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DEVELOPMENT OF HIGH-ANGLE-OF-ATTACK NOSE-DOWN PITCH CONTROL MARGIN DESIGN GUIDELINES FOR COMBAT AIRCRAFT

Marilyn E. Ogburn
John V. Foster

Workshop on Guidance, Navigation, Controls, and Dynamics for Atmospheric Flight

NASA Langley Research Center
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OUTLINE

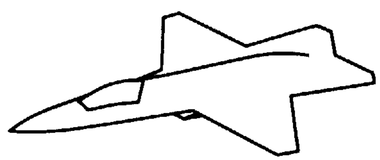
- Background and objectives
- Approach
- Development of preliminary guidelines
- Experimental and flight results
- Summary and Plans

OUTLINE

A broad research program to identify maneuvering requirements for advanced fighters and the corresponding design criteria to aid in making critical design tradeoffs is being conducted under the NASA High-Angle-of-Attack Technology Program (HATP). As part of this activity, NASA and the U.S. Navy are conducting cooperative research to develop high-angle-of-attack control margin requirements. This paper will summarize the status of this program. Following some background information, the simulation study conducted to develop a set of preliminary guidelines for nose-down pitch control is reviewed and the results of some very limited flight tests are described.

CONTROL EFFECTIVENESS REQUIREMENTS FOR MULTI-AXIS RELAXED STABILITY COMBAT AIRCRAFT

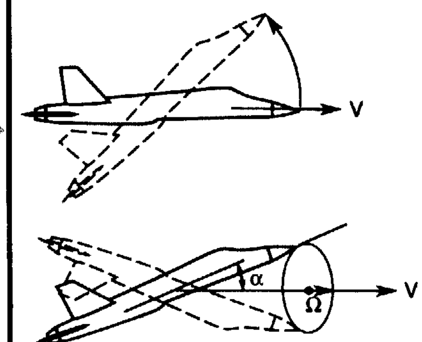
Performance Considerations



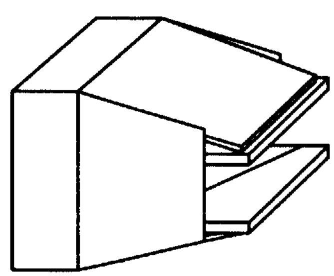
- Relaxed stability in pitch and yaw
- Reduced control surface size

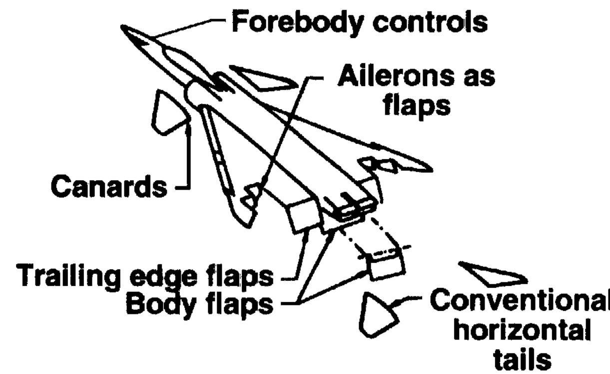
Design Criteria Required

Maneuvering Requirements



Advanced Control Effectors





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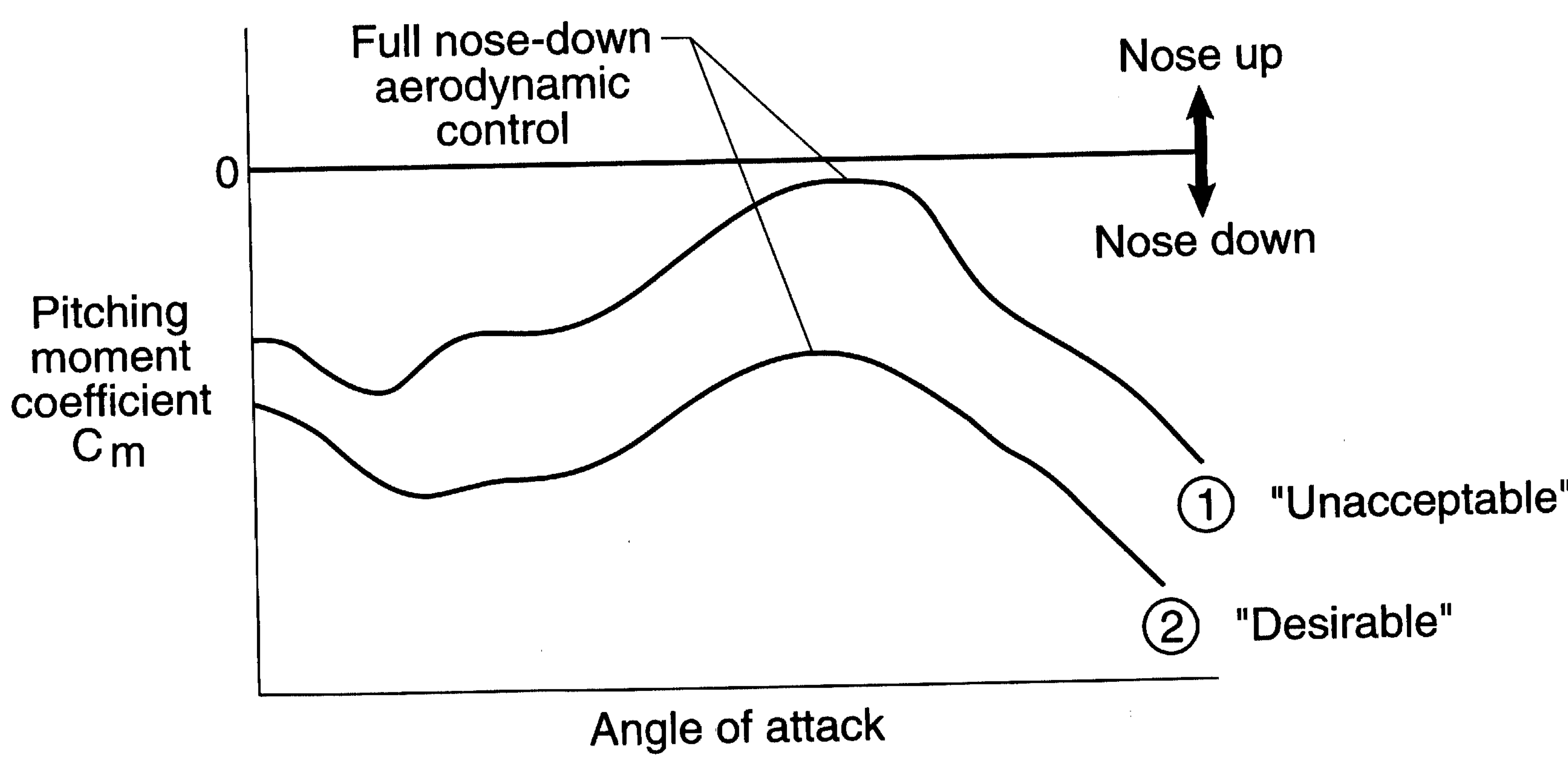
CONTROL EFFECTIVENESS REQUIREMENTS FOR MULTI-AXIS RELAXED STABILITY COMBAT AIRCRAFT

A well-defined set of criteria exists and has been used for the design of combat aircraft for performance considerations. These criteria address the use of concepts such as relaxed stability in pitch and yaw and reduced control surface size to enhance performance characteristics. However, detailed, validated design criteria to define minimum maneuvering requirements, particularly for flight at low speeds and high angles of attack, do not currently exist. These criteria are needed to aid in making the critical design tradeoffs between performance and maneuvering requirements, which often result in conflicting design characteristics. The use of advanced propulsive and aerodynamic control effectors will aid in achieving the control moments to meet enhanced maneuvering requirements; however, these control concepts cannot be utilized most effectively for making design tradeoffs until design criteria for maneuvering are determined.

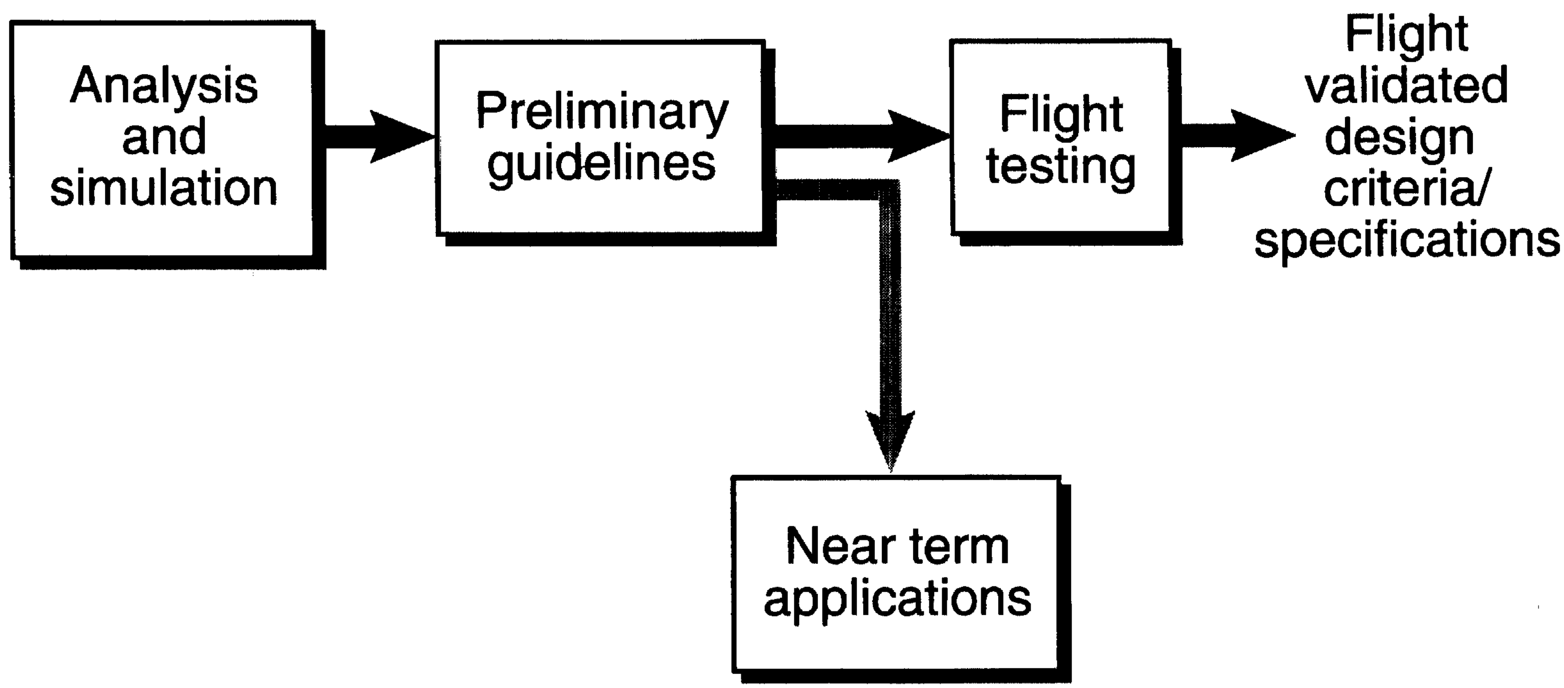
KEY DESIGN ISSUE



KEY DESIGN ISSUE

The first element in the development of control margin requirements is nose-down pitch control at high angles of attack. The key design issue is the level of nose-down pitching moment required for tactical maneuvering and for safety of flight. Guidelines are needed to help the designer determine that, for his particular airplane, the C_m characteristics illustrated by curve 1 are unacceptable whereas the curve 2 characteristics are desirable.

SCOPE OF ACTIVITY



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SCOPE OF ACTIVITY

A cooperative program was formed by NASA and the Navy to address this design issue and is often referred to by the acronym HANG (high-angle-of-attack nose-down guidelines). This chart shows the overall outline of the activity. The first step involved analysis and a simulation study which were used to develop a set of preliminary guidelines. Flight testing for validation of these guidelines has been initiated. The final output of this work will be a set of flight-validated design criteria and specifications for flight test demonstration.

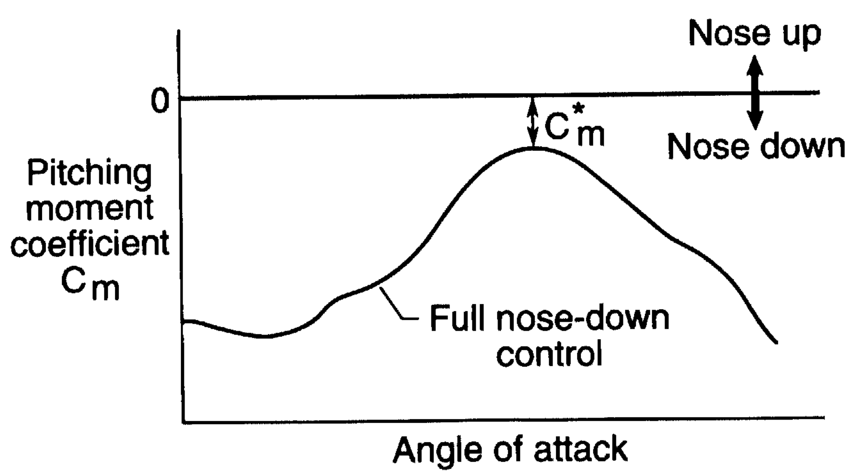
APPROACH TO DEVELOPMENT OF PRELIMINARY GUIDELINES

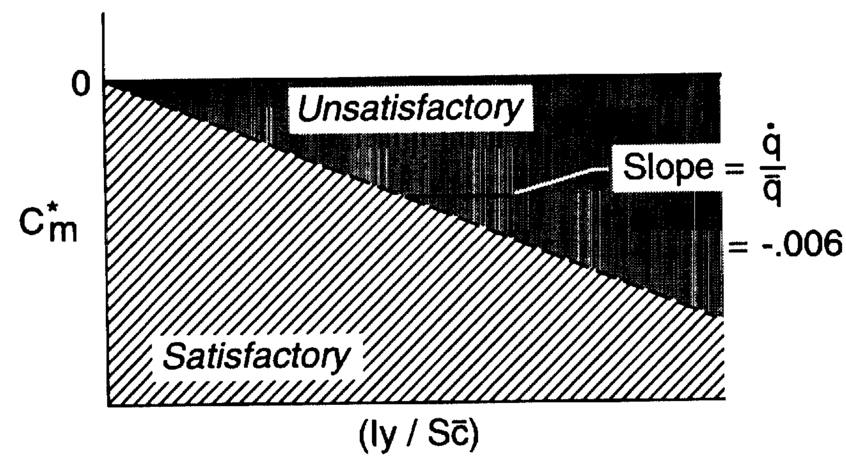
- Examine existing data base for relaxed stability aircraft
- Conduct manned simulation on DMS
  - Systematic parametric variation of key nose-down C_m characteristics
  - Anchored to baseline F-18 model
  - Specific evaluation methodology
    - Maneuvers
    - Pitch recovery rating scale
    - Figures of merit

APPROACH TO DEVELOPMENT OF PRELIMINARY GUIDELINES

The set of preliminary guidelines was developed in two steps. The first involved analysis of information from previous simulation and flight tests of relaxed static stability aircraft to correlate aircraft response in recoveries to available nose-down aerodynamic pitching moment. The next step comprised a more detailed systematic study on the Langley Differential Maneuvering Simulator.

PRELIMINARY GUIDELINE BASED ON EXISTING AIRCRAFT





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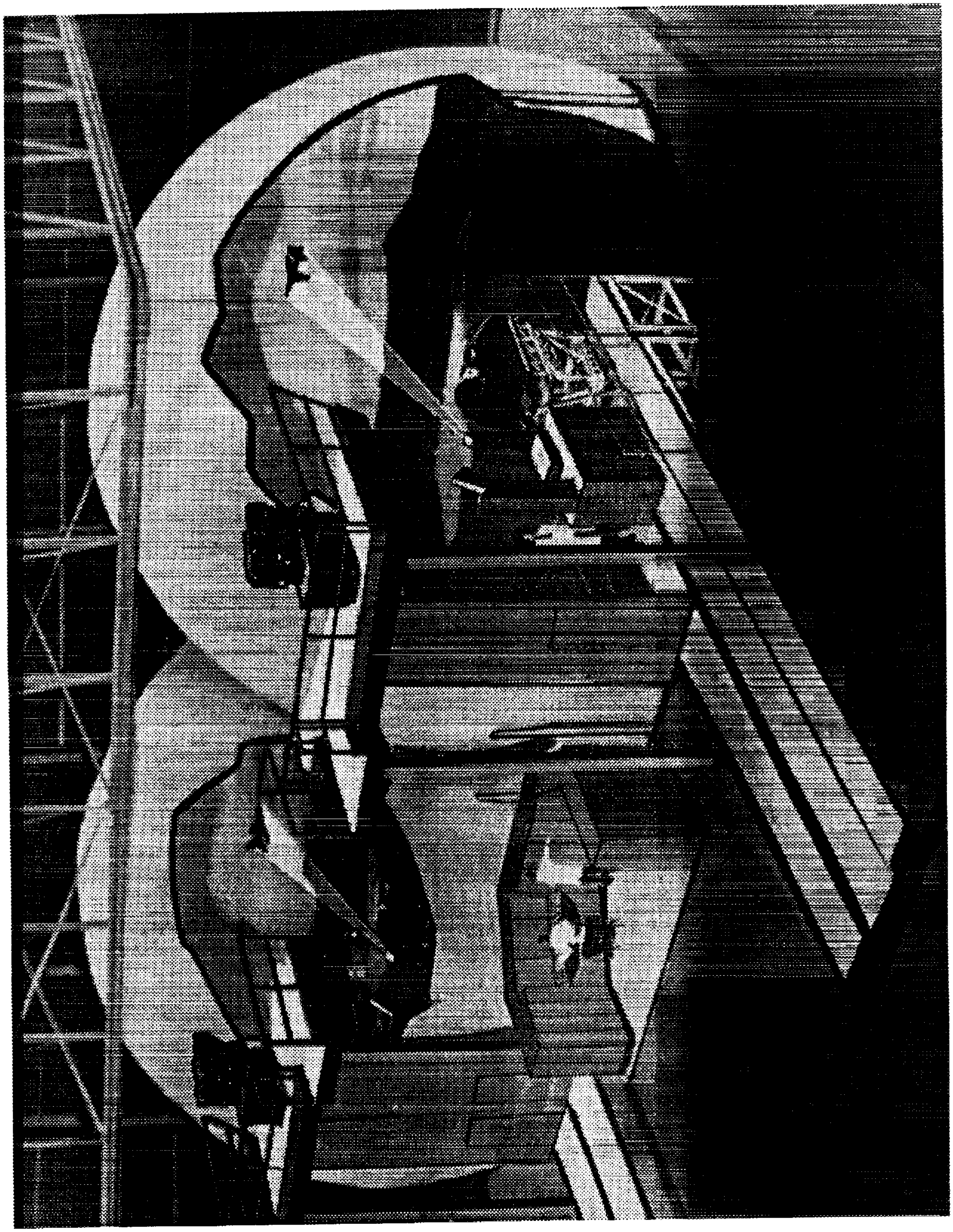
PRELIMINARY GUIDELINE BASED ON EXISTING AIRCRAFT

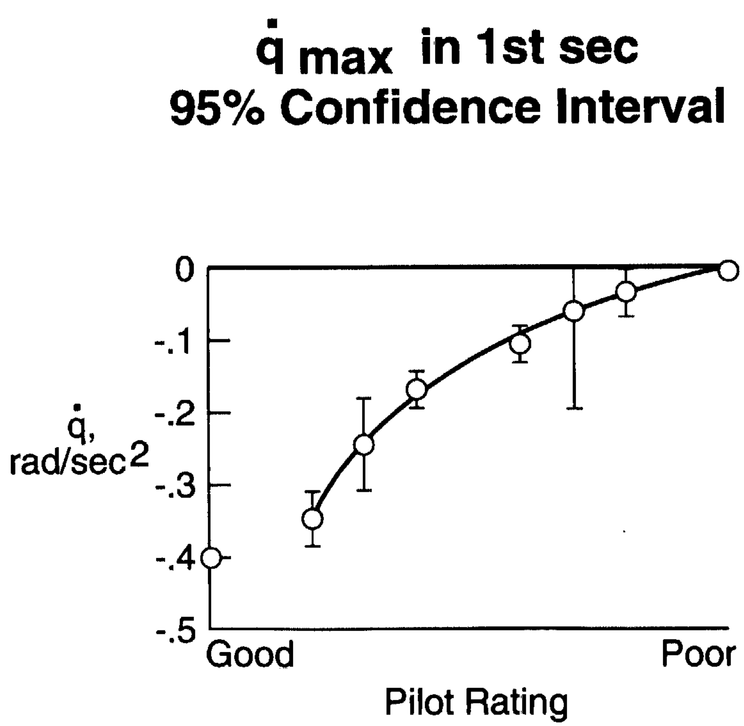
A key parameter for the definition of required nose-down pitching moment is the value of C_m at the minimum point ($C_m{}^*$), as illustrated in the figure. Determination of the smallest value of $C_m{}^*$ that is acceptable from a pitch recovery point of view is important in making critical configuration design tradeoffs. Because C_m can be related to a first-order definition of pitch acceleration by using the aircraft inertia and geometry information, these characteristics were examined for some existing aircraft and correlated with the known high-α nose-down capabilities of these aircraft. The results were used to generate the plot shown which defines a preliminary guideline for $C_m{}^*$ based only on the airplane mass and geometry characteristics. For a given configuration, the designer needs only to calculate the value of $(I_y/S\bar{c})$ and use the chart to determine the minimum levels of $C_m{}^*$ required for "satisfactory" and "unsatisfactory" nose-down control characteristics. Although this result provides a useful, easy-to-apply guideline, particularly during very preliminary design studies, it was felt that a more comprehensive criterion that applies to more than just one point on the C_m curve is needed. As a result, a systematic, parametric study using piloted simulation was conducted as the first step in developing such a design guide.

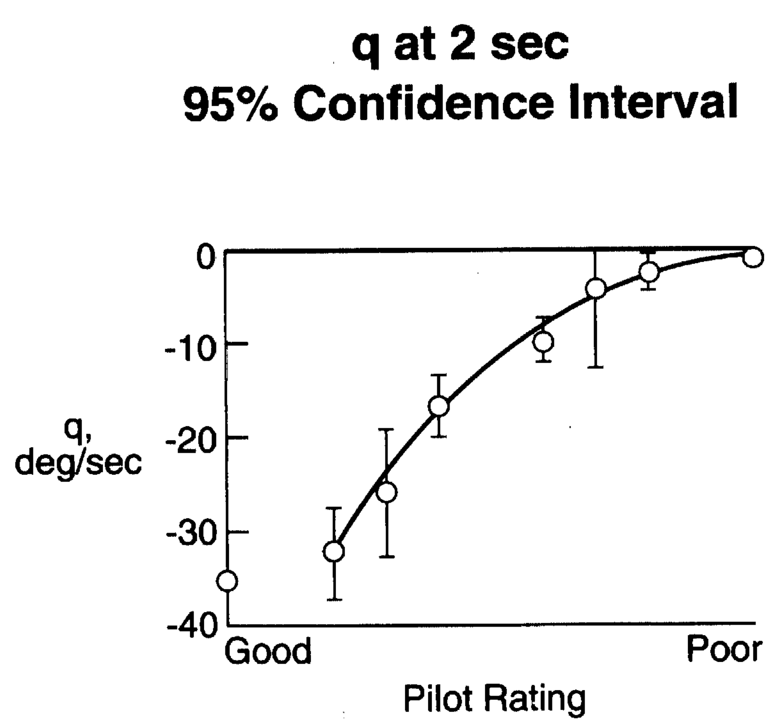


DIFFERENTIAL MANEUVERING SIMULATOR

The Langley Differential Maneuvering Simulator (DMS) was used for the simulation study. As illustrated in the drawing, the DMS is a domed facility with extensive state-of-the-art features that make it a very effective tool for air combat research and high-angle-of-attack flight dynamics studies. These features include a visual scene produced by a computer-generated imaging system, programmable displays and force-feel systems, and artificial "g" cues. A key aspect of the subject simulation study was the systematic variation of the key parameters which define the nose-down pitching moment capability. The parametric variations were anchored to an existing comprehensive F-18 math model, and a specific evaluation methodology was developed to determine the relative merits of the pitch response as the parametric variations were made.

PRELIMINARY DESIGN GUIDELINE





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PRELIMINARY DESIGN GUIDELINE

The results of the simulation evaluation showed clearly that the pilots were evaluating the short-term pitch response. A simple pushover maneuver starting from 1g stabilized trim at high angles of attack to recover to low angles of attack was used as the primary evaluation maneuver. It was determined that two primary figures of merit were needed because the pilots said that they judged two response characteristics during the recovery: (1) the pitch acceleration almost immediately following the forward stick input and (2) the pitch rate buildup over the initial part of the recovery. The two figures of merit that best correlated the pilots' ratings and comments with the airplane response were the maximum pitch acceleration achieved within one second of the initiation of forward stick movement and the pitch rate at two seconds into the recovery. The pilot ratings covered a range of values that indicated good to poor response. Confidence levels are shown about the mean value for several pilot ratings. The pitch acceleration results generally agree well with the preliminary guideline discussed earlier that was based on previous flight and simulation experience and with the results from other related work. The current results have also been checked using piloted simulations of several relaxed static stability configurations besides the F-18, and full-scale flight validation has been initiated.

FLIGHT TESTS

- Objectives
  - Validate/refine research test methodology
  - Validate simulation results and refine design guidelines as necessary
- Approach: Conduct two phase flight program
  - Phase I: Limited study emphasizing ***test methodology***
    - Navy F-18
    - NASA HARV
  - Phase II: Detailed study emphasizing ***guideline validation***
    - NASA HARV with thrust vectoring controls

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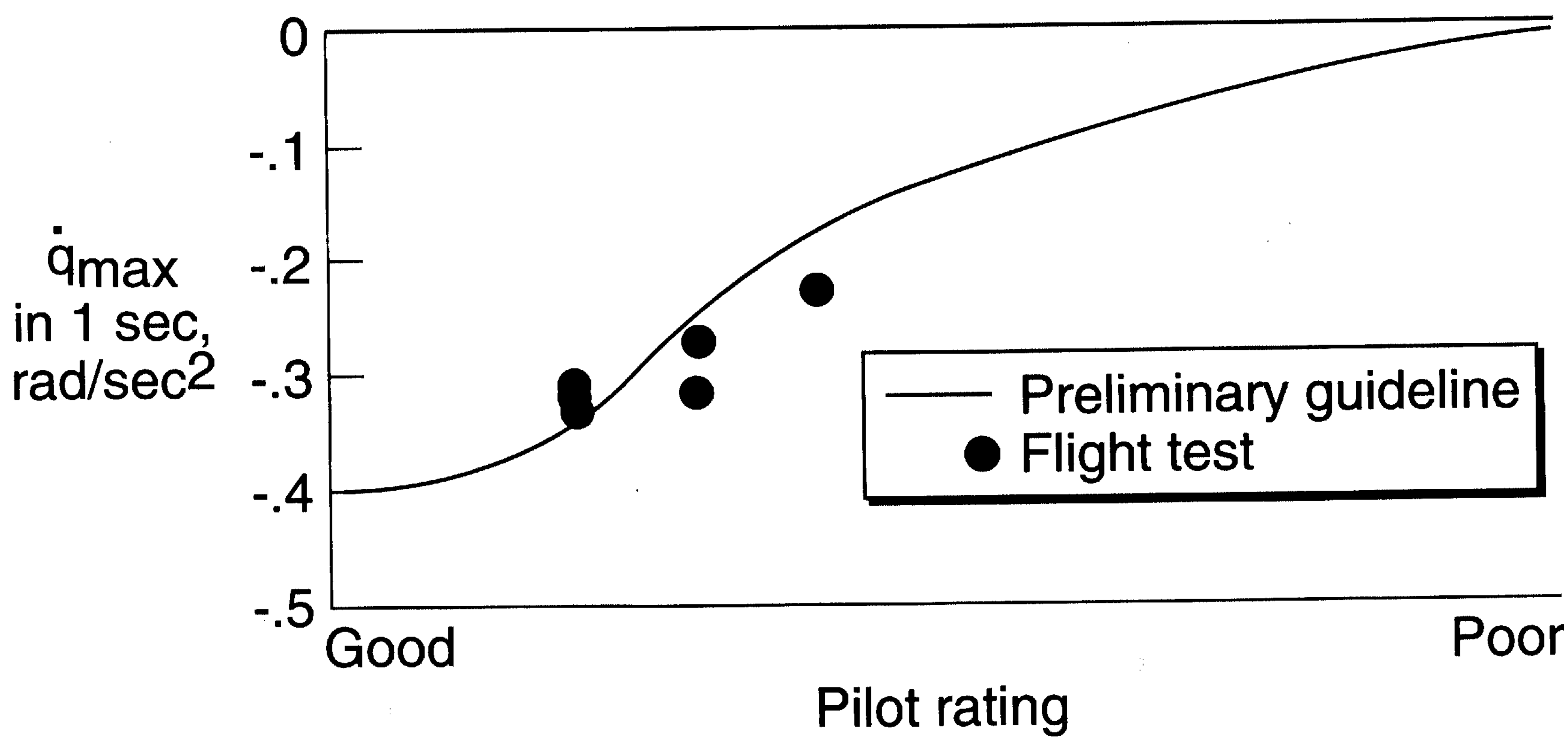
FLIGHT TESTS

The objectives of the flight tests are to validate and refine the test methodology used in the development of the guidelines and the numerical guideline values. A two-phase flight program is being conducted. Phase I, a very limited study to validate the test methodology using a Navy F-18 and the NASA HARV, has been completed. The second phase, which is in progress, is a much more detailed study to validate the guideline values, using the HARV with thrust vectoring controls to provide a wide range of nose-down pitch response.

NATC FLIGHT TEST RESULTS

Two Pilots - Preliminary



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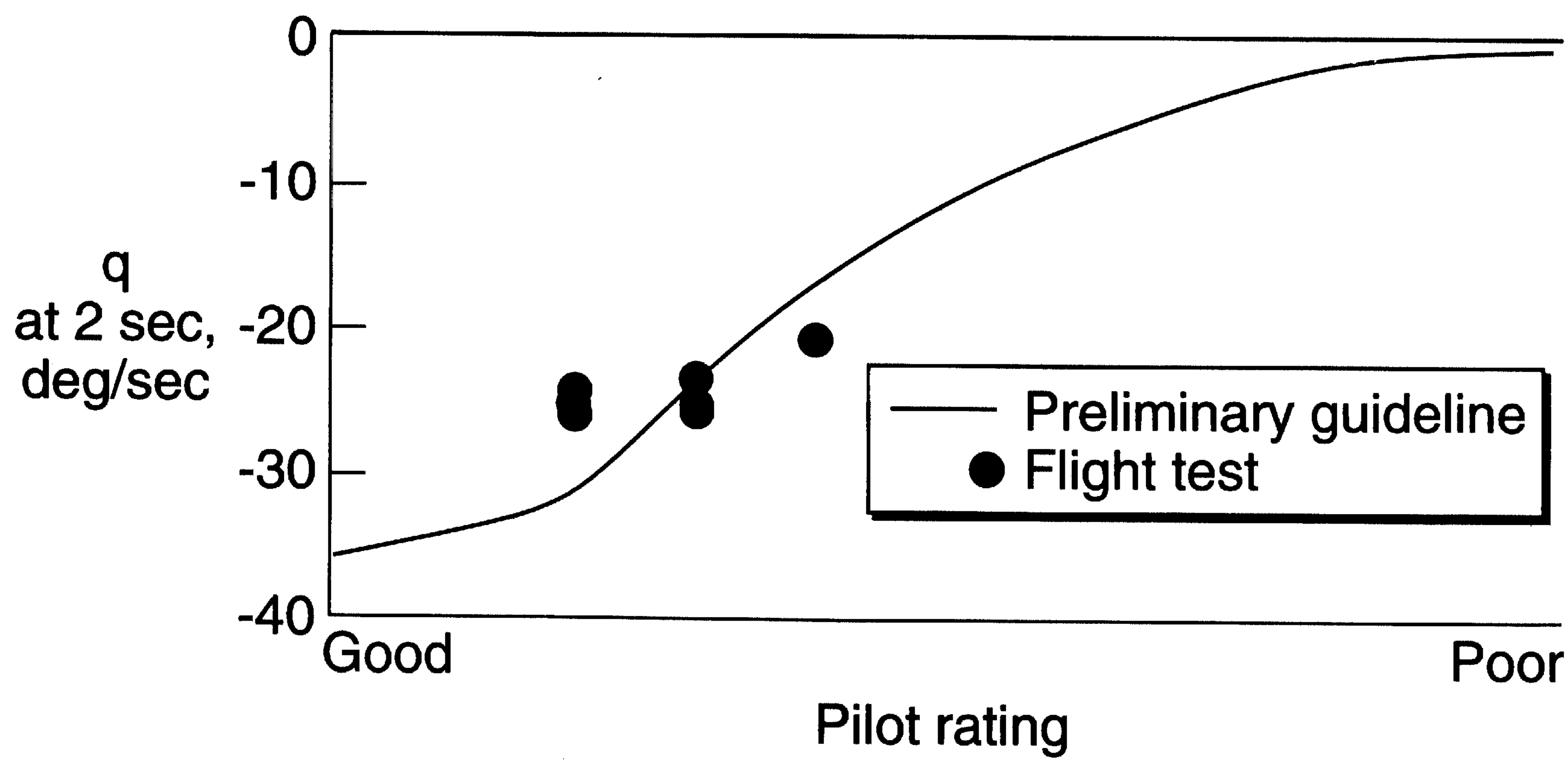
NATC FLIGHT TEST RESULTS

Flight tests of a Navy F-18 were conducted at the Patuxent River Naval Air Test Center. Two Navy pilots performed and rated 32 pushover maneuvers. The center of gravity was varied using a fuel-transfer c.g. control system. The flight program was very successful in achieving its primary objective which was the verification of the fundamental simulation methodology and validation of the key figures of merit ($\dot{q}$ and q). As a very limited, preliminary check of the guidelines developed in the simulation study, the results from flight for the maneuvers with the most linear pitch acceleration response (similar to the simulation responses) were compared with the simulation data shown earlier. The plot shows fairly good correlation for the $\dot{q}_{max}$ in 1 second metric. A comparison of the flight results with the preliminary guideline values for the initial pitch acceleration response shows good agreement between flight and simulation.

NATC FLIGHT TEST RESULTS
Two Pilots - Preliminary



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NATC FLIGHT TEST RESULTS

Similarly, the correlation for the pitch rate in 2 seconds metric was also fairly good. Again, it should be noted that this flight data base is very small so that no conclusions can be drawn based on this data alone. Definitive refinement and validation of the guidelines will be accomplished in the second phase of the flight test program which is currently in progress.

SUMMARY OF FLIGHT TEST RESULTS TO DATE

- Flight tests validated simulation study methodology
  - Pushover maneuver
  - Rating scale
- Results verified that short-term response is primary figure of merit
  - $\dot{q}$ and q are appropriate figures of merit
- Good correlation obtained between simulation and flight for comparable maneuvers

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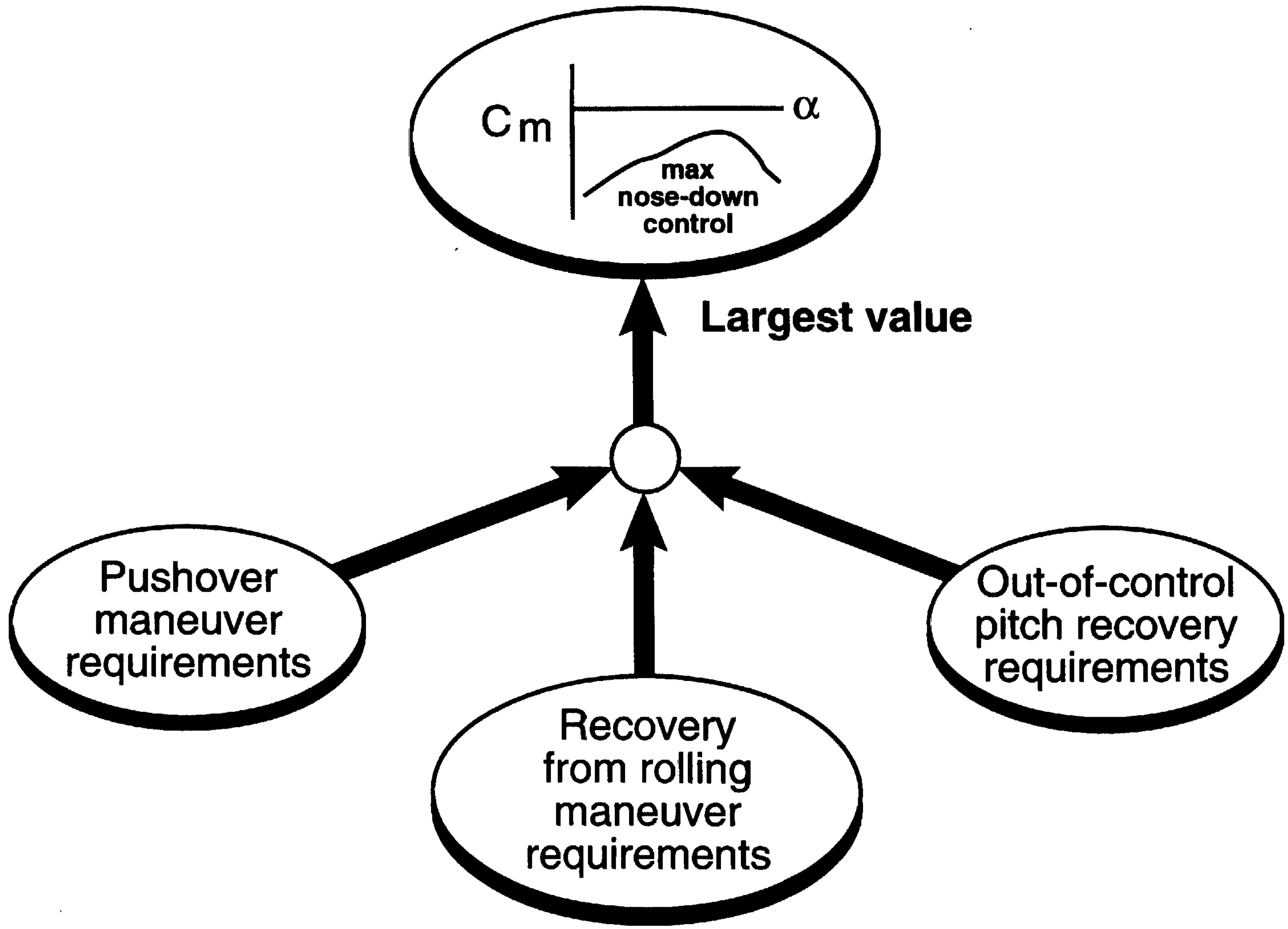
SUMMARY OF FLIGHT TEST RESULTS TO DATE

The limited amount of flight testing that was completed in the first phase of these tests satisfied the primary objective which was to validate the simulation study methodology by confirming the suitability of the pushover as the primary evaluation maneuver and the utility of the rating scale. These preliminary flight tests also provided much information that has been very valuable in the preparation for further tests. The results verified that the pilots' opinions of the recoveries are based on the short-term pitch response, and good agreement for the numerical response values was obtained between the individual pilots' simulation and flight results for maneuvers in which the character of the response was comparable.

NOSE-DOWN PITCH CONTROL DESIGN GUIDELINE



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TOTAL C_m REQUIREMENT

A method for designing the C_m versus angle of attack curve was developed using the preliminary guideline values. The overall design process is accomplished in four steps, the first three of which require separate calculations of the C_m required at each angle of attack. The first step, which satisfies the requirements for the pushover maneuver, is described in a previous publication on this work. The second and third steps involve the calculation of C_m values based on the nose-down pitch control power needed to oppose the inertia coupling generated during commanded roll maneuvers and uncommanded roll/yaw motions. The final step is to select the largest value of Cm computed for any of the first three steps at each angle of attack.

SUMMARY AND PLANS

- Preliminary pitch control guidelines developed
  - Test and analysis methodology developed
  - Extensive simulation results obtained
  - Simulation study methodology validated by first phase of flight tests and additional simulation

- Follow-on activities in progress
  - Continue analysis of existing flight and simulation data
  - Complete systematic HARV experiments with thrust vectoring
    - ◆ Parametric variation of nose-down capability
    - ◆ Perform variety of maneuvers
    - ◆ Analyze flight/simulation results
  - Develop guidelines for roll/yaw axes

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SUMMARY AND PLANS

In summary, the research activity described in this paper has resulted in the development of preliminary nose-down pitch control guidelines. The appropriate study methodologies were developed and validated by limited flight test programs and extensive simulation results have been obtained from which the guidelines were derived. There is still much work to be done to reach the final goal of a complete set of fully-validated design criteria and specifications for demonstrating in flight that the criteria have been met. The analysis of existing data will continue, but the main activity will be to complete experiments in progress using the HARV with thrust vectoring, primarily to validate the numerical guidelines. Using the HARV with thrust vectoring controls enables the evaluation of a wide range of nose-down response. The capability to vary the level of pitch vectoring that is obtained for forward stick inputs means that the character and the level of the pitch response during recoveries from high angles of attack can be specified. A systematic parametric variation of nose-down response is being made and a large number and variety of maneuvers including the pushover maneuver are being performed, rated, and analyzed. In addition, a complementary effort is underway to develop similar design guidelines for the roll/yaw axes.