PITCH CONTROL MARGIN AT HIGH ANGLE OF ATTACK - QUANTITATIVE REQUIREMENTS (FLIGHT TEST CORRELATION WITH SIMULATION PREDICTIONS)

J. Lackey
Capt. C. Hadfield (CAF)
Naval Air Warfare Center - Aircraft Division
Patuxent River, Maryland

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ABSTRACT

Aircraft designs that employ relaxed static stability (RSS) have the following problem: reduced pitching moments associated with RSS at high angle of attack (AOA) require a minimum pitch recovery moment or margin to guarantee a safe return from high AOA maneuvers at the most aft center of gravity (CG) encountered during a mission. Recent incidents and mishaps on Class IV aircraft have demonstrated a need for establishing quantitative longitudinal high AOA pitch control margin design guidelines for future aircraft. The Naval Air Warfare Center - Aircraft Division (NAWC-AD) is currently supporting an effort in conjunction with NASA Langley Research Center (NASA LaRC) to quantify such requirements. NASA LaRC has conducted a series of extensive simulation evaluations to define these design guidelines. The purpose of flight tests were to validate the overall research test methodology by comparing pilot comments, pilot ratings, and aircraft response characteristics gathered during inflight recoveries from high AOA conditions to those gathered during the fixed-base simulation sessions. Tests were completed on an F/A-18A in six flights for a total of 9.8 flight hours using an AOA and CG buildup sequence. Flight test results have validated the simulation studies in that pilot cueing (rating) of high AOA nose-down recoveries were based on the short-term response interval in the forms of pitch acceleration and rate. In addition, flight test has demonstrated that high AOA pitch control margin can be evaluated using a stabilized pushover method.

NOMENCLATURE

AOA	angle of attack
$AOAdot_{\Delta t}$	angle of attack rate change within a time interval
cbar	mean aerodynamic chord
CG	center of gravity
Cm	total pitching moment
ftHp	pressure altitude feet
Iyy	pitch inertia
KCAS	knots calibrated airspeed
MAC	mean aerodynamic chord
Q (at 2 sec)	pitch rate at two seconds from recovery input
qbar	dynamic pressure
qdot	pitch acceleration
Qdot (at 1 sec)	pitch acceleration at one second from recovery input
Qdot (avg≤1 sec)	average pitch acceleration within one second from recovery input
Qdot (max≤1 sec)	maximum pitch acceleration within one second from recovery input
$q_{\Delta t}$	pitch rate change within a time interval
S	reference wing area
Trec	time to recover to less than 10 deg AOA
α	angle of attack
$\dot{\gamma}$	flight path angle rate
$\Delta AOA_{\Delta t}$	angle of attack change within a time interval
Δh_{rec}	altitude required to recover
$\Delta V_{\Delta t}$	airspeed change within a time interval
$\Delta\Theta_{\Delta t}$	pitch angle change within a time interval
Θ	pitch angle

INTRODUCTION

General

In the Navy, there is currently an effort underway in conjunction with NASA Langley Research Center (NASA LaRC) to define quantitative longitudinal high AOA pitch control power / margin requirements so that next generation tactical aircraft can avoid this problem area. Initial work to define such guidelines was conducted from November 1989 to June 1990 at NASA LaRC by a Navy / NASA LaRC team using both a baseline and modified parametric F/A-18A six degree of freedom simulation model in the fixed-base Differential Maneuvering Simulator (DMS). A Pitch Recovery Rating (PRR) scale (see figure 1) was developed to correlate qualitative pilot opinion with nose-down pitch response characteristics of an aircraft to desired mission task and safety considerations. Navy / NASA LaRC

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simulation studies produced specific candidate figures of merit to quantify high AOA longitudinal pitch control margin requirements. In order to validate simulation results, flight tests were planned for two phases. Phase I tests, conducted from 30 September to 8 October 1991, consisted of a limited study using an F/A-18 to validate the overall research test methodology. Phase II tests will consist of a more detailed approach emphasizing guideline validation using the NASA Dryden F/A-18 High Alpha Research Vehicle in which flight test flight control laws can be modified as desired in conjunction with thrust vectoring controls. The Naval Air Systems Command tasked NAWC-AD via reference 1 to conduct the Phase I tests. This paper outlines the Phase I test results.

Description of Test Aircraft

The F/A-18A (see figure 2) is a single seat, high performance, twin engine supersonic fighter characterized by moderately swept, variable camber mid-mounted wings, twin outboard canted vertical stabilizers mounted forward of the horizontal stabilators, a speedbrake located on the upper aft section of the fuselage between the vertical stabilizers, and leading edge extensions mounted on each side of the fuselage from the wing roots to just forward of the windshield. The airplane is configured with full span leading edge flaps, inboard trailing edge flaps, and outboard ailerons on each wing. The flight control system consists of two digital flight control computers that utilize a full authority control augmentation system to operate the hydraulically driven control surfaces. The aircraft is powered by two General Electric F404-GE-400 augmented turbofan engines rated at 16,000 pounds maximum uninstalled static sea level thrust. A detailed description of the F/A-18A airplane is presented in reference 2. The test airplane was BuNo 162445, a Lot VII airplane equipped with version 8.3.3 programmable read only memory flight control laws.

Description of Test Equipment and Instrumentation

A Nose Instrumentation Pallet System was installed in the airplane in order to transmit selected 1553 multiplex bus parameters to the real-time telemetry processing system (RTPS) for monitoring during the tests. AOA was obtained from both the production air data computer and the inertial navigation system (INS). Angle of sideslip was obtained from the INS. A non-production CG control system was installed so that CG position could be changed by the pilot by selectively disabling fuel transfer using motive flow shutoff valves from a cockpit mounted control panel (see figure 3). The shutoff valves controlled fuel transfer from the forward and aft fuel tanks into engine feed tanks (see figure 4). The test airplane was not equipped with a flight test noseboom or a nonproduction backup emergency system (i.e. spin recovery chute).

Scope of Tests

Simulation tests were conducted on the NASA LaRC DMS using a total of six pilots for 55 test hours. Out of the six pilots, two pilots conducted the Phase I flight tests (designated Pilot A and Pilot B) completing a total of 12 and 8 simulation test hours, respectively. Simulation tests were conducted in two phases. Phase A tests consisted of evaluation methodology development using a baseline F/A-18 simulation model to vary nosedown response with CG movement. Phase B tests consisted of developing guidelines via parametric study in which variation of selected pitching moment parametrics allowed evaluation pilots to rate high AOA recoveries at more varied response conditions. The parametric studies were conducted on a modified F/A-18 simulation model, details of which are presented in reference 3.

Preflight ground tests were conducted at the NAWC-AD Aircraft Test and Evaluation Facility (ATEF) to determine the empty weight and moment values for the test loading, to calculate CG error at full, half-full, and empty fuel states by comparing true values calculated at ATEF with values determined via telemetry readings of individual fuel tank quantities, and to ensure that the nonproduction CG control system worked properly.

A total of 6 flights for 9.8 flight hours were completed by two evaluation pilots during this evaluation. The flights were conducted in two phases. Phase IA tests were flown to: (1) ensure that the test airplane was rigged properly to minimize roll-off tendencies at high AOA, (2) allow the pilots to become familiar with the test maneuver at forward CG positions (≤ 23% MAC) through an AOA buildup range, and (3) practice using the CG control system. All phase IA tests were conducted within reference 2 limits. Phase IB consisted of tests that varied the magnitude of pitch control margin available at target AOA's of 40 and 50 deg using various CG positions (22.5 - 26.5 %MAC). Phase IB tests were conducted outside of reference 2 limits as authorized by reference 4. All tests were conducted in the cruise configuration as defined by gear up, flaps AUTO, speedbrake retracted, and thrust as required to maintain test conditions. All tests were conducted in the clean loading as defined by no stores or pylons on any loading stations.

Method of Tests

All test maneuvers consisted of symmetrical, stabilized 1g trim pushovers and were conducted from various AOA's and CG's at an initial pitch attitude of 15 degrees (see figure 5). The tests were not conducted "blind" (i.e. pilot knew aircraft CG position for safety of flight purposes). Test maneuvers were flown in the NAWC-AD local North and South "Spin" areas during daylight visual meteorological conditions. All flights were flown with a safety chase. Telemetry data were transmitted via pulse code modulation received at 20 samples per second to RTPS where NAWC-AD engineers directed and monitored the tests.

RESULTS AND DISCUSSION

Figures of Merit

The development of quantitative nose-down pitch control margin guidelines required the establishment of figures of merit to be used in evaluating recovery characteristics. A large number of candidate figures of merit were considered during the Navy / NASA LaRC simulation studies. The key to establishing their importance with respect to control margin was to chronologically order the parameters relative to initiation of recovery controls (see figure 6). In figure 6, as one progresses from short to long on the time scale, the figure of merit correlation with control margin decreases. It was the purpose of flight test to validate simulation-based figures of merit which most strongly correlated with pilot pitch recovery ratings. It should be noted that in addition to these figures of merit, a multitude of others exist, of which are beyond the scope of this evaluation. During simulation, angle of attack figures of merit ($AOAdot_{\Delta t}$ and $\Delta AOA_{\Delta t}$) and the pitch attitude figure of merit, $\Delta Q_{\Delta t}$, were poor correlators because the evaluation pilots tended to rely more on out-of-the-cockpit, visual cues (i.e. pitch accelerations and rates) during the recoveries vice looking for changes in AOA and pitch attitude readings within a certain period of time. The two figures of merit, $\Delta V_{\Delta t}$ and Δh_{rec}, were also poor correlators because they tended to be based more on airframe performance than control power. The remaining figures of merit, qdot, $q_{\Delta t}$ and Trec were subsequently chosen as candidate figures of merit.

During the NASA LaRC simulation studies, it was determined by the evaluation pilots that pitch acceleration was the most strongly perceived nose-down response cue. In the absence of significant angular rates, pitch acceleration is strongly related to an aircraft's pitch control power due to the direct proportionality to static pitching moment (equation (1)),

$$qdot = \frac{Cm * (qbar*S*cbar)}{Iyy} \qquad (1)$$

Since pitch acceleration was one of the first parameters perceived by the pilots during a pushover recovery from high AOA (within the first second of the recovery), it was considered as the most important figure of merit when attempting to quantify longitudinal control margin requirements. During the simulation studies pitch acceleration was found to correlate best with pilot rating in the form of maximum pitch acceleration within one second from recovery input (Qdot (max ≤1sec)). Pilot comments also indicated that in addition to initial pitch acceleration, pitch rate around two seconds from recovery input was also used in the pitch recovery rating process. Simulation results showed that pitch rate was found to best correlate with pilot rating in the form of pitch rate at two seconds from recovery input (Q (at 2 sec)). The simulation studies defined Trec as the time to reduce AOA to less than 10 degrees (Trec) because for typical tactical aircraft, this marks the central region of the low AOA operational envelope.

Maximum Pitch Acceleration within one from Recovery Input (Qdot (max ≤1 sec))

Flight test matched simulation well only at lower pilot ratings (≤ 3) (see figures 7 and 8). Higher pilot ratings exhibited significant flight test to simulation divergence. These differences can be explained by pitch acceleration nonlinearities produced due to the flight control system, aerodynamic effects, motion cue effects, and approximations in the high AOA aerodynamic simulation model. These nonlinearities explain differences observed between flight test and parametric simulation results because as a result of modifying the simulation as presented in reference 4, flight control logic and modelled aerodynamics were fixed such that nosedown recoveries exhibited "ideal" (no reversal) linear pitch acceleration responses. When rating the flight test maneuvers, evaluation pilots observed the nonlinear tendencies as undesirable rate hesitation, producing higher pilot ratings as a result. Differences between the baseline F/A-18 simulation and flight test are primarily due to motion cue effects and approximations in the high AOA aerodynamic simulation model. Pilot comments indicated motion cues were very important when assessing immediate pitch response inflight. Through motion cues, degraded pitch responses were more evident and made the evaluation pilots more critical of desired response than in the simulator where nosedown response cockpit cues were limited to the HUD and dome visuals. It should be noted that the evaluation pilots knew aircraft CG due to safety of flight purposes and thus had an idea of upcoming aircraft nose-down response tendency. In conclusion, Qdot (max ≤1 sec) was found to have good correlation between simulation and flight test at lower pilot ratings (≤ 3) where flight test maneuvers exhibited "ideal" simulation cases via linear pitch acceleration response. Increasing aft CG resulted in increasing pitch acceleration nonlinearities which contributed to flight test data divergence from predicated simulation pilot rating trends. Motion cue effects became apparent at the higher pilot ratings where increased pilot sensitivity to degraded pitch responses resulted in more critical ratings than compared to simulation.

Pitch Rate At Two Seconds From Recovery Input (Q (at 2 sec))

Variations of pitch rate with pilot rating and CG position are shown in figures 9 and 10. Pilot A nose-down pitch rates tended to be higher than Pilot B values at essentially the same CG's (gross weights) because of differences in dynamic pressure where stabilized pushovers were conducted at lower altitudes. Q (at 2 sec) flight test agrees with predicted simulation pilot rating trends only at lower pilot ratings (≤ 3). A more aft CG decreases the static pitching moment. However in the F/A-18, pitch rate response remained essentially invariant due to the effects of AOA and pitch rate feedback in the flight control system. This flight control system effect can be observed in figure 11 in which for the full forward stick recoveries stabilator saturation duration time is varied as a function of CG. In conclusion, Q (at 2 sec) was found to have good correlation between simulation and flight test at lower pilot ratings (≤ 3). The fact that flight test values of Q (at 2 sec) were essentially constant for pilot ratings from 2 to 4.5 indicates that (1) pitch rate effects were secondary in determining overall response rating and / or (2) pitch rate in the form of Q (at 2 sec) is not the best correlating case.

Time To Recover (Trec)

The variations of Trec with pilot rating are shown in figures 12 and 13. Pilot comments indicated that Trec was never strongly perceived during the pushovers. When comparing flight test results to simulation data, Trec matched fairly well; in both cases it was characterized by essentially negligible variations with pilot rating except in extremely degraded response (high AOA hangup-type) cases which were only investigated during simulation for safety of flight purposes. Essentially constant Trec up until the very high pilot ratings (4.5 to 5) indicates that it is more long term, hang-up response related, in contrast to pitch acceleration and rate which are short term, normal recovery related. In conclusion, Trec was found to have good correlation between simulation and flight test in that minimal variation of this figure of merit was observed during flight tests at low to high pilot ratings (2 to 4).

Other Pitch Acceleration Figures Of Merit

General

Figures 7 and 8 indicate small variation of flight test Qdot (max ≤1 sec) with pilot rating. However, figure 14 shows significant variation of pilot rating with CG. This clearly indicates that the pitch acceleration figure of merit is somewhat weak in not accounting for the nonlinear responses as discussed previously. The pilot is obviously seeing degradation in pitch response, but this effect is not being reflected by Qdot (max ≤1 sec). It should be emphasized that during flight tests, the evaluation pilots knew aircraft CG and thus were better able to predict stabilized pushover response trends. In an effort to correlate data more closely, two other pitch acceleration figure of merit forms were investigated. One form was pitch acceleration at one second from recovery input (Qdot (at 1 sec)) and the other was average pitch acceleration within one second from recovery input (Qdot (avg ≤1 sec)).

Pitch Acceleration At One Second From Recovery Input (Qdot (at 1 sec))

Variation of Qdot (at 1 sec) with pilot rating is presented in figures 15 and 16. Qdot (at 1 sec) flight test values tended to match the simulation better at higher pilot ratings for each evaluation pilot than those observed with Qdot (max ≤1 sec). This improved match supports the argument that the evaluation pilots referred to the pitch acceleration nonlinearities when determining final ratings. However, the degree of Qdot (at 1 sec) data scatter per pilot rating was larger than those observed with qdot (max ≤1 sec). The fact that there exists a larger amount of vertical data scatter (both in the case of simulation and flight test) indicates that evaluation pilots did not rate the response by solely using qdot (at 1 sec) in their overall assessments and this figure of merit is not very consistent. In conclusion, Qdot (at 1 sec) flight test values were found to correlate better with simulation at higher pilot ratings; however, excessive vertical data scatter per rating indicates that this figure of merit is not very strong.

Average Pitch Acceleration Within One Second From Recovery Input (Qdot (avg ≤1 sec))

Variation in Qdot (avg ≤1 sec) with pilot rating is shown in figures 17 and 18. Qdot (avg ≤1 sec) flight test and simulation values exhibited considerably reduced vertical data scatter; however, the magnitude of the gradient with respect to pilot rating is small and some flight test to simulation data divergence is apparent at the higher pilot ratings (≥ 4). Differences in data can be explained by considering that the previously discussed pitch acceleration nonlinearities are being averaged into this figure of merit. In conclusion, Qdot (avg ≤1 sec) was found to have low vertical data scatter per pilot rating; however, it is a poor figure of merit considering that overall variation with pilot rating was small.

Workload Required For Test Maneuver Stabilization

The maneuver test method required that evaluation pilots vary thrust to stabilize at a constant pitch attitude. During flight test it was found that establishing required test conditions using this method was very difficult since the pilot had to "close-the-loop" on trim airspeed with throttles to keep flight path angle rate zero. Pilot B commented that "airspeed control through throttle adjustments was difficult due to large ~15 KCAS airspeed jumps and strong airspeed sensitivity to thrust"; he further stated that "this effort distracted attention from the initial portion of the pushover and may have affected pilot ratings. In simulation, entry conditions were automatic and effortless so all attention was focused on the pushover".

Since the NASA LaRC simulation studies, as documented in reference 3, indicated that initial pitch attitude had a negligible effect on pilot ratings, an alternative approach would be to hold constant thrust and vary pitch attitude to stabilize. Using this approach, the maneuver set-up may be easier with reduced pilot workload and could result in more repeatable results. During flight tests, a stabilized pushover was conducted within reference 3 limits in this manner to compare pilot workload. When approaching a stabilized pushover at constant pitch attitude, significant pilot workload was evident from continuous throttle inputs made while decelerating from 35 deg AOA to the target 50 deg AOA condition. As AOA continuously increased during the deceleration, increased thrust inputs were required to maintain zero flight path angle rate. In addition to the various throttle inputs, continuous longitudinal stick inputs were required to hold the target pitch attitude at 15 deg. When conducting the maneuver at a constant thrust setting (MIL power), however, pilot workload was reduced from two (longitudinal stick and throttles) to one (longitudinal stick) input controllers. During the start of the deceleration, the pilot simply pulled to 35 deg pitch attitude, set thrust to MIL and progressively pulled aft stick to increase AOA, sacrificing pitch attitude in the process of maintaining a stabilized condition with zero flight path angle rate.

Pitch Recovery Rating Scale Improvements

Flight tests showed that improvements for the pitch recovery rating scale should be considered. The first weak area found was mission task ambiguity. Using the PRR scale, as defined from the simulation studies, required that each evaluation pilot generate his own mission scenario to rate the quality of pushovers when recovering from high AOA. Pilot A used: "vertical fight, coming uphill offensively, realizing late that I don't have enough energy to make it over the top, and unloading with full forward stick to gain energy as a bogey moves into a position of advantage." Pilot B used: "pushover from a nose high attitude to point towards a bogey below". Pilots A and B were clearly rating the maneuvers from different mission viewpoints. A more objective scenario should be used in which pilot ratings use a more standardized mission environment. Another weak area found by the evaluation pilots was that the decision trees used in the PRR scale were too ambiguous. The reference 3 proposed PRR scale revisions (shown in figure 19) more clearly define the decision factors involved, particularly with respect to adequacy of safety and a tactically desirable response. Since the prime area of interest in the PRR scale when establishing specification requirements is in the 4 to 5 rating region, this area needs to be expanded to more clearly define the boundary between an undoubtful and doubtful recovery. The reference 5 proposed PRR scale revisions (shown in figure 20) expand this critical area. In conclusion, the PRR scale as defined from the initial simulation studies was found to be weak in not defining a standardized mission scenario, using ambiguous decision tree factors to obtain ratings, and not clearly delineating the definition of an undoubtful versus doubtful recovery.

CONCLUDING REMARKS

Results of the Navy / NASA LaRC pitch control margin simulation studies were validated in that pilot cueing (rating) of high AOA nose-down recoveries during flight test was based on the short-term response in the forms of pitch acceleration and rate figures of merit. The final figures of merit forms to quantify high AOA pitch control margin requirements, however, are yet to be determined. Flight test proved that high AOA pitch control margin can be demonstrated using a stabilized pushover method; however, improvements in method technique are warranted. Once modifications are completed, the pitch recovery rating scale will be a vital tool in quantifying desired pitch control margin during future simulation and follow-on flight test evaluations.

Specific conclusions established during the tests were as follows:

a. Qdot (max ≤1 sec) was found to have good correlation between simulation and flight test at lower pilot ratings (≤ 3) where flight test maneuvers exhibited "ideal" simulation cases via linear pitch acceleration response. Increasing aft CG resulted in increasing pitch acceleration nonlinearities which contributed to flight test data divergence from predicated simulation pilot rating trends. Motion cue effects became apparent at the higher pilot ratings where increased pilot sensitivity to degraded pitch responses resulted in more critical ratings compared to simulation.

b. Q (at 2 sec) was found to have good correlation between simulation and flight test at lower pilot ratings (≤ 3). The fact that flight test values of Q (at 2 sec) were essentially constant for pilot ratings from 2 to 4.5 indicates that (1) pitch rate effects were secondary in determining overall response rating and / or (2) pitch rate in the form of Q (at 2 sec) is not the best correlating case.

c. Trec was found to have good correlation between simulation and flight test in that minimal variation of this figure of merit was observed during flight tests at low to high pilot ratings (2 to 4).

d. Qdot (at 1 sec) flight test values were found to correlate better with simulation at higher pilot ratings; however, excessive vertical data scatter per rating indicates that this figure of merit is not very consistent.

e. Qdot (avg ≤1 sec) was found to have low vertical data scatter per pilot rating; however, it is a poor figure of merit considering that overall variation with pilot rating was small.

f. The PRR scale as defined from the initial simulation studies was found to be weak in not defining a standardized mission scenario, using ambiguous decision tree factors to obtain ratings, and not clearly delineating the definition of an undoubtful versus doubtful recovery.

Specific recommendations established during the tests were as follows:

a. Recommended that further flight tests be conducted using a constant thrust, varying pitch attitude stabilized pushover technique to determine the degree of difficulty to conduct such a maneuver and define the effects of varying initial pitch attitude on pilot ratings.

b. Recommend that a standardized mission scenario be adopted for the PRR scale, the scale be restructured with the reference 3 decision tree revision recommendations, and that the scale be expanded in the 4 to 5 rating region per the reference 5 proposal.

c. Recommend further simulation and flight test studies be conducted to determine a pitch acceleration figure of merit which will better account for a wide range of pitch response conditions in a consistent manner.

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2. NATOPS Flight Manual Navy Model F/A-18A/B/C/D, A1-F18AC-NFM-000, 15 January 1991.

3. NAVAIRWARCENAIRDIV Tech Memo, SA-167R-91, McNamara W.G., et al; Navy High Angle Of Attack Pitch Control Margin Requirements for Class IV Aircraft, April 1992.

4. NAVAIRSYSCOM msg dtg 211736Z November 1990.

5. Hadfield, C., High Angle of Attack Handling Qualities Rating Scales, Thesis presentation for Master of Science degree from University of Tennessee, Knoxville Tennessee, May 1992.

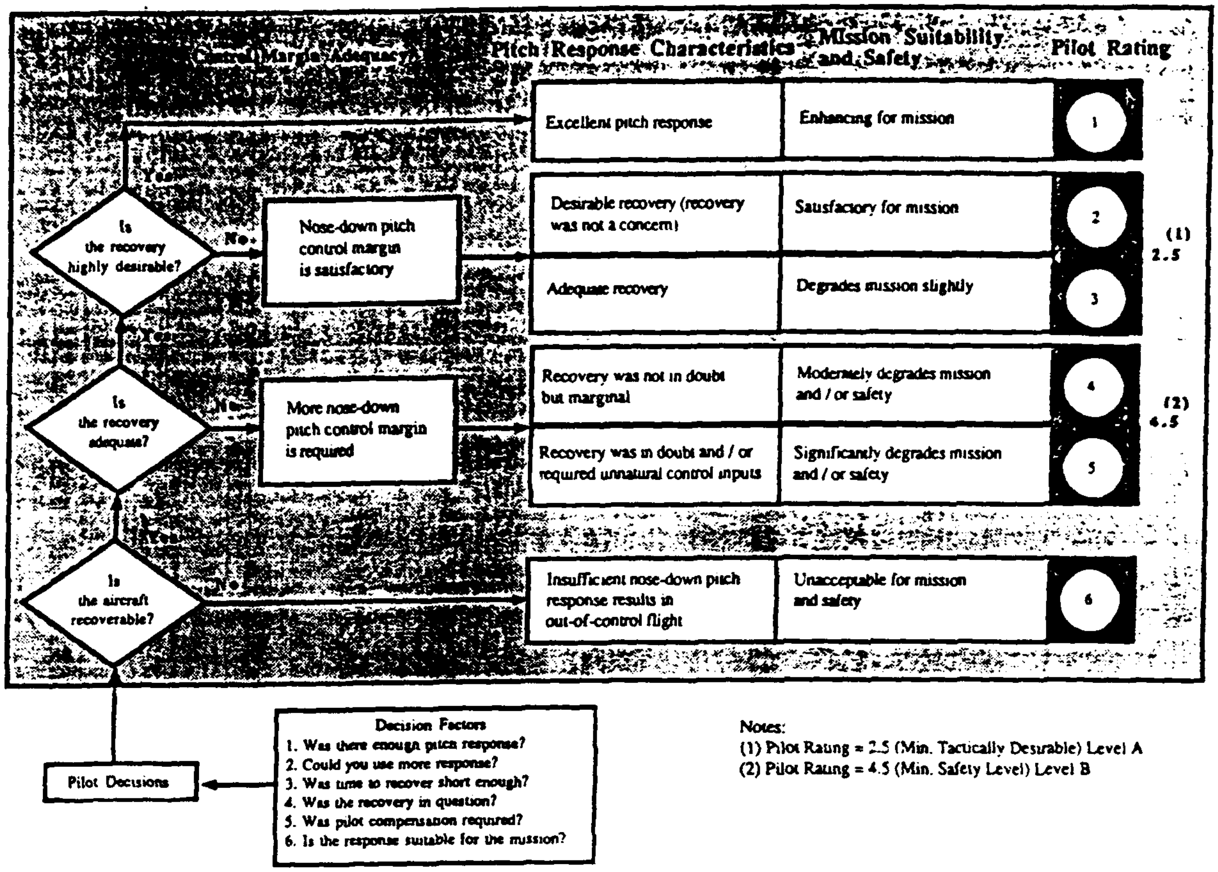


Figure 1 - Pitch Recovery Rating Scale
(Developed Prior To Simulation Studies)

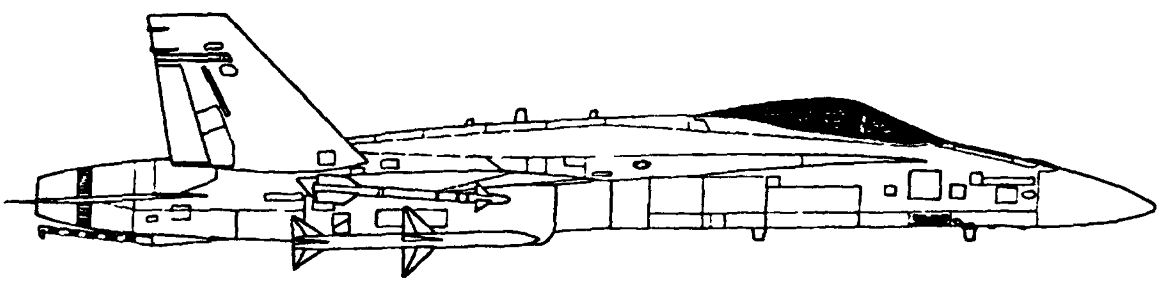


Figure 2 - F/A-18 Hornet

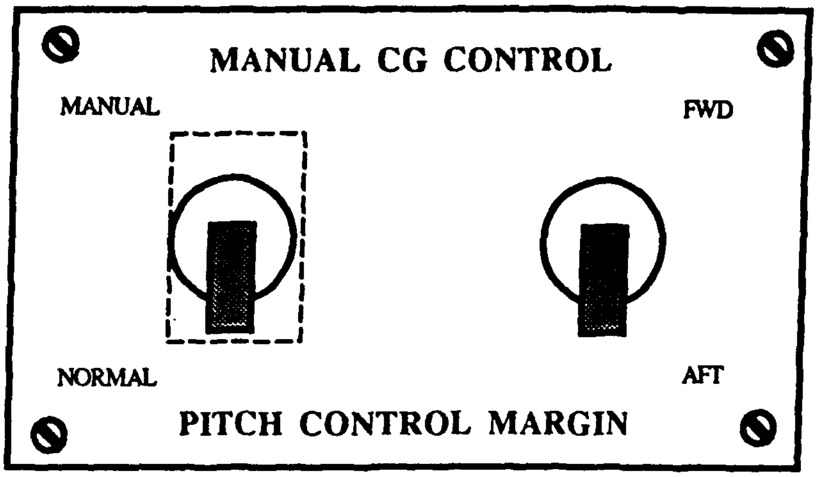


Figure 3 - CG Control System Cockpit Control Panel

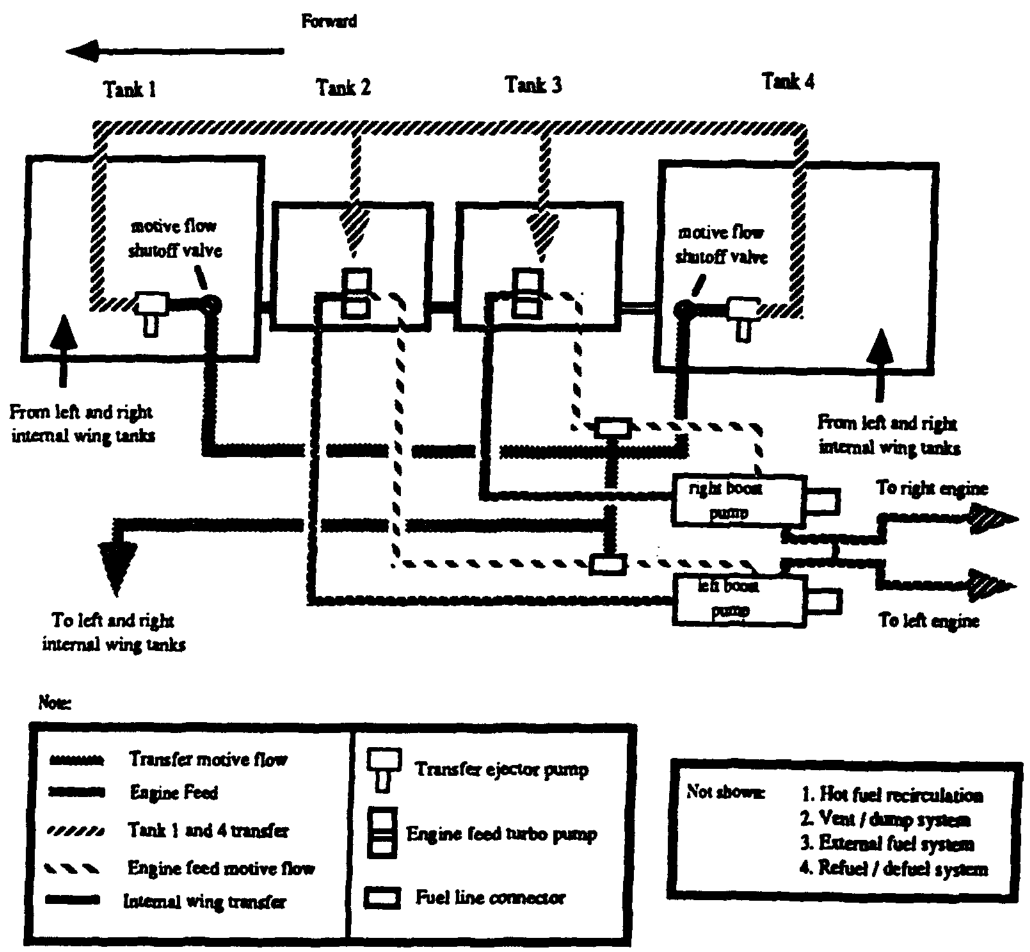


Figure 4 - F/A-18A Fuel System Schematic

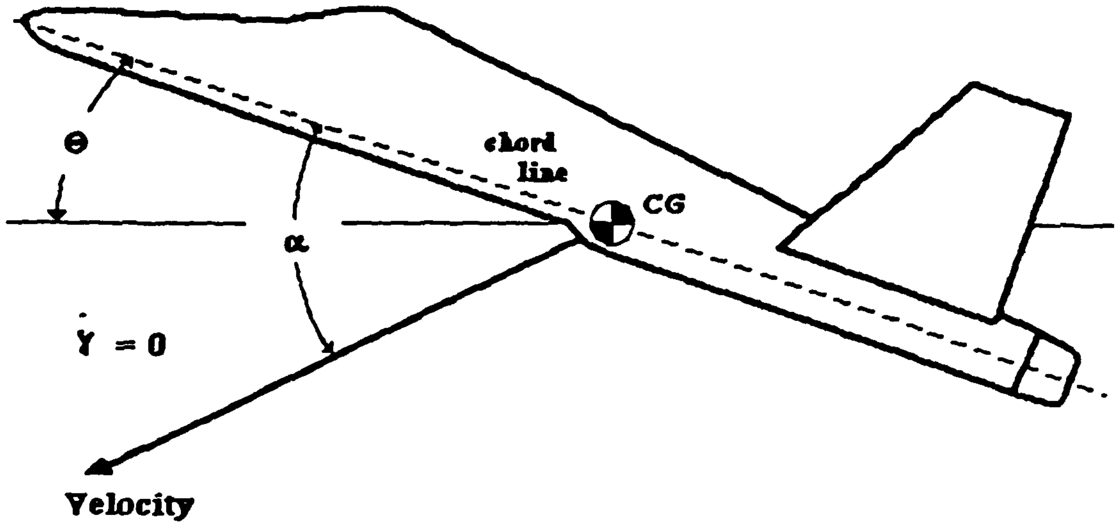


Figure 5 - Stabilized Pushover

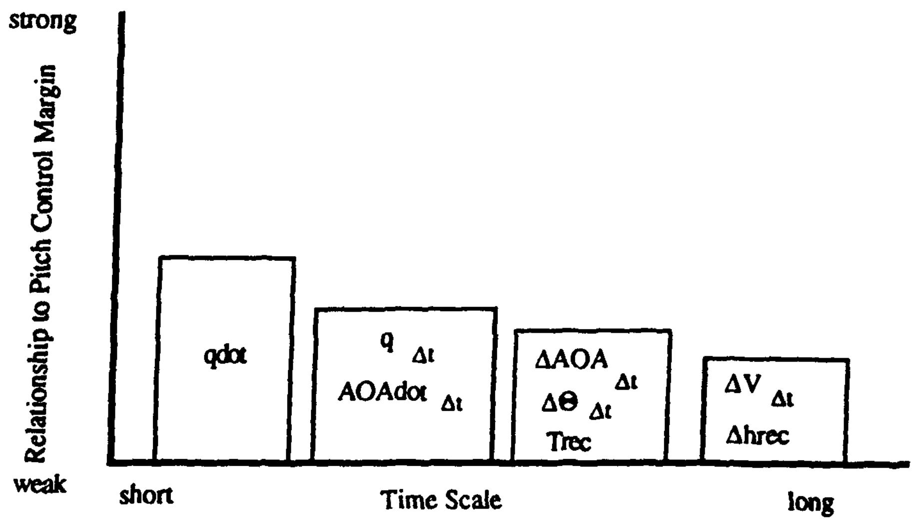


Figure 6 - Figures of Merit

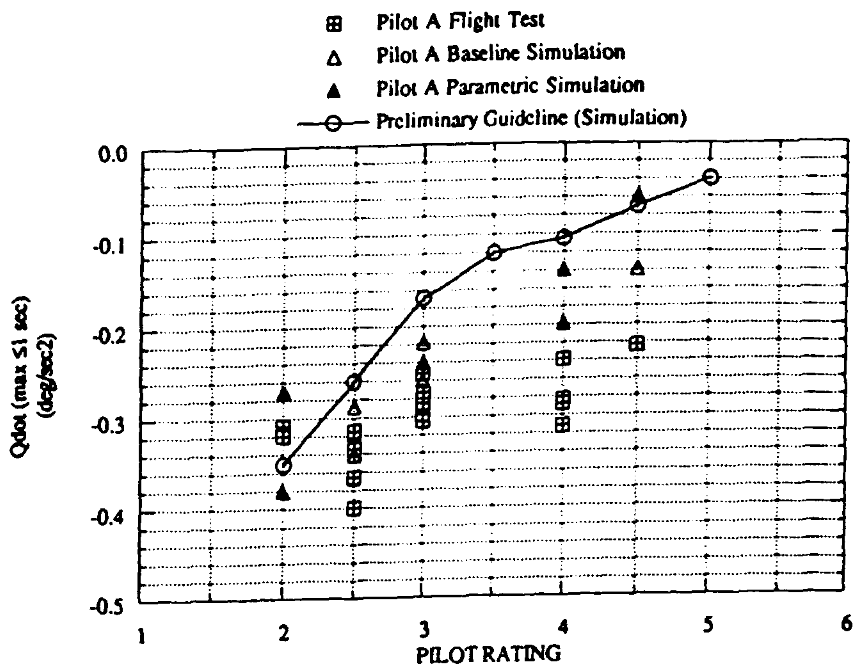


Figure 7 - Qdot (max ≤1 sec) versus Pilot Rating (Pilot A)

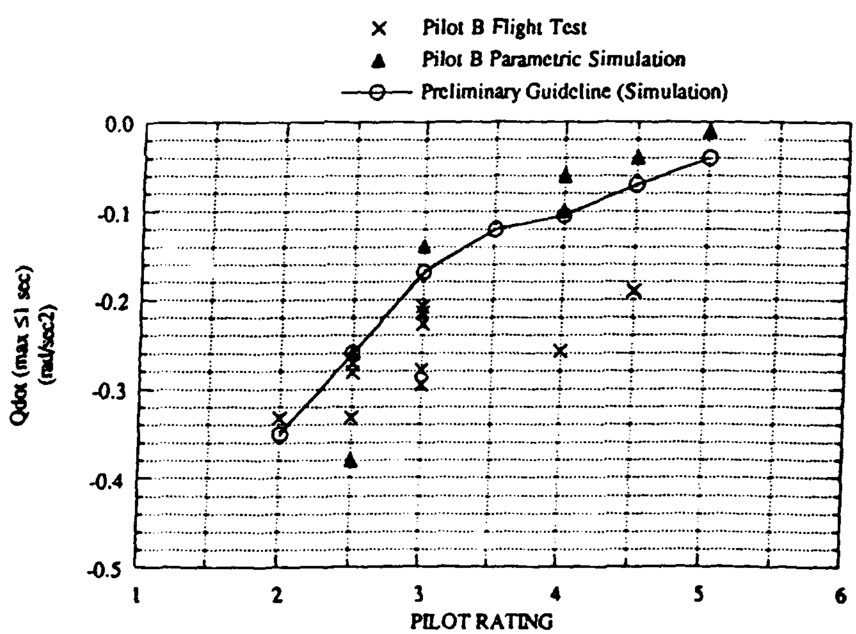


Figure 8 - Qdot (max ≤1 sec) versus Pilot Rating (Pilot B)

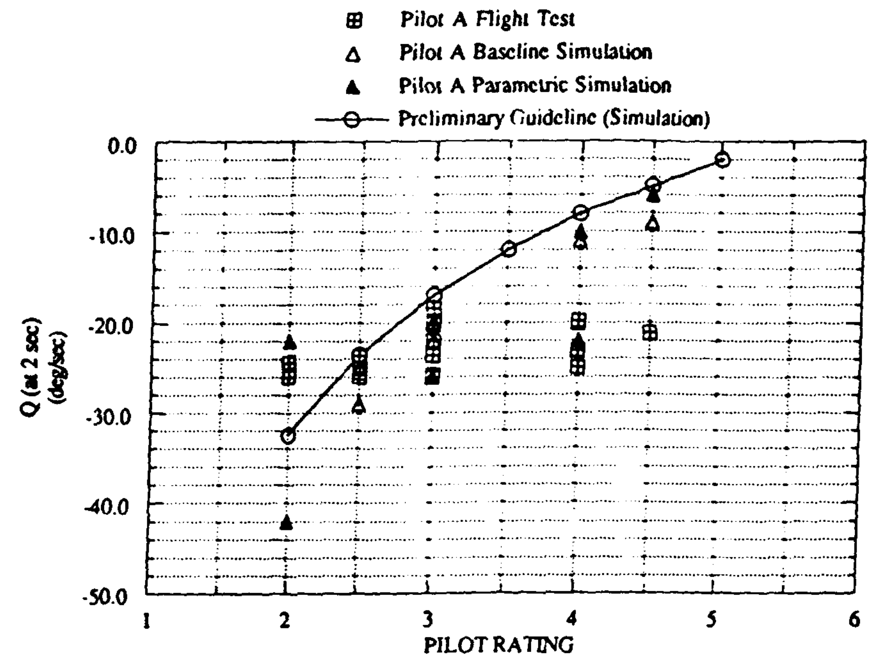


Figure 9 - Q (at 2 sec) versus Pilot Rating (Pilot A)

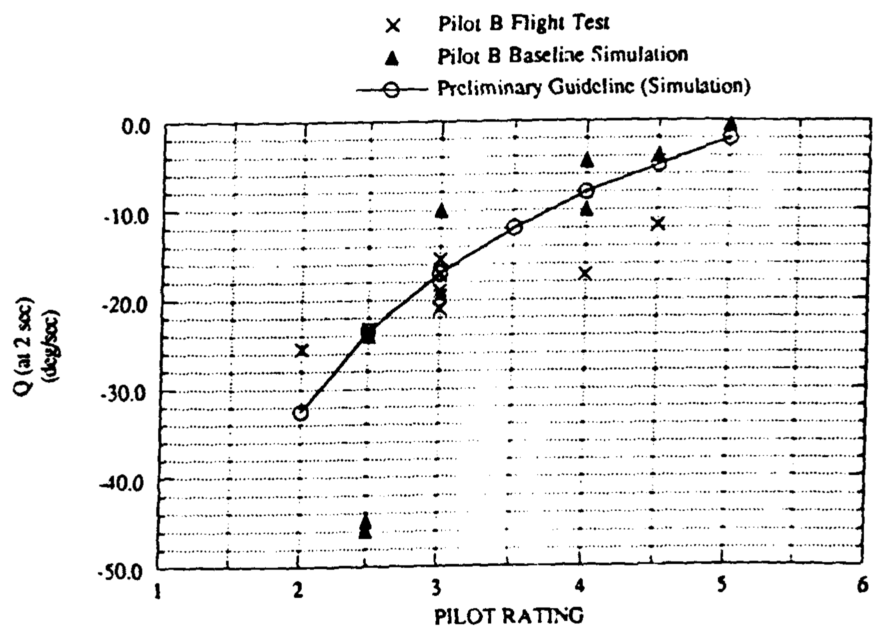


Figure 10 - Q (at 2 sec) versus Pilot Rating (Pilot B)

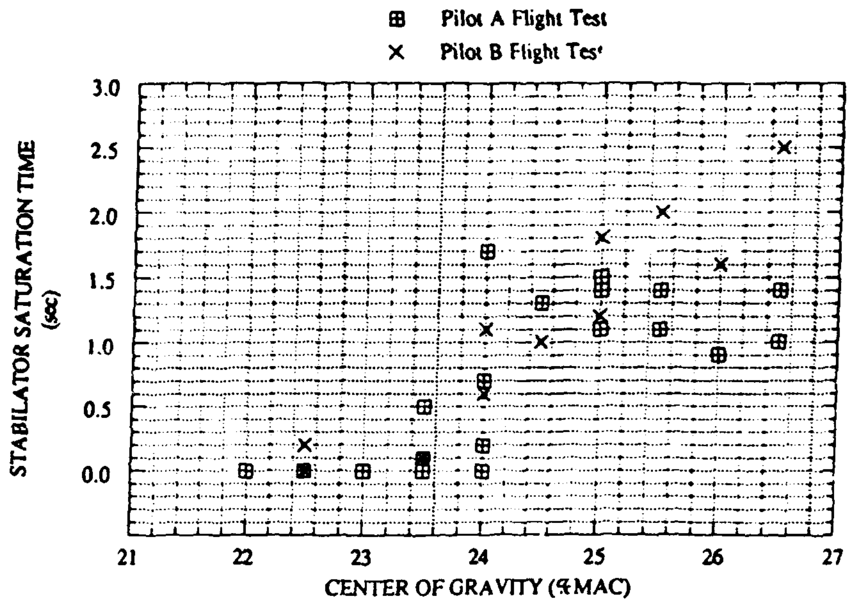


Figure 11 - Stabilator Saturation Time versus CG

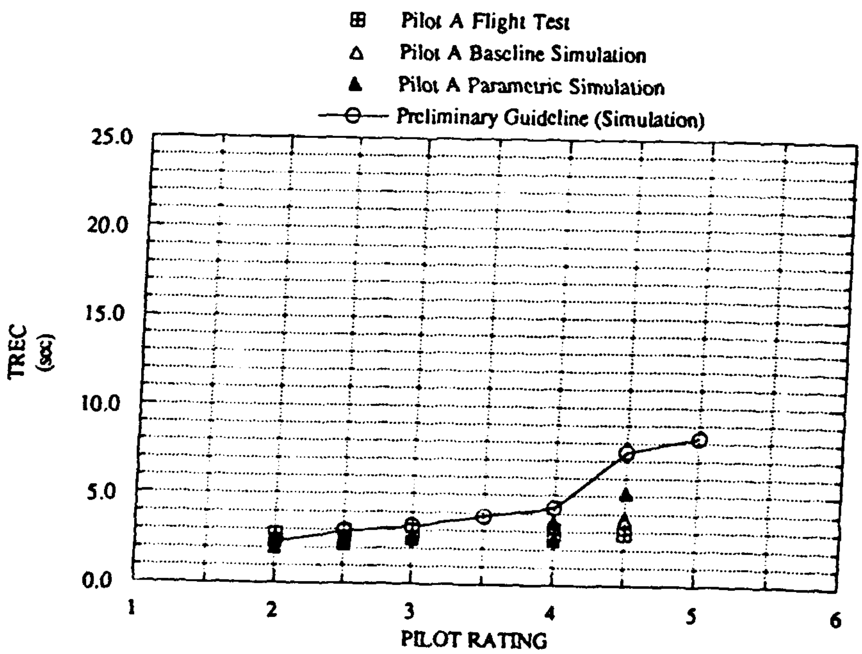


Figure 12 - Trec versus Pilot Rating (Pilot A)

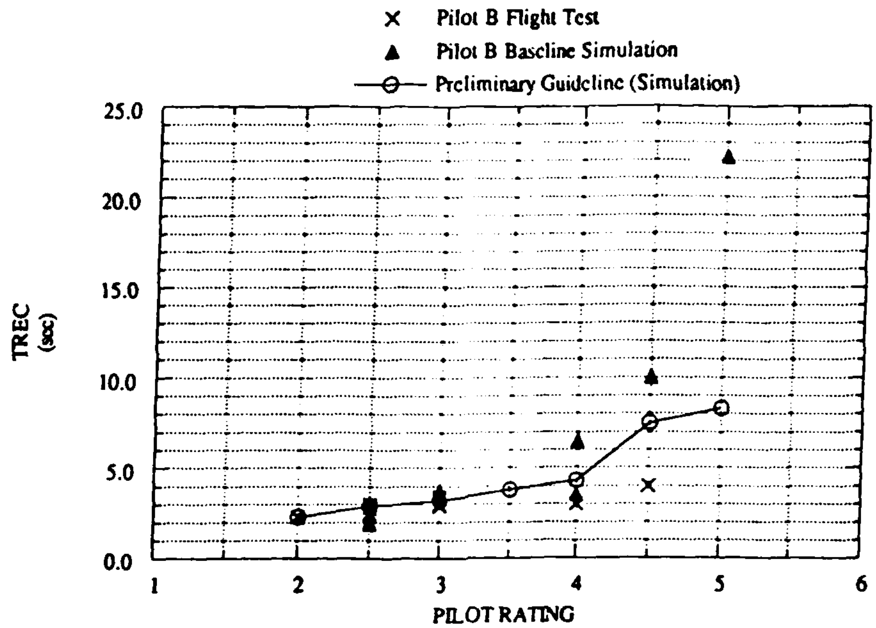


Figure 13 - Trec versus Pilot Rating (Pilot B)

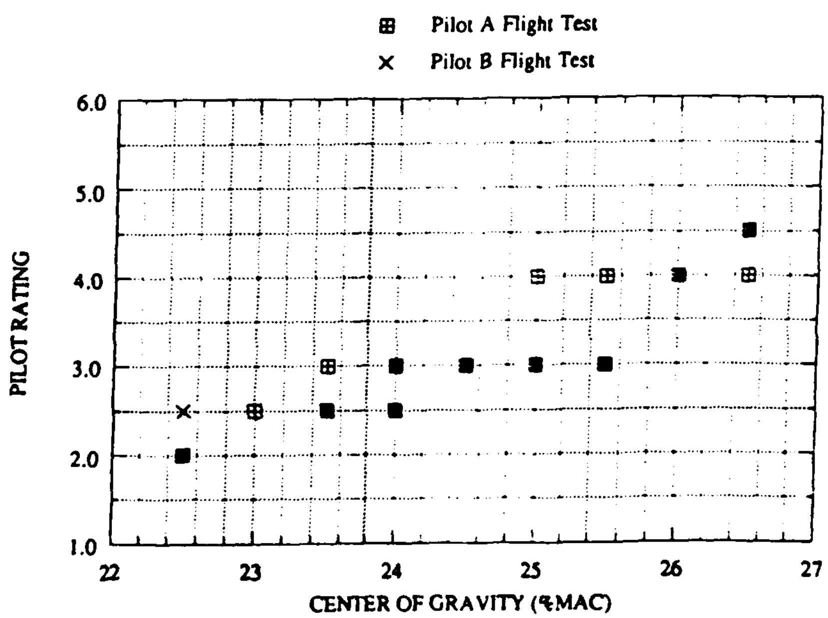


Figure 14 - Pilot Rating versus CG

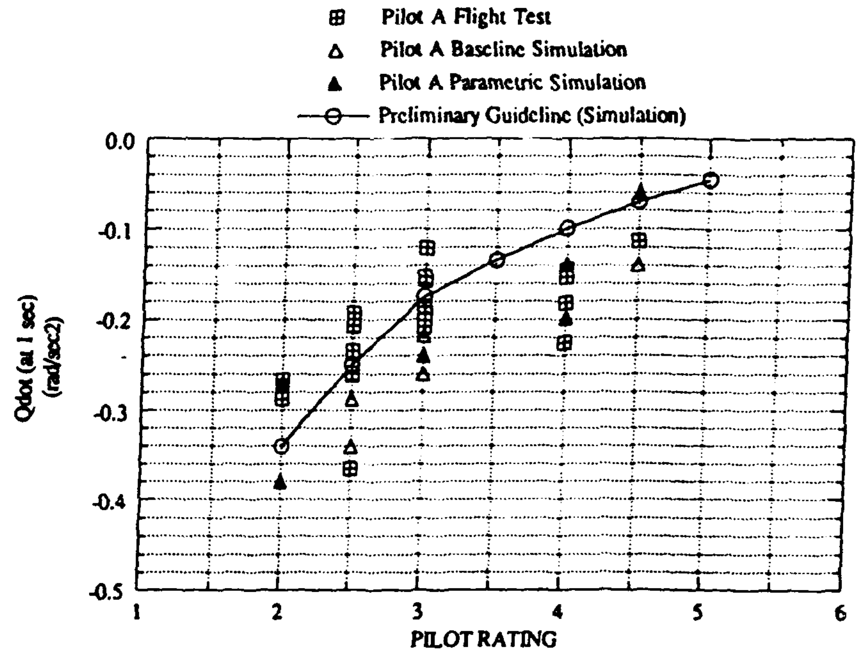


Figure 15 - Qdot (at 1 sec) versus Pilot Rating (Pilot A)

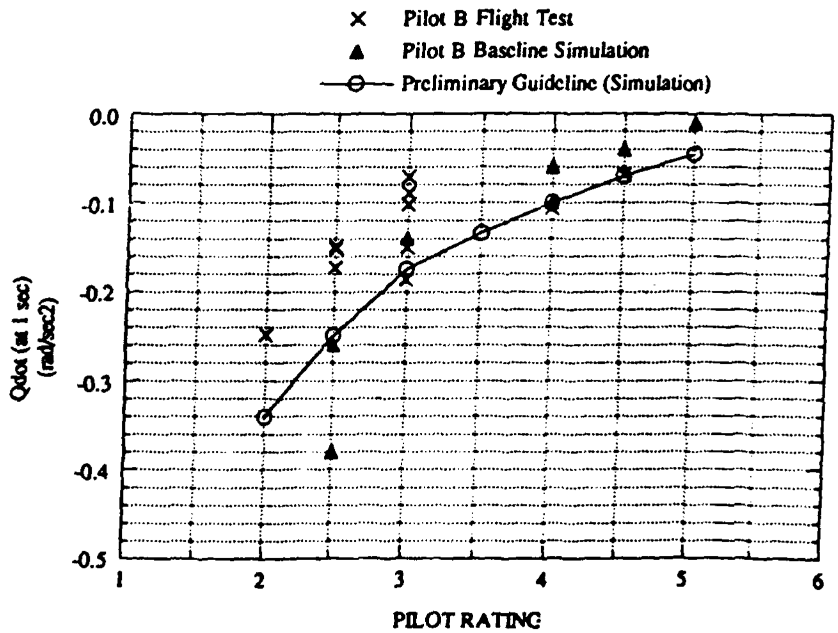


Figure 16 - Qdot (at 1 sec) versus Pilot Rating (Pilot B)

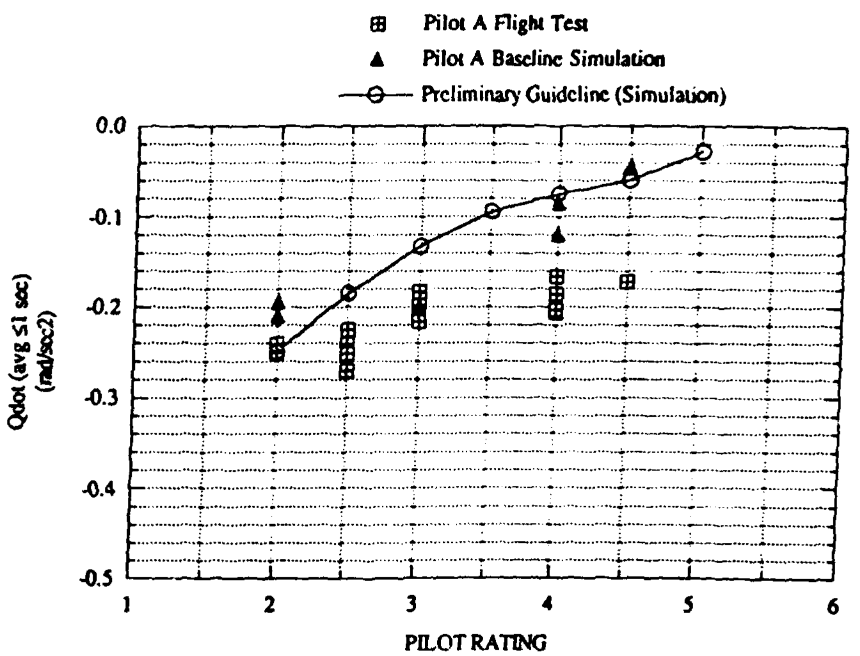


Figure 17 - Qdot (avg ≤1 sec) versus Pilot Rating (Pilot A)

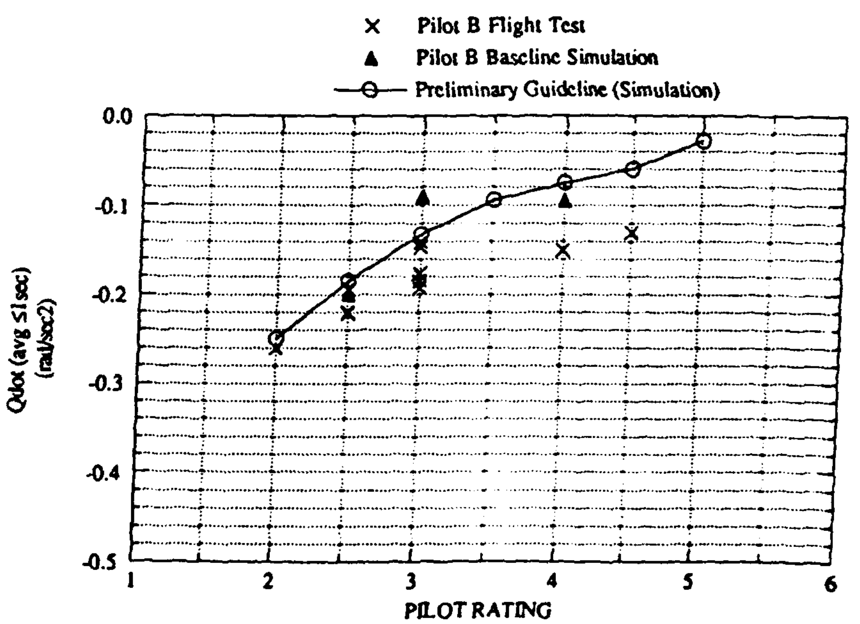


Figure 18 - Qdot (avg ≤1 sec) versus Pilot Rating (Pilot B)

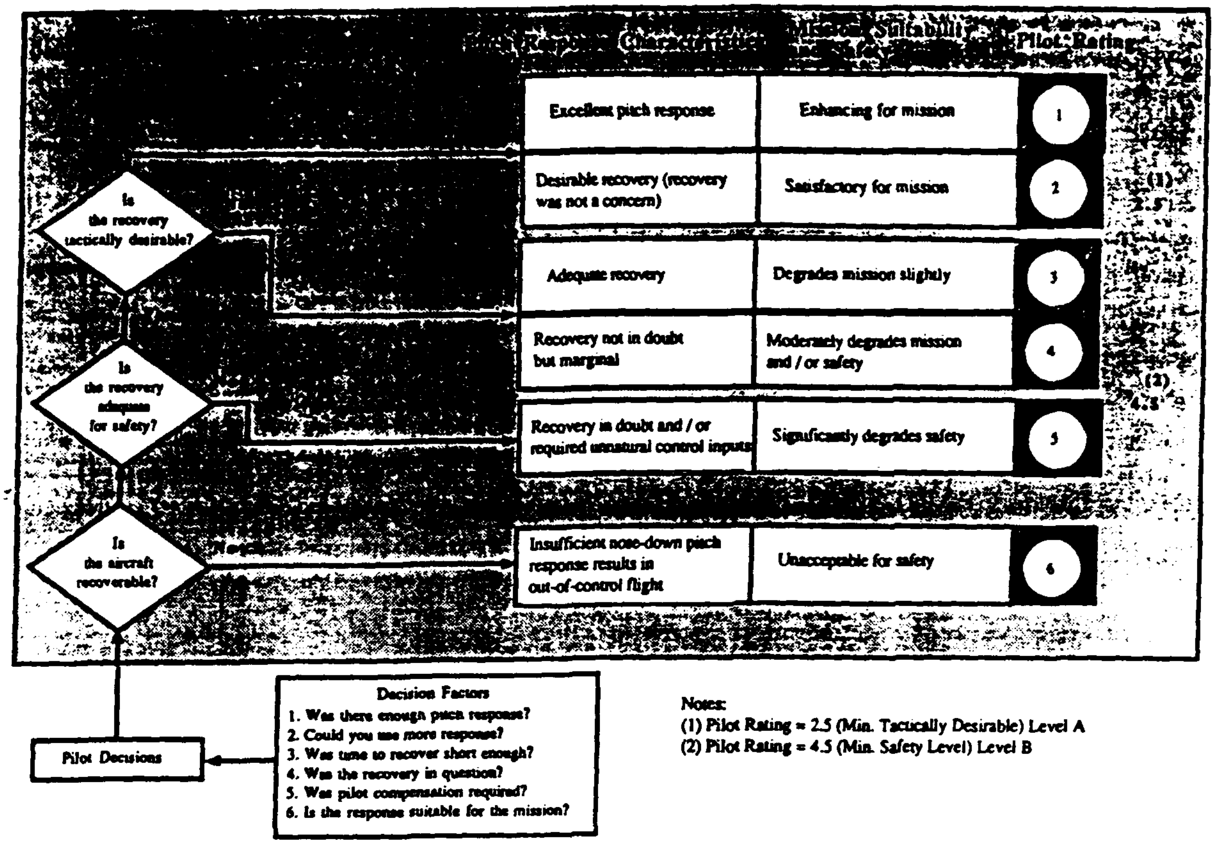


Figure 19 - Revised Pitch Recovery Rating Scale (Developed After Simulation Tests Completed)

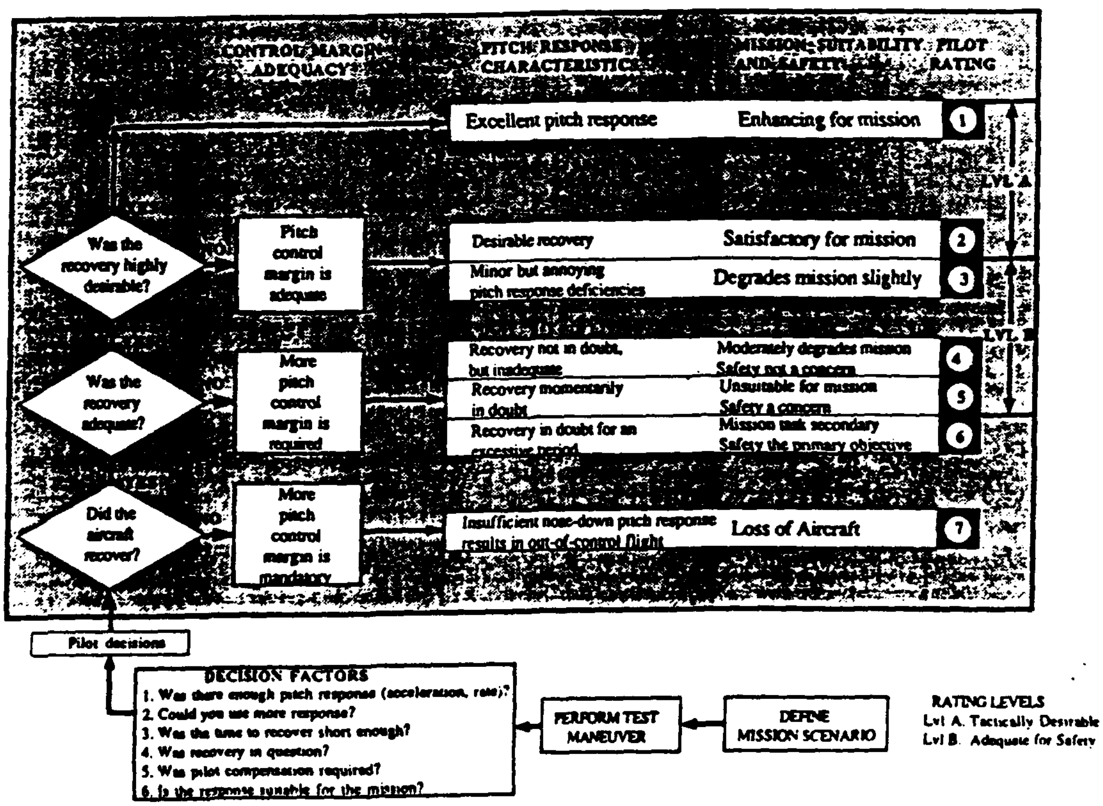


Figure 20 - Revised Pitch Recovery Rating Scale (Developed After Flight Tests Completed)

PITCH CONTROL MARGIN AT HIGH ANGLE OF ATTACK QUANTITATIVE REQUIREMENTS

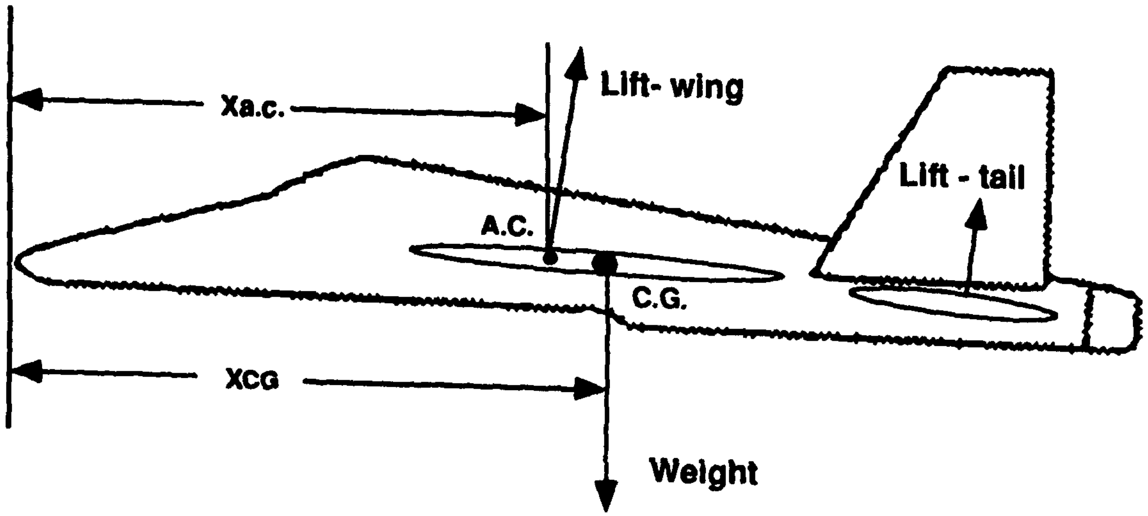
(FLIGHT TEST CORRELATION
WITH SIMULATION PREDICTIONS)

J. LACKEY
Capt. C. HADFIELD (CAF)

Naval Air Warfare Center - Aircraft Division
Patuxent River, Maryland

RELAXED STATIC STABILITY (RSS)

$$\frac{dC_M}{dC_L} = \frac{X_{CG} - X_{AC}}{\bar{c}}$$

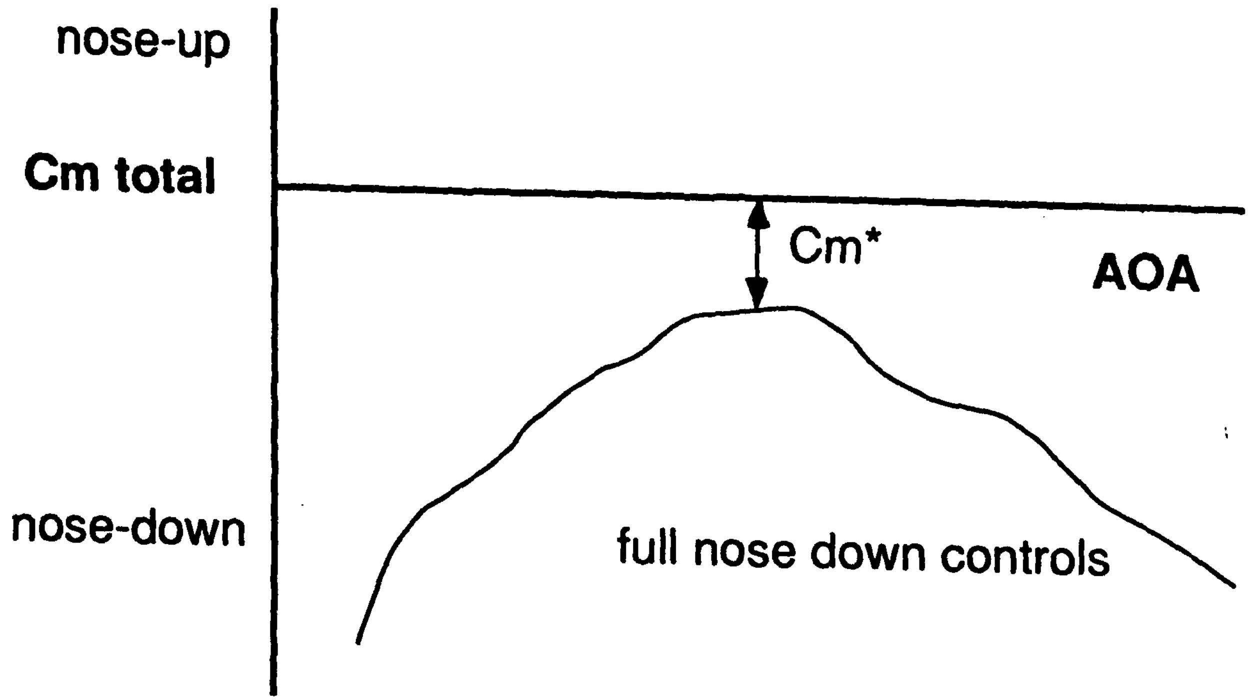


- Requires less downward tail / flap deflection

- **<u>RSS Benefits</u>**
  - Improved "agility" (smaller turn radius at higher rate)
  - Smaller wing (RCS considerations)
  - Reduced carrier approach speed (less wind over deck)
  - Reduced trim drag at supersonic speeds (supercruise)

- **<u>RSS Drawbacks</u>**
  - Complex control system
    - Large actuators (high power consumption)
    - High sensor performance
    - Computer redundancy and increased processing
  - Deep stall or high AOA hangup

RSS DESIGN - Relation to Pitching Moment



- Design must ensure Cm total is adequate to recover from high AOA conditions

How Much Cm* ?

Need to Consider:

- Deep stall recovery
- Inertial Coupling
- Kinematic Coupling
- Aerodynamic Coupling
- Atmospheric Disturbances (gusts)
- etc...

Pitch Control Margin Requirements

- Lack of definitive specification requirement

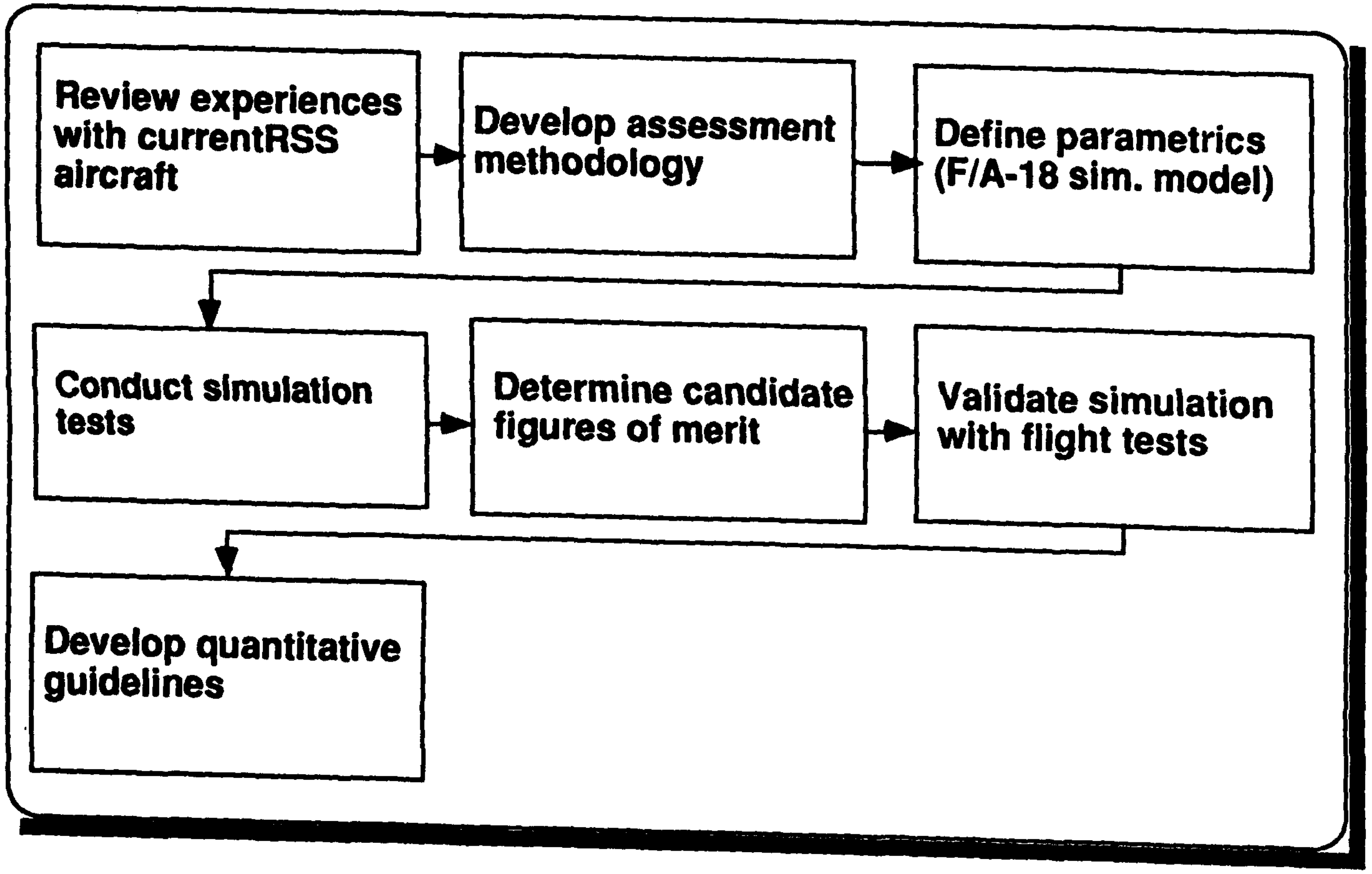
MIL-STD-1797

4.1.11.5 - Control Margin

" Aerodynamic control power, control surface rate and hinge moment capability shall be sufficient to assure safety throughout the combined range of all attainable angles of attack (both positive and negative) and sideslip."

Establishing Quantitative Requirements

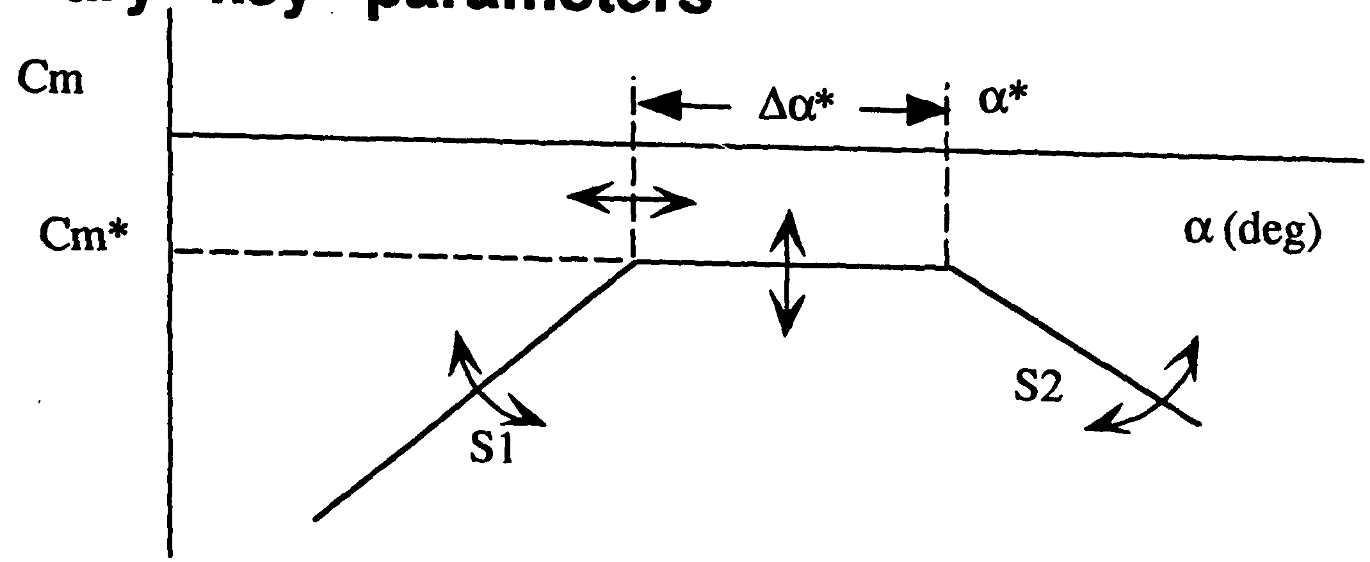
Program Approach:



SIMULATION TESTS - NASA Langley Research Center

- Baseline F/A-18 (Test Methodology)
  - vary pitch response via CG location

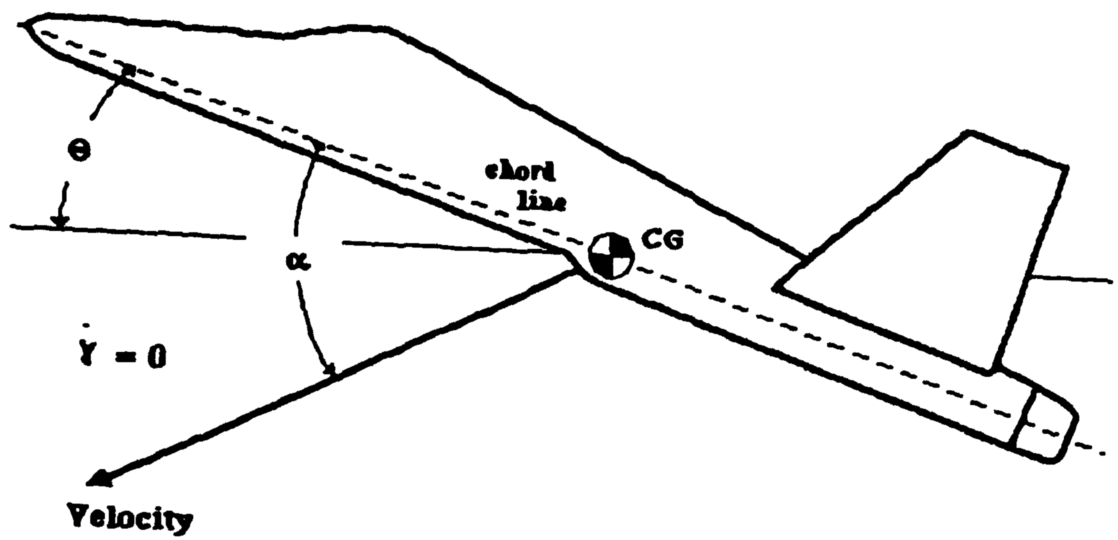
- Parametric Study
  - vary "key" parameters



SIMULATION TESTS - NASA Langley Research Center

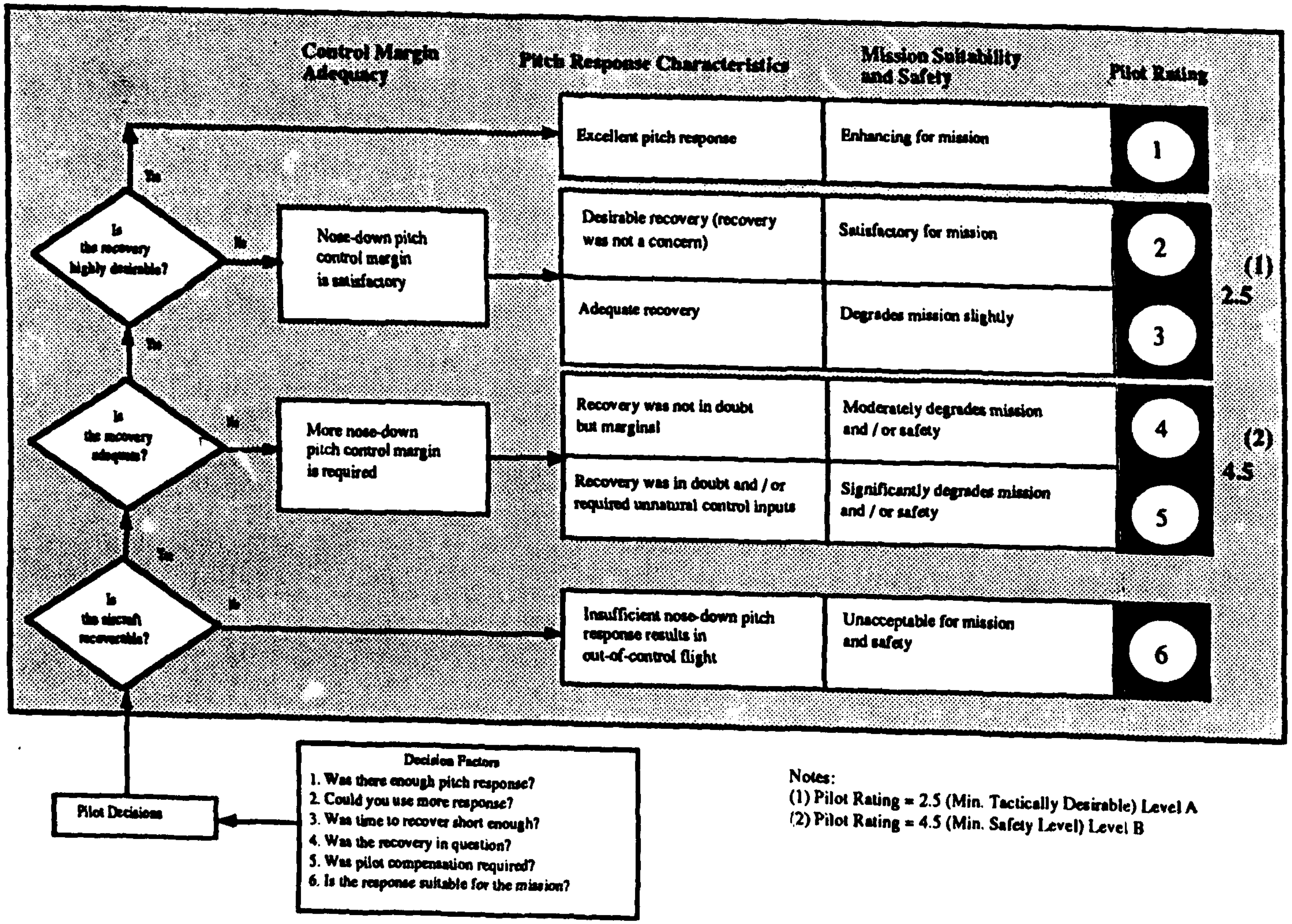
- Demonstrating Pitch Control Margin

  Stabilized Pushover



SIMULATION TESTS - NASA Langley Research Center

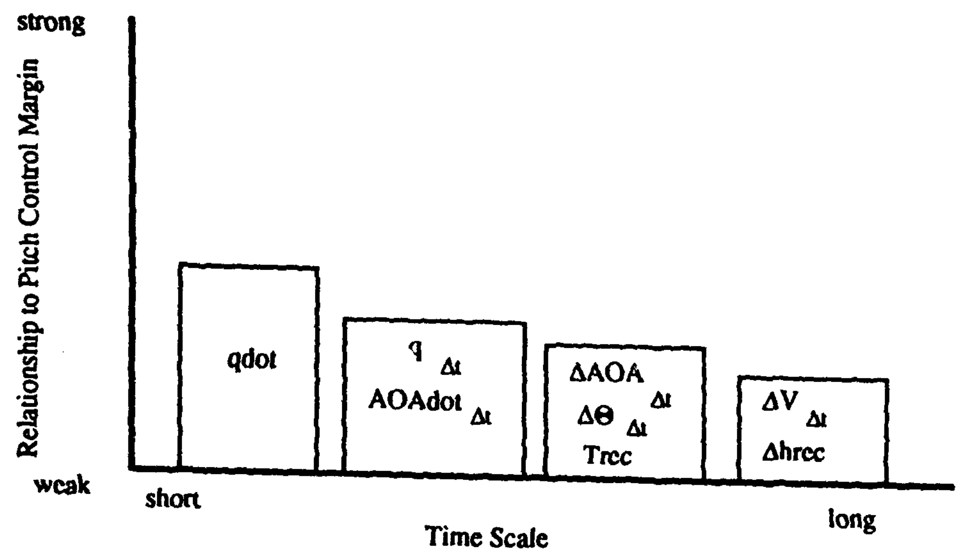
- Pitch Recovery Rating Scale



Notes:
(1) Pilot Rating = 2.5 (Min. Tactically Desirable) Level A
(2) Pilot Rating = 4.5 (Min. Safety Level) Level B

SIMULATION TESTS - NASA Langley Research Center

- Figures of Merit



- Maximum pitch acceleration (≤1 sec) from recovery input
- Pitch rate (at 2 sec) from recovery input
- Time to recover (<10 deg AOA) from recovery input

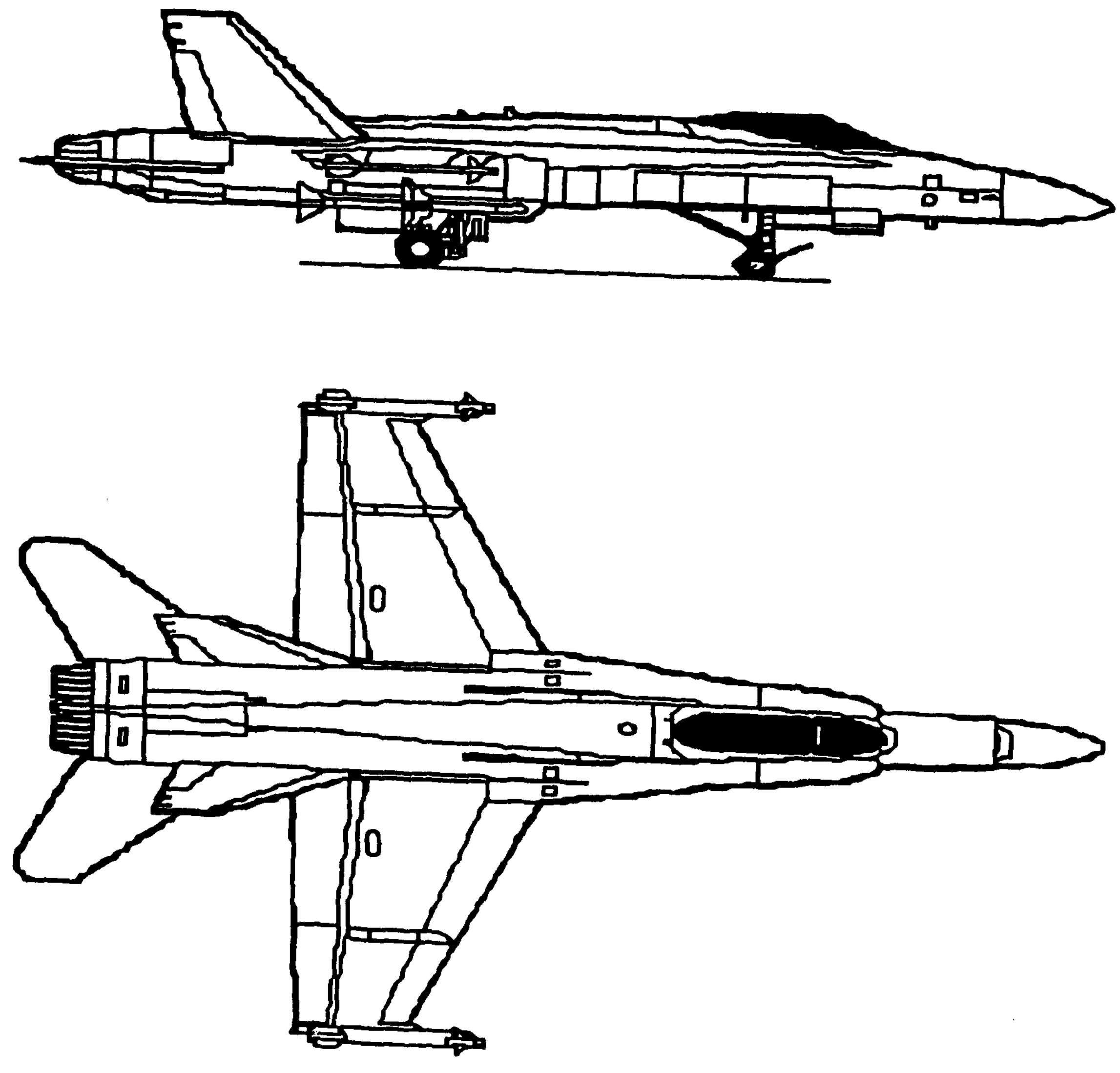
PURPOSE OF FLIGHT TESTS

To validate the overall research test methodology by comparing:

pilot comments
pilot ratings
aircraft response characteristics

TEST AIRCRAFT

- F/A-18A - Lot VII (BuNo 162445)



TEST INSTRUMENTATION

- Pulse Code Modulation Telemetry at 20 Hz
  - real-time
  - production 1553 multiplex bus parameters

- Angle of Attack - conventional vanes and INS computed
- Pitch Acceleration - calculated post-flight from INS pitch rate data

- Varied Nose Down Response via CG (Fuel) Control System
  - controlled fuel transfer shutoff valves
  - manually operated by pilot through cockpit switches

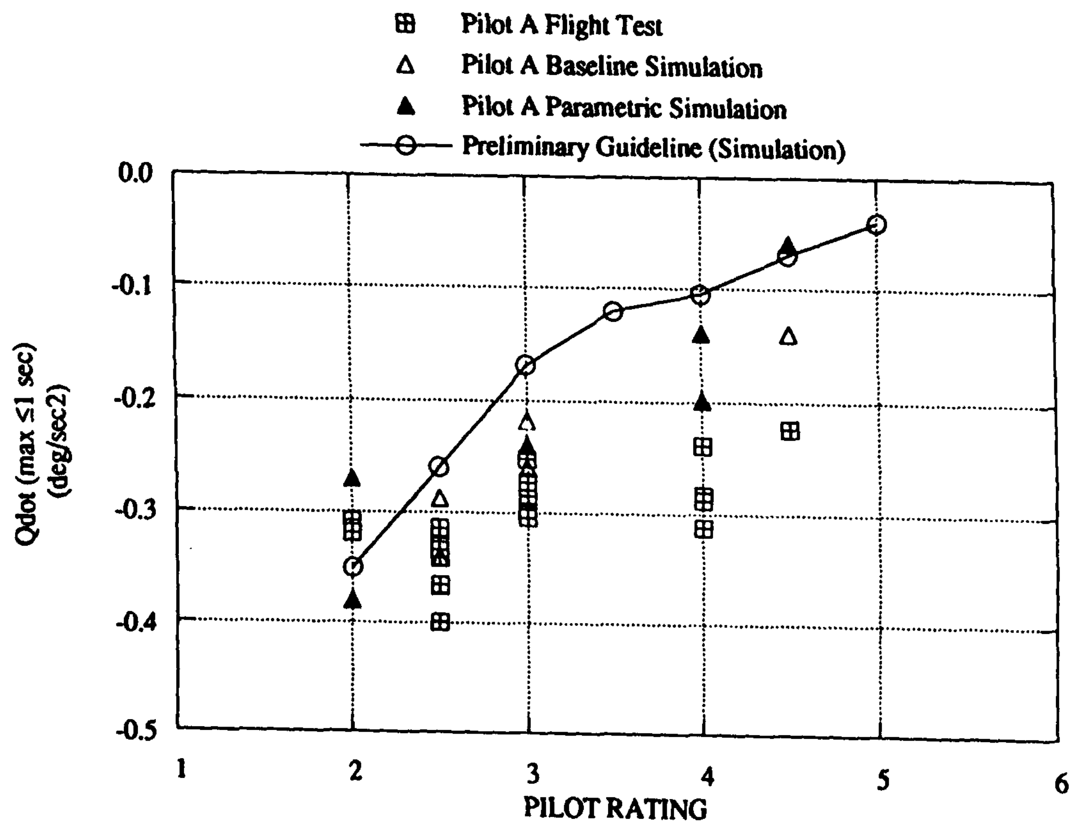
SCOPE OF FLIGHT TESTS

- 6 Flights for 9.8 flight hours

- Phase IA (forward CG's (≤23 %MAC))
  - check airplane control surface rigging at high AOA
  - allow pilots to become familiar w/ test maneuver
  - practice using CG control system

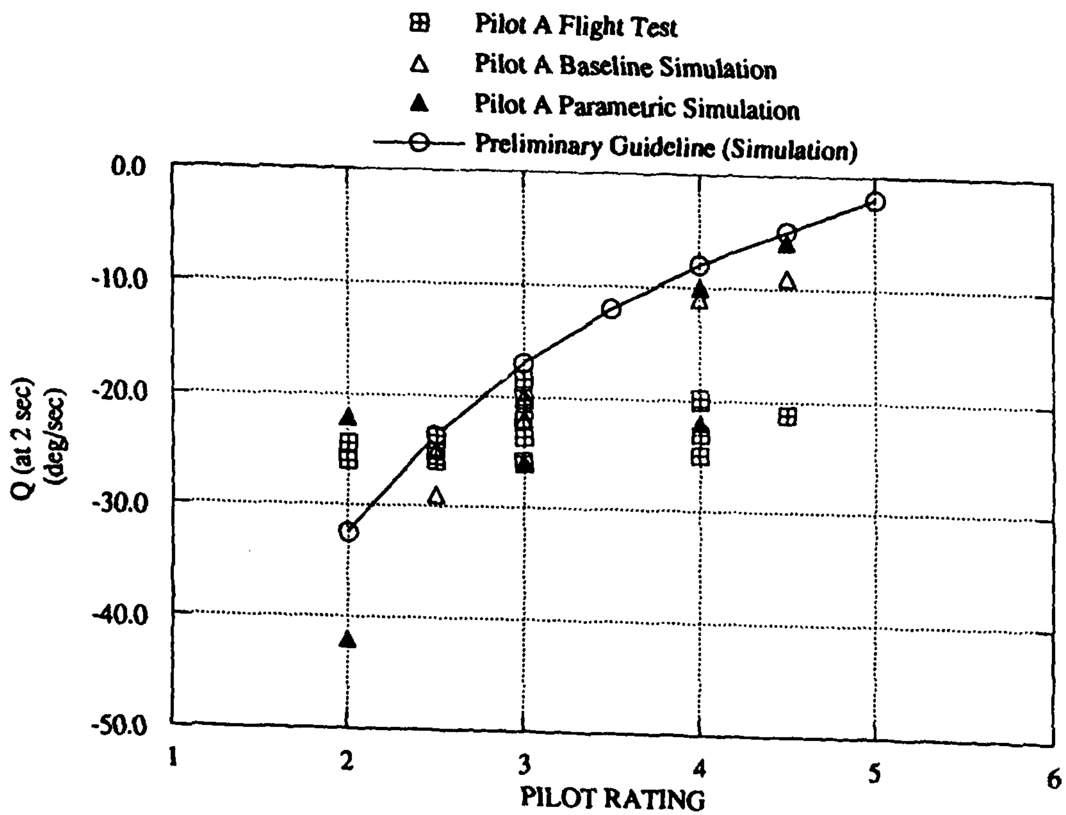
- Phase IB (aft CG's (22.5 - 26.5 %MAC))
  - rate high AOA stabilized pushovers
  - AOA: 40,50 deg

Maximum Pitch Acceleration (≤1 sec)



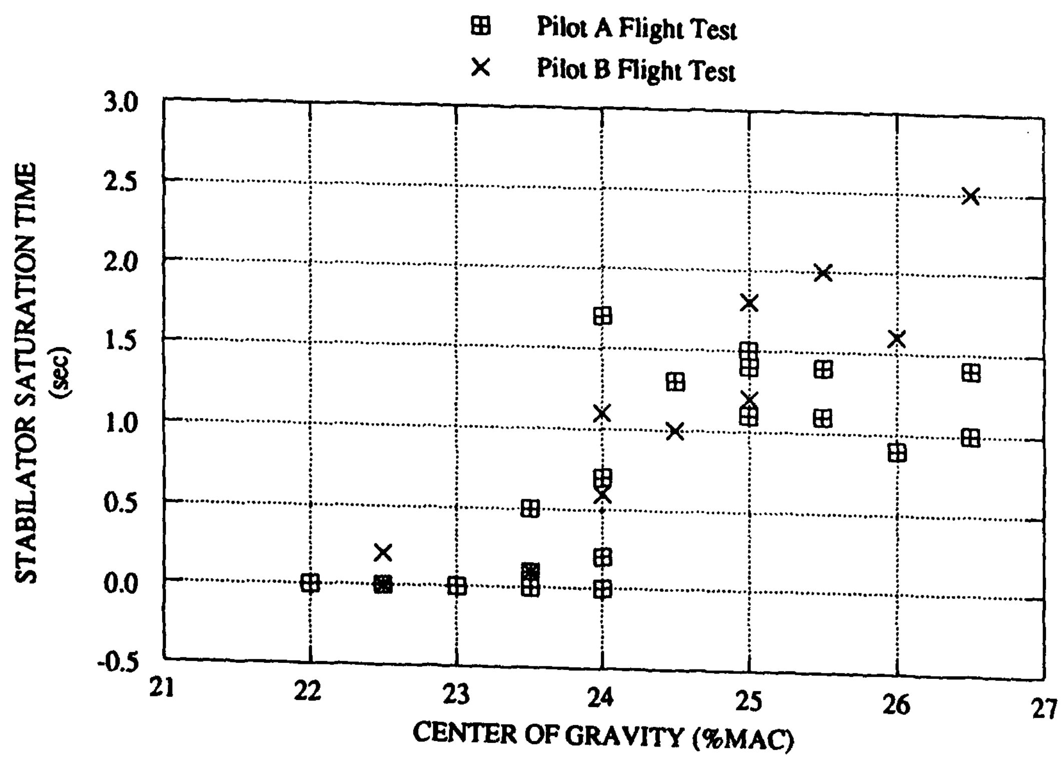
- Nonlinear pitch acceleration response effects
- Motion cue effects

Pitch Rate (at 2 sec)

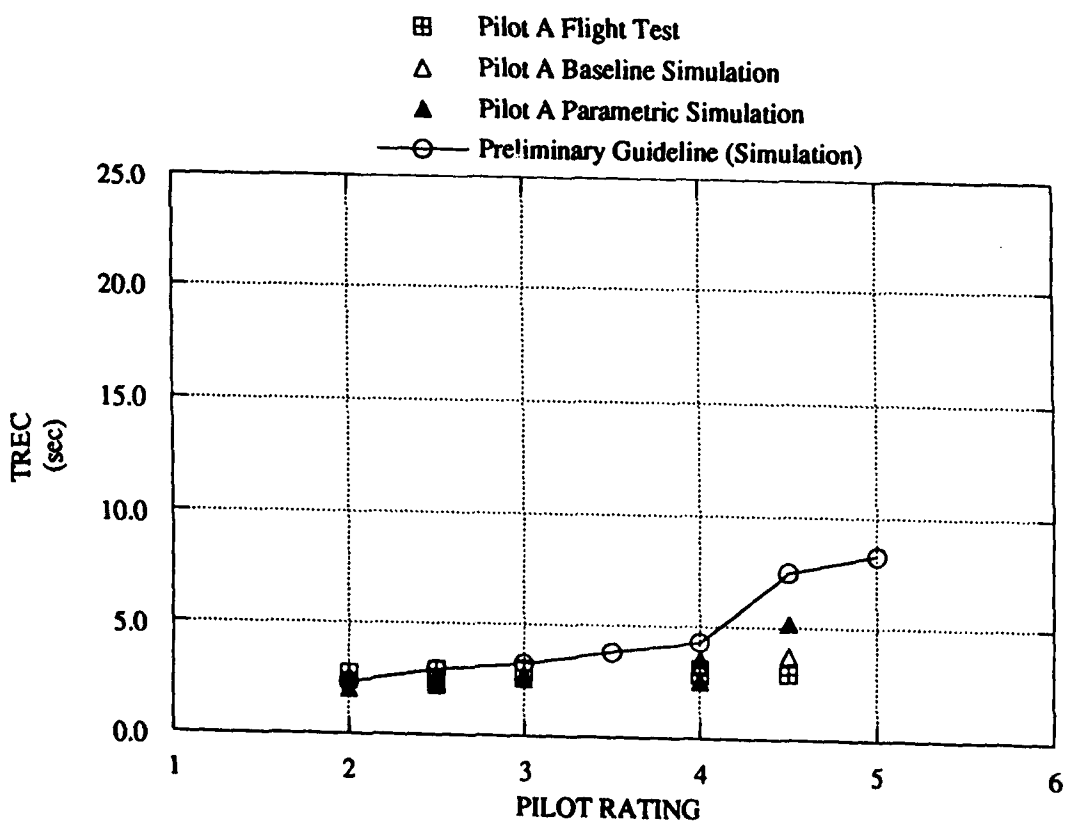


- **Flight control system effects**

Flight Control System Effects on Pitch Recoveries

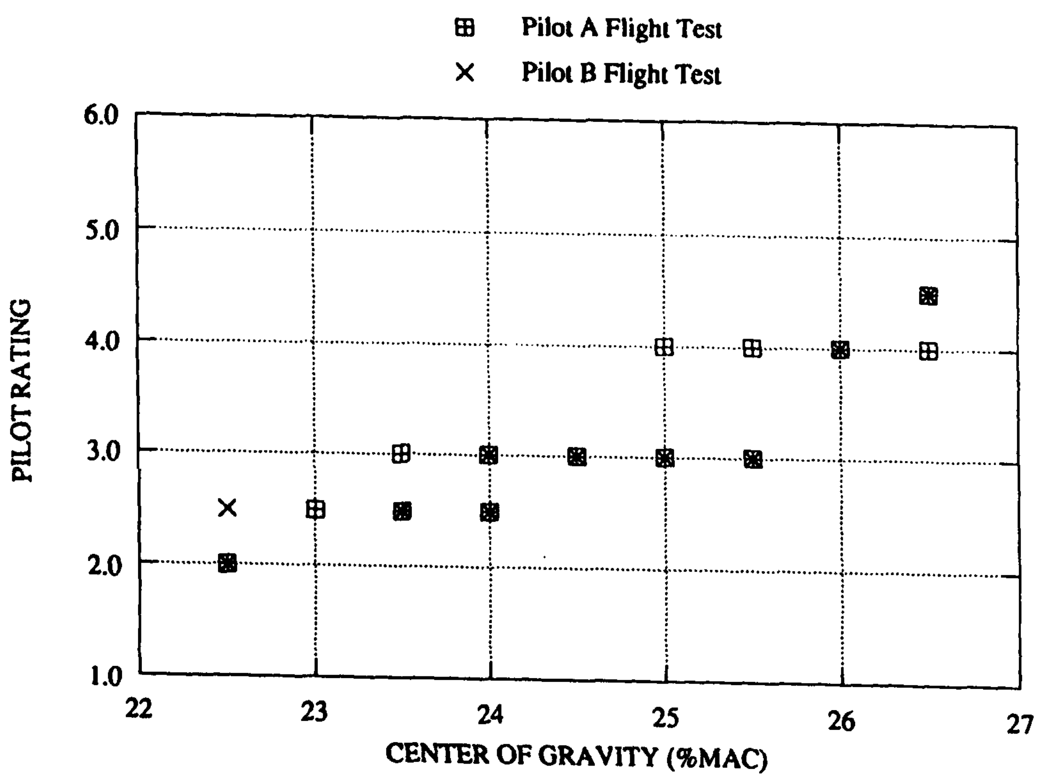


Time to Recover (<10 deg AOA)



- Minimal Variation
- More hangup-response related

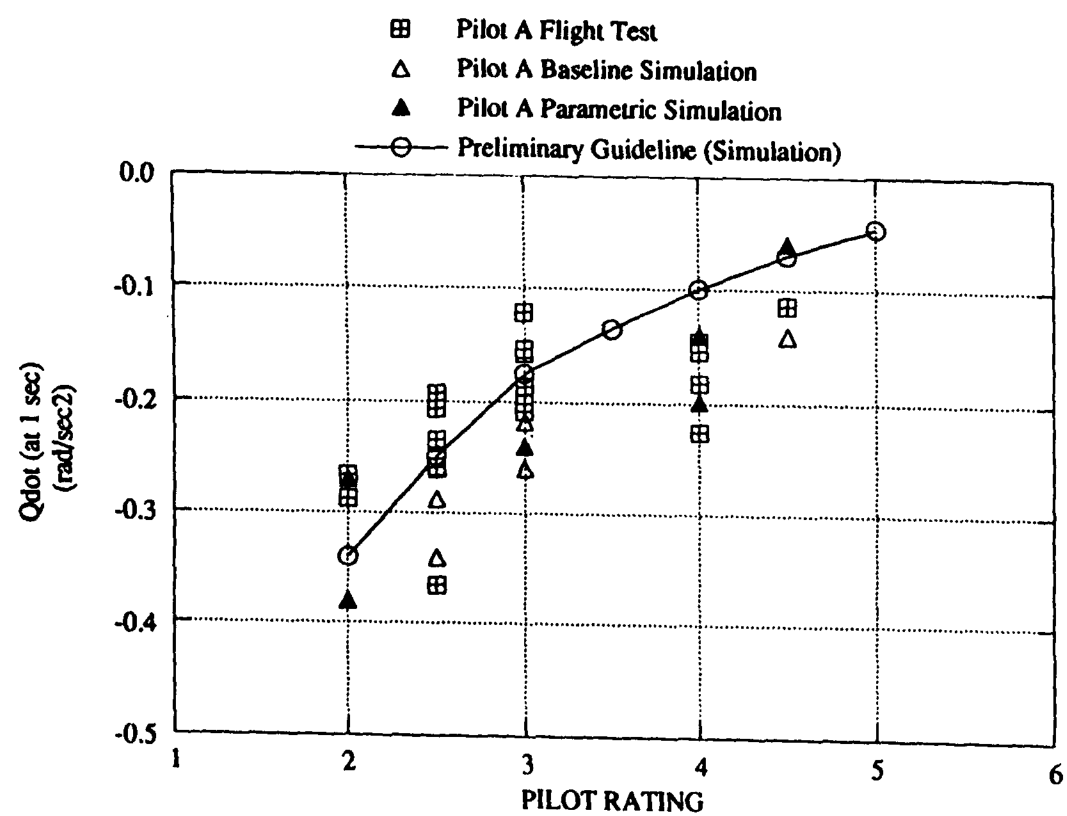
Pilot Rating Versus CG



Other Pitch Acceleration Figures of Merit

Pitch Acceleration (at 1 sec)

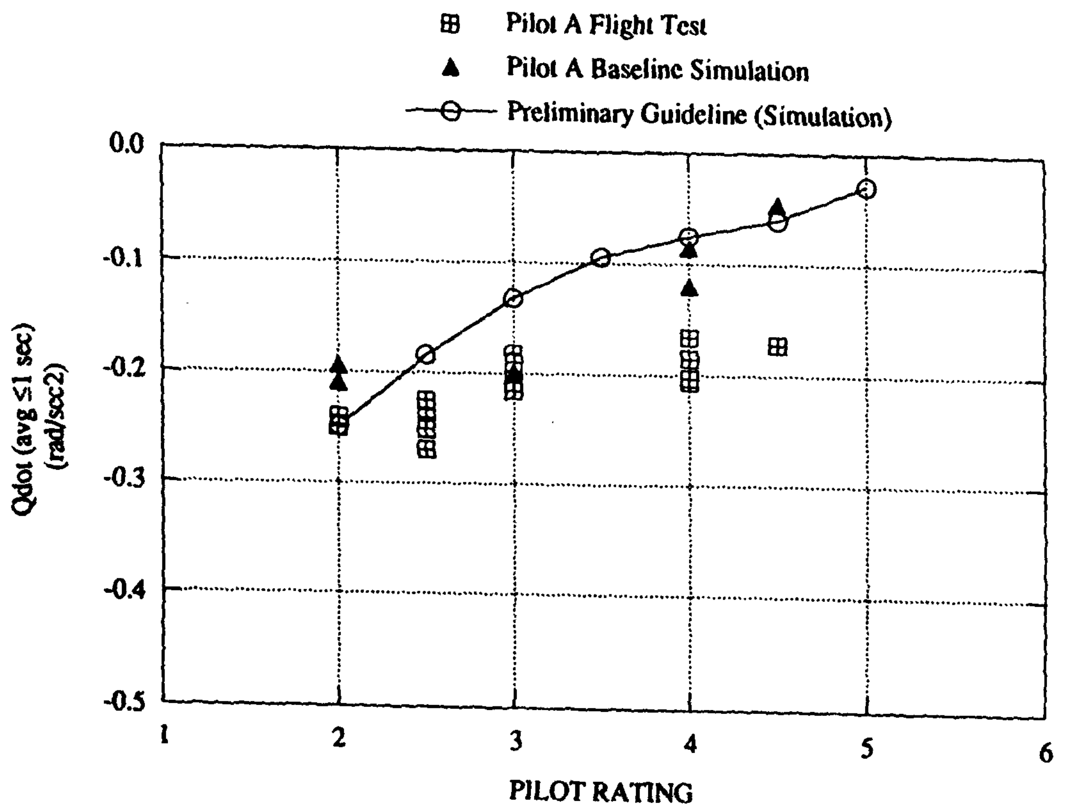
- Better flight test - simulation correlation
- Large data scatter



Other Pitch Acceleration Figures of Merit

Average Pitch Acceleration (≤ 1 sec)

- Reduced data scatter
- Smaller gradient



Workload Required For Test Maneuver Stabilization

- Stabilization requirements:

  $\Theta \pm 5$ deg / $\alpha \pm 2$ deg / $q \pm 2$ deg/sec / $p \pm 5$ deg/sec

  $r \pm 2$ deg/sec / γdot ± 5 deg/sec

- Constant Pitch Attitude Pushover:
  - two input controllers (long. stick & throttle)
  - high workload

- Constant Thrust (MIL) Pushover:
  - one input controller (long. stick)

Pitch Recovery Rating Scale Improvements

- Standardized Mission Scenario
- Clearly defined decision trees
- Expanded 4-5 rating region (most critical)

CONCLUSIONS

- Pilot rating of high AOA nose-down recoveries based on:
  - Short-term response (≤2 sec)
    - Pitch acceleration
    - Pitch rate
- Final figure of merit forms to quantify control margin TBD
- Stabilized pushover - good demonstration maneuver
- Pitch recovery rating scale improvements

CONCLUSIONS

- Qdot (max $\leq$1 sec) - good correlation at low pilot ratings
  - increasing aft CG produced pitch accel nonlinearities
  - increasing aft CG corresponded to increasing rating
  - motion cue effects on rating increased w/ aft CG

- Q (at 2 sec) - good correlation at low pilot ratings
  - essentially constant pitch rate w/pilot rating
  - flight control system effects

- Trec - minimal variation with pilot rating as predicted by simulation