EIGHTH EUROPEAN ROTORCRAFT FORUM

Paper No. 5.2

THE EFFECTS OF PILOT STRESS FACTORS ON HANDLING QUALITY ASSESSMENTS DURING US/GERMAN HELICOPTER AGILITY FLIGHT TESTS

H.-J. Pausder[1)] and R. M. Gerdes[2)]

1) DEUTSCHE FORSCHUNGS- UND VERSUCHSANSTALT FÜR LUFT- UND RAUMFAHRT E.V., INSTITUT FÜR FLUGMECHANIK
BRAUNSCHWEIG, GERMANY

2) NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER
MOFFETT FIELD, CA, U.S.A.

August 31 through September 3, 1982

AIX-EN-PROVENCE, FRANCE

ASSOCIATION AERONAUTIQUE ET ASTRONAUTIQUE DE FRANCE

THE EFFECTS OF PILOT STRESS FACTORS ON HANDLING QUALITY ASSESSMENTS DURING US/GERMAN HELICOPTER AGILITY FLIGHT TESTS

by

H.-J. Pausder

Deutsche Forschungs- und Versuchsanstalt
für Luft- und Raumfahrt e.V.
Braunschweig, Germany

R. M. Gerdes

National Aeronautics and Space Administration
Moffett Field, CA, U.S.A.

ABSTRACT

In a US/German cooperative program, flight tests were conducted with two helicopters to study and evaluate the effects of helicopter characteristics, pilot and task demands on performance in NOE-flight. Different, low-level slalom courses were set up and were flown by three pilots with different experience. An extensive pilot rating questionnaire was used to obtain redundant information and to gain more insight into influences on pilot ratings.

The flight test setups and procedures are described. The summarized pilot ratings are presented and interpreted in close connection with the analyzed test data. Pilot stress is briefly discussed. The influence of demands on the pilot, of the helicopter characteristics, and of other stress factors are outlined with particular emphasis on how these factors affect handling qualities assessment.

1 INTRODUCTION

In the last few years, the operational spectrum of helicopters has been considerably expanded, in particular for military applications. At the same time, technological developments have made it possible to influence the flying characteristics of helicopters to a limited extent. This can be achieved by suitable design of the basic system and/or by the addition of subsystems.

Given this situation, the current military handling qualities criteria MIL-H-8501A had many obvious deficiencies although it gave good guidance in its early years (Ref. 1). There have been several attempts to revise the specification but either they were never completed or the proposed version were not adopted. In order to overcome this situation, a new program has been initiated by the US-Army and Navy to update the helicopter specifications (Ref. 2). The effort will include the development of a new specification structure as well as the incorporation of valid, available criteria and the existing data base. It is expected that significant shortcomings or complete voids will be found in the existing flying qualities data base. Therefore, one main objective of flight mechanical investigations is to produce a data base adequate for deriving recommendations for flying qualities requirements.

As a consequence of the different demands resulting from the required military operations, mission orientation has to be taken into consideration in the investigations. Flying close to the ground in order to use the terrain as cover or to obtain superiority requires well adapted flying qualities of the helicopter system and a good interaction of pilot and helicopter. Otherwise the pilot's workload will be too high and/or the mission performance will decrease considerably.

In response to these needs, research programs in the field of helicopter handling qualities have been initiated at NASA/US-Army and DFVLR, the German Aerospace Research Establishment.

A joint NASA/US-Army research program consisting of analytical studies, ground-based simulations and flight experiments has been underway at Ames Research Center.

These studies commenced with an exploratory piloted-simulator investigation of 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 (Ref. 3).

This was followed by another exploratory simulation that examined the use of various levels of control augmentation to improve terrain flight handling qualities. These consisted of simple control systems that provided inter-axis decoupling as well as rate-command and attitude-command augmentation (Ref. 4).

Ames Research Center's UH-1H variable stability and control research helicopter was used to investigate control augmentation and decoupling requirements for NOE flight (teetering rotor case) and to correlate the results with piloted simulation. Eleven combinations of roll and pitch damping and pitch-roll cross-coupling were evaluated (Ref. 5).

The effects of engine response time and helicopter vertical damping and collective control sensitivity were investigated on the Ames Vertical Motion Simulator. Special emphasis was placed on defining handling quality requirements and helicopter limitations with respect to demanding NOE flying tasks such as quick stops and bob-up/bob-down maneuvers (Ref. 6).

The relevant analytical and experimental activities of DFVLR, Institute for Flight Mechanics at Braunschweig, consist of programs for helicopter system identification from flight test data, tests on the DFVLR-Moving-Cockpit-Simulator, and flight tests for mission oriented handling qualities evaluation.

The efforts in system identification focused on the development and application of parameter identification methods to define and verify rigid-body mathematical models of helicopters in various speed regimes. DFVLR's BO 105 research helicopter was used to produce sufficient good quality flight test data. For the evaluation, the maximum likelihood method was utilized (Ref. 7).

Theoretical studies of the closed-loop pilot/helicopter system led to simulation tests with the objective of improving the mathematical pilot model. Two helicopters were modelled and six pilots were involved in a compensatory tracking task. The determined pilot transfer functions yielded, compared to STI's linear pilot model, a more optimal model consisting of two lead-lag terms for the low and high frequency ranges and the effective time delay (Ref. 8).

In the field of handling qualities evaluation, a procedure was developed at DFVLR that consists of the analysis, correlation and combination of statistical parameters computed from flight test data. Flight test programs were conducted using the BO 105 and UH-1D helicopters in different NOE-related tasks. The measured data and the pilot ratings were evaluated, taking task performance as well as pilot workload into account. For the flight tests, the Cooper-Harper rating scale was modified in order to detect specific influences on the pilot's evaluation. In addition, the influence of the pilot's control strategy on the task performance was analyzed (Ref. 9 -12).

With the objective of coordinating the efforts at NASA/US-Army and DFVLR, a Memorandum of Understanding (MOU) titled 'Helicopter Flight Control' was signed by the two governments in 1979. In the last three years, complementary efforts were performed by the participants of the MOU and the results were exchanged.

Under this MOU, common NASA/US-Army - DFVLR flight tests were conducted, having as one objective the comparison of US and German flight test techniques. The main intention of this paper is to discuss factors which influence pilots' evaluations, as determined, during this program.

2 DESCRIPTION OF EXPERIMENTS

2.1 APPROACH

For the US-Army/NASA studies of the effects of roll damping, roll sensitivity, and pitch/roll coupling on helicopter flying qualities for NOE-operations, a slalom course was constructed. The experiments were conducted using the UH-1H V/STOLAND research helicopter (Ref. 5). The course was flown at 60 knot airspeed and 100 ft altitude. The variation of the configuration parameters was limited by the capabilities of the teetering rotor system.

In the DFVLR-Institute of Flight Mechanics slalom tests were performed with a BO 105 and a UH-1D helicopter. The objectives of the tests were the measurement and definition of task performance and control activity as evaluation parameters for a handling qualities data base (Ref. 11). The course consisted of two realistic obstacles. The tests were flown at 30 ft altitude with a variation of airspeed from 40 up to 100 knots.

As a part of the Memorandum of Understanding a cooperative flight test program was planned with the objectives:

- to verify the compatibility of US and German slalom results,
- to determine the effect of flight task variation, and
- to examine the influencings on pilot evaluations.

The tests were performed in last year (1981) at the German Forces Flight Test Center. The test matrix is shown in Figure 1. Test configurations included:

- the duplicated NASA slalom,
- the DFVLR slalom, and
- the NASA slalom with a reduced 30 ft altitude equivalent to the DFVLR slalom.

For all configurations the airspeed was 60 knots. Two helicopters were used for the tests: (1) BO 105 of the DFVLR, and (2) UH-1D of the Flight Test Center (Figure 2). Three pilots, all of whom had considerable flight test experience and helicopter time were involved in the tests (NASA-Ames, DFVLR-Braunschweig, and Flight Test Center Manching). Each pilot flew both helicopters through all three evaluation courses.

2.2 EVALUATION COURSES

The NASA slalom course, essentially similar to the one used in the previous studies, was set up along a paved road in a parachute- drop area. Six 300 m ground markers formed the course as shown in Figure 3. In the lateral direction they were separated by 80 m. Additionally, two markers were used to indicate run-start and run-end.

The DFVLR course had two 10 m high obstacles placed 350 m apart. The obstacles were alternativly off-set 10 m from the center line. The run-start and run-end was marked similar to the NASA course. Both evaluation courses were symmetrical, to allow for the possibility of flying in either direction depending on the wind.

2.3 DATA ACQUISITION

The data acquisition was provided by an analog magnetic tape recording in the ground station. Recorded variables included control inputs, attitudes, rates, accelerations, airspeed, altitude, torque and rotor speed. The helicopter position data relative to the 'poles' (obstacles) was measured by a laser position tracking system and was recorded time synchronized with the helicopter state and control data. To register these data in the helicopter and to transmit them to the ground a programmable multipurpose instrumentation system was used. The concept made it possible to adapt quickly to the test technique (helicopter type, course, and direction of flight). The data were digitized online in the ground station and were available for data analysis. Sampling frequency was 20 Hz.

2.4 TASKS AND PROCEDURES

The basic flying task of the three evaluation courses was essentially the same: Fly a specified ground track that minimizes the lateral displacement from the obstacles ('poles'), and maintain a constant indicated airspeed and radar altitude throughout the designated course. Ground speed varied with wind velocity.

For the two US slalom courses, the pilot's task was to fly a series of alternating turns around the imaginary 'poles' while holding airspeed at 60 knots and radar altitude at 100 feet in one case and 30 feet in the other. Three runs along both courses were made with each of the two helicopters.

For the DFVLR slalom course, the pilot's task was to enter the course on the centerline at 60 knots indicated airspeed and 30 feet radar altitude, then hold the centerline track as long as possible until committed to turn right to start around the first obstacle, then return to the centerline and repeat the turn to the left around the second obstacle. Seven runs were made with each of the two helicopters.

2.5 PILOT RATING SYSTEMS

One objective of the joint program was to evaluate and compare the flight test techniques employed by the DFVLR and NASA. Therefore, for each evaluation run, the pilots were asked to provide pilot opinion ratings based on the systems used by both organizations.

NASA: For each configuration, the pilots were asked to give an overall Cooper-Harper handling qualities rating and specific commentary relating to: (1) roll control precision, sensitivity and damping, (2) interaxis coupling, (3) pitch and speed control, (4) height control, and (5) yaw control.

DFVLR: The DFVLR modified the Cooper-Harper rating system to adapt it better to mission oriented handling qualities assessments. Using this modified system, the evaluation pilots were asked to rate each configuration with respect to: (1) aircraft characteristics, (2) task performance, and (3) pilot stress. Along with the rating for stress the pilots were instructed to comment upon the factors which influenced their rating.

3 DISCUSSION OF PILOT STRESS

3.1 DEFINITION OF PILOT STRESS

In recent years there has been increased interest in the subject of human stress as it relates to well being and longevity. With the advent of more sophisticated aircraft and the space program, aerospace physiologists and psychologists have been studying the effects of pilot stress with the broad objective of improving the efficiency of cockpit workload. In the discussion of their pilot rating scale in Ref. 13., Cooper and Harper state that handling qualities includes more than just stability and control characteristics, and that other factors influencing handling qualities are cockpit interface (e.g., displays, controls), the aircraft environment (e.g., weather conditions, visibility, turbulence) and pilot stress. They go on to state that these factors influence the closure of the pilot control loop and that their effects cannot be segregated.

The modified Cooper-Harper handling qualities rating scale used by the DFVLR in evaluating mission oriented flying qualities contains a section pertaining to the evaluation of pilot stress in order to identify the significant pilot stress factors associated with the flying task. Reference 14 describes the use of this modified scale in a previous investigation.

At this point we must define what is meant by pilot stress. For the purpose of this discussion, pilot stress is defined simply as 'physical and mental pressure resulting from cockpit workload'. Cooper and Harper define workload as 'the integrated physical and mental effort required to perform a specified piloting task'.

Factors contributing to pilot stress include the following:

- demands fo the task,
- aircraft response,
- environmental conditions,
- adequacy of information, and
- experience and skill.

The cumulative effects of stress result in physical and mental fatigue which impares judgement and flying skill. Thus the pilot's ability to process information, make decisions and arrive at and execute the appropriate control strategy during handling qualities evaluations is likewise diminished. It can be seen that the pilot's ability to make consistent assessments of handling qualities and assign pilot rating numbers can be significantly influenced by stress factors.

3.2 STRESS FACTORS

The pilot stress factors listed above are briefly discussed in this section so that the reader will have a clearer understanding of these terms when they are presented in the results of this paper (Figure 4).

Demands of the task: Demanding tasks that require the evaluation pilot to fly complicated tracks involving rapid and precise maneuvering within specified limits can become very stressful. This is of particular significance when he is asked to perform the task repeatedly.

Aircraft response: Evaluating an aircraft that responds in an erratic or unpredictable manner and that demonstrates deficient flying qualities that require a significant degree of pilot compensation produces pilot stress. The degree of pilot stress is usually commensurate with the level of 'aircraft characteristics' and 'demands on the pilot' listed in the Cooper-Harper rating scale.

Environmental conditions: Environmental situations that contribute to pilot stress are: (1) turbulence, wind shears and cross winds that upset aircraft attitude and drive it away from it's intended track and (2) weather and lighting conditions that hinder the pilot's vision and task tracking performance.

Adequacy of information: The evaluation pilot must process a continuous flow of visual, audio and kinesthetic information which he uses to perform the task and assess the adequacy of the aircraft for the mission. Pilot stress is increased when this information stream is deficient or degraded. For example, inadequate visual information from within (e.g., instrument panel) or outside (e.g., evaluation course) the cockpit can increase pilot stress. Environmental conditions can be a factor in this case.

Experience and skill: Pilot stress is elevated to some degree by the difficulty of the task. An evaluation pilot whose flying background includes familiarity with the aircraft type and mission will undergo less stress as a result of this experience and skill.

4 DISCUSSION OF RESULTS

In the discussion that follows, the ratings from the participating pilots are used to illustrate the influences of the different stress factors on pilot ratings. Also, flight test data are shown to provide an objective measure of the subjective ratings and comments.

4.1 PILOT RATINGS AND COMMENTS

As mentioned in the previous section, the test pilots had to answer both a NASA questionnaire and a DFVLR questionnaire. The ratings are summarized in Figure 5. Three different types of ratings are compared: (1) the overall ratings of the NASA questionnaire, (2) the ratings for pilot's stress, and (3) the ratings for task performance of the DFVLR questionnaire. An impression of the differences in the ratings depending on the pilots are given by the indicated spreads. As a consequence of the nonlinear characteristic of rating scales, an unweighted averaging of pilot ratings cannot be directly used. The average values noted in the rating summary are only intended to demonstrate the tendency of the ratings within the spreads.

In general, the test pilots evaluated the UH-1D well below the BO 105. This expected result reflects the lack of roll agility of the teetering rotor system. The spread in all ratings is found to be higher for UH-1D than for BO 105, particularly in the case of the DFVLR course. This could very well be an example of the effects of a combination of stress factors: demands of the task as influenced by pilot experience and skill. The same tendency can be noted by comparing the spreads of ratings for NASA and DFVLR slalom. In addition, two pilots commented on the higher demands on the pilot/helicopter system of the DFVLR evaluation task. These pilots' statements are based on three factors: (1) a ground track demanding more pilot concentration, judgement, and skill, (2) lower altitude, and (3) real, rather than imaginary obstacles.

For the BO 105, clear differences exist in the ratings of the pilots answering the specific evaluation questions, whereas the ratings for the UH-1D are quite consistent. In summarizing these evaluations it can be seen that, in the case of the BO 105, overall ratings are identical with task performance ratings but they are about one rating number better than the stress ratings. It appears that a lack of rapid maneuverability response had the dominant effect on stress and task performance.

Figure 6 shows the condensed comments of the pilots regarding a degradation of overall and stress ratings: The main helicopter characteristics required for a satisfactory performance of the slalom tasks and a low pilot stress is high roll agility. Additionally, the stress increases with pronounced coupling intensity that produces higher control activity in the secondary axes.

4.2 FLIGHT TEST DATA

One pilot formulated the lower demands of the NASA tasks: 'NASA slalom is a more coordinated flight maneuver'. In Figure 7, plots of both courses for one pilot flying the BO 105 are shown as an example. The requirement for the pilot to reenter the centerline after the obstacles makes it more difficult to fly the DFVLR course. The NASA course includes phases between the poles with only small variations in the roll angle. The differences of course demands are more obvious in the frequency domain (Figure 8). The power spectrum of the roll angle identifies generally a higher energy level and increased bandwidth demands for the DFVLR course. Roll rate and lateral stick input power spectra indicate particularly higher levels for this task.

As a consequence of the higher demand on roll agility and roll control activity, the DFVLR evaluation task seems to be the more realistic simulation of sideward motion in the NOE-flight. The influence of task variations is significant and has to be taken into consideration for the comparison of flight test results and evaluations.

For flying the tasks the pilots require primarily, quick roll response. In the comments they evaluated the roll agility of the BO 105 as good in general and the UH-1D as medium or low, especially for the DFVLR task. The missing roll agility is evident in the power spectra of Figure 9. The roll angle and lateral sticks spectra are quite similar for both helicopters and are determined primarily by the course dynamics. The main difference between the helicopters can be seen in the roll rate diagram. A satisfactory evaluation can only be achieved with a helicopter system which allows quick changes in the roll motion and, consequently, high roll control preciseness.

The lack of rapid maneuverability in the UH, which was not originally designed for this kind of high agility missions, yielded degradation of course accuracy (Figure 10). The crossplots of roll angle and lateral position point out a higher spread in the repeated s-turn maneuvers in the NASA task for the UH-1D. The maneuver phases with constant roll angle are not perceptible. The pilots flew these phases with a combination of roll and sideslip. Also a comparison of the pedal inputs for both helicopters leads to this intensified coupling behaviour of the closed loop pilot/UH-1D system. Increased pilot stress and degraded task performance can be deduced from this low agility effect.

The roll/pitch coupling and the height control precision is an additional, and important, point of interest for the evaluation of helicopters related to slalom tasks. The responses of the test pilots point this out as a typical characteristic for single rotor helicopters. Figure 11 shows this aspect in the power spectra of the pitch rate signal for the two helicopter systems. Correspondingly, the pilots mentioned degraded height control precision as result of pronounced pitch/heave coupling. Interpreting the pilot ratings, the overall rating is more greatly influenced by the roll response, whereas the interaxis coupling influences the pilot stress in particular.

4.3 OTHER STRESS FACTORS

Experience and skill: One of the three evaluation pilots had less total helicopter experience and relatively little time in the BO 105 as compared to the others. It was found that his pilot ratings for stress were also higher than the two more experienced pilots. The pilot that had the most experience flying through the DFVLR course gave the lowest stress ratings. One main reason for this evaluation tendency is the training of the pilots to compensate for the coupling characteristics of the helicopter and/or to introduce closed loop coupling. Figure 12 shows the interrelation of roll angle and load factor in the DFVLR task for the most experienced pilot (A) and the least experienced pilot (B). In a steady turning flight the analytical relation between roll angle and load factor can be expressed as $\Delta n_z = 1/\cos \phi$. This function has to be extended for dynamical turning wiht terms describing kinematic properties. The area of deviation from the steady flight curve function accounts for the precision of course performing.

Diverging load factors with high roll angles are mainly produced by the pitch rate. With low roll angles the load factor is strongly influenced by the sideslip. In the comments, pilot A described the coupling as existing but controllable. On the other hand, pilot B considered the roll/pitch coupling and the height control to be the most pronounced problem of the hingeless rotor.

Environmental conditions: One of the evaluation pilots flew through all three courses on a day when the wind was quite gusty. Pilot rating data for that day was not used because the pilot complained of high stress in coping with the gust effects. Pilot ratings for all cases were one full rating number higher than similar runs repeated on a smooth day. An increase in pilot stress was also reported as a result of reduced visibility due to low sun angles, rain droplets on the windshield and reflections.

Adequacy of information: An essential part of the piloting task was to hold airspeed and altitude constant. This required intermittent scanning of the airspeed indicator and radar altimeter. Pilot stress associated with this workload may become significant by poor arrangement of these two instruments in the cockpit. A specific aspect of the 100 feet tests was the change of the scale on the radar altimeter by a factor of 10 at this altitude. 100' was difficult to hold with this radar altimeter resulting in increased pilot stress.

5. CONCLUDING REMARKS

The need for a viable NOE handling qualities data base requires the inclusion and comparison of data resulting from tests with different test conditions. The cooperatively conducted slalom tests yield a well defined measure of the different factors of pilot stress influencing pilot ratings and test results analyzed from measured data:

- The differentiated ratings, together with the additional pilot comments, facilitate the evaluation of test results. As a result of the redundant information, the reasons for rating deviations are obvious, including the secondary effects.

- The test conditions have to be taken into consideration in a comparison of test results, because of their significant influence on pilot stress and task performance. Test conditions include: (1) definition of task, (2) definition of environment, and (3) experience of test pilots.

- Performing a slalom task with well adapted track accuracy requires high roll agility of the helicopter system. This yields advantages for helicopters with adequate inherent moment control capacity.

- Increased interaxis coupling of helicopter leads to an apparent rise in pilot stress. With regard to the high pilot workload in real missions, a minimum of coupling is recommended.

6. LIST OF REFERENCES

1 "Helicopter Flying and Ground Handling Qualities; General Requirements for Military Specification", MIL-H-8501A, Sept. 1961

2 D.L. Key, The Status of Military Helicopter Handling Qualities Criteria, AGARD-CP-333, Apr. 1982

3 P.D. Talbot, D.C. Dugan, R.T.N. Chen, R.M. Gerdes, Effects of Rotor Parameter Variations on Handling Qualities of Unaugmented Helicopters in Simulated Terrain Flight, NASA TM 81190, Aug. 1980

4 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, March 1979

5 L.D. Corliss, G.D. Carico, A Preliminary Flight Investigation of Cross-Coupling and Lateral Damping for Nap-of-the-Earth Helicopter Operations, Proceedings 37th Annual Forum of the American Helicopter Society, May 1981

6 L.D. Corliss, Helicopter Handling Qualities Study of the Effects of Engine Response Characteristics, Height-Control Dynamics and Excess Power on Nap-of-the Earth Operations, NASA CP 2219, April 1982

7 J. Kaletka, Rotorcraft Identification Experience, AGARD-LS-104, Oct. 1979

8 H. Stenner, H.J. Pausder, K. Sanders, Correlation Aspects of Helicopter Flight Mechanics and Pilot Behaviour, Proceedings of 4th European Rotorcraft and Powered Lift Aircraft Forum, Sept. 1978

9 H.J. Pausder, B.L. Gmelin, Flight Test Results for Task Oriented Flying Qualities Evaluation, Proceedings 36th Annual Forum of the America Helicopter Society, May 1980

10 B.L. Gmelin, H.J. Pausder, The Impact of Helicopter Flight Mechanics on Mission Performance, AGARD-CP-313, Apr. 1981

11 H.J. Pausder, D. Hummes, Flight Test for the Assessment of Task Performance and Control Activity, NASA CP 2219, Apr. 1982

12 P.G. Hamel, B.L. Gmelin, H.J. Pausder, Missionsspezifische Einflüsse auf die Hubschrauber-Flugmechanik, Paper presented at the 14th International Helicopter Forum Bückeburg, May 1982

13 G.E. Cooper, R.P. Harper, The Use of Pilot Rating in the Evaluation of Aircraft Handling Qualities, AGARD Report 567, Apr. 1969

14 K. Sanders, H.J. Pausder, D. Hummes, Flight Tests and Statistical Data Analysis for Flying Qualities Investigations, Proceedings of 6th European Rotorcraft and Powered Lift Aircraft Forum, Sept. 1980

TEST	ALTITUDE	BO 105	UH-1D
NASA SLALOM	100 FT	3 RUNS	3 RUNS
NASA SLALOM	30 FT	3 RUNS	3 RUNS
DFVLR SLALOM	30 FT	7 RUNS	7 RUNS

Figure 1. Test Matrix

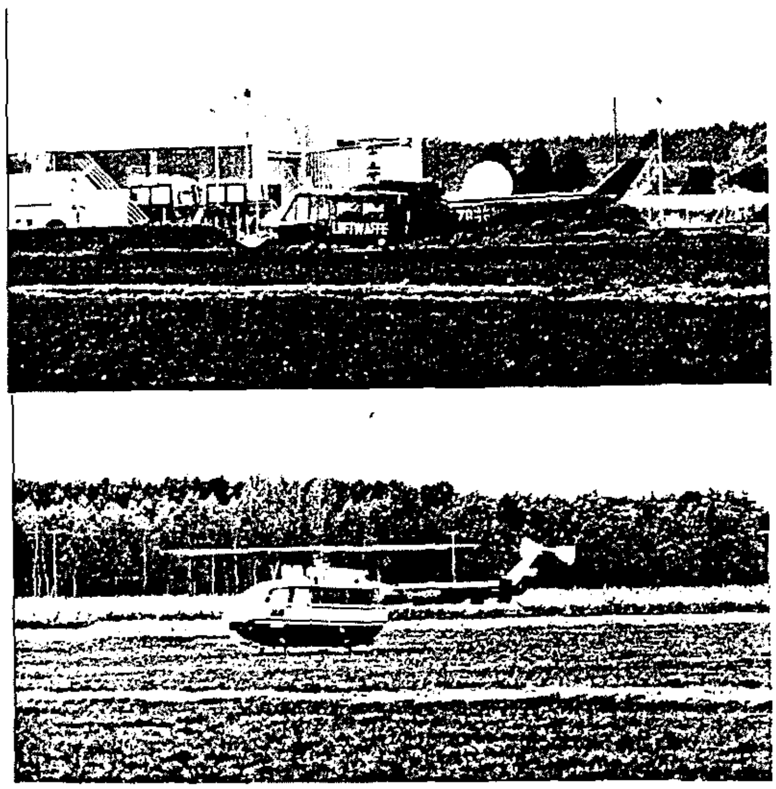

Figure 2. Test Helicopters

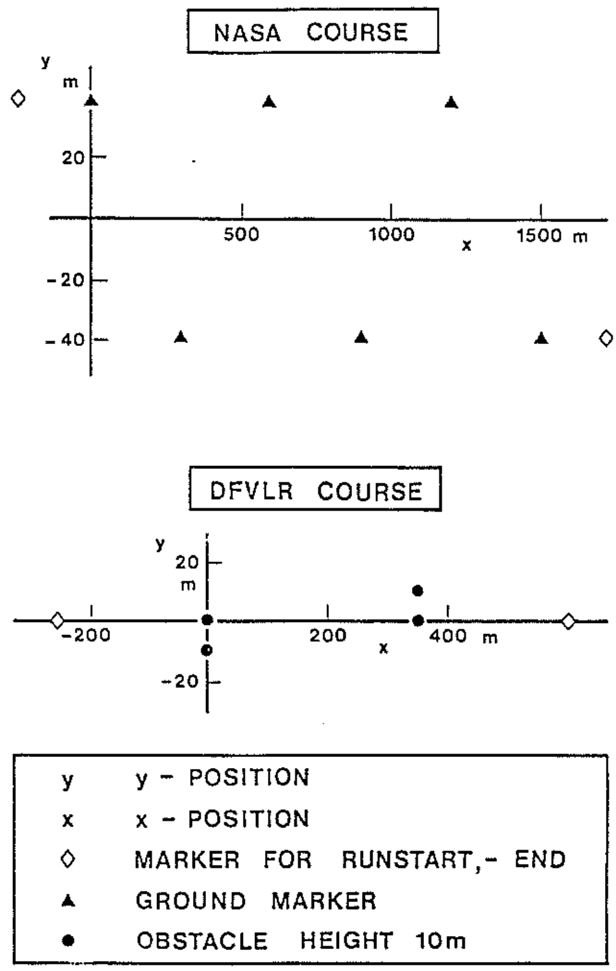

Figure 3. Slalom Courses

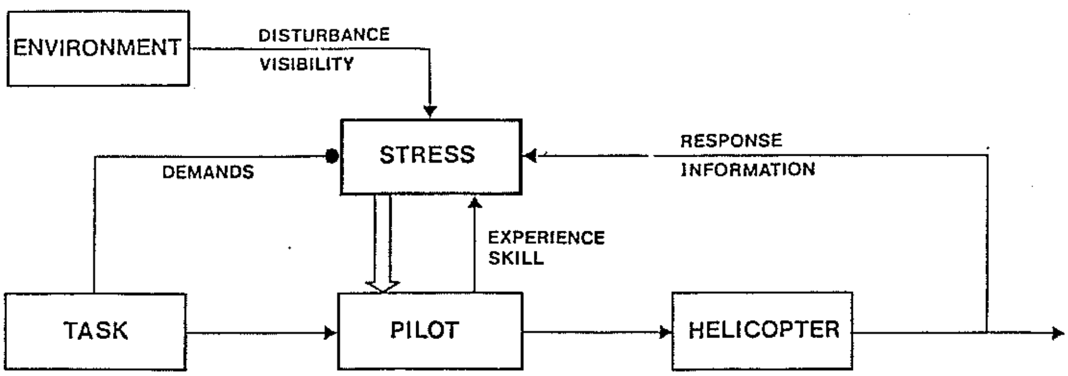

Figure 4. Influences on Pilot Stress

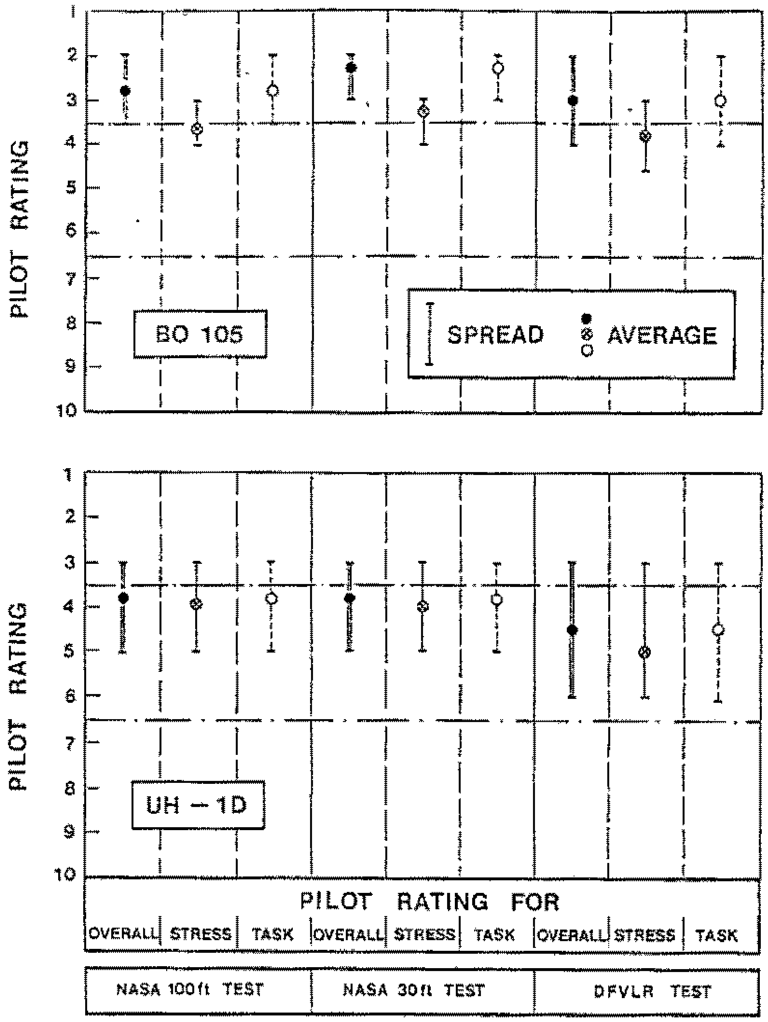

Figure 5. Pilot Rating Summary

MAIN COMMENTS FOR DEGRADATION OF OVERALL AND STRESS RATING

① HIGHER DEMANDS OF TASK

② LOW ROLL AGILITY

③ HIGH PEDAL ACTIVITY

④ HIGH ROLL/PITCH COUPLING

⑤ PROBLEMS IN HEIGHT CONTROL

Figure 6. Pilot Comment Summary

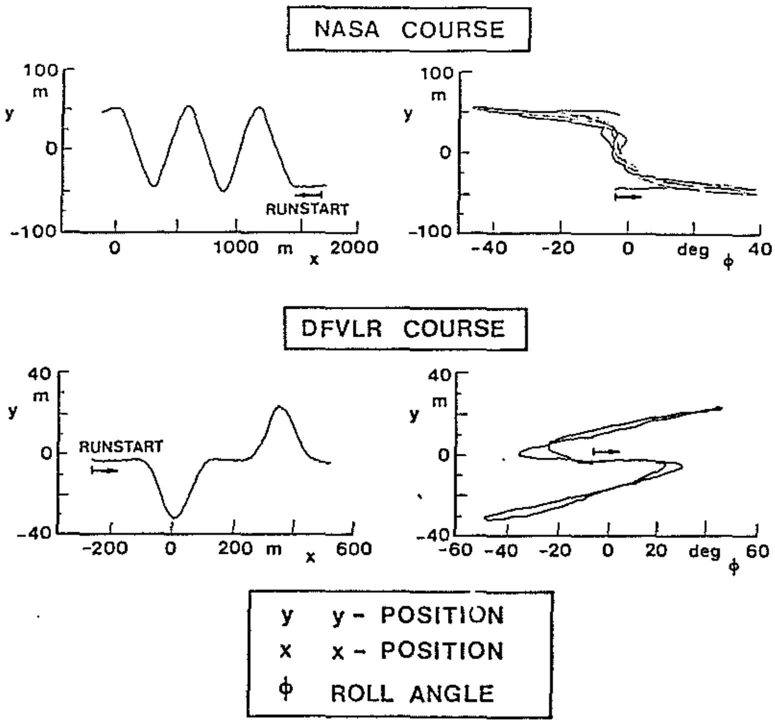

Figure 7. Course Characteristics
(BO 105)

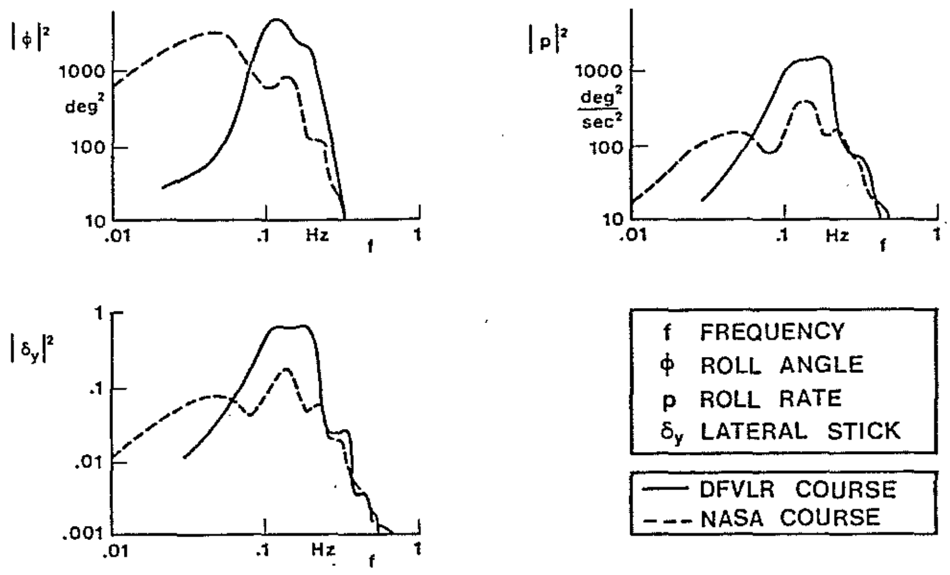

Figure 8. Power Spectra of Main Task
Variables (BO 105)

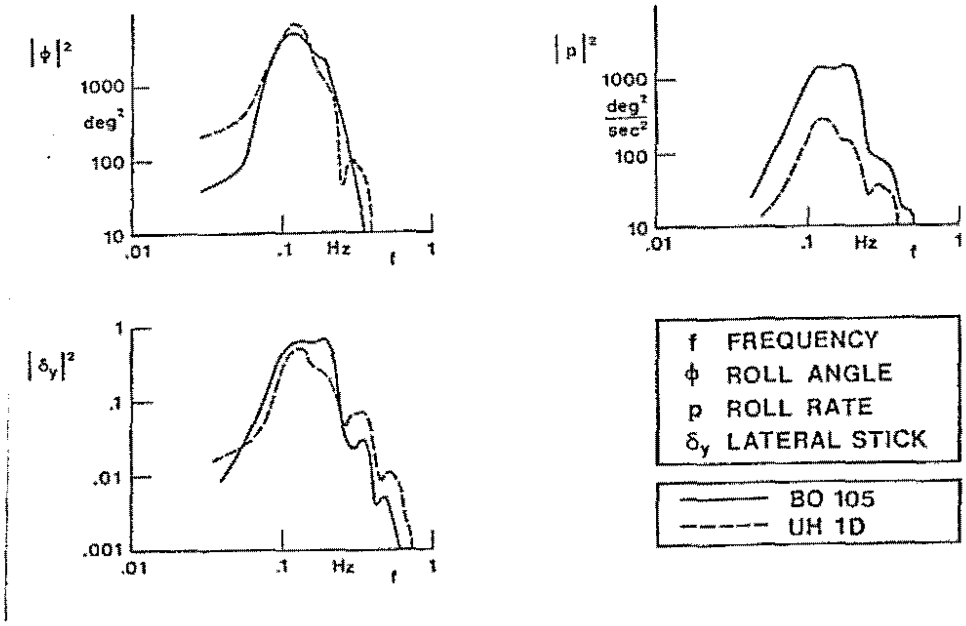

Figure 9. Power Spectra of Roll Agility Parameters (DFVLR Course)

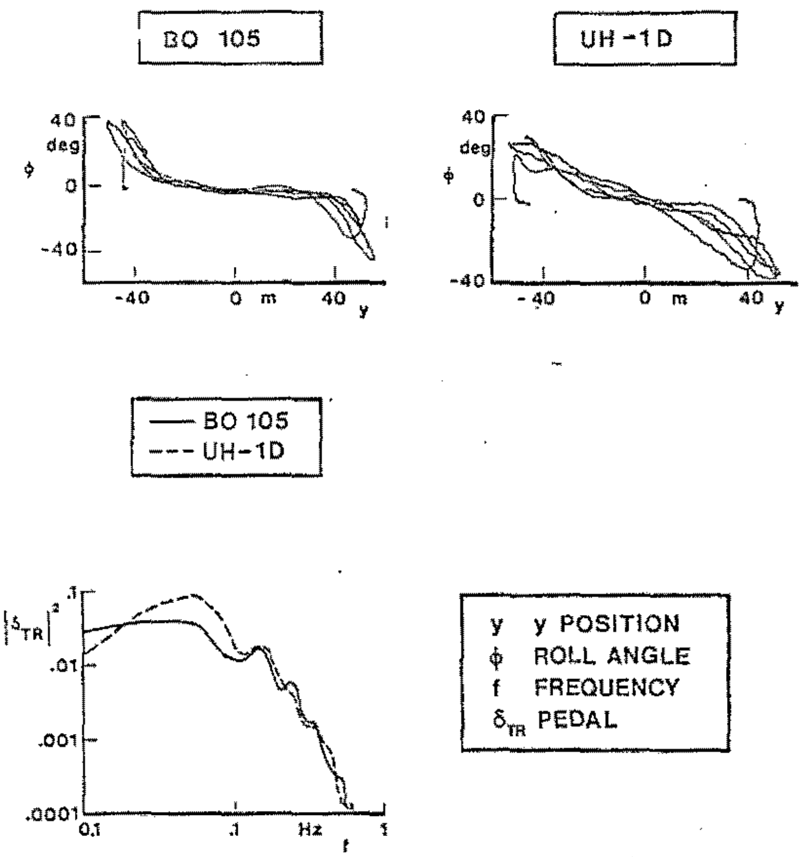

Figure 10. Course Accuracy (NASA Course)

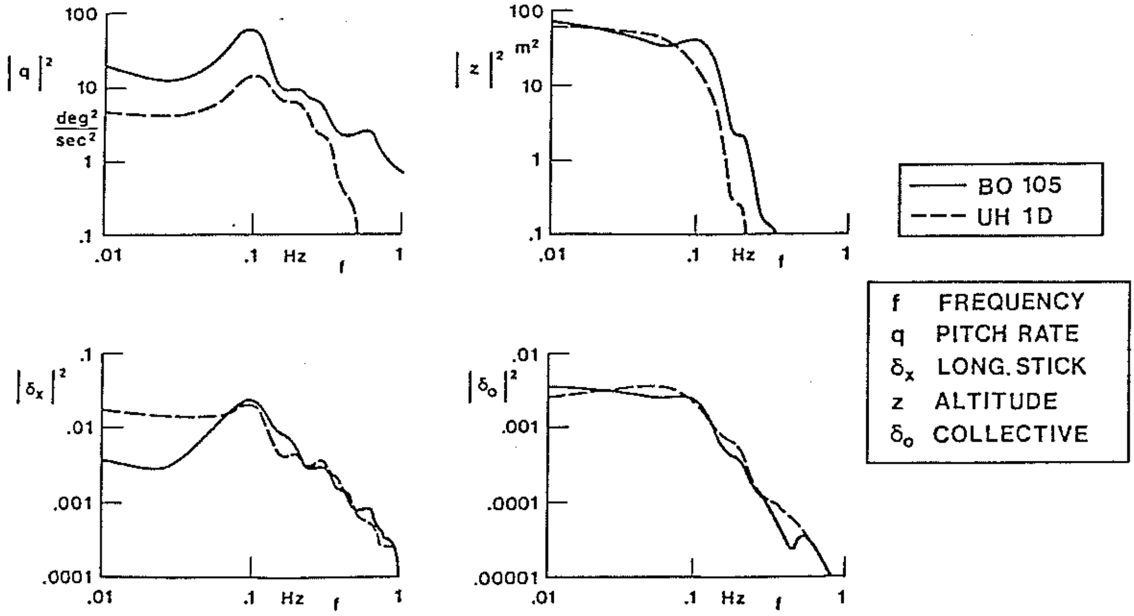

Figure 11. Power Spectra of Coupling Parameters (NASA Course)

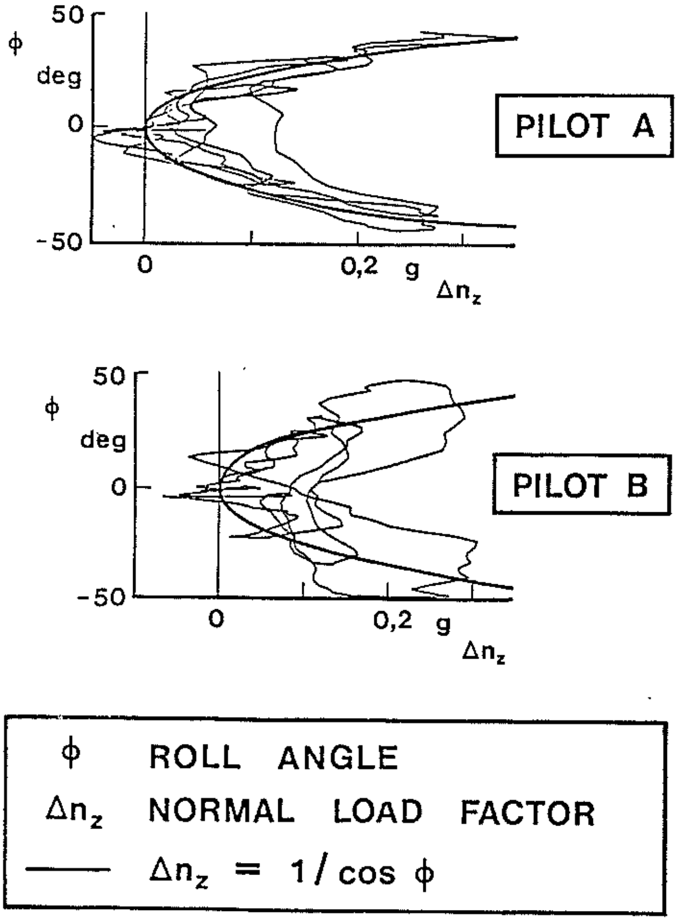

Figure 12. Influence of Pilot's Experience on Task Performance