NASA TECHNICAL NOTE

NASA TN D-3246

c 1

NASA TN D-3246

A SIMULATOR STUDY TO DETERMINE PILOT OPINION OF THE TRIM CHANGES WITH POWER FOR DEFLECTED SLIPSTREAM STOL AIRPLANES

by Richard F. Vomaske and Fred J. Drinkwater III

Ames Research Center
Moffett Field, Calif.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • FEBRUARY 1966

A SIMULATOR STUDY TO DETERMINE PILOT OPINION OF THE TRIM CHANGES WITH POWER FOR DEFLECTED SLIPSTREAM STOL AIRPLANES

By Richard F. Vomaske and Fred J. Drinkwater III

Ames Research Center
Moffett Field, Calif.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151 – Price $2.00

A SIMULATOR STUDY TO DETERMINE PILOT OPINION OF THE TRIM CHANGES WITH POWER FOR DEFLECTED SLIPSTREAM STOL AIRPLANES

By Richard F. Vomaske and Fred J. Drinkwater III
Ames Research Center

SUMMARY

A simulator study was made of the effects on pilot opinion of trim change with power. The landing approach and wave-off of a high performance deflected slipstream aircraft was simulated. A wide range of changes of pitching moments with power was investigated at several levels of static longitudinal stability. A configuration that tended to pitch-up and one that showed a reduction of static stability with increasing power were also studied.

The study showed that at the more positive levels of static longitudinal stability the lift produced by power markedly affected the apparent pitching moment due to power.

In general, the pilots preferred configurations which exhibited the least trim change with power or those for which the power effects did not aggravate the stall or pitch-up margin.

A comparison of the test results with current and proposed stability requirements is made. In addition, the test data are compared with flight data available.

INTRODUCTION

In high performance STOL aircraft, power changes sometimes produce undesirable trim and stability changes. Some of these trim problems (discussed in refs. 1-5) are caused by the inclination and location of the engine thrust axis and the slipstream or jet efflux, which can also markedly alter the longitudinal stability and the elevator effectiveness. High horizontal tail location can alleviate some of the problems; however, the pitch-up tendency at high angles of attack may then be a concern. Another less common cause of large trim changes is the combination of a large change in lift due to power and relatively high static longitudinal stability. The changes in angle of attack resulting from power changes can be excessive, depending on the dynamic and static longitudinal stability, the stall margin, and the variation with angle of attack of pitching moment.

The present tests were conducted to determine pilot preference as to the direction and magnitude of the pitching-moment changes with power for a COIN-type (fig. 1) aircraft which has substantial changes in lift with power. Variations in the pitching moment with power were tested at several levels of static longitudinal stability to allow some generalization of results. The flight conditions simulated included the landing approach, wave-off, and engine failure. The landing-approach configuration was selected for the tests since it was felt that power changes would be largest for a maximum power wave-off from the relatively low power required in the approach. There is the possibility that an engine failure just after take-off might dictate the variation in pitching moment with power desired because of the proximity to the stall and the higher nose-up pitch attitudes attained immediately after take-off. The pitch attitude encountered in the climbout might exceed 30° for the aircraft simulated, while in the landing configuration with maximum power the pitch attitude would be considerably less because the lift-drag ratio is lower with the landing flap deflected.

Another concern is the lateral-directional response to an engine failure of a twin-engined configuration with a high thrust-to-weight ratio. In the present tests the propellers were assumed to be interconnected to eliminate any asymmetry due to engine failure so that the longitudinal response could be examined more readily. In addition, as indicated in reference 6, the simulated flight condition (48 knots) was below the minimum speed for adequate lateral control with one engine out and the other engine at maximum power. Minimum speed for adequate control would be around 60 knots for this case.

A moving cab simulator which included a visual runway presentation was used in the present tests.

NOTATION

C_D drag coefficient

C_{D_α} drag variation with angle of attack, $\frac{\partial C_D}{\partial \alpha}$, per radian

C_L lift coefficient

$C_{L_{T_c'}}$ lift variation with thrust coefficient, $\frac{\partial C_L}{\partial T_c'}$

C_{L_α} lift variation with angle of attack, $\frac{\partial C_L}{\partial \alpha}$, per radian

$C_{L_{\delta_e}}$ lift variation with elevator deflection, $\frac{\partial C_L}{\partial \delta_e}$, per radian

C_m pitching-moment coefficient, $\frac{\text{pitching moment}}{\bar{q}Sc}$

C_{m_q} pitching moment due to pitching velocity, $\frac{\partial C_m}{\partial (qc/2u)}$, per radian/sec

$C_{m_{T_c'}}$ pitching moment due to thrust coefficient, $\frac{\partial C_m}{\partial T_c'}$

C_{m_u} pitching moment due to forward velocity, $\frac{\partial C_m}{\partial u}$, per ft/sec

C_{m_α} pitching moment due to angle of attack, $\frac{\partial C_m}{\partial \alpha}$, per radian

$C_{m_{\delta_e}}$ pitching moment due to elevator deflection, $\frac{\partial C_m}{\partial \delta_e}$, per radian

c wing chord, ft

F_{δ_s} control stick force due to displacement, lb/in.

I_y moment of inertia about the airplane Y axis, slug-ft^2

$M_{T_c'}$ rate of change of pitching acceleration with thrust coefficient, radians/sec^2

P period of short-period oscillation, sec

P.R. pilot rating

q pitching velocity, radians/sec

$\bar{q}$ dynamic pressure, lb/ft^2

S wing area, ft^2

T propeller thrust, lb

T_c' thrust coefficient, $\frac{T}{\bar{q}S}$

t time, sec

u forward velocity, ft/sec

V forward velocity, knots except as noted

W airplane weight, lb

α angle of attack, radians except as noted

γ flight-path angle, deg

δ_e elevator deflection, radians except as noted

δ_s control stick deflection, in.

ζ damping ratio

θ pitch attitude, deg

ω_n undamped airplane natural frequency, radians/sec

Subscripts

max maximum

p phugoid

sp short period

EQUIPMENT

A moving cab simulator with stick-type lateral and longitudinal controls was used. Pitch and roll attitudes, attenuated to avoid the motion limits, were programmed into the cab motion. The pilot's visual display included the conventional flight instruments and a closed-loop televised runway presentation. The lighting of this runway made the landing approaches appear similar to those encountered in night operations with about 1-1/2 miles visibility. Figures 2 and 3 are photographs of the simulator and figure 4 is a block diagram of its functional elements. This equipment is described and motion requirements of simulators are discussed in reference 7.

PROCEDURE

Aircraft Characteristics

A cross-shafted twin-engined airplane, such as the one shown in figure 1, was simulated in this study. It had a relatively high installed thrust-to-weight ratio (0.7 at the approach speed) and high lift due to thrust. Changing the power from idle to maximum increased the lift coefficient by 2.66; this is the lift effect due to thrust alone at the approach speed. Table I presents the important parameters used in the simulation and figure 5(a) shows the performance envelope. The tests were made in the landing-approach configuration at the condition for approximately maximum STOL performance ($C_L = 3.8$). This test condition was selected because power changes might be expected to be maximum in the wave-off. Several combinations of center-of-gravity location (C_{m_α}) and pitching moment due to thrust coefficient ($C_{m_{T_c}'}$) were tested. Figures 5(b) and (c) depict the pitching-moment variation with angle of attack for the conditions tested. The stability change with angle of attack shown in figure 5(b) was selected to simulate pitch-up at a high angle of attack. The characteristics shown in figure 5(c) were to simulate the Ryan VZ-3 (ref. 8) in which increased thrust has a destabilizing effect typical of many STOL aircraft. The lift-drag characteristics simulated for the 48-knot approach speed required a thrust increase with decreasing speed for stabilized flight.

The longitudinal dynamic and static stability varied considerably, depend- depending on the value of C_{m_α}, $C_{m_{T_c'}}$, and T_c'. Figure 6 shows the variation with $C_{m_{T_c'}}$ and C_{m_α} of the dynamic-stability parameter $(\zeta\omega_n)$ and the static-stability parameter (ω_n^2). With approach power, and when pitching moment varied linearly with angle of attack, lowering the thrust axis below the center of gravity (positive values of $C_{m_{T_c'}}$) increased the short-period damping and static stability while reducing the phugoid damping and static stability. With wave-off power, the stability variation was similar to that with approach power. For a practical range of $C_{m_{T_c'}}$ $(0.15 > C_{m_{T_c'}} > -0.15)$, the static and dynamic stability is positive in the short-period mode, even when $C_{m_\alpha} = 0$. At $C_{m_{T_c'}} = -0.24$, the short-period dynamic stability is negative. The change of stability with $C_{m_{T_c'}}$ is primarily due to the relationship $C_{m_{T_c'}}$ to C_{m_u}. At approach power $C_{m_u} = -0.06\ C_{m_{T_c'}}$ while at wave-off power $C_{m_u} = -0.09\ C_{m_{T_c'}}$.

Piloting Task

The handling qualities of the test configurations were evaluated by two research pilots. Simulated landing-approach runs were initiated in level flight at 70 knots and 1000 feet altitude. The initial task was to reduce speed to 48 knots, maintaining level flight until an approach path of 10° to the runway as indicated by the instrument landing-approach crosspointer. The landing approach was then continued on the 10° path at 48 knots airspeed. During the initial approach, the pilots evaluated the stability and flight-path control. At an altitude of 50 to 100 feet, the pilots attempted a maximum power wave-off while maintaining the speed at 48 knots. After the flight path and pitch attitude were stabilized, an engine failure was simulated. The pilots made additional runs so that they could observe the airplane response to throttle steps, and they observed flare characteristics during simulated landings. No attempt was made to simulate ground effect, and all tests were conducted in simulated smooth air. In this study the pilots excluded from their evaluation, as far as they were able, the elevator effectiveness and stick forces which were not varied and were considered satisfactory. Pilot ratings of the airplane characteristics and maneuvering tasks were assigned to each configuration. The pilot-rating scale is given in table II, which is from reference 9.

RESULTS AND DISCUSSION

In a previous study (ref. 10) it was noted that any excessive trim change due to power was undesirable. When adding power the pilots were concerned with the increased attention required if the airspeed decreased rapidly or if back stick was required to keep the nose from dropping. In general, during the present tests, the pilots expressed a similar concern depending on the task. In the following paragraphs the test results of the effect of trim change on approach-path control, wave-off, engine failure, longitudinal stability, stall margin, and pitch-up are discussed. The configuration variables for the various pilot evaluation maneuvers and tasks are summarized in table III.

Approach-Path Considerations

The pilot ratings for the approach-path controllability are shown in figure 7 for the combinations of C_{m_α} and $C_{m_{T_c'}}$ tested. The pilots indicated a preference for $C_{m_{T_c'}} = 0$ for the more stable configurations ($C_{m_\alpha} < -1.6$) because of the small angle-of-attack variation with throttle changes. They preferred small angle-of-attack changes with power variations because the stall margin in STOL landing operation is normally small. The near zero $C_{m_{T_c'}}$ was the only test condition in which the angle-of-attack variation resulting from moderate power changes was small. For $C_{m_\alpha} = 0$, data were insufficient to determine pilot preference; however, in the engine-failure tests (which will be discussed later), the angle-of-attack variation was small only for zero $C_{m_{T_c'}}$.

Controls fixed stability.- The pilot ratings of the stick-fixed stability characteristics are presented in figure 8. Based solely on stick-fixed stability considerations, sufficient data were not obtained to determine the effect of $C_{m_{T_c'}}$ on pilot rating. However, more favorable pilot ratings for the negative value of $C_{m_{T_c'}}$ at $C_{m_\alpha} = 0$ were obtained in the engine failure tests because of an improvement in stability characteristics over the zero to positive values of $C_{m_{T_c'}}$. From the stability characteristics shown in figure 6 for $C_{m_\alpha} = 0$, it would be expected that $C_{m_{T_c'}} = -0.08$ would be approximately optimum. The phugoid mode exhibits a static divergence for positive values of $C_{m_{T_c'}}$ and the short-period damping becomes zero at $C_{m_{T_c'}} = -0.23$. The case of $C_{m_{T_c'}} = -0.08$ shows well-damped short-period and phugoid modes which imply a possible optimum stability configuration.

Pilot-opinion boundaries.- From the ratings and comments obtained for the approach path control and stability considerations, the pilot-rating boundaries as a function of the short-period dynamic and static longitudinal stability parameters, ($\zeta\omega_n$) and (ω_n^2), are shown in figure 9. Also shown are the military specifications for Class I and II airplanes from reference 11 and the V/STOL recommendations from reference 12. The satisfactory-unsatisfactory boundary shown (P.R. = 3-1/2) for the present tests coincides with the military specifications in the region of $\omega_n^2 = 2$ to 3. The present test results also agree well with the AGARD recommendations (ref. 12) for the "single failure limit" condition which corresponds to the unsatisfactory-unacceptable (P.R. = 6-1/2) boundary shown. The landing-approach P.R. ≈ 6-1/2 condition of reference 13 is shown in figure 9 for the $\omega_n = 0$ in both smooth and rough air. Since the present tests were conducted in simulated smooth air, the P.R. = 6-1/2 boundaries in figure 9 may be somewhat lenient as indicated by the comparison of the smooth and rough air data of reference 13. Also shown in figure 9 are test points from references 1 and 3 which indicate that the satisfactory-unsatisfactory boundary may not extend to $(\omega_n^2)_{sp} < 0.5$ in the damping region of $(\zeta\omega_n)_{sp}$ less than unity.

Phugoid stability.- The pilot ratings in figures 7 and 8 also indicate a satisfactory-unacceptable boundary for the phugoid mode. Pilot ratings of about 6-1/2 were obtained for $C_{m_\alpha} = 0$, $C_{m_{T_c'}} = 0$ for which there is a well-damped short-period mode (see fig. 6) and neutral phugoid static stability with $(\zeta\omega)_p = 0.16$. This agrees well with the smooth air mirror approach data of reference 13, which indicates a $\zeta\omega_n \approx 0.15$ at $\omega_n = 0$ for the pilot rating of 6-1/2. The reference 13 data also show the effect of turbulence on pilot rating. For the same neutral static-stability condition, to maintain a pilot rating of 6-1/2, the damping parameter $(\zeta\omega_n)$ must be approximately doubled when going from a smooth air to the rough air condition. It would be expected that for STOL operation the degree of turbulence would have a more noticeable effect when operating close to the stall.

Wave-Off Considerations

The pilot ratings obtained in the wave-off tests are given in figure 10. In these tests, as well as the engine failure tests, the apparent large increase in pitching moment with power resulting from the combination of large lift due to thrust and positive static stability was most noticeable. As shown in figure 10, the near optimum $C_{m_{T_c'}}$ was about -0.2 for the configurations with more positive static stability. For the $C_{m_\alpha} = 0$ condition the optimum $C_{m_{T_c'}}$ was near zero. Time histories of airplane response to throttle steps $(\Delta T_c' = 0.62)$ are shown in figures 11(a) and 11(b). From these time histories it is evident that, for $C_{m_\alpha} = -1.7$, the most stable airspeed response to the throttle step was for $C_{m_{T_c'}} = -0.225$. This preference for good airspeed stability with throttle changes agrees with the comments in reference 10. In addition, for this case, the pitch attitude change is small (about 1°) for the first 3 seconds after the throttle step. In figure 11(b) it can be seen that the combination $C_{m_\alpha} = 0$, $C_{m_{T_c'}} = 0$ is the only case which showed small angle of attack, velocity, and pitch attitude disturbances resulting from the throttle step and also agrees with the preferred response noted in reference 10. Since the disturbance created by the throttle step is smaller for $C_{m_\alpha} = 0$ rather than -1.7 with $C_{m_{T_c'}} = 0$, it would be expected that the former would be preferred and the pilot ratings (fig. 10) show this.

Flight-test comparison of wave-off.- Figure 11(c) presents the angle-of-attack response to a throttle change of two of the present test configurations $(C_{m_\alpha} = 0)$ (fig. 11(b)), and time histories from flight tests of a throttle-elevator interconnect used successfully in a deflected slipstream airplane as reported in reference 1. The time histories of reference 1 show angle-of-attack response very similar to the two configurations studied in the present tests. The test airplane of reference 1 exhibited low longitudinal stability and was considered unsatisfactory without the throttle-elevator interconnect because of an undesirably large nose-down pitch attitude response with added power. This response was nearly the same as the $C_{m_{T_c'}} = -0.225$, $C_{m_\alpha} = 0$

configuration in the simulator tests. With the interconnect, the airplane response, which was considered satisfactory in reference 1, was like the simulator response for the $C_{m_{T_c'}} = 0$, $C_{m_\alpha} = 0$ configuration.

Pilot opinion boundaries.- The pilot opinion boundaries (P.R. = 3-1/2 and 6-1/2) as a function of the static-stability parameter $(\omega_n^2)_{sp}$ and the angular acceleration in pitch due to a throttle step from approach to wave-off power $(M_{T_c'}\Delta T_c')$ for the wave-off task are given in figure 12. For both boundaries there is shown a lesser tolerance for pitching-moment changes with power at decreasing levels of static stability. A satisfactory-unsatisfactory boundary dictated by the phugoid characteristics is presented in figure 12. Also shown are the two conditions from the tests of reference 1. The ratings given for these two points are from unpublished comments of the evaluating pilot and indicate the simulator obtained boundaries may be slightly lenient.

Engine Failure Considerations

The ratings obtained in the engine failure tests are given in figure 13. These data show a definite preference for the negative values of $C_{m_{T_c'}}$. For the configurations exhibiting high static stability, the nose-up pitching moment with power reduction prevented excessive nose-down attitudes when an engine failed. For the low static-stability configuration ($C_{m_\alpha} = 0$), the primary concern was the stability characteristics. It would be expected that there would be a preference for some nose-down pitching moment with loss of power ($C_{m_{T_c'}} > 0$) for the $C_{m_\alpha} = 0$ case. A reasonable explanation for this lack of preference for the positive values of $C_{m_{T_c'}}$ is the unstable phugoid mode shown in figure 6.

Tests of Stability Change With Power

The pilot ratings for the configuration exhibiting a stability change with power change are presented in figure 14. The effect of power on C_{m_α} for this configuration is shown in figure 5(c). The more negative values of $C_{m_{T_c'}}$ were considered adverse because in the wave-off the nose-down attitude attained was excessive and when an engine failed the speed fell off too rapidly. At the higher power levels where the airplane is unstable, the optimum engine pitching moment would be such as to give the best angle-of-attack stability. For the engine failure case, with the good engine operating at full power, C_{m_α} is approximately zero. The optimum $C_{m_{T_c'}}$ for this case would be zero based on the small angle-of-attack response to a throttle step shown in figure 11(b). The dashed portion of the curve shown in figure 14 represents the deterioration in pilot rating shown in figure 13 for $C_{m_{T_c'}}$ greater than 0.

Pitch-Up Tests

When pitch-up at high angle of attack was simulated, the static stability was positive ($C_{m_\alpha} = -1.7$) at the lower angles of attack. The stability change with angle of attack for this case is presented in figure 5(b). The pilot ratings for this case are presented in figure 15. For the wave-off task, the zero to negative values of $C_{m_{T_c}}$, tested were preferred over the positive values because of better velocity stability (illustrated in the time histories shown in figure 11(a)); this was also noted in the wave-off tests without the pitch-up (see fig. 10). The phugoid mode exhibits negative static stability for $C_{m_{T_c}}$, greater than about 0.04 ($C_{m_\alpha} = -1.7$) for the wave-off power condition. The more unsatisfactory ratings given for the pitch-up study were a result of the pilot's concern with encountering the pitch-up. In the engine failure tests, the more positive values of $C_{m_{T_c}}$, were preferred because they reduced the angle of attack attained when power failed and there was less likelihood of encountering the pitch-up. The angle-of-attack margin was quite small ($C_{m_\alpha} = 0^\circ$ at $3\text{-}1/2^\circ$ above the approach angle of attack) so that the pitch-up was occasionally encountered inadvertently in the tests usually because of a small speed reduction. In general, the tendency to pitch-up was more likely during rapid power changes unless the pilot made immediate elevator corrections. These observations for the pitch-up case could be applied also to a stall without the pitch-up since the pilot would be reluctant to operate near the stall while in the landing approach or wave-off.

CONCLUDING REMARKS

Pilot's opinion of the direction and magnitude of the pitching moment produced by power changes depends on many factors. In this study the piloting task, the longitudinal stability including the stall or pitch-up margin, the thrust inclination or direct lift effect of power, and the elevator power available and trim rate were found to have the most influence.

Considering the most critical task (i.e., wave-off), if the stall margin or pitch-up is not a concern, the pilots show a preference for little or no trim change with power for the low static-stability conditions typical of many STOL aircraft.

For operation near the stall or pitch-up the most critical task tested was the wave-off. For this task the pilots preferred a moderate nose-down pitching moment with increased power because this improved the velocity stability.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., Oct. 28, 1965

REFERENCES

1. Quigley, Hervey C.; Innis, Robert C.; and Holzhauser, Curt A.: A Flight Investigation of the Performance, Handling Qualities, and Operational Characteristics of a Deflected Slipstream STOL Transport Airplane Having Four Interconnected Propellers. NASA TN D-2231, 1964.

2. Turner, Howard L.; and Drinkwater, Fred J., III: Longitudinal Trim Characteristics of a Deflected Slipstream V/STOL Aircraft During Level Flight at Transition Flight Speeds. NASA TN D-1430, 1962.

3. Holzhauser, Curt A.; Innis, Robert C.; and Vomaske, Richard F.: A Flight and Simulator Study of the Handling Qualities of a Deflected Slipstream STOL Seaplane Having Four Propellers and Boundary-Layer Control. NASA TN D-2966, 1965.

4. Innis, Robert C.; and Quigley, Hervey C.: A Flight Examination of Operating Problems of V/STOL Aircraft in STOL-Type Landing and Approach. NASA TN D-862, 1961.

5. Campbell, John P.: Status of V/STOL Research and Development in the United States. J. Aircraft, vol. 1, no. 3, May-June 1964, pp. 97-106.

6. Kuhn, Richard E.; and Hammond, Alexander D.: Control Requirements Affecting STOLs. Astronaut. Aeron., vol. 3, no. 5, May 1965, pp. 48-52.

7. Clousing, Lawrence A.: Simulator Requirements Deduced From Comparisons of Pilot's Performance in Ground Simulators and in Aircraft. ICAS Paper 64-554, 1964.

8. James, Harry A.; Wingrove, Rodney C.; Holzhauser, Curt A.; and Drinkwater, Fred J., III: Wind-Tunnel and Piloted Flight Simulator Investigation of a Deflected-Slipstream VTOL Airplane, the Ryan VZ-3RY. NASA TN D-89, 1959.

9. Cooper, George E.: Understanding and Interpreting Pilot Opinion. Aero. Engr. Rev., vol. 16, no. 3, March 1957, pp. 47-51, 56.

10. Drinkwater, Fred J., III; and Cooper, George E.: A Flight Evaluation of the Factors Which Influence the Selection of Landing Approach Speeds. NASA MEMO 10-6-58A, 1958.

11. Anon.: Flying Qualities of Piloted Airplanes. Military Specification MIL-F-8785 (ASG), Nov. 12, 1957.

12. AGARD Flight Mechanics Panel Working Group: Recommendations for V/STOL Handling Qualities. AGARD Rep. 408A, Oct. 1964.

13. Bull, G.: Minimum Flyable Longitudinal Handling Qualities of Airplanes. Cornell Aero. Lab., Inc. Rep. TB-1313-F-1, Dec. 1959.

TABLE I.- STABILITY DERIVATIVES AND GEOMETRIC DATA FOR THE APPROACH CONDITION OF $V = 48$ KNOTS ($\gamma = -10^{\circ}$)

$$C_L = 3.79$$

$$C_D = 0.67$$

$$C_{L_\alpha} = 7.33$$

$$C_{L_{T_c'}} = 1.15$$

$$C_{D_\alpha} = 5.15$$

$$C_{L_{\delta_e}} = 1.09$$

$$C_{m_q} = -21.2$$

$$C_{m_{\delta_e}} = -2.8$$

$S = 200$ sq ft

$c = 6.8$ ft

$I_Y = 10{,}500$ slug-ft^2

$W = 5950$ lb

$\delta_{e_{max}} = 0.53$ radian up; 0.42 radian down

$F_{\delta_s} = 1.95$ lb/in. with ±2 lb breakout force

$\delta_{s_{max}} = 7\text{-}1/2$ in. aft; 5 in. forward

$T_c' = 0.50$ (idle) to 2.80 (maximum power) at 48 knots

$\partial(T/W)/\partial V = -0.004$ per knot

TABLE II.- PILOT OPINION RATING SYSTEM

	Adjective rating	Numerical rating	Description	Primary mission accomplished	Can be landed
Normal operation	Satisfactory	1	Excellent, includes optimum	Yes	Yes
		2	Good, pleasant to fly	Yes	Yes
		3	Satisfactory, but with some mildly unpleasant characteristics	Yes	Yes
Emergency operation	Unsatisfactory	4	Acceptable, but with unpleasant characteristics	Yes	Yes
		5	Unacceptable for normal operation	Doubtful	Yes
		6	Acceptable for emergency condition only[1]	Doubtful	Yes
No operation	Unacceptable	7	Unacceptable even for emergency condition[1]	No	Doubtful
		8	Unacceptable - dangerous	No	No
		9	Unacceptable - uncontrollable	No	No

[1]Failure of a stability augmenter

TABLE III.- RANGE OF VALUES OF STABILITY AND CONTROL PARAMETERS STUDIED

	$C_{m_{\alpha}}$	$C_{m_{\alpha_{T_c}}}$'	$C_{m_{T_c}}$'	Figure
Approach path control	0 -1.7 -2.8	0 0 0	0 to -0.225 0.225 to -0.45 0.14 to -0.28	7 & 9 7 & 9 7 & 9
Approach path stability	0 -1.7 -2.8	0 0 0	0 0.225 to -0.45 0.14 to -0.28	8 & 9 8 & 9 8 & 9
Wave-off	0 -1.7 -2.8	0 0 0	0.225 to -0.225 0.225 to -0.45 0.14 to -0.28	10, 11, & 12 10, 11, & 12 10 & 12
Engine failure	0 -1.7 -2.8	0 0 0	0.225 to -0.225 0.225 to -0.45 0.14 to -0.28	13 13 13
Stability change with power:				
Wave-off	---	0.26	0.225 to -0.225	14
Engine failure	---	0.26	0 to -0.225	14
Stability change with angle of attack:				
Wave-off	f(α)	0	0.225 to -0.225	15
Engine failure	f(α)	0	0.225 to -0.225	15

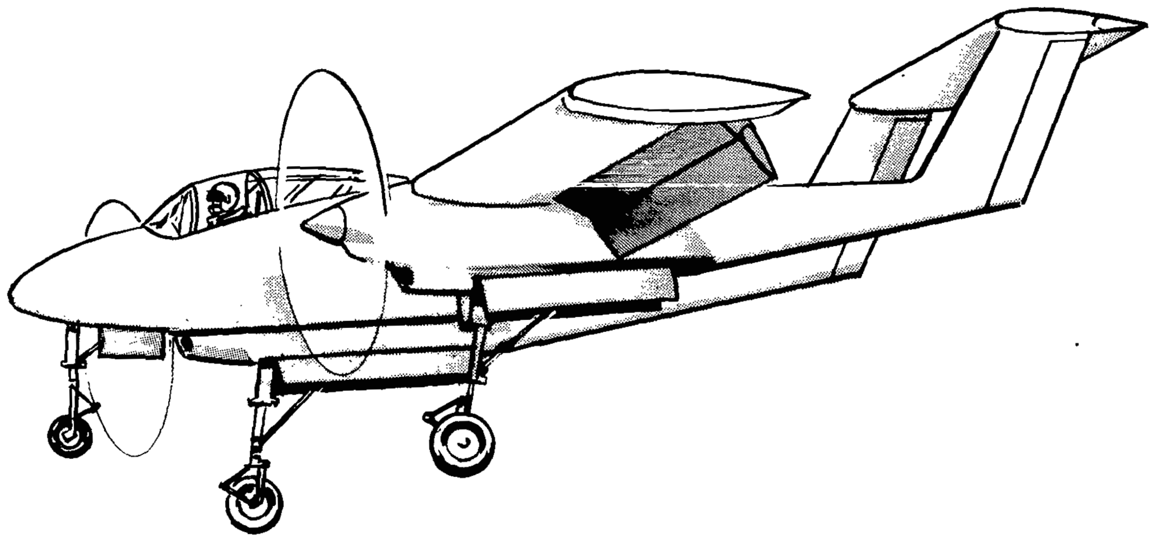
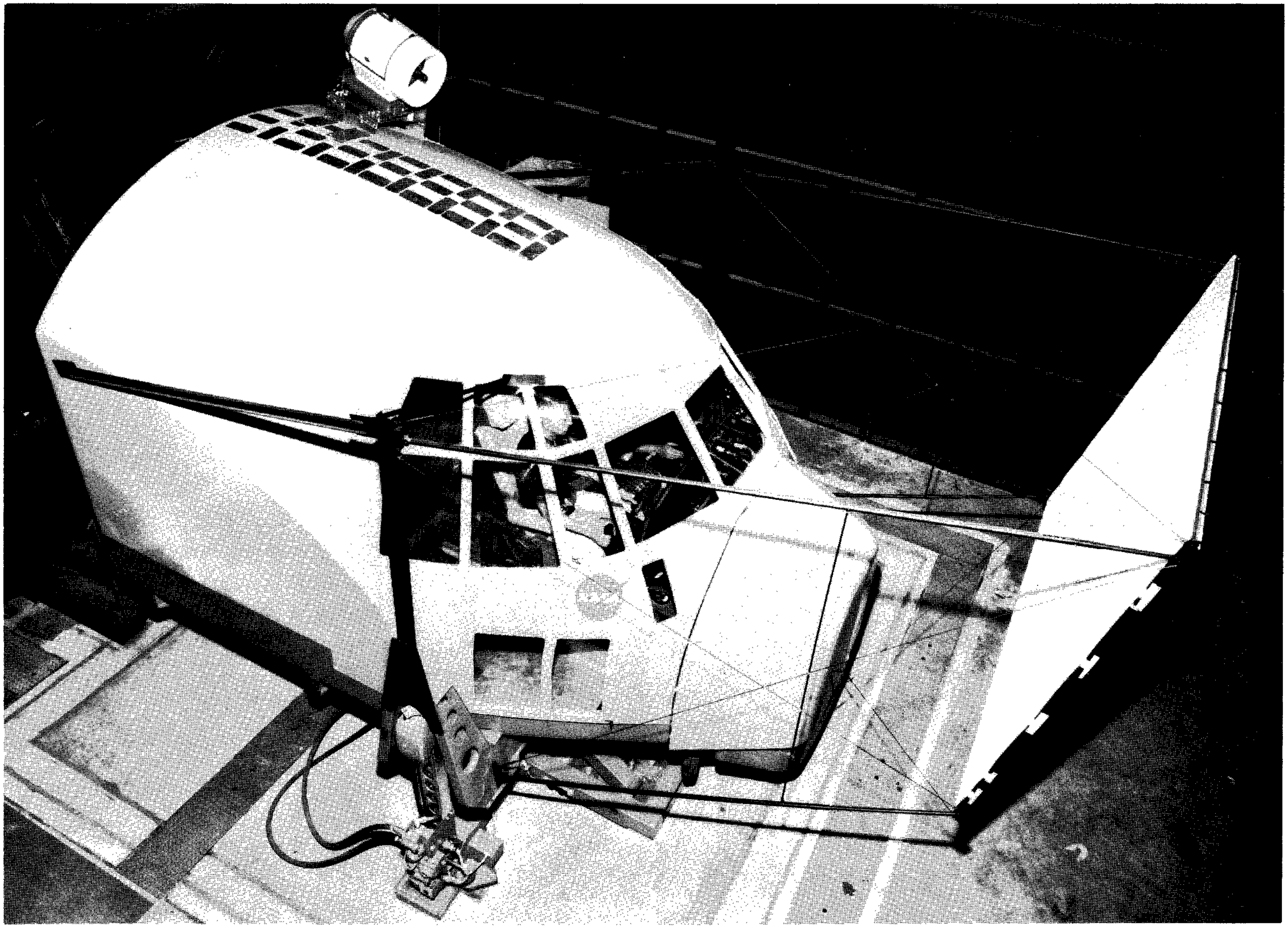
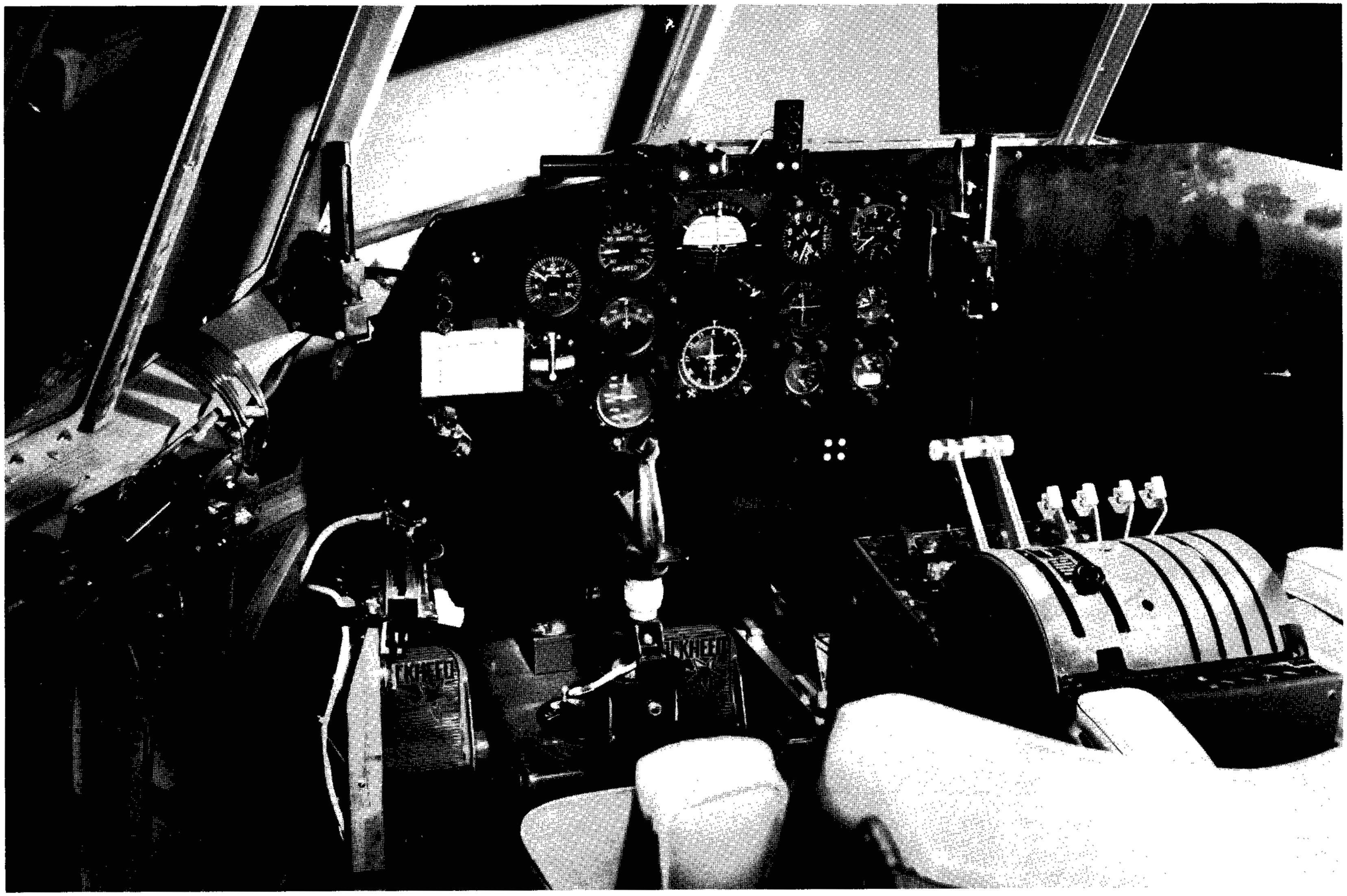


Figure 1.- Sketch of the general configuration studied.



A-30526-15

Figure 2.- External view of simulator showing cab, video projector, and screen.



A-30526-18

Figure 3.- Interior view of simulator cab.

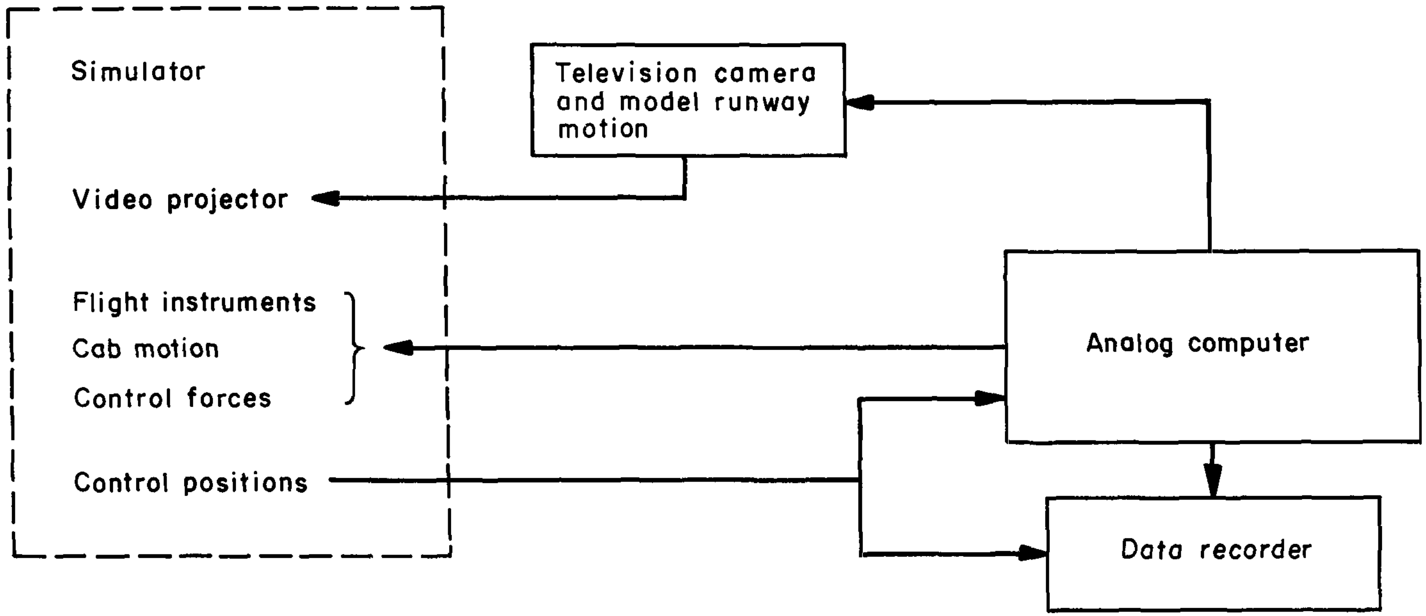
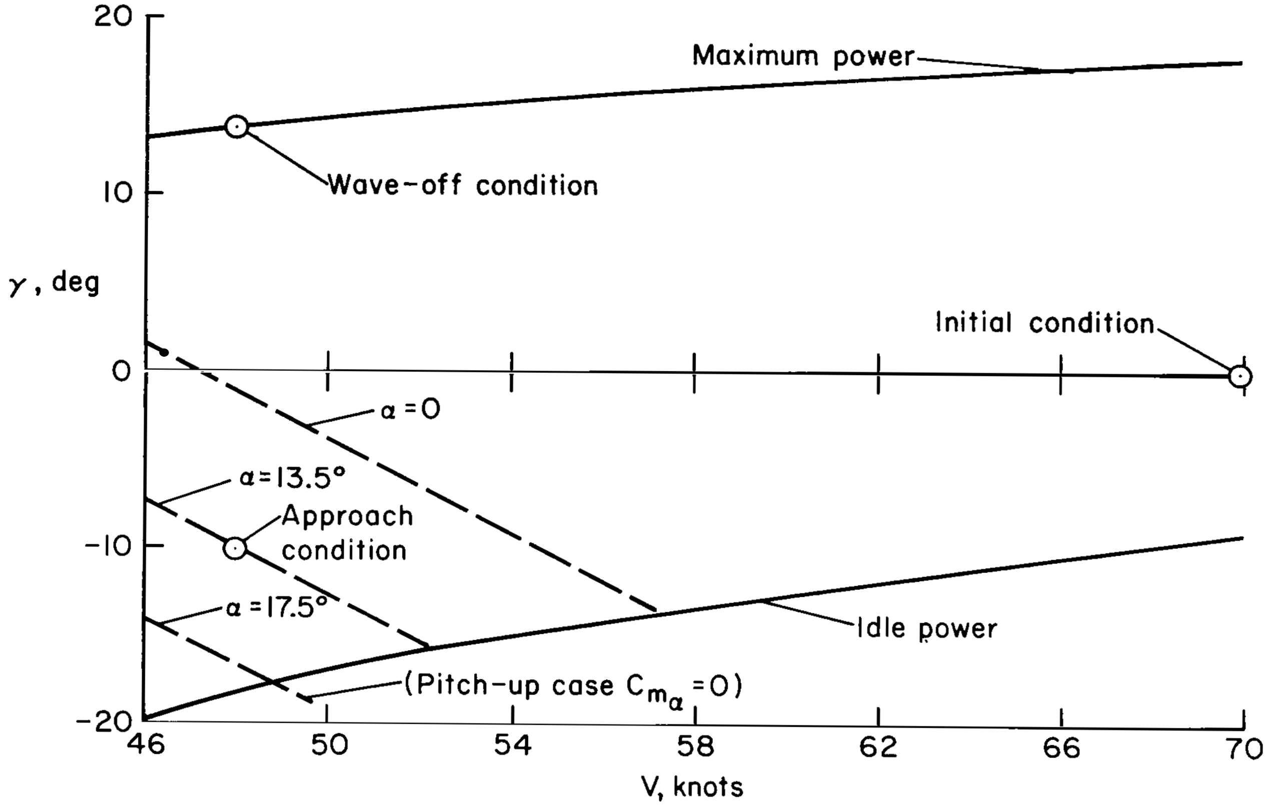
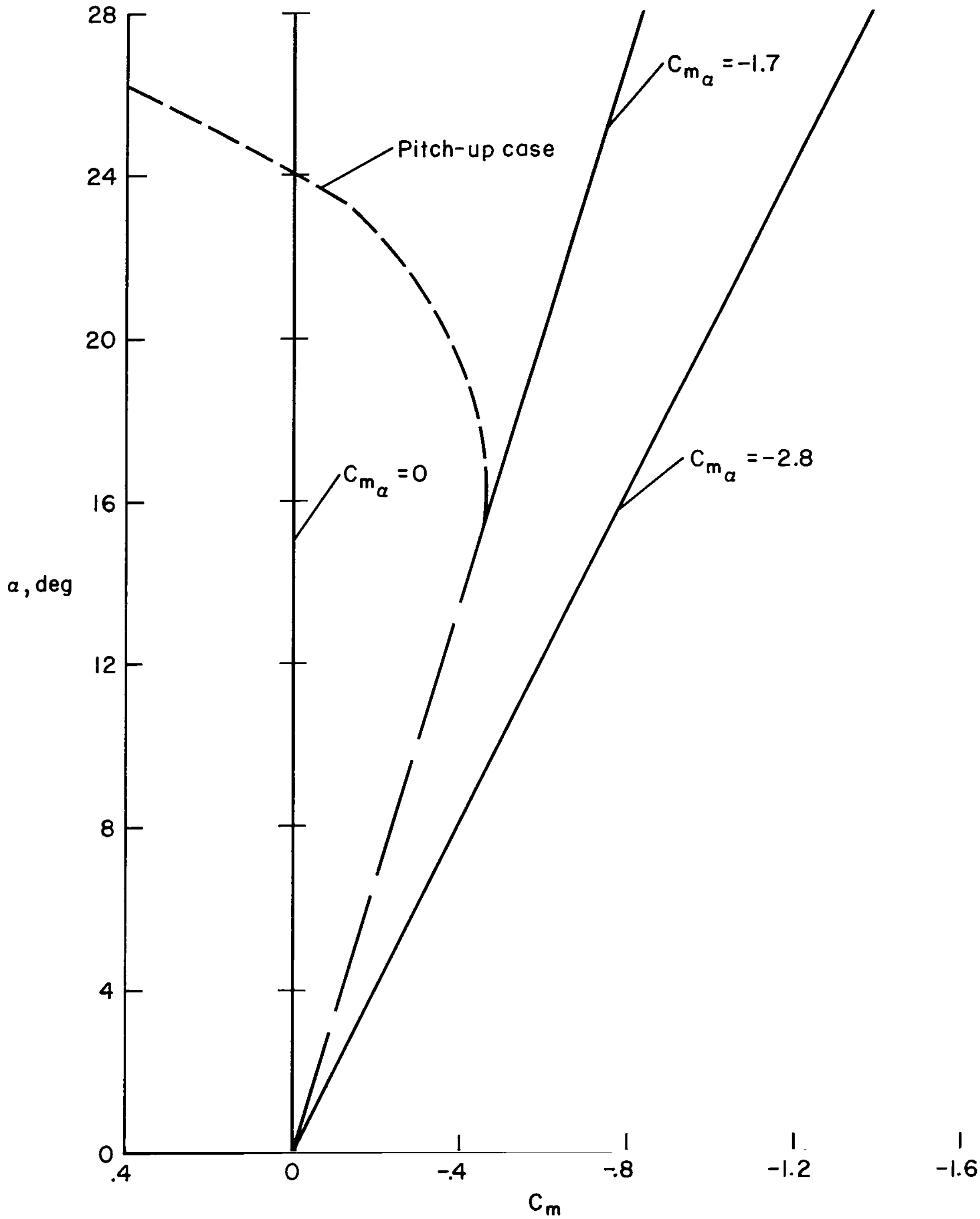


Figure 4.- Functional block diagram of the simulator components.



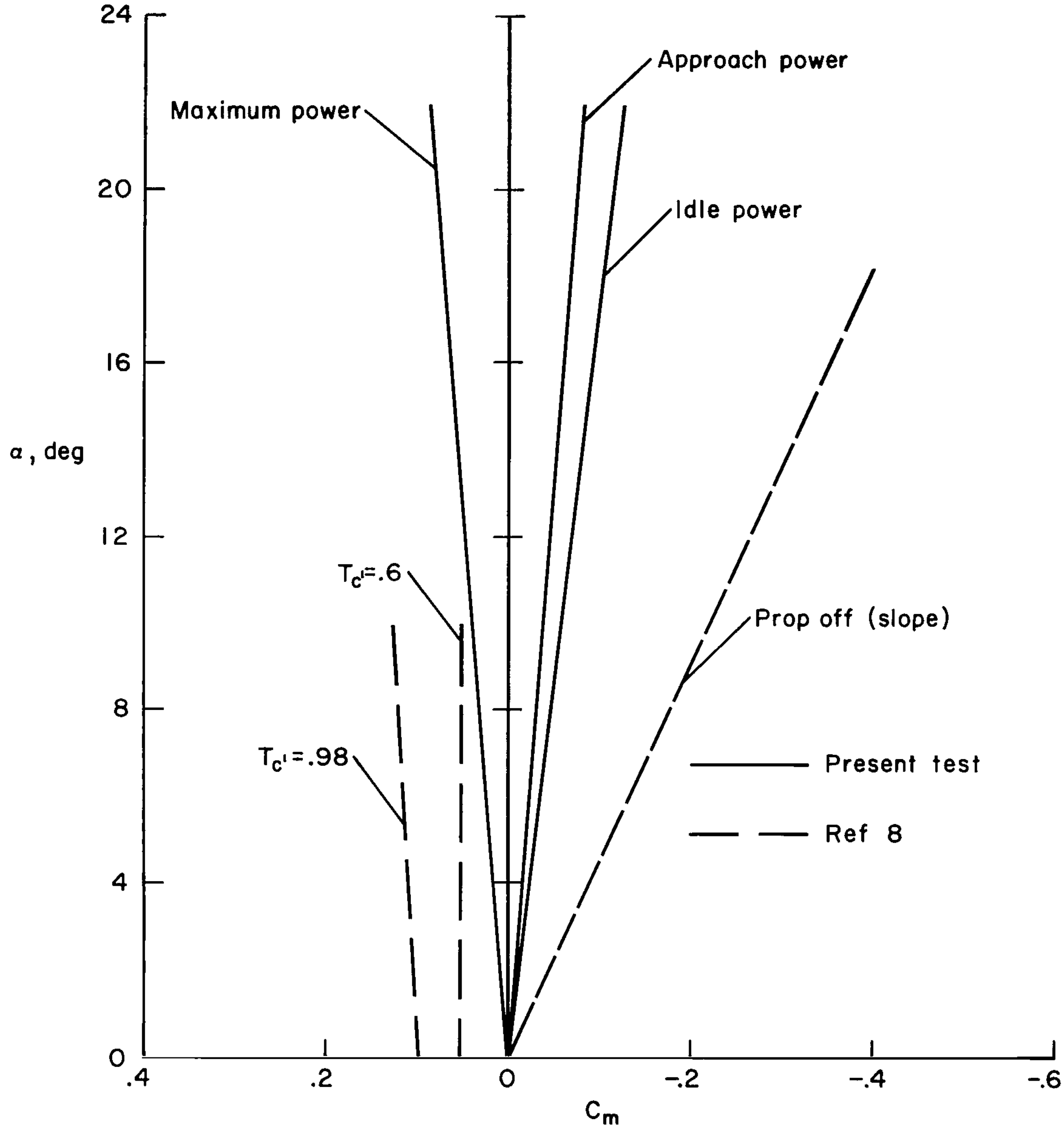
(a) Performance envelope.

Figure 5.- Performance and static longitudinal stability characteristics.



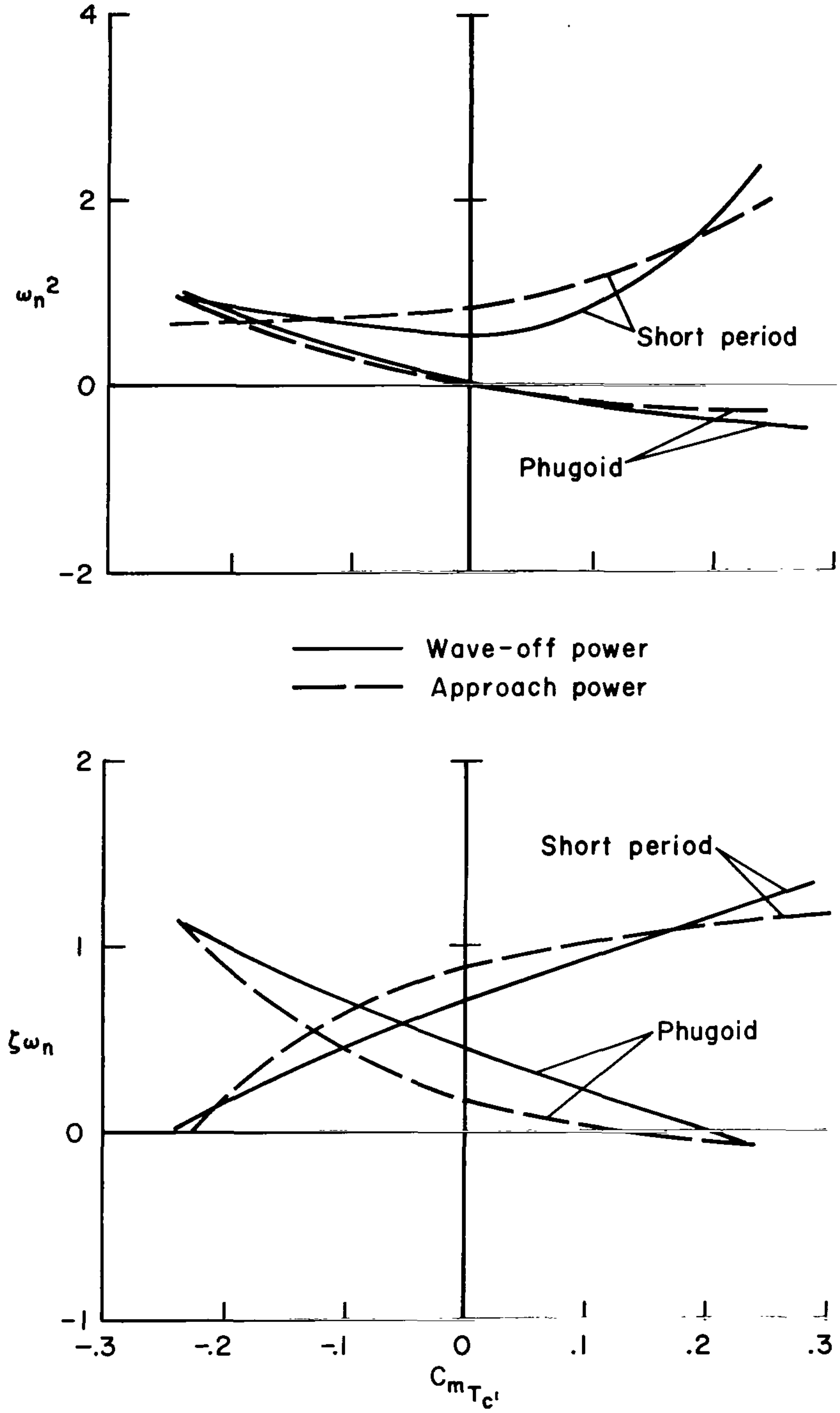
(b) C_m versus α

Figure 5.- Continued.



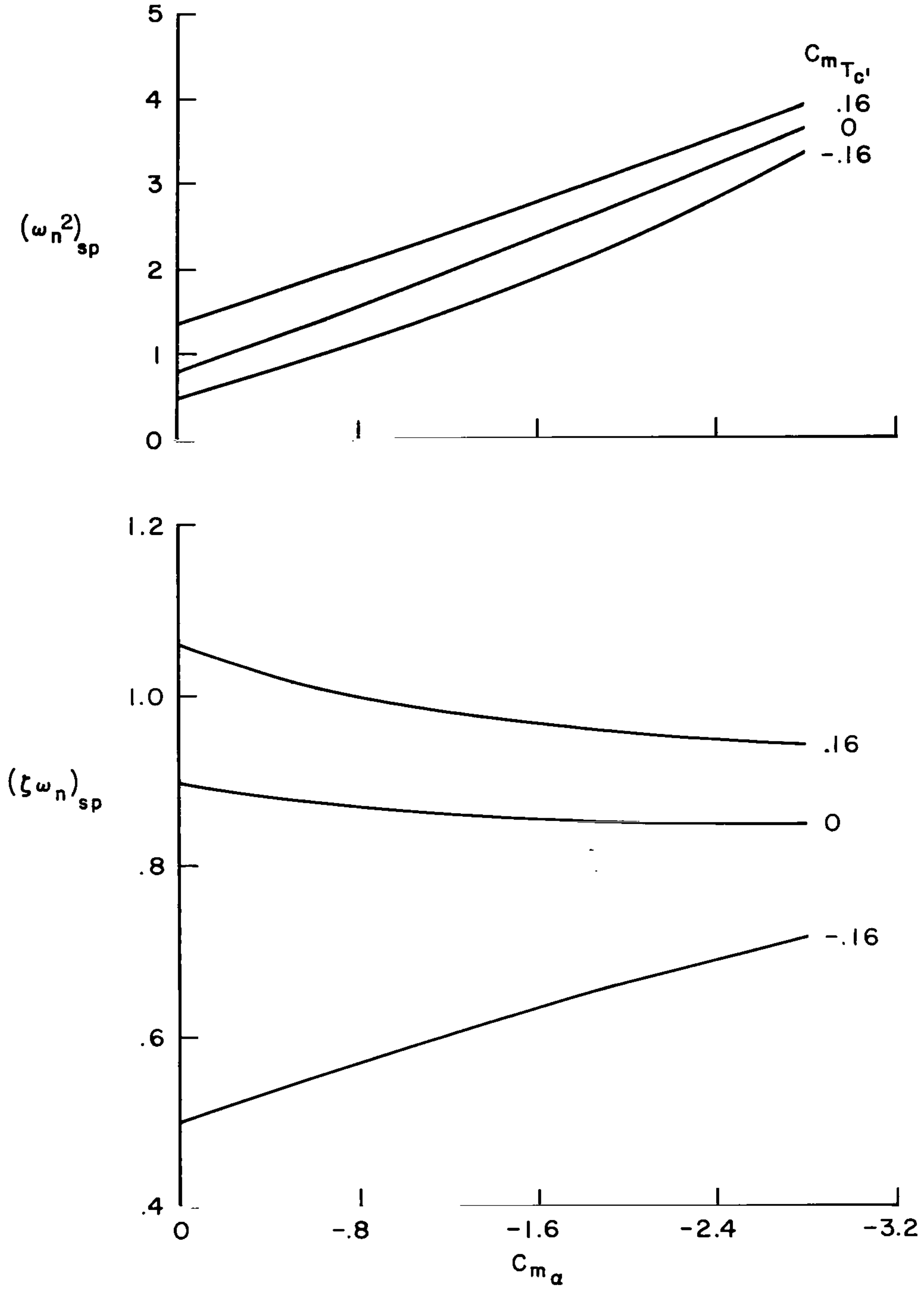
(c) C_{m_α} versus α as a function of T_c'.

Figure 5.- Concluded.



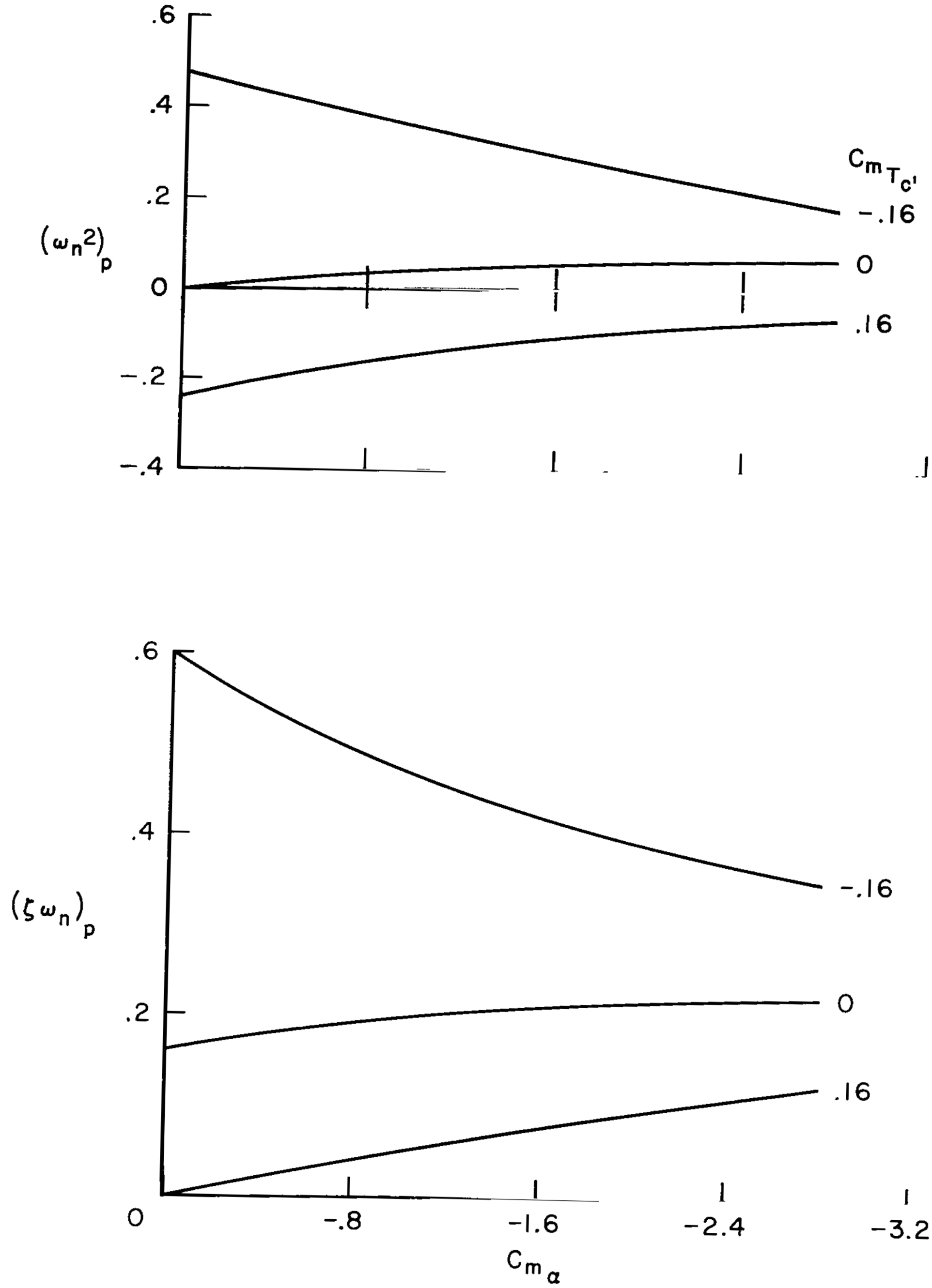
(a) Phugoid and short period ($C_{m_\alpha} = 0$).

Figure 6.- Longitudinal stability as a function of C_{m_α} and engine location.



(b) Short period (approach power).

Figure 6.- Continued.



(c) Phugoid (approach power).

Figure 6.- Concluded.

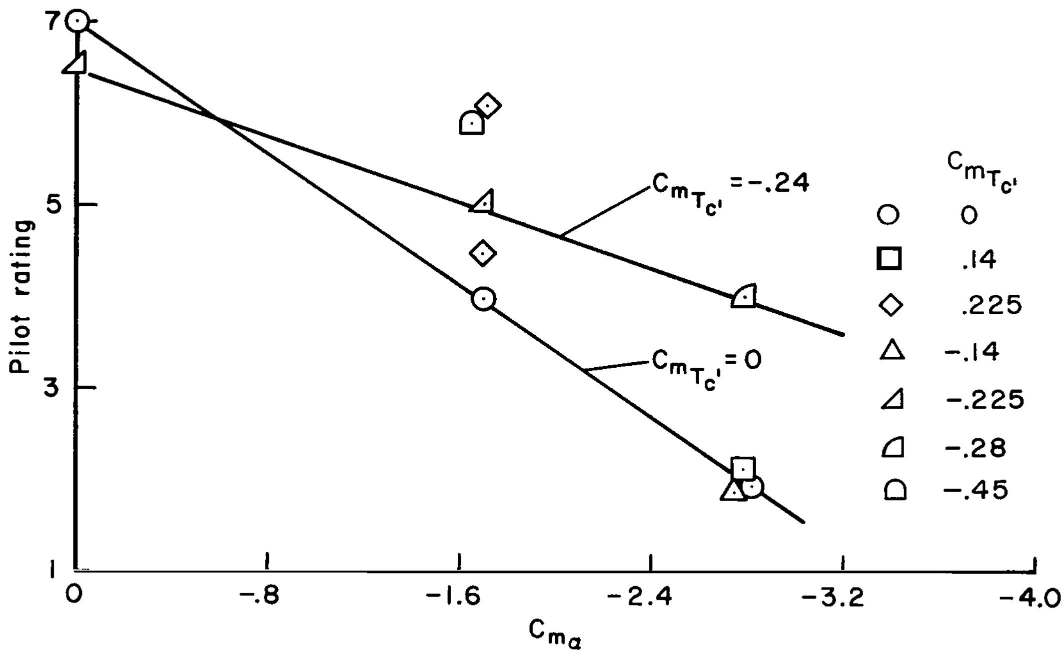


Figure 7.- Pilot ratings of approach-path controllability.

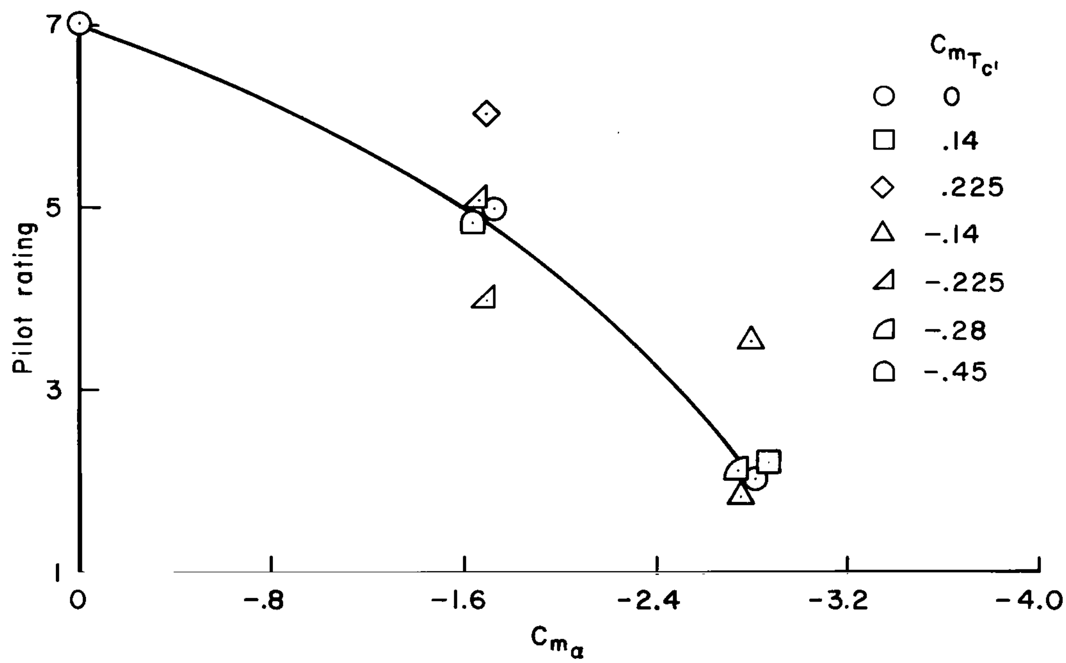


Figure 8.- Pilot ratings of controls fixed stability characteristics.

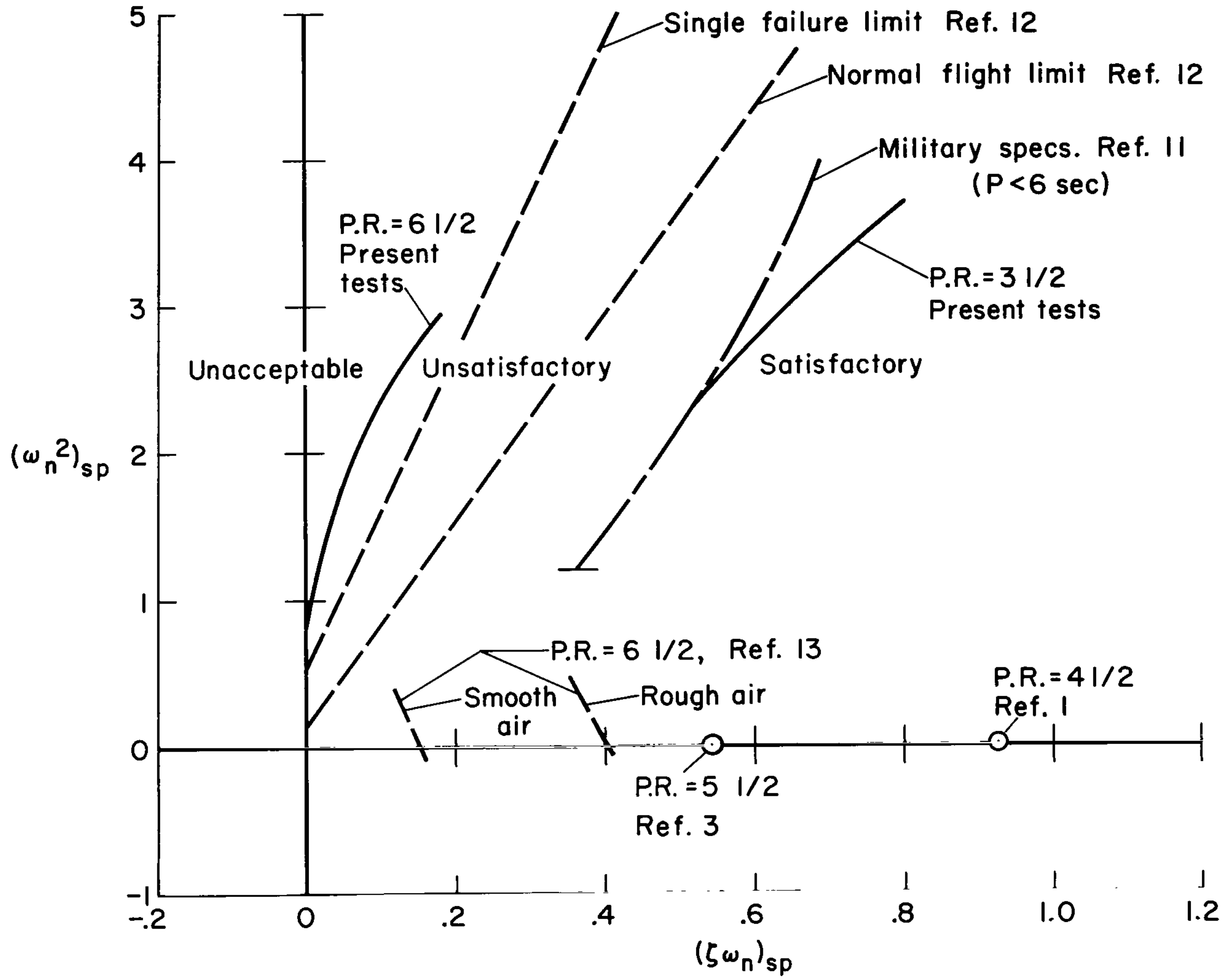


Figure 9.- Pilot opinion boundaries for approach-path control and stability.

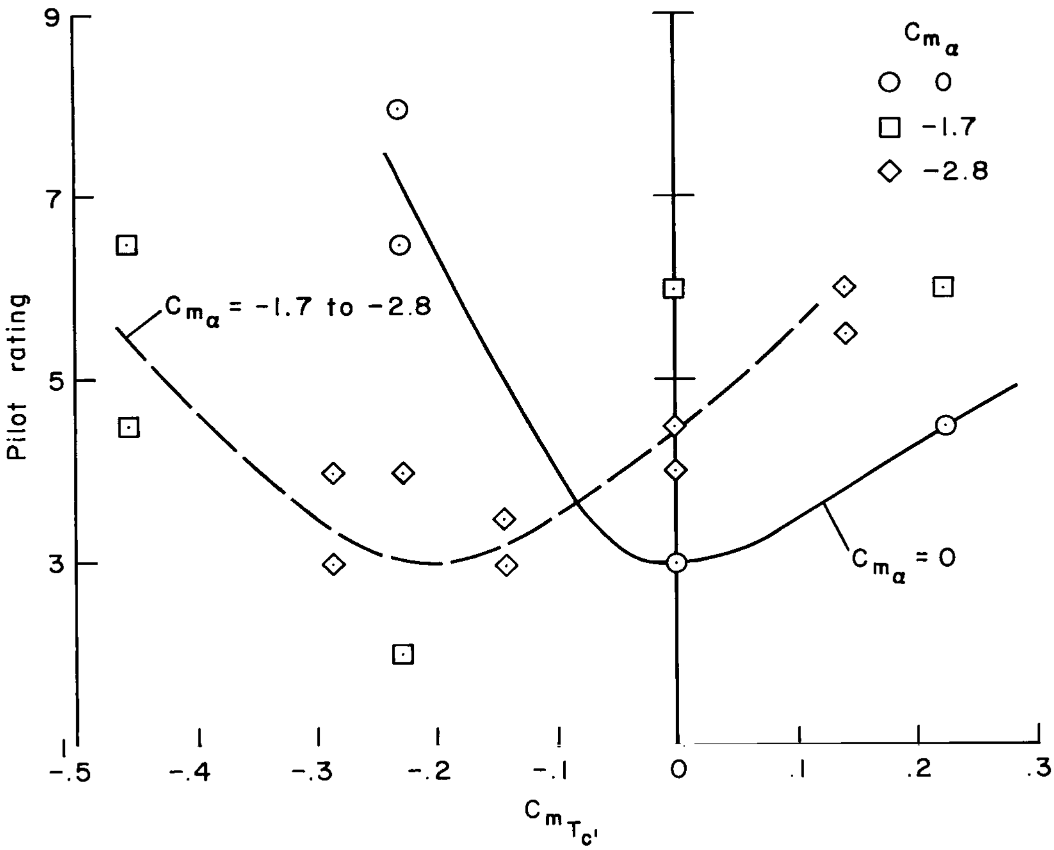
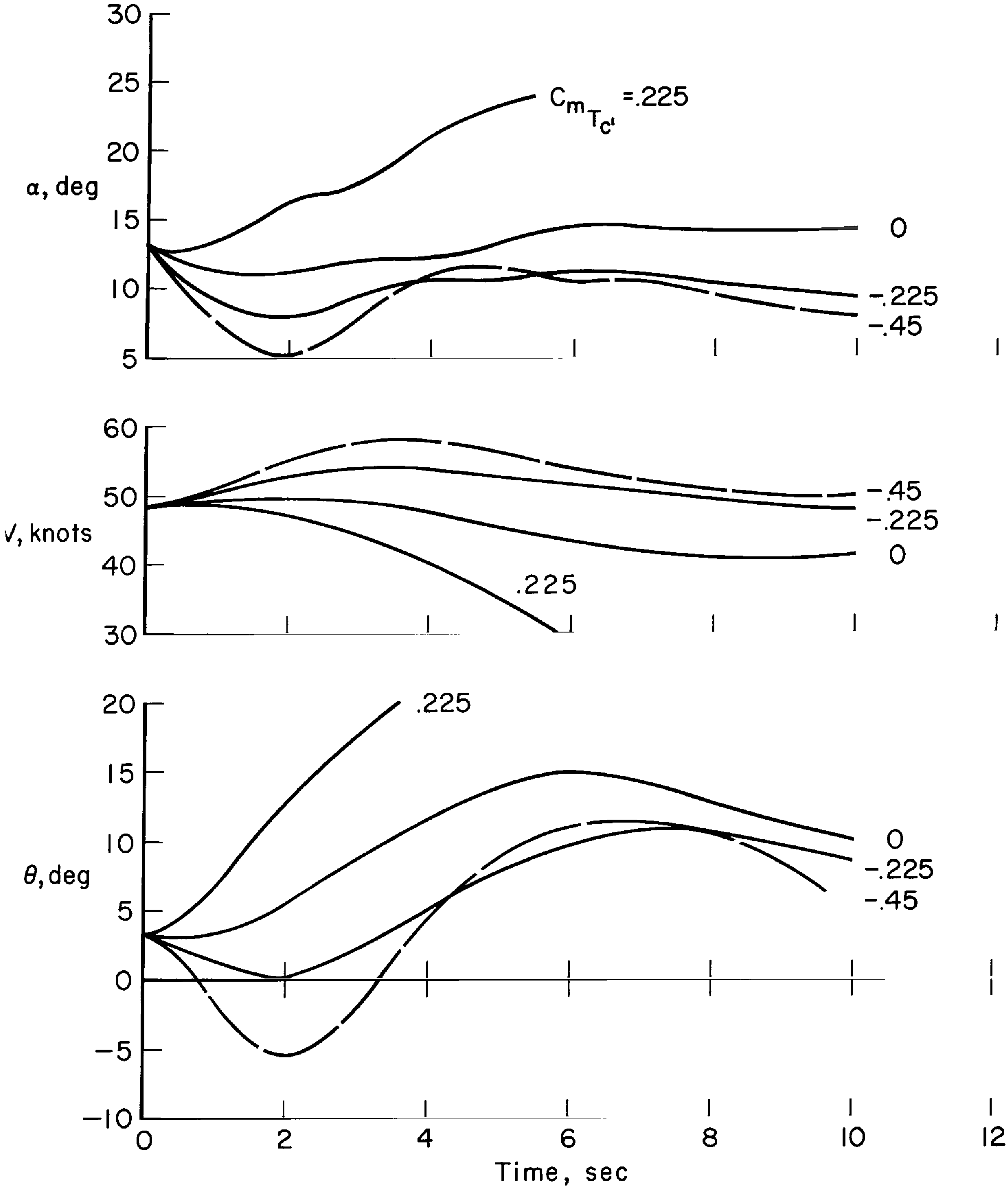
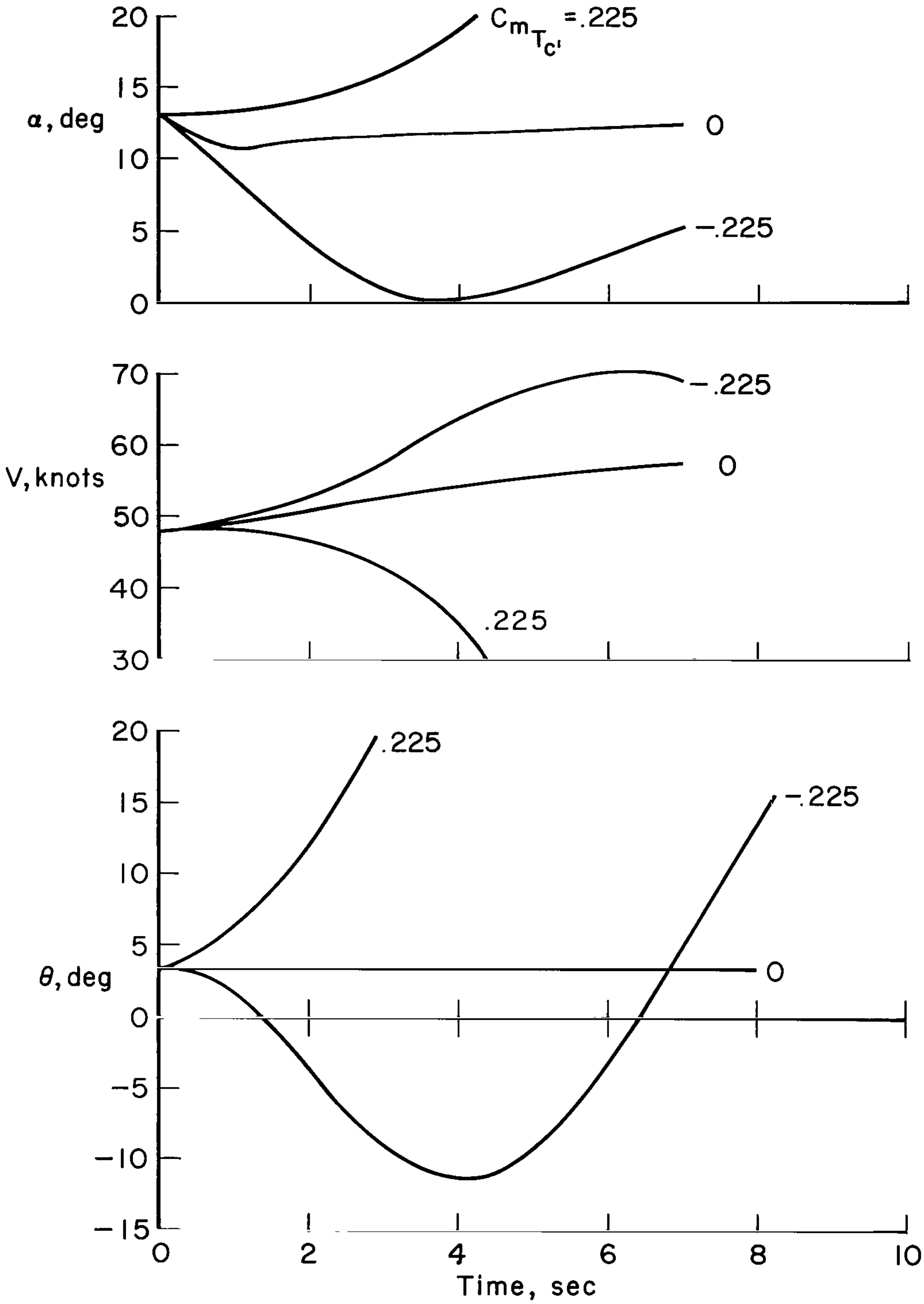


Figure 10.- Pilot ratings for the wave-off task.



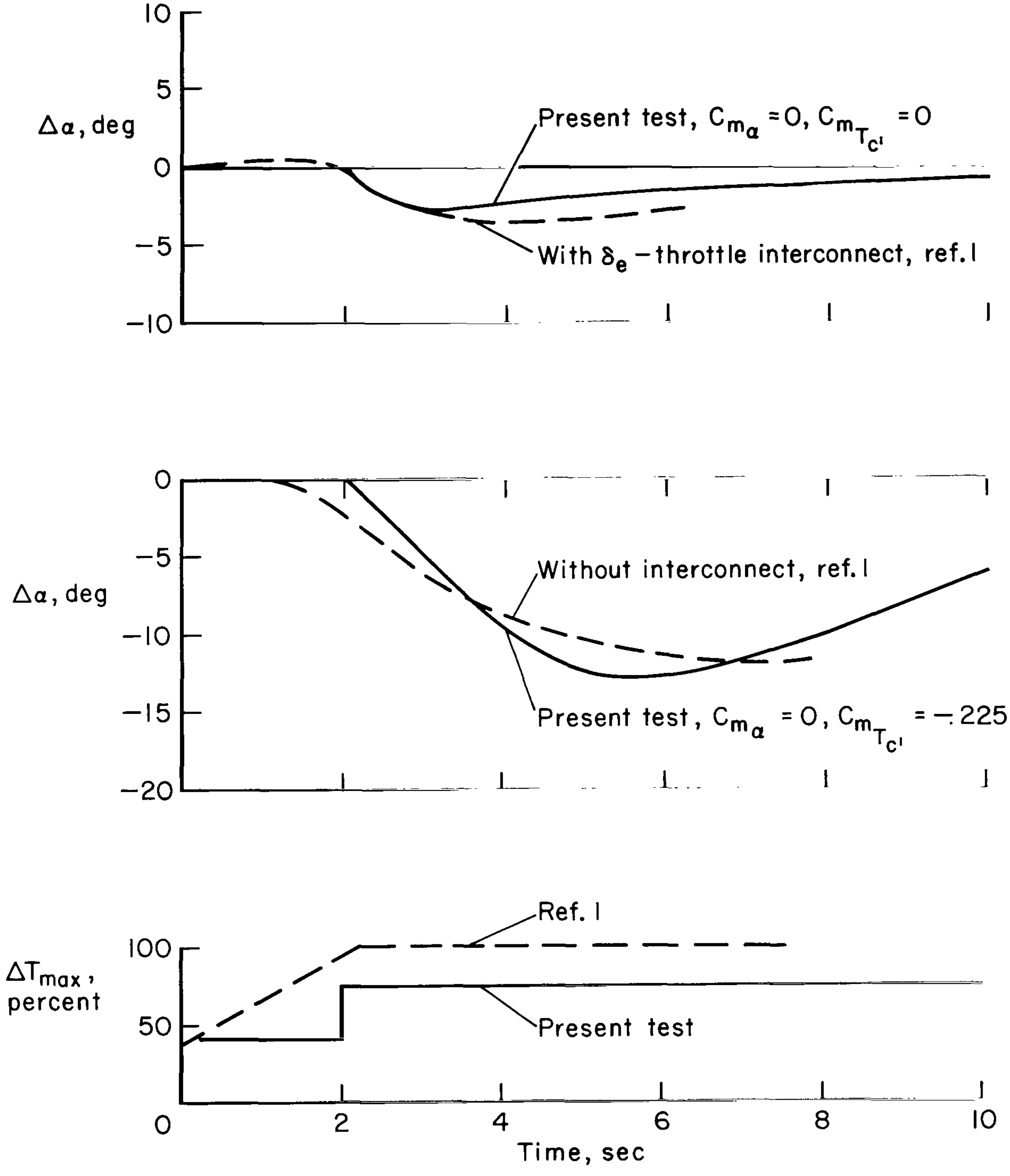
(a) $C_{m_\alpha} = -1.7$

Figure 11.- Airplane response to throttle steps.



(b) $C_{m_{\alpha}} = 0$

Figure 11.- Continued.



(c) Flight.

Figure 11.- Concluded.

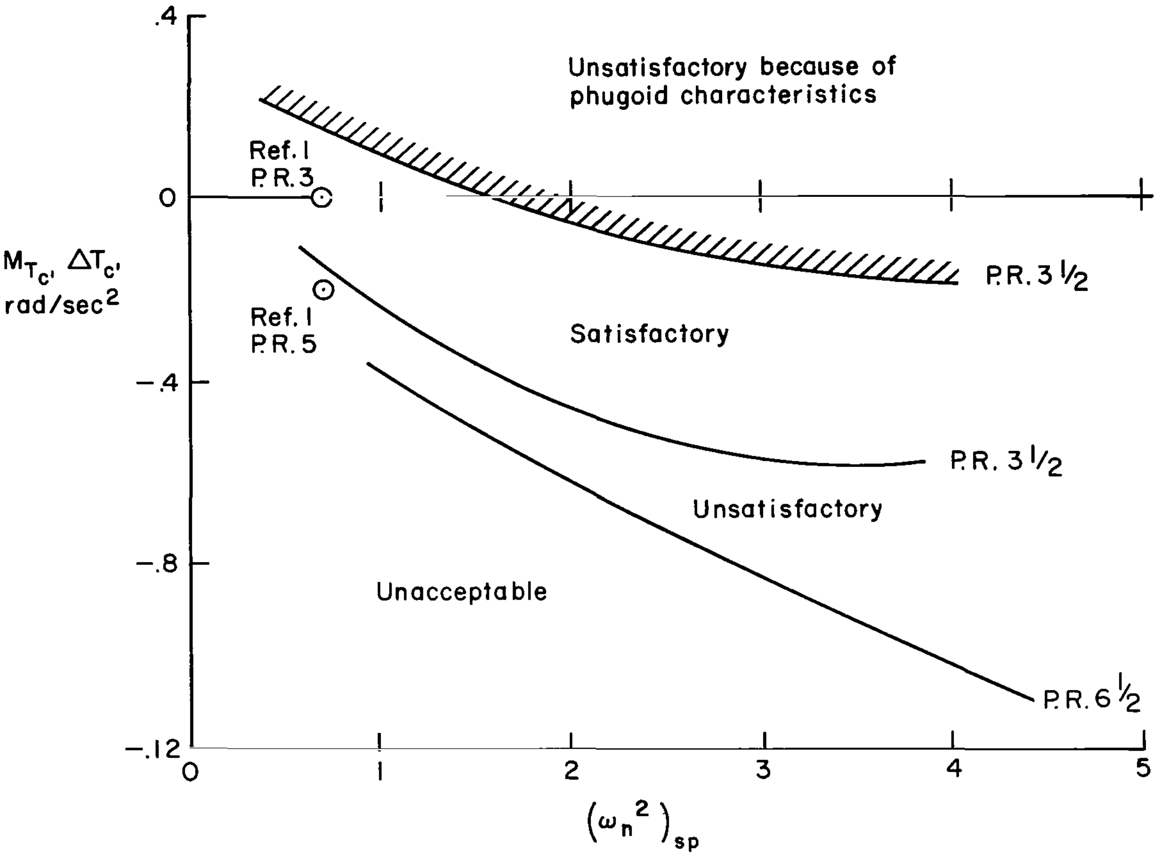


Figure 12.- Pilot rating boundaries for the wave-off task.

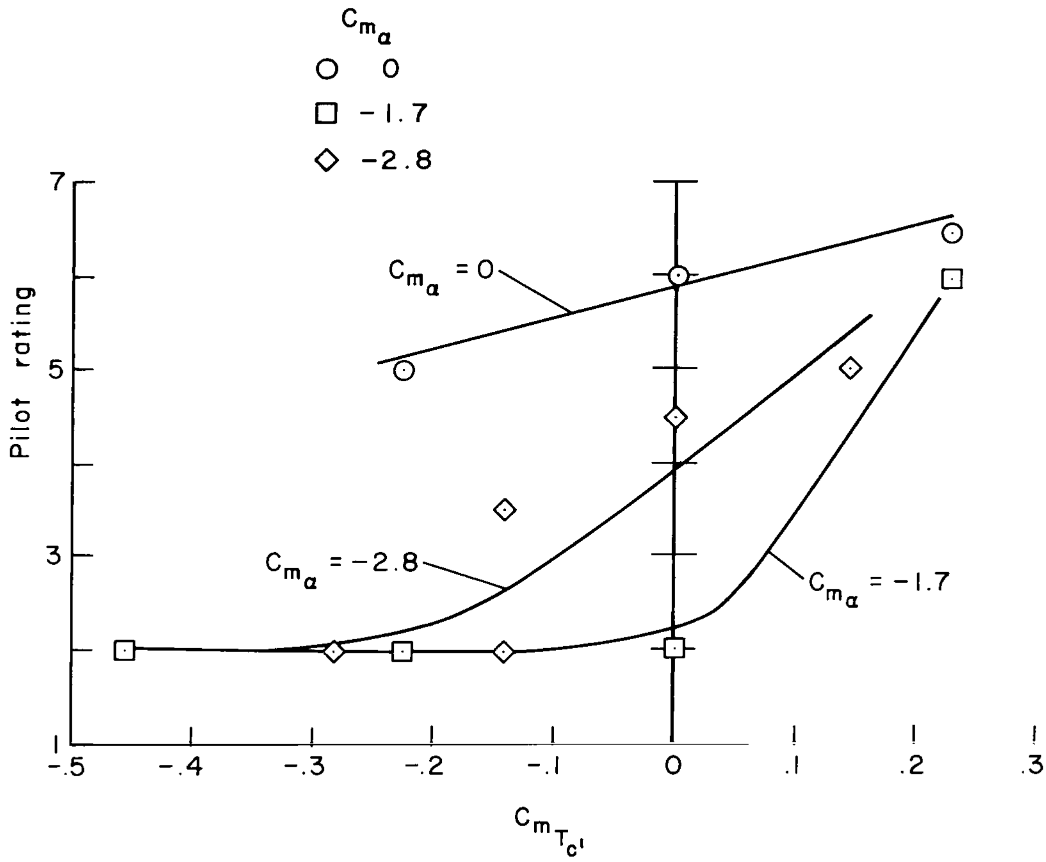


Figure 13.- Pilot opinions for the engine failure tests.

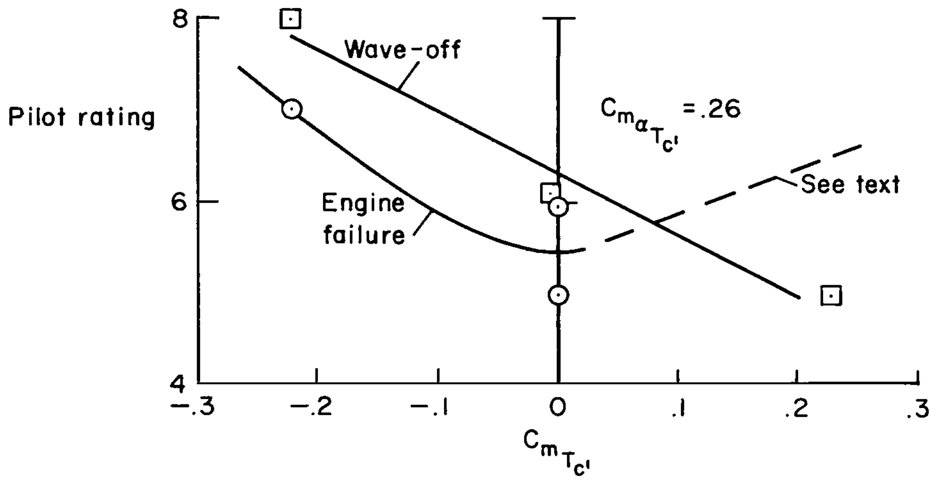


Figure 14.- Pilot opinions of stability change with power tests.

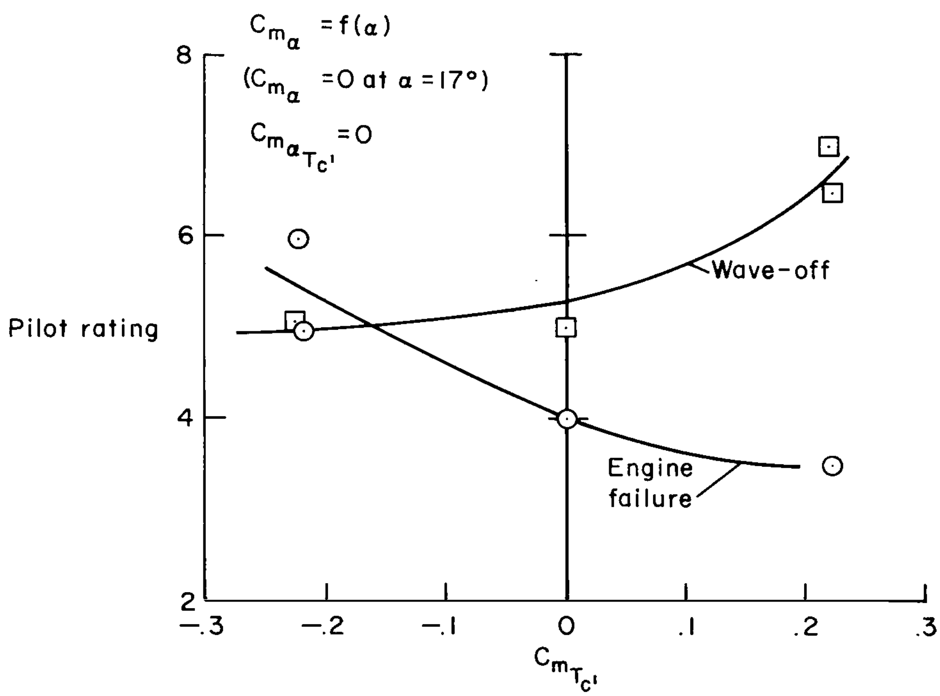


Figure 15.- Pilot opinions of the pitch-up.

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Technical information generated in connection with a NASA contract or grant and released under NASA auspices.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

TECHNICAL REPRINTS: Information derived from NASA activities and initially published in the form of journal articles.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities but not necessarily reporting the results of individual NASA-programmed scientific efforts. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546