FLIGHT VALIDATION OF GROUND-BASED ASSESSMENT FOR CONTROL POWER REQUIREMENTS AT HIGH ANGLES OF ATTACK

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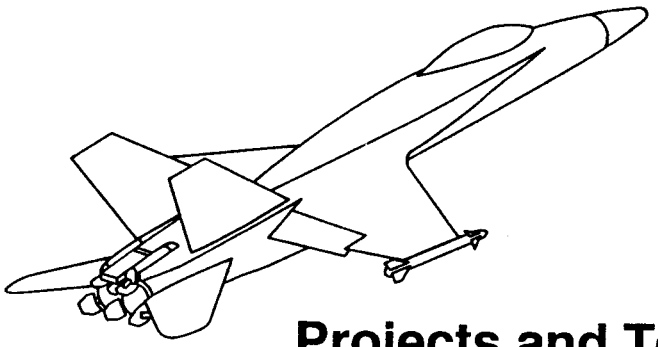

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OUTLINE

This paper presents a review of an ongoing NASA/U.S. Navy study to determine control power requirements at high angles of attack for the next-generation high-performance aircraft. This paper will focus on recent flight test activities using the NASA High Alpha Research Vehicle (HARV), which are intended to validate results of previous ground-based simulation studies. The purpose of this study will be discussed, and the overall program structure, approach, and objectives will be described. Results from two areas of investigation will be presented: (1) nose-down control power requirements and (2) lateral-directional control power requirements. Selected results which illustrate issues and challenges that are being addressed in the study will be discussed including test methodology, comparisons between simulation and flight, and general lessons learned.

OUTLINE

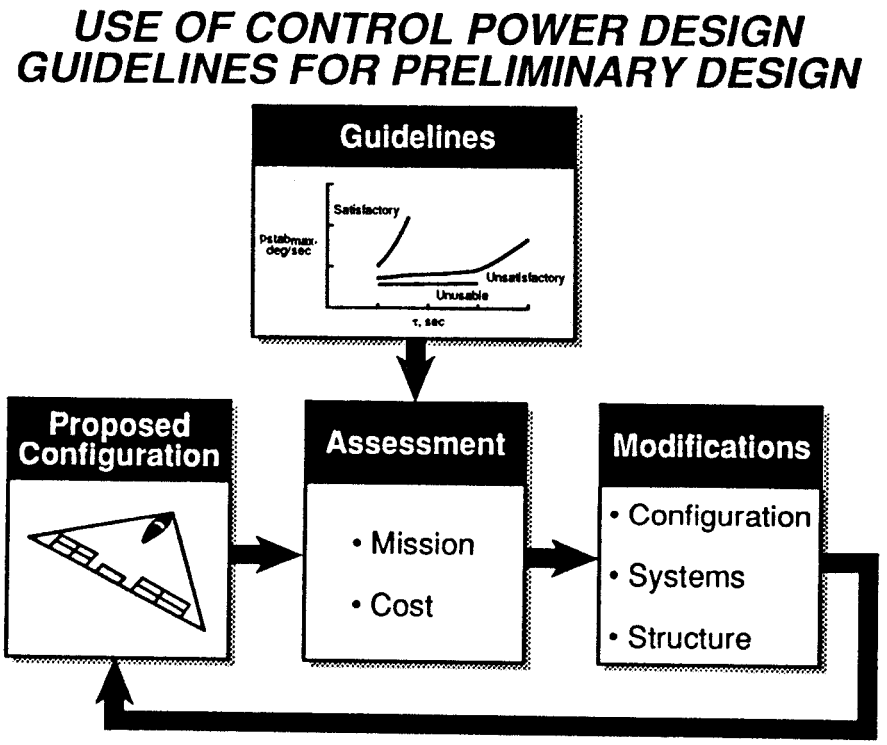
- Introduction *Presenter: Marilyn Ogburn*
- Approach, status, and flight test objectives
- Issues for control power flight validation
- Results from nose-down requirements study
- Results from lateral-directional study *Presenter: Holly Ross*
- Concluding remarks

USE OF CONTROL POWER DESIGN GUIDELINES FOR PRELIMINARY DESIGN

In recent years, significant advances have been made in key technologies for high performance military aircraft to meet demands for increased tactical effectiveness. These advances include novel controls for high angles of attack, reduced radar signature, improved propulsion systems, and materials. As a result, designers of the next-generation fighter aircraft are faced with new challenges in designing configurations with unprecedented levels of maneuverability throughout a greatly expanded flight envelope as well as superior cruise performance and low radar signature.

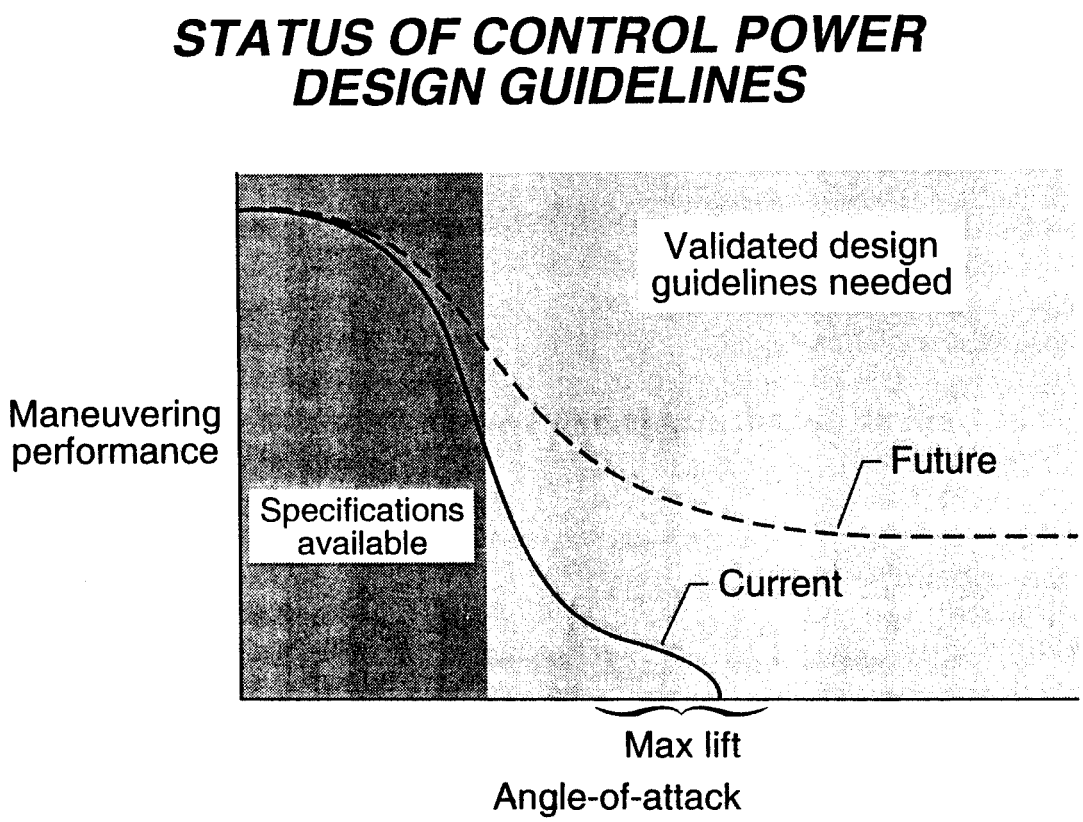
During the preliminary design stage one of the key tasks is controls integration where the goal is to provide sufficient control power to achieve the desired stability and control characteristics throughout the desired flight envelope. This is a critical element in preliminary design because increasing control power typically results in increased weight and complexity and therefore can have a major effect on the overall configuration design. For example, nose-down pitch control requirements at high angles of attack can determine the longitudinal control sizing, weight and center of gravity, structures, and hydraulic system requirements. Therefore, careful integration of controls is essential in order to achieve the design goals while maintaining a balanced and affordable design.

As illustrated in the figure, the controls integration process typically involves a series of assessments and modifications where tradeoffs are made between control power and mission performance. The designer must know the impact of changes in the available control power on mission performance in order to determine the appropriate tradeoff. Therefore, comprehensive, well-understood guidelines are required that allow an assessment of the configuration's performance.



STATUS OF CONTROL POWER DESIGN GUIDELINES

Currently, there are many well-accepted control power design guidelines for low angles of attack; however, there are few comprehensive, flight-validated guidelines for high angles of attack for either the longitudinal or lateral-directional axes. In recent years numerous studies have been undertaken to determine high-angle-of-attack control power and flying qualities requirements. These studies have provided critical handling qualities design guidance and exposed the need for further analysis of the complex, non-linear flight dynamics issues and the need for flight-validated control power design guidelines.



APPROACH, STATUS, AND FLIGHT TEST OBJECTIVES

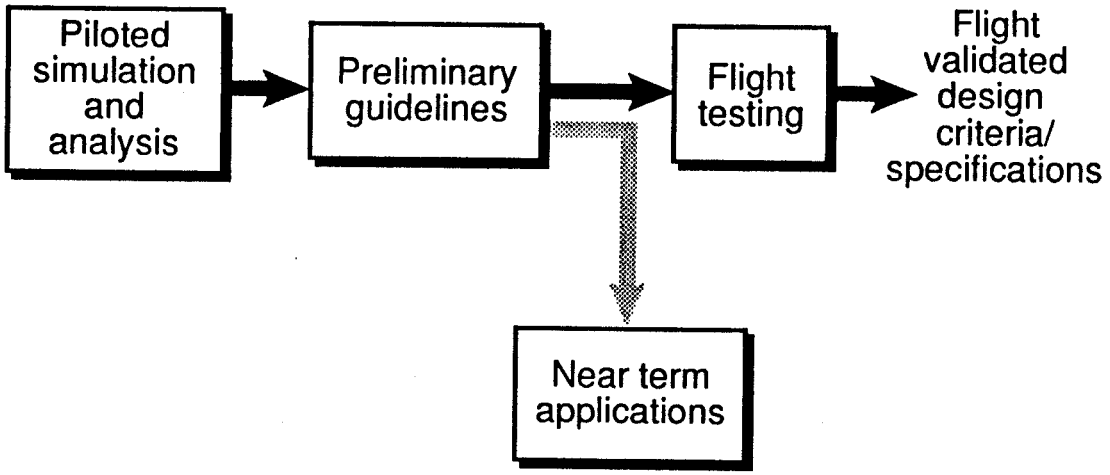
A joint NASA/U.S. Navy program has been in progress since 1990 to develop these guidelines. Throughout the program there have been extensive interactions with the U.S. Air Force and industry as well as the participation of academia (Virginia Polytechnic Institute and State University).

The general approach to this program is shown in the figure and involves extensive piloted simulation studies, the results of which are used to develop preliminary guidelines. Flight testing is then performed to validate the ground-based results. The final product of the program will be flight-validated design criteria and specifications for flight test demonstration. A variety of unique methodologies has been developed as part of this program, including those relating to the test maneuvers and ratings of the response.

The primary objectives of flight testing in this program are to: (1) validate the test methodology used during piloted simulation studies and (2) validate the quantitative simulation results and refine the design guidelines. Careful attention must be paid in the flight tests to ensure that the maneuvers and rating process utilized for ground-based simulation are appropriate for the flight evaluation and produce accurate evaluations of the desired response characteristics. In addition, flight testing provides additional insight into the design issues.

A comprehensive evaluation of nose-down pitch control requirements is nearly complete and has included piloted simulation testing and flight validation. Starting in October 1991, over 110 nose-down maneuvers have been tested using the NASA F-18 HARV and a U.S. Navy F-18. An assessment of lateral-directional control power requirements for tactical maneuvering is currently in progress. To date, a comprehensive database from piloted simulation has been generated and preliminary flight validation has been initiated involving 17 maneuvers using the NASA F-18 HARV.

APPROACH



ISSUES FOR CONTROL POWER FLIGHT VALIDATION

In the process of developing preliminary control power design guidelines and evaluating them in flight tests, numerous issues have been addressed that will be illustrated in this paper using results from the simulation studies and flight tests. The general issues include maneuver selection, performance of the maneuvers in flight, and quantification of the pilot's opinion of the maneuver response.

The selection of maneuvers which isolate the response characteristics of interest was considered to be a critical element in this study. Several factors were taken into account in the maneuver selection process, including: (1) the definition of the mission, including whether the primary design issue is related to the safety of flight and/or tactical (offensive and/or defensive) applications, and the relevance of open-loop maneuvers (i.e. does not involve a capture of final conditions) versus closed-loop tasks, (2) the minimum set of critical flight conditions sufficient to define guidelines that are applicable to the entire high-angle-of-attack flight envelope, and (3) the maneuver attributes required to generate figures of merit from which guidelines can be easily developed. Issues were also addressed that were of particular concern for the successful performance and evaluation of the flight test maneuvers. These issues included: (1) testability (i.e. overall ease of performing a maneuver), (2) achievement of initial conditions, (3) maneuver performance criteria, (4) parametric variations of aircraft response, and (5) the evaluation of motion effects. Finally, an appropriate rating methodology was required that was easy to use and provided a comprehensive assessment of the pilot's opinion of control power requirements. Selected results from the nose-down and lateral-directional control power evaluations will be used to illustrate these issues.

ISSUES FOR CONTROL POWER FLIGHT VALIDATION

- Selection of maneuvers
- Performance of maneuvers in flight
- Rating methodology

MANEUVERS FOR ISOLATION OF CONTROL POWER CHARACTERISTICS

One of the challenges associated with the establishment of control power design criteria is the development of evaluation maneuvers which isolate the characteristics of interest at critical flight conditions, are simple to execute, and minimize extraneous effects that could complicate the analysis of the results. The maneuver used in the evaluation of the requirements for nose-down pitch control power which was found to be the most relevant for isolating the pitching moment coefficient characteristics was a pushover from stabilized, unaccelerated, trimmed, wings-level flight at high angles of attack. Performing the maneuver at these conditions minimizes dynamic and kinematic effects, as well as thrust and performance effects, so that the changes in angle of attack are due almost solely to the nose-down moment generated by the application of nose-down controls. The results of the simulation study were derived from the pilots' comments and a statistical analysis of the correlation between the numerical ratings and response characteristics. These results indicated that although several figures of merit are considered by a pilot during a recovery from high angles of attack, the recovery is judged primarily by the short-term response characteristics and that one of the key figures of merit was the initial pitch acceleration ($\dot{q}$) as an immediate indication of control moment capability. For the establishment of pitch control power design criteria, it is clear that, in the absence of significant angular rates, pitch acceleration bears a strong relationship to pitch control power because it is directly proportional to static pitching moment coefficient (C_m). The results of the simulation study showed that the maximum pitch acceleration obtained within one second of the initiation of the forward stick command correlated very closely with pilot rating. These simulation results were used to develop a preliminary set of design guidelines which are shown in the figure and are being evaluated in flight tests.

Results from the HARV tests versus pilot rating are shown in the figure for two types of maneuvers performed with parametric variations of the nose-down control power capability: (1) pushovers and (2) recoveries to a low angle of attack from zoom climb (high pitch attitude, low airspeed) conditions. The zoom climb maneuver usually results in an initial increase in angle of attack following the nose-down command which is due to a decrease in the flight path angle which occurs at these conditions; therefore, the pitch response is not as directly associated with pitch control power as the pushover maneuver. However, the use of this maneuver allows the opportunity to determine whether the pilot's opinion is based on the short-term response in recoveries from high pitch attitude, low airspeed conditions. The figure shows that the flight results for both maneuvers agree well with the simulation study results, confirming the importance of the short-term pitch response as the primary figure of merit for the pilot's opinion.

MANEUVERS FOR ISOLATION OF CONTROL POWER CHARACTERISTICS

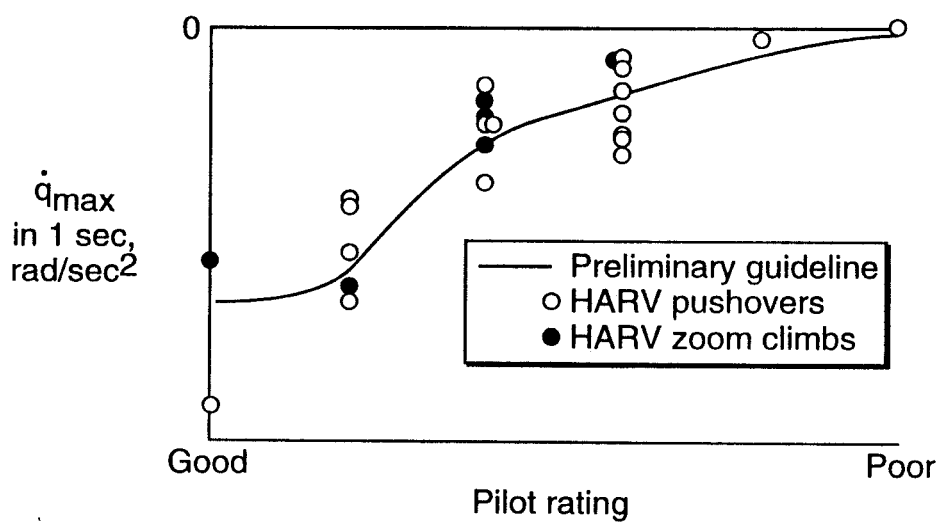
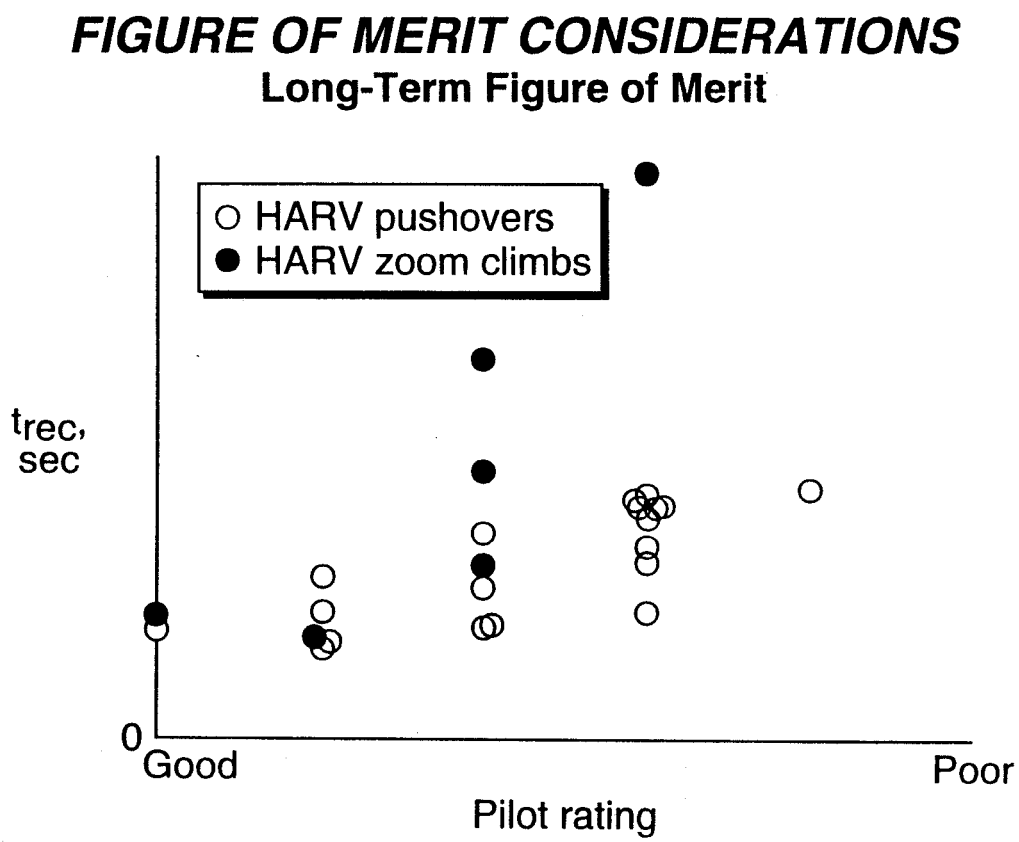


FIGURE OF MERIT CONSIDERATIONS

An important issue regarding the analysis of flight and simulation results for the evaluation of candidate control power design criteria is the establishment of figures of merit to be used in evaluating the aircraft response characteristics. In order to accurately determine the characteristics the pilot uses to judge the aircraft response, as many potential figures of merit as possible should be considered. They can be compared by characterizing them according to the strength of their relationship to the parameter under design and an appropriate time scale. Although for some control power design considerations the short-term figures of merit are more closely associated with the aircraft control moment characteristics, longer term figures of merit should also be considered in case they are a primary influence on the pilot's opinion. For example, the time to recover the aircraft is a long-term figure of merit that has been evaluated for its impact on the pilot's opinion of nose-down pitch response during recoveries from high angles of attack to the recovery angle of attack of 10 degrees.

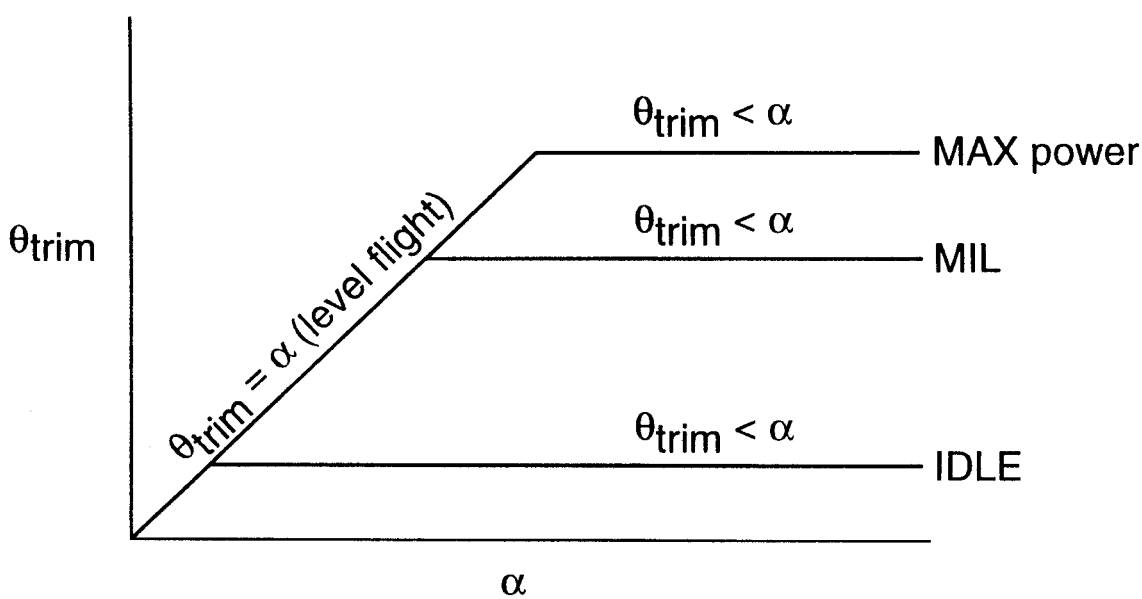
The figure shows the HARV flight test results for the time to recover (t_{rec}) versus pilot rating for the same pushover and zoom climb maneuvers shown in the previous figure. The previous figure showed the short-term figure of merit, $\dot{q}_{max}$ in 1 sec. This figure shows a long-term figure of merit, time to recover to 10 degrees angle of attack. The figure shows that, although there is some association between the time to recover and the rating, the correlation is not nearly as close as it is for the short-term pitch acceleration figure of merit. In particular, for the maneuvers that were judged to have poorer responses, the range of recovery times was quite large. This range of values would not be accounted for by considering the angle of attack at which the nose-down command was initiated. Note that the zoom climb maneuver was useful for generating longer recoveries for the purpose of evaluating this figure of merit. These results thus provide additional evidence that for nose-down pitch control power, the long-term response has only a secondary effect on the pilot's opinion.



INFORMATION REQUIRED TO MINIMIZE WORKLOAD TO STABILIZE AT HIGH ANGLES OF ATTACK

A lesson learned from the flight tests performed in an early phase of the nose-down pitch control flight program was that there is a way to minimize the workload required for the pilot to stabilize the airplane at an unaccelerated, trimmed condition at high angles of attack. For some of these flights, a specific target pitch attitude angle of 15 degrees was used to match the primary value used in the simulation study. In the simulation study, the initial conditions for the maneuvers, including the required throttle settings, were calculated and pre-set by the computer so that the pilot only needed to perform the maneuver itself. The figure shows the general trend of the pitch attitude values that correspond to the trimmed conditions (θ_{trim}) for a range of angle of attack (α) and throttle settings such that there are no net forces or moments acting on the airplane. The method used in some of the early flight tests for achieving these initial conditions required that the pilot vary the thrust to stabilize at the pitch attitude of 15 degrees. During the flights, it was found that establishing the required test conditions for angle of attack and pitch attitude using this method was very difficult because the pilot had to "close the loop" on trim airspeed with the throttles to stabilize the flight path angle. The pilot workload required to accomplish this task had a tendency to distract the pilot's attention from the initial portion of the maneuver and may have affected his ratings. For most of the flight test maneuvers flown on the HARV, the throttle setting and initial angle of attack were specified, and initial pitch attitude values for trimmed conditions which were based on the simulation math model were provided in order to minimize this workload.

INFORMATION REQUIRED TO MINIMIZE WORKLOAD TO STABILIZE AT HIGH ANGLES OF ATTACK



PARAMETRIC VARIATIONS OF RESPONSE CHARACTERISTICS

One of the objectives of the flight tests has been to validate the nose-down pitch control design guideline values that were derived from a simulation study that involved parametric variations of the nose-down response. Various methods can be used in flight tests to vary the airplane motions in response to pilot inputs. The initial conditions of the maneuver, including angle of attack, angular orientation, dynamic pressure, power setting (particularly in conjunction with a thrust vectoring system), and center of gravity position, in addition to the magnitude of the pilot's input can all be used to vary the response. Some of these methods offer more flexibility for specifying the response than others such that the desired range of response can be achieved, and any nonlinear motions which can complicate the assessment of the response are minimized.

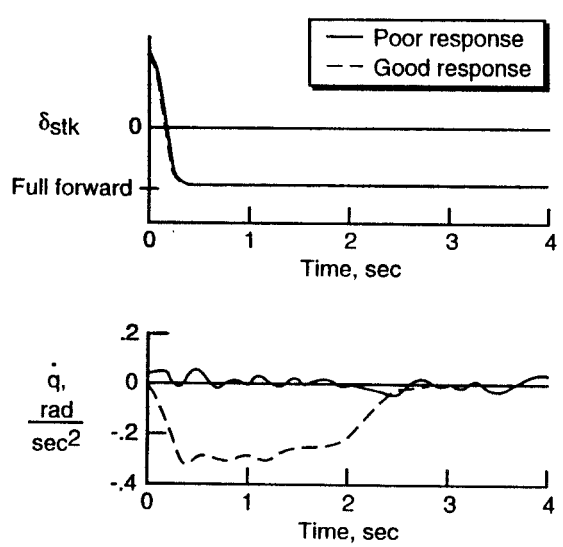
The HARV is uniquely suited for the flight investigation of control power requirements because of the wide range of nose-down pitch response available through the use of its thrust-vectoring system combined with the normal aerodynamic tail control. A research flight control system has been integrated into the basic F-18 flight control system for research testing. The vehicle can, in effect, be used as a variable stability airplane by taking advantage of the capability to vary parametrically and systematically control law features within the research flight control system. By varying certain control law values, the pitch response magnitude and shaping were specified to provide pitch acceleration responses that varied over a much wider range of magnitude than those of earlier flight tests performed on an F-18 without a thrust vectoring system. Time histories which show the range of response that was achieved in flight with the application of a full nose-down command (δ_{stk}) and the variation of several parameters, including control law values, are shown in the figure. A specific code number was designated for each set of control law values, which were programmed in the research flight control system and engaged by the pilot's selection of the code in the cockpit; however, the pilot did not know the corresponding control law values. The use of codes minimized the possibility that the pilot had pre-conceived expectations of the pitch responses and there was no particular ordering of the maneuvers with respect to the level of response. These tests were therefore more "blind" than those performed without the use of the coded control law variations.

PARAMETRIC VARIATIONS OF RESPONSE CHARACTERISTICS

Parameters that Affect Longitudinal response

- Initial conditions
  - Angle of attack
  - Pitch attitude
  - Dynamic pressure
  - Center of gravity location
- Power effects
  - Throttle setting
  - Thrust vectoring
- Magnitude of pilot input
- Control laws

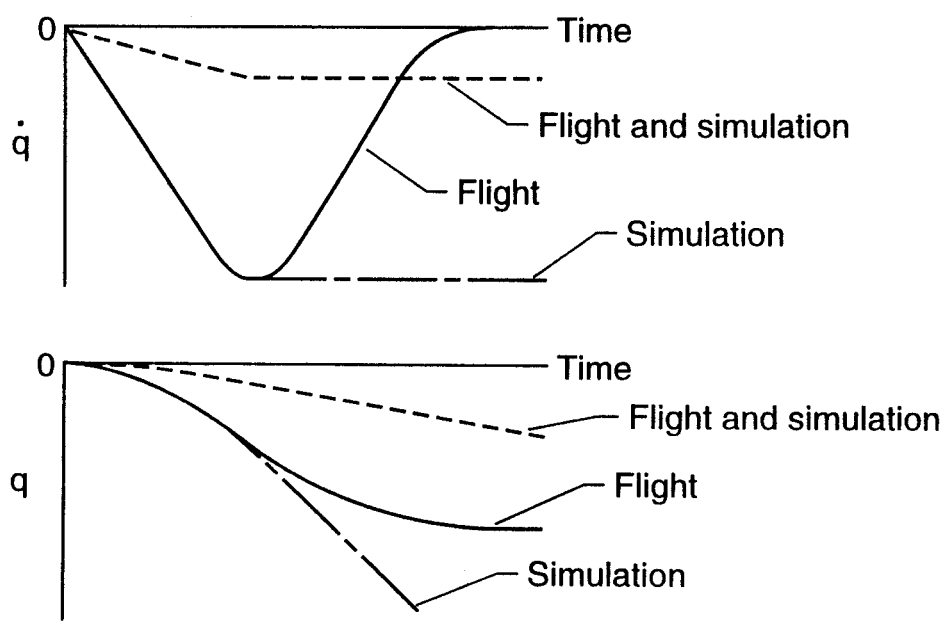
Range of Response Achieved in Flight



EFFECT OF MOTION ON PREFERRED PITCH RESPONSE CHARACTERISTICS

Some useful information was obtained from the pilot comments and flight data regarding the effect of motion cues in flight which were not available in the simulation studies. Two noteworthy motion characteristics were experienced in some of the pushover maneuvers that were performed to evaluate the nose-down pitch response. The first characteristic that was sometimes experienced was that the pilot felt the nose of the airplane might "tuck under" through the vertical before the airplane could be completely recovered, although this never occurred. This feeling was experienced only in maneuvers that had a good nose-down response and were initiated at relatively low pitch attitudes and/or high initial angles of attack. The second motion characteristic related to the desired response shaping following the initial peak pitch acceleration, and is illustrated in the figure. In the simulation study, which involved parametric variations of static pitching moment coefficient, continuously increasing pitch rate (q) was provided for the entire recovery which approximated a pitch acceleration command system. During this study, the pilots stated that this type of response was highly desirable as it made the response predictable and simplified the rating decision. In flight, however, for the better, more tactically desirable responses, a rapid increase in pitch rate to a constant high value (i.e. a pitch rate command system) was preferred over a continuously increasing pitch rate. This preference was not revealed in the simulation study due to the lack of good cues at high angular rates. For those cases with poor initial response, however, in the simulation study and in flight, a continued pitch rate increase was considered to be more appropriate to give the pilot increasing confidence that the aircraft would recover.

EFFECT OF MOTION ON PREFERRED PITCH RESPONSE



FLIGHT TEST MANEUVER DEVELOPMENT

Flight test maneuvers must be developed properly in order to ensure that the flight validation is done in an efficient manner and that the maneuvers are easy to perform. In a ground-based simulator, conditions can be set up that may not be easily achieved in flight. The success of the flight validation suffers if the maneuvers are more difficult to perform and are therefore not repeatable. The maneuvers must involve pilot techniques that are simple enough to be successfully repeated many times by one or more pilots so that individual maneuver attempts and pilot techniques do not significantly affect the aircraft response. The initial conditions must also be easily achieved so that valuable flight time is not wasted in setting up the maneuvers. These attributes also improve the agreement between ground-based simulation and flight results.

In the lateral-directional control power study, much effort was devoted to maneuver development. Because flight test validation was planned, one of the maneuver requirements was that the maneuvers should be easy to perform in flight. Maneuvers that did not meet that requirement were modified. Piloted ground-based simulation was used very successfully for this maneuver development. The maneuvers that were developed were a lateral gross acquisition, an offensive loaded reversal, and a defensive roll. These maneuvers involved well defined pilot technique that was easy to repeat.

Results from the HARV flights indicated that the maneuvers developed in the simulator could be used to efficiently perform the tests and that they were repeatable in flight. The pilots stated that they were able to perform the maneuvers in flight just as they had in the simulator with very few modifications. Any needed adjustments to the maneuvers in flight were easily performed because the pilots were so familiar with the timing of the maneuvers from their experience in the simulator.

FLIGHT TEST MANEUVER DEVELOPMENT

Challenge:

- Develop maneuvers that can be easily and efficiently tested in flight

Issues:

- Pilot technique well defined and repeatable
- Initial conditions easily achieved in flight

Results:

- Piloted simulation very valuable for maneuver development and training
- Maneuvers easily executed and repeated in flight

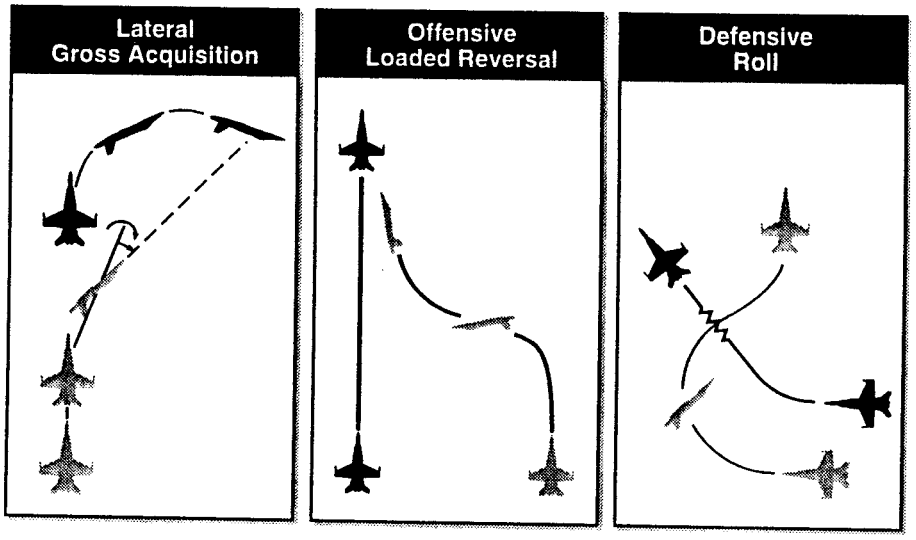
USE OF TARGETS

The maneuvers developed in the lateral-directional study were intended to be tactically relevant and thus required the use of a target. For each maneuver, the task of the target aircraft was carefully developed using piloted ground-based simulation. These tasks were designed so that they would be easily executed in flight tests. Target aircraft in flight tests must be used efficiently so that flight time is not wasted. To do this, the target must have a well-defined task and initial conditions for the maneuver that are easily achieved. The target's task must also be repeatable so that its motion is consistent for multiple test points.

The three maneuvers developed in the simulation study were the lateral gross acquisition, offensive loaded reversal, and defensive roll. In the lateral gross acquisition maneuver, which was originally developed by McDonnell Douglas Aerospace (MDA), the target flies ahead of and slightly above the test aircraft. The target then enters a constant speed descending turn. This maneuver was easy to perform in flight and produced a repeatable target for the test aircraft to follow. For the offensive loaded reversal, the target begins co-altitude with the test aircraft and maintains straight and level flight throughout the maneuver, thus this target task is very easy and very repeatable. In the defensive roll, the test aircraft is in a defensive position initially, so the task of the chase aircraft is to be an offensive threat and is positioned at the test aircraft's 4 or 8 o'clock position with 50-100 knots of closure speed. The test aircraft performs the defensive roll and the threat aircraft zoom climbs in an attempt to remain offensive. The maneuver is complete when the test aircraft's pilot regains situational awareness after performing the roll. The role of the attacking aircraft is merely to pose a threat and to provide relative positioning cues.

The results from the HARV flights showed that these tasks were simple and effective for assessing the lateral-directional response and were therefore useful and efficient flight test tasks. No significant changes needed to be made to the tasks during the flight tests. The pilot comments indicated that the initial conditions were easy to achieve and repeatable, resulting in the efficient use of flight time. The target provided the test aircraft with a repeatable task that could be used to consistently judge the roll performance of the aircraft in terms of its mission effectiveness.

USE OF TARGETS

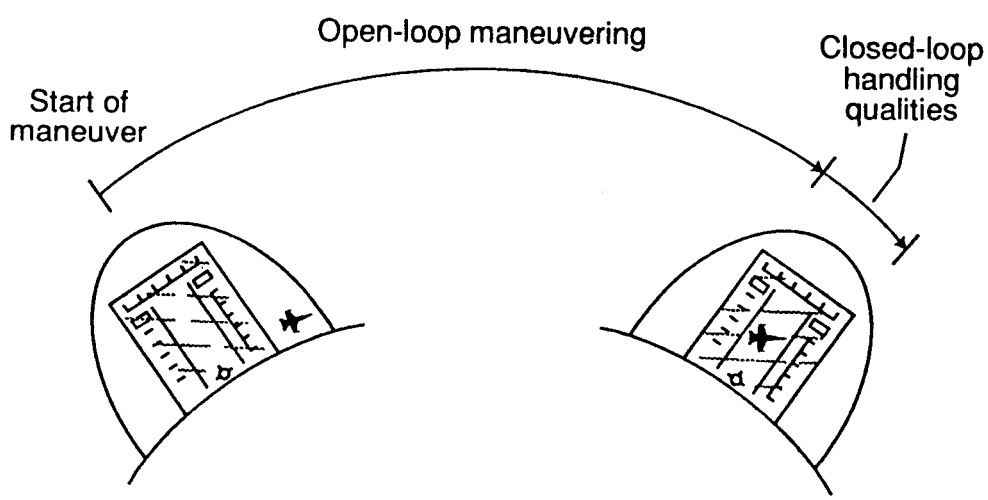


RATING METHODOLOGY

The rating methodology developed for any control power study must be able to properly isolate and evaluate the particular response characteristics of interest. If the proper rating methodology is not used, critical information can be lost or overlooked. For the lateral-directional control power study, the level of roll performance was the primary focus of the pilots' assessments. In order to effectively isolate and evaluate the roll performance, two distinct maneuver phases were defined; open-loop maneuvering and closed-loop handling qualities. The open-loop maneuvering phase was defined as the part of the maneuver during which the pilot holds a nearly full lateral stick input and is therefore commanding a large amplitude change in the aircraft's position or attitude. During this phase the pilot judges characteristics such as roll acceleration, peak roll rate, roll mode time constant, and the time to roll, all of which are characteristics that describe the roll performance. This open-loop phase continues until the pilot takes out the lateral stick input and begins to perform a closed-loop target capture. Once the pilot is in the loop, he is performing a more precise, smaller-amplitude task, and evaluates the handling qualities of the configuration.

Pilot comments indicated there was no difficulty in separating the roll performance from the handling qualities, so this rating approach was used very successfully during the development of the simulation data base. The pilots used this same method during the flight tests and commented that the use of this approach was equally successful in flight and that no changes would be needed for further flight validation.

RATING METHODOLOGY



ROLL PERFORMANCE CLASSIFICATION

A unique rating approach was developed for the purposes of the lateral-directional study to separately evaluate the open-loop and closed-loop portions of the evaluation maneuvers. The roll performance classification (RPC) scale was developed during the ground-based simulation study and has been used to rate the open-loop roll performance based on the perceived mission effectiveness of the configuration. For maneuvers that involve a target capture, the Cooper-Harper scale has also been used to evaluate only the closed-loop handling qualities. The RPC scale has four different categories of roll performance based on mission effectiveness, and the pilot chooses the category that best agrees with his comments about the roll performance. The determination of mission effectiveness is left to the pilot's judgment based on his background and experience. This scale is a simple rating tool that has been easy for the pilots to use. By separately rating the open- and closed-loop characteristics, a good understanding of the overall lateral-directional characteristics was obtained as well as insight into the trade-offs that occur between roll performance and handling qualities.

The RPC scale was used very successfully during the development of the ground-based simulation data base, and the pilot comments from the flight tests indicated that no problems arose from using the RPC scale in flight. Pilot comments also indicated that the RPC scale was useful for evaluating the roll performance in terms of mission suitability and that the Cooper-Harper scale was easily used for separately evaluating the handling qualities. RPC ratings given during the flights were consistent between the pilots and correlated well with their comments.

ROLL PERFORMANCE CLASSIFICATION

Roll Performance for Mission Effectiveness	Improvements in Roll Performance	Numerical
Enhancing - Tactically superior	None warranted	1
Satisfactory - Mission requirements met	May be warranted, but not required	2
Unsatisfactory - Mission requirements not met	Required	3
Unacceptable - Tactically useless	Mandatory	4

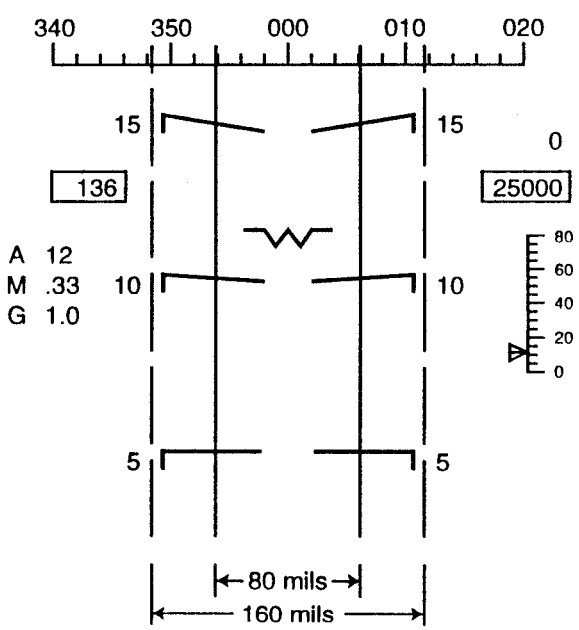
CLOSED-LOOP HANDLING QUALITIES CRITERIA

Criteria for evaluation of the closed-loop handling qualities were defined that were representative of realistic tactical situations, easy for the pilot to judge if they were met, and could be used consistently in both simulation and flight for maneuvers that involved a target capture. For this study the pilots used the Cooper-Harper scale to rate the closed-loop handling qualities during the target capture portion of the maneuver. Because this study focused on the lateral-directional characteristics, the longitudinal capture was not evaluated. Vertical acquisition bars spaced 80 mils apart were used on the heads up display (HUD) instead of the standard reticle so that the longitudinal position of the target at capture was not a factor. Thus, the pilot's workload was only in the lateral-directional axes. This method had previously been used successfully in a MDA handling qualities study.

According to the criteria set early in the study, one overshoot of the target beyond the vertical bars was judged to constitute adequate capture performance when using the Cooper-Harper scale. Early simulation results showed that for certain combinations of steady-state roll rate and roll mode time constant, a large amplitude overshoot would occur. The pilot comments indicated that even though they were able to complete a successful capture after the initial large overshoot, they did not believe that the capture dynamics were adequate. Therefore, a second, wider set of vertical bars 160 mils apart was added to the HUD, and the capture criteria were modified so that an overshoot larger than the 160 mil outer bars was no longer considered to be adequate. The capture was only considered to be adequate if there were no overshoots outside of the 160 mil bars. The pilots felt that this method gave a more accurate assessment of the capture dynamics and that it was easy to use.

For the flight tests, the vertical bars were programmed on the HARV HUD. According to the pilot comments, the use of the double vertical bars worked as well in flight as they did in the simulator, and no changes were deemed necessary in order to use the bars in further flight evaluations. The pilots also stated that the bars were easy to use in flight and were much more useful for determining a lateral capture than a reticle alone. The 160 mil bars enabled the accurate evaluation of the magnitude of the overshoots. The pilots commented that using the double bars allowed them to more accurately assess the handling qualities of the airplane.

CLOSED-LOOP HANDLING QUALITIES CRITERIA

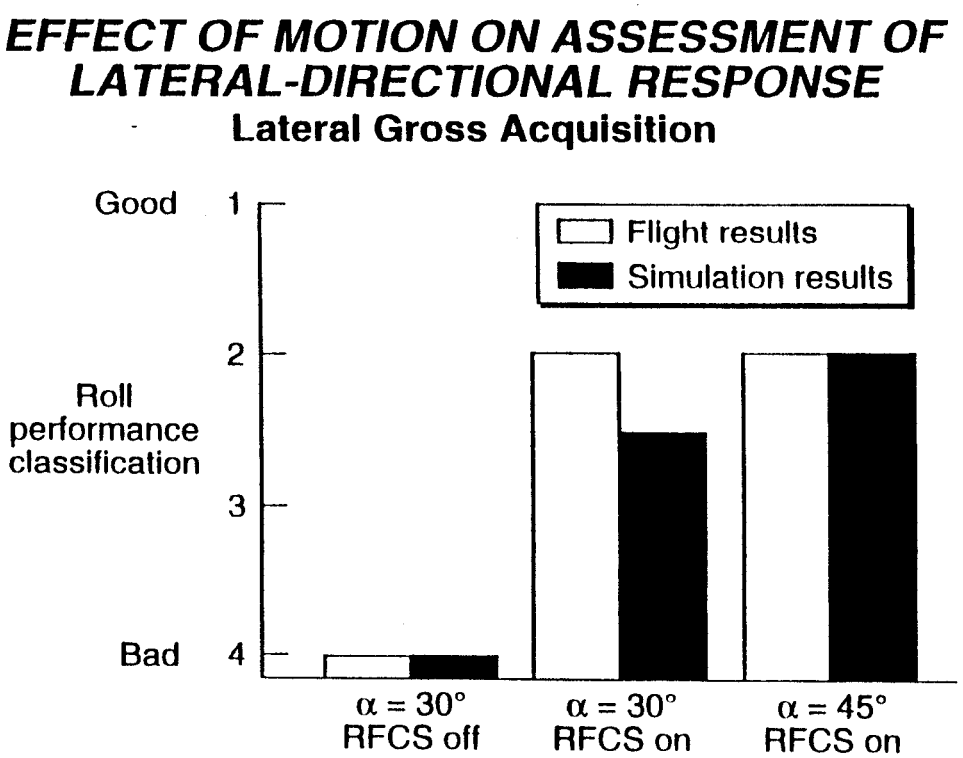


EFFECT OF MOTION ON ASSESSMENT OF LATERAL-DIRECTIONAL RESPONSE

As has been previously stated, the effects of motion can cause discrepancies between ground-based simulation results and flight results. For maneuvers that produce high rates and accelerations or highly dynamic maneuvers, motion cues in flight may significantly influence the pilot's evaluation of the maneuver.

The maneuvers that have been used in the lateral-directional control power study involve high-angle-of-attack rolls about the velocity vector, and it was not known if motion cues would affect the evaluation of this type of unconventional maneuver. One of the purposes of the flight tests was to validate the test methodology, a part of which involved the investigation of the effects of motion on the pilot comments and ratings. The dynamic model that was used during the ground-based simulation provided a generic first-order response in the lateral-directional axes. Parametric changes in the steady-state roll rate and roll mode time constant were made to vary the response characteristics. The ratings for each flight maneuver were compared to the ratings given in the simulator for a response with the same steady-state roll rate and roll mode time constant as the flight data point. The figure shows the comparison of RPC ratings from the simulation and flight tests for the lateral gross acquisition maneuver at 30 degrees angle of attack with the research flight control system (RFCS) off and on and at 45 degrees angle of attack with RFCS on. The simulation and flight test data correlated well indicating that the motion cues present in flight did not have a significant influence on the pilots evaluation of the roll performance.

The pilot comments indicated that the motion effects in flight were not significant and that the maneuvers in flight felt just like they did in the simulator. Prior to the flight tests, the pilots had flown the maneuvers in the simulator repeatedly and had become acclimated to the high-angle-of-attack visual "coning" effect. Apparently, during these maneuvers, the rates and accelerations in flight were low enough that the visual cues were more dominant than the motion cues. Thus, the motion was not disorienting to the pilots and had very little impact on their ratings and comments.



CONCLUDING REMARKS

The results of flight tests are being used to validate test methodology and design guidelines for control power requirements at high angles of attack that were derived from the results of simulation studies. Several issues and challenges were addressed in order to successfully develop the guidelines and perform the flight test evaluations. Careful attention was paid to the development of appropriate maneuvers for isolating the aircraft response characteristics that are the most relevant to control power design. A variety of figures of merit have been examined in order to determine which characteristics had the greatest influence on the pilot opinion of the response. Numerical rating methodologies were developed and validated in flight in order to quantify the pilot opinion of the response and enable statistical correlation of his opinion with candidate figures of merit. Experience from previous flight tests and simulation was beneficial for assuring the success of setting up and performing the evaluation maneuvers in flight. Several methods were used in flight to achieve parametric variations of the aircraft response in a systematic way. Some motion effects were encountered in flight which resulted in minor differences in pilot opinion of the response from those of the simulation study.

Additional work remains to be done in order to complete the development of these high-angle-of-attack control power requirement studies for high angles of attack. Analysis of the existing flight and simulation data will continue so that the validation and refinement of the numerical design guideline values can be completed. Control power requirements based on the results of these studies will be proposed for future revised military specifications for flying qualities.

CONCLUDING REMARKS

- Flight validation of simulation-derived control power guidelines in progress
  - Guideline development issues addressed concerning development of evaluation maneuvers, figures of merit, and rating methodologies
  - Flight test challenges addressed, including maneuver set-up/performance, parametric variations of response, and evaluation of motion effects
- Post-flight test activities planned
  - Continue analysis of flight and simulation data
  - Complete validation/refinement of numerical guideline values
  - Propose requirements for future flying qualities MIL SPEC revisions

NASA/NAVY CONTROL POWER PUBLICATIONS AND PRESENTATIONS

Nose-Down Pitch Control (HANG) Publications:

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2. Ogburn, Marilyn E.; et. al.: High-Angle-of-Attack Nose-Down Pitch Control Requirements for Relaxed Static Stability Combat Aircraft. NASA High-Angle-of-Attack Technology Conference, NASA Langley Research Center, Hampton, VA, October 30-November 1, 1990. NASA CP-3149, 1992, Volume I, Part 2, Paper No. 24.

3. Ogburn, Marilyn E.; Foster, John V.; and Hoffler, Keith D.: Use of Piloted Simulation for High-Angle-of-Attack Agility Research and Design Criteria Development. AIAA Flight Simulation Technologies Conference, New Orleans, LA, August 12-14, 1991. AIAA Paper No. 91-2954.

4. Ogburn, Marilyn E.; Foster, John V.; and Hoffler, Keith D.: Application of Piloted Simulation to High-Angle-of-Attack Flight-Dynamics Research for Fighter Aircraft. AGARD Symposium on Piloted Simulation Effectiveness, Brussels, Belgium,October 14-17, 1991. AGARD-CP-513, Paper No. 29.

5. Ogburn, Marilyn E.; et. al.: Status of the Development of High-Angle-of-Attack Control Margin Requirements. NASA High-Angle-of-Attack Projects and Technology Conference, NASA Dryden Flight Research Facility, Edwards, CA, April 21-23, 1992. NASA CP-3137, Volume 2, pp. 99-147.

6. Hadfield, Christopher A. (Capt., CAF): High Angle of Attack Handling QualitiesRating Scales. Thesis presented for the Master of Science degree from the University of Tennessee, Knoxville, TN, May 1992.

7. McNamara, W. G.; et. al.: Navy High Angle of Attack Pitch Control Margin Requirements for Class IV Aircraft. NAVAIRWARCENACDIV Technical Memorandum 91-167 SA, June 25, 1992.

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11. Lackey, J.; and Prater, D. (Lt., USN): Limited Navy Flying Qualities and Performance Evaluation of the NASA F/A-18 HARV. NAWC-AD Technical Memorandum 93-11 SA, June 21, 1993.

12. Ogburn, Marilyn E.; et. al.: Status of the Validation of High-Angle-of-Attack Nose-Down Pitch Control Margin Design Guidelines. AIAA Atmospheric Flight Mechanics Conference, Monterey, CA, August 9-11, 1993. AIAA Paper No. 93-3623.

Lateral-Directional Control (HAIRRY) Publications:

1. Foster, John V.; Ross, Holly M.; and Ashley, Patrick A.: Investigation of High-Alpha Lateral-Directional Control Power Requirements for High-Performance Aircraft. AIAA Atmospheric Flight Mechanics Conference, Monterey, CA, August 9-11, 1993.AIAA Paper No. 93-3647.

Presentations:

1. "High-Alpha Nose-Down Pitch Control Requirements Study". Program review presented at NASA-Langley Research Center, Hampton, VA, December 13, 1989.

2. "High Angle-of-Attack Nose-Down Guidelines (HANG)". Program review presented at NASA-Langley Research Center, Hampton, VA, April 11, 1990.

3. "NASA/Navy High-Alpha Nose-Down Control Margin Requirements". Program review presented at the Naval Air Warfare Center, Patuxent River, MD, July 25, 1990.

4. McNamara, William G.: Pitch Control Margin Guidelines for RSS Tactical Jet Aircraft. Presented at the Society of Flight Test Engineers 22nd Annual Symposium, August 5-9, 1991.

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7. "HAIRRY: High Angle-of-Attack Investigation of Requirements for Roll and Yaw". Program review presented at the Naval Air Warfare Center, Patuxent River, MD, April 27, 1993.