NASA TECHNICAL NOTE

NASA TN D-6811

c. /

NASA TN D-6811

IN-FLIGHT PILOT EVALUATIONS OF THE FLYING QUALITIES OF A FOUR-ENGINE JET TRANSPORT

by Euclid C. Holleman and Glenn B. Gilyard

Flight Research Center
Edwards, Calif. 93523

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • MAY 1972

1. Report No. NASA TN D-6811	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle IN-FLIGHT PILOT EVALUATIONS OF THE FLYING QUALITIES OF A FOUR-ENGINE JET TRANSPORT		5. Report Date May 1972
		6. Performing Organization Code
7. Author(s) Euclid C. Holleman and Glenn B. Gilyard		8. Performing Organization Report No. H-680
		10. Work Unit No. 126-62-10-00-24
9. Performing Organization Name and Address NASA Flight Research Center P. O. Box 273 Edwards, California 93523		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Note
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D. C. 20546		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The flying qualities of the CV-990 jet transport were evaluated over the normal operating flight envelope and in smooth air to provide baseline data for transport airplanes. Pilot ratings of airplane handling characteristics for specific test conditions and configurations from approach to normal cruise were compared with various flying qualities criteria. In general, the CV-990 flying qualities were evaluated as satisfactory, and the evaluations supported transport flying qualities criteria. The Dutch roll damping was rated more satisfactory than was predicted by the flying qualities criteria. The pilots found rudder coordination for the yaw generated during high roll rates very difficult. They preferred to control with roll and pitch controls and to use the yaw damper to provide the required rudder coordination.

17. Key Words (Suggested by Author(s)) Transport airplane; Longitudinal and lateral-directional flying qualities; Pilot ratings	18. Distribution Statement Unclassified - Unlimited		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 52	22. Price* $3.00

*For sale by the National Technical Information Service, Springfield, Virginia 22151

IN-FLIGHT PILOT EVALUATIONS OF THE FLYING QUALITIES OF A FOUR-ENGINE JET TRANSPORT

Euclid C. Holleman and Glenn B. Gilyard
Flight Research Center

INTRODUCTION

Present jet transport airplanes have been accepted by pilots and passengers as a significant advancement over previous transports; however, a review of the published literature concerning flying qualities for jet transports revealed little pilot evaluation data and flight-measured response and aerodynamic derivative data. The documentation of present jet transport flying qualities and response characteristics will provide a basis for future transport flying qualities criteria. Therefore, the flying qualities of the CV-990 jet transport were evaluated, and the response of the airplane to control inputs was analyzed for aerodynamic stability and control derivatives. Four pilots evaluated the flying qualities during typical transport operational maneuvers within the normal operating flight envelope.

Pilot evaluations of longitudinal and lateral-directional handling are presented in this report. The aerodynamic stability and control derivatives of the airplane are summarized in reference 1, and pilot evaluations of lateral controllability during landing approaches are given in reference 2.

SYMBOLS

Physical quantities in this report are given in the International System of Units (SI) and in U.S. Customary Units. The measurements were taken in Customary Units. Details concerning the use of SI, together with the physical constants and conversion factors, are given in reference 3.

k	ratio of commanded roll performance to applicable roll performance requirement (ref. 4)
L_α	dimensional lift-curve slope, 1/sec
$L_\delta \delta$	total roll angular acceleration or total roll power available from roll control, rad/sec^2
M	Mach number

$\frac{n}{\alpha}$ — steady-state normal acceleration change per unit change in angle of attack for an incremental elevator change, g/rad

P_p — period of phugoid mode, sec

p — roll velocity, deg/sec

p_{max} — maximum rolling velocity, deg/sec or rad/sec

$\frac{p_{osc}}{p_{av}}$ — ratio of oscillatory component of roll rate to average component of roll rate following step aileron command (ref. 4)

r — yaw rate, deg/sec

t_{30} — time for bank angle to change 30°, sec

V_i — indicated airspeed, knots

β — sideslip angle, deg

$\Delta\beta_{max}$ — maximum sideslip excursion at center of gravity occurring within 2 seconds or one-half period of the Dutch roll oscillation, whichever is greater, for a step aileron control command (ref. 4)

ζ — damping ratio of longitudinal short-period mode

ζ_d — damping ratio of Dutch roll mode

ζ_p — damping ratio of phugoid mode

τ_R — roll mode time constant, sec

τ_S — spiral mode time constant, sec

φ — bank angle, deg

ψ_β — phase angle expressed as a lag for a cosine representation of the Dutch roll oscillation in sideslip, deg (ref. 4)

ω_d — undamped natural frequency of Dutch roll mode, rad/sec

ω_n — undamped natural frequency of longitudinal short-period mode, rad/sec

ω_φ undamped natural frequency of the roll-per-aileron transfer function numerator, rad/sec

AIRPLANE DESCRIPTION

The CV-990 airplane is a swept-wing, swept-tail, four-engine jet transport (figs. 1 and 2) designed for cruise at approximately $M = 0.85$ at altitudes up to approximately 12,200 meters (40,000 feet). The weight of the test airplane ranged from approximately 90,700 kilograms (200,000 pounds) to approximately 58,970 kilograms (130,000 pounds). Overall dimensions are given in table 1.

The airplane was controlled conventionally but had a yaw damper and Mach trim compensation device. A Sperry SP-30 flight control system (yaw damper) provided center-of-gravity transverse acceleration compensation and yaw damping. Forward and center-of-gravity transverse accelerometers provided a signal that, after being filtered and lagged, actuated the rudder control. The speed stability system, or Mach trim compensator, counteracted the nose-down pitching moments that resulted from increased Mach number in the transonic speed range: It trimmed the horizontal stabilizer to a more airplane nose-up position, thereby providing a positive stick force gradient. Mach trim was limited to 2.5° of stabilizer deflection.

Aerodynamic Controls

The airplane's aerodynamic controls consisted of the following movable surfaces: ailerons, spoilers, wing flaps, leading edge flaps, elevators, horizontal stabilizer, and rudder. The primary pilot controls were ailerons, spoilers, rudder, and elevator.

The ailerons and spoilers provided lateral control. The ailerons were actuated by aerodynamic boost from pilot-controlled aileron flight control tabs. The flight tabs deflected ±20° and commanded ±15° of aileron deflection. Internal balance panels reduced pilot control forces to desirable levels.

Two spoilers were mounted on the top surface of each wing forward of the inboard and outboard flaps. They were hydraulically actuated and provided about 80 percent of the total lateral control. Full travel deflection limits of the spoilers were 60° for the inboard spoilers and 75° for the outboard spoilers. The spoiler deflection angles were limited by the hinge moment capabilities of the actuators operating with full hydraulic pressure.

For directional control a 30-percent-chord rudder was provided that was controlled hydraulically or manually through conventional rudder pedals. For manual control a one-to-one control-tab-to-rudder deflection and a trim tab were provided. Maximum available rudder deflection was physically limited to 25° and to allowable limits by the hinge moment capability of the dual hydraulic system. Complete dual hydraulic system failure resulted in automatic reversion to conventional aerodynamic control. Rudder pedal force was a function of aerodynamic hinge moment, deflection of the centering spring, and differential cable motion in the manual mode. In the powered mode it was a function of the dynamic-pressure-sensitive feel system, spring, and cable motion.

Longitudinal control was accomplished by moving either control column forward or aft. The motion was transmitted to the flight tabs, which moved opposite to the desired elevator movement. Auxiliary elevator tabs were geared to the elevator and tended to keep the elevators faired to the stabilizer. Elevator travel limits were 25° up and 12° down from the streamlined stabilizer position. Flight tab limits were 12° up and 25° down from streamline. Elevator auxiliary tab travel was approximately 4° to 25° trailing edge down.

The horizontal tail was used for longitudinal trim by varying its angle of incidence. This control was actuated either hydraulically, electrically, or mechanically. It was also positioned by the autopilot and speed stability system.

Two slotted Fowler flaps were installed on either side of the aileron on the trailing edge of the wing. The flap design provided high lift and low drag when partially extended and high lift and high drag when fully extended. The flaps had five detents (0°, 10°, 27°, 36°, and 50°). Eight leading edge Krueger flaps were hinge-mounted to the underside of each wing at about the 2-percent-chord position. These flaps were fully closed or extended and were used for takeoff and landing. They extended from 96° to 118°, the deflection increasing from inboard to outboard along the wing span. However, for 50° trailing edge flaps the inboard leading edge flap sections were retracted to reduce buffet.

Pilot Controls

Side-by-side control wheels of conventional design were provided for the pilot and copilot. The copilot's wheel rotated ±63° and commanded full spoiler deflection and ±14° of aileron flight tab deflection. The pilot's wheel had a total travel of ±90° and commanded full 20° of aileron flight tab deflection and full spoiler deflection. The increased wheel travel of the pilot to 90° over the 63° of the copilot's control wheel was obtained by overriding a spring force of approximately 173.5 newtons (39 pounds) in the crossover tube which connected the two pilot's controls.

The rudder control system consisted of adjustable rudder pedals, a feel system, hydraulic control system, flight tab, and rudder. For normal operation rudder control was fully powered. Rudder feel was simulated by an impact-pressure-sensing system which varied resistance to rudder pedal movement to correspond to variations in airspeed. Maximum rudder deflection was ±25°.

The pilot's column was connected to the left elevator flight tab, and the copilot's column was connected to the right elevator flight tab. The columns were interconnected by two spring-loaded crossover tubes. Bobweights and balance springs were installed at the base of each pilot's column to provide desirable stick forces during turns. Elevator down springs provided stick-free stability. The down springs provided a restoring stick force exceeding the control system friction whenever the airplane speed was at least 10 percent below or above the trim speed. The down springs exerted the greatest force with the airplane in the clean configuration. The force was decreased as wing flaps were lowered. The friction force in the longitudinal control system was approximately 26.7 newtons (6 pounds).

PILOT EXPERIENCE

Four NASA engineering test pilots performed the in-flight evaluations. The pilots' experience varied from 26 years of flying and more than 10,000 flight hours to approximately 10 years of flying and 4000 flight hours. All had been military pilots, but none had airline transport flight experience, although two pilots had extensive flight experience piloting government transport aircraft. The pilots had flown a wide variety of aircraft including supersonic jet bombers and fighters, subsonic transports, research gliders, and helicopters. All were familiar with flying qualities and pilot rating evaluations. The pilot evaluation procedures used were similar to those discussed in reference 5. The pilot rating scale used is presented in table 2.

TEST CONDITIONS

The operational flight envelope covered during the investigation is shown in figure 3. Pilot evaluations of general handling were obtained for takeoff, climb, cruise, descent, slow cruise, approach, and landing. These maneuvers were performed according to the procedures recommended by the pilot's handbook. All flight conditions were within the FAA certificated flight envelope.

In addition, pilot evaluations of flying qualities were obtained at specific points in the flight envelope (fig. 4). Flight maneuvers were performed at these points and recorded for analysis of airplane aerodynamic stability and control derivatives (ref. 1). These derivatives were in turn converted to flying qualities parameters.

Flights were made only during good weather conditions; instrument conditions were simulated when necessary by hooding the evaluation pilot to prevent outside visual reference.

RESULTS AND DISCUSSION

General Flying Evaluations

Pilot evaluations of the handling of the CV-990 jet transport were obtained throughout the operational flight envelope, and comments were recorded on tape immediately after the evaluations. Only normal maneuvering was required; however, the pilots made additional evaluation maneuvers as desired. The pilot evaluation guides are presented in appendix A. A report of turbulence using the weather bureau's turbulence reporting criteria (ref. 6) was part of each evaluation. Only very light turbulence, which did not significantly affect the evaluations, was reported.

Average pilot ratings from the evaluations are shown in figure 5 for various parts of the flight envelope. Actual ratings are summarized in table 3. The pilot ratings are relatively uniform throughout the flight envelope. The results are for maneuvers made with the yaw damper on except for takeoff, approach, and landing; however, for general operational flying in smooth air little yaw damper effect was noted. Pilot comments concerning the takeoff, climb, cruise, descent, slow cruise, and approach and landing are summarized in the following sections. Detailed pilot comments are presented in appendix B.

Takeoff.— The longitudinal control forces required for rotation for takeoff were reasonable and were estimated to be approximately 133 newtons to 178 newtons (30 pounds to 40 pounds). The ability to accelerate to and hold a desired airspeed was satisfactory. Maintaining takeoff attitude at 15° required concentration: The nose tended to ease over slightly because of speed change and flap retraction, and the pilot had to work to hold the nose up. The longitudinal control force for small corrections in airspeed or attitude was generally light. The wheel-force-to-elevator gradient was approximately 18 newtons (4 pounds) per degree. During climbout, roll control force was approximately 4 newtons to 9 newtons (1 pound to 2 pounds) per degree of wheel rotation. With the pitch control force gradient about twice the value for roll, the control force harmony was good. Lateral control was sensitive for holding a steady wing position. Simulating an instrument takeoff resulted in a slight tendency to overcontrol laterally. Because of this tendency the lateral control was considered to be less satisfactory than the longitudinal control. Longitudinal control was positive, but control forces were considered to be high. Longitudinal stability and damping were satisfactory.

The ability to hold heading was good with the yaw damper inoperative (normal operation for takeoff). Rudder forces were considered to be high. With the powered rudder the pedal forces were a function of pedal position and dynamic pressure, but primarily a function of dynamic pressure. The rudder pedal force per degree of rudder deflection was approximately 22 newtons (5 pounds).

Directional control and handling were rated satisfactory during takeoff with an engine inoperative. During training flights lateral oscillations were sometimes pilot-sustained following loss of thrust of one engine; however, with training the pilots learned to minimize lateral control and thereby avoided inducing a lateral oscillation. Lateral-directional handling was also good during a takeoff with a 15-knot crosswind.

Climb.— During transition to climb speed there was a tendency for speed to increase; however, once speed was established it was easy to hold with moderate monitoring. Operation of the Mach trim system was excellent. The trim rate (0.25 deg/sec) was satisfactory for climb, and leveling off at the desired altitude was accomplished easily. For small control movements during normal climb in smooth air, there was no measurable difference between airplane controllability with the yaw damper on or off. The yaw damper was very effective in coordinating the required rudder when high roll rates were commanded. The longitudinal control was judged to be more acceptable than the lateral control, because there was a tendency to induce oscillations with the lateral control (as discussed later). The longitudinal and lateral control forces were slightly higher than desired. The longitudinal-control-force-to-elevator gradient was approximately 53 newtons to 67 newtons (12 pounds to 15 pounds) per degree, and the roll-control-force-to-aileron deflection was approximately 9 newtons (2 pounds) per degree. Both force gradients increased with increasing dynamic pressure. The lateral control forces were more acceptable because the higher forces helped reduce the tendency to induce lateral oscillations. Airplane stability, damping, and response to control were evaluated as good in all axes. The rudder control was not normally used during the climb.

Cruise.– Trimming to level flight was accomplished easily, and the ability to hold heading, altitude, and Mach number was good. Spiral stability was near neutral and presented no control problem. Roll control was satisfactory at slow rates of roll used to bank 30° or less. The yaw generated by small control wheel deflections could be controlled with the rudder. Rudder coordination by the pilot was not required with the yaw damper on. The damper provided rudder coordination. The larger roll control angles required for high roll rates resulted in undesirable spoiler buffet and drag. High roll rates first produced proverse yaw and then adverse yaw. The pilots had difficulty coordinating the rudder control, and usually did not attempt to coordinate rudder for the proverse yaw; but they did coordinate the rudder to minimize adverse yaw. Considering the roll control in terms of the ability to roll out precisely on a desired heading, control of heading during turns with bank angles of 20° or less was satisfactory with the yaw damper on or off. It was much more difficult to roll out on a desired heading, yaw damper on or off, from bank angles of 45° or greater. Control coordination was more difficult.

The lateral and longitudinal control forces appeared to be higher at cruise speeds than during climb. (Actually, the control force gradients were nearly the same at normal cruise as during climb, because the dynamic pressure was about the same.) The control harmony was good. In general, the controls at cruising flight were evaluated as satisfactory. The longitudinal stability and damping were good. Directional stability was good, and directional damping without the yaw damper operating was low but satisfactory for the cruise flight condition evaluated.

Descent.– In general, the airplane stability and control characteristics were satisfactory during descent, even during a simulated upset and recovery. The lateral and longitudinal control forces appeared to increase more rapidly above 300 knots indicated airspeed and were judged to be higher than desired. Control forces were higher if the descent dynamic pressure was higher. Two examples of force gradients were approximately 13 newtons (3 pounds) per degree of aileron for roll control and approximately 71 newtons to 89 newtons (16 pounds to 20 pounds) per degree of elevator for longitudinal control. The control harmony was good. The airplane was easily controlled with the yaw damper on or off. Lateral-directional damping was low (damping ratio of approximately 0.05) with the yaw damper off; however, yaw damping was satisfactory. The longitudinal stability and damping were good.

Slow cruise.– The transition to slow cruise flight typical of a holding pattern was easy, with little trimming required. The ability to hold heading deteriorated slightly from the cruise condition; the airplane tended to wander some in heading at the reduced speed. The phugoid mode was divergent, was easily disturbed, and made close control of altitude slightly more difficult. The airplane responded to power changes, but this speed-power range required a great deal of throttle modulation to maintain constant speed. A small spoiler deflection slowed the airplane, and more power was required. Airplane response to control at the slow rates of attitude change typical of instrument flight was good. At high roll rates the response was rapid, and the ability to stop at the bank angle desired was much more difficult. More anticipation or lead was required of the pilot than was desired to perform precise turns.

The longitudinal stability and damping and lateral-directional stability and damping with yaw damper operating were good. Lateral and longitudinal control forces were slightly higher than desired for small bank angle maneuvering, but control harmony was good. The lateral control gradient was approximately 4 newtons (1 pound) per degree of aileron deflection, and the longitudinal control gradient was approximately 36 newtons (8 pounds) per degree of elevator control. One pilot noted a small deadband in the control yoke which detracted from precise controllability.

Approach and landing. – The pilots evaluated normal approaches and landings in smooth air. One landing was made in a 15-knot crosswind.

The airplane was easily disturbed and lightly damped ($\zeta_d \approx 0.03$) laterally-directionally, resulting in wallowing in light turbulence with poor heading control. The oscillation could be sustained, and even increased, by the roll control, so the pilot had to be careful with roll control inputs. Coordinating rudder and roll controls was difficult. Most pilots controlled with the wheel control only. Although the pilots evaluated this flight phase as poorer than the others, the airplane was considered to be acceptable. Directional control after landing was satisfactory.

Pilot Evaluations at Specific Flight Conditions

In addition to obtaining pilot evaluations of transport airplane flying qualities during normal operational maneuvering, pilot evaluations and airplane responses were obtained at specific flight-test conditions (fig. 4). The pilot ratings are summarized in table 4 (longitudinal) and table 5 (lateral-directional). Evaluation guidelines were suggested and were generally followed. Airplane responses to controls were recorded at each flight condition and analyzed for aerodynamic stability and control derivatives (ref. 1). Converting these data to flying qualities parameters allowed pilot rating evaluations of this typical subsonic jet transport to be compared with flying qualities criteria such as the Military Specification (ref. 4). The approach-to-land configuration was emphasized because fewer airplane response data and pilot-rating data correlations exist in this region. Typical pilot comments are given in appendix C.

Phugoid mode.– The phugoid mode of the airplane at various test conditions was recorded for analysis. Following the recording the airplane was stabilized at the test altitude and velocity and its response in the phugoid mode and the ability of the pilot to control and damp the motion were evaluated and rated.

The damping of the phugoid mode (fig. 6) of the airplane with 27° flaps and gear down appeared to increase from neutral damping at an indicated airspeed of 140 knots (table 4) to a damping ratio of approximately 0.1 at 195 knots. The phugoid damping also increased as indicated airspeed decreased from 140 knots to 120 knots. The phugoid damping variation with indicated airspeed appears to result from front side to back side lift-to-drag-ratio operation. The data for the landing configuration (50° flaps and landing gear down) show a similar trend with change in airspeed. These phugoidal characteristics were rated 2 to 3, which may be interpreted as satisfactory.

The phugoid characteristics were also recorded at low altitude and airspeed with the airplane in the clean configuration and with only the landing gear down. For these two configurations the phugoid damping was divergent and the pilot ratings were 4 and 7. The pilots appreciated positive damping.

The clean-configuration airplane at cruise flight conditions also had divergent phugoid damping ($\zeta_p = -0.04$). Pilot ratings of the controllability of the damping were

2.5 to 5.5. The amplitude of the phugoid motion doubled in as little as 1.5 cycles to 2 cycles; however, the frequency was low, approximately 0.01 cycle per second.

The Military Specification for piloted airplanes (ref. 4) requires that the airplane phugoid response have a damping ratio of 0.04 for level 1 flying qualities. For level 2 flying qualities the phugoid must have a damping ratio of at least zero, and for level 3 flying qualities a minimum of 55 seconds to double amplitude. Neither airplane class nor flight phase category is specified.

The CV-990 in the approach configuration was evaluated as satisfactory (pilot rating less than 3.5), which supports the Military Specification for level 1 flying qualities. In cruising flight with the airplane in the clean configuration, the phugoid mode was divergent and the configuration was rated 2.5 to 7. The pilot ratings were more lenient than the Military Specification; only one rating of unacceptable (pilot rating greater than 6.5) was given. (Pilot ratings of 3.5 to 6.5 are considered equivalent to level 2 flying qualities.)

No natural period or frequency requirements for the phugoid motion are set by the Military Specification. The phugoid period was long (40 seconds to 100 seconds) and the pilots could control and damp the phugoid response without difficulty. These evaluations were made during visual flight in which a phugoid mode might not present the control problem that it could during instrument flight.

Short-period dynamics.— The longitudinal short-period response characteristics and pilot evaluations are summarized in figure 7 and table 4. The short-period response characteristics were rated as satisfactory in both the approach and cruise configurations. The damping ratio of the longitudinal short-period mode was 0.4 or higher for all the test conditions. The Military Specification (ref. 4) requires damping ratios of 0.35 for transport airplanes during the approach (category C) and 0.30 during cruise flight (category B). The CV-990 pilot evaluation data agree with these requirements. The longitudinal frequencies at the low-speed approach condition are low, but the airplane response for the approach control task was acceptable.

The longitudinal short-period response is compared with the tentative criterion of reference 7 in figure 8. The CV-990 characteristics were rated acceptable, and most of the data are in the acceptable augmented region proposed by the reference. Some data are above this region, indicating that higher frequencies with good damping produce acceptable flying qualities.

Maneuvering requirements.— Pilot evaluations of maneuvering control were also obtained (table 4) and are compared with the Military Specification (ref. 4) requirements for approach in figure 9(a) and for cruise in figure 9(b). The CV-990 longitudinal maneuverability for all test conditions was evaluated as satisfactory for both flight phases; these evaluations agree with the Military Specification. Similar conclusions may be drawn from a comparison of the pilot evaluation data and the criteria, $\frac{L_\alpha}{\omega_n}$ (fig. 10) and $\frac{n/\alpha}{\omega_n}$, of reference 8. In general, the experimental data substantiate the Military Specification and other longitudinal criteria.

Spiral stability. – The spiral stability of the airplane was evaluated as neutral or stable at all flight conditions investigated, was described by the pilots as excellent, and was rated from 1 to 3 (table 5). The inverse of the spiral time constant, which was predicted from the experimentally determined stability derivatives, is shown in figure 11. For level 1 flying qualities, the Military Specification (ref. 4) allows the airplane response to double in 20 seconds. Although no pilot reported the spiral response to be divergent in flight, two test conditions were predicted to be divergent. The calculations also predicted most conditions to be convergent rather than neutral as noted by the pilots. This is a difficult response parameter to determine experimentally, because several factors, including trim, control system friction, and turbulence, can influence the results. The pilot observations indicate a neutral spiral to be satisfactory; therefore, the results are not in conflict with the Military Specification.

Dutch roll.– The Dutch roll damping of the CV-990 (yaw damper off), like that for most swept-wing configurations, was light over the flight envelope evaluated. The pilot evaluations of the lateral-directional characteristics are summarized in table 5 and figure 12. The calculated characteristics are also summarized in the table. Most of the stability and damping characteristics evaluated were rated satisfactory during both the operational flight evaluations and the specific test evaluations. Comparing these data with the Military Specification (fig. 12) for Dutch roll dynamics for Class III airplanes in the approach and cruise (category B and C) flight phases indicates that the pilots were lenient. They gave more satisfactory pilot ratings for lower damping ratios than would be suggested by the Specification. The approach condition damping was given the highest rating numbers; however, this condition was rated only 3 to 5, not as low as would be predicted by the Military Specification for Dutch roll damping. The Specification would predict a rating of greater than 6.5. These tests were conducted in smooth air; however, the Specification does not state what effect turbulence might have on the requirements. Some satisfactory pilot ratings were given for Dutch roll damping ratios as low as 0.02.

Roll mode.– The roll response characteristics of the airplane and pilot evaluations of these characteristics are presented in figure 13 and table 5. Although the roll response in roll rate and roll damping was predicted to be satisfactory and was, in general, rated satisfactory, the pilots were very critical of proverse yaw produced by the spoilers at moderate-to-large roll control deflections. Roll response was considered much more satisfactory at slow rates of roll than at high rates. The pilots indicated that some coordination with the rudder was needed, but that the rudder coordination required was unnatural and difficult. They appreciated the yaw damper as a rudder coordination device as well as a damping device. Most roll control was accomplished with wheel control only, accepting the accompanying proverse yaw. However, the pilots had to be careful not to induce or sustain the lightly damped Dutch roll oscillation with the yaw damper off.

The cruise configuration roll acceleration capability and roll mode time constant (fig. 13(a)) were predicted (ref. 9) to be satisfactory, and both were evaluated as satisfactory. (Overall lateral control ratings were used.) The data also substantiate the Military Specification for roll time constant. The CV-990 roll rates (fig. 13(b)) for approach and cruise flight were rated acceptable by the pilots and also confirm the specification of reference 7. As expected, roll response in terms of time to bank (fig. 13(c)) was also satisfactory, and the data generally agreed with the criteria cited.

Lateral-directional dynamic response.– For most flight conditions the test airplane

$\left|\frac{\omega_\varphi}{\omega_d}\right|$ was greater than 1 (table 5), and the Dutch roll damping was low ($\zeta_d \approx 0.04$). Many studies (for example, refs. 10 to 12) indicate that when the pilot is controlling bank angle normally, a pilot-airplane combination with these characteristics may become unstable. The root locus for increasing pilot roll control gain indicates, first, decreased closed-loop damping and, then, with a further increase in gain, instability. Therefore, it was important that the pilots not attempt to control bank angle closely. During their first flights in the airplane, the pilots were trained not to control bank angle closely to lessen the likelihood of inducing roll oscillation.

The recently revised Military Specification for piloted airplanes (ref. 4) provides a specification for roll control excitation of Dutch roll dynamics in terms of roll rate and bank angle overshoot over the steady-state values commanded and a cosine equivalent phase angle of the sideslip oscillation. This criterion is for small control inputs. The parameters of roll-rate ratio, $\frac{p_{osc}}{p_{av}}$, and phase angle, ψ_β, were determined in order to compare the CV-990 characteristics with the Military Specification (figs. 14(a) to 14(c)). The Specification allows a much greater roll rate oscillation amplitude for a roll control which produces adverse yaw than for a roll control which produces proverse yaw. Rudder coordination for adverse yaw was considered to be less difficult than for proverse yaw. Only small overshoots in roll rate were allowed when roll control produced proverse yaw.

The flying qualities of the CV-990 airplane for category B and C flight conditions during slow rolls of approximately 5 degrees per second were given ratings from 1.5 to 3.5. The pilot evaluations for category B (fig. 14(b)) support the Specification, which is for small control inputs only. The data for category C (fig. 14(b)) fall generally along but outside the level 1 boundary. The category C characteristics were rated 2 to 3 during slow rolls. During approach, the airplane characteristics were rated less acceptable than during other flight phases. These evaluations resulted from the low Dutch roll damping; the proverse yaw of the roll control; and the need for, but difficulty in, coordinating rudder during rolls, which could result in pilot-sustained oscillations. The data for slow rolls for both categories support the sideslip specification for small control inputs (fig. 14(c)).

A time history of airplane response to approximately 15° of wheel control was calculated to illustrate the roll control problem with the CV-990 airplane (fig. 15). The sideslip is airplane nose right initially; however, as roll rate nears a steady-state level, the sideslip reverses to airplane nose left and oscillates about a positive value of sideslip. Initially, left rudder was required to coordinate the rudder with the roll control because of the proverse yaw produced by the roll controls. Then right rudder was required to counter the right sideslip resulting from rolling. This rudder coordination requirement was described by the pilots as being difficult—almost impossible. Rolls at low rates produced much less sideslip, which the pilots usually accepted without attempting to coordinate rudder with the roll control. These results support the Military Specification and indicate that only very small (preferably zero) $\frac{p_{osc}}{p_{av}}$ and $\frac{\beta_{max}}{k}$ ratios are acceptable when the airplane Dutch roll mode is lightly damped and the roll controls produce proverse yaw and then adverse yaw during rolls.

Pilot evaluation of flying qualities during fast rolls ranged from 2.5 to 5.5 because the rudder coordination problem was more difficult at high roll rates. The Specification does not, of course, apply to these high-roll-rate maneuvers.

CONCLUDING REMARKS

A general flying qualities evaluation of a CV-990 jet transport revealed the flying qualities to be satisfactory at all flight conditions evaluated (primarily in smooth air) for operational flying except during approach, which was evaluated as acceptable. The yaw damper was appreciated but was not considered necessary for satisfactory handling in up-and-away smooth-air flight. Rudder coordination by the yaw damper was appreciated by the pilots, who controlled the airplane primarily with the roll and pitch controls. Both pitch and roll control forces were slightly higher than desired.

Comparisons of the pilot evaluations of the test airplane's flying qualities at specific flight conditions with various flying qualities criteria indicated that the evaluations of the longitudinal characteristics in general supported the various longitudinal stability, damping, and maneuvering criteria for transport airplanes. The results are also in general agreement with the criteria for satisfactory roll-mode characteristics. The CV-990 Dutch roll damping was evaluated in these smooth-air tests as somewhat more satisfactory than would be expected from the Military Specification for Class III airplanes. The evaluation results for small roll control inputs support the Military Specification for roll-rate requirements for small control inputs. The airplane response to large roll control commands was evaluated as generally unsatisfactory. Rudder coordination during fast rolls, first for proverse yaw and then for adverse yaw, was difficult for the pilots. They preferred to control with the roll and pitch controls and to allow the yaw damper to provide the required rudder coordination.

Flight Research Center,
National Aeronautics and Space Administration,
Edwards, Calif., December 2, 1971.

APPENDIX A

PILOT EVALUATION GUIDE FOR GENERAL FLYING QUALITIES EVALUATIONS

1. Takeoff

Evaluate the rotational forces, control deflections, and ease of trim for precise control during takeoff. Note lateral-directional stability and control.

Comment:

Ability to hold heading and attitude

Ability to accelerate

Acceptability of control forces, trim, harmony, displays, cockpit layout, etc.

Overall pilot rating of takeoff:

Longitudinal __________ Lateral __________ Directional __________

2. Climbout and descent (dampers on and off)

Evaluate ease of transition to normal climb and descent and of holding attitude, speed, and heading. Perform banked turns of approximately 30° with heading change of approximately 45° to evaluate such factors as longitudinal and lateral control feel and ability to roll out on and maintain heading. Make an abrupt level-off at specified altitude. Perform mild maneuvering and typical maneuvering on instruments.

Comment:

Ability to hold heading, airspeed, attitude (if desired)

Ease of correcting above

Ability to maneuver and control aircraft response

Longitudinal stability, damping, and control

Lateral-directional stability, damping, and control

Control forces, trim, and harmony

Overall pilot rating:

Longitudinal __________ Lateral __________ Directional __________

3. Normal cruise (dampers on and off; $M \approx 0.87$; altitude, 10,668 m (35,000 ft))

Evaluate ease of trim in transition to cruise and of holding desired altitude, Mach number, and heading. Evaluate level-flight turns with 15°, 30°, 45° of bank angle, recovery from upset maneuver, rapid heading changes, and other maneuvers for stability and control. Perform instrument flight pattern.

Comment:

Ability to hold heading, airspeed, and altitude

Ability to control aircraft response and maneuver slowly, rapidly

Longitudinal stability, damping, and control

Lateral-directional stability, damping, and control

Control forces, trim, and harmony

Overall pilot rating:

Longitudinal__________ Lateral__________ Directional__________

4. Slow cruise (dampers on and off; V_i = 200 knots; altitude, 4572 m (15,000 ft))

Evaluate ease of trim in transition to slow flight and of holding desired altitude, speed, and heading. Evaluate level-flight turns with 15°, 30°, and 45° of bank angle, recovery from mild upset maneuvers, and other maneuvers for stability and control. Perform holding pattern.

Comment:

Ability to hold heading, airspeed, and altitude

Ability to control aircraft response and maneuver slowly, rapidly

Longitudinal stability, damping, and control

Lateral-directional stability, damping, and control

Control forces, trim, and harmony

Overall pilot rating:

Longitudinal__________ Lateral__________ Directional__________

5. Approaches

Make normal approaches and hooded instrument approaches to about 61 m (200 ft). The approaches should include the interception of the instrument landing system, go-around from middle marker, offset to the runway with correction, and other maneuvers as desired by the pilot.

Comment:

Ability to hold desired heading, airspeed, and altitude

Ability to maneuver and control aircraft response

Longitudinal stability, damping, and control

Lateral-directional stability, damping, and control

Control forces, trim, and harmony

Displays and controls layout

Cockpit, outside visual

Airplane attitude

Overall pilot rating:

Longitudinal__________ Lateral__________ Directional__________

6. Landings

Several landings will be made, some touch and go. The airplane handling will be evaluated in the landing pattern and on the ground during rollout. Normal and cross-wind landings will be made if possible.

Comment:

Ability to hold desired heading, airspeed, and altitude

Ability to maneuver and control airplane response

Longitudinal stability, damping, and control

Lateral-directional stability, damping, and control

Control forces, trim, and harmony

Displays and controls layout

Cockpit, outside visual

Airplane attitude

Overall pilot rating:

Longitudinal__________ Lateral__________ Directional__________

APPENDIX B

DETAILED PILOT COMMENTS[1] - GENERAL OPERATIONS

Takeoff

The takeoff was normal with a reference speed of 155 knots. As soon as we were airborne with the landing gear up, I attempted to go on instruments using my visor cap as a hood and keeping my head down. I had originally intended to hold reference speed plus 10 knots during the climbout, but the attitude was too steep; therefore, I held close to 15° pitch attitude which gave a reference speed plus 20 knots rather than plus 10 knots. Once stabilized, I climbed holding approximately 175 knots until we reached a little over 305 meters (1000 feet) and then raised the flaps. There was very light turbulence. I did note that as soon as I went from visual to instruments I had a slight tendency to overcontrol laterally, but within a few hundred feet of climb I had overcome this and did not have any particular difficulty. I did have the yaw damper on during the climb. After reaching 610 meters (2000 feet) to 762 meters (2500 feet), we accelerated to 250 knots. The longitudinal control was good and there was no problem laterally, even in the light turbulence. I attempted to level off at 2134 meters (7000 feet). I had started a turn at approximately a 30° bank prior to reaching that altitude, and I was able to roll out on my heading and my altitude simultaneously with relative ease. The throttles were retarded approaching the altitude.

I would rate the handling qualities during the climb as laterally-directionally 3 and longitudinally 2. The longitudinal control was a little better than the lateral because there is a tendency to overcontrol slightly with the spoilers. The ability to roll out on the heading and the ability to level out on a desired altitude from the control standpoint would be rated 2. They were both fairly good. We did make some turns up to 45° of bank. I made a left turn at 45° bank with the yaw damper off, and I would rate the handling qualities 3. Laterally, there was no significant difference with the yaw damper on or off because I rolled in fairly slowly. The longitudinal control forces are high; therefore, I gave a rating of 3 instead of 2. The longitudinal control was very positive, but the control forces were very high longitudinally.

Commenting on a takeoff with 98-percent power and a gross weight of 80,500 kilograms (177,500 pounds), a reasonably light takeoff weight: The longitudinal forces required for rotation are reasonable; I would estimate probably around 133.5 newtons to 178 newtons (30 pounds to 40 pounds). Maintaining the takeoff attitude at 15° is a little difficult. It required some concentration. The nose tends to ease over to about 10°. The pilot must work to hold the nose up to 15°. The climbout speed was completely unrealistic for a lightweight takeoff even with the reduced power of 98 percent because the aircraft accelerates extremely rapidly and it would take over a 20° nose pitch attitude to keep the speed within reason, so this condition really is academic. The yaw damper was inoperative. Ability to hold heading was good. The control force harmony was good, although the lateral control of the aircraft was sensitive as far as holding a steady wing position. Overall pilot rating of takeoff is longitudinally 1.5, laterally 2.5, and directionally 2. This was a smooth-air takeoff condition.

---

[1]Each flight phase category includes comments from several pilots.

Commenting on another takeoff: The reference speed for safe rotation was 140 knots. The aircraft was allowed to go to 145 knots before the rotation was initiated. The rotation was made in a positive manner—just up to 15° attitude—and the aircraft came off cleanly. There were no unusual problems or difficulty in controlling the pitch attitude of the aircraft at 15° pitch attitude with a safe rotation airspeed plus 5 knots. Longitudinal control was good (a rating of 1.5 or 2), the air was smooth, and the lateral controls felt good. There was no problem and no tendency to oscillate laterally.

The copilot throttled the number 4 engine back to idle power during the takeoff. The airplane yawed mildly to the right at the time of the throttle chop. With about one-third rudder pedal I was able to keep the runway heading deviation from the centerline to less than 1.5 meters (5 feet). There did not seem to be much deviation. I held the rudder through the rotation and the initial 61 meters (200 feet) or 91 meters (300 feet) of climb. I did not use much aileron. I tried to prevent using aileron and did not seem to set up much of a lateral oscillation, as we have sometimes on some of the training missions. I felt that the control was very good, and I would rate the lateral control 3 and the directional control 2 for this type of maneuver. I know from the training missions it is easy to set up a lateral oscillation. With experience in the airplane I did not have the tendency to set up this oscillation. This is usually caused by using too much lateral control and spoilers. The climb rate was good. We had adequate climb and picked up the safe climb airspeed plus 10 to 15 knots during the climbout and had something like 213 meters (700 feet) or 244 meters (800 feet) per minute climb rate at this weight. Control was good throughout the maneuver.

Comments on the takeoff with an engine cut at the decision airspeed: Rotation was just a little higher than the safe rotation airspeed. The directional control and the handling qualities were satisfactory. Takeoff was made with about 15 knots crosswind. The handling qualities were rated good laterally-directionally. There was no question that there was a large drift as the aircraft separated from the runway, and there was a large crab required to hold track. It did not seem too turbulent or gusty, and the aircraft handled well on takeoff.

Climb

An airspeed of 250 knots was held to about 3048 meters (10,000 feet). The ability to hold speed was excellent and was rated about 1.5. The lateral-directional characteristics rate about 2.5, with the yaw damper on. After the aircraft passed 3658 meters (12,000 feet), the speed was increased to about 320 knots. Holding 320 knots in a climb, the airplane handling is essentially the same as at 250 knots. The ability to hold speed is very good, rated 1.5. With the yaw damper off I did some mild turns, and with small control inputs the airplane handles nicely. I would rate it about 3 and with the yaw damper on, approximately 2. The aileron control forces are a little heavy, but this decreases the tendency to overcontrol with the ailerons.

In the climb at 320 knots and 9600 meters (31,500 feet) the Mach trimmer operated ($M = 0.85$). The ability to hold speed was still excellent. I had to use some forward trim on the stabilizer because of compensation by the Mach trimmer, but the ability to hold the speed is still excellent. I would still rate it as about 1.5. No complaints laterally either; it is still around 2. The aileron forces are fairly high. If the aileron forces alone are rated, I would probably rate them about 4—too high. The high force results in no tendency to overcontrol.

This was a climb from approximately 914 meters (3000 feet) to 6096 meters (20,000 feet). After departing from the traffic pattern, I increased the airspeed from 200 knots to 250 knots. As 3048 meters (10,000 feet) was passed, the airspeed was increased to 300 knots for the climb. The climb was with the yaw damper on, and the airplane was steady as a rock directionally. Directionally, the handling rated 1.5. There was no turbulence, with the exception of a bump or two. The ability to hold heading during the climb was excellent. Heading was held without any difficulty. Turning 30° left and 30° right, I was able to roll in and out of the turns easily using essentially no rudder, just ailerons. The aileron forces are high. The airplane was steady rolling into the 30° bank. It required just a slight trim during the roll-in because of the increased bank. Once the new heading course was reached, the trim was taken out with about 1 beep. The ability to hold the heading and airspeed was excellent. The elevator forces are still high, as mentioned in previous comments. The airplane has very good speed stability. The climb and bank angles were reduced to zero at the same time and power was reduced starting at approximately 91 meters (300 feet) before reaching 7620 meters (25,000 feet). The ability to do this entire maneuver would be rated as 1.5 to 2 because of the excellent speed stability and the excellent directional control with the yaw damper on. Aileron inputs were low; therefore, there was no tendency for proverse yaw to cause control problems. Large aileron inputs would probably give more proverse yaw. The airplane overall characteristics are considered to be good during the climb. Overall rating would be 1.5 to 2.

Some comments on the safe-climb-airspeed-plus-15-knots climbout from the surface (701 meters (2300 feet)) to 3048 meters (10,000 feet) follow. The initial rotation right after takeoff and holding the airspeed were not difficult until the gear retracted. It was obvious that as the gear came up drag was reduced and the nose rotated positively. An approximate 14° or 15° nose-high attitude was required in order to maintain the safe climb airspeed plus 15 knots. During the climbout the airspeed varied about 3 knots, from approximately 167 to 170 knots. A moderate amount of monitoring and small longitudinal control inputs were required by the pilot. The task of maintaining speed was comfortable. No directional task was maintained other than holding heading with slight lateral maneuvering. A rating of the longitudinal control, in the maneuver, would be 2. Airplane response was very good.

This is an evaluation of the handling qualities for the climbout, dampers on and off, and level off. I accomplished 30° bank turns during the climbout to 6096 meters (20,000 feet). Yaw damper was on and off and flight was by instruments. The handling qualities of the aircraft were good. I could not detect any measurable difference between the dampers on and the dampers off flying qualities. Climb schedule was held at 250 knots to 3048 meters (10,000 feet) and at 300 knots to 6096 meters (20,000 feet). The trim rate is very good for this type of maneuver and for the level-off at altitude. I felt that the controls were slightly heavy laterally. Lateral-directional handling qualities were good. There was no real problem holding heading or rolling out accurately on a given heading. It was easy compared to holding attitude and airspeed. The aircraft responded well. The stability, damping, and control were good, although rudder was not used normally. I would give it a rating of 2. The phugoid motion was the only thing that seemed to bother me occasionally. You must pay attention to the longitudinal axis and keep an instrument scan going to avoid deviating from altitude.

This is an evaluation of the climbout, dampers off. Ease of transition to normal climb was good. The 30° bank turns for 45° heading changes were easy to accomplish.

The lack of the yaw damper was noticed only when larger roll inputs were introduced in rolling out of a turn. The yaw damper was not missed much at these speeds in a climb at 300 knots indicated. It was easy to hold heading. A little anticipation was required in rolling out on the exact heading. The Dutch roll was not highly damped but well enough. The air was smooth today at this climb condition. There was no tendency for the Dutch roll to develop. Control forces were reasonable for a transport, and the harmony was very good. I would give it a rating on harmony of about 1.5 and an overall rating of longitudinally 1.5, laterally 2, and directionally 2.5 in the climb configuration.

In the climb it was easy to stabilize on 250 knots. It seemed fairly easy to hold at 250 knots during the climb, and at approximately 152 meters (500 feet) before reaching 3048 meters (10,000 feet) I anticipated the level-off and still overshot about 61 meters (200 feet) above 3048 meters (10,000 feet). I then accelerated up to 300 knots, transitioned into a climb again, and climbed up to 4572 meters (15,000 feet). Again trying to level off at 4572 meters (15,000 feet) and 300 knots, I was able to level off within about ±15 meters (±50 feet) of the desired altitude. However, I overshot the airspeed by about 10 knots and ended up at 310 knots. I would rate the transition from the climb to level-off as 3. The ability to hold the airspeed at 250 knots I rate as 2. The ability to level off at 3048 meters (10,000 feet) without overshooting the altitude I would rate at about 2.5, and the transition from 3048 meters (10,000 feet) to 300 knots and then transitioning to the climb I would rate about 2.5. Holding the airspeed was slightly more difficult while climbing between 3048 meters (10,000 feet) and 4572 meters (15,000 feet). I would rate that as 3. I would also rate the level-off at 4572 meters (15,000 feet) at 3.

At 3658 meters (12,000 feet) and 250 knots the airplane was accelerated to 300 knots for a climb to and level-off at 6096 meters (20,000 feet) at 0.7 Mach number. Yaw damper was on. The acceleration to the climb speed of 300 knots was made fairly easily. The ability to hold heading during the climb I would rate as 3. It seemed that the heading wandered a bit. I may have been just slightly out of trim but I did not feel that I was very much out and I found that the tendency was to drift to the left during the climb. The ability to hold the airspeed I felt was satisfactory, and I would rate that as 2. In the longitudinal mode the forces were generally quite light and a 5- to 10-knot increase or decrease in speed was not difficult. The lateral control forces seemed to be somewhat on the high side. With the yaw damper on, the rudder forces were fighting against the damper forces, so the rudder forces were quite heavy. I cannot give any evaluation on that. Longitudinal stability seemed to be positive throughout. Damping was satisfactory and longitudinal control was satisfactory. Overall pilot ratings were longitudinally 2, laterally 3, and directionally 2.

During the climb and transition to cruising flight, I felt ease of trim was satisfactory. I would rate that as a 2. The ease of leveling out at the desired altitude, Mach number, and heading I would rate as 2.

Cruise

The airplane was leveled off at 10,363 meters (34,000 feet). We terminated climb at 10,363 meters (34,000 feet) rather than at 10,668 meters (35,000 feet) because of the slow rate of climb. It was easy to level off at 10,363 meters (34,000 feet). It required only a small power reduction to level off at approximately 0.87 Mach number, and, therefore, longitudinal control during the level-off maneuver under these conditions was rated 1.5. Longitudinal control has been excellent throughout the flight. With the yaw damper on, some turns were made at 20° bank angle. Heading was changed as much as 180°. The ability to hold the bank angle has been excellent. There has been no problem with spiral stability, which was essentially neutral. There was no oscillating around the lateral axis, so that lateral-directional stability and damping were rated 2.

At 10,363 meters (34,000 feet) cruise and 0.87 Mach number, the ability to hold altitude was still excellent. Turns were made with up to 30° bank in each direction with the yaw damper off and on. With the yaw damper on, rolls to desired bank angles can be made without requiring any rudder. The yaw damper did the job. It makes a nice, smooth turn which is rated about 2. With the yaw damper off there was some tendency to yaw, but not too great, so the rating is 3. There was no tendency to induce the Dutch roll oscillation; however, rudder to check the yaw did set up a slight Dutch roll oscillation. I was able to damp it. I would say that once the oscillation is set up, the Dutch roll characteristics are about 4. It takes just a little time to damp it out with the yaw damper off.

Evaluating cruise conditions, the ability to hold heading was excellent. The ability to hold airspeed was excellent, and the ability to hold altitude was very good, almost excellent. There were some slight altitude changes, maybe 3 meters (10 feet) or 4.6 meters (15 feet), which required a little work. The ease of correcting all three was excellent. I would say overall ability to hold heading, altitude, and airspeed was 1.5 to 2. The airplane maneuvered well and the airplane responded well to the lateral control at this altitude. At 30° bank there was some slight buffet at the weight of approximately 82,200 kilograms (179,000 pounds), but it was very mild.

I commented on the damping characteristics with the yaw damper off previously and rated it about 3, but if an induced oscillation is set up, I would say that the control task to get that damped would be rated 4—not quite as good. Longitudinal stability was excellent. The aileron control forces were very high, but there were no objectionable characteristics. Longitudinal forces were a little high; therefore the harmony between ailerons and elevator seemed to be good. I would say airplane characteristics generally seem to be good, and the overall rating was about 2.

Mach trim seemed to be taking care of longitudinal characteristics nicely. As I commented during the climb, I had to trim nose down slightly. The trim gradient was fairly shallow, therefore the Mach trim compensator was doing a reasonable job.

The control feel was extremely good; however, the power speed situation or adjustment was difficult. The aircraft with its inertia tended to stabilize or appear stabilized and then the speed drifted off or increased. During maneuvering turns the damper-off lateral-directional handling was not too good. A certain amount of yaw occurred with moderate control inputs. I would rate the lateral-directional characteristics at about 3.5 with the damper off. Indicated airspeed, by the way, was 255 knots at 10,058 meters (33,000 feet). With the yaw damper, the lateral-directional characteristics were rated 1.5 to 2. Response was adequate for the wheel input, and the yaw was damped out by the rudder. The Dutch roll mode was also damped. The larger inputs of roll control resulted in a definite speed bleed-off due to the drag of the spoilers. It was a marked effect, and the pilot should be careful to keep his roll inputs down to a reasonable value, possibly one-third aileron or less.

The overall airplane characteristics were considered to be acceptable. They were actually good in the longitudinal mode and poor laterally-directionally with the damper off, but the overall rating would be acceptable.

At normal cruise with 250 knots at 6096 meters (20,000 feet), the ability to hold heading was excellent (1.5). Ability to hold altitude was also excellent (1.5). One could level off right on altitude with little difficulty. The airplane responded rapidly to power inputs to increase and decrease the speed. With the yaw damper on the airplane could be maneuvered to headings precisely and rolled out on the heading within 1° with ease. This was using moderate roll rates. The lateral input rolling in and out needed to be smooth and not too rapid; otherwise the proverse yaw developed.

One could use up to 20° of wheel throw and get a nice roll rate and not develop any appreciable yaw, but aileron forces were high. If 30° or more of wheel throw was used, you got some spoiler buffet which was undesirable. Even 20° of wheel throw was likely to result in spoiler buffet at this speed and altitude. I would rate the maneuver characteristics laterally with the yaw damper on 3 and with the yaw damper off 4.5.

The lateral stability with the damper on was very good. The only problem was that the lateral and longitudinal forces were a little high, but they made it easy to hold the desired conditions. The control harmony was excellent because both forces were high. The airplane required very little trimming in the transition from a climb or descent into the level-off. Airplane characteristics were considered to be good in this condition. The overall pilot rating with damper on would be 2, and with damper off probably 3. Those numbers are fine laterally; longitudinally, the rating is 2 all the way.

Commenting on normal cruise at 10,668 meters (35,000 feet) and 0.87 Mach: The initial level-off or transition from climb to cruise was not difficult. The climb performance was rather low. There was ample time to transition over. The ability to hold heading and Mach number was similar. The control forces appeared to be heavier in this cruise condition than in the climb at 300 knots indicated airspeed. The harmony was good. It seems that the longitudinal and lateral forces increased together. The rapid maneuvers were no problem rolling in and out, but there was a little light spoiler buffet at times. There was no problem controlling the aircraft response. Longitudinal stability was good and damping was good. The lateral-directional Dutch roll damping was a little low, but again it did not seem to be a problem with the yaw damper off. The overall ratings are: longitudinally 1.5 to 2; laterally 2; and directionally 2. Evaluating level-flight turns with 15°, 30°, and 45° bank angles with damper on, I would rate the ability to make turns with a 15° bank angle as satisfactory—easy to make, easy to roll out on desired headings. The turns at a 30° bank angle are also satisfactory. However, the turns at a 45° bank angle required much more coordination, and it is much more difficult to roll out on a desired heading. With the damper off the 15° bank angles were easy to obtain and maintain and it was easy to roll out on a desired heading. The 30° bank angles are fairly easy to obtain. It is more difficult to roll out on a desired heading. With 45° bank angles with the damper off, it is difficult to roll out on the desired heading. I would have to rate the bank with ability to roll out on desired heading as follows: with a 15° bank angle, 2; with the 30° bank angle, 3; with the 45°

bank angle, 5. Overall pilot rating for the cruise portion would be longitudinally 2, laterally 3, and directionally 2.

Descent

The descent was made at 320 knots indicated airspeed, from about 10,668 meters (35,000 feet) to about 5486 meters (18,000 feet) with maneuvering turns. The control forces were a little high laterally at 320 knots for roll maneuvering. There seemed to be a large increase in lateral control force above 300 knots indicated. The overall damping in a high-speed descent was similar to the high-speed cruise, and the ratings for the descent were similar to the climbout. With the airspeed reading 325 knots indicated, the aileron seemed to stiffen up a little over the climb condition of 300 knots.

Another descent was made from 6096 meters (20,000 feet) with simulated instrument flight vectors under hooded conditions and in an area of clouds. Light turbulence was experienced. The aircraft was easy to control and flew nicely with damper on and off. Little difference was noted with damper on or off. Speed was maintained at approximately 275 knots during the descent. Then the airplane was slowed, and an instrument landing approach to 61 meters (200 feet) and waveoff was made. The handling qualities are considered to be about 2 to 2.5 at 275 knots during the descent with damper on and off. The phugoid detracted slightly from the longitudinal control. The pilot had to work to maintain accurate airspeed and altitude. The forces were slightly high.

Starting at $M = 0.87$, we pitched the airplane over 7°, 7.5°, and held it for 10 seconds. The speed pickup was fairly fast to 391 knots or 392 knots, causing the horn to blow as it should. Buffet was moderate, not really too bad. After this attitude was held for 10 seconds, the air brake was extended and the throttle was retarded. About 1.4g was held for a gentle pullout. As the airplane slowed up, I had to hold about 111 newtons to 133 newtons (25 pounds to 30 pounds) of forward stick force. The initial pull back to change the pitch attitude from 7.5° down to level was fairly light. The airplane characteristics were excellent. There was no tendency to roll off in either direction and nothing unusual laterally-directionally. The characteristics would be rated overall as 3, 2.5, to 3. They are quite good.

Slow Cruise

Evaluating slow cruise at 190 knots indicated and 4572 meters (15,000 feet), which is typical of a holding pattern: A one-turn holding pattern was accomplished with normal instrument flight rates and bank angles. The primary items on handling qualities that were noticeable were the power modulation, the altitude control, and the high lateral forces required for reasonably small bank-angle maneuvering. The ability to hold heading deteriorated slightly from the higher cruise speeds. The aircraft seemed to wander off more on heading. Longitudinal stability, control, and damping in the short-period mode were good; however, in the long-period mode holding altitude does require work. Lateral-directional stability was more of a problem with the Dutch roll at the lower speed. Overall pilot ratings are: longitudinally 2 to 2.5, just on the plus side of 2; laterally-directionally 2.5, due to high control forces required in the lateral mode and the lack of damping. These ratings are for yaw damper off.

The holding slow cruise configuration evaluated was 207 knots at 6096 meters (20,000 feet). During recovery from upset maneuvers, the aircraft responded nicely to all control inputs, and recovery from these mild upset maneuvers was straightforward. During turns with the damper on, the airplane responded nicely. Lateral control force was slightly high. The phugoid detracted slightly from the longitudinal control. Longitudinal control would be rated 2 to 2.5. With yaw damper off there was a residual oscillation. It was a little difficult for the pilot to damp out an oscillation of about $\pm 2^\circ$ in roll, so the pilot rating for slow cruise configuration with the yaw damper off is 3.

Overall pilot rating for the slow cruise with damper on is as follows: longitudinally 2, laterally 3, directionally 2. Damper-off ratings are longitudinally 2, laterally 3, and directionally 3. The transition to slow flight was quite easy. Altitude was held constant fairly easily. Speed was easy to obtain and maintain. Control of bank angles up to 30° was satisfactory. The heading was held easily. Airspeed and altitude were also quite easy to hold. The aircraft response was still good at an indicated airspeed of about 200 knots. Slow maneuvering was good. However, when rapid control inputs were made, the roll response was fairly quick but stopping on a desired heading was more difficult. Longitudinal stability was positive. Damping was good and longitudinal control was good. Lateral-directional stability was positive. Again, damping and control were good. Control forces were rather light longitudinally. I would rate them 2. The trim I would rate 2 and the control harmony 3. I think the lateral control forces are a little high, and I would rate control harmony 3.

At slow cruise, 0.73 Mach at 10,058 meters (33,000 feet), a simulated instrument pattern was flown under hooded conditions with the yaw damper both off and on. With yaw damper on the lateral-directional and longitudinal control was rated 2. One control was very bad; the power in this speed range required a great deal of throttle modulation. A little spoiler into the turn slowed the aircraft and required more power. Lateral-directional maneuvering with approximately 20° to 30° of bank with moderate inputs for instrument flight is rated 2.5 to 3 for the damper off. The characteristics were much worse during rapid maneuvering with the damper off. However, with the rates normally used for instrument flight, the pilot did not tend to induce large Dutch roll oscillations. That is the reason for a little higher damper-off rating than might be expected.

For the evaluation of slow cruise, a deceleration from 300 knots to 207 knots and one complete holding pattern under instrument conditions were made at 6096 meters (20,000 feet). It was slightly difficult to maintain an altitude accurately, and the phugoid got into the act again just a little. The longitudinal control forces were slightly higher than one would desire. A little deadband in the yoke detracted slightly from the controllability. The lateral forces were also considered a little high. The lateral-directional and longitudinal forces were rated 2.5. Rolling in and out of turns was fairly easy, but the turns have to be anticipated slightly more than would normally be expected.

Approach and Landing

These comments concern an instrument approach down to 91 meters (300 feet) with breakout to visual flight followed by a touch-and-go landing. The crosswind was from the right, and it required about a 4° or 5° crab angle. The lateral-directional characteristics with the damper off were degraded compared with other conditions evaluated. I rate it about 4 to 4.5. The flare and landing were easy, although the longitudinal forces were a little high and the landing was rated 2.5. Directional control after touchdown was no problem.

The following comments concern an offset maneuver (about 70 m (230 ft) to the right and 61 m (200 ft) altitude) with 20 knots of slightly right crosswind. The maneuvering back to the runway was busy, although there was a little more time with the headwind. With the wind around 20 knots there was a little more time to get back to the centerline, and I felt a little better about the lineup. I did not chop the power until I was lined up and probably within 4.5 meters (15 feet) of the ground. I really do not feel I would like to be any slower on that approach because of the maneuvering required to line up on the centerline.

For the simulated instrument approach with yaw damper off, I would give the longitudinal characteristics an overall rating of 2, the lateral 3, and the directional 4. It appeared to be hard to maintain a constant heading. The airplane drifted back and forth across the centerline, and I had difficulty in maintaining the desired heading and the proper azimuth for the instrument landing approach. The control coordination with the yaw damper off was poor; I was unable to coordinate the rudder with the aileron. The lateral control forces were on the high side. I tended to concentrate more on lateral control than on coordinating with the rudder. I would say that control harmony in the instrument landing approach would be 3 to 3.5.

Two landings were made with a crosswind, probably 12 knots to 15 knots, from the right. The first landing was with 36° flaps and the second with full flaps. There were no differences noted due to the different flap settings. The airplane control was adequate. On the final approach there was about 2° to 3° of right wing down at touchdown, and left rudder was required to compensate for the drift. The touchdowns were not real smooth, just a bit on the firm side, but certainly acceptable landings. I felt that the crosswind control available would be rated 2.5. Both rudder and aileron were good in each case. On final approach the airplane bounced around a little in the turbulence, and there was a tendency for a lateral oscillation. Once near the runway there was no tendency to oscillate and the airplane could be placed at about the bank angle desired to compensate for the crosswind.

In this type of turbulence the pilot must concentrate not to overcontrol laterally or an actual pilot-sustained oscillation could result. The airplane is going back and forth on the approach, and yaw must be taken out just prior to touchdown. The longitudinal flare energy and the aircraft response are similar to those in any other landing. The biggest things are control of the lateral-directional motion and straight control on the runway after landing. The pilot must be a bit more careful about the rudder and the nose as he brings it over. With the damper off in the approach configuration the aircraft wallowed and the pilot tended to couple with it. Lateral-directional handling qualities are 4 to 4.5 in the approach configuration. Longitudinal is about 2.5. The trim rate was considered to be a little slow but was satisfactory for the approaches. It detracted slightly from the handling qualities. The approach was made on instruments. Only light turbulence was experienced.

APPENDIX C

DETAILED PILOT COMMENTS ON THE APPROACH CONFIGURATION

160 Knots, 27° Landing Flaps, Pilot A

The first maneuver was a gradual pullup to 1.35g and release. The damping was positive, almost deadbeat. Damping would be rated 2. From wings level, rolled to 45° bank left, and rolled from there to 45° right bank. The stick forces were reasonable, probably around 111 newtons (25 pounds) pull force at 45° bank. It is easy to hold altitude and speed without too much work. Longitudinally it would be rated 2.

At 3962 meters (13,000 feet) the first check was speed stability at 160 knots, with gear down and 27° flaps. To increase speed 10 knots required around 44.5 newtons to 66.7 newtons (10 pounds to 15 pounds) push force. The stabilized decreased speed was 150 knots, and it took 44.5 newtons to 66.7 newtons (10 pounds to 15 pounds) of pull force, so the gradient looks like it is about the same on either side of center, and it was very positive. For the phugoid check we decreased speed about 8 to 10 knots, released it, and after about 3 cycles the airplane motion was essentially damped out. The phugoid was very positively damped. I would rate the phugoid 2. Repeating the speed stability was rated 2. Both are good. At 160 knots the throttle was advanced to takeoff power. The airplane nosed up strongly. It did not seem to be quite as strong as previously at 120 knots or 140 knots, but the airplane does pitch up. It was allowed to pitch up to around 15° before recovering. The airplane would have continued to pitch up. I would rate that 4. That is an undesirable characteristic. Although it is certainly controllable, it is worse than in some other airplanes. The last maneuver was a pullup to increase pitch attitude; the column was pulled aft about 13 centimeters (5 inches), and the normal acceleration was around 1.5g to 1.6g. Response was immediate and positive. I would rate the longitudinal response 2.

I made a lateral maneuver with a slow roll to a 30° bank and then turned to a predetermined heading and rolled out rapidly. Uncoordinated, the airplane did a fine job. There was no problem rolling slow. During fast rolls the airplane has proverse yaw initially, so opposite rudder has to be used. Opposite rudder was needed to center the ball, but it is not too badly uncoordinated. Next, I attempted to coordinate wheel and rudder, and again had no problem with the slow entry but during the rapid rollout I needed opposite rudder to coordinate. I did not coordinate very well. In fact, the airplane did a much better job when the rudder was not used than it did when I was coordinating by using the rudder. I would rate the uncoordinated slow entry and the uncoordinated rapid roll 4. The coordinated slow, I would rate 2 and rapid coordinated 5, because it is very difficult to coordinate.

The next maneuvers were a series of doublets. The damping was very good following an aileron doublet with spoilers operating. Approximately 1.5° to 2° of sideslip were generated. Full control was used for an aileron doublet without spoilers. Only about 1° to 1.5° of sideslip was generated. The third maneuver was a rudder doublet. The rudders were very effective even at this speed and resulted in about 3° of sideslip in each direction. The damping was good on all maneuvers, and I would rate it 3; it is positive, but it takes a while. It is not a "bang, bang, snap" damping, but it is positive.

Checking the spiral stability at 160 knots with zero bank, there was no tendency to roll in either direction. With 10° bank, both left and right, the airplane had no tendency to roll in either direction, so it was essentially neutral spiral stability. It is very good. I would rate that 1 at this speed.

140 Knots, Full Flaps, Pilot B

Commenting on the longitudinal handling qualities at 140 knots indicated airspeed with gear down and full flaps: The stability was reduced longitudinally as witnessed by the difficulty to trim and maintain the speed and also the force required to change airspeed 10 knots. The longitudinal control rating was down a little too from the 180-knot case. You do not have quite the control response longitudinally. It was adequate for landing and approach, but lower. I would rate the longitudinal stability 2.5 and the control about 2. Normally I think it was rated about 1.5. The pitch acceleration was adequate.

Commenting on lateral-directional stability and control: It was very difficult to coordinate the turn with rudder. It can be done now and then, but it is extremely difficult. There was proverse yaw that required opposite rudder inputs. The lateral-directional stability was low. It is rated about 3 because of low Dutch roll damping. The controllability was adequate and is rated about 2.5.

The spiral stability was just about neutral; however, there was a lot more response to Dutch roll. The airplane just wallowed around wings level or 10° right or left bank. That is a very undesirable characteristic with the damper off. I would rate the Dutch roll characteristics 4.

REFERENCES

1. Gilyard, Glenn B.: Flight-Determined Derivatives and Dynamic Characteristics of the CV-990 Airplane. NASA TN D-6777, 1972.

2. Holleman, Euclid C.; and Gilyard, Glenn B.: In-Flight Evaluation of the Lateral Handling of a Four-Engine Jet Transport During Approach and Landing. NASA TN D-6339, 1971.

3. Mechtly, E. A.: The International System of Units - Physical Constants and Conversion Factors. NASA SP-7012, 1969.

4. Anon.: Flying Qualities of Piloted Airplanes. Military Specification MIL-F-8785B (ASG), Aug. 7, 1969.

5. Cooper, George E.; and Harper, Robert P., Jr.: The Use of Pilot Rating in the Evaluation of Aircraft Handling Qualities. NASA TN D-5153, 1969.

6. Anon.: Airman's Information Manual. Part 1 - Basic Flight Manual and ATC Procedures. Federal Aviation Administration, Feb. 1971, p. 1-79.

7. Anon.: Design Objectives for Flying Qualities of Civil Transport Aircraft. Aerospace Recommended Practice (ARP) 842, SAE, Aug. 1, 1964.

8. Shomber, H. A.; and Gertsen, W. M.: Longitudinal Handling Qualities Criteria: An Evaluation. AIAA Paper No. 65-780, 1965.

9. Holleman, Euclid C.: Flight Investigation of the Roll Requirements for Transport Airplanes in Cruising Flight. NASA TN D-5957, 1970.

10. Harper, Robert P., Jr.: In-Flight Simulation of Lateral-Directional Handling Qualities of Entry Vehicles. WADD Tech. Rep. 61-147, Aeronaut. Systems Div., Wright-Patterson Air Force Base, Nov. 1961.

11. Taylor, Lawrence W., Jr.: Analysis of a Pilot-Airplane Lateral Instability Experienced With the X-15 Airplane. NASA TN D-1059, 1961.

12. Ashkenas, Irving L.; and McRuer, Duane T.: The Determination of Lateral Handling Quality Requirements From Airframe-Human Pilot System Studies. WADC Tech. Rep. 59-135, Wright Air Dev. Center, U.S. Air Force, June, 1959. (Available from ASTIA as AD212152.)

TABLE 1.– PHYSICAL CHARACTERISTICS OF THE CV-990 AIRPLANE

Fuselage –	
Maximum width, m (ft)	3.5 (11.50)
Maximum height, m (ft)	3.8 (12.40)
Length, m (ft)	42.6 (139.75)
Wing –	
Incidence (root), deg	4
Aerodynamic span, m (ft)	35.96 (118)
Area, m^2 (ft^2)	209 (2250)
Root chord, m (ft)	8.25 (27.06)
Tip chord, m (ft)	2.69 (8.83)
Mean aerodynamic chord, m (ft)	6.34 (20.83)
Dihedral, deg	7
Aspect ratio	6.2
Sweep at leading edge, deg	39
Horizontal tail –	
Area, m^2 (ft^2)	39.6 (426.50)
Dihedral, deg	7.5
Leading edge sweep, deg	41
Span, m (ft)	11.8 (38.74)
Aspect ratio	3.52
Vertical tail –	
Area, m^2 (ft^2)	27.4 (295)
Sweep (30-percent chord), deg	35
Span, m (ft)	6.45 (21.20)
Aspect ratio	1.52

TABLE 2.– COOPER-HARPER SCALE FOR PILOT RATING

CONTROLLABLE CAPABLE OF BEING CONTROLLED OR MANAGED IN CONTEXT OF MISSION, WITH AVAILABLE PILOT ATTENTION	ACCEPTABLE MAY HAVE DEFICIENCIES WHICH WARRANT IMPROVEMENT, BUT ADEQUATE FOR MISSION. PILOT COMPENSATION, IF REQUIRED TO ACHIEVE ACCEPTABLE PERFORMANCE, IS FEASIBLE.	SATISFACTORY MEETS ALL REQUIREMENTS AND EXPECTATIONS, GOOD ENOUGH WITHOUT IMPROVEMENT CLEARLY ADEQUATE FOR MISSION.	EXCELLENT, HIGHLY DESIRABLE	A1
			GOOD, PLEASANT, WELL BEHAVED	A2
			FAIR. SOME MILDLY UNPLEASANT CHARACTERISTICS. GOOD ENOUGH FOR MISSION WITHOUT IMPROVEMENT.	A3
		UNSATISFACTORY RELUCTANTLY ACCEPTABLE. DEFICIENCIES WHICH WARRANT IMPROVEMENT. PERFORMANCE ADEQUATE FOR MISSION WITH FEASIBLE PILOT COMPENSATION.	SOME MINOR BUT ANNOYING DEFICIENCIES. IMPROVEMENT IS REQUESTED. EFFECT ON PERFORMANCE IS EASILY COMPENSATED FOR BY PILOT.	A4
			MODERATELY OBJECTIONABLE DEFICIENCIES. IMPROVEMENT IS NEEDED. REASONABLE PERFORMANCE REQUIRES CONSIDERABLE PILOT COMPENSATION.	A5
			VERY OBJECTIONABLE DEFICIENCIES. MAJOR IMPROVEMENTS ARE NEEDED. REQUIRES BEST AVAILABLE PILOT COMPENSATION TO ACHIEVE ACCEPTABLE PERFORMANCE.	A6
	UNACCEPTABLE DEFICIENCIES WHICH REQUIRE MANDATORY IMPROVEMENT. INADEQUATE PERFORMANCE FOR MISSION EVEN WITH MAXIMUM FEASIBLE PILOT COMPENSATION.		MAJOR DEFICIENCIES WHICH REQUIRE MANDATORY IMPROVEMENT FOR ACCEPTANCE. CONTROLLABLE. PERFORMANCE INADEQUATE FOR MISSION, OR PILOT COMPENSATION REQUIRED FOR MINIMUM ACCEPTABLE PERFORMANCE IN MISSION IS TOO HIGH.	U7
			CONTROLLABLE WITH DIFFICULTY. REQUIRES SUBSTANTIAL PILOT SKILL AND ATTENTION TO RETAIN CONTROL AND CONTINUE MISSION.	U8
			MARGINALLY CONTROLLABLE IN MISSION. REQUIRES MAXIMUM AVAILABLE PILOT SKILL AND ATTENTION TO RETAIN CONTROL.	U9
UNCONTROLLABLE CONTROL WILL BE LOST DURING SOME PORTION OF MISSION.			UNCONTROLLABLE IN MISSION.	10

TABLE 3.– PILOT RATINGS OF CV-990 HANDLING CHARACTERISTICS IN SMOOTH AIR DURING TYPICAL OPERATIONAL FLIGHTS

(a) Takeoff (yaw damper off)

Pilot	Longitudinal	Lateral	Directional
A	2	3	2
B	1.5	2.5	2
C	2	3	2
D	2	3.5	3.5

(b) Climb

Pilot	Longitudinal	Lateral		Directional	
		Yaw damper		Yaw damper	
		On	Off	On	Off
A	1.5	2	3	2	3
B	1.5	-	2	-	2.5
C	2	3	-	2	---
D	2	2	-	2	---

(c) Cruise

Pilot	Longitudinal	Lateral		Directional	
		Yaw damper		Yaw damper	
		On	Off	On	Off
A	2	2	3	2	3
B	1.5 to 2	-	2	-	2
C	2	3	-	2	-
D	2	2	2	2	2

(d) Slow cruise

Pilot	Longitudinal	Lateral		Directional	
		Yaw damper		Yaw damper	
		On	Off	On	Off
A	2	2 to 3	4.5	2	3
B	2 to 2.5	2	2.5 to 3	2	2.5 to 3
C	2	3	3	2	3
D	2 to 2.5	2.5	-------	2.5	2.5

(e) Descent

Pilot	Longitudinal	Lateral		Directional	
		Yaw damper		Yaw damper	
		On	Off	On	Off
A	3	2.5	-	3	-
B	1.5 to 2	2	-	2	-
C	2	3	3	2	3
D	2 to 2.5	2 to 2.5	-	2 to 2.5	-

(f) Approach and landing (yaw damper off)

Pilot	Longitudinal	Lateral	Directional
A	2 to 2.5	1.5 to 2	-------
B	1.5 to 2.5	2 to 2.5	2.5
C	2	3	4
D	2.5	4 to 4.5	4 to 4.5

TABLE 4.– PILOT RATINGS AND LONGITUDINAL RESPONSE CHARACTERISTICS OF CV-990 AIRPLANE AT SPECIFIC TEST CONDITIONS

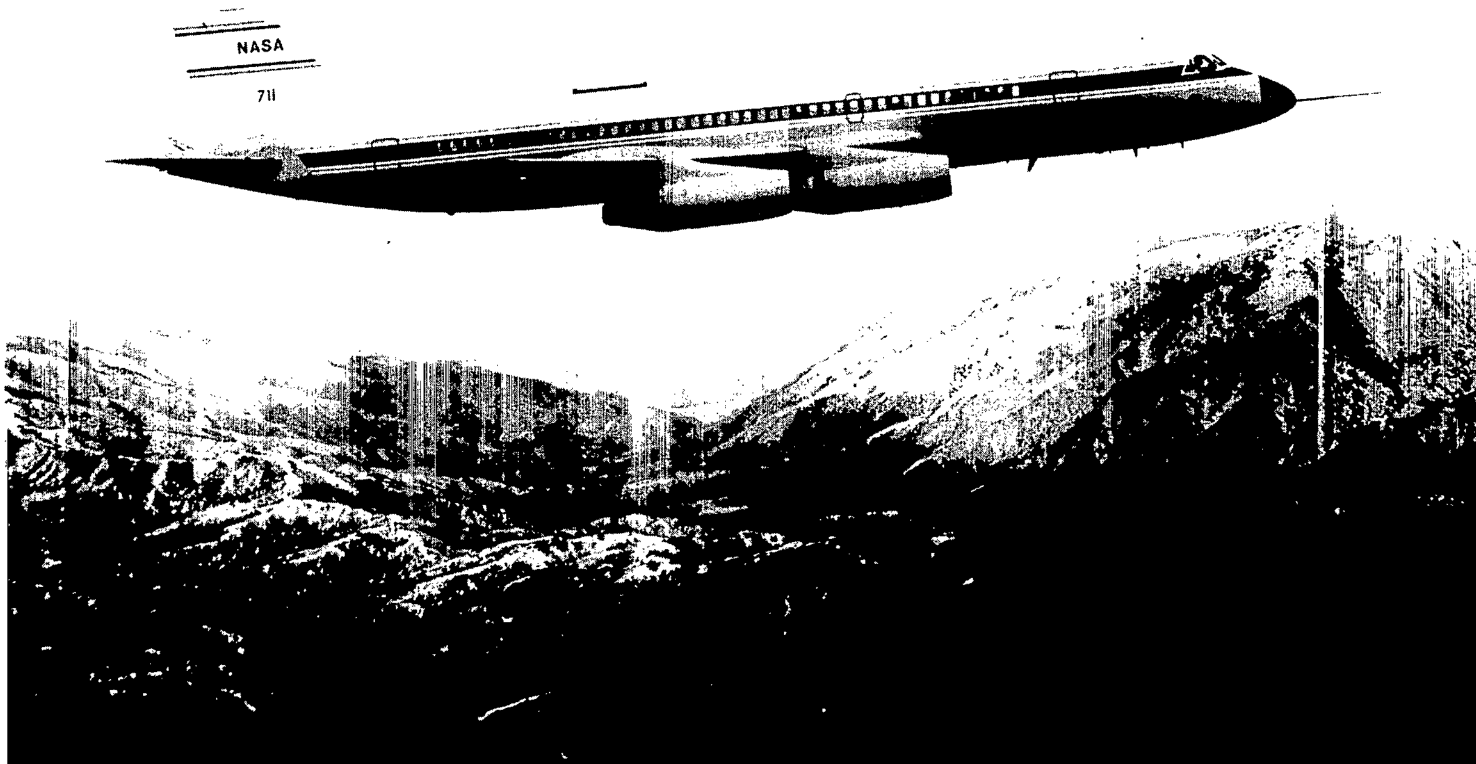
[Center-of-gravity range = 20.5 percent to 26.5 percent mean aerodynamic chord (ref. 1)]

Test conditions				Longitudinal characteristics				n/α	Pilot ratings		
				Phugoid		Short period					
V_i, knots or M	Altitude, m (ft)	Flaps, deg	Gear	Period, sec	Damping ratio	Frequency, rad/sec	Damping ratio		Phugoid	Short period	Maneuvering control
120	3,962 (13,000)	27	Down	40	0.13	0.71	0.80	2.4	2.0	3.0	3.0
140	3,962 (13,000)	50	Down	48	.11	1.04	.66	4.5	2 to 2.5	2.5	2.0
140	3,962 (13,000)	27	Down	44	0	.76	.85	3.0	2.5	2.5	2.0
160	3,962 (13,000)	50	Down	58	.14	1.29	.65	8.1	2.0	2.0	2.0
160	3,962 (13,000)	27	Down	53	.06	1.24	.65	6.6	2.0	2.0	2.0
175	3,962 (13,000)	50	Down	62	.12	1.37	.61	7.5	2.5	2.0	2.5
180	3,962 (13,000)	27	Down	56	.06	1.43	.59	7.4	3.0	2.5	1.5
195	3,962 (13,000)	27	Down	66	.09	1.57	.55	10.6	2.5	2.0	2.0
195	3,962 (13,000)	0	Down	58	-.05	1.46	.62	9.0	4.0	2.0	2.0
195	3,962 (13,000)	0	Up	54	-.09	1.42	.66	8.7	7.0	2.0	2.0
0.4	6,096 (20,000)	0	Up	--	----	.96	.62	6.1	3 to 3.5	3.0 to 3.5	2.5
.5	6,096 (20,000)	0	Up	68 [a]61	-.06 -.08	1.29	.60	9.7	4	2.0	2.0 response 3.0 force
.6	6,096 (20,000)	0	Up	82 71	-.04	1.82	.45	15.3	5 to 6.0	1.5 to 2.0	1.5 to 2.0
.7	6,096 (20,000)	0	Up	[a]103 [a]72	0 -.04	2.64	.42	21.5	3.0	1.5	3.0
.8	6,096 (20,000)	0	Up	--	----	2.73	.59	30.7	5.0	1.5	2.5
.85	6,096 (20,000)	0	Up	[a]76	-.03	3.15	.59	37.5	5.0	2.0	2.5 response 4.0 force
.7	8,534 (28,000)	0	Up	[a]107	-.04	2.12	.51	18.5	4.0	2.0	2.0
.6	10,668 (35,000)	0	Up	[a]75	-.03	.77	.60	5.8	4.0	1.5 to 2.0	1.5 to 2.0
.7	10,668 (35,000)	0	Up	[a]74	-.02	1.14	.53	8.1	4.0	2.0	2.0
.8	10,668 (35,000)	0	Up	90 [a]62	-.07 -.02	2.01	.60	17.0	2.5	1.5 to 2.0	1.5
.86	10,668 (35,000)	0	Up	[a]72	-.05	2.39	.45	21.9	2.5	1.5 to 2.5	1.5 to 2.5

[a]Mach trim on.

TABLE 5.- PILOT RATINGS AND LATERAL-DIRECTIONAL CHARACTERISTICS OF CV-990 AIRPLANE AT SPECIFIC TEST CONDITIONS

Test conditions: V_i, knots or M	Test conditions: Altitude, m (ft)	Test conditions: Flaps, deg	Test conditions: Gear	Pilot ratings: Lateral control: Coordinated: Slow	Pilot ratings: Lateral control: Coordinated: Fast	Pilot ratings: Lateral control: Uncoordinated: Slow	Pilot ratings: Lateral control: Uncoordinated: Fast	Pilot ratings: Transport operations	Pilot ratings: Lateral-directional control: Stability	Pilot ratings: Lateral-directional control: Damping: Dampers On	Pilot ratings: Lateral-directional control: Damping: Dampers Off	Pilot ratings: Lateral-directional control: Spiral stability	Lateral-directional characteristics: ω_d, rad/sec	ζ_d	τ_R, sec	$1/\tau_S$, 1/sec	$L_\delta \delta$, rad/sec^2	$\left\lvert \frac{\omega_\varphi}{\omega_d} \right\rvert$	$\left\lvert \frac{\varphi}{\beta} \right\rvert$	p_{max}, rad/sec
120	3,962 (13,000)	50	Down	3.0	5.5	3.0	5.0	4.0	5.0	---	5.0	1.5	0.85	0.025	1.18	-0.016	0.54	0.98	1.78	0.60
120	3,962 (13,000)	27	Down	2.5	3.5	2.5	3.5	3.5	3.5	---	4.0	2.0	.84	.031	1.06	.016	.34	.99	1.87	.35
140	3,962 (13,000)	50	Down	2.5	3.5 4.0	2.5	3.5 4.0	2.5	3.0	---	4.0	1.5	.91	.035	.97	.004	.65	1.10	1.84	.75
140	3,962 (13,000)	27	Down	2.5	4.0	2.5	4.0	3.0	2.0	---	5.5	1.5	.89	.044	.95	.025	.48	1.04	1.77	.50
160	3,962 (13,000)	50	Down	2.0	4.0	2.0	4.0	3.0	3.0	---	3.0	1.0	.98	.049	.91	.001	.82	1.16	1.78	1.01
160	3,962 (13,000)	27	Down	2.0	5.0	2.0	4.0	3.0	3.0	---	3.0	1.0	.94	.043	.91	.013	.54	1.10	1.84	.60
175	3,962 (13,000)	50	Down	2.5	5.0	2.5	5.0	3.0	3.0	---	3.0	2.0	1.02	.057	.93	.008	.90	1.14	1.70	1.09
180	3,962 (13,000)	27	Down	3.0	4.0	3.0	4.0	3.5	3.5	---	3.5	1.5	.98	.059	.87	.019	.61	1.17	1.75	.72
195	3,962 (13,000)	27	Down	2.5	4.5	2.5	5.0	2.5 3.0	2.0	---	2.5	1.5	1.11	.056	.80	.013	.87	1.13	1.58	.90
195	3,962 (13,000)	0	Down	3.0	4.5	3.0	4.5	2.5 3.5	2.5	---	4.0 2.5	3.0	1.08	.057	.86	.021	.57	1.08	2.09	.58
195	3,962 (13,000)	0	Up	1.5	2.5	2.0	4.0	3.0	2.5 2.5	2.5	4.0	2.0	1.11	.069	.77	.018	.78	1.06	1.78	.67
0.4	6,096 (20,000)	0	Up	3.0 3.5	3.5 5.0	3.0 2.0	4.5 4.0	3.5	3.5 3.0	2.5	3.5 3.5	2.0	.99	.038	1.07	.014	.41	1.03	2.07	.46
.5	6,096 (20,000)	0	Up	3.0	5.5	3.0	5.0	4.0	5.0	---	5.0	1.5	1.13	.039	1.03	-.002	.68	1.05	1.86	.78
.6	6,096 (20,000)	0	Up	2.5 1.5	3.5 3.0	2.5 2.0	4.5 4.0	3.5 3.0	2.5 2.0	2.0 2.0	3.0 3.0	1.5	1.33	.056	.87	.013	.95	1.12	1.82	1.03
.7	6,096 (20,000)	0	Up	2.5 2.0	4.0 4.5	2.5 2.0	4.0 5.0	3.5	2.5 2.0	1.5	2.5 4.0	1.5	1.55	.061	.75	.025	1.45	1.10	1.71	1.32
.8	6,096 (20,000)	0	Up	3.0	4.5	3.0	4.5	3.5 4.0	4.0	---	6.0	1.5	1.85	.072	.61	.005	1.95	1.11	1.68	1.47
.85	6,096 (20,000)	0	Up	2.0	5.0	2.0	4.0	3.0	2.0	---	2.0	1.5	1.97	.071	.56	.001	1.75	1.13	1.70	1.25
.7	8,534 (28,000)	0	Up	2.5	4.0	3.0	4.5	3.0	3.0	---	4.0	2.0	1.40	.055	.79	.012	1.22	1.12	1.95	1.21
.6	10,668 (35,000)	0	Up	2.5	5.0	3.0	4.5	3.5	3.0 4.0	2.0 3.0	3.0 4.0	2.0	.98	.022	1.74	.016	.38	1.09	2.34	.78
.7	10,668 (35,000)	0	Up	2.5 2.0	4.0 2.5	3.0 3.5	4.5 3.0	2.0 3.0	3.0 2.0	2.0	3.0 3.5	2.0	1.13	.012	1.23	0	.75	1.08	2.22	1.07
.8	10,668 (35,000)	0	Up	2.5	5.0	3.0	4.5	2.5	2.0	2.5 2.0	3.0 3.0	2.0	1.31	.031	1.03	.019	1.05	1.11	2.07	1.33
.86	10,668 (35,000)	0	Up	2.5	4.0	3.0	4.0	2.0	2.0	2.0 1.5	2.0 3.0	2.0	1.54	.053	.84	.018	1.25	1.12	1.73	1.31



E-19752

Figure 1. CV-990 airplane.

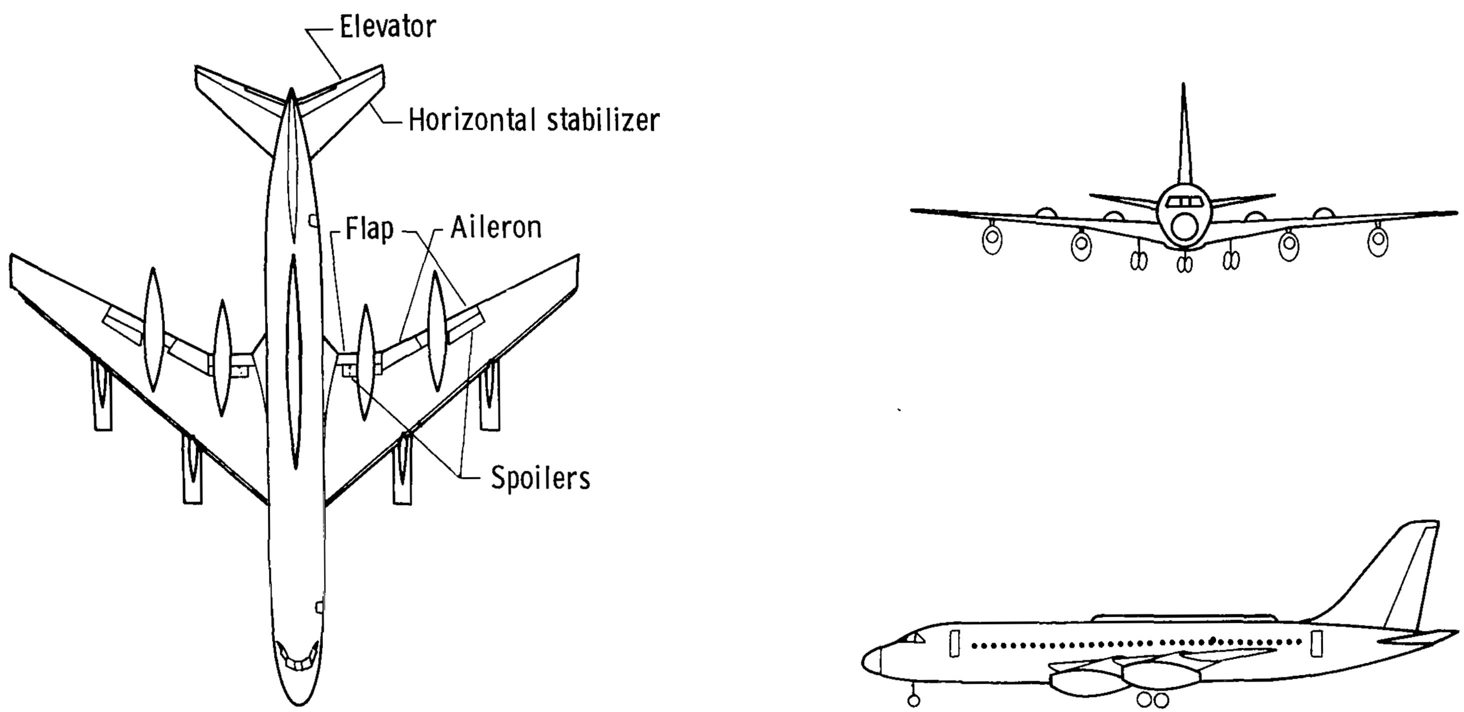


Figure 2. Three-view drawing of the CV-990 airplane.

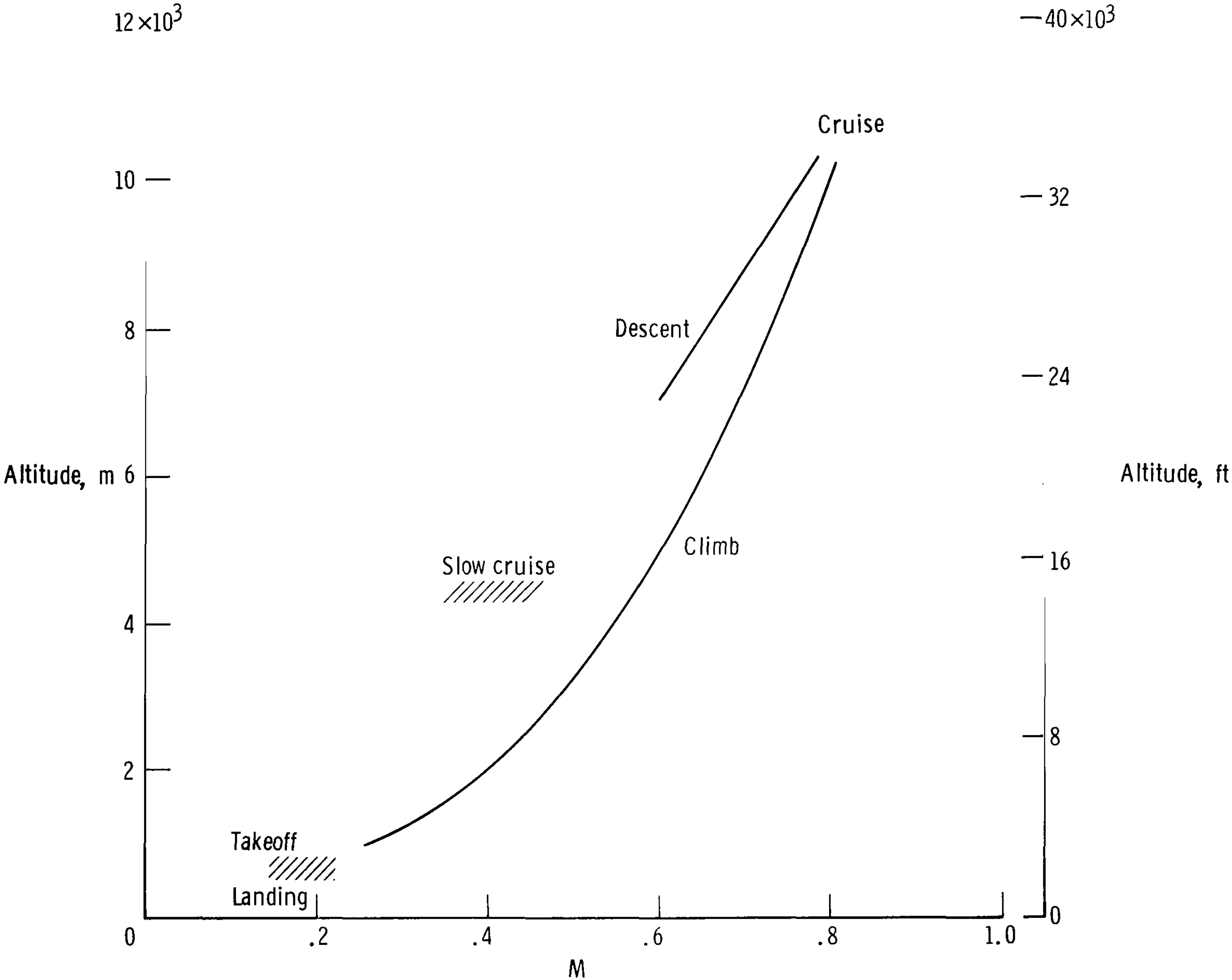


Figure 3. Flight envelope covered during pilot evaluations of CV-990 operational flying.

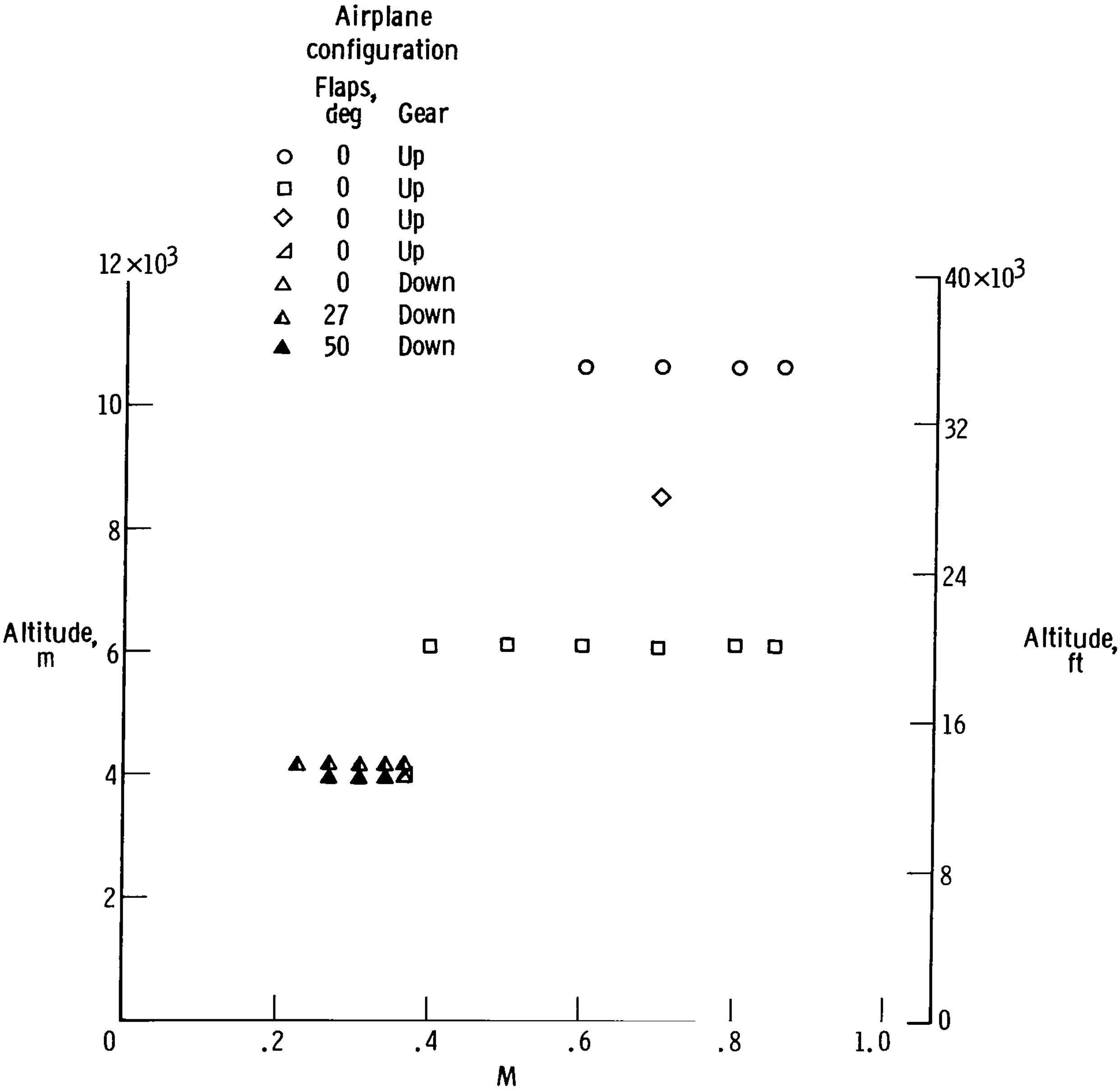


Figure 4. Specific test conditions evaluated by the pilots.

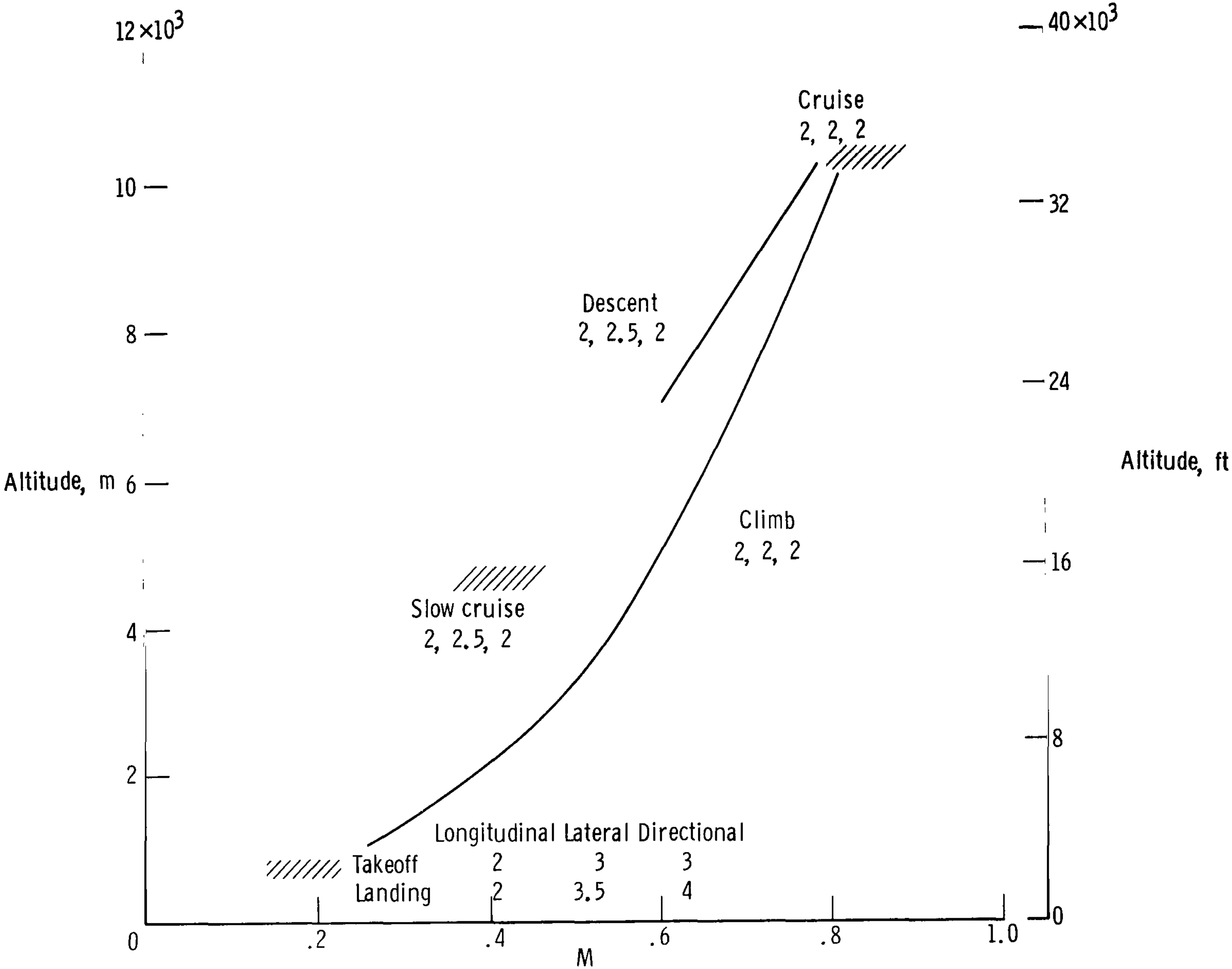


Figure 5. Average pilot ratings of CV-990 flying qualities during normal operational flying. Yaw damper on except during takeoff and landing.

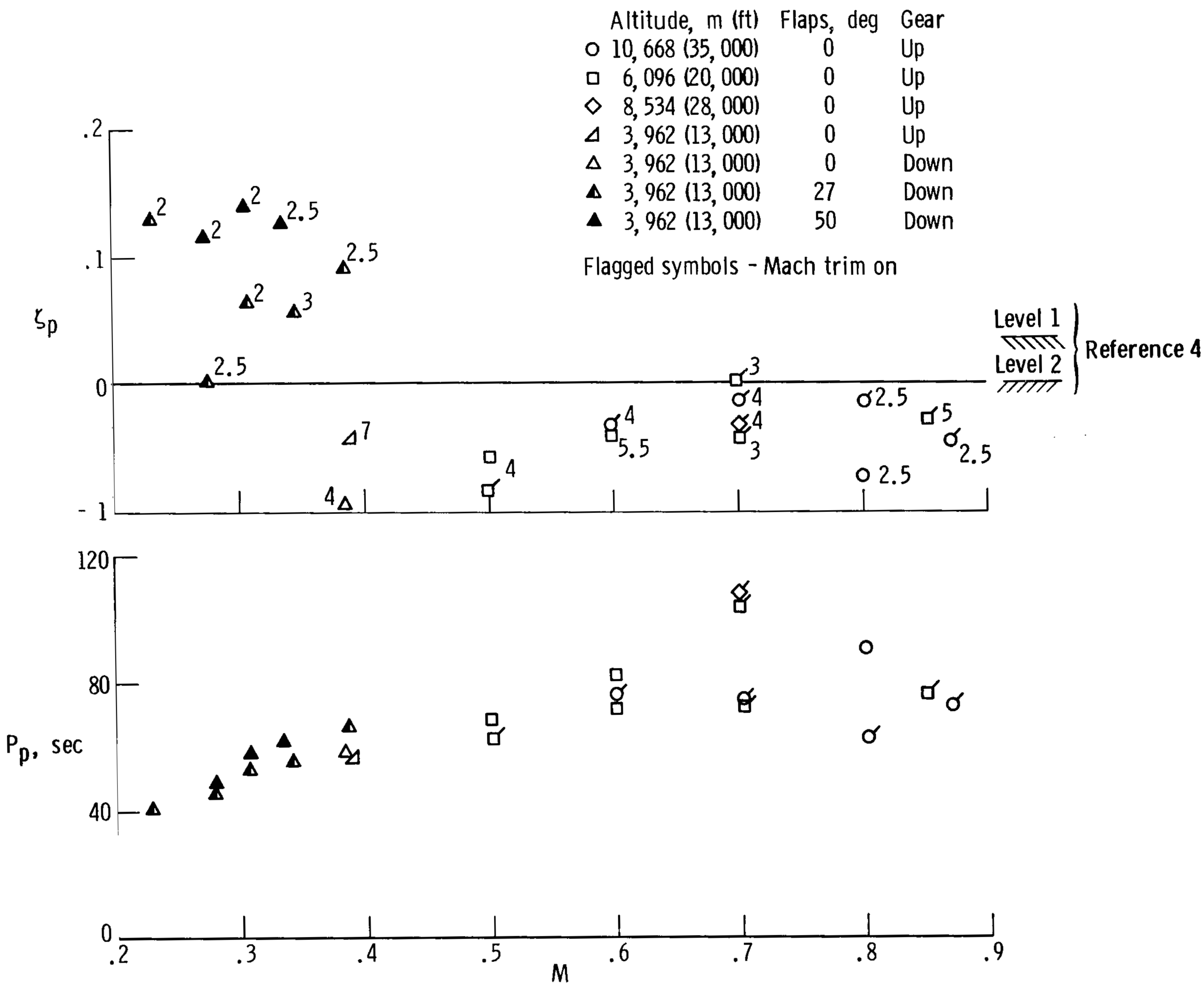


Figure 6. Pilot ratings of CV-990 phugoid characteristics and comparison with the Military Specification for damping for piloted airplanes (ref. 4).

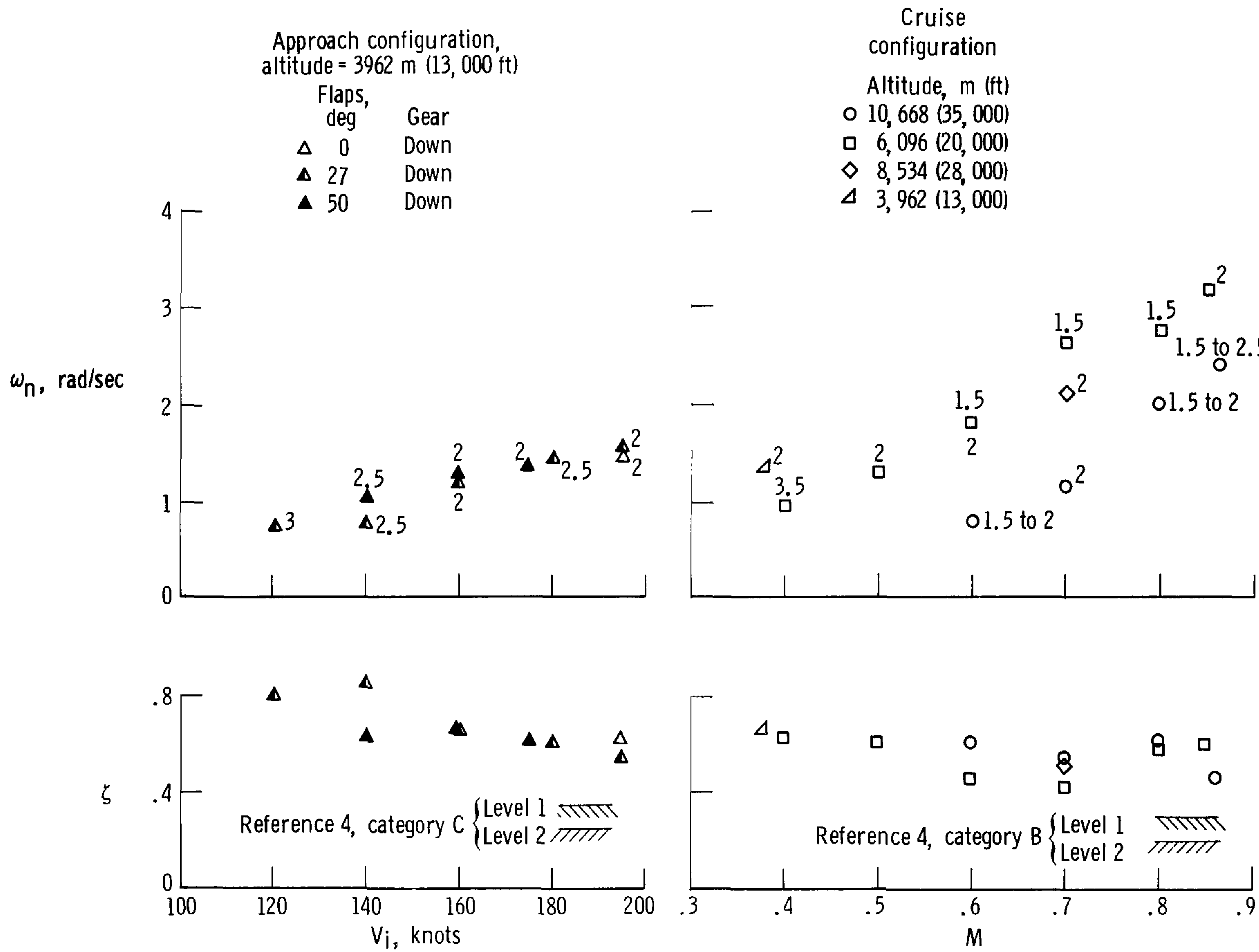


Figure 7. Pilot ratings of CV-990 longitudinal short-period characteristics and comparison with Military Specification for damping for Class III piloted airplanes (ref. 4).

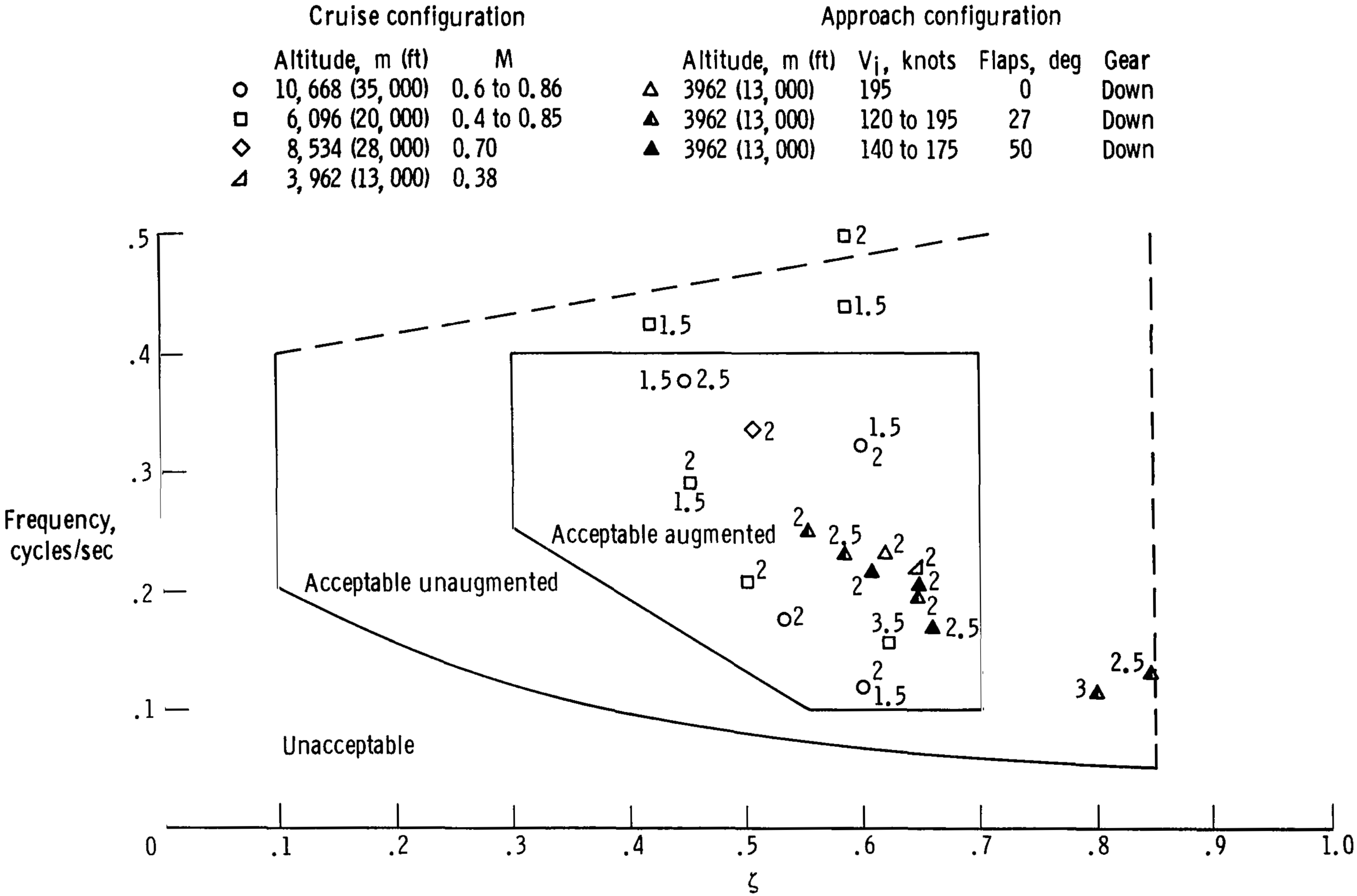
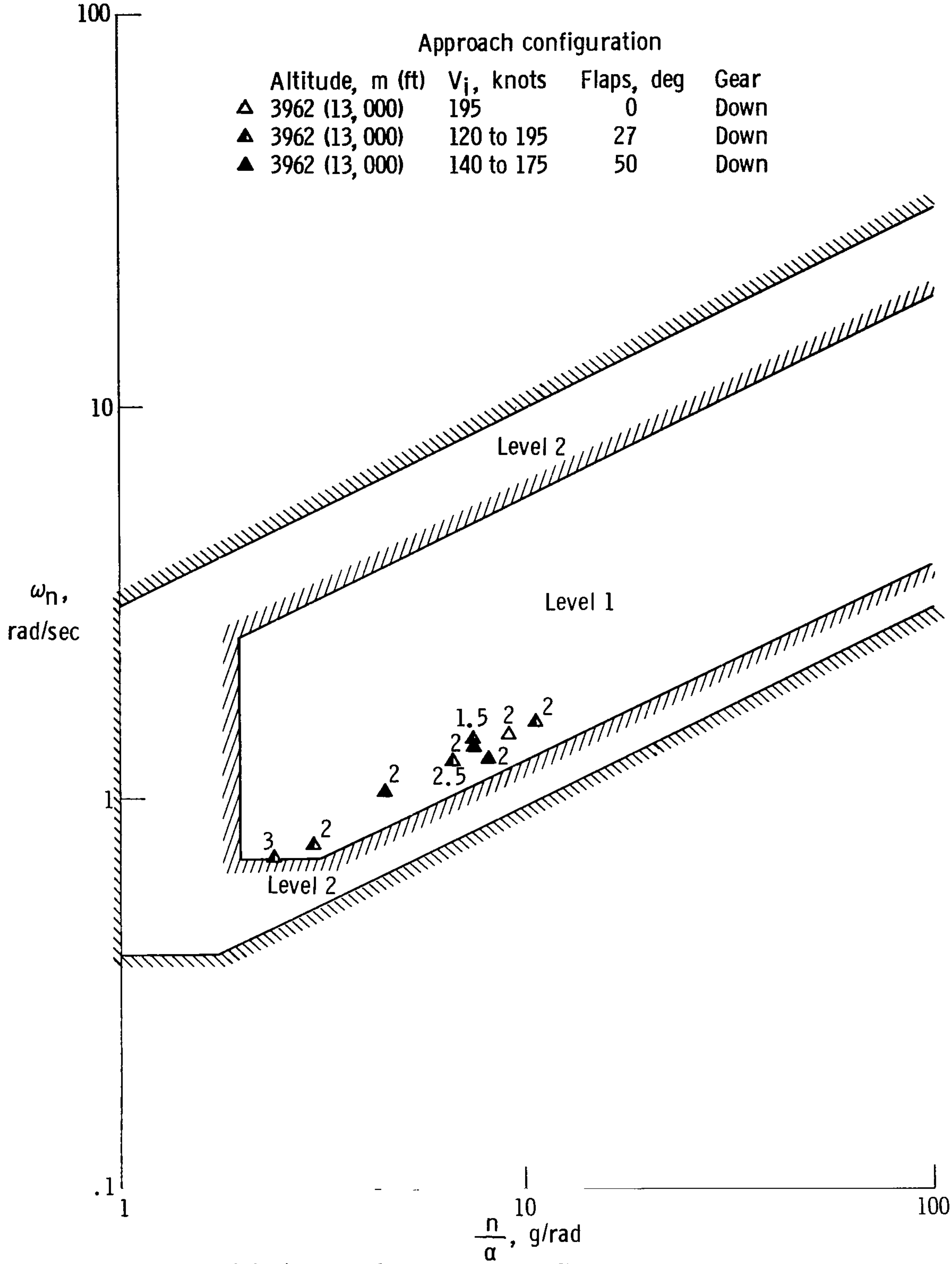
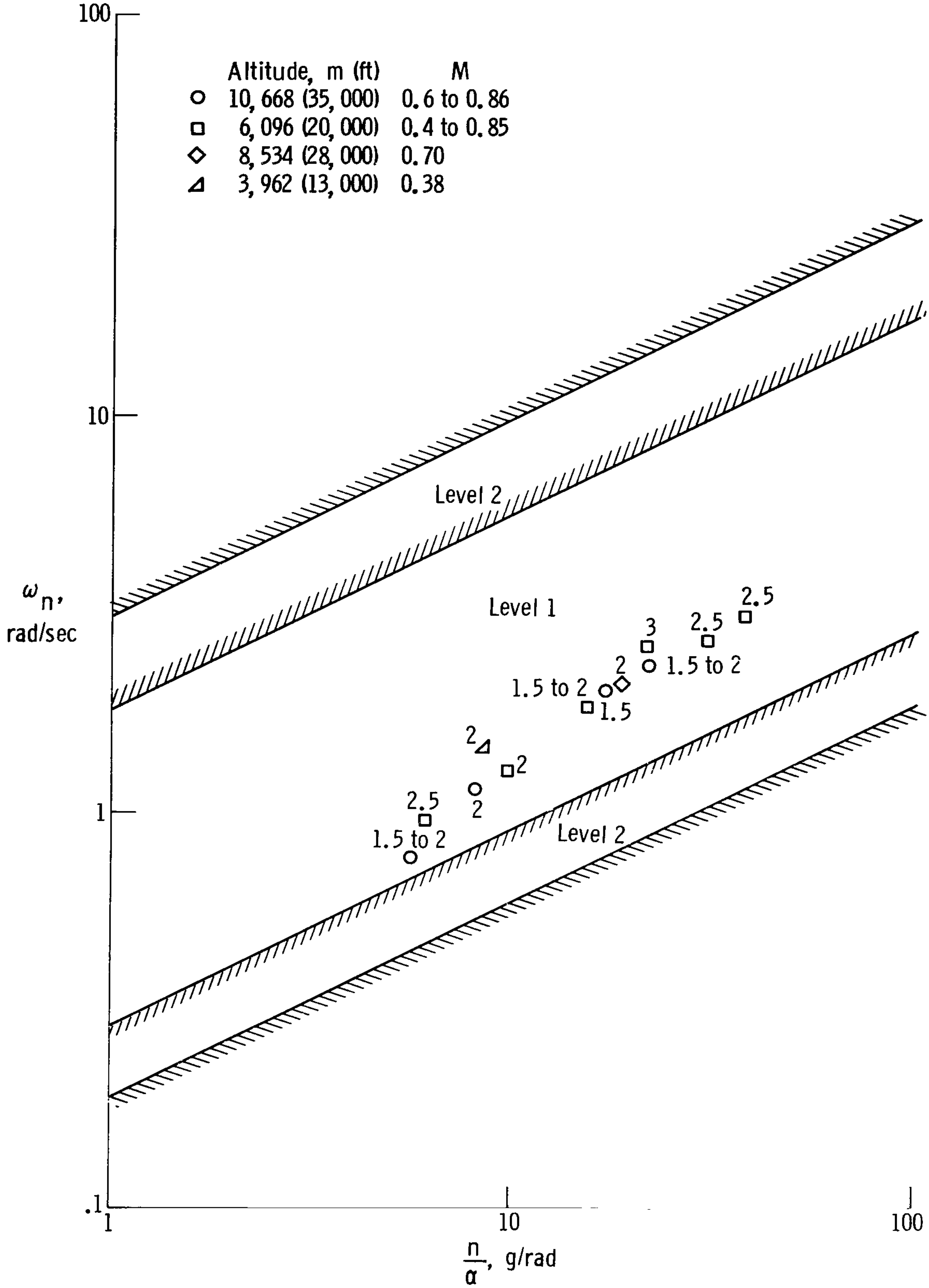


Figure 8. Pilot ratings of CV-990 longitudinal short-period characteristics and comparison with the tentative criterion of reference 7.



(a) Approach (category C) flight phases.

Figure 9. Pilot ratings of CV-990 longitudinal maneuvering capability and comparison with the Military Specification (ref. 4) for Class III airplanes.



(b) Cruise (category B) flight phases.

Figure 9. Concluded.

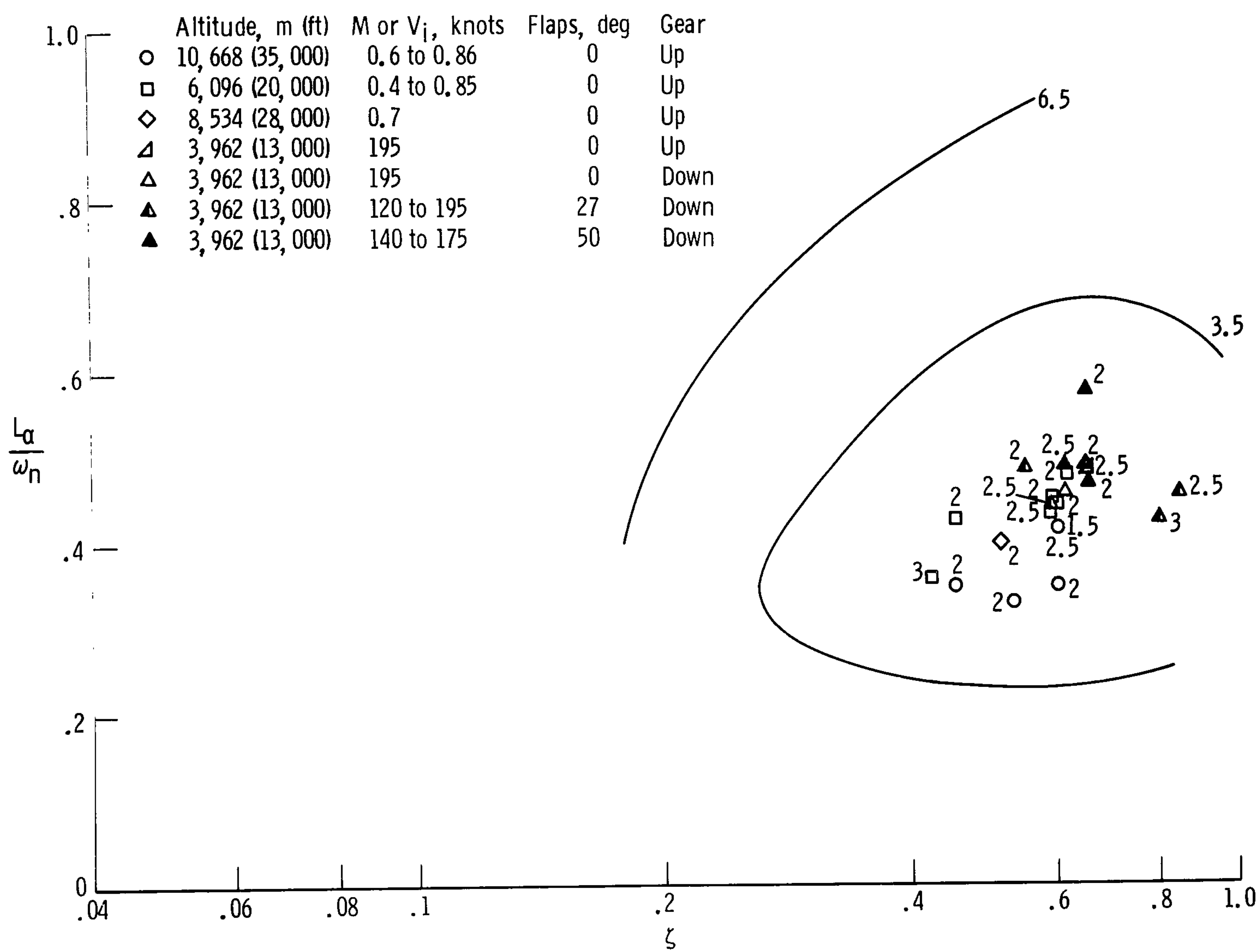


Figure 10. Pilot ratings of CV-990 longitudinal characteristics and comparison with the criterion of reference 8.

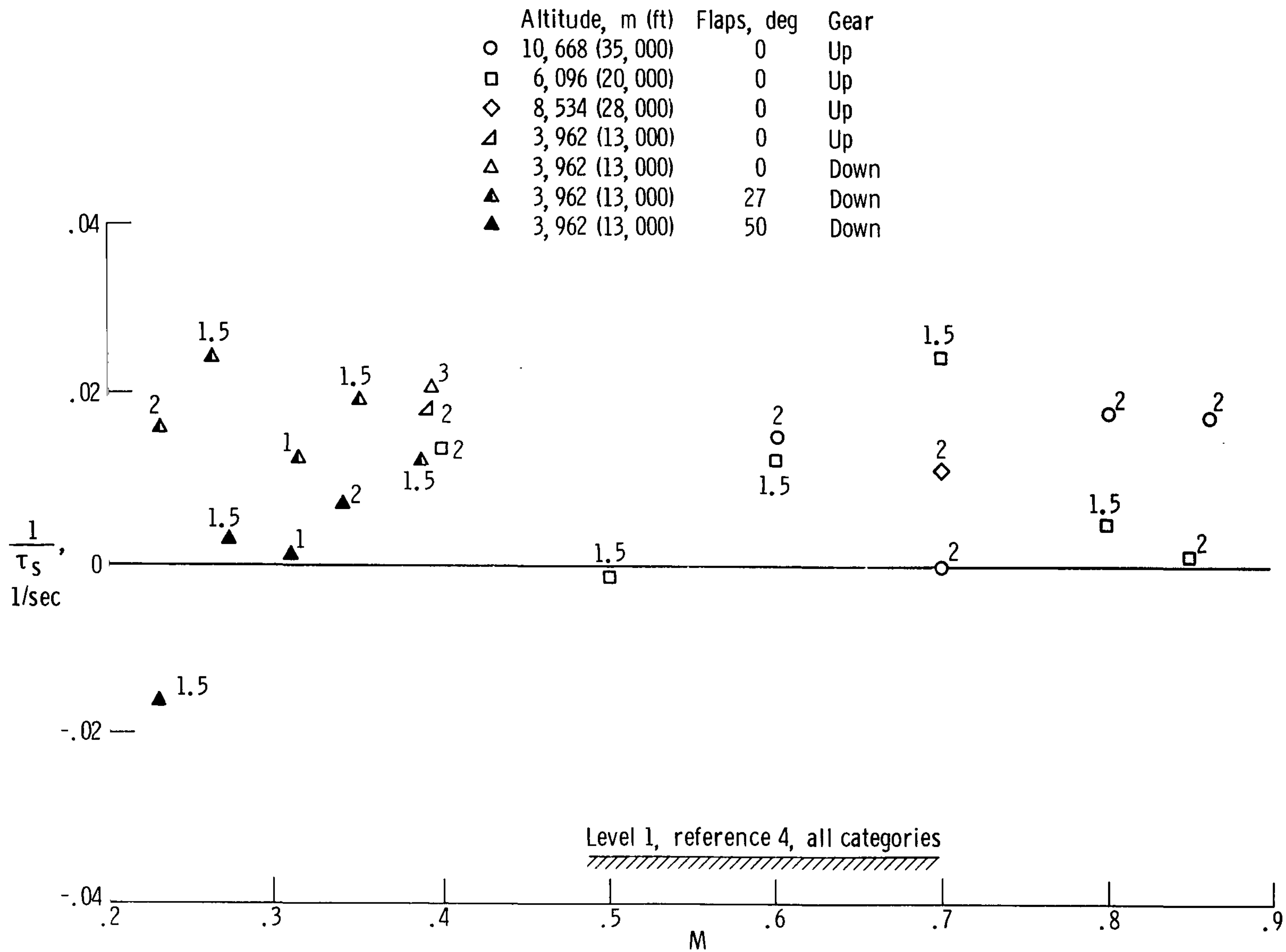


Figure 11. Pilot ratings of CV-990 spiral-mode data and comparison with Military Specification (ref. 4) for Class III airplanes.

	Altitude, m (ft)	M or V_i, knots	Flaps, deg	Gear
○	10,668 (35,000)	0.6 to 0.86	0	Up
□	6,096 (20,000)	0.4 to 0.85	0	Up
◇	8,534 (28,000)	0.7	0	Up
◺	3,962 (13,000)	195	0	Up
△	3,962 (13,000)	195	0	Down
◭	3,962 (13,000)	120 to 195	27	Down
▲	3,962 (13,000)	120 to 175	50	Down

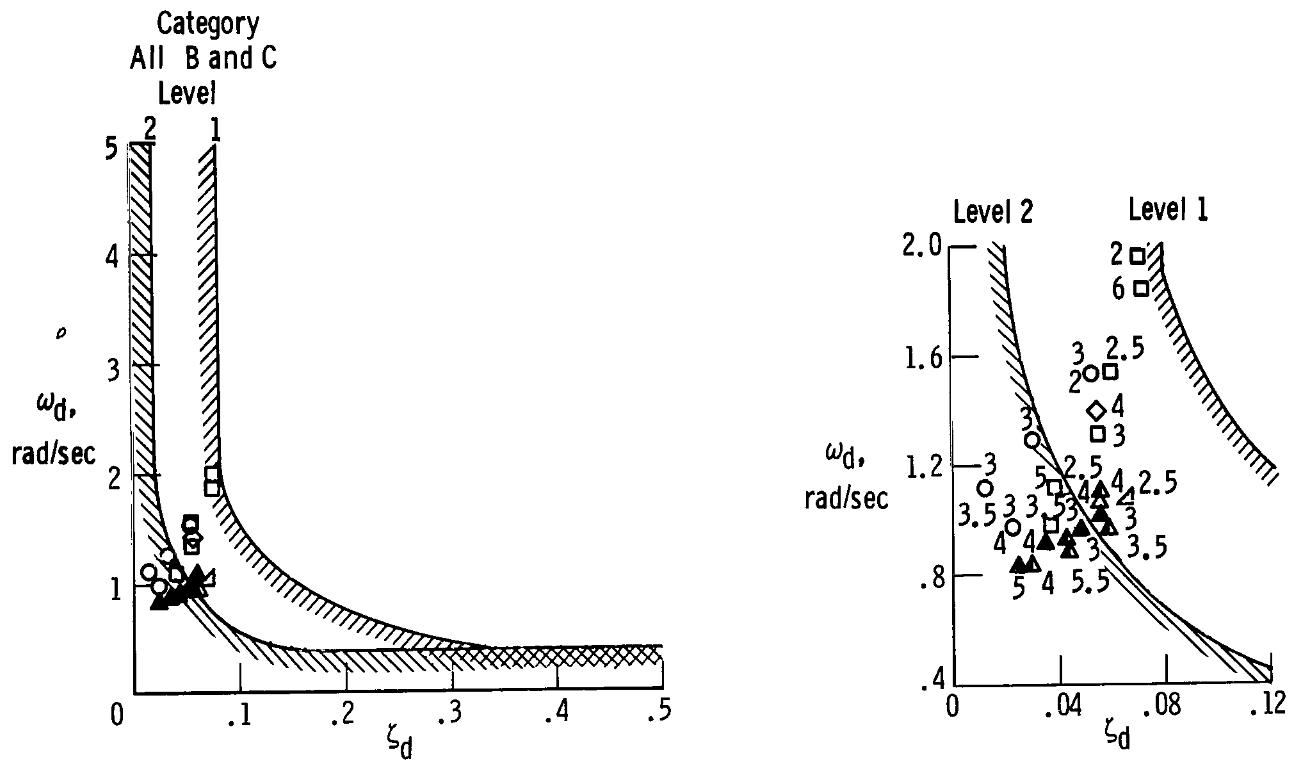
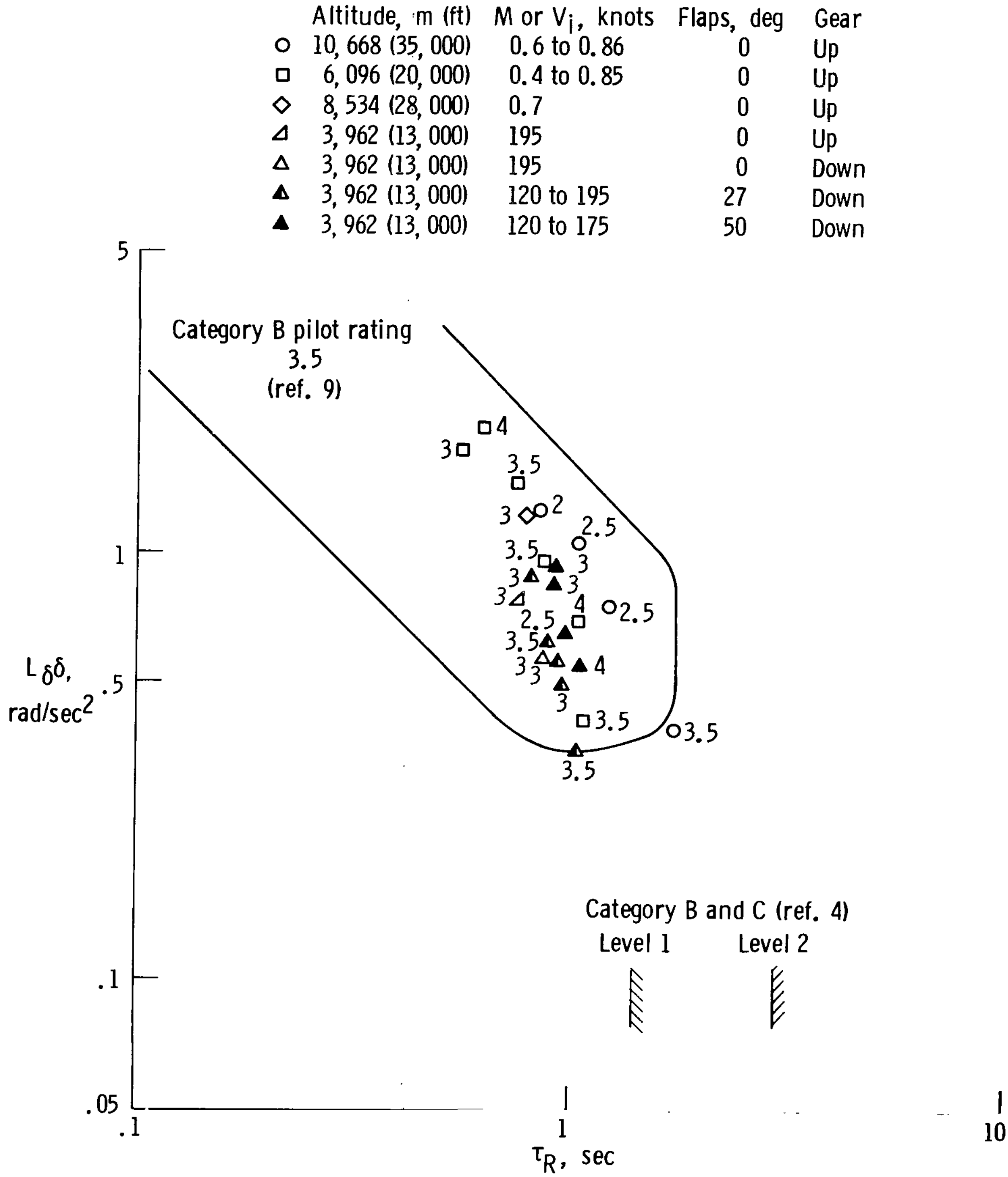
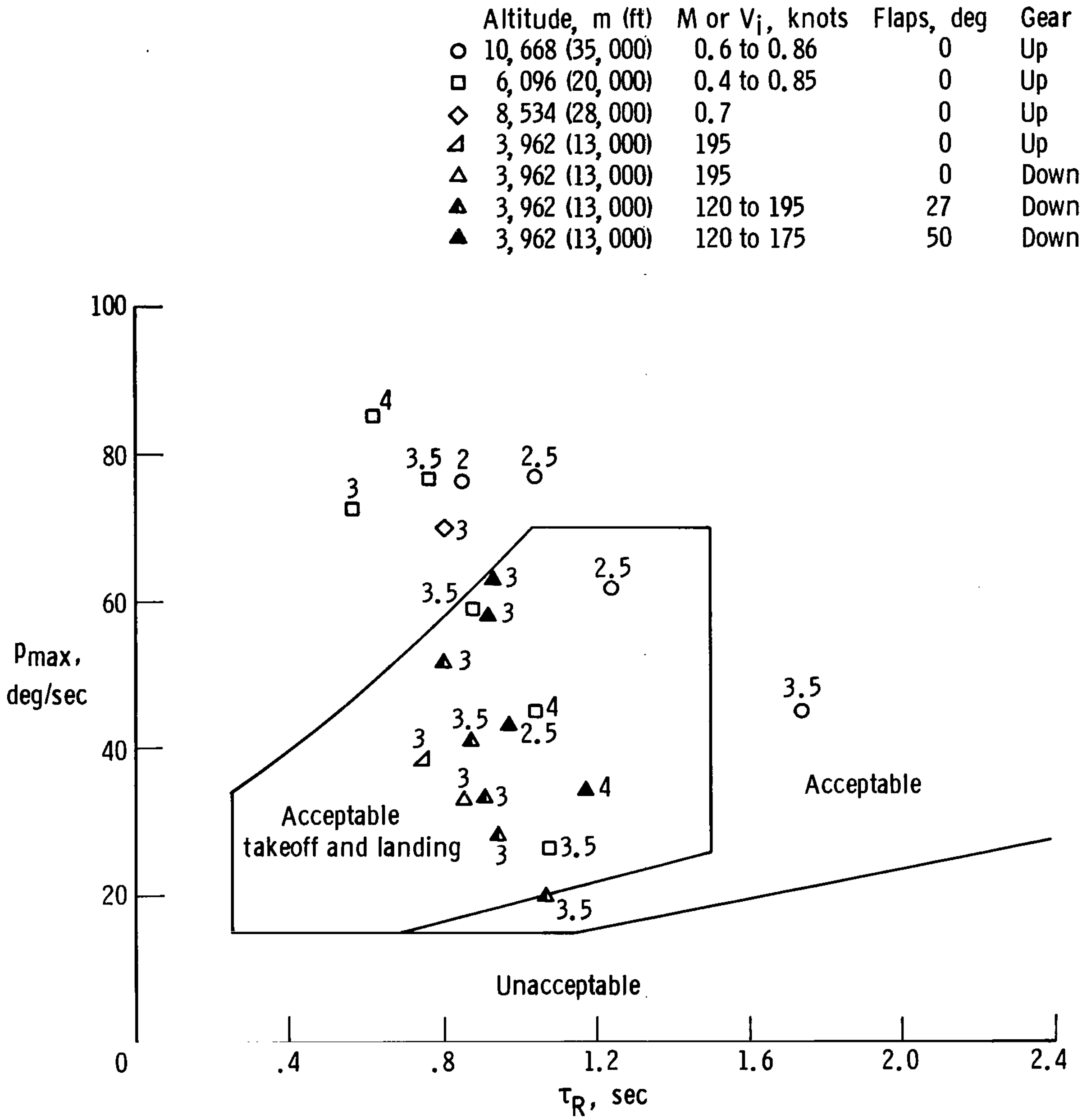


Figure 12. Pilot ratings of CV-990 Dutch roll characteristics (yaw damper off) and comparison with reference 4 Class III airplanes. $\omega_d^2 |\varphi/\beta| < 7$.



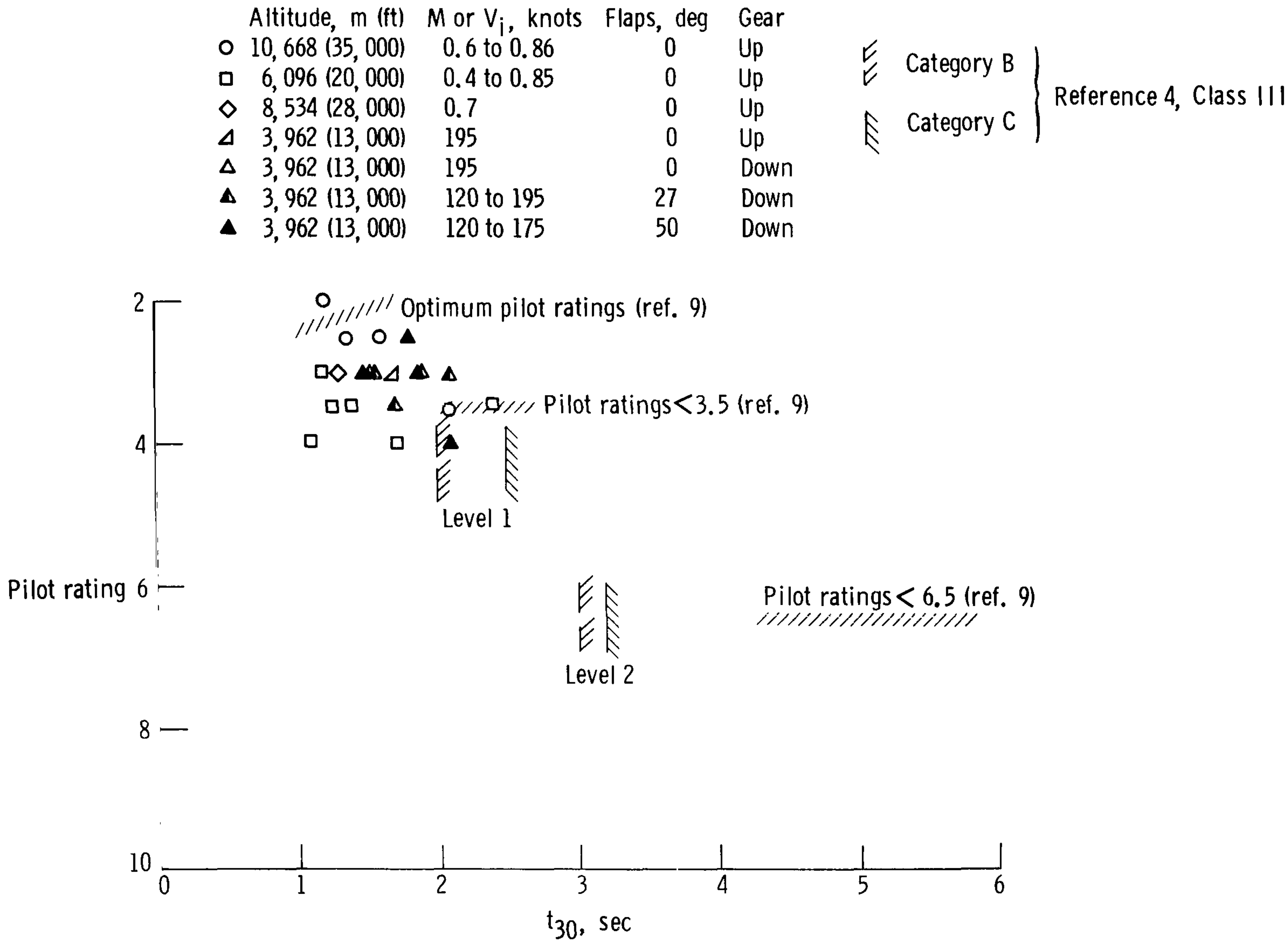
(a) Roll acceleration and time constant (refs. 4 and 9).

Figure 13. Pilot ratings of CV-990 roll characteristics and comparison with roll criteria for transport airplanes (refs. 4 and 9). Overall pilot ratings from table 5.



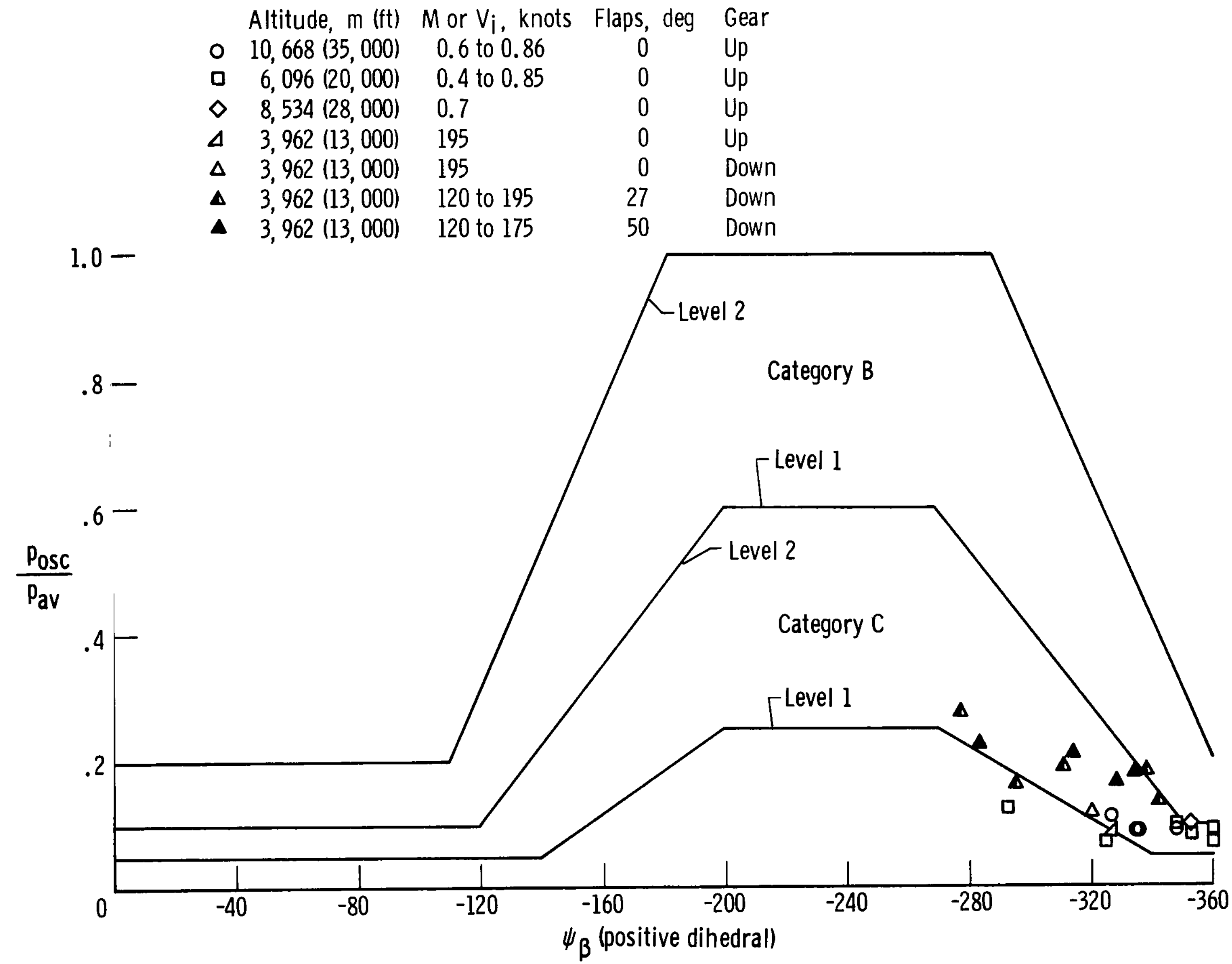
(b) Roll rate and time constant (ref. 7).

Figure 13. Continued.



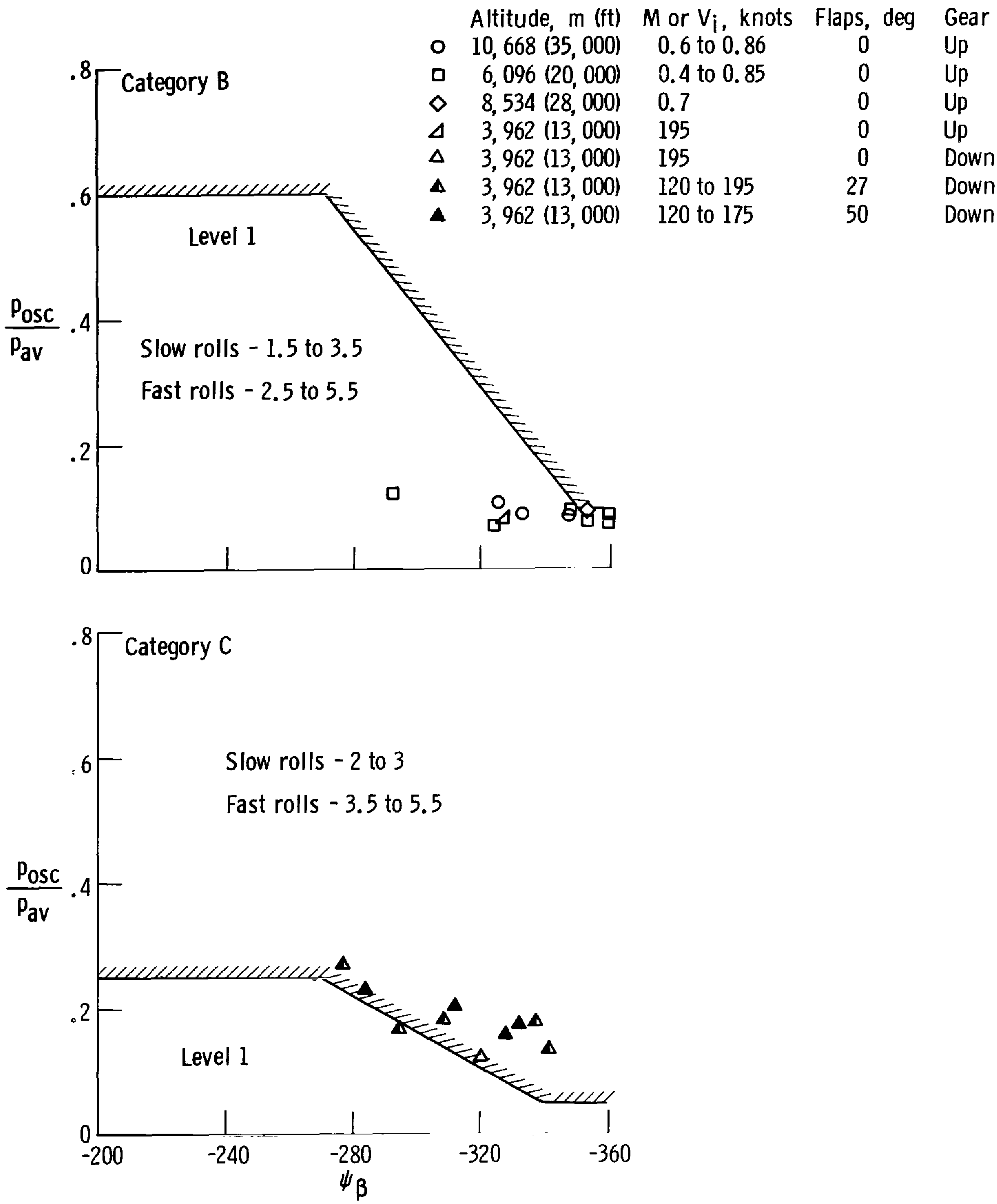
(c) Time to bank 30° (ref. 4 (category B and C) and ref. 9 (category B only)).

Figure 13. Concluded.



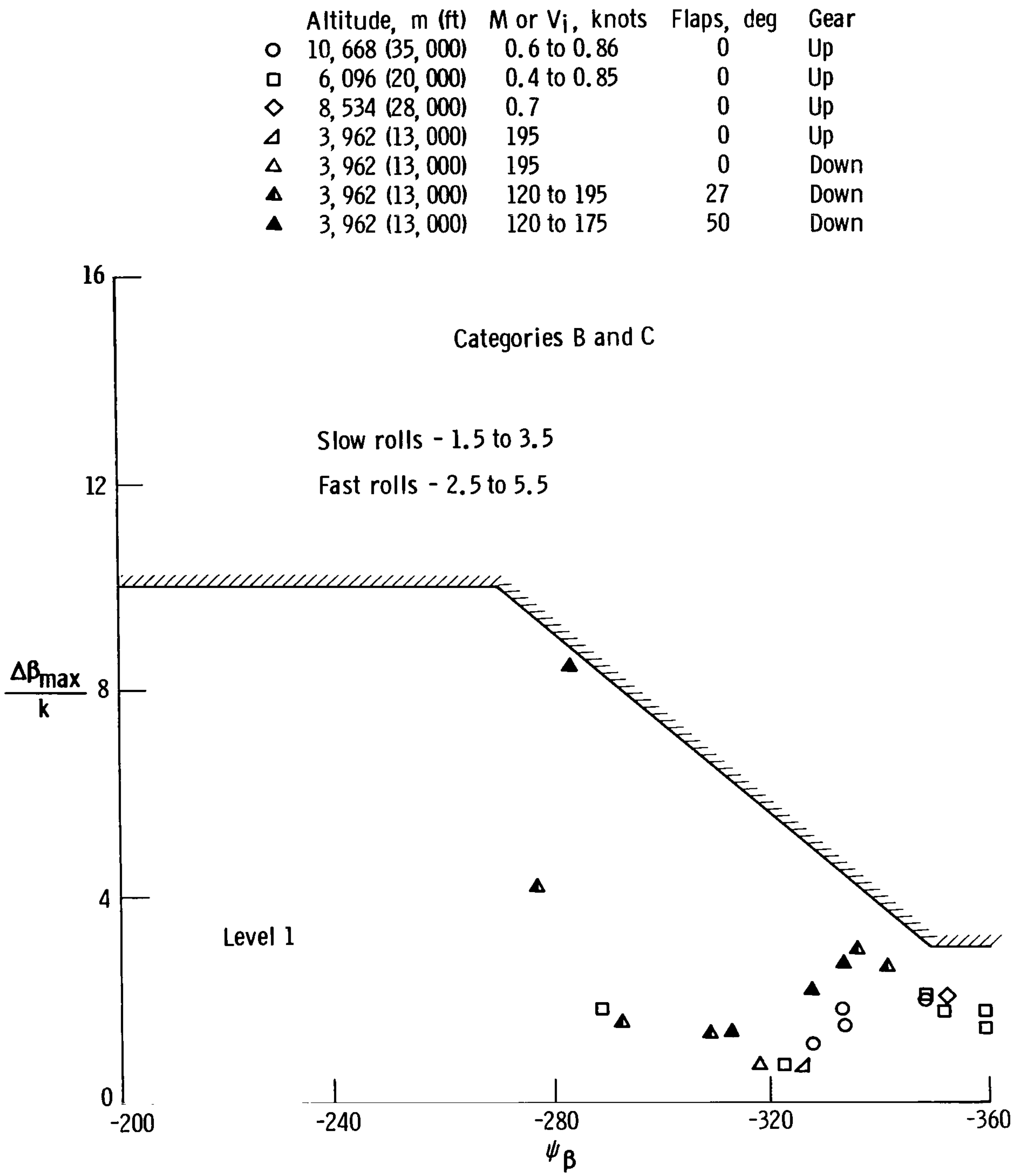
(a) Roll rate requirement for small inputs.

Figure 14. CV-990 response to roll control compared with the Military Specification for small inputs (ref. 4).



(b) Detailed comparison of category B and C, including pilot ratings.

Figure 14. Continued.



(c) Comparison with sideslip requirement, including pilot ratings.

Figure 14. Concluded.

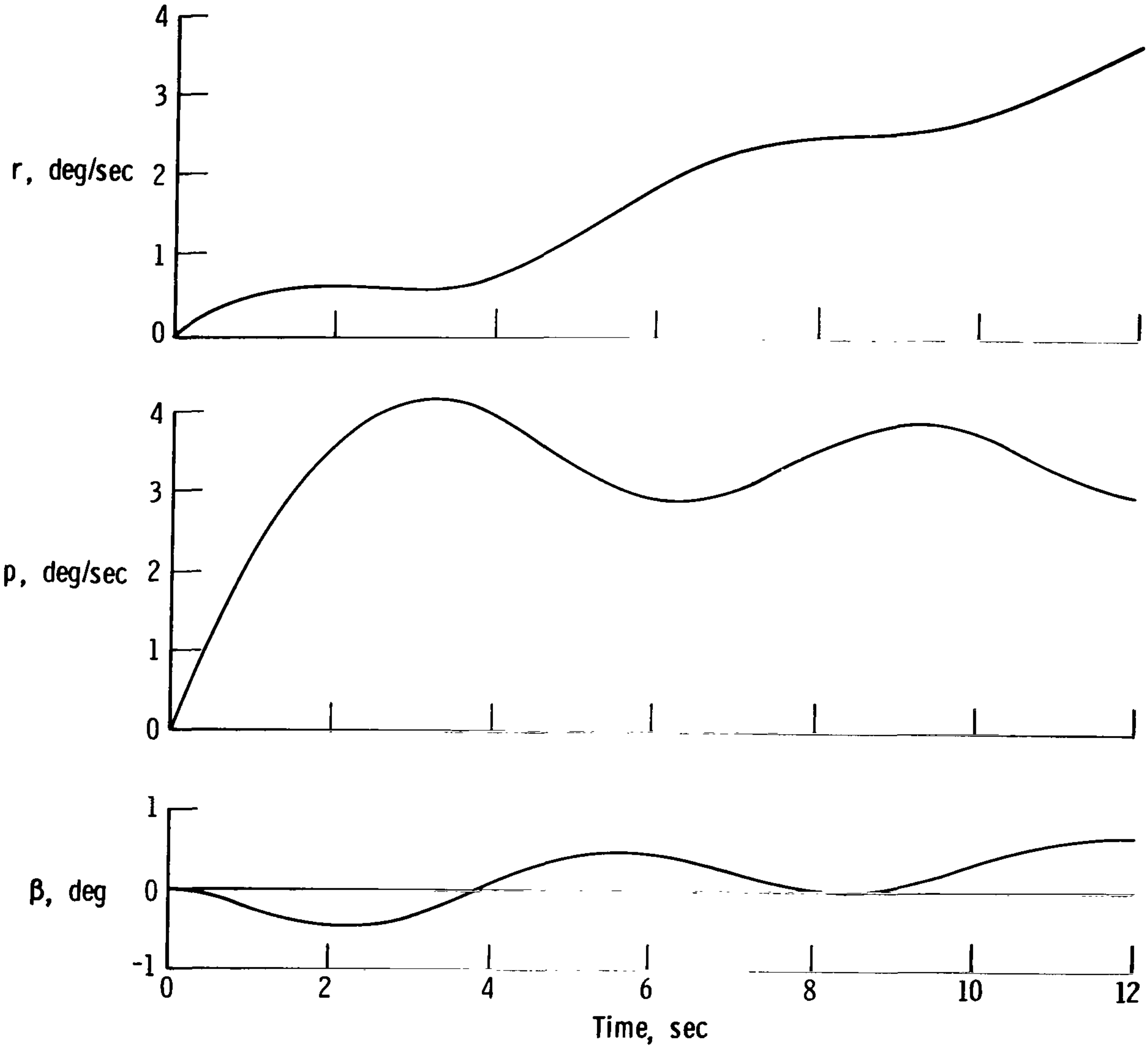


Figure 15. Typical CV-990 calculated Dutch roll oscillation resulting from a step wheel input. Approach configuration: 50° flaps, gear down; altitude = 3962 m (13,000 ft); airspeed = 175 knots; gross weight = 74,091 kg (163,000 lb).

NASA-Langley, 1972 —— 2 H-680

NATIONAL AERONAUTICS AND SPACE ADMISTRATION
WASHINGTON, D.C. 20546

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300

FIRST CLASS MAIL

POSTAGE AND FEES PAID
NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION

U.S.MAIL

009 001 C1 U 02 720428 S009C3DS
DEPT OF THE AIR FORCE
AF WEAPONS LAB (AFSC)
TECH LIBRARY/WLOL/
ATTN: E LOU BOWMAN, CHIEF
KIRTLAND AFB NM 87117

POSTMASTER: If Undeliverable (Section 1
Postal Manual) Do Not Re

"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: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

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

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Technology Surveys.

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

SCIENTIFIC AND TECHNICAL INFORMATION OFFICE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546