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EVALUATIONS OF HELICOPTER INSTRUMENT-FLIGHT HANDLING QUALITIES

by

S.R.M. Sinclair, S. Kereliuk

National Aeronautical Establishment

OTTAWA
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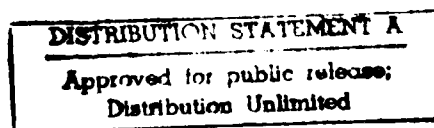
**EVALUATIONS OF HELICOPTER INSTRUMENT —
FLIGHT HANDLING QUALITIES**

**ÉVALUATION DE LA MANIABILITÉ DES HELICOPTÈRES
POUR LE VOL AUX INSTRUMENTS**

by/par

S.R.M. Sinclair, S. Kereliuk

**S.R.M. Sinclair, Head/Chef
Flight Research Laboratory/
Laboratoire des recherches en vol**



**G.M. Lindberg
Director/Directeur**

SUMMARY

The NAE Airborne Simulator, a modified and suitably equipped Bell 205A helicopter, was used in experiments to provide background information on the handling qualities requirements for helicopter instrument flight. This investigation was in support of a regulatory review undertaken by the U.S. Federal Aviation Administration as part of an overall assessment of the helicopter certification process.

The results illustrate the inter-dependence of the various stability and control characteristics which contribute to safe instrument flight handling qualities, and underline the importance of good mission simulation in conducting certification-related experiments.

SOMMAIRE

Le simulateur aéroporté EAN, un Bell 205A modifié et convenablement équipé, a servi de sujet d'expérience pour déterminer les caractéristiques essentielles de maniabilité des hélicoptères pour le vol aux instruments. Ces études s'inscrivent dans la revue de la réglementation entreprise par la Federal Aviation Administration des É.-U. dans son évaluation générale des méthodes de certification des hélicoptères.

Les résultats révèlent l'interdépendance des diverses caractéristiques de stabilité et de contrôle qui contribuent à assurer une maniabilité sûre pour le vol aux instruments. En outre, ils font ressortir l'importance de procéder à des vols simulés convenables pour les expériences reliées à la certification des hélicoptères.



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EVALUATIONS OF HELICOPTER INSTRUMENT-FLIGHT HANDLING QUALITIES

1.0 INTRODUCTION

Although the first civil IFR certification for a helicopter was granted by the Federal Aviation Agency in 1960, it is only in very recent years that a strong demand has developed for all-weather capability in civil helicopter operations. The helicopter manufacturers have responded to this demand, first with a series of retro-fit instrument flight systems for helicopter types which have already been approved for visual-flight, and more recently with a new generation of helicopters designed for the instrument flight environment.

The introduction of these new systems and aircraft has focussed attention on the procedures for civil helicopter certification, particularly upon the handling qualities requirements for safe instrument flight. For helicopters, as for fixed wing aircraft, the controlling airworthiness legislation in Canada and the United States is contained within the Federal Aviation Regulations (FAR's) enacted by the U.S. Federal Aviation Administration (FAA). These rules in general make similar demands of helicopter and fixed-wing applicants, however in the area of handling qualities requirements the regulations for the two types of aircraft differ fundamentally in their approach. While the specified levels of stability, control and manoeuvrability for airplanes apply equally to VFR and IFR flight, the helicopter handling qualities regulations directly address only visual-referenced flight and refer to "additional characteristics required for night and instrument operations, if certification for these kinds of operation is requested".* The "additional characteristics" have been reformulated several times since they were first defined for the Cessna YH-41 certification program in 1960 but in each version the objective has been to ensure a greater degree of static and dynamic stability than the regulations demand for VFR flight. Since 1970 these supplementary requirements have been published as the Interim Standards for Helicopter IFR Certification (Ref. 1).

The FAA has undertaken a review of the Interim Standards as part of an overall reassessment of the helicopter certification process. The review program has encompassed a wide range of activities involving the manufacturers and users of civil helicopters, government research laboratories and the FAA, culminating in the publication on 18 December 1980 of a notice of proposed rulemaking — "Rotorcraft Regulatory Review Program, Notice No. 1" (Ref. 2). If the recommendations of the notice are adopted, a set of helicopter IFR handling qualities requirements similar to those contained in the Interim Standards will be incorporated within revised versions of FAR's 27 and 29.

The airborne simulation experiments described in the report were undertaken in support of the regulatory review to provide background information on the handling qualities requirements for helicopter instrument flight. The flight testing was conducted in three distinct phases: in the first — a preliminary experiment — the emphasis was directed toward the design of appropriate instrument flight tasks and test procedures for assessing the suitability of flying qualities for single-pilot or two-pilot IFR operations; in the two subsequent flight phases these procedures were applied in an investigation of the effects of various levels of longitudinal static and dynamic stability on helicopter instrument-flight handling qualities. All three of the experiments were conducted at the National Aeronautical Establishment (NAE) facilities using the NAE Airborne Simulator as the flight test aircraft and employing experienced test pilots as evaluators. Since an underlying objective of the program was to relate flying qualities assessments to airworthiness requirements for instrument flight it was considered important that test pilots with experience in helicopter IFR certification programs be included as subjects in each test phase. This was accomplished through the participation of pilots from the FAA and Transport Canada who augmented the list of research pilot evaluators from NAE and the U.S. National Aeronautics and Space Administration.**

* FAR 27.141(c) and FAR 29.141(c).

** This program was jointly funded by the United States Federal Aviation Administration, under memorandum of agreement A1A-CA-22, and by the National Aeronautical Establishment.

The systems and parameter variations which were investigated in simulated single-pilot and two-pilot IFR operational environments fall into the general categories listed below:

- a. improvement in angular rate damping (limited authority SAS)
- b. improvement in angular rate damping with a selectable wing-leveller (limited authority SAS and roll autostabilization)
- c. improvement in angular rate damping with selectable roll and pitch attitude retention (limited authority SAS and roll/pitch autostabilization)
- d. variations in static longitudinal stability through augmentation of the speed stability derivative, M_u (simultaneous changes to static stability and phugoid mode characteristics)
- e. variations in static longitudinal stability through combinations of M_u , M_u^* , M_q augmentation (varying static stability and short period characteristics; phugoid frequency and damping unchanged; augmented lateral-directional characteristics, and
- f. as in e., above, but with degraded lateral directional stability and control characteristics.

The modelling techniques and the characteristics of the evaluated models are described in detail below.

The general objectives of the experimental program were, then, to assess the influence of these austere augmentation and autostabilization systems and of the various levels of longitudinal stability on the suitability of helicopter flying qualities for instrument flight.

2.0 THE AIRBORNE SIMULATOR

The NAE Airborne Simulator (Fig. 1) is an extensively modified Bell Model 205A-1 helicopter. In converting the aircraft to its airborne simulator configuration the standard hydraulically-boosted mechanical control actuators have been replaced with a set of dual-mode electrohydraulic actuators. The electro-mechanical servo valves can drive the actuators in a conventional power-boost mode in response to mechanical signals from the conventional stick, pedals and collective lever at left seat, or in a full-authority electric mode from the right-seat fly-by-wire station. Electric controllers and the electric actuators of the fly-by-wire system are integrated with a set of motion sensors, a hybrid computing system and a variable control-force feel system to provide the simulator with a flexible and powerful aircraft simulation capability. A description of these systems can be found in Reference 3.

Two additional alterations have been made to the Bell 205 control systems of the simulator: the stabilizer bar has been removed, and the longitudinal-cyclic-to-elevator link has been disconnected to accommodate an electrohydraulic actuator which allows operation of the elevator as part of the fly-by-wire system. The effects of the stabilizer bar removal (an improvement in cyclic control channel bandwidth and reduction in inherent roll and pitch damping) have only an indirect influence on the operation of the simulator; use of the "electric" elevator was, on the other hand, of primary importance in modelling the combinations of longitudinal static and dynamic characteristics which were of interest in this program.

The layout of the evaluation pilot's cockpit for the instrument flying qualities experiments is shown in Figure 2, where the conventional helicopter cyclic stick, collective lever and anti-torque pedal arrangement can be seen. Selection and control functions for the guidance, navigation and communication systems were accessible for left hand operation. The guidance and navigation aids which were available to the evaluation pilot for the instrument flight tasks included an ADF receiver with bearing pointer displayed on a conventional Radio Magnetic Indicator (RMI), a VOR/ILS receiver with localizer and glideslope information indicated on an Omni Bearing Selector (OBS), and a Micro-wave Landing System (MLS) receiver. The MLS provided localizer and variable-gradient glideslope information which was displayed in the form of raw signals on the Main Attitude display of the flight director.

3.0 MODELLING

The helicopter models were implemented using the response feedback technique whereby the control response and apparent natural modes of the simulator are modified by a direct feedback augmentation of its inherent characteristics. Although this approach has shortcomings which can be avoided with the more elegant model-controlled or model-following method of simulation, there are compensating factors which weighed heavily on the side of the simple response feedback for this program: using this method the stability and control characteristics which were not of primary concern in the program and which were not explicitly "modelled" in the simulation software, exhibited Bell 205 behaviour. This meant, for example, that the models had all of the asymmetries, cross-coupling and non-linearities associated with conventional helicopter control systems — without necessitating an elaborate modelling of the mechanisms which produce these effects. The background "Huey" characteristics also provided a relatively well known baseline against which the various evaluated configurations could be judged.

The models were therefore conceptually very simple. Roll damping changes were accomplished by varying the gain in a roll-rate-gyro to lateral-cyclic feedback path and roll attitude stabilization (wing-leveler) was implemented through a roll attitude feedback to the same control. Similar feedback paths were provided for yaw rate and lateral velocity to tail rotor collective; for pitch attitude, pitch attitude rate and forward speed to longitudinal cyclic; and for the rate of change of forward speed ($\dot{u}$) to the electric elevator.

The qualitative effects of most of these augmentation paths are well understood and require no elaboration. All of the models used in the first experiment, for example, required only rate and attitude feedback in the rotary degrees of freedom and the general characteristics of these simulated helicopters are summarized in Table 1. However, since the interactions among three of the feedback paths were of particular importance in the design of the models for the final two experiments, the effects of variations in gain in these paths on the static and dynamic longitudinal stability of the helicopter are illustrated in Figures 3 and 4. It can be seen that an increase in the speed stability derivative, M_u , tends to increase the phugoid mode frequency and reduce long period damping — at the same time as it increases the static longitudinal (stick position) stability. The M_u^* -augmentation, on the other hand, controls phugoid damping without significantly affecting phugoid frequency or static stability. (These effects and the insensitivity of the short-period characteristics to both M_u and M_u^* augmentation can be seen in Figure 3.) The models used in the second experiment were based on the combined effects of augmentation to the speed stability derivatives and u-damping. Table 2 presents a brief description of these models.

In the third and final experiment the pitch damping derivative $M_{\dot{\theta}}$ was used in conjunction with M_u and M_u^* to vary the static stability while keeping both the frequency and damping of the phugoid mode sensibly constant (Fig. 4). Since the static stability is affected by the value of M_u , but is independent of both M_u^* and $M_{\dot{\theta}}$, this isolation of static longitudinal stability from phugoid characteristics is possible. The variations in $M_{\dot{\theta}}$ do nevertheless have an effect on the short period mode and this fact must be considered when interpreting the pilot assessments for the third test phase.

Finally, an artificial turbulence model was available to increase pilot workload and to produce a more representative operational environment. The "canned" turbulence was not used at all in the preliminary experiment; in the second series of tests, models were evaluated both in the presence of turbulence and in relatively stable conditions without the artificial disturbances. In the final experiment the turbulence was phased in gradually between 1700 and 1500 feet above ground, producing a moderate level of disturbance during the final stages of the approach and during the missed approach procedure.

4.0 EXPERIMENTAL PROCEDURES

From a pilot workload standpoint the essential differences between single-pilot and two-pilot IFR operations are related to the management of non-control auxiliary tasks and to pilot fatigue

in long duration missions. In the airborne simulation program the long-term fatigue factor was not addressed, however the evaluation tasks were designed to highlight differences in auxiliary-task workload associated with the single-pilot and two-pilot operational situations. The flight tests were all conducted within the terminal area control zone of Ottawa International Airport, using approach patterns and a final approach aid dedicated to the experiment and not available to other traffic. (Figure 5 is a copy of the "terminal area chart" used in the experiments.) The sequences of sub-tasks prescribed for each evaluation are depicted in Figure 6 and a sample of the approach plates used for the precision MLS approaches is shown in Figure 7.

The evaluation of each helicopter configuration entailed the completion of the two approach patterns — Task 1 and Task 2 as depicted in Figure 6 — following which the pilot provided written responses to a handling qualities questionnaire. The format of the questionnaire is illustrated in Figure 8. The evaluator was asked to rate each of the Tasks using the Cooper-Harper rating scale and to comment on the helicopter's stability and control characteristics in support of the ratings. The final section of the questionnaire requested a mission-related assessment of suitability for IFR operations: the assignment of the helicopter to one of four categories was made with reference to the extended description of these categories reproduced below.

BASED ON YOUR SHORT EVALUATION, IN WHICH THE FOLLOWING CATEGORIES WOULD YOU PLACE THIS CONFIGURATION:

1. The helicopter has *excellent* flying qualities and could be operated safely in a high-density IFR environment by *one pilot* without the assistance of additional crew members. ☐
2. The helicopter had *good* flying qualities and could be operated safely in a high-density IFR environment by *one pilot* without the assistance of additional crew members. ☐
3. The helicopter has flying qualities deficiencies which make it unsuitable for single-pilot operations in a high-density IFR environment, however it could be operated safely within such an environment if the pilot-in-command were relieved of all non-control tasks by an additional qualified crew member. ☐
4. The helicopter has major flying qualities deficiencies which make it unsuitable for operation within a high-density IFR environment. ☐

To emphasize the differences between the demands of single-pilot and two-pilot IFR operations, Task 1 was designed to be a "hands-on" exercise, simulating the two-pilot where a second crew member can assume responsibility for all non-control tasks. Task 2 on the other hand included a variety of auxiliary, non-control demands representative of the situation facing the lone crew member in a single-pilot operation. In addition to the control workload in Task 2, the evaluation pilot was required to tune and identify navigation facilities and navigate the circuit; to conduct all necessary radio communications and copy, repeat and act upon clearances; and to perform the precision approach in a manner that would enable him to change to the published non-precision approach if this were required.

The workload of the pilot was further augmented in Task 2 by varying the approach clearances and the applicable approach chart. Since cards were provided for six different precision approaches to the MLS facility, the additional workload entailed selection of the required card and assimilation of the published information while controlling the helicopter. (The six variations of the approach were in fact simulated by biasing the evaluation pilot's compass heading before he assumed control of the simulator, by specifying different NDB aids and VOR radials for navigation, and by altering the procedural heights and simulated field elevations.)

The instrument flight procedural tasks formed the basis for the handling qualities evaluations of all three experiments. In the *final experiment only*, this operational evaluation was preceded by a preliminary series of tests wherein the pilots investigated the stability and control characteristics of each model using conventional flight test techniques. The model and the programmed values of its stability and control characteristics were identified for the pilot before he performed this systematic assessment in accordance with the test card shown in Figure 9.

5.0 THE FLIGHT EXPERIMENTS

Eight test pilots representing the U.S. Federal Aviation Administration (3), the National Aeronautics and Space Administration (1), Transport Canada (1), and the National Aeronautical Establishment (3) participated in the evaluation flight testing. All are qualified helicopter test pilots, some with extensive IFR experience, although in most cases this IFR experience has been acquired exclusively on fixed-wing aircraft. Three of the pilots are airworthiness test pilots who have performed instrument flight certification programs for helicopters. Table 4 gives a general summary of the flying experience of the evaluators and lists the phases of the program in which each participated.

In total the pilots flew over 150 hours in simulated IFR terminal area operations. The three experiments are described and their results discussed below. The first two tests are treated briefly since they were essentially preparatory experiments for the third which is presented in detail.

5.1 The First Experiment

Much of the effort in this preliminary experiment was directed toward the design of suitable instrument flight tasks for assessing the relative "certifiability" of various helicopter models for IFR flight. The evaluations of the models selected for these tests are of interest, nevertheless, since they illustrate the improvements in instrument-flight handling qualities which can be achieved through the application of simple stability augmentation and autostabilization techniques. These techniques form the basis of simple, safe and inexpensive systems for improving the inherent flying characteristics of a helicopter.

Four simple models were evaluated in this series of tests, each having the simulator's inherent static stability characteristics. The four were:

- a. the unaugmented Bell 205
- b. the Bell 205 with rate augmentation in roll, pitch and yaw (SAS authority, $\pm 10\%$)
- c. the Bell 205 with rate augmentation in roll, pitch and yaw — and a selectable "wing levelling" attitude stabilizer (total authority of SAS and autostabilizer, $\pm 10\%$, and
- d. the Bell 205 with rate augmentation in roll, pitch and yaw — and a selectable "attitude hold" stabilizer in roll and pitch (total authority of SAS and autostabilizer, $\pm 10\%$).

This experiment has been described in detail in Reference 4, however results of the evaluations are restated here to provide a context for the presentation of subsequent phases of the program. Table 1 summarizes the mission assessments of the four evaluated models.

For all instrument flight operations the pilots preferred configurations which possessed a greater degree of dynamic stability than that exhibited by the unaugmented helicopter. For two-pilot operations, simple rate damping in roll, pitch and yaw was enough to bring the overall IFR workload within reasonable limits and the handling qualities of the rate-augmented helicopter were considered suitable for two-pilot Category I IFR operations.

For single-pilot IFR flight, however, the pilots demanded a usable level of overall static stability — usable in the sense that the helicopter could be left unattended for periods of time required for non-control "housekeeping" tasks without risking large divergences from the original trimmed state. In this experiment the static stability levels were unchanged from the inherent values of the simulator (see Table 1) but improvements in trim retention were provided in the form of the selectable attitude stabilization modes described above. Although these systems were primitive both in design and implementation they provided a degree of relief from the control task workload, and confidence that the helicopter would not diverge if left unattended, enabling a lone-pilot to fly the helicopter and manage avionics systems, navigation tasks and ATC interactions. The rate-augmented helicopter with either the single-axis "wing-leveler" or with roll and pitch attitude hold was considered suitable for single-pilot IFR operations in a high traffic-density environment.

5.2 The Second Experiment

In this experiment, as in the subsequent one, the variables of primary interest were longitudinal static and dynamic stability. The main features of the models which were established for this second experiment are listed in Table 2. Static longitudinal stability was varied from strongly positive to neutral through augmentation of the speed stability derivative M_u , while $\dot{u}$ -damping was used to control the damping ratio of the resulting phugoid modes. In the primary series of models, A, B, C, the phugoid modes of the latter two were well damped while Model A, which had neutral speed stability, did not exhibit a low frequency oscillatory mode. When the neutrally stable Model A was disturbed from a trimmed state it tended to diverge slowly in speed (positively or negatively) while pitch attitude remained bounded and essentially constant.

The three models designed B_1 , C_1 , and C_2 were developed from B and C: Models B_1 and C_1 were identical to B and C respectively with the exception that the phugoid mode damping of B_1 and C_1 was reduced to zero by eliminating the $\dot{u}$ -damping. Model C_2 was another variant of C, the strongly speed-stable model, with the pitch rate damping increased to produce a lower frequency phugoid mode and improved short period characteristics while retaining the same high level of static stability.

Each of the models was flown with a control-force-feel system which provided positive breakout and positive force gradients in roll, pitch and yaw, and in a separate series of tests, with friction-only control forces. The models which possessed positive speed stability exhibited positive *stick position* stability in the absence of force gradients and positive *stick force* stability when gradients were present. (Control force levels are listed in Table 2.)

The results from the evaluation pilots' subjective assessment of the six models are presented briefly in the following paragraphs.

Longitudinal Stick Position Stability

Static longitudinal stick position stability without an accompanying stick force gradient does not appear to provide the pilot with usable information in a high-workload IFR environment. Force gradients were considered desirable, even in the case of neutral speed stability, to avoid the introduction of inadvertent and undetected pilot control inputs. Light stick gradients with well-defined breakout forces were considered essential for single-pilot IFR flight and desirable for two-pilot IFR operations.

Longitudinal Stick Force Stability

The pilot ratings and the responses to the questionnaire indicated a clear preference for positive stick force stability accompanied by "good" dynamic characteristics. Model C_2 with its strong speed stability, good short-period behavior and damped phugoid mode of moderate frequency ($T_p \approx 25$ seconds) was generally considered to be a good single-pilot IFR helicopter. The other two models which had this same high level of stick force stability — Models C and C_1 — were, however, consistently rejected for single-pilot IFR flight in turbulence, primarily because the speed stability was accompanied by a relatively high-frequency phugoid mode. (This undesirable dynamic behavior is discussed below.)

The models which had the low level of stick force stability were generally considered to be suitable for IFR flight. Model B, for example, with its low level of speed stability and positive phugoid damping was rated acceptable for two-pilot instrument flight by three of the six evaluators and for single-pilot IFR by two of the remaining three.

Finally, the neutrally stable Model A was rejected for instrument flight by half (3) of the subject pilots, and was considered safe for two-pilot IFR operations only, by two others.

Phugoid Mode Characteristics

The two models which had high frequency phugoid modes ($T_p \simeq 13$ seconds) exhibited very unpleasant handling qualities in turbulence, primarily because the pitch rates associated with these relatively high-frequency oscillations gave the impression that the helicopter was "digging-in" and therefore required immediate pilot compensation. In retrospect it is clear that the level of speed stability which produced these undesirable characteristics was an exaggerated one, incompatible with IFR manoeuvring requirements. Nevertheless there is evidence here that such an intermediate-frequency mode, whatever its source, should be *strongly* damped to be compatible with instrument flight in turbulence.

5.3 The Third Experiment

In the final flight experiment of the series, a narrower and more practical range of speed stability was investigated (refer to Table 3). In Models 1, 2 and 3, three levels of static longitudinal stability were evaluated in the presence of augmented lateral-directional characteristics and a work-load relieving wing-leveller. The same three levels of speed stability were repeated in Models 1B, 2B and 3B but the lateral directional handling qualities of these helicopters were degraded to the level of the unaugmented Bell 205 and the roll axis stabilization (wing-leveller) was not available.

Two additional models were included to assess the interacting effects of phugoid damping and static stability: Models 2A and 3A were derived from 2 and 3 by eliminating the $\dot{u}$ -damping to produce neutrally stable ($\zeta \simeq 0$) phugoid modes.

The time histories of Figure 10 show the dynamic responses of several of the models to pulse inputs in the longitudinal cyclic control.

The subjective results from the flight evaluations of these eight models are summarized in Figures 11 and 12. The histograms of Figure 11 show *two* mission assessments for each model — one for the conventional flight test evaluation (labelled FLIGHT TEST) and the other for the IFR procedural tasks (labelled PROCEDURAL). Figure 12 presents all of the pilot ratings for the single-pilot (TASK 2) procedural evaluations.

In the following paragraphs the significance of the primary experimental variables are discussed in the light of these pilot assessments.

Longitudinal Static Stability

Considering the data from Models 1, 2 and 3, it is evident that in these cases where lateral-directional characteristics did not dominate the handling qualities, the pilots perceived the increase in speed stability and considered its effects to be significant and beneficial for instrument flight. There was disagreement upon the suitability of the neutrally stable Model 1 for instrument flight: half of the pilots assessed Model 1 to be safe for single-pilot IFR while two evaluators considered it unacceptable even for two-pilot instrument operations. The written comments confirm that there was unanimous concern over the lack of longitudinal "stiffness" in this helicopter but the seriousness of this deficiency was judged differently by the various evaluation pilots.

Model 2, on the other hand, with a low positive level of static longitudinal (speed) stability was considered satisfactory for single-pilot IFR by half of the pilots and was rated suitable for two-pilot operations by the remaining half of the group. Here the annoyance of collective-to-pitch cross-coupling and an uncomfortable pitch sensitivity to gusts were cited as problems. Both of these complaints may be attributed to the lower level of pitch rate damping present in Model 2. In order to maintain the same phugoid frequency for all of the models in this group which exhibited phugoid oscillations, it was necessary to reduce the pitch damping of Models 2, 2A and 2B to the simulator's inherent level. (It should be noted that in the first of these experiments a helicopter very similar to Model 2 was assessed to be acceptable for single-pilot IFR. That aircraft, with similar static longitudinal stability and lateral-directional characteristics to Model 2, had significantly greater pitch rate damping ($\Delta M_q \approx -1$).)

The situation is much clearer in the case of Model 3: with the moderate level of speed stability, good pitch damping and the augmented lateral-directional characteristics, this helicopter was considered satisfactory for single-pilot IFR operations by five of the six evaluation pilots. The one dissenting view was a "borderline single-pilot" assessment based on the undesirable level of collective-to-pitch cross-coupling. All of the pilots considered the level of speed-stability of this model to be agreeable.

Interactions Between Lateral-Directional and Longitudinal Characteristics

When the lateral-directional characteristics of the modelled helicopters were degraded, the workload associated with lateral-directional stabilization and control dominated the handling qualities assessments. Models 1B, 2B and 3B received mixed ratings which do not appear to be correlated with the static stability levels. The pilot ratings were as much as 2.5 points higher than those for the corresponding models with good lateral-directional characteristics, and the mission assessments categorized these helicopters as unacceptable for IFR flight or suitable for two-pilot IFR only.

Phugoid Damping

A decrease in the phugoid damping of Models 2 and 3, as implemented in 2A and 3A, had little influence on the pilot ratings but a decided effect on the mission assessments. (Figures 11(d), 11(e) and Figure 12). The comments of several of the pilots indicated that the onset of the slow periodic motion of these undamped phugoid modes was mistakenly interpreted as a lack of speed stability and the ratings were downgraded on this basis. There was support for both of these models as single-pilot IFR helicopters: in the procedural evaluations four of the pilots suggested that 2A was safe for single-pilot IFR. The dissenting views were nevertheless stronger in these cases than in the evaluations of the damped-phugoid versions of the same helicopters.

Cross-Coupling

The control cross-coupling of collective into the pitch, roll and yaw axes was cited by a number of pilots as a major contributor to workload during the missed approach procedure. (The level of control cross-coupling exhibited by the models in these experiments was that of the Bell 205.) During a typical transition to missed approach, prior to retrimming, the pilot was required to provide approximately 15% of total nose down cyclic authority, 15% left pedal, and 8% left cyclic to maintain aircraft attitude and speed. These effects were also evident during approach tracking when collective-to-pitch coupling tended to contaminate the speed stability of the aircraft. The dominance of this undesirable coupling in some cases obscured the assessment of the primary parameter variations in the experiments.

6.0 CONCLUDING REMARKS

The form and content of the static longitudinal stability requirements contained in the Interim Standards for Helicopter IFR Certification were the basis for the initial design of the experiments described in this report. It was nevertheless inevitable that the subject matter of the program should be broadened to address the interacting effects of static and dynamic stability, and the importance of good lateral-directional characteristics on the overall handling qualities of a helicopter. The results from these experiments suggest that the following stability and control characteristics are important considerations in the development of helicopter instrument flight handling qualities requirements:

- a. good rate damping in the rotary degrees of freedom (damping levels between -1.0 and -2.0 sec^{-1} were used in the rate augmented systems evaluated in this program),
- b. no rapid spiral mode departures. (Requirements for spiral mode time constants were not directly addressed in the experiments but many of the models eliminated this mode using the simple wing-leveller. Experiments specifically addressing the effect of lateral and longitudinal aperiodic departures on instrument flight handling qualities are presently being carried out at the NAE.),
- c. minimal levels of control coupling and dynamic cross-coupling, and
- d. good positive speed stability along with light, positive breakout and gradient forces for the roll and pitch cyclic controls. (Speed stability derivative values in the range from 0.004 and $0.007 \text{ (rad/sec}^2\text{)/(ft/sec)}$ were considered satisfactory for instrument flight.)

All four of these conditions should be met to ensure good single-pilot instrument flight handling qualities; however, in the absence of any one of the four, an equivalent level of safety can most easily be provided by some form of attitude stabilization.

Finally, the minimum required levels of handling qualities for two-pilot IFR operations are more difficult to define since the helicopter pilot's traditional tolerance for "bad" flying qualities appears to carry over to the IFR environment if he is able to concentrate on the control tasks. If adopted, the provisions of the Notice of Proposed Rulemaking (Ref. 4) would continue the practice of establishing less stringent stability and control requirements for instrument-flight certification of helicopters when the minimum crew complement is two instrument-qualified pilots. As helicopter control systems evolve and the instrument flight mission plays a more important part in the design process of future helicopters, the need for these two-tiered handling qualities requirements should diminish. Then for helicopters, as for fixed-wing aircraft, there should be no relaxation of IFR stability and control requirements based on workload relief provided by additional crew.

7.0 ACKNOWLEDGEMENT

The names and affiliations of the participating test pilots are listed below:

P. Balfe	FAA
R.M. Gerdes	NASA
S.W. Grossmith	Transport Canada
S. Kereliuk	NAE
J.M. Morgan	NAE
J.C. Watts	FAA
H. White	FAA
A.D. Wood	NAE

8.0 REFERENCES

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2. *Rotorcraft Regulatory Review Program Notice No. 1.*
Aviation Administration, December 1980.
3. Sinclair, S.R.M. *The NAE Airborne V/STOL Simulator.*
Roderick, W.E.B. Proceedings of the AGARD Flight Mechanics Panel Symposium
Lum, K. on Rotorcraft Design. AGARD CP-223, May 1977.
4. Kereliuk, S. *Evaluation of IFR Handling Qualities of Helicopters Using the*
Sinclair, S.R.M. *NAE Airborne V/STOL Simulator.*
Atlantic Aeronautical Conference, Williamsburg, Va, 1979.

TABLE 1
DESCRIPTION OF MODELS USED IN THE FIRST EXPERIMENT

Model Designation	Static Longitudinal Stability*	Phugoid Mode Frequency/Damping	Pitch Rate Damping	Lateral-Directional Characteristics	Autostabilization
Baseline	Low	0.23 rps/lightly damped	Unaugmented	Unaugmented	None
Augmented	Low	Low/lightly damped	Augmented	Augmented roll, pitch, yaw rate damping	None
Wing-Leveller	Low	Low/lightly damped	Augmented	Augmented roll, pitch, yaw rate damping	Wing-Leveller
Attitude Hold	Low	Low/lightly damped	Augmented	Augmented roll, pitch, yaw rate damping	Roll, pitch attitude hold

*Static Longitudinal Stability

Low $\delta \text{cyc}/\Delta U \approx 0.25 \text{ in./10 knots}$ $M_u \approx 0.004 \text{ rps}^2/\text{fps}$

Control Forces

Longitudinal Cyclic 0.5 lb breakout 0.5 lb/in. gradient

Lateral Cyclic 0.5 lb breakout 0.5 lb/in. gradient

Pedals Very light breakout Self-centering

Collective Adjustable friction

TABLE 2
DESCRIPTION OF MODELS USED IN THE SECOND EXPERIMENT

Model	Static Longitudinal Stability*	Phugoid Mode Frequency/Damping	Pitch Rate Damping	Lateral-Directional Characteristics	Autostabilization
A	Neutral	—	Unaugmented	Unaugmented	None
B	Low	0.25 rps/damped	Unaugmented	Unaugmented	None
B ₁	Low	0.25 rps/zero damping	Unaugmented	Unaugmented	None
C	High	0.5 rps/damped	Unaugmented	Unaugmented	None
C ₁	High	0.5 rps/zero damping	Unaugmented	Unaugmented	None
C ₂	High	0.25 rps/damped	Augmented	Unaugmented	None

*Static Longitudinal Stability Levels

Low $\delta \text{cyc}/\Delta U \approx 0.25 \text{ in./10 knots}$ $M_u \approx 0.004 \text{ rps}^2/\text{fps}$
 High $\delta \text{cyc}/\Delta U \approx 1.0 \text{ in./10 knots}$ $M \approx 0.015 \text{ rps}^2/\text{fps}$

Control Forces

Primary Set

Lateral Cyclic 0.5 lb breakout 0.5 lb/in. gradient
 Longitudinal Cyclic 0.5 lb breakout 0.5 lb/in. gradient
 Pedals Very low breakout Self-centering
 Collective Adjustable friction

Secondary Set

Lateral Cyclic Zero breakout Friction (held position when released)
 Longitudinal Cyclic Zero breakout Friction (held position when released)
 Pedals Zero breakout Friction (held position when released)
 Collective Adjustable friction

TABLE 3
DESCRIPTION OF MODELS USED IN THE THIRD EXPERIMENT

Model	Static Longitudinal Stability*	Phugoid Mode Frequency/Damping	Pitch Rate Damping	Lateral-Directional Characteristics	Autostabilization
1 1 _B	Neutral	—	Augmented Augmented	Augmented Unaugmented	Wing-Leveller None
2 2 _A 2 _B	Low	0.23 rps/damped 0.23 rps/zero damping 0.23 rps/damped	Unaugmented Unaugmented Unaugmented	Augmented Augmented Unaugmented	Wing-Leveller Wing-Leveller None
3 3 _A 3 _B	Moderate	0.23 rps/damped 0.23 rps/zero damping 0.23 rps/damped	Augmented Augmented Augmented	Augmented Augmented Unaugmented	Wing-Leveller Wing-Leveller None

* Static Longitudinal Stability Levels

Low $\delta_{cyc}/\Delta U \simeq 0.25$ in./10 knots $M_u \simeq 0.004$ rps²/fps

Moderate $\delta_{cyc}/\Delta U \simeq 0.45$ in./10 knots $M_u \simeq 0.007$ rps²/fps

Control Forces

Lateral Cyclic 0.5 lb breakout 0.5 lb/in. gradient

Longitudinal Cyclic 0.5 lb breakout 1.0 lb/in. gradient

Pedals Very light breakout Self-centering

Collective Adjustable friction

TABLE 4

FLYING EXPERIENCE AND PROJECT INVOLVEMENT OF THE EVALUATION PILOTS

Pilot	Flying Times			Participation
	Total	Helicopter	Instrument	
A	6,900	900	950	Experiments 2, 3
B	5,700	400	980	Experiments 1, 2, 3
C	8,300	1,200	2,100	Experiment 3
D	13,000	200	1,500	Experiment 3
E	13,000	3,500	1,300	Experiments 1, 2, 3
F	6,350	3,310	200	Experiments 2, 3
G	5,600	1,550	480	Experiments 1, 2
H	8,050	5,100	925	Experiment 2

TABLE 5

SUMMARY OF MISSION ASSESSMENTS

	Basic Helicopter	Rate Augmented Configuration	Augmented with "Wing-Leveller"	Augmented with Attitude Hold
Pilot 'A'	VFR only	IFR-2 pilot	IFR-1 pilot	IFR-1 pilot
Pilot 'B'	IFR-2 pilot	IFR-2 pilot	IFR-1 pilot	IFR-1 pilot
Pilot 'C'	VFR only	IFR-2 pilot	IFR-1 pilot	IFR-1 pilot



FIG. 1: NAE AIRBORNE SIMULATOR



FIG. 2: EVALUATION COCKPIT

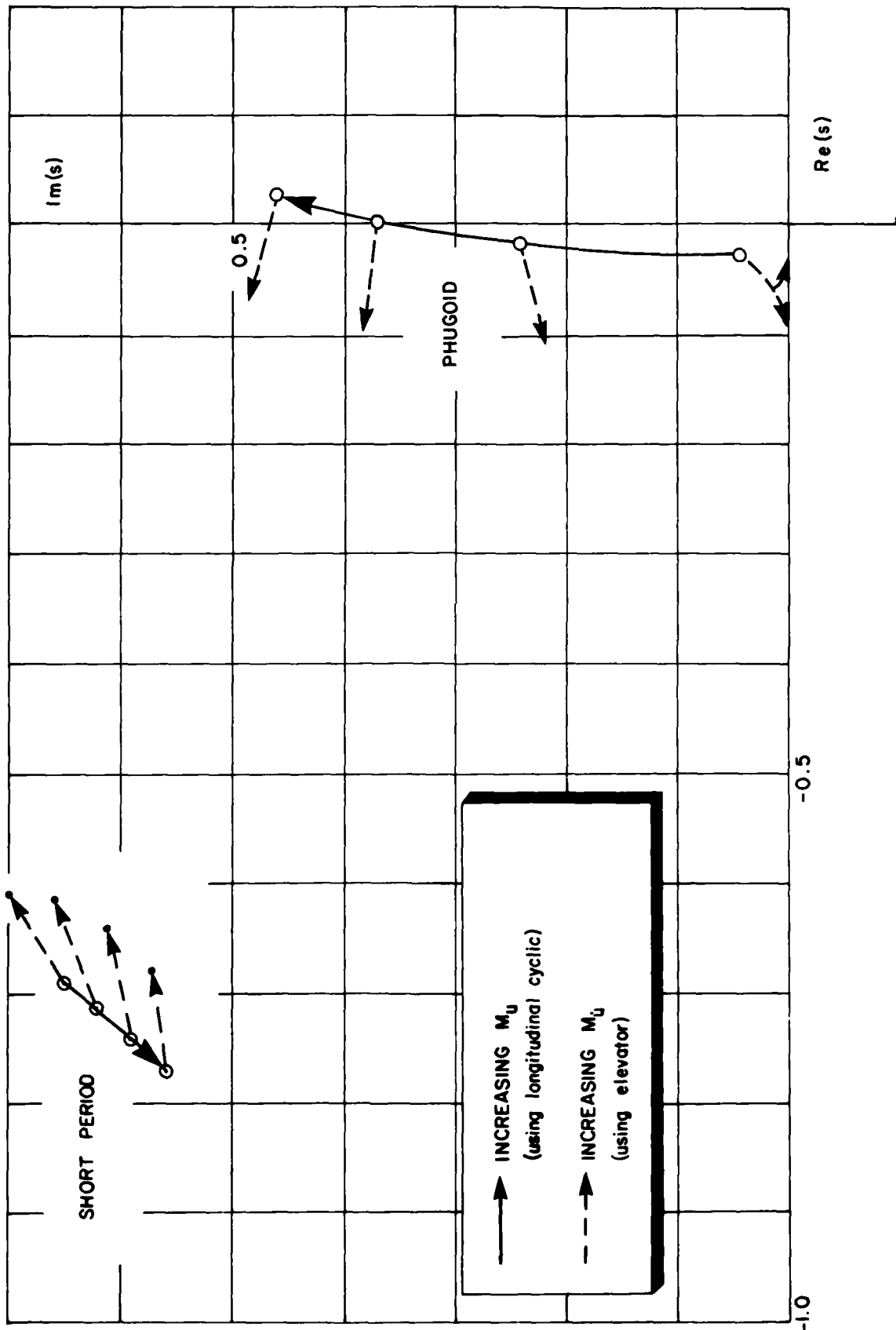


FIG. 3: EFFECTS OF COMBINING M_u AND M_u AUGMENTATION

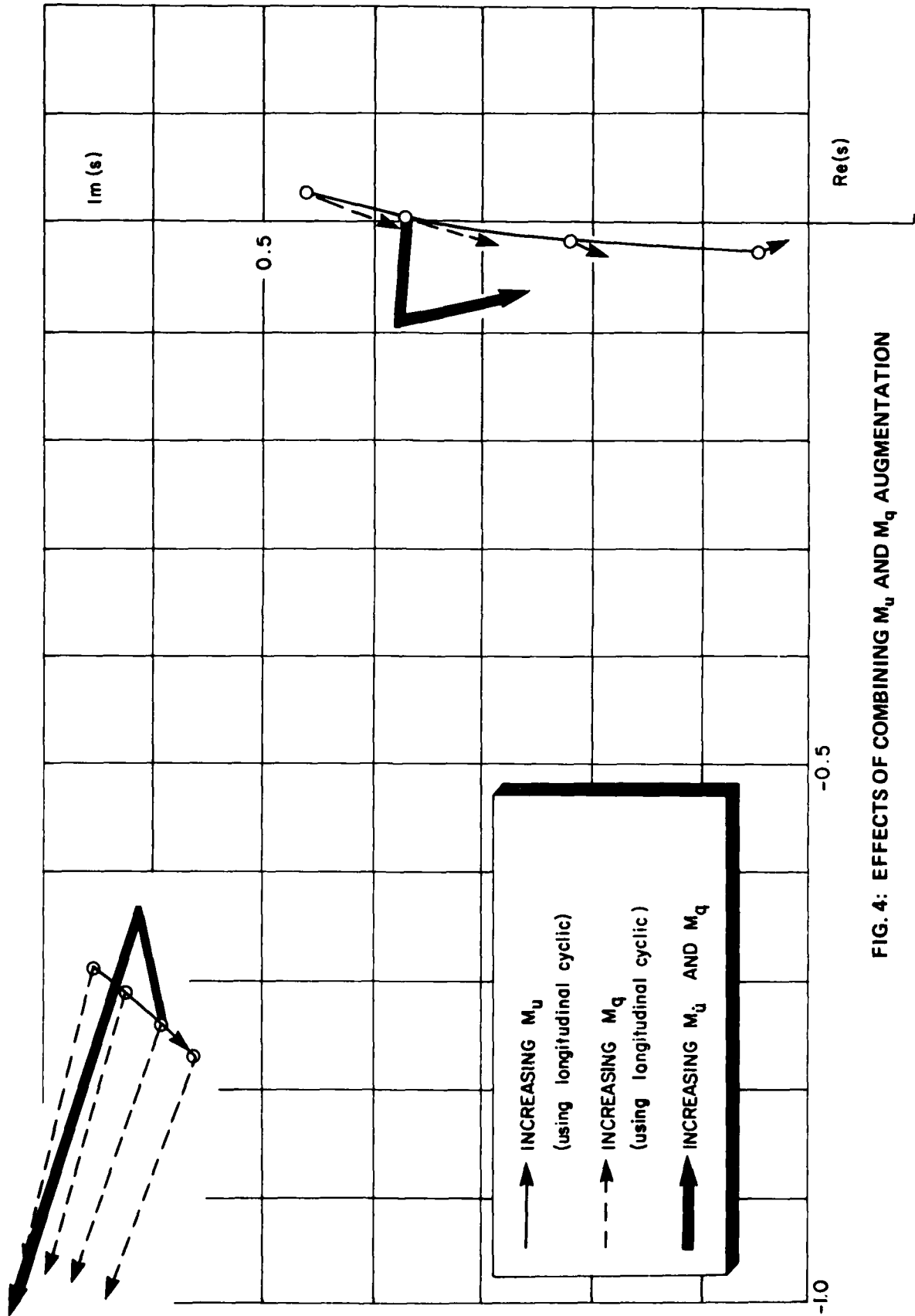


FIG. 4: EFFECTS OF COMBINING M_u AND M_q AUGMENTATION

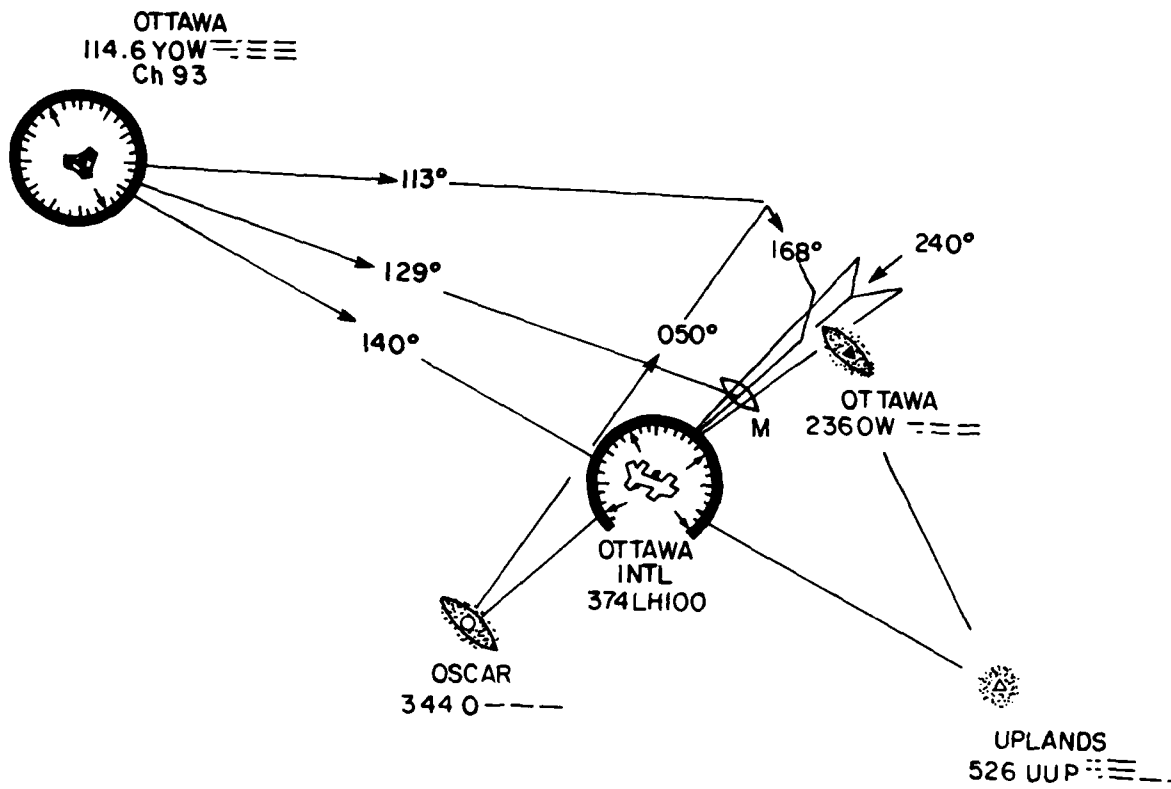


FIG. 5: MLS TERMINAL PROCEDURE

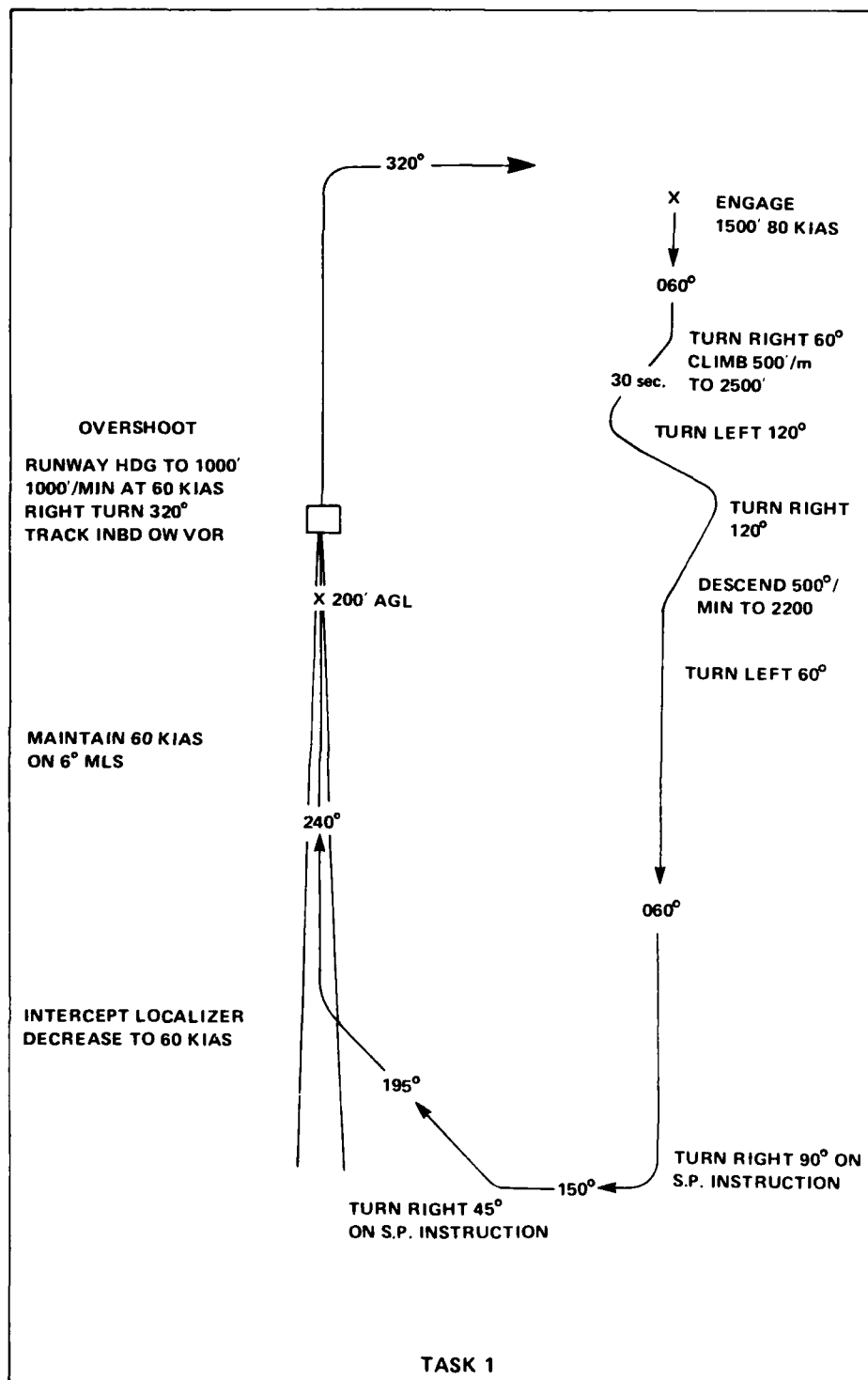


FIG. 6(a): DUAL - PILOT TASK

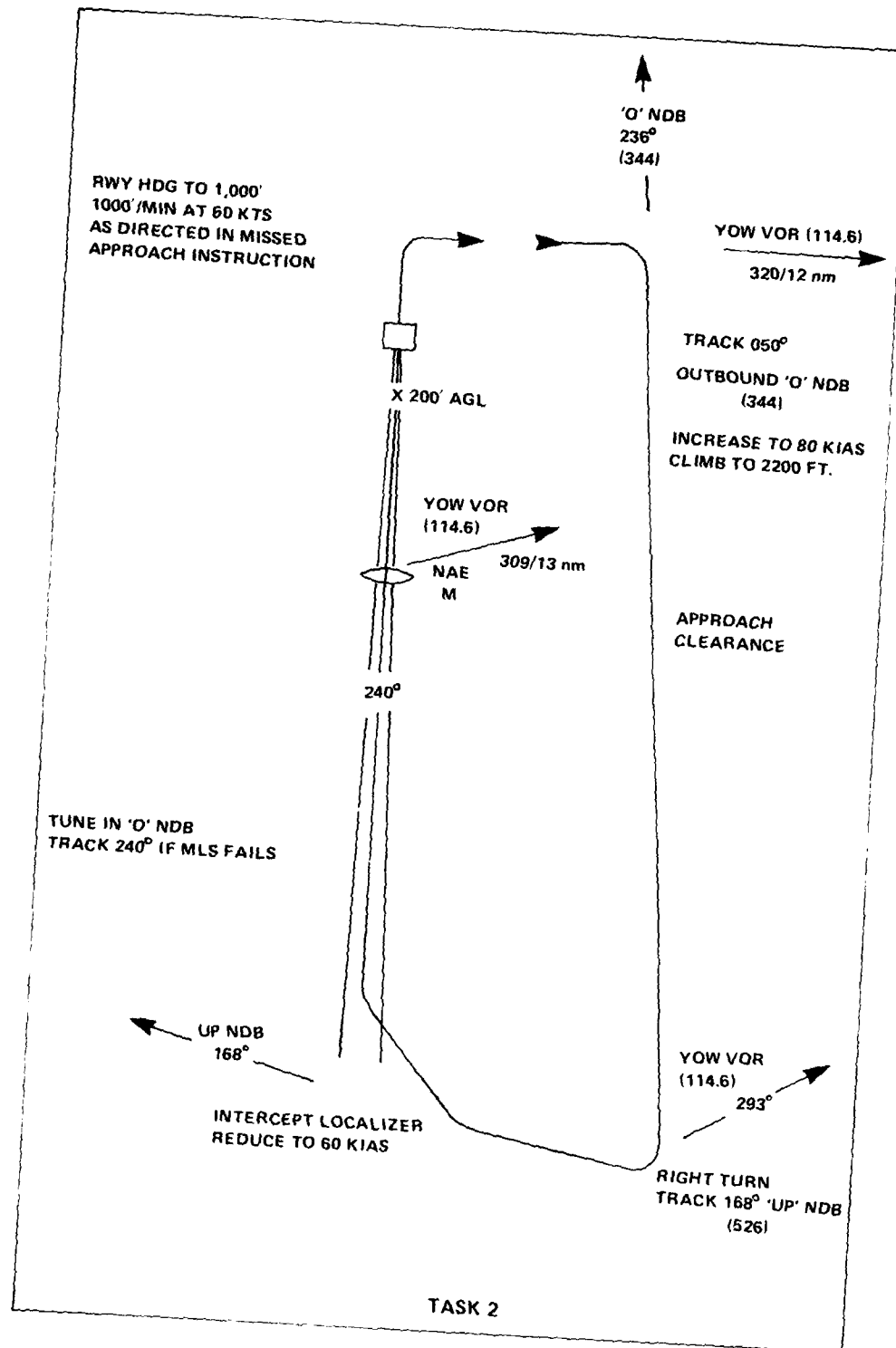


FIG. 6(b): SINGLE - PILOT TASK

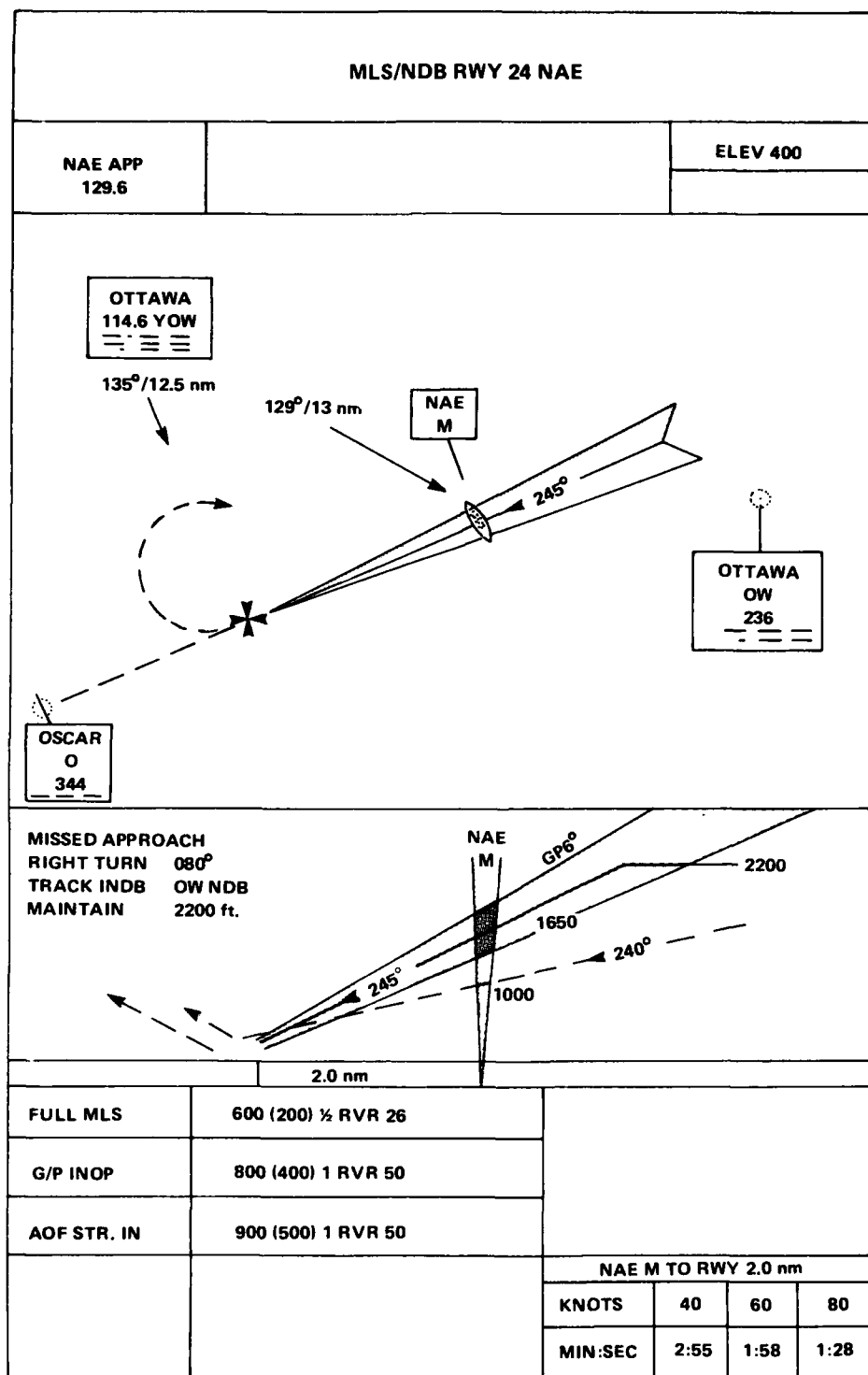


FIG. 7: SAMPLE MLS APPROACH PLATE

EVALUATION PILOT: _____ FLIGHT #: _____
CONFIGURATION #: _____ DATE: _____
WEATHER AND WINDS: _____

A. TWO-PILOT TASK SEQUENCE RECORDER RUN #: _____

1. COOPER-HARPER RATING

☐

COMPUTER GENERATED
TURBULENCE: _____

2. Comment on distinguishing characteristics or features which support this rating:

a. LONGITUDINAL CHARACTERISTICS _____

b. LATERAL-DIRECTIONAL CHARACTERISTICS _____

c. OTHER FEATURES _____

FIG. 8: PILOT QUESTIONNAIRE

B. SINGLE-PILOT TASK SEQUENCE

RECORDER RUN #: _____

1. COOPER-HARPER RATING ☐

COMPUTER GENERATED
TURBULENCE: _____

2. Comment on distinguishing characteristics or features which support this rating.

a. LONGITUDINAL CHARACTERISTICS _____

b. LATERAL-DIRECTIONAL CHARACTERISTICS _____

c. OTHER FEATURES _____

C. IFR CERTIFICATION LEVEL (See Extended Description of Categories)

1. EXCELLENT 1-Pilot ☐

GOOD 1-Pilot ☐

2-Pilot ☐

NOT CERTIFIABLE ☐

2. COMMENTS _____

FIG. 8: PILOT QUESTIONNAIRE (Cont'd)

1. **DYNAMIC RESPONSE** TRIMMED 70 KIAS
STRAIGHT AND LEVEL
 - a. LATERAL CYCLIC PULSES ($\Delta\phi < 10^\circ$)
LEFT
RIGHT
 - b. LONGITUDINAL CYCLIC PULSES ($\Delta\theta < 5^\circ$)
NOSE UP
DOWN
 - c. PEDAL PULSES ($\Delta\beta < 10^\circ$)
LEFT
RIGHT
 - d. COLLECTIVE STEPS ($\Delta\delta_c < 1''$)
UP
DOWN
2. **LONGITUDINAL STATIC STABILITY** TRIMMED 70 KIAS
STRAIGHT AND LEVEL
 - a. 70 KIAS $\rightarrow$ 80 $\rightarrow$ 60 $\rightarrow$ 70
CONSTANT ALTITUDE, NO TRIMMING
 - b. 70 KIAS $\rightarrow$ 80 $\rightarrow$ 60 $\rightarrow$ 70
CONSTANT ALTITUDE, NO TRIMMING
3. **TURNING MANOEUVRES** TRIMMED 70 KIAS
STRAIGHT AND LEVEL

20 DEGREE BANK TURN RIGHT 90°

REVERSE LEFT 90°
4. **STABILITY IN CLIMBS AND DESCENTS** TRIMMED 70 KIAS
STRAIGHT AND LEVEL
 - a. $\uparrow$ 1000FPM, $\Delta h = 500'$, RETRIM
 - b. $\downarrow$ 1000FPM, $\Delta h = 500'$, RETRIM

FIG. 9: FLIGHT TEST ROUTINE

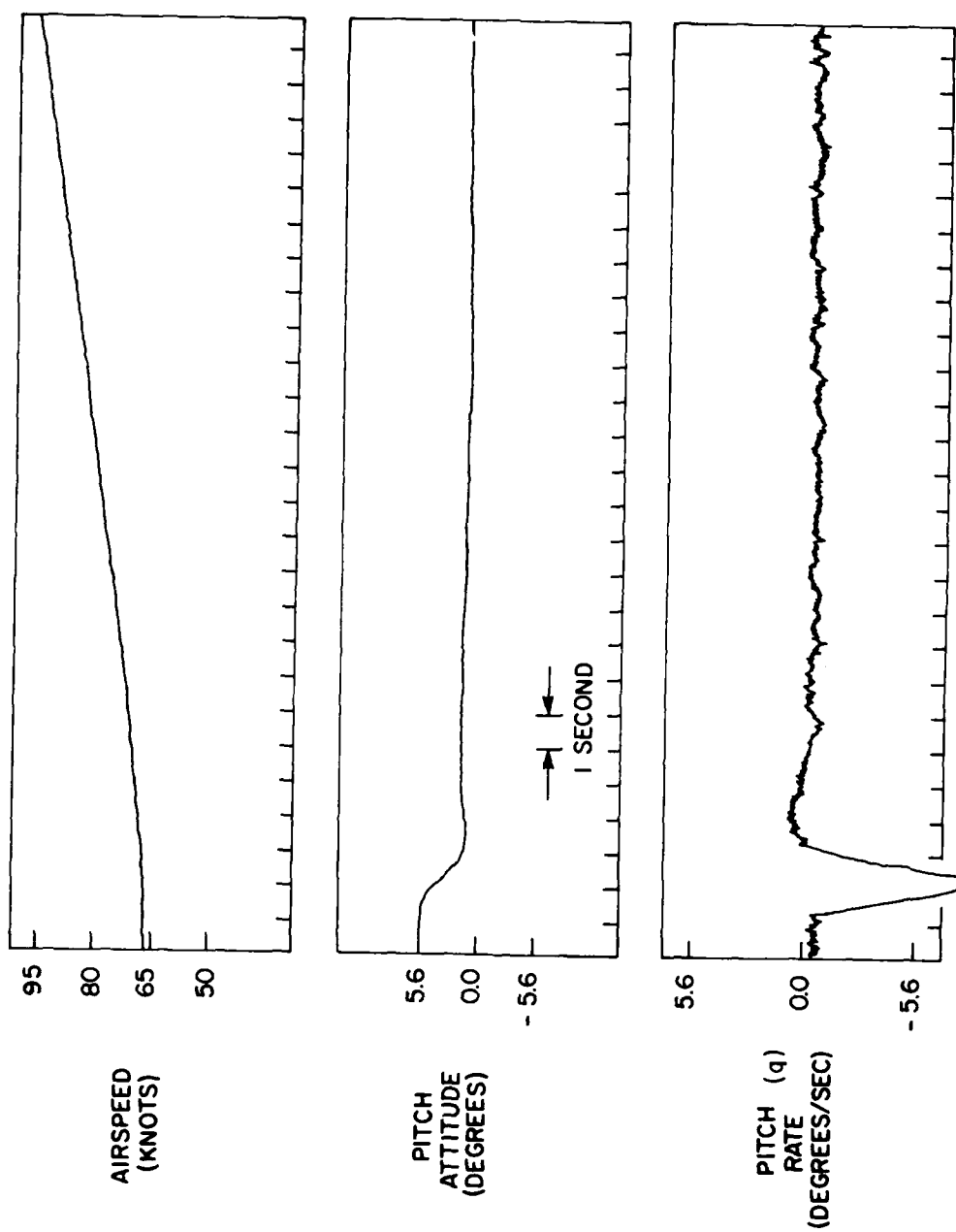


FIG. 10(a): MODEL 1 - LONGITUDINAL DYNAMIC RESPONSE

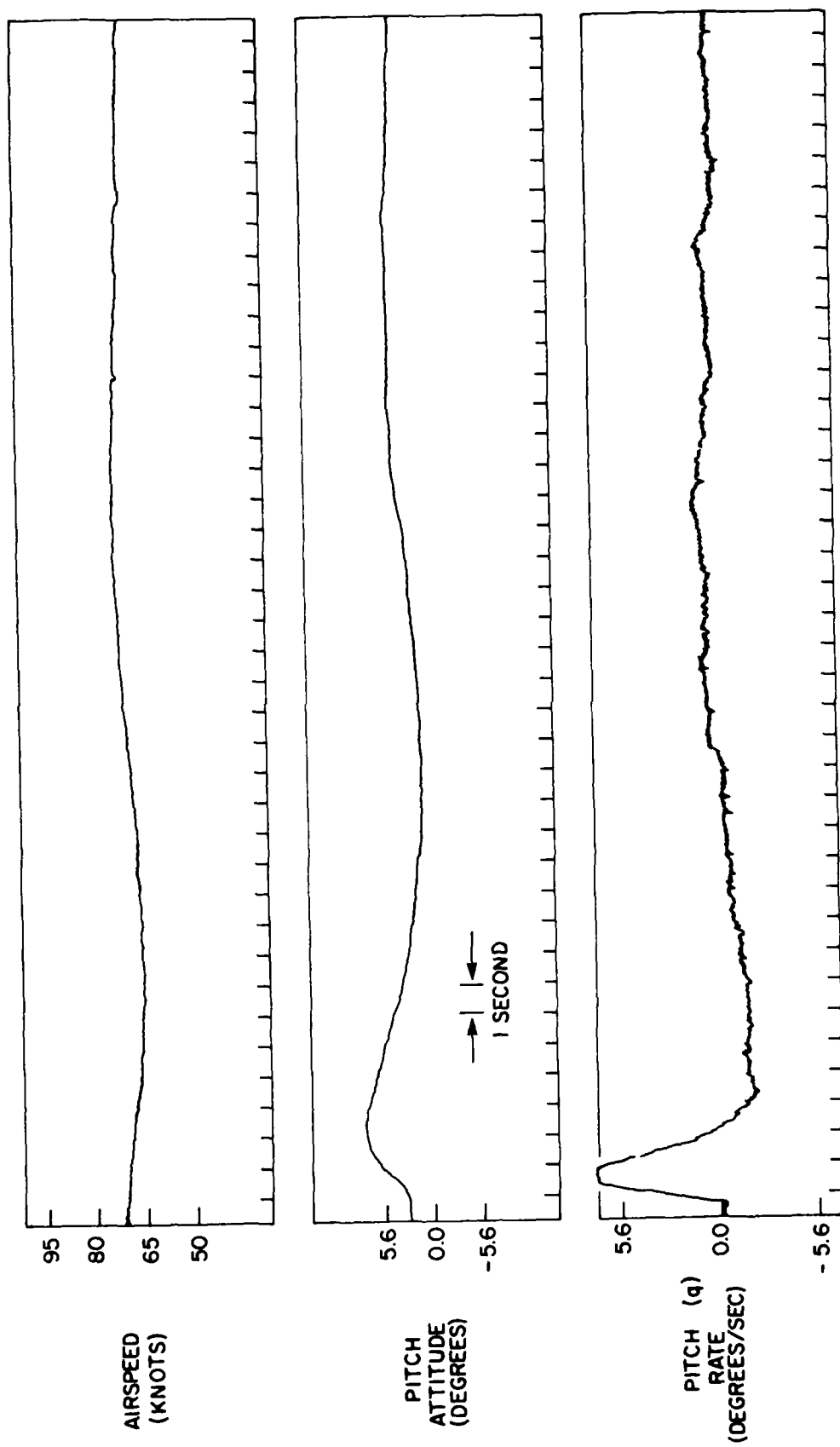


FIG. 10(b): MODEL 2 - LONGITUDINAL DYNAMIC RESPONSE

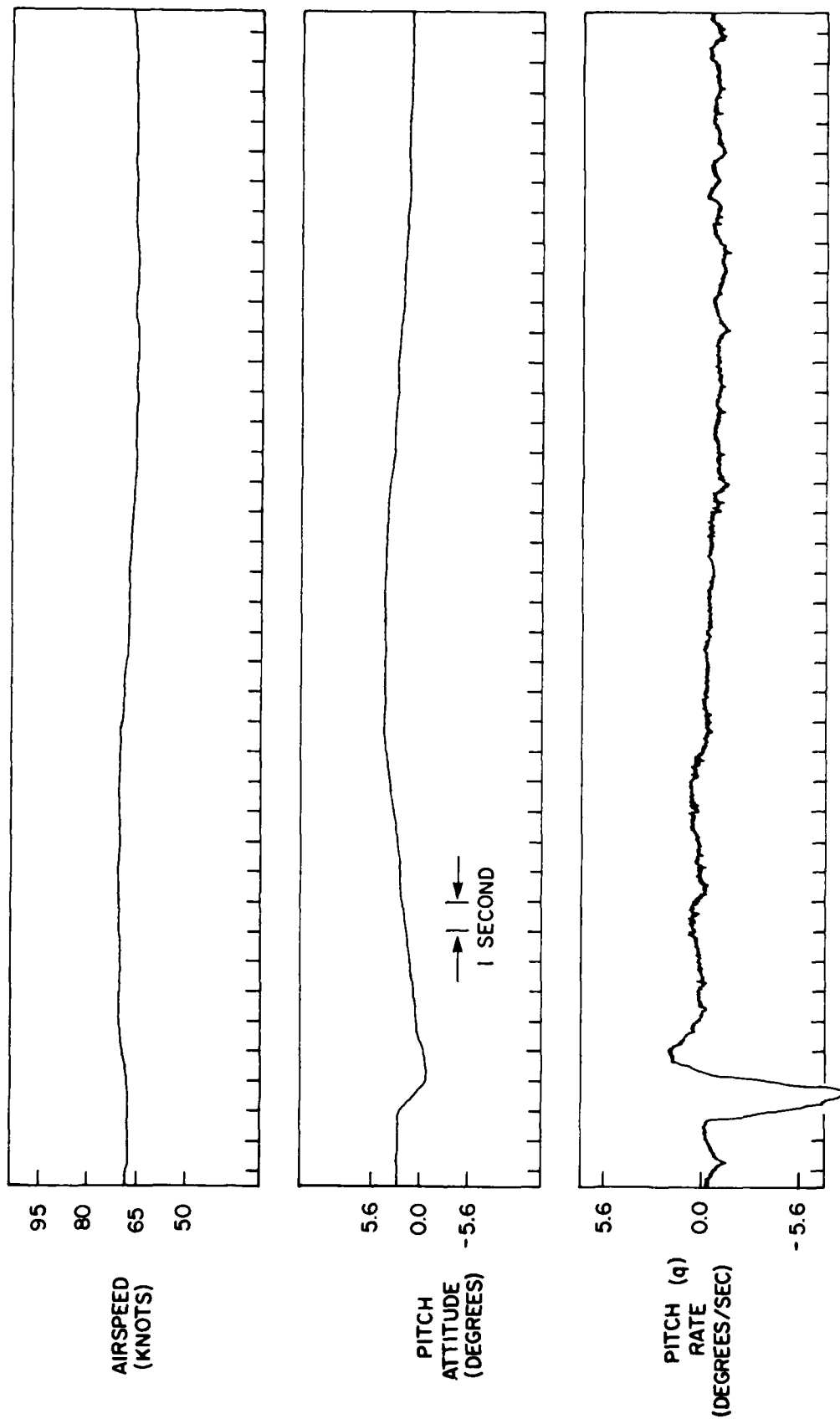


FIG. 10(c): MODEL 3 - LONGITUDINAL DYNAMIC RESPONSE

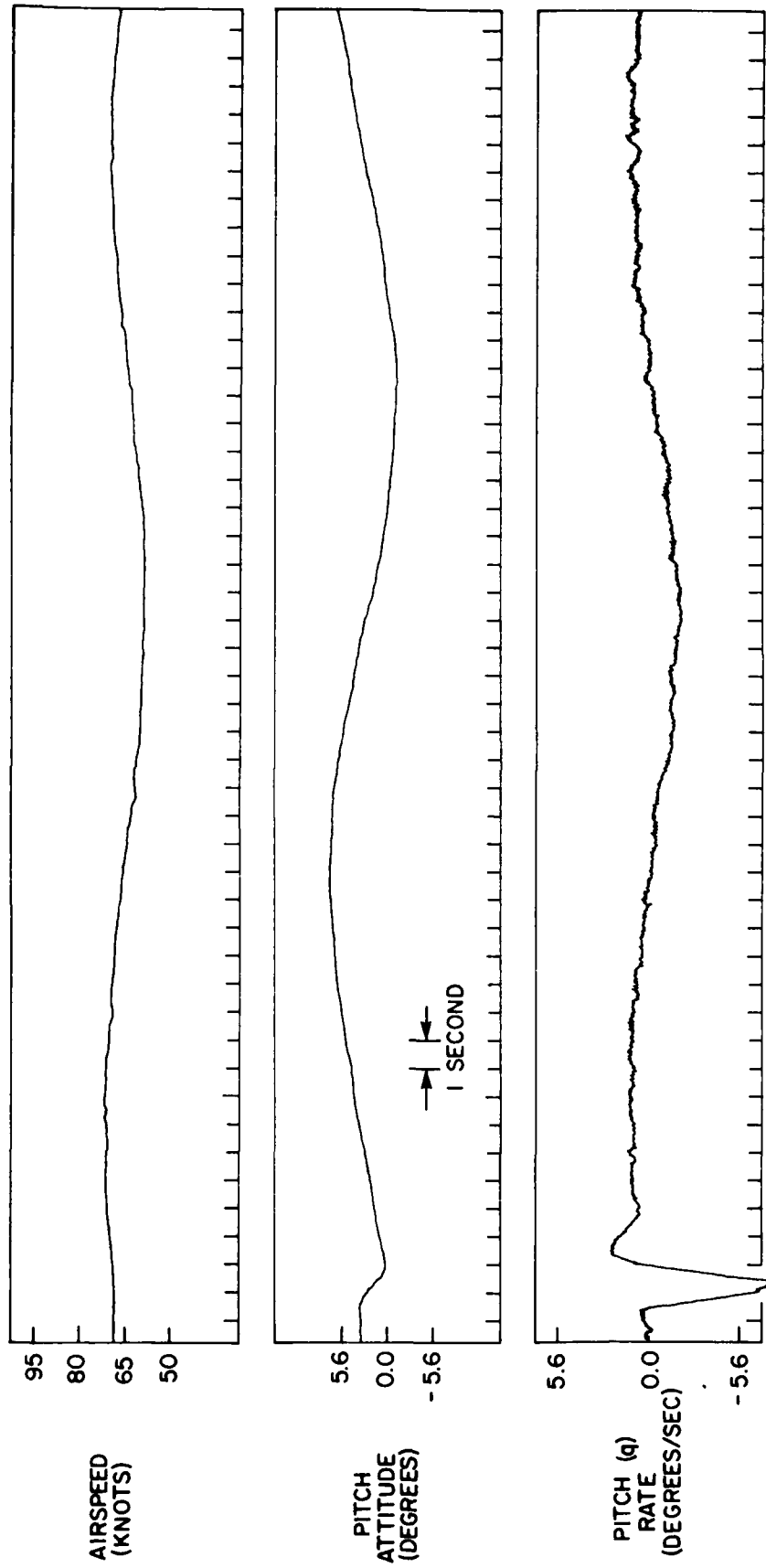


FIG. 10(d): MODEL 2A - LONGITUDINAL DYNAMIC RESPONSE

1-P RECOMMENDED FOR SINGLE PILOT IFR
2-P RECOMMENDED FOR TWO-PILOT IFR
NC NOT RECOMMENDED FOR IFR FLIGHT

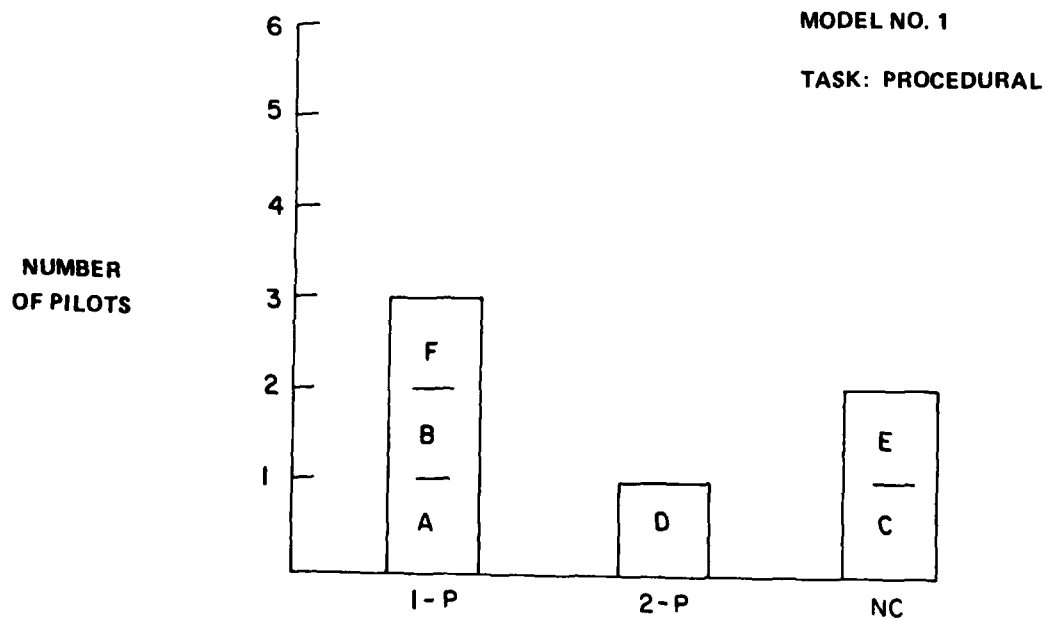
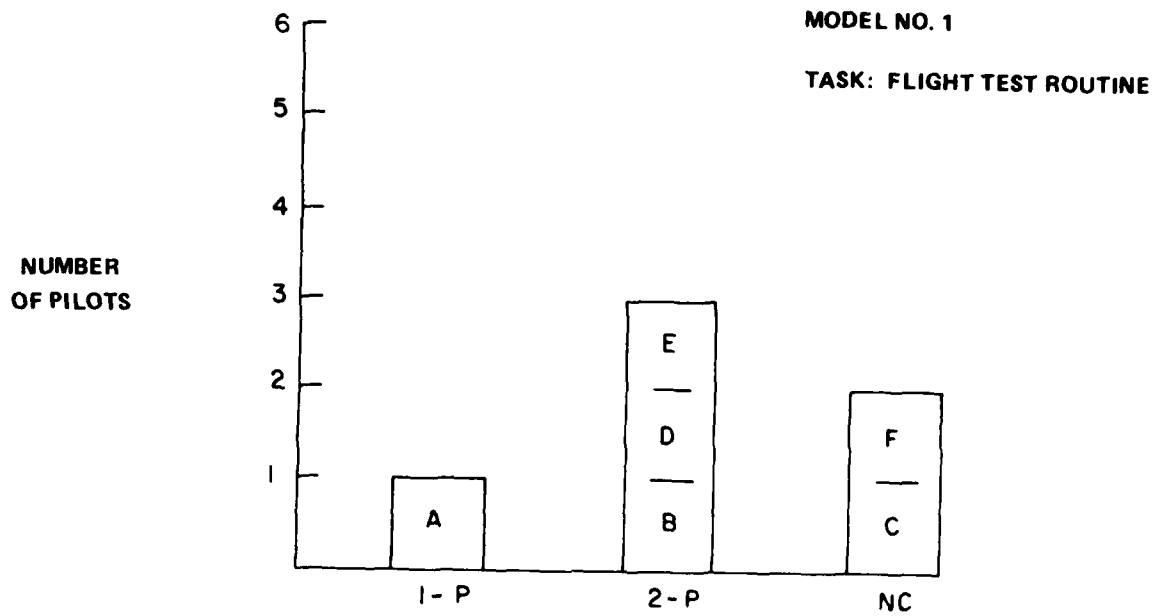


FIG. 11(a): CERTIFICATION ASSESSMENTS

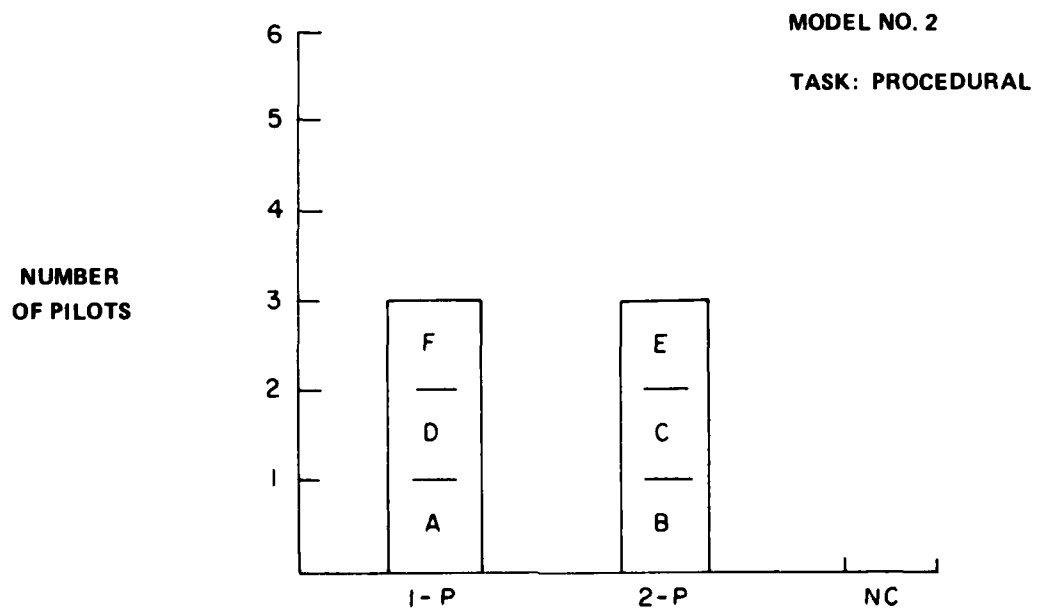
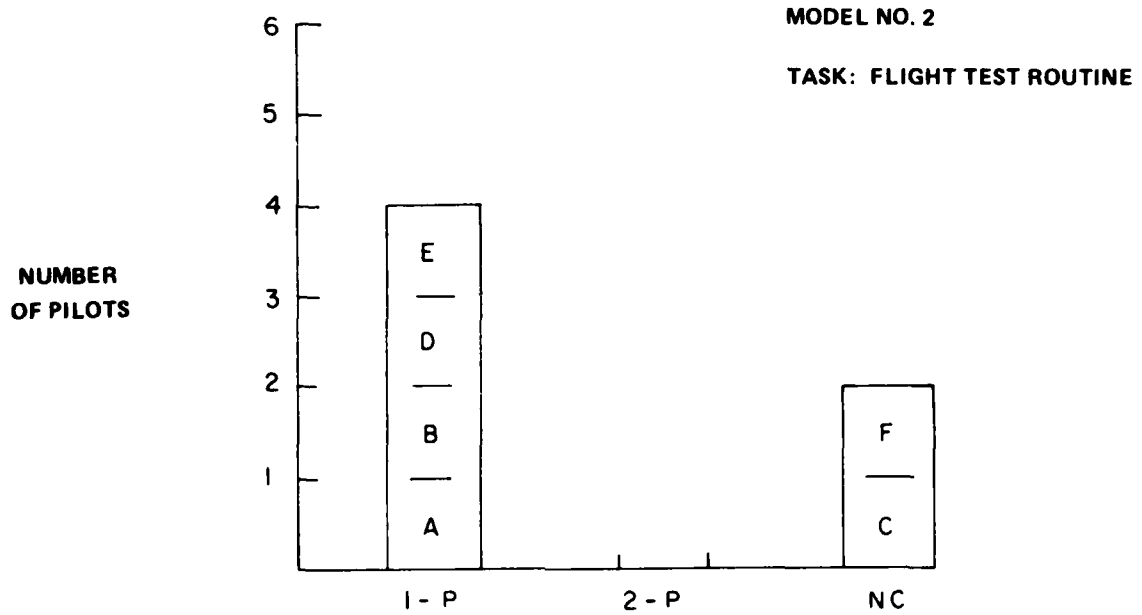


FIG. 11(b): CERTIFICATION ASSESSMENTS

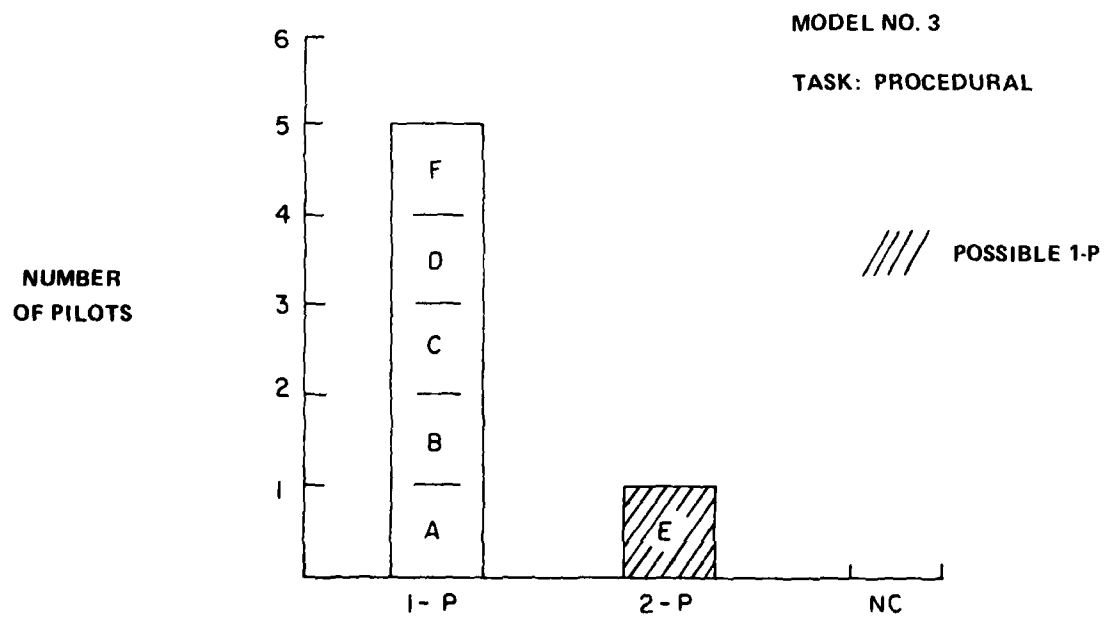
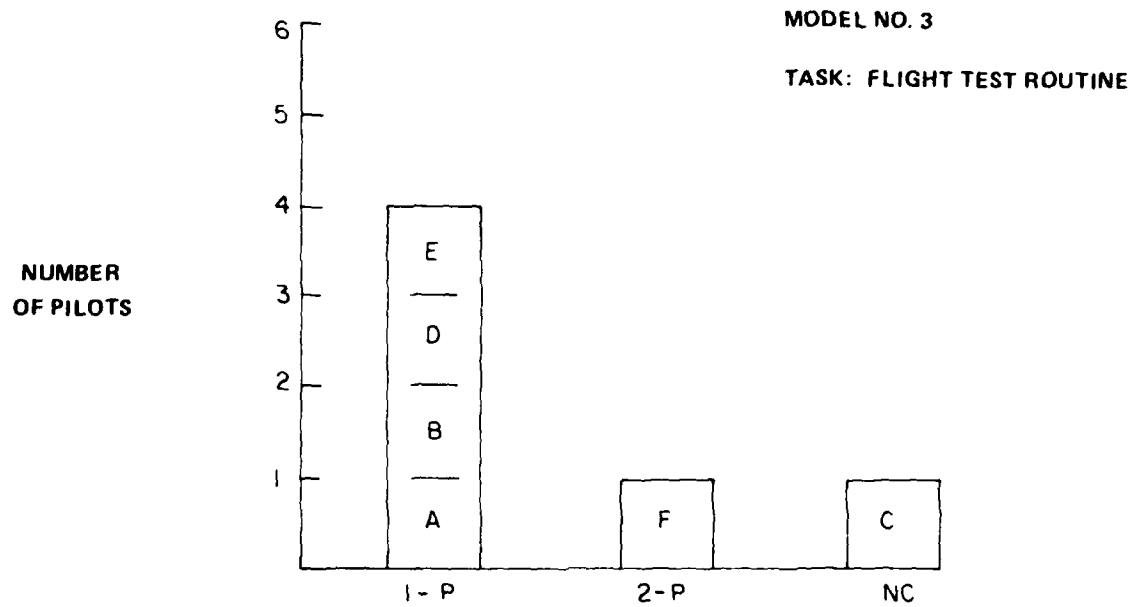


FIG. 11(c): CERTIFICATION ASSESSMENTS

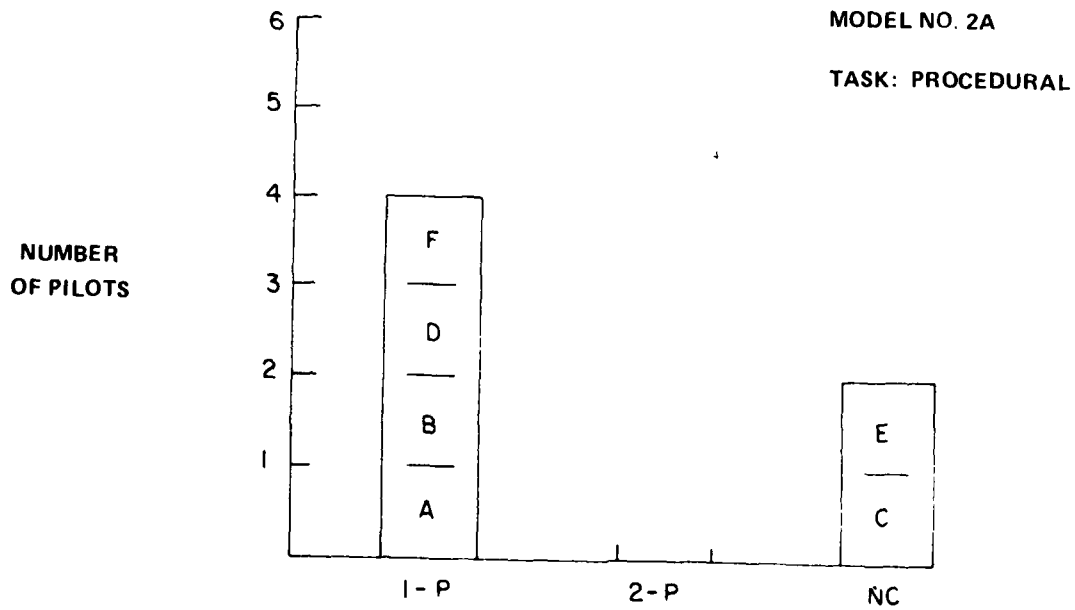
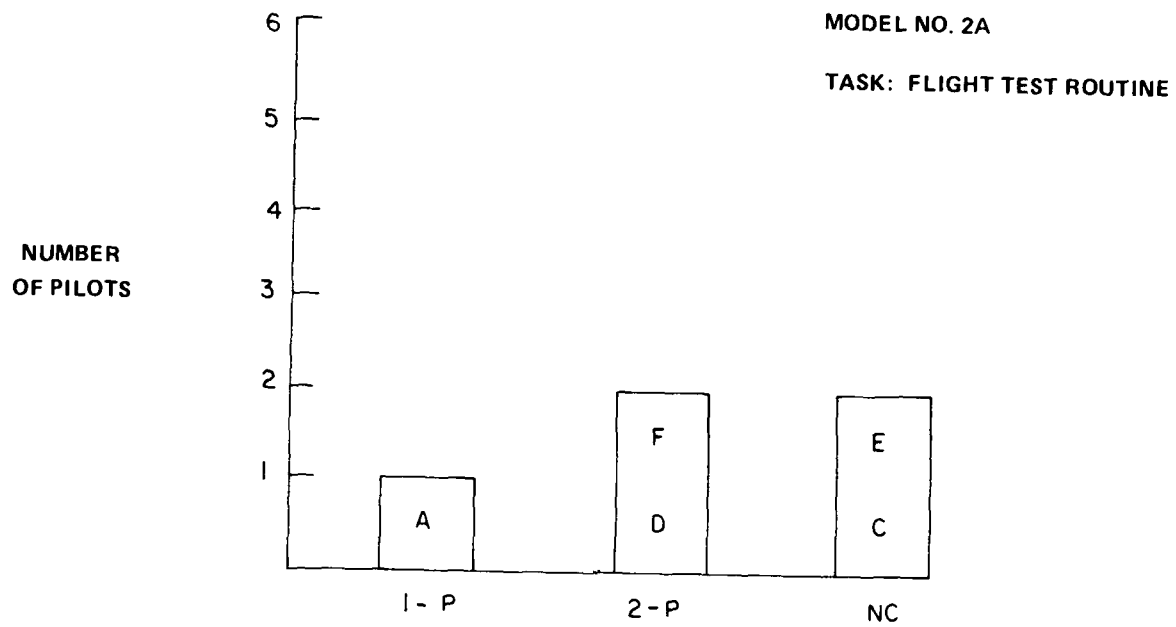


FIG. 11(d): CERTIFICATION ASSESSMENTS

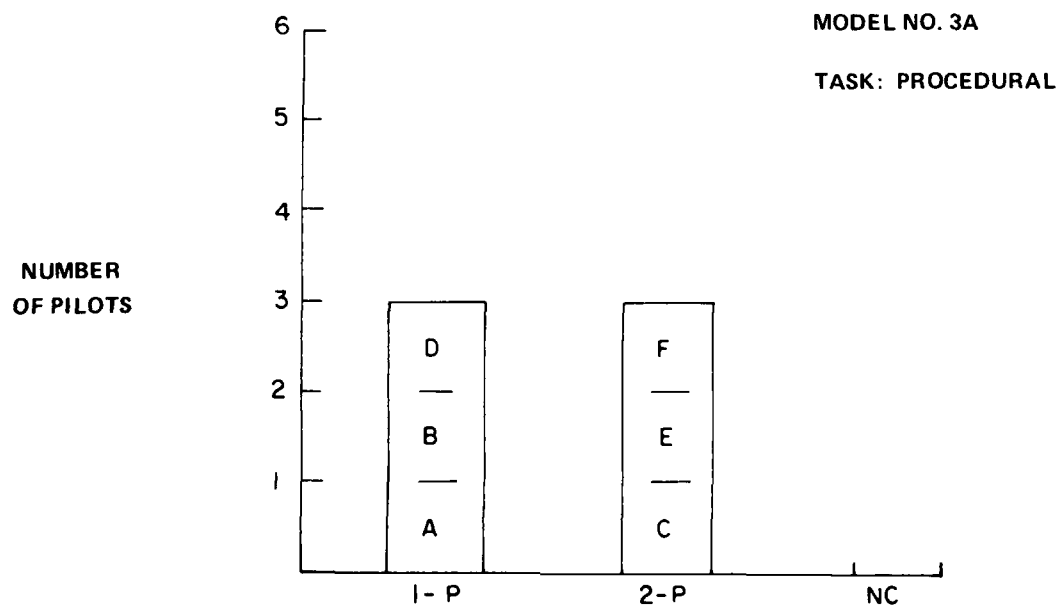
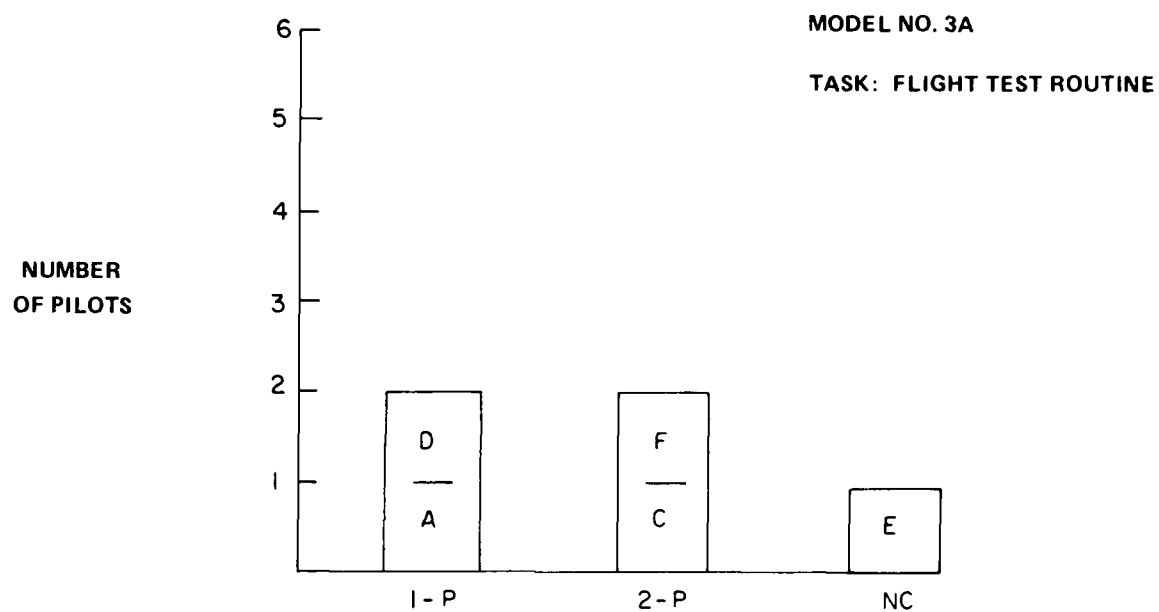


FIG. 11(e): CERTIFICATION ASSESSMENTS

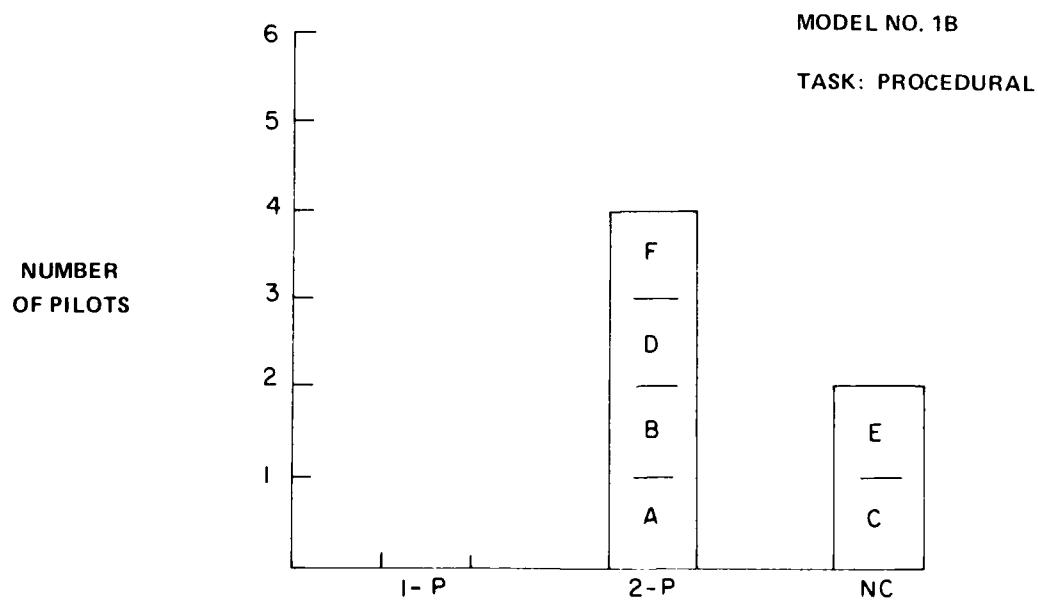
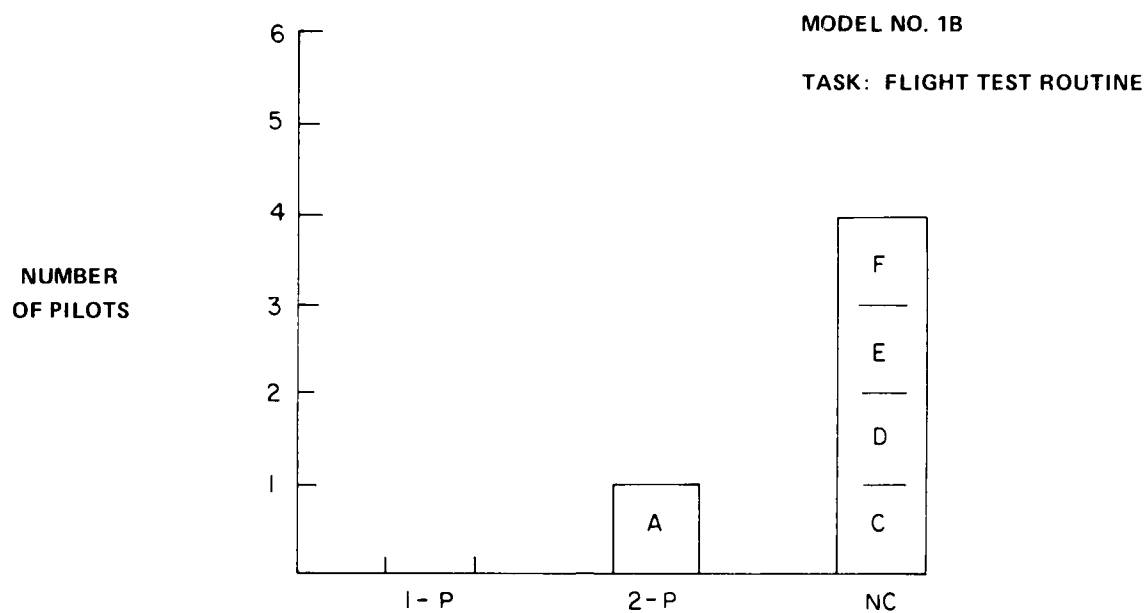


FIG. 11(f): CERTIFICATION ASSESSMENTS

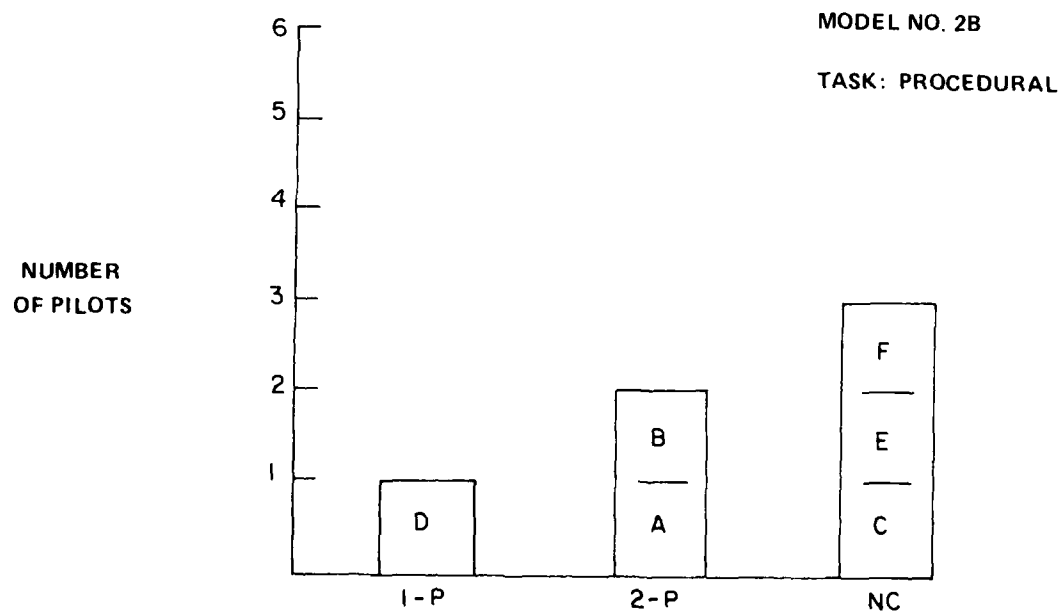
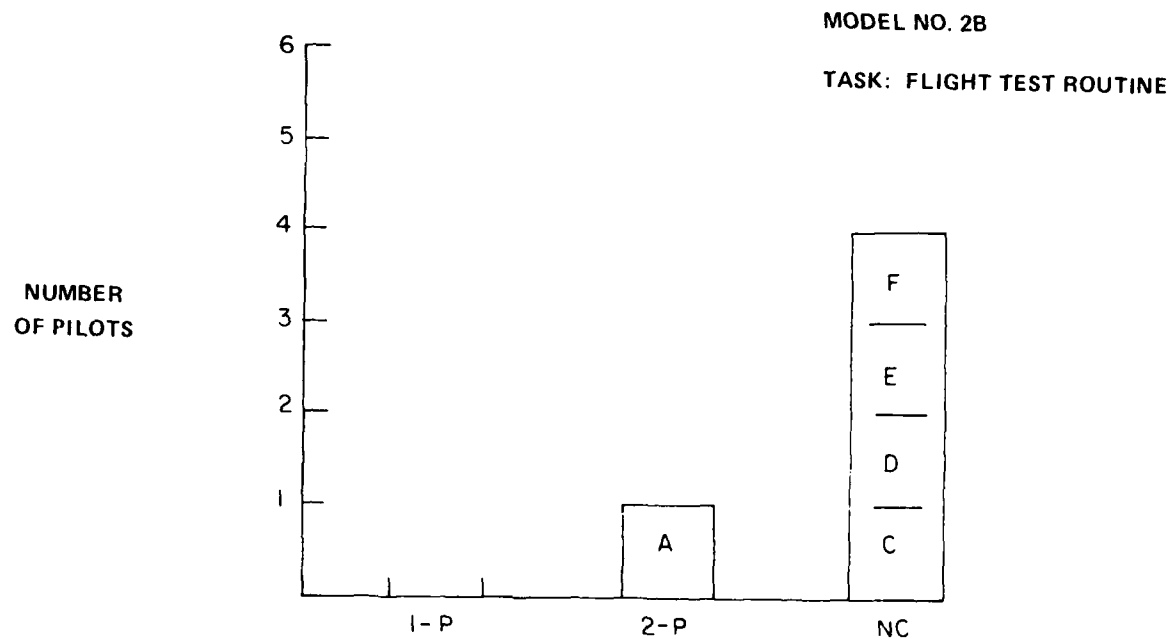


FIG. 11(g): CERTIFICATION ASSESSMENTS

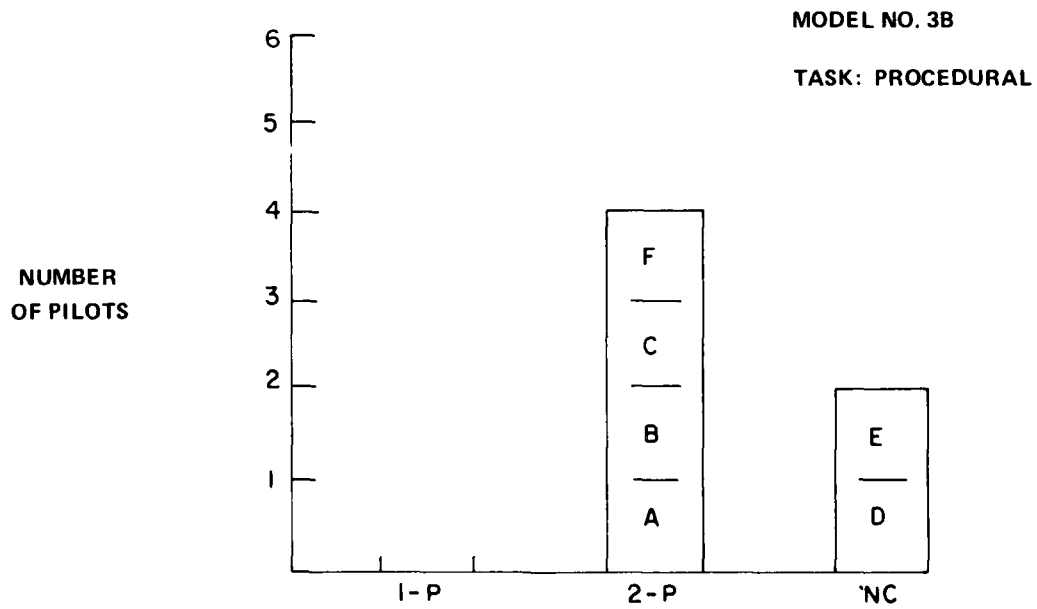
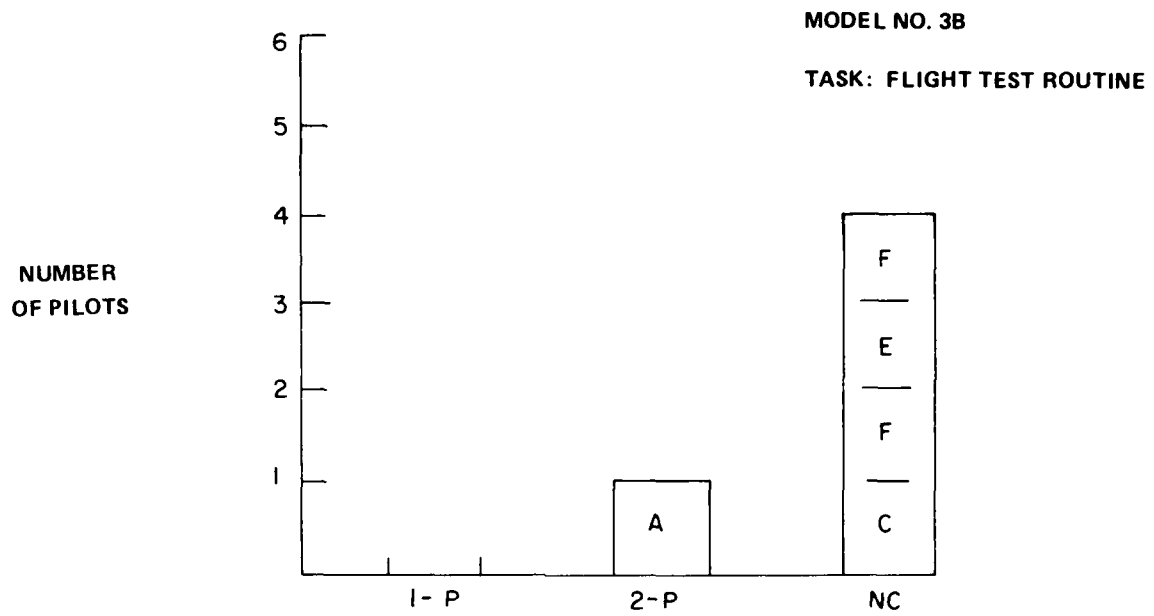


FIG. 11(h): CERTIFICATION ASSESSMENTS

PILOT: "A"

TASK: SINGLE PILOT IFR (PROCEDURAL)

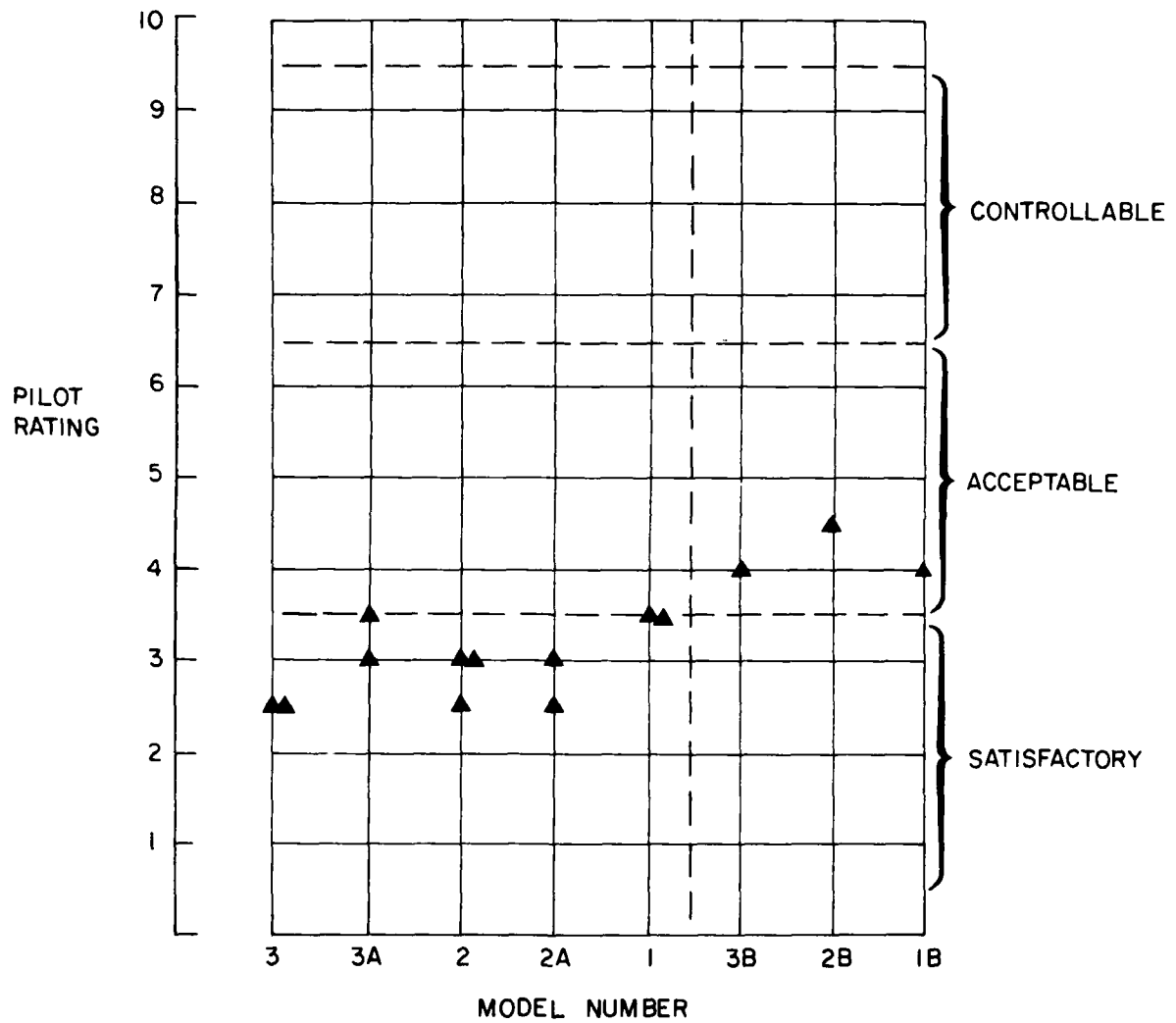


FIG. 12(a): COOPER-HARPER RATINGS FOR EVALUATED MODELS

PILOT: "B"

TASK: SINGLE PILOT IFR (PROCEDURAL)

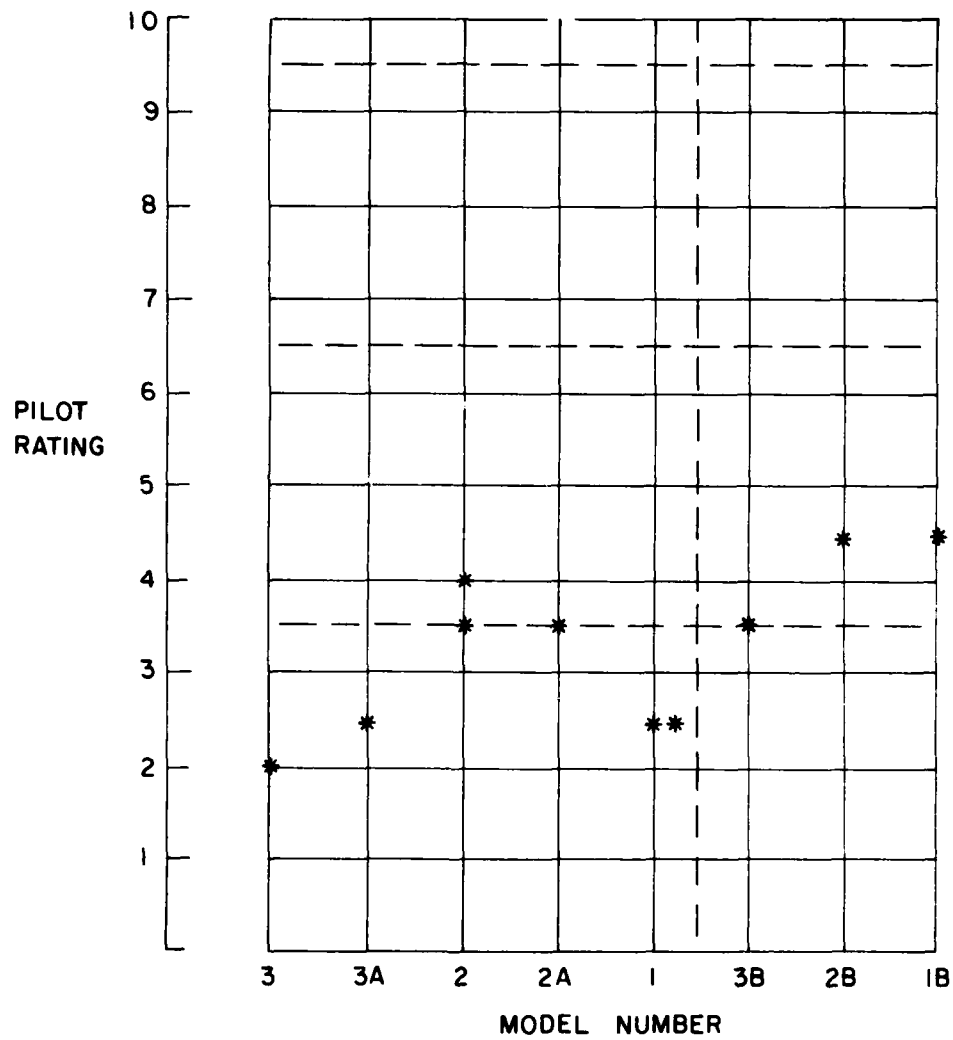


FIG. 12(b): COOPER-HARPER RATINGS FOR EVALUATED MODELS

PILOT: "C"

TASK: SINGLE PILOT IFR (PROCEDURAL)

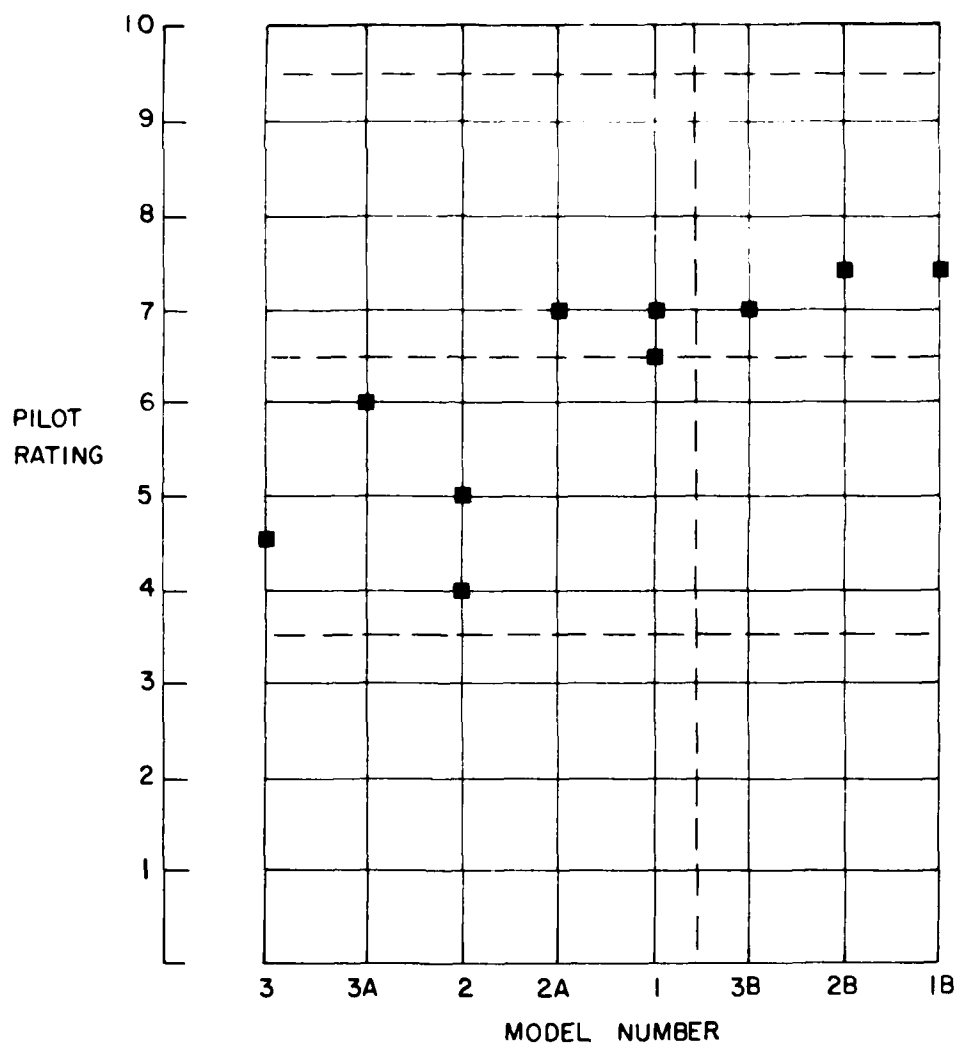


FIG. 12(c): COOPER-HARPER RATINGS FOR EVALUATED MODELS

PILOT: "D"
TASK: SINGLE PILOT IFR (PROCEDURAL)

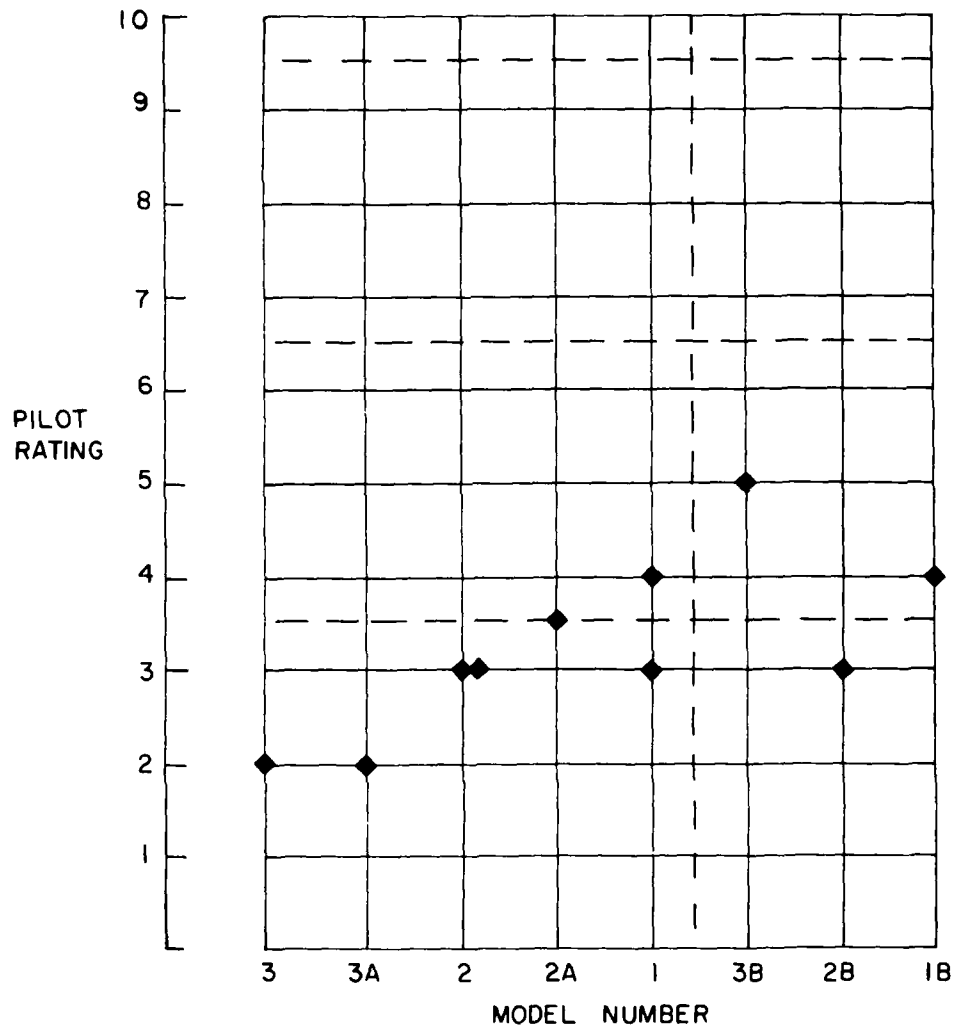


FIG. 12(d): COOPER-HARPER RATINGS FOR EVALUATED MODELS

PILOT: "E"

TASK: SINGLE PILOT IFR (PROCEDURAL)

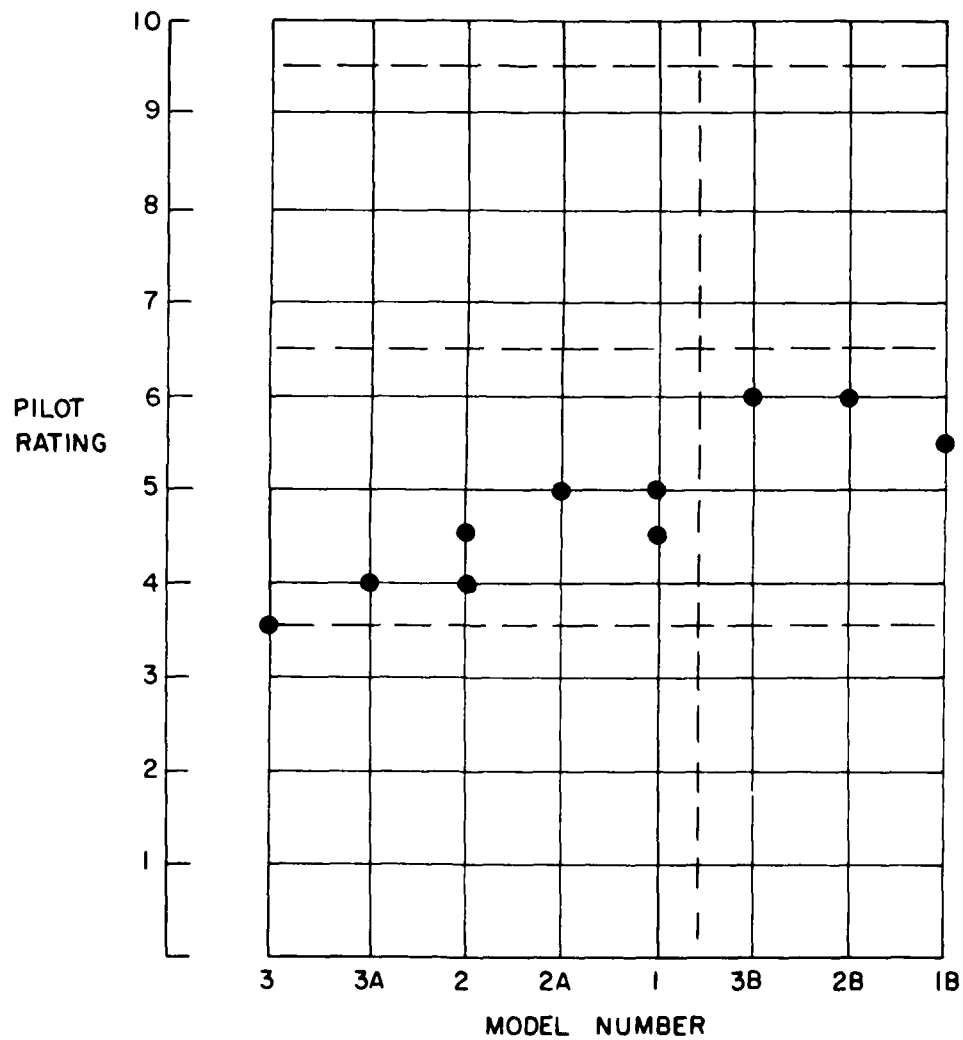


FIG. 12(e): COOPER-HARPER RATINGS FOR EVALUATED MODELS

PILOT: "F"

TASK: SINGLE PILOT IFR (PROCEDURAL)

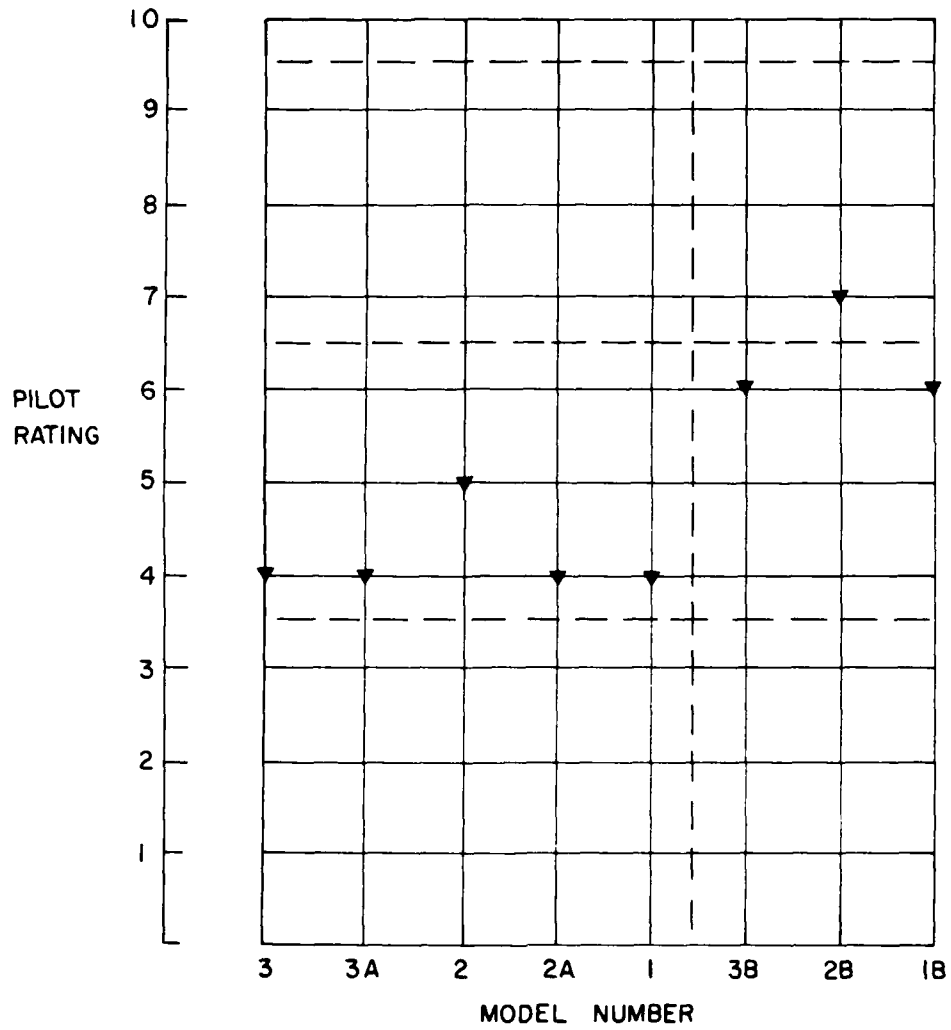


FIG. 12(f): COOPER-HARPER RATINGS FOR EVALUATED MODELS

NRC, NAE LR 608

National Research Council Canada, National Aeronautical Establishment.

EVALUATIONS OF HELICOPTER INSTRUMENT -- FLIGHT

HANDLING QUALITIES.

Sinclair, S.R.M., Kerchuk, S. January 1982. 48 pp. (incl. tables and figures).

UNCLASSIFIED

1. Flight simulation.
2. Helicopters.
3. Instrument flight rules.

I. Sinclair, S.R.M.

II. Kerchuk, S.

III. NRC, NAE LR 608

The NAE Airborne Simulator, a modified and suitably equipped Bell 205A helicopter, was used in experiments to provide background information on the handling qualities requirements for helicopter instrument flight. This investigation was in support of a regulatory review undertaken by the U.S. Federal Aviation Administration as part of an overall assessment of the helicopter certification process.

The results illustrate the interdependence of the various stability and control characteristics which contribute to safe instrument flight handling qualities, and underline the importance of good mission simulation in conducting certification-related experiments.

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