pitch and roll static gradients were then evaluated with three levels of SCAS: turn-following directional augmentation; turn-following plus pitch- and roll-attitude command; and turn-following plus rate command with attitude hold. The FSAA simulator and a piloting task similar to that of IS-1 were used.

3.3 Supplemental Flight Evaluations

To obtain a realistic insight into the operational aspects and problem areas of NOE flying tasks, the writer was given the opportunity to fly indoctrinational NOE flights with the U.S. Army at Fort Rucker in the United States, and with the British Army Air Corps at Middle Wallop in England. This experience was a great help in validating the simulations and establishing realistic simulation tasks.

At Fort Rucker, NOE flights were flown along training routes in the TH-1G Cobra (attack), OH-58A (scout), and UH-1H (utility) helicopters. Night NOE flights with night-vision goggles were also flown in the OH-58A and UH-1H. The terrain in this area is relatively flat and heavily wooded.

At Middle Wallop, training flights were flown in the Gazelle and Lynx attack helicopters. The terrain in this area is rolling and only sparsely wooded.

4 PILOT RATING PHILOSOPHY

Assessment of the handling qualities discussed in this paper are quantitatively expressed in terms of the Cooper-Harper handling-qualities rating scale described in Reference 7. Simulation and flight evaluation tasks were selected after careful consideration of the NOE and instrument flying missions. During the task, the evaluation pilot had to judge the adequacy of the selected configuration in meeting mission requirements. This judgment was based primarily on two considerations:

1. The pilot's assessment of his task performance

2. Pilot workload and compensation exerted to attain that performance.

Using a scale of 1 (excellent) to 10 (loss of control), pilot ratings (PR) can be divided into three areas separated by two boundaries that have particular significance to the helicopter designer — PR = 3-1/2 and PR = 6-1/2. If desired performance was attained with little or no compensation (low workload), a rating between PR - 1 and PR = 3-1/2 was assigned, that is, "satisfactory." If adequate performance required moderate to extensive compensation, ratings were between PR = 3-1/2 and PR = 6-1/2 — "acceptable." Pilot ratings of 6-1/2 or greater — "unacceptable" — were assigned if adequate performance was not attainable.

The general philosophy used in judging the adequacy of performance for the NOE agility and instrument missions was based on the pilot's ability to control desired flightpath trajectory or helicopter attitude as discussed earlier. For example, poor ratings were assigned when extensive pilot attention was directed to compensating for handling-quality deficiencies, such as low control power, overcontrol tendency, cross-coupling, or low stability. In the case of the NOE task, characteristics like these could mean near-collision with an obstacle or detection by hostile forces. For instrument flight, one could expect poor airspeed control, inprecise heading control, and overcontrol of navigation radio aid tracking.

5 RESULTS AND DISCUSSION

Pilot rating data, selected from each of the six experiments, are presented to illustrate common handling-quality factors and the effects of various stability and control augmentation schemes for the three basic rotor systems. NOE agility results are presented first.

5.1 NOE Agility Experiments

5.1.1 AS-1

Pitch and roll control sensitivity and damping relationships for all 44 rotor configurations were correlated with pilot comments and pilot opinion data. Few of these configurations were found to have satisfactory terrain-following flying qualities. Results showed that sensitivity and damping characteristics alone were insufficient for the specification of satisfactory NOE-agility handling qualities, and that other considerations, such as stability and cross-coupling, should be taken into account. Rapid and precise roll response, without a tendency to overcontrol or to develop pilot-induced oscillations, and minimum coupling effects were found to be desirable qualities.

Cross-coupling due to aircraft angular rate was identified as a highly significant handling-quality factor during this investigation. For example, the effect on pilot rating of rolling-moment coupling due to pitch rate (L_q) is shown in Figure 1 for two combinations of roll sensitivity and damping. Note that handling qualities deteriorated from "satisfactory" to "unacceptable" in the high-sensitivity and damping case. This study also showed that cross-coupling effects could be reduced and handling qualities improved by increasing the rate damping of the coupled axis. This is illustrated in Figure 2, which is a plot of pilot rating as a function of the ratio of roll coupling to roll damping (L_q/L_p). Satisfactory handling qualities were maintained as long as this ratio did not exceed a value of about 0.35. Thus, cross-coupling due to aircraft angular rate is a factor that can degrade NOE agility and increasing the rate damping of the coupled axis can reduce this effect.

5.1.2 AS-2

Three baseline rotor configurations, selected from AS-1, were first evaluated and found to have the following major handling-quality deficiencies:

Teetering rotor

- Low control sensitivity and damping in pitch and roll
- Excessive yaw due to collective coupling

Articulated rotor

- Excessive roll control sensitivity
- Strong pitch-roll coupling due to angular rate
- Excessive yaw due to collective coupling

Hingeless rotor

- Excessive pitch and yaw due to collective coupling

In each case, the deficiencies in control response and cross-coupling caused overcontrol of helicopter attitude and significantly degraded NOE performance. Compensating for these handling-quality factors caused a high pilot workload and resulted in poor pilot ratings. Various augmentation schemes, devised to correct these traits were evaluated; the results are discussed below for each rotor configuration.

(a) Hingeless rotor. Cross-feed control laws were used to directly decouple the pitch and yaw responses to collective input (input decoupling); results are shown in Figure 3. The effects of doubling and eliminating the pitching moment due to collective input (M_{δ_c}) are shown, plus the addition of yaw due to collective (N_{δ_c}) decoupling. The elimination of pitch and yaw coupling due to collective input was an important factor that improved NOE performance and handling qualities.

(b) Articulated rotor. Two augmentation schemes were investigated. The first one, called rate-command and decoupling-type SCAS, dealt directly with the specific deficiencies noted above. The results of this study are plotted in Figure 4. A progressive improvement in pilot opinion can be noted as SCAS complexity was increased to compensate for cross-coupling and overcontrol due to high roll sensitivity. This resulted in good attitude control.

The second SCAS, which was more sophisticated, consisted of pitch and roll attitude command with yaw axis rate damping and collective-to-yaw decoupling. Pitch and roll attitude-control response was improved as attitude SCAS gains were optimized during the simulation runs (Fig. 5). Attitude SCAS alone was sufficient to decouple the pitch-roll axes and improve the attitude response. The above SCAS mechanizations were rated about the same for the NOE task.

(c) Teetering rotor. The same two augmentation systems used in the articulated-rotor case were evaluated with this configuration. The data for the rate-command and decouple SCAS are shown in Figure 6. A progressive improvement in handling qualities is evident as SCAS complexity was increased, similar to the results of the articulated-rotor case. Figure 7 presents the attitude SCAS data, which show the same kind of handling-qualities improvement trend.

5.1.3 AS-3

Most of the 12 combinations of blade stiffness and inertia used in this hingeless-rotor experiment were rated as unacceptable for the task for the following reasons:

- Pitch axis very unsteady and overly sensitive; speed control difficult due to poor pitch attitude precision
- Large collective-to-pitch coupling; pitch-up due to up-collective-induced overcontrol of pitch attitude
- Roll sensitivity tended to be too low
- Directionally loose or underdamped; collective-to-yaw coupling continually perturbed yaw axis

In combination, these handling-quality factors were hindrances to task performance and at times resulted in near misses with obstacles along the course. Poor longitudinal dynamics also forced the pilot to increase altitude at times and to expose the helicopter. Rolling into and reversing the 2-g turns was hazardous because of overcontrol in pitch which was further aggravated by the collective-to-pitch coupling. Collective-to-yaw coupling caused large yaw disturbances as collective pitch was increased to hold speed in the turns.

The evaluation matrix was flown again with the addition of a simple pitch and yaw damper augmentation system. This resulted in significantly improved agility characteristics which were judged to be "acceptable" but not "satisfactory." The following handling-quality improvements were noted:

- Significant reduction in overcontrol of pitch attitude; improved speed control
- Pitching moment due to collective less abrupt and easier to counter with cyclic pitch
- Increased directional stiffness; significantly easier to counter yaw due to collective with pedal

A plot of the data from this study is shown in Figure 8. For most of the evaluated configurations, pilot ratings were "unacceptable" for the basic helicopter and "acceptable" with pitch and yaw damping. Two important factors should be noted:

1. Rate damping augmentation about the pitch and yaw axes significantly reduced the pitch-axis instability and reduced the pitch and yaw disturbances induced by collective input coupling

2. Nevertheless, satisfactory pilot ratings were never attained due to lack of sufficient decoupling augmentation.

5.1.4 AF-1

Preliminary pilot opinion data, shown in Figure 9, are presented as a function of the ratio of pitch and roll cross-coupling to damping (L_q/L_p and M_p/M_q) for three levels of pitch and roll damping (sensitivities were held fixed). A definite preference for the medium damping level was indicated for the no-cross-coupling cases. With pitch and roll sensitivities fixed, the helicopter was found to be a little oscillatory with low damping and sluggish with high damping. Increasing cross-coupling ratio degraded the handling qualities only slightly for the low- and medium-damping cases; a significant degradation was indicated for the high-damping (sluggish control response) case.

Handling-quality factors that degraded pilot opinion the most were influences of poor damping and cross-coupling on attitude precision, resulting in large deviations in airspeed and altitude along the slalom course. For example, the pitching moment due to roll rate had the effect of pitching the helicopter down and increasing speed when the helicopter was rolled into a turn in one direction and the opposite effect when it was rolled into the next turn in the opposite direction.

5.2 Instrument Flying Experiments

5.2.1 IS-1

The three baseline rotor configurations were evaluated in visual meteorological conditions (VMC) and instrument meteorological conditions (IMC); they were found to have major handling-quality deficiencies. The deficiencies included the following:

Teetering rotor

- Sluggish response about pitch, roll, and yaw axes
- Pronounced coupling of collective into all three axes

Articulated rotor

- Pitch, roll, and yaw axes underdamped
- Pronounced coupling of collective into pitch and yaw axes

Hingeless rotor

- Low yaw damping
- Pronounced coupling of collective into all three axes

Performance of the VOR approach task was seriously hampered as a result of these handling-quality factors, and the following specific relationships were noted:

Handling-Quality Factor	Effect on VOR Approach Task
• Low damping in pitch and roll	- Inability to precisely control pitch and roll attitude during the approach - Increased difficulty in coping with pitch and roll coupling from collective pitch inputs
• Low damping in yaw	- Imprecise heading control decreases VOR tracking precision - Increased difficulty in coping with yaw coupling from collective pitch inputs
• Pitch coupling due to collective input	- Inability to hold precise airspeed - Difficulty establishing desired rate of descent - Difficulty in execution of missed-approach procedure (combined task)
• Roll coupling due to collective input	- Inability to hold precise roll attitude (turn rate) or heading during power changes - Difficulty in execution of missed-approach procedure (combined task)
• Yaw coupling due to collective input	- Inability to hold precise heading or turn-rate during power changes — decreases VOR radial tracking precision - Difficulty in execution of missed-approach procedure (combined task)

Difficulties in controlling some parameters, such as airspeed, vertical velocity, and VOR radial tracking, were directly attributed to lack of precise attitude control. For example, airspeed and vertical velocity disturbances were induced by collective-to-pitch coupling when transitioning from level to descending flight or when executing the "missed-approach" procedure. One would expect pitch-attitude command augmentation to help in this case.

Results from this study are summarized in Figure 10. Pilot rating data for the rate-command plus decoupled-collective augmentation in the teetering- and articulated-rotor cases have been purposely omitted because of unstable levels of longitudinal static stability that were inadvertently introduced during the mechanization of the collective decoupling system. The effects of SCAS on each baseline rotor case are discussed separately.

(a) Teetering rotor. The addition of rate-command augmentation about all three axes quickened control responses and significantly improved instrument flying handling qualities. A small improvement in pilot rating resulted with the addition of attitude-command plus collective-decouple SCAS. Satisfactory handling qualities were only achieved for the VMC case. The IMC approach was rated down because of speed control and residual cross-coupling problems, which were probably influenced by the aforementioned collective decoupling mechanization.

(b) Articulated rotor. Rate-command augmentation did not make a significant improvement in the IMC case but did reduce the disturbances induced by collective coupling enough to enhance the VMC approach. Attitude SCAS provided the most obvious improvement in handling qualities for this rotor.

(c) Hingeless rotor. This configuration was superior to the others from a handling-qualities point of view and was the only rotor system to merit satisfactory ratings for both VMC and IMC. Adding rate-command augmentation compensated for low yaw damping, but pilot ratings did not improve much due to collective coupling — particularly into the pitch axis. The addition of decoupling augmentation reduced the pilot-compensation workload and thus enhanced handling qualities significantly. Attitude-command SCAS provided further improvement in instrument flying precision.

5.2.2 IS-2

The baseline cases for this experiment were somewhat different from the others due to the emphasis placed on static stability characteristics. Stick force versus velocity and sideslip gradients (longitudinal and lateral static stability) were set near neutral and directional static stability was set at a low stable gradient. Baseline SCAS was mechanized with three-axis rate-damping and control input decoupling. Furthermore, pilot rating data for the articulated-rotor case have been omitted because the SCAS evaluation runs were adversely affected by tail-fin stall characteristics and thus are considered invalid for the purpose of this discussion.

Pilot opinion data for the teetering- and hingeless-rotor cases are presented in Figure 11. Despite the rate-damping and control-input decoupling contained in the baseline configurations, relatively low pilot ratings were assigned due to the effects of low static stability characteristics on three-axis attitude control. Difficulties were experienced with all phases of the approach. Airspeed and heading control as well as VOR radial tracking required extensive pilot compensation.

(a) Teetering rotor. Turn-following directional augmentation resulted in a significant improvement in pilot rating because of improved heading and VOR tracking capability, but assistance for airspeed and attitude control were still lacking; the result was only an acceptable rating. When attitude-command SCAS was added, handling qualities were judged to be satisfactory. Rate-command plus attitude-hold SCAS also was rated above a PR = 3-1/2.

(b) Hingeless rotor. Pilot opinion data for the hingeless rotor are almost identical to those of the teetering-rotor case, with the exception of a slight preference for attitude-command over rate-command and attitude hold. These results corroborate and extend the results of experiment IS-1; the implications of both experiments are that use of pitch- and roll-attitude augmentation is necessary for satisfactory helicopter instrument flight tasks.

It will be noted that in the two instrument flying experiment cases (IS-1 and IS-2), cross-coupling due to aircraft angular rate was not specifically cited as a handling-quality factor despite the presence of this characteristic in the baseline rotor configurations. All values of the ratios of roll coupling to roll damping (L_q/L_p) were less than 0.35 and should not have caused significant control problems, as previously discussed in AS-1. Moreover, angular rates are typically held at low levels during instrument flight maneuvering, and pitch-into-roll coupling disturbances, for example, could have been masked by collective-input coupling motions. These secondary effects, however, did contribute to attitude-control degradation and were subsequently suppressed by rate- and attitude-command augmentation.

5.3 Supplemental Flight Evaluations

5.3.1 U.S. Army — Fort Rucker

Thus far, discussions of NOE agility have concerned the high-speed and rapid maneuvering aspects of the mission that were used in the simulation tasks and slalom evaluations. Agility has been equated to high maneuverability; with respect to the NOE task, this maneuverability must be available throughout the entire speed envelope, including the low-speed regime. In the heavily wooded areas of Fort Rucker, much of the NOE flying was carried out at low airspeeds (0 to 30 knots) while "air taxiing through the tree tops" just high enough to keep the rotor disk clear of branches. Back and forth changes in airspeed through the translational lift region and gust disturbances combined to upset helicopter attitude about all three axes. The tail rotor had to be protected from strikes by keeping it aligned with the flightpath and avoiding tail-low attitudes and overcontrol in pitch. Demands such as these also place a high workload on the pilot. Again, it is apparent that precise control of attitude is a key handling-quality factor in ensuring adequate NOE agility even while maneuvering gently at low airspeeds.

All three helicopters had teetering rotors. The UH-1H was criticized for low sensitivity and damping; also, it exhibited a continual lateral-directional unsteadiness in the low-speed regime. The OH-58A had pronounced directional control and damping deficiencies which caused concern for tail-rotor strikes. The TH-1G, which had a three-axis rate-command SCAS, displayed the best handling qualities of the three. The author's report of this evaluation contained the following statement: "Certainly the addition of stability and control augmentation would result in marked improvements in handling qualities and reduction in pilot workload and fatigue. For example, an attitude control system with good directional characteristics would be one solution."

5.3.2 British Army Air Corps — Middle Wallop

The British Army stressed the same NOE flying techniques as those taught in the United States; primary emphasis is on staying concealed. The sparsely wooded terrain at Middle Wallop afforded an opportunity to explore NOE agility throughout most of the speed envelope of the helicopters. In contrast to the flights at Fort Rucker, flightpath trajectories went around the trees rather than over them.

These flights were flown on a clear and windy day (30 knots with gusts to 40 knots). The Lynx handled well under these adverse conditions with auto-stabilization equipment (ASE) engaged. With ASE off, the helicopter was "loose" about all three axes, had high collective-to-pitch coupling, and became increasingly unsteady in pitch-attitude control as airspeed was increased. The ASE, which included three-axis rate-command augmentation, collective-input decoupling, heading-hold and pitch-roll attitude-command stabilization (within 6° to 8° of trim) significantly reduced pilot workload by absorbing external disturbances, decoupling the controls, and providing good attitude control response. The Gazelle, which had no control augmentation, was highly responsive, but pilot workload and compensation required to maintain desirable attitude were noticeably higher than in the Lynx.

6 SUMMARY OF COMMON HANDLING-QUALITY FACTORS

The purpose of this paper has been to discuss handling-quality factors that are common to NOE agility and instrument flight and to present supporting data extracted from a series of simulation and flight experiments. The rationale that was used is summarized in the block diagram of Figure 12.

After analyzing typical maneuvers required to perform NOE-agility and instrument flying tasks, it was determined that precise control of flightpath trajectory was a major handling-quality consideration that was common to both regimes of flight, and that the pilot must have precise attitude control to perform either task successfully. Handling-quality factors that degraded attitude precision were (1) improper levels of control sensitivity and damping, (2) cross-coupling due to aircraft angular rate, and (3) cross-coupling due to collective pitch input. Application of rate-command and attitude-command SCAS and input decoupling augmentation schemes provided significant improvements in NOE-agility and instrument flying handling qualities. Attitude control and decoupling augmentation should be considered at the very inception of future helicopter designs in order to assure the helicopter pilot of precise attitude control throughout the entire flight envelope.

7 CONCLUSIONS

A series of helicopter simulation and flight investigations to study basic flying qualities and the effects of stability and control augmentation for NOE-agility and instrument flying tasks have been completed. The author, a research pilot, participated in those experiments and identified handling-quality factors that were found to be common to both tasks. The following conclusions were drawn as a result of this assessment:

1. A major handling-quality consideration applicable to both NOE-agility and instrument flying tasks is precise control of helicopter attitude.

2. The characteristic responses of three baseline rotor systems (teetering, articulated, and hingeless) were found to degrade attitude controllability during agility and instrument tasks for the same reasons:

(a) Improper levels of control sensitivity and damping and

(b) Control cross-coupling due to aircraft angular rate and collective input.

3. Stability and control augmentation provided significant improvements in the handling qualities for both tasks through attitude-control enhancement. Rate-command, attitude-command, and input-decoupling augmentation were found to be most effective.

4. Future helicopter designs should provide for satisfactory handling qualities throughout the operational envelope. Attitude-control and decoupling augmentation should be considered at the inception of the design to ensure adequate attitude control precision.

REFERENCES

1.	R. T. N. Chen P. D. Talbot	An Exploratory Investigation of the Effects of Large Variations in Rotor System Dynamics Design Parameters on Helicopter Handling Characteristics in Nap-of-the-Earth Flight. Proceedings of the 33rd Annual National Forum of the American Helicopter Society, Washington, D.C., May 1977
2.	R. T. N. Chen P. D. Talbot R. M. Gerdes D. C. Dugan	A Piloted Simulator Study on Augmentation Systems to Improve Helicopter Flying Qualities in Terrain Flight. NASA TM-78571, 1979
3.	G. D. Padfield B. N. Tomlinson P. M. Wells	Simulation Studies of Helicopter Agility and Other Topics. RAE Technical Memo, Structures 927, FS 197, 1978
4.	L. D. Corliss D. Carico	A Preliminary Flight Investigation of Control Augmentation and Crosscoupling for NOE Helicopter Operations Using the UH-1H V/STOLAND System. Prospective NASA TM
5.	R. D. Forrest R. T. N. Chen R. M. Gerdes T. S. Alderete D. R. Gee	Piloted Simulator Investigation of Helicopter Control Systems Effects on Handling Qualities During Instrument Flight. Proceedings of the 35th Annual National Forum of the American Helicopter Society, Washington, D.C., May 1979
6.	J. V. Lebacqz R. D. Forrest	A Piloted Simulator Investigation of Static Stability and Stability/Control Augmentation Effects on Helicopter Handling Qualities for Instrument Approach. Proceedings of the 36th Annual National Forum of the American Helicopter Society, Washington, D.C., May 1980
7.	G. E. Cooper R. P. Harper, Jr.	The Use of Pilot Rating in the Evaluation of Aircraft Handling Qualities. NASA TN D-5153, 1969

TABLE 1. HANDLING-QUALITY EXPERIMENTS

Designation	Simulator-helicopter[a]	Rotor system[b]	Control augmentation	Ref.
NOE agility task				
AS-1	Ames S.19	T, A, H	Rate damping	1
AS-2	Ames FSAA	T, A, H	Input decoupling Rate command Attitude command	2
AS-3	RAE Sim. No. 1	H	Rate damping	3
AF-1	UH-1H V/STOLAND	T	Rate damping	4
Instrument flight task				
IS-1	Ames FSAA	T, A, H	Input decoupling Rate command Attitude command	5
IS-2	Ames FSAA	T, A, H	Turn following Attitude command Rate command, attitude hold	6

[a] Ames S.19 Fixed-Base, colored TV modelboard display; Ames FSAA six-degree-of-freedom base, colored TV modelboard display; RAE Simulator No. 1, three-degree-of-freedom, black-and-white TV modelboard display.

[b] T = teetering rotor; A = articulated rotor; H = hingeless rotor.

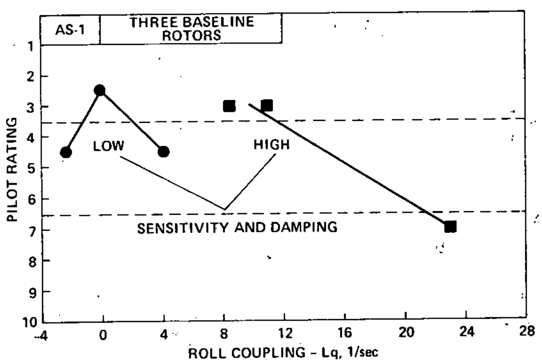

Figure 1. Pilot ratings for roll due to pitch-rate coupling for three baseline rotors.

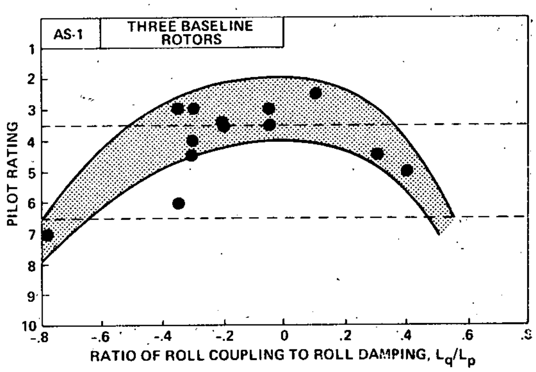

Figure 2. Pilot ratings for the ratio of roll coupling to roll damping.

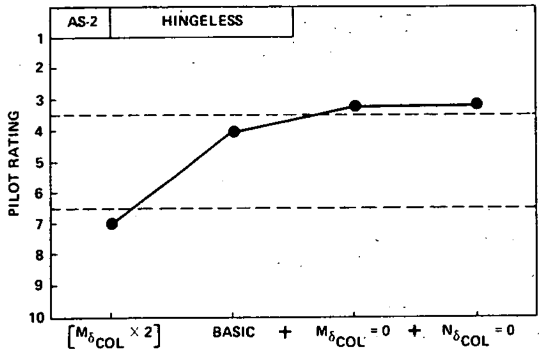

Figure 3. Pilot ratings for input decoupling of a hingeless rotor.

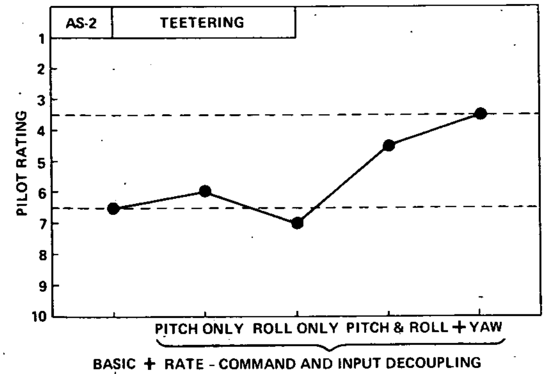

Figure 6. Pilot ratings for rate-command and input-decoupling augmentation for a teetering rotor.

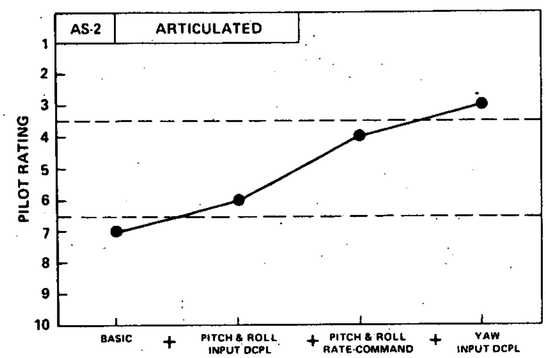

Figure 4. Pilot ratings for input decoupling and rate-command augmentation for an articulated rotor.

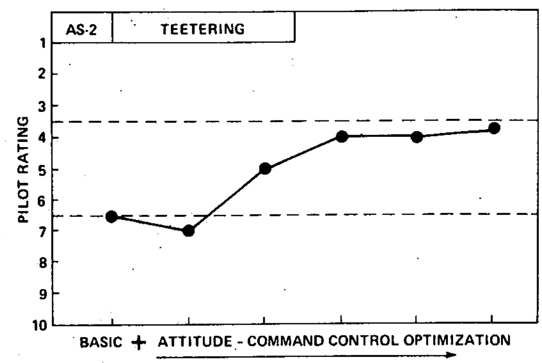

Figure 7. Pilot ratings for attitude-command augmentation for a teetering rotor.

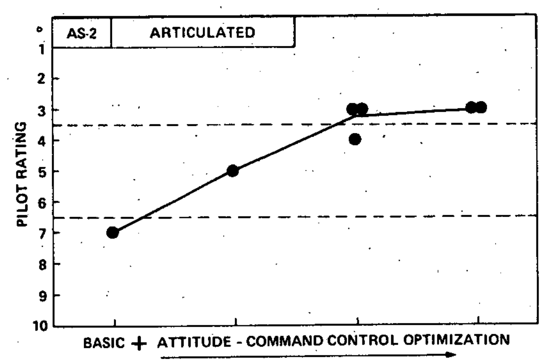

Figure 5. Pilot ratings for attitude-command augmentation for an articulated rotor.

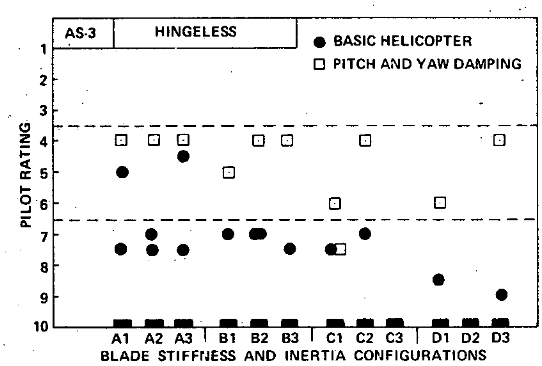

Figure 8. Effects of pitch and yaw damping augmentation on hingeless-rotor configurations with varying stiffness and inertia.

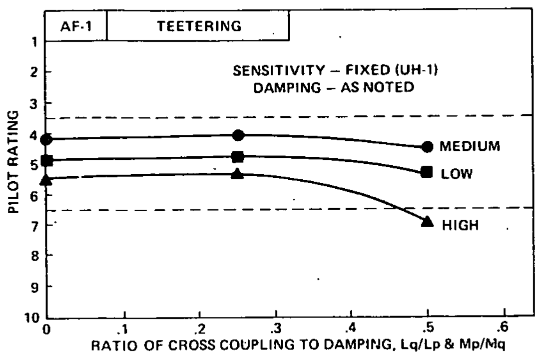

Figure 9. Pilot ratings for variations in the ratio of cross coupling to damping for a teetering-rotor helicopter.

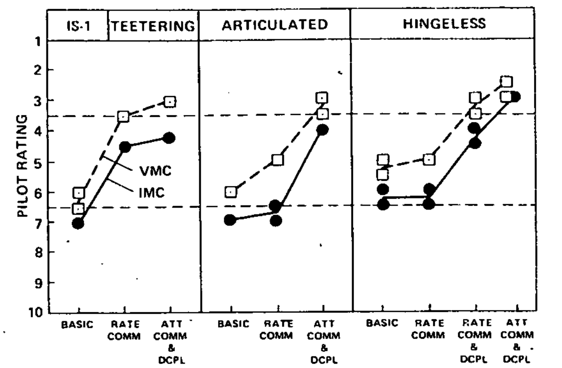

Figure 10. Pilot ratings for various control-augmentation schemes for three rotor systems.

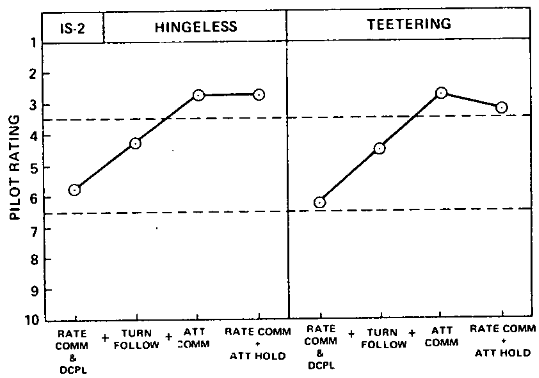

Figure 11. Pilot ratings for various control-augmentation schemes for two rotor systems.

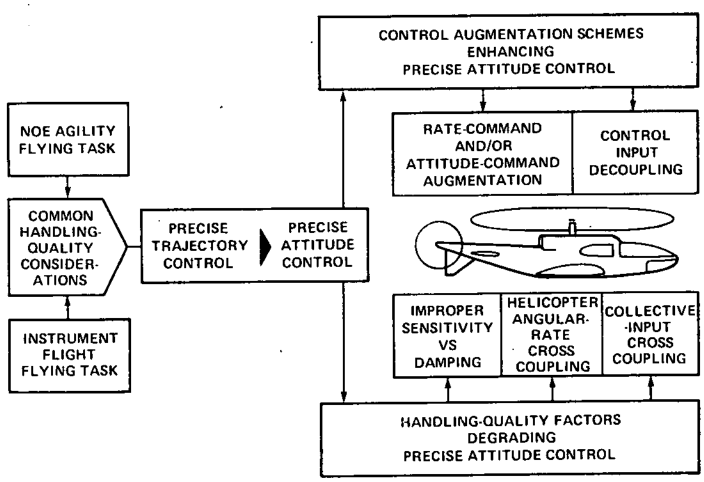

Figure 12. Summary of common handling-quality factors.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-81217		

4. Title and Subtitle	5. Report Date
A Pilot's Assessment of Helicopter Handling Quality Factors Common to Both Agility and Instrument Flying Tasks	
	6. Performing Organization Code
7. Author(s) Ronald M. Gerdes	8. Performing Organization Report No. A-8263
	10. Work Unit No. 505-42-21
9. Performing Organization Name and Address NASA Ames Research Center Moffett Field, CA 94035	11. Contract or Grant No.
	13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Results from a series of simulation and flight investigations to study helicopter flying qualities and the effects of control system augmentation for NOE agility and instrument flying tasks were analyzed to assess common handling quality factors. Precise attitude control was determined to be a key requirement for successful accomplishment of both tasks. Factors which degraded attitude controllability were improper levels of control sensitivity and damping and rotor system crosscoupling due to helicopter angular rate and collective pitch input. Application of rate-command, attitude-command and control input decouple augmentation schemes enhanced attitude control and provided significant improvements in handling qualities for both tasks. NOE agility and instrument flying handling quality considerations, pilot rating philosophy and supplemental flight evaluations are also discussed.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
	Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	20	$4.00

*For sale by the National Technical Information Service, Springfield, Virginia 22161