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A Ground-Simulator Investigation of Helicopter Longitudinal Flying Qualities for Instrument Approach

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        computerized functions were needed to complete the procedure: approximate
        analysis with the established input variables, optimization of an
        objective function, and refined analysis for design verification.


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A GROUND-SIMULATOR INVESTIGATION OF HELICOPTER LONGITUDINAL FLYING QUALITIES FOR INSTRUMENT APPROACHES

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SUMMARY

A ground-simulation experiment was conducted to investigate the direct and interactive influences of several longitudinal static and dynamic stability parameters on helicopter flying qualities during terminal-area operations in instrument conditions. Variations that were examined included five levels of static control-position gradients ranging from stable to unstable; two levels of dynamic stability for the long-period oscillation; two levels of the steady-state pitch-speed gradient; two levels of angle-of-attack stability and pitch-rate damping; and two levels of stability and control augmentation. These variations were examined initially in calm air and then in simulated light-to-moderate turbulence and wind shear. Five pilots performed a total of 223 evaluations of these parameters for a representative microwave landing system precision approach task conducted in a dual-pilot crew-loading situation. Pilot ratings indicated (1) that the system is clearly adequate for the IMC approach in calm air for neutral and slightly unstable static control-position gradients but that adding turbulence causes a significant degradation in system performance; (2) that high angle-of-attack stability has an adverse effect because of pitch-to-rate of descent coupling; and (3) that the steady-state pitch-speed gradient has a minimal influence.

INTRODUCTION

The increase in civil helicopter operations during the past decade has led to greater emphasis on providing a more fundamental understanding of the aeromechanics and flight-control requirements of helicopters in the flight regimes of interest. One such regime is all-weather operations, and in particular terminal-area operations in instrument meteorological conditions (IMC). As a part of their continuing efforts to provide design and airworthiness information for helicopter IMC flight, the National Aeronautics and Space Administration (NASA) and the Federal Aviation Administration (FAA) instituted in 1978 a joint program of analyses, ground simulation, and flight experiments at Ames Research Center. This program is directed at the following two general goals:

1. Provide analyses and experimental data to support or amplify the Airworthiness Criteria for Helicopter Instrument Flight (ref. 1), which are the final proposed appendices to FAR Parts 27 and 29, respectively (refs. 2,3).

2. Provide analyses and experimental data to determine the flying-qualities, flight-control, and display aspects required for a good helicopter IMC capability, and to relate these aspects to design parameters of the helicopter.

The first four experiments that were conducted in this joint NASA/FAA program are described in references 4-7. In the first two ground simulation experiments, the influences of neutral versus stable static control gradients and the requirements for various levels of stability and control augmentation systems (SCAS) were examined for a nonprecision very-high-frequency omnidirectional range (VOR) instrument approach task, assuming a dual-pilot crew-loading situation (no auxiliary tasks) and raw-data displays without flight directors. Cooper-Harper pilot ratings (CHPRs) indicated (1) a need for some level of SCAS above the bare airframe to ensure a level of adequate performance with tolerable workload (CHPR < 6.5)(ref. 4), (2) a requirement for attitude augmentation in pitch and roll to obtain a level of satisfactory (CHPR < 3.5) (refs. 4,5), and (3) that neutral longitudinal and lateral static stabilities were acceptable (ref. 5). In the third ground simulation experiment, the influences of flight-director display assistance and the effects of representative single-pilot auxiliary tasks on the suitability of the static stabilities and SCAS concepts considered in the first two experiments were examined in relation to precision MLS instrument approaches (ref. 6). The Cooper-Harper pilot ratings indicated, among other things, that the hypothesized trade-off between control complexity and display sophistication for equivalent levels of acceptability was evident only for combinations rated as satisfactory (CHPR < 3.5); little average improvement for control systems rated as only adequate (CHPR < 6.5) was provided by changing the display from raw-data-only to three-axis flight directors. As in the first two experiments, pitch- and roll-attitude augmentation were required for ratings of satisfactory and, for the single-pilot case, were effectively required for ratings better than marginally adequate (CHPR < 5.5).

The fourth experiment was conducted, using the variable-stability UH-1H V/STOLAND helicopter, to verify in flight some of the results of the first three ground-simulation experiments (ref. 7). Neutral and stable longitudinal static stability, rate-damping and attitude-command SCAS implementation, and raw-data and three-axis flight directors were examined for a precision MLS approach task with a dual-pilot crew-loading situation. The results of this experiment corroborated the conclusions from the ground experiments for these variables: (1) rate-damping augmentation provided an adequate but unsatisfactory system, (2) neutral longitudinal static stability provided a degraded but still adequate (with rate-damping augmentation) system, (3) attitude augmentation in pitch and roll was required to achieve a satisfactory system, and (4) three-axis flight directors provided little average improvement for the rate-damping system and a small but noticeable improvement with attitude augmentation (ref. 7).

As is indicated by this summary, the major thrust of the first four experiments was to examine the interactive influences of static stability, SCAS type, flight-director displays, and crew loading. This focus was determined to some extent by the initial version of the IFR criteria (ref. 8), as well as industry questions concerning them and proposed alternatives (ref. 9). During the 2 years between the time the experiment reported in reference 4 was conducted and the time the experiment described in this report was conducted, the criteria set forth in reference 8 were modified and used as the proposed instrument flight rules (IFR) appendix given in reference 1. The general goal of this present experiment was to provide data in support of the final versions of the criteria on static and dynamic stability, thereby bringing to a conclusion this initial sequence of experiments.

To place the parameters selected for investigation in context, the IFR Appendix criteria dealing with static and dynamic stability from reference 1 are summarized in table 1 for normal- and transport-category rotorcraft. The category definitions are

(1) normal--9 passenger seats or fewer and less than 6,000 lb; (2) transport B--9 passenger seats or fewer, over 6,000 lb (with some additional restrictions if over 20,000 lb); and (3) transport A--10 passenger seats or more, all weights. No differentiation between transport categories A and B is made for the static and dynamic criteria, nor is any distinction made between dual-pilot and single-pilot crew loadings for transport-category helicopters.

Three points are worth noting about these criteria. First, they are intended to assure minimum safety. It is tacitly understood that an aircraft could be certified for IFR if one of these criteria is barely met, but it is unlikely that certification would be granted if several criteria were only marginally satisfied. Second, no distinction among longitudinal, lateral, and directional characteristics is made for dynamic stability, nor is any effort made to limit interaxis coupling or to prescribe desirable rapidity of response. In addition, the requirement for a positive longitudinal static-force gradient effectively precludes an unstable aperiodic root longitudinally for most realizable situations; as a result, the dynamic criteria relating to aperiodic roots appear to be overridden by the static criteria for longitudinal motions. Third, the criteria do not address any SCAS or display requirements as a function of crew loading in terms of their influences on the flying qualities, nor is the influence of turbulence explicitly discussed, as it was in the reference 8 proposal.

For this experiment, some aspects of these criteria that were not directly addressed in the previous experiments were selected for examination. Because of the importance of glide-slope and airspeed control in terminal-area maneuvers, only longitudinal variations were considered. The intent was to have the parameters overlap those of the previous experiments in some cases so that collectively the experiments would constitute a data set pertinent to the applicability of these criteria for constant-speed helicopter IFR terminal-area operations. On this basis, the primary variables selected for investigation were

1. Longitudinal static stability, as measured by cockpit control-position gradient with speed, with variations from stable to unstable yielding unstable aperiodic responses

2. Longitudinal long-term ($P > 10$ sec) oscillations ranging from damped to unstable

3. Longitudinal steady-state pitch-attitude-to-speed gradient ranging from nearly neutral to highly stable

4. Longitudinal short-term pitch-attitude and angle-of-attack responses to cyclic and collective inputs

5. Longitudinal stability and control-system implementation rate and attitude command

6. Level of turbulence: none and light-to-moderate

Cooper-Harper pilot ratings were obtained from five pilots for several values of each parameter during the performance of a precision 60-knot IFR approach task, with and without simulated turbulence. The Vertical Motion Simulator (VMS) at Ames Research Center was used in conjunction with a generic nine-degree-of-freedom helicopter mathematical model to implement and examine the experimental configuration.

The remainder of this report is organized as follows. The design and conduct of the experiment to address the variables outlined above are described in the next two sections. Flying qualities results are then presented and discussed, followed by conclusions and recommendations.

The authors wish to express their appreciation to Mr. G. W. Hall, Ames Research Center, and Lt. Col. R. K. Merrill, U.S. Army, who served as evaluation pilots. In addition, the authors wish particularly to express their gratitude to Mr. P. L. G. Harper of the Civil Aviation Authority, England, and Mr. Dennis Tuck of the Federal Aviation Administration, Southwest Region, who also served as evaluation pilots; their professionalism and interest greatly enhanced many aspects of the experiment.

DESIGN OF EXPERIMENT

Mathematical Model

The basic mathematical model used to simulate the flight dynamics of the helicopters investigated in this experiment was the same nine-degree-of-freedom model that was used in the previous ground simulator studies (refs. 4-6). The model explicitly includes the three-degrees-of-freedom tip-path-plane dynamic equations for the main rotor (ref. 10) and the six-degree-of-freedom rigid-body equations. The main-rotor model includes several major rotor system design parameters, such as flapping-hinge restraint, flapping-hinge offset, blade Lock number, and pitch-flap coupling. Simulation of different rotor systems (e.g., hingeless, articulated, and teetering) may be accomplished by appropriate combinations of those design parameters.

The model is structured to permit full state feedback to any of the four controllers (longitudinal and lateral cyclic, collective stick, and directional pedals) plus control interconnects and gearings. All feedback and control gains may be programmed as functions of flight parameters, such as airspeed. This structure permits the construction of typical SCAS networks; it may also be used as a response-feedback variable-stability system to modify the basic characteristics of the simulated helicopters.

In the previous experiments, the rotor design and helicopter geometric parameters of the mathematical model were selected and tuned to simulate stability and control characteristics similar to those of the UH-1H, OH-6A, and BO-105 aircraft, which use teetering-, articulated-, and hingeless-rotor systems, respectively (refs. 4,5). For this experiment, only the generic teetering-rotor aircraft model was used, as in the reference 6 experiment, to reduce the scope of the study to a manageable level. Because the intent of the experiment was to focus upon variations in the longitudinal degrees of freedom, a lateral-directional SCAS consisting of a high-gain rate-command-attitude-hold roll channel plus yaw-rate damping and enhanced directional weathercock stiffness was implemented for all configurations.

Experimental Configurations

For convenience in discussing the experimental configurations, they have been broken into three groups: (1) high-rate-damping, low-drag-damping; (2) high-rate-damping, high-drag-damping; and (3) low-rate-damping, low-drag-damping.

Group 1: High rate-damping, low drag-damping configurations—In the high rate-damping, low drag-damping group a fairly high level of pitch-rate damping (τ_p = 0.33 sec) was incorporated to be consistent with the rate SCAS systems investigated in the experiment of reference 6; this pitch-rate SCAS was held constant for the configurations in this group. The variations in longitudinal dynamics and statics that were considered in this group were achieved by feedback of aircraft states to the longitudinal cyclic. Accordingly, the inherent steady-state speed-to-pitch-attitude relationship (with collective fixed) of the simulation model was unchanged by these variations. For the basic model, the steady-state attitude-to-speed gradient is very low (about 0.03°/knot), which considerably aggravates the difficulty of controlling speed. This characteristic was constant for all these configurations.

Four major types of variations were considered in this group (table 2 and Appendix A) and may be summarized as follows:

1. Static control-position stability: Variations in the static control-position stability were achieved by feedback of airspeed to longitudinal cyclic. Five levels were considered: two stable (~1.0 in./15 knot and ~0.5 in./15 knot), one neutral (~0.0 in./15 knot) and two unstable (unstable aperiodic roots) giving times-to-double-amplitude of ~10.0 sec and ~6.0 sec.

2. Angle-of-attack stability: Each of the five levels of static control-position stability defined in (1) was examined with two levels of angle-of-attack stability: zero, and a fairly-high stable value to give a "short-period" frequency of about 2.5 rad/sec with a damping ratio of about 0.8. These variations were achieved with feedback of the angle of attack to longitudinal cyclic. As can be seen in table 2, unlike the case with fixed-wing aircraft, the angle-of-attack stability variations had a negligible effect on the static control-position gradients for the stable and neutral gradient cases; to maintain the aperiodic instability at the same level, however, somewhat more unstable gradients were required for the two unstable cases.

3. Long-term dynamic stability: The two stable levels of static control-position stability with both levels of angle-of-attack stability were examined with two levels of damping of the phugoid or long-term oscillation: stable ($\zeta \doteq 0.10$), and unstable (time-to-double-amplitude of ~15.0 sec). These variations were achieved by feedback of rate-of-change of longitudinal speed ($\dot{u}$) to the longitudinal cyclic. As is evident in table 2, this variation had a negligible effect on the phugoid frequency and a minor effect on the short-term damping.

4. Pitch-attitude augmentation: The five levels of static control-position stability in combination with zero angle-of-attack stability were considered with the pitch-rate SCAS only and also with an attitude-command SCAS. This latter stabilization system was achieved by feedback of pitch attitude to the longitudinal cyclic in addition to the pitch-rate feedback of the rate SCAS; for consistency with the experiment reported in reference 7, the level of stabilization was selected to provide an undamped natural frequency of about 1.5 rad/sec; it was constant for each of the five attitude-stabilized configurations. As shown in table 2, this stabilization augments the static control-position gradients of the baseline configurations and modifies the short-term dynamics.

The variations in this group were selected for the following reasons. With regard to the static control-position stability variations, the neutral and lower stable levels correspond to those considered for a hingeless-rotor helicopter in the experiment of reference 5; the higher stable level was added to provide a more clearly perceptible level of static stability (the resultant phugoid frequency (~0.34 rad/sec) is still low enough to remain well separated from the short-term response dynamics). The unstable level with a 10-sec time-to-double-amplitude aperiodic root was selected to meet barely the normal-category, dual-pilot criteria; the 6-sec root level exceeds the criteria but is consistent with earlier examinations of permissible levels of static instability for transport aircraft (ref. 11).

The zero angle-of-attack stability case is effectively equivalent to the hingeless-rotor configurations examined in the previous experiments; the stable value was considered to ascertain any beneficial influences of a more "airplane-like" short-term response, as well as any deleterious influences of the pitch-to-rate-of-descent coupling it introduced. Figure 1 illustrates this coupling for responses to a step 1-in. collective input; as can be seen, the stable value of M_w increases the peak pitch-attitude response by a factor of 5 and the velocity change by a factor of 15, thereby eliminating the uncoupled appearance of the $M_w = 0$ responses. Because the achievement of a stable control-position gradient with velocity stability (M_u) in a helicopter tends to increase the frequency of the long-term roots while decreasing their damping, an unstable phugoid was examined that met the normal-category dual-pilot criteria but did not meet the transport-category criteria; an "unnatural" feedback of $\dot{u}$ was used to vary the stability of this oscillation so that equivalent levels of instability for different frequencies could be examined (see Appendix B for description of $\dot{u}$ feedback). Finally, even though the difference between a longitudinal rate-damping SCAS and pitch-attitude-command SCAS had been examined in the previous experiments (refs. 4-6), it was repeated here both for consistency among the experiments and to examine the influence of an effectively neutral stick gradient, even with attitude augmentation, which arose when the most unstable static configuration was attitude augmented.

Group 2: High rate-damping, high drag-damping configurations—In the high rate-damping, high drag-damping configurations (table 3 and Appendix A), the same variations in static control-position gradient (excluding the more stable value), angle-of-attack stability, and pitch-attitude augmentation were considered for an aircraft with a much higher steady-state pitch-attitude-to-speed gradient. The intent was to determine if the low attitude-speed gradient of the baseline configurations exacerbated the speed-control problems occasioned by neutral or unstable stick gradients, as was suggested in reference 6. This variation was implemented by including an additional drag force that varied linearly with velocity to add $\Delta X_u = -0.1 \text{ sec}^{-1}$ to the baseline configuration ($X_u \doteq -0.03 \text{ sec}^{-1}$). As a result of this addition, the steady-state, collective-fixed attitude-speed gradient was increased from 0.03°/knot to about 0.33°/knot for this group of configurations. A concomitant change in the power-required curve resulted from this implementation: The same torque was required at 60 knots as with the low-gradient baseline configurations, but an increase of about 12% was required for 80 knots with the modified high gradient; only a 2 percent increase was required with the baseline configurations.

Group 3: Low rate-damping, low drag-damping configurations—The low rate-damping, low drag-damping configuration (table 4 and Appendix A) again included the same variations in static control-position stability, angle-of-attack stability, and long-term dynamic stability with the baseline low steady-state attitude-speed relationship, but with no pitch attitude and with reduced pitch-rate feedback. The intent here was to consider in effect an SCAS failure (in the feedback loops) of the configurations of the first group (high rate-damping, low drag-damping); in particular, for example, the longitudinal-control sensitivity was not reduced to be consistent with the reduced pitch-rate damping. The reduced rate feedback yielded an augmented M_q of -1.0 sec^{-1} at 60 knots, which is only slightly above the unaugmented model value; an augmented value of $M_q = -3.0 \text{ sec}^{-1}$ was used in the first two configuration groups. It is important to note that these configurations were designed such that the resulting changes in the short-term dynamics still meet the IFR criteria given in table 1 (primarily because the criteria do not specifically require a given rapidity or sensitivity for the short-term responses).

Turbulence Model

Turbulence was included as an experimental variable in addition to the stability and control variations of the 43 configurations outlined above (19 in group 1, 10 in group 2, and 14 in group 3). The purpose was to determine the influence of atmospheric disturbances on the suitability of those stability and control characteristics for IFR operations. The wind model was identical to that of reference 6, and consisted of a 10-knot crosswind which sheared in direction from 49° right to 49° left and back to 30° left over a range of 1,200 ft, starting from a range-to-go of 6,600 ft; the intent of this shear was to impose a lateral tracking perturbation in the middle of the approach to distract attention from the longitudinal tasks. Three independent Gaussian gusts (u,v,w) were generated through Dryden spectral filters and added to the wind, with break frequencies of about 0.1 rad/sec for u and v and a range from 0.06 rad/sec to 0.17 rad/sec for w, depending on altitude. The intensities used in the previous experiments (refs. 5,6) were again implemented: $\sigma_u = \sigma_v = 3.0$ ft/sec, and $\sigma_w = 1.5$ ft/sec; in addition a higher level with intensities 1.5 times greater was available. A more complete description of this turbulence model is given in references 5 and 12.

CONDUCT OF EXPERIMENT

Equipment

The Vertical Motion Simulator (VMS) ground-based simulation facility at Ames Research Center was used for this experiment (fig. 2). It includes a complex movable structure that provides six-degrees-of-freedom motion, including vertical travel of ±30 ft to enhance simulation fidelity of longitudinal motions. A visual scene from a terrain board is presented through the cab window on a color television monitor with a collimating lens. In this experiment, the approaches were made to a model of an offshore oil rig, with simulated fog obscuring the visual scene down to an altitude of 350 ft above ground level (AGL); partial clearing began thereafter, followed by re-fogging at the decision height of 300 ft AGL, thus forcing a missed approach.

The flight instruments, arranged in a standard "T" for this experiment, were conventional with the exception of the attitude indicator, which was a 5-in. unit incorporating heading (through longitudinal lines on the ball), as well as pitch-roll information. Turn-rate-slip information was presented on a separate instrument. The controls consisted of cyclic stick, collective stick, and directional pedals, with force-feel characteristics provided by programmable electrohydraulic units; table 5 lists the control throws and gradient and friction forces used for all the configurations. Force trimming could be accomplished either by a momentary switch on the cyclic, which simultaneously released the forces on both cyclic axes and the pedals, or by single-axis rate "beeper" trimmers, which were located on the cyclic stick for the cyclic and on the collective stick for the pedals.

Evaluation Task and Procedure

For this experiment, the simulated aircraft was defined to be a transport-category dual-pilot helicopter, performing terminal-area operations in instrument conditions. The specific tasks to be accomplished for each configuration were as follows:

1. Practice MLS approaches in visual conditions

2. Dual-pilot IMC approach and missed approach

3. Second IMC approach as above, assign Cooper-Harper pilot rating (ref. 13), and make comments in response to a comment card

The approach elements consisted of MLS azimuth capture at 80 knots and approximately 1,200 ft AGL, a deceleration to 60 knots, capture of a 6° glide slope and tracking at 60 knots, and, following the re-fogging at the decision height of 300 ft AGL, execution of a missed-approach maneuver consisting of a standard-rate turn and a 1,000-ft/min climb.

During the first half of the experiment, all of the configurations were evaluated for these tasks in no turbulence; most of the configurations were then evaluated in the lower level of turbulence, and a few at the higher level. Neither the order of the configurations nor any previous ratings assigned was known to the pilots.

Scope

Five pilots participated in this experiment: two from NASA, and one each from the FAA, the Army, and the Civil Aviation Authority of the United Kingdom. A total of 223 evaluations were conducted: 138 in no turbulence, 74 in the lighter turbulence level, and 11 in the heavier turbulence level.

PILOT RATING RESULTS

Because of the volume of the data, experimental results are discussed here primarily in terms of averaged pilot ratings. This averaging is done in the interest of simplifying the discussion and highlighting major trends. It is recognized, however, that the Cooper-Harper scale is ordinal rather than interval (ref. 13), and that caution must be exercised when a large spread of ratings is averaged; in this experiment, a total spread of ±1 CHPR was rarely exceeded for a given configuration among the five pilots. The actual ratings as assigned are given in tables 6 through 11.

Influence of Long-Term Dynamics

Consider initially the influences of longitudinal control-position gradient and the concomitant variation in long-term dynamics. The data for configurations with high pitch-rate damping and low drag damping (group 1) are shown in figure 3 as

Cooper-Harper pilot ratings versus the inverse of time-to-half-or-double amplitude of the long-term oscillation. In no turbulence, very little change in average rating with control-position stability is evident except for the most unstable level (that which yields the 6-sec time-to-double aperiodic root), at which point a degradation of CHPR > 1 occurs. These results extend those of reference 5 — in which no significant difference between a neutral gradient and a 0.5-in/15 knot gradient was found — to include both a higher level of stability (-1.0 in./15 knot) and a low level of instability (T_2 = 10 sec).

Pilot comments indicated equivalent types of difficulty in maintaining trim speed for the neutral and mildly unstable gradients, but noted that, because of good pitch dynamics and the absence of coupling from other inputs, compensation for this deficiency was not too difficult. With the higher level of instability (T_2 = 6 sec), however, it was noted that speed control required considerable attention to pitch attitude, with any upsets from other inputs (such as the power change and bank-angle change for the missed approach) contributing to speed changes in excess of 10 knots. As in the previous experiments, the neutral and stable gradients were rated on average in the clearly adequate category, but not as satisfactory without improvement; attention to pitch attitude was required for some of the pilots, even with the stable gradient.

The influence of turbulence on the ratings for these configurations is also shown in figure 3. As can be seen, the effect of turbulence was minimal with the highest static gradient, but turbulence degraded the ratings increasingly as the static gradient decreased to neutral and unstable. The turbulence inputs, therefore, clearly show the benefit of static control-position stability (provided by M_u in the absence of pitch-attitude or angle-of-attack stability), with speed control in particular degrading in turbulence for the neutral and unstable configurations; the average rating of 5.3 for the neutral static configuration in turbulence is consistent with the results presented in references 5 and 6 (CHPR = 5.8 and 5.5, respectively, without the rate-command-attitude-hold lateral SCAS).

A different effect of the long-term dynamics was also considered by artificially destabilizing the phugoid root oscillations for the two levels of stable static-control-position gradient; in both cases, the instability corresponds to a time-to-double-amplitude of about 15 sec. Figures 4 and 5 show the influences of the change from stable ($\zeta \doteq 0.10$) to unstable (T_2 = 15 sec) long-term oscillations on the time-history responses to longitudinal cyclic inputs (fig. 4) and collective inputs (fig. 5). Note that for the time duration shown for this configuration, the major difference is about 1.5 times as much longitudinal velocity response for either input with the unstable oscillation. For comparison, the responses to step inputs in both controls for a configuration with an unstable aperiodic response (T_2 = 10 sec, unstable gradient) are given in figure 6, where it can be seen that the velocity responses are similar in magnitude to those with an unstable oscillation over the time region of interest.

The pilot ratings assigned to the unstable oscillation cases (with $M_w = 0$) are shown in figure 7. Also shown in figure 7 is the plotting of the pilot ratings for the same static gradients (from fig. 3) but with stable oscillations, plus the ratings for the unstable gradient yielding a long-term unstable aperiodic response with a time-to-double amplitude of 10 sec. For these configurations with no turbulence, the average rating was about 0.5 units worse than with the damped long-term oscillation; three of the five pilots indicated difficulty in maintaining speed within the desired bounds, although the comments from the other two are similar to their comments for the damped oscillation. The degrading influence of the unstable long-term oscillation was more apparent in turbulence, however, with a change in rating of over one unit compared with that of the stable cases; the pilots noted considerable difficulties in both speed and glide-slope steady-state tracking for these configurations in turbulence. Although the average ratings still fall in the adequate category, it is possible that the unstable gradient or unstable long-term dynamic configurations may not produce a sufficient margin from the CHPR = 6.5 boundary in turbulence, and that such characteristics may not be acceptable for certification.

A final variation involving long-term and steady-state characteristics was the introduction of artificially high drag damping, X_u. As was discussed, this change increased the steady-state collective-fixed attitude-speed gradient to about 0.33°/knot; this gradient was 0.03°/knot for the baseline case. A concomitant change occurs in $d\gamma/dV$, going from -0.05°/knot for the baseline cases to -0.34°/knot for the high drag cases, thereby producing operation well on the front side of the power-required curve. The change in drag damping does not, however, modify the control-position gradient with speed (unless pitch-attitude augmentation is added), so that this steady-state characteristic is the same as the baseline configurations with equivalent values of M_u. The pilot ratings for the high-drag cases ($M_w = 0$, high pitch-rate damping) are plotted in figure 8 and compared with the baseline low-drag data. As can be seen, little change in average rating is evident for the neutral or stable gradients, with a small improvement for the unstable gradient.

The pilot comments for these configurations demonstrate mixed reactions and difficulties. One of the pilots consistently rated the high-drag configurations as better than the low-drag ones, because small speed changes caused fairly significant rate-of-climb changes as a result of the increased stable $d\gamma/dV$; hence rate of climb could be well controlled using pitch attitude. However, the other pilots noted that the requirement for large power changes with speed was a detriment, particularly since the power was still the primary controller for rate-of-descent. As a result, the required changes for speed led to apparent speed-and-rate-of-descent coupling, thereby negating any advantages of more precise speed control. Consequently, in general the average ratings for the equivalent high-drag and low-drag configurations were about the same, both in no turbulence and in light turbulence.

One final note about the data in figure 8: the unstable cases shown have an unstable aperiodic root with a time-to-double amplitude of 10 sec, but the actual control-position gradient is more unstable than that of the corresponding low-drag configurations because of the influence of drag-damping on the low-frequency roots. The pilot ratings are approximately equivalent to those of the low-drag, 10-sec instability configurations, indicating that it is the magnitude of this root and not the resulting control-position gradient that has the major influence on the pilot ratings.

Influence of Short-Term Dynamics

As was discussed in the experimental design section, other variations that were considered in this experiment were aimed at modifying primarily the short-term response characteristics, either independently or in combination with modified long-term characteristics. Consider initially the influences of adding a significant level of angle-of-attack stability. As noted above, the angle-of-attack stability had only a minor influence on the control-position gradient but did introduce a well-damped "airplane-like" short-period mode. It was hypothesized that this characteristic might improve the vernier control of rate-of-descent with pitch attitude for short-term changes. Pilot comments indicated, however, that for all these configurations the angle-of-attack stability coupled through pitch attitude to large inadvertent speed changes when large changes in rate-of-descent were made with the collective; the greatest difficulty was experienced during the transition to the missed approach.

These characteristics are illustrated in figure 9 — for the configurations with the highest stable-control-position gradient — as sketches of the Bode asymptotes for pitch-attitude response to longitudinal cyclic and collective, respectively. As can be seen, a considerable amplification of the pitch response to collective (about a factor of 3 at 1 rad/sec) is introduced by the angle-of-attack stability over a wide frequency range ($0.1 < \omega < 3.0$); it is this amplification that causes the concomitant speed variations for collective inputs. The "insidious" nature of this coupling should be noted, because any high-frequency coupling of collective pitch was eliminated with control cross-gearings.

The pilot ratings for some of the configurations with $M_w = -0.025$ are shown in figure 10 for configurations with low drag damping and high pitch-rate damping; similar trends were observed with either high drag damping or low pitch-rate damping (see table 6). As in the $M_w = 0$ cases, little influence of control-position gradient (or time-to-half-or-double amplitude) is evident until the most unstable case ($T_2 = 6$); the ratings assigned to the $M_w = -0.025$ cases were between 0.5 and 1.5 units worse (higher number) than the $M_w = 0$ cases. Only three of these configurations with the high angle-of-attack stability were considered in turbulence. As shown in figure 10, the neutral- and unstable-gradient cases were considered inadequate for the task. Pilot comments for these configurations note considerable pitch-control problems coupling into poor performance of both airspeed and glide-slope tracking. Finally, one rating was obtained for a $M_w = -0.025$ case with an unstable long-term oscillation (most stable control-position gradient, configuration L06u). It indicates a considerable degradation compared with the damped-oscillation case; pilot comments indicate difficulty in controlling glide-slope as a major problem. Figure 11 shows the reason for this degradation: the unstable phugoid in combination with $M_w = -0.025$ led to about 50% more speed excitation through the first one-fourth phugoid cycle than did the stable phugoid (refer to fig. 1(b)).

Influence of Stability and Control Augmentation System

A final variation, which affected both short-term and long-term characteristics, was the level of stability and control augmentation. All of the cases discussed so far had a baseline SCAS consisting of a high level of pitch-rate augmentation ($M_q \doteq -3.0 \text{ sec}^{-1}$). Two variations were considered, one with low-pitch-rate damping ($M_q \doteq -1.0$), approximately the inherent value of the helicopter model), and one with pitch-attitude stabilization added to the high pitch-rate damping. Several of the pilot ratings are given in figure 12 to indicate trends; all of the data are provided in tables 6-11.

Consider initially the low pitch-rate damping cases. As was noted in the discussion of the experimental design, these configurations may be considered to represent an SCAS failure of pitch-rate and attitude characteristics, but with the stable-gradient (and stable long-term oscillation) configurations still meeting the static and dynamic criteria of reference 1. As shown in figure 12, the ratings in smooth air for these configurations range from adequate (CHPR $\doteq$ 5.5) with stable statics to marginally inadequate for the neutral and unstable static cases; in turbulence the ratings range from marginally adequate (CHPR = 6.2 or 6.3) to clearly inadequate. The pilot comments uniformly noted the match of pitch sensitivity to pitch damping as being much too high, which when coupled with the poor pitch predictability led to extensive pilot compensation being required to perform the tasks. These two short-term characteristics (overly sensitive, poor predictability) overshadowed to a large extent the variations in the static characteristics. The important point from a certification aspect, of course, is that the criteria as written were met by these configurations because neither control sensitivity nor short-term response predictability characteristics are specifically required.

Finally, the use of pitch-attitude augmentation around the baseline aircraft was required to obtain ratings in the clearly satisfactory category (fig. 12). This result is consistent with those obtained in all the previous experiments in this program (refs. 4-7). Pilot comments note both good short-term response and long-term stability, with the ability to fly a portion of the approach "hands-off" in smooth air. Although one of the baseline aircraft configurations was sufficiently statically unstable that the stick gradient remained unstable (positive) even after applying the attitude stabilization, it was still rated as satisfactory; again a minimal influence of the amount of stick-position stability on the pilot ratings is evident for the other configurations.

A significant degradation in average rating was exhibited for the pitch-attitude stabilized configurations in turbulence, with the ratings generally indicating a marginally satisfactory to marginally unsatisfactory suitability for the task in turbulence. The range of ratings is consistent with the dual-pilot results of reference 7 (average CHPR = 4.0); the pilot comments indicate that the wind shear in azimuth plus the turbulence degraded the lateral tracking performance noticeably for the configurations. Further, it is possible that the rate-command-attitude-hold lateral control system, in conjunction with an attitude-command longitudinal control system, led to harmony problems; an exploratory look at changing the lateral system also to attitude command improved one pilot's ratings from 4-1/2 to 3 in turbulence. Although the baseline rate-damping configuration with the most stable control gradient is not significantly worse than the best of the attitude-stabilized configurations, the attitude-stabilized results still confirm the conclusions from the previous experiments that this type of SCAS is in effect required to obtain ratings of satisfactory.

CONCLUSIONS

This piloted-simulator experiment was conducted to investigate the influence of several longitudinal stability and control parameters on helicopter flying qualities for terminal-area operations in instrument meteorological conditions. Simulated test configurations were evaluated for a precision microwave landing system approach with 6° glide slope to an offshore oil rig both in smooth air and in simulated light turbulence and variable crosswind. The baseline helicopter model was representative of a medium-weight, teetering-rotor helicopter, with parameter variations of interest being achieved through use of a simulated programmable fly-by-wire control system.

Based on the characteristics of the baseline helicopter and the implementation of the parameter variations, the following conclusions may be drawn from the results of this experiment.

1. Considering the static-gradient influences with no angle-of-attack or pitch-attitude stability and without turbulence, very little influence of position gradient was evident among the values investigated except for the most unstable. The rating range of 3-1/2 to 4-1/2 for the neutral and 0.5-in./knot configurations in smooth air is consistent with ratings assigned to equivalent configurations in previous experiments; it was shown to exist both for a more stable case (~1.0 in./15 knots) and a slightly unstable case (time-to-double-amplitude of 10 sec for the aperiodic root). In light turbulence, a clear trend of degrading suitability with reduced control-position gradient was shown by the pilot ratings, with the most stable case being effectively unchanged from the smooth-air results; however, an average rating degradation of about 1.0 was shown for the neutral and slightly unstable gradients. Nevertheless, the slightly unstable (10-sec time-to-double-amplitude), neutral, and stable cases were still rated on average as adequate in light turbulence. The ratings assigned the neutral and 0.5-in./15-knot configurations in light turbulence were consistent with ratings given similar configurations in previous experiments. The exclusion of neutral or slightly unstable gradients by the IFR criteria was not supported by the results of this or the previous experiments, if Cooper-Harper ratings indicating adequate performance are the basis for acceptability.

2. The unstable gradient with a 10-sec time-to-double-amplitude aperiodic root was rated as clearly adequate in smooth air (average ratings = 4.0) and adequate in light turbulence (average rating = 5.5). The unstable gradient with a 6-sec time-to-double-amplitude aperiodic root was adequate in smooth air (average rating = 5.5) but marginally inadequate in light turbulence (average rating = 6.2). These results support the IFR criteria for dual-pilot conditions in terms of allowable aperiodic roots, although the unstable control-position gradients that led to the aperiodic roots would not be permitted by the criteria.

3. For the stable-gradient cases, unstable long-term oscillations with a time-to-double-amplitude of 15 sec led to a degradation in pilot ratings of about 1.0 in light turbulence when compared with stable long-term oscillations. The ratings were about the same as those assigned to the slightly unstable gradient case — that is, in the adequate category. It is not possible on the basis of these results to verify the validity of the dual-pilot, normal-category criteria boundary on unstable oscillations (time-to-double-amplitude of greater than 10 sec), but the level investigated here, which does meet the criteria, was found to be adequate.

4. Pitch-attitude augmentation was required to achieve average ratings of satisfactory for the IMC task. No significant influence of control-position gradient was evident on the ratings except the most unstable level. Light turbulence caused significant degradation in average ratings for the pitch-attitude-augmented configurations: from clearly satisfactory in no turbulence to marginally unsatisfactory in turbulence. The range of ratings is consistent with ratings given equivalent configurations in previous experiments as is the conclusion regarding the necessity of pitch-attitude augmentation to achieve a satisfactory capability.

5. The addition of angle-of-attack stability had an insignificant effect on static control-position stability, and the level used in this experiment introduced undesirable coupling of pitch attitude to rate-of-climb. The net result was a degradation in pilot rating of 0.5 to 1.0 unit in smooth air; the degradation rates higher in light turbulence. As a result, the neutral and slightly unstable-gradient cases received ratings of inadequate.

6. With a stable control-position gradient, configurations with the higher level of pitch rate-damping (0.33-sec pitch-attitude response-time constant) and no angle-of-attack or pitch-attitude stability were rated as marginally unsatisfactory; the lower level of pitch damping, used to simulate an SCAS failure (response-time constant of 1.0 sec with a corresponding increase in pitch rate for unit control deflection by a factor of about 3) was used to simulate operation with an SCAS failure and resulted in average rating degradations of about 2.0. Configurations with the lower level of pitch-rate damping were rated marginally inadequate to inadequate in light turbulence.

7. The addition of artificial drag damping had mixed effects: speed control with pitch attitude was improved, but speed-power coupling increased also. No net change in pilot rating resulted.

APPENDIX A

CONFIGURATION CHARACTERISTICS

Details regarding the evaluation configurations are given in Tables 12 and 13. The stability and control derivatives of the configurations are given in first-order form in table 12 for a 60-knot, level-flight condition. The elements of the matrices include the body-axes stability/control derivatives, plus lumped gravitational/kinematic terms; in addition, the influence of $\dot{u}$ feedback is included as modified values of these parameters in the manner described in appendix B.

Table 13 summarizes the longitudinal eigenvalues and transfer-function numerators of the evaluation configurations. The notation used to indicate the values of the poles and zeroes is:

$\Delta(S)$ characteristic equation

N_j^i transfer-function numerator of i response to j input

$K(S + 1/\tau)(S^2 + 2\zeta wS + w^2) \Rightarrow K(1/\tau)(\zeta;w)$

APPENDIX B

INFLUENCE OF $\dot{u}$ FEEDBACK

Consider the longitudinal linearized equations of motion in a stability-axis system for longitudinal cyclic inputs:

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \dot{u} \\ \dot{w} \\ \dot{q} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} X_u & X_w & X_q & -g\cos\theta_o \\ Z_u & Z_w & +u_o + Z_q & -g\sin\theta_o \\ M_u & M_w & M_q & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} u \\ w \\ q \\ \theta \end{bmatrix} + \begin{bmatrix} X_{\delta_{ES}} \\ Z_{\delta_{ES}} \\ M_{\delta_{ES}} \\ 0 \end{bmatrix} \delta_{ES}$$

Now let $\dot{u}$ be fed back through the longitudinal cyclic:

$$\delta_{ES} = k_{\dot{u}}\dot{u} + \delta_{ES_c}$$

Then:

$$\begin{bmatrix} 1 - X_{\delta_{ES}}k_{\dot{u}} & 0 & 0 & 0 \\ -Z_{\delta_{ES}}k_{\dot{u}} & 1 & 0 & 0 \\ -M_{\delta_{ES}}k_{\dot{u}} & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \dot{u} \\ \dot{w} \\ \dot{q} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} X_u & X_w & X_q & -g\cos\theta_o \\ Z_u & Z_w & u_o + Z_q & -g\sin\theta_o \\ M_u & M_w & M_q & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} u \\ w \\ q \\ \theta \end{bmatrix} + \begin{bmatrix} X_{\delta_{ES}} \\ Z_{\delta_{ES}} \\ M_{\delta_{ES}} \\ 0 \end{bmatrix} \delta_{ES_c}$$

To write this equation in "conventional" first-order state-variable form, we multiply through by

$$\begin{bmatrix} 1 - X_{\delta_{ES}}k_{\dot{u}} & 0 & 0 & 0 \\ -Z_{\delta_{ES}}k_{\dot{u}} & 1 & 0 & 0 \\ -M_{\delta_{ES}}k_{\dot{u}} & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}^{-1} = \begin{bmatrix} \dfrac{1}{1 - X_{\delta_{ES}}k_{\dot{u}}} & 0 & 0 & 0 \\ \dfrac{Z_{\delta_{ES}}k_{\dot{u}}}{1 - x_{\delta_{ES}}k_{\dot{u}}} & 1 & 0 & 0 \\ \dfrac{M_{\delta_{ES}}k_{\dot{u}}}{1 - x_{\delta_{ES}}k_{\dot{u}}} & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The resulting equation is

$$\begin{bmatrix} \dot{u} \\ \dot{w} \\ \dot{q} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \bar{X}_u & \bar{X}_w & \bar{X}_q & -\bar{g}\cos\theta_o \\ \hat{Z}_u & \hat{Z}_w & u_o + \hat{Z}_q & -g\cos\theta_o + \hat{Z}_o \\ \hat{M}_u & \hat{M}_w & \hat{M}_q & \hat{M}_\theta \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} u \\ w \\ q \\ \theta \end{bmatrix} + \begin{bmatrix} \bar{X}_{\delta_{ES}} \\ \hat{Z}_{\delta_{ES}} \\ \hat{M}_{\delta_{ES}} \\ 0 \end{bmatrix} \delta_{ES_c}$$

where

$$\bar{X}_i = \frac{X_i}{1 - X_{\delta_{ES}} k_{\dot{u}}} \qquad i = u,w,q,\theta,\delta_{ES}$$

$$\hat{Z}_i = Z_i + Z_{\delta_{ES}} k_{\dot{u}} \bar{X}_i$$

$$\hat{M}_i = M_i + M_{\delta_{ES}} k_{\dot{u}} \bar{X}_i$$

As can be seen from this equation, the influence of the $\dot{u}$ feedback is to modify all of the terms in the state and control matrices. Note in particular the addition of a "pitch-attitude-stability" from $\hat{M}_\theta$, as well as the modified values for M_u and M_w. For this reason, the aircraft characteristics given in appendix A show all derivatives to be different for the stable and unstable long-term oscillation cases.

It is important to recognize that although all of the individual derivatives are effectively modified by using this type of feedback, the way they are changed relative to each other has different influences on the resulting characteristics than would individual changes. As a primary example, since the feedback in question is of $\dot{u}$, there should be no change in the steady-state gradient of stick position with velocity; individual feedbacks of u, w, or θ all change this gradient, however, and so it is the ratios as determined by the equations above that are important. In particular, it is straightforward to show that

$$\left.\frac{u}{\delta_{ES}}\right|_{SS} = \frac{\begin{vmatrix} \bar{X}_{\delta_{ES}} & \bar{X}_w & -\bar{g} \\ \hat{Z}_{\delta_{ES}} & \hat{Z}_w & \hat{Z}_\theta \\ \hat{M}_{\delta_{ES}} & \hat{M}_w & \hat{M}_\theta \end{vmatrix}}{\begin{vmatrix} \bar{X}_w & \bar{X}_w & -\bar{g} \\ \hat{Z}_u & \hat{Z}_w & \hat{Z}_\theta \\ \hat{M}_u & \hat{M}_w & \hat{M}_\theta \end{vmatrix}} \qquad (\text{for } \theta_o = 0)$$

$$= \frac{\begin{vmatrix} X_{\delta_{ES}} & X_w & -g \\ Z_{\delta_{ES}} & Z_w & 0 \\ M_{\delta_{ES}} & M_w & 0 \end{vmatrix}}{\begin{vmatrix} X_u & X_w & -g \\ Z_u & Z_w & 0 \\ M_u & M_w & 0 \end{vmatrix}} \quad \text{, no influence of } \dot{u} \text{ feedback}$$

For the range of $\dot{u}$ feedback considered in this experiment, the primary influence was therefore on the damping of the long-term roots, with a minor influence on the frequency and damping of the short-term roots. As an initial approximation to the effect, consider a hovering cubic with feedback having yielded an effective $M_{\dot{u}}$:

$$\begin{bmatrix} s - X_u & g \\ -sM_{\dot{u}} - M_u & s(s-M_q) \end{bmatrix} = \begin{bmatrix} u \\ \theta \end{bmatrix} = \begin{bmatrix} 0 \\ M_\delta \end{bmatrix} \delta$$

The characteristic equation is

$$s^3 + (-M_q - X_u)\, s^2 + (M_q X_u + gM_{\dot{u}})\, s + gM_u = 0$$

Then the Bairstow approximation is

$$\lambda^2 \doteq \frac{gM_u}{M_q + X_u}$$

therefore,

$$(-M_q - X_u)\, s^2 + \left(M_q\, X_u + \frac{M_u g}{M_q + X_u} + gM_{\dot{u}}\right) s + gM_u = 0$$

As can be seen, the influence of $m_{\dot{u}}$ is to change the "phugoid" damping term by

$$\Delta(2\zeta_{ph}\,\omega_{ph}) = \frac{gM_{\dot{u}}}{-M_q - X_u} \doteq \frac{gM_{\dot{u}}}{-M_q}$$

To the level of accuracy of the approximation, therefore, the feedback has no influence on the undamped natural frequency of the oscillating roots in the cubic. This expression was used to estimate the levels of feedback required, following which computer studies using the full longitudinal equations were conducted to select the exact levels.

REFERENCES

1. Rotorcraft Regulatory Review Program Notice No. 1; Proposed Rulemaking. Federal Register, Vol. 45, No. 245, 18 Dec. 1980.

2. Federal Aviation Regulation Part 27 — Airworthiness Standards: Normal Category Rotorcraft. Federal Aviation Administration, Feb. 1965.

3. Federal Aviation Regulation Part 29 — Airworthiness Standards: Transport Category Rotorcraft. Federal Aviation Administration, Feb. 1965.

4. Forrest, R. D.; Chen, R. T. N.; Gerdes, R. M., Alderete, T. S., and Gee, D. R.: Piloted Simulator Investigation of Helicopter Control Systems Effects on Handling Qualities during Instrument Flight. Paper No. 79-26, 35th Annual National Forum of the American Helicopter Society. Washington, D.C., May 1979.

5. Lebacqz, J. V., and Forrest, R. D.: A Piloted Simulator Investigation of Static Stability and Stability/Control Augmentation Effects on Helicopter Handling Qualities for Instrument Approach. Paper No. 80-30, 36th Annual National Forum of the American Helicopter Society, Washington, D.C., May 1980.

6. Lebacqz, J. V.; Forrest, R. D.; Gerdes, R. M.; and Merrill, R. K.: Investigation of Control, Display, and Crew-Loading Requirements for Helicopter Instrument Approach. AIAA Paper No. 81-1820, Albuquerque, N.M., Aug. 1981.

7. Lebacqz, J. V.; Weber, J. M.; and Corliss, L. D.: A Flight Investigation of Static Stability, Control Augmentation, and Flight Director Influences on Helicopter IFR Handling Qualities. Paper No. 81-25, 37th Annual National Forum of the American Helicopter Society, New Orleans, La., May 1981.

8. Airworthiness Criteria for Helicopter Instrument Flight. Federal Aviation Administration draft, 15 Dec. 1978.

9. Airworthiness Criteria for Helicopter Instrument Flight. Helicopter Association of America revision to FAA proposals 151, 413, submitted at FAA Rotorcraft Regulatory Review Program, New Orleans, La., 10-14 Dec. 1979.

10. Chen, R. T. N.: A Simplified Rotor System Mathematical Model for Piloted Flight Dynamics Simulation. NASA TM-78575, 1979.

11. Snyder, C. T.; Fry, E. B.; Drinkwater, F. J. III; Forrest, R. D.; Scott, B. C.; and Benefield, T. D.: Motion Simulator Study of Longitudinal Stability Requirements for Large Delta Wing Transport Airplanes during Approach and Landing with Stability Augmentation Systems Failed. NASA TM X-62,200, 1972.

12. Aiken, E. W.: A Mathematical Representation of an Advanced Helicopter for Piloted Simulator Investigations of Control System and Display Variations. USAAVRADCOM TM80-A-Z-2, Apr. 1980.

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

TABLE 1.- SUMMARY OF STATIC AND DYNAMIC CRITERIA FROM REFERENCE 1

Characteristic	Normal (single pilot)	Normal (dual pilot)	Transport (single and dual)
1. Trim	1. All forces trim to zero	1. Same	1. Same
2. Static longitudinal	2. Demonstrate positive force stability ±20 knots from trim for climb, cruise, slow cruise, descent, approach	2. Demonstrate positive force stability ±20 knots from trim for cruise, approach	2. Same as "Normal single pilot"
3. Static lateral/ directional	3. Stable directional control position; no negative dihedral apparent through force or position	3. Same	3. Same
4. Dynamic stability (all axes)	4. • Period $P < 5$ sec: damp to 1/2 amplitude in < 1 cycle • Period $5 < P < 10$: damp to 1/2 amplitude in < 2 cycles • Period $10 < P < 20$: damped • Period $P > 20$ or aperiodic: double amplitude > 20 sec	4. • Period $P < 5$ sec: damp to 1/2 amplitude in < 2 cycles • Period $5 < P < 10$: damped • Period $P > 10$ or aperiodic: double amplitude > 10 sec	4. Same as "Normal single pilot"

TABLE 2.- EXPERIMENTAL CONFIGURATIONS: GROUP 1

Group 1S: Low X_u, M_q = -3.0, Stable oscillations
SS: Control position gradient, in/15 kt
(λ): s + λ [ζ; ω]: ($s^2 + 2\zeta \omega s + \omega^2$)

	M_w = 0, M_θ = 0	M_w = -0.025, M_θ = 0	M_w = 0, M_θ = 2.25
Stable 2	L01S (2.92)(1.33)[0.10;0.34] SS = -1.03	L06S [0.79;2.46][0.10;0.27] SS = -1.05	L11 (1.91)(1.50(0.78)(0.22) SS = -1.08
Stable 1	L02S (2.95)(1.33)[0.10;0.24] SS = -0.53	L07S [0.79;2.47][0.11;0.20] SS = -0.55	L12 (1.72(1.59)(0.98)(0.10) SS = -0.58
Neutral	L03 (3.00)(1.33)[0.17;0.057] SS = -0.03	L08 [0.79;2.49][0.13;0.057] SS = -0.05	L13 [0.99;1.61](1.14)(0.011) SS = -0.08
Unstable 1	L04 (3.01)(1.33)(0.07) (-0.062) SS = +0.03	L09 [0.79;2.49](0.069) (-0.061) SS = +0.053	L14 [0.99;1.61](1.16)(0.0014) SS = -0.01
Unstable 2	L05 (3.01)(1.33)(0.12) (-0.11) SS = +0.125	L10 [0.79;2.49](0.096) (-0.10) SS = 0.138	L15 [0.99;1.61](1.19)(-0.016) SS = 0.092
	Group 1U: Low Xu, Mq = -3.0, unstable oscillations		
Stable 2	L01U σ = 0.043 (3.24)(1.35)[-0.13;0.34] SS = -1.03	L06U σ = 0.046 [0.84;2.61][-0.17; 0.28] SS = -1.05	
Stable 1	L02U σ = 0.050 (3.25)(1.35)[-0.21;0.24) SS = -0.53	L07U σ = 0.048 [0.83;2.60](-0.24;0.20] SS = -0.55	

TABLE 3.- EXPERIMENTAL CONFIGURATIONS: GROUP 2

Group 2: High X_u, $M_q = -3$			
	$M_w = 0$, $M_\theta = 0$	$M_w = -0.25$, $M_\theta = 0$	$M_w = 0$, $M_\theta = -2.25$
Stable gradient	L16 (3.05)(1.34)[0.20;0.24] SS = -0.53	L20 [0.80;2.49][0.29;0.196] SS = -0.55	L24 (1.75)(1.57)(0.96)(0.22) SS = -1.23
Neutral gradient	L17 (3.02)(1.33)[0.94;0.06] SS = -0.03	L21 [0.79;2.49][0.89;0.04] SS = -0.04	L25 [0.99;1.62](1.14)(0.12) SS = -0.73
Unstable 2	L18 (3.01)(1.33)(0.19) (-0.075) SS = +0.125	L22 [0.79;2.49](0.17) (-0.063) SS = 0.145	L26 [0.99;1.61](1.20)(0.085) SS = -0.55
Unstable 3	L19 (3.01)(1.33)(0.18) (-0.066) SS = +0.10		

TABLE 4.- EXPERIMENTAL CONFIGURATIONS: GROUP 3

Group 3S: Low X_u, M_q = -1.0 stable oscillations		
	M_w = 0	M_w = -0.025
Stable 2	L28S (0.96)(1.31)[0.10;0.59] SS = -1.03	L33S [0.51;1.89][0.10;0.36]
Stable 1	L29S (0.98)(1.30)[0.099;0.43] SS = -0.53	L34S [0.50;1.90][0.13;0.26] SS = -0.53
Neutral	L30 (1.09)(1.25)[0.009;0.098)	L35 [0.51;1.92][-0.0041;0.075]
	L31	L36
Unstable 1	(1.07)(1.26)(0.063)(-0.063)	[0.51;1.92](0.073)(-0.069)
	L32 -	L37
Unstable 3	(1.05)(1.27)(0.12)(-0.11)	[0.51;1.92](0.10)(-0.11)
Group 3U: Low X_u, M_q = -1.0, unstable oscillations		
Stable 2	L28U σ = 0.047 (1.25)(1.25)[-0.086;0.54] SS = -1.03	L33U σ = 0.050 [0.55;1.91][-0.14;0.37]
Stable 1	L29U σ = 0.045 (1.23)(1.23)[-0.11;0.40]	L34U σ = 0.045 [0.54;1.92][-0.17;0.26]

TABLE 5.- COCKPIT CONTROLLER CHARACTERISTICS

Characteristic	Pitch	Roll	Yaw	Collective
Maximum throw, in	±5.6	±5.5	±3.2	10
Gradient, lb/in	0.5	0.5	3.0	0
Breakout, lb	1.0	1.0	3.0	0
Hysteresis, lb	0.75	0.75	1.6	2[a]

[a] Adjustable

TABLE 6.- PILOT EVALUATION DATA: GROUP 1, L01-L15 NO TURBULENCE

L01S	L01U	L06S	L06U	L11
3 1/2 (G-11/24) 4 1/2 (H-11/26) 4 (M-12/2) 3 (P-12/5) 3 1/2 (T-12/9)	3 (G-12/1) 6 (H-12/2) 3 1/2 (P-12/8) 4 1/2 (T-12/10) 4 (M-12/18)	4 1/2 (G-17/3) 5 1/2 (M-12/5)	7 (G-12/5)	2 (G-12/3) 2 1/2 (P-12/5) 2 (T-12/9) 2 (H-12/15) 2 (M-12/18) L11 + 2 (P-12/11)
L02S	L02U	L07S	L07U	L12
3 (G-11/24) 3 (H-11/26) 5 1/2 (M-12/1) 3 (P-12/3) 4 (T-12/9) 5 (M-12/18)	3 (G-11/24) 4 1/2 (M-12/1) 5 1/2 (H-12/2) 4 1/2 (P-12/3) 5 (T-12/9)	5 1/2 (G-12/1) 4 (H-12/2) 3 1/2 (M-12/5) 5 (P-12/8) 5 1/2 (T-12/10)		2 (G-12/3) 2 (P-12/11)
	L03	L08	L13	
	5 (G-11/24) 5 1/2 (H-11/26) 4 (M-12/1) 4 (P-12/5) 3 1/2 (T-12/9)	5 1/2 (G-12/1) 5 1/2 (H-12/2) 5 (P-12/8) 4 (T-12/10) 4 1/2 (M-12/18)	3 (G-11/24) 2 (H-11/26) 3 (M-12/1) 2 (T-12/9)	
	L04	L09	L14	
	4 (G-11/24) 4 (H-11/26) 3 1/2 (M-12/3) 4 1/2 (P-12/5) 4 (T-12/9)	6 1/2 (G-12/1) 4 1/2 (M-12/3) 5 (P-12/8) 3 (T-12/10) 5 (H-12/15)	2 1/2 (G-12/1) 3 (M-12/3)	
	L05	L10	L15	
	5 1/2 (G-11/24) 6 (H-11/26) 5 (M-12/2) 5 (P-12/5) 6 (T-12/9)	6 1/2 (G-12/3)	4 (G-11/24) 3 (H-11/26) 2 1/2 (M-12/2) 3 (P-12/8) 2 (T-12/9)	

Note: (I - j/k) = pilot identification and date; L11+designates attitude command in roll.

TABLE 7.- PILOT EVALUATION DATA: GROUP 2, L16-L26, NO TURBULENCE

L16	L20	L24
3 1/2 (G-11/26) 5 (H-12/1) 3 (M-12/3) 4 1/2 (P-12/8) 3 1/2 (T-12/10)	5 (G-12/3)	2 1/2 (G-11/26) 1 1/2 (H-12/1) 3 1/2 (P-12/8) 2 (T-12/10)
L17	L21	L25
3 1/2 (G-11/26) 3 (M-12/3) 4 1/2 (P-12/8) 4 (T-12/10) 5 1/2 (H-12/15)	6 1/2 (G-12/5)	2 (G-11/26)
L19	L22	L26
4 (G-11/26) 6 (H-12/1) 3 (M-12/3) 5 1/2 (P-12/8) 2 1/2 (T-12/10) 4 1/2 (P-12/11)	3 1/2 (M-12/3) 6 1/2 (G-12/3)	2 (H-12/1) 2 1/2 (M-12/3) 2 (G-12/5) 3 1/2 (P-12/8) 2 (T-12/10) 3 (P-12/10)
L18		

Note: Pilot identification in parentheses.

TABLE 8.- PILOT EVALUATION DATA: GROUP 3, L28-L37, NO TURBULENCE

L28S	L28U	L33S	L33U
4 (G-11/24) 5 (H-11/26) 6 (M-12/2) 5 1/2 (P-12/5) 6 (T-12/9)	6 1/2 (H-11/26) 5 (G-12/1) 6 (P-12/8) 6 (T-12/9)	6 1/2 (G-12/3)	5 (G-12/5)
L29U	L29u	L34S	L34U
5 (G-12/1) 6 1/2 (H-12/2) 4 (M-12/3) 5 (P-12/8) 7 (T-12/9)	5 (G-12/4)		
	L30	L35	
	6 (G-12/1) 6 1/2 (H-12/2) 6 (P-12/8) 6 (T-12/9	7 (G-12/3)	
	L31	L36	
	7 (G-12/1) 6 1/2 (P-12/8) 7 (T-12/9) 7 (H-12/15) 6 (M-12/18)	7 (G-12/5)	
	L32	L37	
	6 1/2 (G-11/24) 7 (M-12/2) 6 1/2 (H-12/2) 6 (P-12/5) 5 (T-12/9)		

Note: Pilot identification in parentheses.

TABLE 9.- PILOT EVALUATION DATA: GROUP 1, L01-L15, TURBULENCE

L01S	L01U	L06S	L06U	L11
5 (P-12/9) 3 (T-12/11) 6 HVY (T-12/11) 3 (G-12/16) 4 1/2 (H-12/16) 3 1/2 (M-12/18)	5 1/2 (P-12/16) 4 (G-12/17) 6 (H-12/19)			2 (H-12/15) 3 (M-12/18) 4 (M-12/19)HVY 4 1/2 (P-12/9) 3 (T-12/10) 3 (T-12/11) 4 1/2 (T-12/11)HVY 3 (G-12/11) 4 (P-12/11) L11+ 3 (P-12/11) 4 1/2 (P-12/11)HVY
L02S	L02U	L07S		L12
5 (P-12/9) 2 1/2 (T-12/10) 4 (G-12/11) 6 (H-12/15) 4 (M-12/18) 5 HVY (M-12/19)	6 (P-12/9) 3 (T-12/10) 5 1/2 (G-12/11) 5 1/2 (H-12/15) 6 1/2 (M-12/18) 7 HVY (M-12/19)	5 1/2 (G-12/16) 5 (H-12/19)		3 1/2 (G-12/15)
	L03	L08	L13	
	5 1/2 (P-12/9) 4 (T-12/10) 5 1/2 (G-12/15) 6 1/2 (M-12/18) 5 (H-12/19)	7 (6-12/16)	4 1/2 (P-12/10) 3 1/2 (G-12/15) 4 (H-12/19)	
	L04	L09	L14	
	6 (P-12/9) 4 (T-12/10) 6 (H-12/15) 5 1/2 (G-12/15) 6 (M-12/18) 6 HVY (M-12/19)	7.5 (6-12/16)	3 1/2 (6-12/16)	
	L05	L10	L15	
	6 1/2 (P-12/9) 4 1/2 (T-12/11) 7 1/2 (T-12/11) HVY 7 (G-12/16) 6 (H-12/16) 7 (M-12/18)		5 (P-12/9) 3 (G-12/16) 4 1/2 (M-12/18 5 HVY (M-12/19)	

Notes: Pilot identification in parentheses; HVY indicates higher level of turbulence.

TABLE 10.- PILOT EVALUATION DATA: L16-L26, TURBULENCE

L16	L20	L24
5 (P-12/10) 5 (G-12/17)		4 1/2 (P-12/10)
L17	L21	L25
5 (P-12/10)		
L19	L22	L26
6 (P-12/10) 4 (G-12/17)		4 1/2 (P-12/10)
L18		

Note: Pilot identification in parentheses.

TABLE 11.- PILOT EVALUATION DATA: GROUP 3, L28-L37, TURBULENCE

L28S	L28U	L33S	L33U
7 (P-12/9) 4 1/2 (T-12/11) 6 1/2 (G-12/16) 6 (H-12/16) 7 (M-12/18	6 1/2 (P-12/10)		
L29S	L29U	L34S	L34U
6 (P-12/10) 6 1/2 (G-12/17)	6 1/2 (G-12/15)		
	L30	L35	
	7 (P-12/10)		
	L31	L36	
	7 (P-12/10)		
	L32	L37	
	7 (P-12/9) 5 (T-12/11) 7 1/2 (T-12/11) HVY 7 1/2 (G-12/16) 7 1/2 (M-12/18)	9 HVY (T-12/11)	

TABLE 12.- STABILITY AND CONTROL DERIVATIVES: 60 KNOT LEVEL FLIGHT

CONFIGURATION L01U

```
    F MATRIX IS

    U             W               Q              THETA             V               P              PHI             R


-.70008E-01   .14719E-01     .11876E 02     -.33455E 02     .69580E-03    -.93315E 00     .17656E-01     .11861E 01
-.19110E 00  -.13190E 01     .14069E 03     -.49097E 01    -.24703E-01    -.30264E 01    -.30922E 00     .83886E-01
 .11497E-01  -.94533E-04    -.31142E 01      .24115E 00     .17821E-04     .15038E 00     .11607E-03    -.27570E-02
 .00000E 00   .00000E 00     .10000E 01      .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00
-.22521E-01  -.37489E-02    -.34668E-01     -.13878E 00    -.11060E 00    -.11846E 02     .22269E 02    -.97517E 02
-.80793E-02  -.40198E-02     .82694E-04     -.20118E-01    -.21078E-01    -.10042E 02    -.62585E 01     .51105E 00
 .00000E 00   .00000E 00     .00000E 00      .00000E 00     .00000E 00     .10000E 01     .00000E 00     .38939E-01
 .10602E-01  -.49112E-02     .54351E-01      .12995E 00     .47332E-01    -.15010E 01    -.82873E 00    -.35396E 01

    G MATRIX IS

  DELTA E       DELTA C          DELTA A        DELTA P


-.19876E 01   .55095E 00    -.29528E-02      .30744E-01
-.56826E 01  -.97167E 01     .51719E-01      .10021E-02
 .37474E 00   .41036E-02    -.19744E-04     -.36684E-02
 .00000E 00   .00000E 00     .00000E 00      .00000E 00
-.21566E 00  -.80156E-01     .16555E 01     -.11827E 01
-.31262E-01  -.38747E-01     .10458E 01     -.29981E 00
 .00000E 00   .00000E 00     .00000E 00      .00000E 00
 .20194E 00   .34698E-01     .13848E 00      .86560E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L01S

```
      F MATRIX IS

       U             W              Q              THETA          V              P              PHI            R


  -.64496E-01    .13560E-01     .10941E 02    -.30820E 02     .64101E-03    -.85968E 00     .16266E-01     .10927E 01
  -.17534E 00   -.13223E 01     .13802E 03     .26213E 01    -.24859E-01    -.28163E 01    -.31319E 00    -.18312E 00
   .10457E-01    .12397E-03    -.29379E 01    -.25548E 00     .28150E-04     .13653E 00     .37817E-03     .14851E-01
   .00000E 00    .00000E 00     .10000E 01     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00
  -.21922E-01   -.38746E-02    -.13613E 00     .14703E 00    -.11060E 00    -.11838E 02     .22269E 02    -.97527E 02
  -.79926E-02   -.40381E-02    -.14625E-01     .21314E-01    -.21079E-01    -.10040E 02    -.62585E 01     .50958E 00
   .00000E 00    .00000E 00     .00000E 00     .00000E 00     .00000E 00     .10000E 01     .00000E 00     .38939E-01
   .10042E-01   -.47935E-02     .14936E 00    -.13768E 00     .47337E-01    -.15085E 01    -.82859E 00    -.35301E 01

       G MATRIX IS

     DELTA E        DELTA C          DELTA A        DELTA P


  -.18311E 01    .50757E 00    -.27203E-02     .28323E-01
  -.52352E 01   -.98408E 01     .52384E-01    -.59187E-02
   .34523E 00    .12282E-01    -.63578E-04    -.32120E-02
   .00000E 00    .00000E 00     .00000E 00     .00000E 00
  -.19868E 00   -.84863E-01     .16555E 01    -.11830E 01
  -.28801E-01   -.39429E-01     .10459E 01    -.29985E 00
   .00000E 00    .00000E 00     .00000E 00     .00000E 00
   .18604E 00    .39106E-01     .13846E 00     .86585E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L02S

```
F MATRIX IS

    U              W              Q            THETA            V              P             PHI            R


-.37915E-01    .13789E-01    .11125E 02   -.31336E 02    .65174E-03   -.87408E 00    .16571E-01    .11108E 01
-.99561E-01   -.13216E 01    .13855E 03    .11464E 01   -.24923E-01   -.28576E 01   -.31260E 00   -.13081E 00
 .54537E-02    .81210E-04   -.29724E 01   -.15822E 00    .26533E-04    .13926E 00    .32236E-03    .11412E-01
 .00000E 00    .00000E 00    .10000E 01    .00000E 00    .00000E 00    .00000E 00    .00000E 00    .00000E 00
-.20322E-01   -.38520E-02   -.11625E 00    .91060E-01   -.11060E 00   -.11840E 02    .22269E 02   -.97525E 02
-.63929E-02   -.40362E-02   -.11731E-01    .13202E-01   -.21077E-01   -.10041E 02   -.62585E 01    .50987E 00
 .00000E 00    .00000E 00    .00000E 00    .00000E 00    .00000E 00    .10000E 01    .00000E 00    .38939E-01
 .11530E-01   -.48176E-02    .13077E 00   -.85264E-01    .47337E-01   -.15070E 01   -.82862E 00   -.35319E 01

 G MATRIX IS

  DELTA E        DELTA C        DELTA A        DELTA P


-.18618E 01    .51599E 00   -.27467E-02    .28759E-01
-.53228E 01   -.98174E 01    .52252E-01   -.44031E-02
 .35101E 00    .10699E-01   -.58278E-04   -.32998E-02
 .00000E 00    .00000E 00    .00000E 00    .00000E 00
-.20201E 00   -.83924E-01    .16555E 01   -.11829E 01
-.29289E-01   -.39284E-01    .10458E 01   -.29984E 00
 .00000E 00    .00000E 00    .00000E 00    .00000E 00
 .18916E 00    .38244E-01    .13846E 00    .86579E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L02U

```
 F MATRIX IS
       U             W               Q              THETA          V              P                PHI            R

-.40966E-01    .14898E-01     .12020E 02    -.33858E 02    .70418E-03    -.94441E 00     .17904E-01     .12002E 01
-.10828E 00   -.13185E 01     .14110E 03    -.60623E 01   -.24773E-01    -.30586E 01    -.30879E 00     .12472E 00
 .60288E-02   -.12797E-03    -.31412E 01     .31716E 00    .16646E-04     .15252E 00     .70977E-04    -.54396E-02
 .00000E 00    .00000E 00     .10000E 01     .00000E 00    .00000E 00     .00000E 00     .00000E 00     .00000E 00
-.20653E-01   -.37316E-02    -.19127E-01    -.18253E 00   -.11059E 00    -.11847E 02     .22269E 02    -.97516E 02
-.64408E-02   -.40187E-02     .23506E-02    -.26464E-01   -.21076E-01    -.10042E 02    -.62585E 01     .51128E 00
 .00000E 00    .00000E 00     .00000E 00     .00000E 00    .00000E 00     .10000E 01     .00000E 00     .38939E-01
 .11840E-01   -.49303E-02     .39830E-01     .17091E 00    .47332E-01    -.14999E 01    -.82875E 00    -.35410E 01

   G MATRIX IS

   DELTA E       DELTA C          DELTA A        DELTA P

-.20116E 01    .55751E 00    -.29677E-02     .31073E-01
-.57511E 01   -.96987E 01     .51620E-01     .22127E-02
 .37925E 00    .28717E-02    -.16610E-04    -.37361E-02
 .00000E 00    .00000E 00     .00000E 00     .00000E 00
-.21827E 00   -.79419E-01     .16555E 01    -.11827E 01
-.31645E-01   -.38631E-01     .10458E 01    -.29980E 00
 .00000E 00    .00000E 00     .00000E 00     .00000E 00
 .20438E 00    .34026E-01     .13848E 00     .86556E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L03

```
     F MATRIX IS

         U              W               Q             THETA            V               P              PHI             R

  -.10490E-01     .14083E-01     .11366E 02    -.32017E 02     .66394E-03    -.89306E 00     .16908E-01     .11351E 01
  -.21470E-01    -.13208E 01     .13923E 03    -.79894E 00    -.24788E-01    -.29110E 01    -.31139E 00    -.62037E-01
   .29202E-03     .25341E-04    -.30180E 01    -.29936E-01     .23592E-04     .14281E 00     .25838E-03     .68532E-02
   .00000E 00     .00000E 00     .10000E 01     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00
  -.18621E-01    -.38222E-02    -.90040E-01     .17227E-01    -.11060E 00    -.11842E 02     .22269E 02    -.97523E 02
  -.47766E-02    -.40329E-02    -.79384E-02     .24970E-02    -.21079E-01    -.10041E 02    -.62585E 01     .51025E 00
   .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .10000E 01     .00000E 00     .38939E-01
   .12927E-01    -.48478E-02     .10621E 00    -.16132E-01     .47335E-01    -.15051E 01    -.82864E 00    -.35344E 01

      G MATRIX IS

     DELTA E        DELTA C         DELTA A        DELTA P

  -.19022E 01     .52725E 00    -.28357E-02     .29422E-01
  -.54382E 01    -.97843E 01     .52082E-01    -.27756E-02
   .35863E 00     .85701E-02    -.42327E-04    -.34193E-02
   .00000E 00     .00000E 00     .00000E 00     .00000E 00
  -.20638E 00    -.82690E-01     .16555E 01    -.11829E 01
  -.29913E-01    -.39095E-01     .10458E 01    -.29983E 00
   .00000E 00     .00000E 00     .00000E 00     .00000E 00
   .19325E 00     .37111E-01     .13847E 00     .86574E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L04

```
      F MATRIX IS

      U             W              Q              THETA          V              P              PHI            R


-.66998E-02    .14162E-01     .11422E 02    -.32176E 02     .41763E-03    -.89744E 00     .16913E-01     .11408E 01
-.10660E-01   -.13206E 01     .13940E 03    -.12529E 01    -.24763E-01    -.29235E 01    -.31115E 00    -.45763E-01
-.42173E-03    .10753E-04    -.30286E 01     .00000E 00     .51804E-04     .14364E 00     .25548E-03     .57942E-02
 .00000E 00    .00000E 00     .10000E 01     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00
-.18388E-01   -.38079E-02    -.83975E-01     .00000E 00    -.10046E 00    -.11842E 02     .22269E 02    -.97522E 02
-.45603E-02   -.40274E-02    -.70856E-02     .00000E 00    -.18509E-01    -.10041E 02    -.62586E 01     .51036E 00
 .00000E 00    .00000E 00     .00000E 00     .00000E 00     .00000E 00     .10000E 01     .00000E 00     .38939E-01
 .13107E-01   -.48539E-02     .10047E 00     .00000E 00     .39913E-01    -.15047E 01    -.82866E 00    -.35350E 01

       G MATRIX IS

    DELTA E       DELTA C          DELTA A        DELTA P


-.19117E 01    .52984E 00    -.28104E-02     .29568E-01
-.54653E 01   -.97770E 01     .52042E-01    -.23584E-02
 .36041E 00    .80835E-02    -.46439E-04    -.34468E-02
 .00000E 00    .00000E 00     .00000E 00     .00000E 00
-.20739E 00   -.82439E-01     .16555E 01    -.11828E 01
-.30056E-01   -.39078E-01     .10458E 01    -.29983E 00
 .00000E 00    .00000E 00     .00000E 00     .00000E 00
 .19422E 00    .36834E-01     .13847E 00     .86572E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L05

```
 F MATRIX IS

      U             W             Q           THETA           V             P            PHI            R

 -.19054E-02   .14147E-01   .11422E 02  -.32176E 02   .41075E-03  -.89747E 00   .17026E-01   .11407E 01
  .31131E-02  -.13206E 01   .13940E 03  -.12529E 01  -.24858E-01  -.29242E 01  -.31133E 00  -.45943E-01
 -.13250E-02   .13458E-04  -.30286E 01   .00000E 00   .53697E-04   .14367E 00   .23714E-03   .57934E-02
  .00000E 00   .00000E 00   .10000E 01   .00000E 00   .00000E 00   .00000E 00   .00000E 00   .00000E 00
 -.18084E-01  -.38130E-02  -.83952E-01   .00000E 00  -.10046E 00  -.11842E 02   .22269E 02  -.97522E 02
 -.42838E-02  -.40313E-02  -.70506E-02   .00000E 00  -.18506E-01  -.10041E 02  -.62585E 01   .51034E 00
  .00000E 00   .00000E 00   .00000E 00   .00000E 00   .00000E 00   .10000E 01   .00000E 00   .38939E-01
  .13331E-01  -.48557E-02   .10053E 00   .00000E 00   .39915E-01  -.15047E 01  -.82865E 00  -.35350E 01
 G MATRIX IS

   DELTA E       DELTA C       DELTA A       DELTA P

 -.19117E 01   .52986E 00  -.28301E-02   .29539E-01
 -.54653E 01  -.97770E 01   .52042E-01  -.22012E-02
  .36041E 00   .80776E-02  -.41254E-04  -.34450E-02
  .00000E 00   .00000E 00   .00000E 00   .00000E 00
 -.20739E 00  -.82431E-01   .16555E 01  -.11828E 01
 -.30054E-01  -.39075E-01   .10458E 01  -.29982E 00
  .00000E 00   .00000E 00   .00000E 00   .00000E 00
  .19422E 00   .36830E-01   .13847E 00   .86571E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L06S

```
      F MATRIX IS

        U             W               Q             THETA           V              P               PHI            R


 -.65582E-01    .14370E 00     .11125E 02    -.31337E 02     .65079E-03    -.87407E 00     .16527E-01     .11109E 01
 -.17836E 00   -.95138E 00     .13855E 03     .11448E 01    -.24923E-01    -.28574E 01    -.31241E 00    -.13076E 00
  .10661E-01   -.24373E-01    -.29725E 01    -.15812E 00     .26728E-04     .13926E 00     .32828E-03     .11405E-01
  .00000E 00    .00000E 00     .10000E 01     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00
 -.22044E-01    .42291E-02    -.11621E 00     .91005E-01    -.11060E 00    -.11840E 02     .22269E 02    -.97525E 02
 -.80116E-02    .35627E-02    -.11710E-01     .13197E-01    -.21077E-01    -.10041E 02    -.62585E 01     .50986E 00
  .00000E 00    .00000E 00     .00000E 00     .00000E 00     .00000E 00     .10000E 01     .00000E 00     .38939E-01
  .10153E-01    .16492E-02     .13077E 00    -.85206E-01     .47337E-01    -.15070E 01    -.82861E 00    -.35319E 01

       G MATRIX IS

     DELTA E       DELTA C          DELTA A        DELTA P


 -.18619E 01    .51602E 00    -.27563E-02     .28759E-01
 -.53227E 01   -.98164E 01     .52096E-01    -.44016E-02
  .35102E 00    .10686E-01    -.55838E-04    -.32999E-02
  .00000E 00    .00000E 00     .00000E 00     .00000E 00
 -.20203E 00   -.83919E-01     .16555E 01    -.11829E 01
 -.29296E-01   -.39291E-01     .10458E 01    -.29984E 00
  .00000E 00    .00000E 00     .00000E 00     .00000E 00
  .18915E 00    .38225E-01     .13847E 00     .86579E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L06U

```
     F MATRIX IS

     U              W              Q              THETA          V              P              PHI            R

 -.73828E-01     .16176E 00     .12524E 02    -.35277E 02     .73263E-03    -.98397E 00     .18605E-01     .12505E 01
 -.20193E 00    -.89973E 00     .14254E 03    -.10120E 02    -.24689E-01    -.31716E 01    -.30647E 00     .26855E 00
  .12216E-01    -.27779E-01    -.32362E 01     .58474E 00     .11301E-04     .15998E 00    -.63506E-04    -.14929E-01
  .00000E 00     .00000E 00     .10000E 01     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00
 -.22939E-01     .61896E-02     .35573E-01    -.33655E 00    -.11059E 00    -.11852E 02     .22269E 02    -.97510E 02
 -.81414E-02     .38470E-02     .10301E-01    -.48803E-01    -.21076E-01    -.10042E 02    -.62585E 01     .51206E 00
  .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .10000E 01     .00000E 00     .38939E-01
  .10991E-01    -.18646E-03    -.11345E-01     .31510E 00     .47329E-01    -.14959E 01    -.82882E 00    -.35461E 01
      G MATRIX IS

   DELTA E       DELTA C         DELTA A        DELTA P

 -.20960E 01     .58091E 00    -.31029E-02     .32376E-01
 -.59920E 01    -.96310E 01     .51105E-01     .59363E-02
  .39516E 00    -.15468E-02     .95024E-05    -.39817E-02
  .00000E 00     .00000E 00     .00000E 00     .00000E 00
 -.22743E 00    -.76879E-01     .16555E 01    -.11825E 01
 -.32980E-01    -.38270E-01     .10458E 01    -.29978E 00
  .00000E 00     .00000E 00     .00000E 00     .00000E 00
  .21294E 00     .31633E-01     .13850E 00     .86543E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L07S

```
F MATRIX IS

      U             W              Q              THETA            V              P              PHI            R


-.38059E-01    .14424E 00     .11167E 02    -.31455E 02     .65805E-03    -.87743E 00     .16579E-01     .11153E 01
-.99972E-01   -.94993E 00     .13867E 03     .80676E 00    -.24822E-01    -.28671E 01    -.31242E 00    -.11897E 00
 .54807E-02   -.24474E-01    -.29804E 01    -.13583E 00     .25046E-04     .13987E 00     .31984E-03     .10601E-01
 .00000E 00    .00000E 00     .10000E 01     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00
-.20334E-01    .42899E-02    -.11171E 00     .78165E-01    -.11060E 00    -.11840E 02     .22269E 02    -.97525E 02
-.63940E-02    .35733E-02    -.11104E-01     .11329E-01    -.21077E-01    -.10041E 02    -.62585E 01     .50993E 00
 .00000E 00    .00000E 00     .00000E 00     .00000E 00     .00000E 00     .10000E 01     .00000E 00     .38939E-01
 .11542E-01    .15960E-02     .12645E 00    -.73197E-01     .47338E-01    -.15067E 01    -.82863E 00    -.35324E 01

  G MATRIX IS

   DELTA E       DELTA C          DELTA A        DELTA P


-.18689E 01    .51809E 00    -.27763E-02     .28906E-01
-.53428E 01   -.98107E 01     .52067E-01    -.42512E-02
 .35234E 00    .10300E-01    -.52340E-04    -.33220E-02
 .00000E 00    .00000E 00     .00000E 00     .00000E 00
-.20276E 00   -.83709E-01     .16555E 01    -.11829E 01
-.29387E-01   -.39247E-01     .10459E 01    -.29984E 00
 .00000E 00    .00000E 00     .00000E 00     .00000E 00
 .18988E 00    .38055E-01     .13847E 00     .86580E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L07U

```
      F MATRIX IS

        U              W               Q             THETA            V               P                PHI            R

 -.42506E-01     .16109E 00     .12471E 02    -.35131E 02     .73494E-03    -.97996E 00      .18516E-01     .12456E 01
 -.11269E 00    -.90174E 00     .14240E 03    -.97007E 01    -.24602E-01    -.31602E 01     -.30688E 00     .25358E 00
  .63191E-02    -.27651E-01    -.32264E 01     .55710E 00     .10550E-04     .15920E 00     -.45374E-04    -.13968E-01
  .00000E 00     .00000E 00     .10000E 01     .00000E 00     .00000E 00     .00000E 00      .00000E 00     .00000E 00
 -.20816E-01     .61184E-02     .29851E-01    -.32060E 00    -.11059E 00    -.11851E 02      .22269E 02    -.97511E 02
 -.64640E-02     .38383E-02     .94137E-02    -.46466E-01    -.21076E-01    -.10042E 02     -.62585E 01     .51198E 00
  .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .10000E 01      .00000E 00     .38939E-01
  .11994E-01    -.11627E-03    -.61139E-02     .30022E 00     .47330E-01    -.14963E 01     -.82882E 00    -.35456E 01
       G MATRIX IS

     DELTA E        DELTA C          DELTA A         DELTA P


 -.20872E 01     .57863E 00    -.31007E-02     .32284E-01
 -.59671E 01    -.96377E 01     .51139E-01     .54049E-02
  .39351E 00    -.11130E-02     .88192E-05    -.39588E-02
  .00000E 00     .00000E 00     .00000E 00     .00000E 00
 -.22645E 00    -.77142E-01     .16555E 01    -.11826E 01
 -.32821E-01    -.38296E-01     .10459E 01    -.29979E 00
  .00000E 00     .00000E 00     .00000E 00     .00000E 00
  .21206E 00     .31904E-01     .13850E 00     .86546E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L08

```
     F MATRIX IS

      U             W             Q           THETA           V             P            PHI             R


-.10438E-01    .14610E 00    .11310E 02   -.31860E 02    .66068E-03   -.88868E 00    .16792E-01    .11294E 01
-.21307E-01   -.94456E 00    .13908E 03   -.34942E 00   -.24813E-01   -.28981E 01   -.31145E 00   -.77969E-01
 .28231E-03   -.24825E-01   -.30074E 01   -.59579E-01    .24365E-04    .14198E 00    .27810E-03    .79155E-02
 .00000E 00    .00000E 00    .10000E 01    .00000E 00    .00000E 00    .00000E 00    .00000E 00    .00000E 00
-.18616E-01    .44928E-02   -.96106E-01    .34286E-01   -.11060E 00   -.11841E 02    .22269E 02   -.97523E 02
-.47762E-02    .36028E-02   -.88223E-02    .49694E-02   -.21079E-01   -.10041E 02   -.62585E 01    .51017E 00
 .00000E 00    .00000E 00    .00000E 00    .00000E 00    .00000E 00    .10000E 01    .00000E 00    .38939E-01
 .12922E-01    .14060E-02    .11188E 00   -.32107E-01    .47336E-01   -.15056E 01   -.82864E 00   -.35338E 01

      G MATRIX IS

    DELTA E       DELTA C        DELTA A       DELTA P


-.18929E 01    .52464E 00   -.27828E-02    .29288E-01
-.54117E 01   -.97917E 01    .51964E-01   -.31889E-02
 .35687E 00    .90598E-02   -.49163E-04   -.33921E-02
 .00000E 00    .00000E 00    .00000E 00    .00000E 00
-.20537E 00   -.82995E-01    .16555E 01   -.11829E 01
-.29766E-01   -.39151E-01    .10458E 01   -.29983E 00
 .00000E 00    .00000E 00    .00000E 00    .00000E 00
 .19232E 00    .37372E-01    .13847E 00    .86575E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L09

```
F MATRIX IS

    U             W              Q              THETA          V              P              PHI            R


-.47777E-02    .14754E 00     .11422E 02    -.32176E 02     .41370E-03    -.89751E 00     .16970E-01     .11407E 01
-.51885E-02   -.94040E 00     .13940E 03    -.12529E 01    -.24779E-01    -.29236E 01    -.31115E 00    -.45763E-01
-.78348E-03   -.25098E-01    -.30286E 01     .00000E 00     .52525E-04     .14365E 00     .24644E-03     .58035E-02
 .00000E 00    .00000E 00     .10000E 01     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00
-.18262E-01    .46503E-02    -.83970E-01     .00000E 00    -.10046E 00    -.11842E 02     .22269E 02    -.97522E 02
-.44478E-02    .36259E-02    -.70892E-02     .00000E 00    -.18507E-01    -.10041E 02    -.62585E 01     .51035E 00
 .00000E 00    .00000E 00     .00000E 00     .00000E 00     .00000E 00     .10000E 01     .00000E 00     .38939E-01
 .13195E-01    .12592E-02     .10046E 00     .00000E 00     .39915E-01    -.15047E 01    -.82866E 00    -.35350E 01
  G MATRIX IS

 DELTA E       DELTA C         DELTA A        DELTA P


-.19117E 01    .52978E 00    -.28301E-02     .29568E-01
-.54653E 01   -.97770E 01     .52042E-01    -.23584E-02
 .36041E 00    .80932E-02    -.42832E-04    -.34468E-02
 .00000E 00    .00000E 00     .00000E 00     .00000E 00
-.20742E 00   -.82413E-01     .16555E 01    -.11828E 01
-.30070E-01   -.39061E-01     .10458E 01    -.29983E 00
 .00000E 00    .00000E 00     .00000E 00     .00000E 00
 .19422E 00    .36836E-01     .13848E 00     .86572E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L10

```
F MATRIX IS
  U            W              Q             THETA           V              P              PHI            R

.11792E-04    .14754E 00     .11422E 02    -.32176E 02     .41862E-03    -.89745E 00     .16970E-01     .11408E 01
.84902E-02   -.94043E 00     .13940E 03    -.12529E 01    -.24779E-01    -.29245E 01    -.31115E 00    -.45943E-01
-.16854E-02  -.25097E-01    -.30286E 01     .00000E 00     .51781E-04     .14365E 00     .24618E-03     .57828E-02
.00000E 00    .00000E 00     .10000E 01     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00
-.17959E-01   .46495E-02    -.83960E-01     .00000E 00    -.10046E 00    -.11842E 02     .22269E 02    -.97522E 02
-.41728E-02   .36253E-02    -.70753E-02     .00000E 00    -.18508E-01    -.10041E 02    -.62585E 01     .51033E 00
.00000E 00    .00000E 00     .00000E 00     .00000E 00     .00000E 00     .10000E 01     .00000E 00     .38939E-01
.13416E-01    .12587E-02     .10048E 00     .00000E 00     .39915E-01    -.15047E 01    -.82865E 00    -.35350E 01
 G MATRIX IS
 DELTA E       DELTA C        DELTA A        DELTA P

-.19116E 01    .52983E 00    -.28202E-02     .29568E-01
-.54653E 01   -.97768E 01     .51885E-01    -.23584E-02
 .36041E 00    .80835E-02    -.43959E-04    -.34466E-02
 .00000E 00    .00000E 00     .00000E 00     .00000E 00
-.20741E 00   -.82412E-01     .16555E 01    -.11828E 01
-.30063E-01   -.39067E-01     .10458E 01    -.29982E 00
 .00000E 00    .00000E 00     .00000E 00     .00000E 00
 .19422E 00    .36823E-01     .13848E 00     .86570E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L11

```
      F MATRIX IS

      U                W                Q              THETA              V                P                PHI              R

 -.67330E-01      .14148E-01      .11422E 02     -.20175E 02      .41862E-03     -.89745E 00      .16958E-01      .11407E 01
 -.18347E 00     -.13206E 01      .13940E 03      .32953E 02     -.24763E-01     -.29236E 01     -.31097E 00     -.45943E-01
  .10992E-01      .12940E-04     -.30286E 01     -.22591E 01      .51691E-04      .14364E 00      .24670E-03      .58063E-02
  .00000E 00      .00000E 00      .10000E 01      .00000E 00      .00000E 00      .00000E 00      .00000E 00      .00000E 00
 -.22230E-01     -.38092E-02     -.83974E-01      .76113E 00     -.10046E 00     -.11842E 02      .22269E 02     -.97522E 02
 -.80381E-02     -.40287E-02     -.70834E-02      .68871E 00     -.18508E-01     -.10041E 02     -.62586E 01      .51034E 00
  .00000E 00      .00000E 00      .00000E 00      .00000E 00      .00000E 00      .10000E 01      .00000E 00      .38939E-01
  .10327E-01     -.48553E-02      .10048E 00      .55011E 00      .39913E-01     -.15047E 01     -.82866E 00     -.35350E 01

       G MATRIX IS

    DELTA E          DELTA C          DELTA A          DELTA P

 -.19117E 01      .52987E 00     -.28301E-02      .29568E-01
 -.54653E 01     -.97768E 01      .51885E-01     -.23584E-02
  .36041E 00      .80758E-02     -.42381E-04     -.34468E-02
  .00000E 00      .00000E 00      .00000E 00      .00000E 00
 -.20740E 00     -.82434E-01      .16555E 01     -.11828E 01
 -.30062E-01     -.39075E-01      .10458E 01     -.29983E 00
  .00000E 00      .00000E 00      .00000E 00      .00000E 00
  .19422E 00      .36835E-01      .13848E 00      .86572E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L12

```
        F MATRIX IS

U              W              Q              THETA          V              P              PHI            R

-.38932E-01    .14150E-01     .11422E 02     -.20175E 02    .41370E-03     -.89746E 00    .16913E-01     .11407E 01
-.10256E 00    -.13206E 01    .13940E 03     .32953E 02     -.24763E-01    -.29245E 01    -.31097E 00    -.45943E-01
.56462E-02     .12511E-04     -.30286E 01    -.22591E 01    .52435E-04     .14365E 00     .25393E-03     .58035E-02
.00000E 00     .00000E 00     .10000E 01     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00
-.20429E-01    -.38129E-02    -.83920E-01    .76117E 00     -.10046E 00    -.11842E 02    .22269E 02     -.97522E 02
-.64083E-02    -.40308E-02    -.70533E-02    .68874E 00     -.18510E-01    -.10041E 02    -.62585E 01    .51033E 00
.00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .10000E 01     .00000E 00     .38939E-01
.11629E-01     -.48547E-02    .10047E 00     .55011E 00     .39914E-01     -.15047E 01    -.82866E 00    -.35350E-01

        G MATRIX IS

DELTA E        DELTA C        DELTA A        DELTA P

-.19116E 01    .52981E 00     -.28399E-02    .29578E-01
-.54653E-01    -.97768E-01    .51885E-01     -.23584E-02
.36040E 00     .80853E-02     -.40803E-04    -.34470E-02
.00000E 00     .00000E 00     .00000E 00     .00000E 00
-.20741E 00    -.82405E-01    .16555E 01     -.11828E 01
-.30061E-01    -.39050E-01    .10458E-01     -.29983E 00
.00000E 00     .00000E 00     .00000E 00     .00000E 00
.15422E 00     .36851E-01     .13846E 00     .86572E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L13

```
     F MATRIX IS

U                W                Q                THETA            V                P                PHI              R

-.1C541E-C1      .14154E-01       .11422E C2      -.20175E 02       .41567E-03      -.89752E 00       .16902E-01       .11407E 01
-.21619E-C1     -.13206E-01       .13940E-03       .32953E 02      -.24779E-01      -.29245E 01      -.31115E 00      -.45763E-01
 .3C147E-C3      .12061E-04      -.30286E C1      -.22591E 01       .52255E-04       .14366E 00       .25703E-03       .58027E-02
 .0C000E 00      .0C000E 00       .10000E 01       .00000E 00       .00CC0E 00       .00000E 00       .00000E 00       .00000E 00
-.18630E-01     -.38087E-02      -.83957E-01       .76117E 00      -.10046E 00      -.11842E 02       .22269E 02      -.97522E 02
-.47798E-02     -.40289E-02      -.70766E-02       .68874E 00      -.185C8E-01      -.10041E 02      -.62586E 01       .51035E 00
 .0C000E 00      .00000E 00       .00000E C0       .00000E 00       .00CC0E 00       .1000CE 01       .00000E 00       .38939E-01
-.12931E-01     -.48562E-02       .10047E 00       .55011E 00       .39915E-C1      -.15047E-01      -.82866E 00      -.35350E-01

     G MATRIX IS

DELTA E          DELTA C          DELTA A          DELTA P

-.19116E 01      .52983E 00      -.27908E-02       .29578E-01
-.54653E-01     -.97768E-01       .52042E-01      -.23584E-02
 .36041E 00      .80814E-02      -.49595E-04      -.34466E-02
 .0C000E 00      .00000E 0C       .00000E C0       .00000E 00
-.2C740E 00     -.82404E-01       .16555E C1      -.11828E 01
-.3C063E-01     -.39057E-01       .10458E-01      -.29983E 00
 .0C000E 00      .00000E 00       .00000E 00       .0000CE 00
-.15421E 00      .36837E-01       .13848E C0       .86572E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L14

```
      F MATRIX IS

U                W                Q                THETA            V                P                PHI              R

-.67028E-02      .14157E-01       .11422E 02       -.20175E 02      .41370E-03       -.89751E 00      .16958E-01       .11408E 01
-.10660E-01      -.13206E-01      .13940E-03       .32953E-02       -.24779E-01      -.29236E-01      -.31115E 00      -.45763E-01
-.42101E-03      .11677E-04       -.30286E 01      -.22591E 01      .52570E-04       .14365E 00       .24799E-03       .57942E-02
.00000E 00       .00000E 00       .10000E 01       .00000E 00       .00000E 00       .00000E 00       .00000E 00       .00000E 00
-.18383E-01      -.38090E-02      -.83933E-01      .76113E 00       -.10046E 00      -.11842E 02      .22269E 02       -.97522E 02
-.45570E-02      -.40287E-02      -.70614E-02      .68871E 00       -.18508E-01      -.10041E 02      -.62585E 01      .51034E 00
.00000E 00       .00000E 00       .00000E 00       .00000E 00       .00000E 00       .10000E 01       .00000E 00       .38939E-01
.13108E-01       -.48553E-02      .10047E 00       .55010E 00       .39915E-01       -.15047E-01      -.82867E 00      -.35350E-01

      G MATRIX IS

DELTA E          DELTA C          DELTA A          DELTA P

-.19116E 01      .52978E 00       -.28399E-02      .29568E-01
-.54652E-01      -.97770E-01      .52042E-01       -.23584E-02
.36041E 00       .80925E-02       -.41254E-04      -.34466E-02
.00000E 00       .00000E 00       .00000E 00       .00000E 00
-.20739E 00      -.82416E-01      .16555E 01       -.11828E 01
-.30052E-01      -.39060E-01      .10458E-01       -.29983E 00
.00000E 00       .00000E 00       .00000E 00       .00000E 00
.15423E 00       .36845E-01       .13847E 00       .86572E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L15

```
        F MATRIX IS

U               W               Q               THETA           V               P               PHI             R

 .26532E-04      .14158E-01      .11422E 02     -.20175E 02      .41665E-03     -.89745E 00      .16879E-01      .11407E 01
 .85688E-02     -.13206E-01      .13940E-03      .32953E 02     -.24842E-01     -.29244E 01     -.31115E 00     -.45763E-01
-.16883E-02      .11677E-04     -.30286E 01     -.22591E 01      .52728E-04      .14367E 00      .25962E-03      .58025E-02
 .00000E 00      .00000E 00      .10000E 01      .00000E 00      .00000E 00      .00000E 00      .00000E 00      .00000E 00
-.17963E-01     -.38132E-02     -.83939E-01      .76119E 00     -.10046E 00     -.11842E 02      .22269E 02     -.97522E 02
-.41747E-02     -.40318E-02     -.70426E-02      .68876E 00     -.18507E-01     -.10041E 02     -.62585E 01      .51033E 00
 .00000E 00      .00000E 00      .00000E 00      .00000E 00      .00000E 00      .10000E 01      .00000E 00      .38939E-01
 .13417E-01     -.48566E-02      .10052E 00      .55011E 00      .39915E-01     -.15047E-01     -.82865E 00     -.35350E-01

        G MATRIX IS

DELTA E         DELTA C         DELTA A         DELTA P

-.19117E 01      .52982E 00     -.28202E-02      .29539E-01
-.54653E 01     -.97778E-01      .52042E-01     -.22012E-02
 .36041E 00      .80914E-02     -.42832E-04     -.34450E-02
 .00000E 00      .00000E 00      .00000E 00      .00000E 00
-.20740E 00     -.82428E-01      .16555E 01     -.11828E 01
-.30061E-01     -.39074E-01      .10458E-01     -.29982E 00
 .00000E 00      .00000E 00      .00000E 00      .00000E 00
 .15422E 00      .36830E-01      .13847E 00      .86571E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L16

```
      F MATRIX IS
      U               W               Q               THETA           V               P               PHI             R

-.13891E 00     .14164E-01      .11423E 02     -.32176E 02      .67607E-03     -.89749E 00      .17026E-01      .11404E 01
-.10253E 00    -.13206E 01      .13940E 03     -.12528E 01     -.24779E-01     -.29235E 01     -.31133E 00     -.45763E-01
 .56461E-02     .10009E-04     -.30286E 01      .00000E 00      .21979E-04      .14358E 00      .23714E-03      .57906E-02
 .00000E 00     .00000E 00      .10000E 01      .00000E 00      .00000E 00      .00000E 00      .00000E 00      .00000E 00
-.20415E-01    -.38092E-02     -.83905E-01      .00000E 00     -.11060E 00     -.11842E 02      .22269E 02     -.97522E 02
-.64043E-02    -.40292E-02     -.70749E-02      .00000E 00     -.21078E-01     -.10041E 02     -.62585E 01      .51036E 00
 .00000E 00     .00000E 00      .00000E 00      .00000E 00      .00000E 00      .10000E 01      .00000E 00      .38936E-01
 .11620E-01    -.48562E-02      .10040E 00      .00000E 00      .47335E-01     -.15047E 01     -.82866E 00     -.35350E 01
       G MATRIX IS
     DELTA E         DELTA C          DELTA A         DELTA P

-.19116E 01     .52984E 00     -.75665E-02      .29676E-01
-.54653E 01    -.97773E 01      .52356E-01     -.22012E-02
 .36041E 00     .80808E-02      .50632E-03     -.34522E-02
 .00000E 00     .00000E 00      .00000E 00      .00000E 00
-.20740E 00    -.82388E-01      .18464E 01     -.11829E 01
-.30057E-01    -.39045E-01      .10942E 01     -.29984E 00
 .00000E 00     .00000E 00      .00000E 00      .00000E 00
 .19422E 00     .36838E-01     -.12987E-02      .86576E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L17

```
      F MATRIX IS

       U              W              Q            THETA           V              P             PHI            R

-.11052E 00     .14162E-01     .11422E 02    -.32176E 02     .67411E-03    -.89750E 00     .16958E-01     .11410E 01
-.21509E-01    -.13207E 01     .13940E 03    -.12528E 01    -.24779E-01    -.29244E 01    -.31133E 00    -.46664E-01
 .30151E-03     .11114E-04    -.30286E 01     .00000E 00     .21979E-04     .14358E 00     .24851E-03     .58097E-02
 .00000E 00     .00000E 00     .10000E 01     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00
-.18615E-01    -.38081E-02    -.83874E-01     .00000E 00    -.11060E 00    -.11842E 02     .22269E 02    -.97522E 02
-.47753E-02    -.40281E-02    -.70564E-02     .00000E 00    -.21079E-01    -.10041E 02    -.62585E 01     .51034E 00
 .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .10000E 01     .00000E 00     .38936E-01
 .12922E-01    -.48552E-02     .10041E 00     .00000E 00     .47334E-01    -.15047E 01    -.82866E 00    -.35350E 01
       G MATRIX IS

    DELTA E        DELTA C         DELTA A        DELTA P

-.19116E 01     .52986E 00    -.76058E-02     .29686E-01
-.54652E 01    -.97773E 01     .52356E-01    -.22012E-02
 .36040E 00     .80780E-02     .51060E-03    -.34520E-02
 .00000E 00     .00000E 00     .00000E 00     .00000E 00
-.20740E 00    -.82425E-01     .18464E 01    -.11829E 01
-.30051E-01    -.39071E-01     .10942E 01    -.29984E 00
 .00000E 00     .00000E 00     .00000E 00     .00000E 00
 .19424E 00     .36831E-01    -.12835E-02     .86575E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L18

```
         F MATRIX IS
         U              W               Q              THETA           V              P               PHI            R

  -.10188E 00     .14162E-01     .11422E 02    -.32176E 02     .67411E-03    -.89750E 00     .16958E-01     .11410E 01
   .31288E-02    -.13207E 01     .13940E 03    -.12528E 01    -.24779E-01    -.29244E 01    -.31133E 00    -.46664E-01
  -.13251E-02     .11114E-04    -.30286E 01     .00000E 00     .21979E-04     .14358E 00     .24851E-03     .58097E-02
   .00000E 00     .00000E 00     .10000E 01     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00
  -.18068E-01    -.38081E-02    -.83874E-01     .00000E 00    -.11060E 00    -.11842E 02     .22269E 02    -.97522E 02
  -.42800E-02    -.40281E-02    -.70564E-02     .00000E 00    -.21079E-01    -.10041E 02    -.62585E 01     .51034E 00
   .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .10000E 01     .00000E 00     .38936E-01
   .13318E-01    -.48552E-02     .10041E 00     .00000E 00     .47334E-01    -.15047E 01    -.82866E 00    -.35350E 01
          G MATRIX IS
       DELTA E        DELTA C          DELTA A        DELTA P

  -.19116E 01     .52986E 00    -.76058E-02     .29686E-01
  -.54652E 01    -.97773E 01     .52356E-01    -.22012E-02
   .36040E 00     .80780E-02     .51060E-03    -.34520E-02
   .00000E 00     .00000E 00     .00000E 00     .00000E 00
  -.20740E 00    -.82425E-01     .18464E 01    -.11829E 01
  -.30051E-01    -.39071E-01     .10942E 01    -.29984E 00
   .00000E 00     .00000E 00     .00000E 00     .00000E 00
   .19424E 00     .36831E-01    -.12835E-02     .86575E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L19

```
F MATRIX IS

   U              W              Q              THETA          V              P              PHI            R

-.10360E 00    .14162E-01     .11422E 02    -.32176E 02     .67411E-03    -.89750E 00     .16958E-01     .11410E 01
-.18238E-02   -.13207E 01     .13940E 03    -.12528E 01    -.24779E-01    -.29244E 01    -.31133E 00    -.46664E-01
-.10008E-02    .11114E-04    -.30286E 01     .00000E 00     .21979E-04     .14358E 00     .24851E-03     .58097E-02
 .00000E 00    .00000E 00     .10000E 01     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00
-.18180E-01   -.38081E-02    -.83874E-01     .00000E 00    -.11060E 00    -.11842E 02     .22269E 02    -.97522E 02
-.43809E-02   -.40281E-02    -.70564E-02     .00000E 00    -.21079E-01    -.10041E 02    -.62585E 01     .51034E 00
 .00000E 00    .00000E 00     .00000E 00     .00000E 00     .00000E 00     .10000E 01     .00000E 00     .38936E-01
 .13238E-01   -.48552E-02     .10041E 00     .00000E 00     .47334E-01    -.15047E 01    -.82866E 00    -.35350E 01
  G MATRIX IS

  DELTA E       DELTA C           DELTA A        DELTA P

-.19116E 01    .52986E 00    -.76058E-02     .29686E-01
-.54652E 01   -.97773E 01     .52356E-01    -.22012E-02
 .36040E 00    .80780E-02     .51060E-03    -.34520E-02
 .00000E 00    .00000E 00     .00000E 00     .00000E 00
-.20740E 00   -.82425E-01     .18464E 01    -.11829E 01
-.30051E-01   -.39071E-01     .10942E 01    -.29984E 00
 .00000E 00    .00000E 00     .00000E 00     .00000E 00
 .19424E 00    .36831E-01    -.12835E-02     .86575E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L20

```
F MATRIX IS

     U            W            Q            THETA         V            P            PHI          R

-.13891E 00   .14755E 00   .11422E 02  -.32176E 02   .67411E-03  -.89750E 00   .16958E-01   .11410E 01
-.10245E 00  -.94050E 00   .13940E 03  -.12528E 01  -.24779E-01  -.29244E 01  -.31133E 00  -.46664E-01
 .56460E-02  -.25098E-01  -.30286E 01   .00000E 00   .21979E-04   .14358E 00   .24851E-03   .58097E-02
 .00000E 00   .00000E 00   .10000E 01   .00000E 00   .00000E 00   .00000E 00   .00000E 00   .00000E 00
-.20415E-01   .46505E-02  -.83874E-01   .00000E 00  -.11060E 00  -.11842E 02   .22269E 02  -.97522E 02
-.64044E-02   .36259E-02  -.70564E-02   .00000E 00  -.21079E-01  -.10041E 02  -.62585E 01   .51034E 00
 .00000E 00   .00000E 00   .00000E 00   .00000E 00   .00000E 00   .10000E 01   .00000E 00   .38936E-01
 .11619E-01   .12588E-02   .10041E 00   .00000E 00   .47334E-01  -.15047E 01  -.82866E 00  -.35350E 01

  G MATRIX IS

   DELTA E      DELTA C        DELTA A      DELTA P

-.19116E 01   .52986E 00  -.76058E-02   .29686E-01
-.54652E 01  -.97773E 01   .52356E-01  -.22012E-02
 .36040E 00   .80780E-02   .51060E-03  -.34520E-02
 .00000E 00   .00000E 00   .00000E 00   .00000E 00
-.20740E 00  -.82425E-01   .18464E 01  -.11829E 01
-.30051E-01  -.39071E-01   .10942E 01  -.29984E 00
 .00000E 00   .00000E 00   .00000E 00   .00000E 00
 .19424E 00   .36831E-01  -.12835E-02   .86575E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L21

```
     F MATRIX IS

     U              W                 Q             THETA            V               P                PHI            R

-.11052E 00     .14755E 00      .11422E 02     -.32176E 02      .67411E-03     -.89750E 00      .16958E-01      .11410E 01
-.21509E-01    -.94050E 00      .13940E 03     -.12528E 01     -.24779E-01     -.29244E 01     -.31133E 00     -.46664E-01
 .30151E-03    -.25098E-01     -.30286E 01      .00000E 00      .21979E-04      .14358E 00      .24851E-03      .58097E-02
 .00000E 00     .00000E 00      .10000E 01      .00000E 00      .00000E 00      .00000E 00      .00000E 00      .00000E 00
-.18615E-01     .46505E-02     -.83874E-01      .00000E 00     -.11060E 00     -.11842E 02      .22269E 02     -.97522E 02
-.47753E-02     .36259E-02     -.70564E-02      .00000E 00     -.21079E-01     -.10041E 02     -.62585E 01      .51034E 00
 .00000E 00     .00000E 00      .00000E 00      .00000E 00      .00000E 00      .10000E 01      .00000E 00      .38936E-01
 .12922E-01     .12588E-02      .10041E 00      .00000E 00      .47334E-01     -.15047E 01     -.82866E 00     -.35350E 01

      G MATRIX IS

   DELTA E        DELTA C          DELTA A        DELTA P

-.19116E 01     .52986E 00     -.76058E-02      .29686E-01
-.54652E 01    -.97773E 01      .52356E-01     -.22012E-02
 .36040E 00     .80780E-02      .51060E-03     -.34520E-02
 .00000E 00     .00000E 00      .00000E 00      .00000E 00
-.20740E 00    -.82425E-01      .18464E 01     -.11829E 01
-.30051E-01    -.39071E-01      .10942E 01     -.29984E 00
 .00000E 00     .00000E 00      .00000E 00      .00000E 00
 .19424E 00     .36831E-01     -.12835E-02      .86575E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L22

```
     F MATRIX IS

       U              W                Q              THETA             V               P               PHI             R

-.99953E-01     .14755E 00     .11422E 02    -.32176E 02     .67411E-03    -.89750E 00     .16958E-01     .11410E 01
 .85688E-02    -.94050E 00     .13940E 03    -.12528E 01    -.24779E-01    -.29244E 01    -.31133E 00    -.46664E-01
-.16880E-02    -.25098E-01    -.30286E 01     .00000E 00     .21979E-04     .14358E 00     .24851E-03     .58097E-02
 .00000E 00     .00000E 00     .10000E 01     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00
-.17946E-01     .46505E-02    -.83874E-01     .00000E 00    -.11060E 00    -.11842E 02     .22269E 02    -.97522E 02
-.41691E-02     .36259E-02    -.70564E-02     .00000E 00    -.21079E-01    -.10041E 02    -.62585E 01     .51034E 00
 .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .10000E 01     .00000E 00     .38936E-01
 .13406E-01     .12588E-02     .10041E 00     .00000E 00     .47334E-01    -.15047E 01    -.82866E 00    -.35350E 01
      G MATRIX IS

    DELTA E        DELTA C          DELTA A        DELTA P


-.19116E 01     .52986E 00    -.76058E-02     .29686E-01
-.54652E 01    -.97773E 01     .52356E-01    -.22012E-02
 .36040E 00     .80780E-02     .51060E-03    -.34520E-02
 .00000E 00     .00000E 00     .00000E 00     .00000E 00
-.20740E 00    -.82425E-01     .18464E 01    -.11829E 01
-.30051E-01    -.39071E-01     .10942E 01    -.29984E 00
 .00000E 00     .00000E 00     .00000E 00     .00000E 00
 .19424E 00     .36831E-01    -.12835E-02     .86575E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L24

```
   F MATRIX IS

   U              W              Q              THETA          V              P              PHI            R

-.13891E 00    .14162E-01     .11422E 02    -.20175E 02     .67411E-03    -.89750E 00     .16958E-01     .11410E 01
-.10245E 00   -.13207E 01     .13940E 03     .32954E 02    -.24779E-01    -.29244E 01    -.31133E 00    -.46664E-01
 .56460E-02    .11114E-04    -.30286E 01    -.22591E 01     .21979E-04     .14358E 00     .24851E-03     .58097E-02
 .00000E 00    .00000E 00     .10000E 01     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00
-.20415E-01   -.38081E-02    -.83874E-01     .76119E 00    -.11060E 00    -.11842E 02     .22269E 02    -.97522E 02
-.64044E-02   -.40281E-02    -.70564E-02     .68874E 00    -.21079E-01    -.10041E 02    -.62585E 01     .51034E 00
 .00000E 00    .00000E 00     .00000E 00     .00000E 00     .00000E 00     .10000E 01     .00000E 00     .38936E-01
 .11619E-01   -.48552E-02     .10041E 00     .55008E 00     .47334E-01    -.15047E 01    -.82866E 00    -.35350E 01

    G MATRIX IS

 DELTA E        DELTA C        DELTA A        DELTA P

-.19116E 01    .52986E 00    -.76058E-02     .29686E-01
-.54652E 01   -.97773E 01     .52356E-01    -.22012E-02
 .36040E 00    .80780E-02     .51060E-03    -.34520E-02
 .00000E 00    .00000E 00     .00000E 00     .00000E 00
-.20740E 00   -.82425E-01     .18464E 01    -.11829E 01
-.30051E-01   -.39071E-01     .10942E 01    -.29984E 00
 .00000E 00    .00000E 00     .00000E 00     .00000E 00
 .19424E 00    .36831E-01    -.12835E-02     .86575E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L25

```
   F MATRIX IS

    U              W              Q              THETA          V              P              PHI            R

-.11052E 00     .14162E-01     .11422E 02    -.20175E 02     .67411E-03    -.89750E 00     .16958E-01     .11410E 01
-.21509E-01    -.13207E 01     .13940E 03     .32954E 02    -.24779E-01    -.29244E 01    -.31133E 00    -.46664E-01
 .30151E-03     .11114E-04    -.30286E 01    -.22591E 01     .21979E-04     .14358E 00     .24851E-03     .58097E-02
 .00000E 00     .00000E 00     .10000E 01     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00
-.18615E-01    -.38081E-02    -.83874E-01     .76119E 00    -.11060E 00    -.11842E 02     .22269E 02    -.97522E 02
-.47753E-02    -.40281E-02    -.70564E-02     .68874E 00    -.21079E-01    -.10041E 02    -.62585E 01     .51034E 00
 .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .10000E 01     .00000E 00     .38936E-01
 .12922E-01    -.48552E-02     .10041E 00     .55008E 00     .47334E-01    -.15047E 01    -.82866E 00    -.35350E 01

     G MATRIX IS

   DELTA E        DELTA C        DELTA A        DELTA P

-.19116E 01     .52986E 00    -.76058E-02     .29686E-01
-.54652E 01    -.97773E 01     .52356E-01    -.22012E-02
 .36040E 00     .80780E-02     .51060E-03    -.34520E-02
 .00000E 00     .00000E 00     .00000E 00     .00000E 00
-.20740E 00    -.82425E-01     .18464E 01    -.11829E 01
-.30051E-01    -.39071E-01     .10942E 01    -.29984E 00
 .00000E 00     .00000E 00     .00000E 00     .00000E 00
 .19424E 00     .36831E-01    -.12835E-02     .86575E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L26

```
     F MATRIX IS

     U              W               Q               THETA           V               P               PHI             R


 -.99953E-01     .14162E-01      .11422E 02     -.20175E 02      .67411E-03     -.89750E 00      .16958E-01      .11410E 01
  .85688E-02    -.13207E 01      .13940E 03      .32954E 02     -.24779E-01     -.29244E 01     -.31133E 00     -.46664E-01
 -.16880E-02     .11114E-04     -.30286E 01     -.22591E 01      .21979E-04      .14358E 00      .24851E-03      .58097E-02
  .00000E 00     .00000E 00      .10000E 01      .00000E 00      .00000E 00      .00000E 00      .00000E 00      .00000E 00
 -.17946E-01    -.38081E-02     -.83874E-01      .76119E 00     -.11060E 00     -.11842E 02      .22269E 02     -.97522E 02
 -.41691E-02    -.40281E-02     -.70564E-02      .68874E 00     -.21079E-01     -.10041E 02     -.62585E 01      .51034E 00
  .00000E 00     .00000E 00      .00000E 00      .00000E 00      .00000E 00      .10000E 01      .00000E 00      .38936E-01
  .13406E-01    -.48552E-02      .10041E 00      .55008E 00      .47334E-01     -.15047E 01     -.82866E 00     -.35350E 01

      G MATRIX IS

   DELTA E        DELTA C          DELTA A        DELTA P


 -.19116E 01     .52986E 00     -.76058E-02      .29686E-01
 -.54652E 01    -.97773E 01      .52356E-01     -.22012E-02
  .36040E 00     .80780E-02      .51060E-03     -.34520E-02
  .00000E 00     .00000E 00      .00000E 00      .00000E 00
 -.20740E 00    -.82425E-01      .18464E 01     -.11829E 01
 -.30051E-01    -.39071E-01      .10942E 01     -.29984E 00
  .00000E 00     .00000E 00      .00000E 00      .00000E 00
  .19424E 00     .36831E-01     -.12835E-02      .86575E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L28S

```
F MATRIX IS

    U             W              Q              THETA          V              P              PHI            R

-.62711E-01    .13184E-01     .68952E 00    -.29970E 02     .62059E-03    -.83594E 00     .15786E-01     .10626E 01
-.17024E 00   -.13234E 01     .10881E 03     .50518E 01    -.24925E-01    -.27479E 01    -.31465E 00    -.27037E 00
 .10121E-01    .19518E-03    -.10082E 01    -.41575E 00     .31738E-04     .13206E 00     .46878E-03     .20537E-01
 .00000E 00    .00000E 00     .10000E 01     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00
-.21733E-01   -.39170E-02    -.76643E 00     .23926E 00    -.11061E 00    -.11836E 02     .22269E 02    -.97531E 02
-.79663E-02   -.40451E-02    -.62071E 00     .34681E-01    -.21080E-01    -.10040E 02    -.62585E 01     .50909E 00
 .00000E 00    .00000E 00     .00000E 00     .00000E 00     .00000E 00     .10000E 01     .00000E 00     .38939E-01
 .98615E-02   -.47556E-02    -.38431E 00    -.22404E 00     .47340E-01    -.15109E 01    -.82854E 00    -.35270E 01

  G MATRIX IS

 DELTA E       DELTA C        DELTA A        DELTA P

-.17806E 01    .49349E 00    -.26361E-02     .27514E-01
-.50908E 01   -.98809E 01     .52439E-01    -.79892E-02
 .33570E 00    .14932E-01    -.77146E-04    -.30636E-02
 .00000E 00    .00000E 00     .00000E 00     .00000E 00
-.19319E 00   -.86335E-01     .16555E 01    -.11830E 01
-.28003E-01   -.39621E-01     .10458E 01    -.29986E 00
 .00000E 00    .00000E 00     .00000E 00     .00000E 00
 .18090E 00    .40527E-01     .13846E 00     .86592E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L28U

```
F MATRIX IS

     U            W            Q           THETA          V             P            PHI          R

-.65818E-01   .13837E-01   .72368E 00  -.31455E 02   .65133E-03  -.87736E 00   .16568E-01   .11152E 01
-.17913E 00  -.13215E 01   .10891E 03   .80683E 00  -.24837E-01  -.28663E 01  -.31242E 00  -.11987E 00
 .10707E-01   .72036E-04  -.10147E 01  -.13582E 00   .25942E-04   .13987E 00   .32134E-03   .10612E-01
 .00000E 00   .00000E 00   .10000E 01   .00000E 00   .00000E 00   .00000E 00   .00000E 00   .00000E 00
-.22070E-01  -.38461E-02  -.76272E 00   .78164E-01  -.11060E 00  -.11840E 02   .22269E 02  -.97525E 02
-.80151E-02  -.40349E-02  -.62018E 00   .11330E-01  -.21079E-01  -.10041E 02  -.62585E 01   .50992E 00
 .00000E 00   .00000E 00   .00000E 00   .00000E 00   .00000E 00   .10000E 01   .00000E 00   .38939E-01
 .10177E-01  -.48220E-02  -.38778E 00  -.73193E-01   .47337E-01  -.15067E 01  -.82862E 00  -.35324E 01

  G MATRIX IS

  DELTA E      DELTA C       DELTA A      DELTA P

-.18688E 01   .51794E 00  -.27667E-02   .28878E-01
-.53430E 01  -.98110E 01   .52066E-01  -.40921E-02
 .35233E 00   .10323E-01  -.52524E-04  -.33205E-02
 .00000E 00   .00000E 00   .00000E 00   .00000E 00
-.20276E 00  -.83683E-01   .16555E 01  -.11829E 01
-.29390E-01  -.39236E-01   .10458E 01  -.29983E 00
 .00000E 00   .00000E 00   .00000E 00   .00000E 00
 .18987E 00   .38043E-01   .13847E 00   .86578E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L29S

```
     F MATRIX IS
     U              W              Q              THETA          V              P              PHI            R

-.37431E-01     .13609E-01     .71171E 00    -.30934E 02     .63866E-03    -.86282E 00     .16358E-01     .10968E 01
-.98249E-01    -.13222E 01     .10888E 03     .22959E 01    -.24868E-01    -.28247E 01    -.31321E 00    -.17248E 00
 .53632E-02     .11526E-03    -.10124E 01    -.23402E 00     .28141E-04     .13713E 00     .36322E-03     .14093E-01
 .00000E 00     .00000E 00     .10000E 01     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00
-.20270E-01    -.38698E-02    -.76402E 00     .13467E 00    -.11060E 00    -.11838E 02     .22269E 02    -.97527E 02
-.63853E-02    -.40387E-02    -.62036E 00     .19521E-01    -.21079E-01    -.10040E 02    -.62585E 01     .50964E 00
 .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .10000E 01     .00000E 00     .38939E-01
 .11481E-01    -.48009E-02    -.38656E 00    -.12611E 00     .47336E-01    -.15082E 01    -.82859E 00    -.35305E 01
      G MATRIX IS

    DELTA E        DELTA C          DELTA A         DELTA P

-.18379E 01     .50938E 00    -.27209E-02     .28390E-01
-.52545E 01    -.98362E 01     .52197E-01    -.54581E-02
 .34650E 00     .11947E-01    -.61161E-04    -.32305E-02
 .00000E 00     .00000E 00     .00000E 00     .00000E 00
-.19940E 00    -.84614E-01     .16555E 01    -.11829E 01
-.28904E-01    -.39376E-01     .10458E 01    -.29984E 00
 .00000E 00     .00000E 00     .00000E 00     .00000E 00
 .18672E 00     .38910E-01     .13846E 00     .86583E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L29U

```
F MATRIX IS

     U              W              Q             THETA            V              P              PHI             R

-.38778E-01     .14099E-01     .73731E 00    -.32047E 02     .66163E-03    -.89385E 00     .16947E-01     .11362E 01
-.10210E 00    -.13208E 01     .10895E 03    -.88524E 00    -.24802E-01    -.29135E 01    -.31152E 00    -.59698E-01
 .56170E-02     .22974E-04    -.10172E 01    -.24244E-01     .23810E-04     .14298E 00     .25229E-03     .66550E-02
 .00000E 00     .00000E 00     .10000E 01     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00
-.20416E-01    -.38167E-02    -.76124E 00     .13952E-01    -.11060E 00    -.11842E 02     .22269E 02    -.97523E 02
-.64065E-02    -.40310E-02    -.61996E 00     .20223E-02    -.21079E-01    -.10041E 02    -.62585E 01     .51026E 00
 .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .10000E 01     .00000E 00     .38939E-01
 .11618E-01    -.48506E-02    -.38916E 00    -.13064E-01     .47334E-01    -.15050E 01    -.82865E 00    -.35345E 01

 G MATRIX IS

  DELTA E        DELTA C          DELTA A        DELTA P

-.19040E 01     .52770E 00    -.28188E-02     .29411E-01
-.54435E 01    -.97838E 01     .51917E-01    -.25386E-02
 .35896E 00     .84926E-02    -.42710E-04    -.34230E-02
 .00000E 00     .00000E 00     .00000E 00     .00000E 00
-.20657E 00    -.82627E-01     .16555E 01    -.11828E 01
-.29944E-01    -.39088E-01     .10458E 01    -.29983E 00
 .00000E 00     .00000E 00     .00000E 00     .00000E 00
 .19343E 00     .37048E-01     .13847E 00     .86573E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L30

```
      F MATRIX IS

U                W                Q                THETA            V                P                PHI              R

-.10542E-01      .14154E-01       .74023E 00       -.32176E 02      .41370E-03       -.89745E 00      .16992E-01       .11408E 01
-.21619E-01      -.13206E 01      .10896E 03       -.12529E 01      -.24763E-01      -.29236E 01      -.31119E 00      -.45943E-01
 .30185E-03      .11993E-04       -.10178E 01      .00000E 00       .52435E-04       .14364E 00       .24231E-03       .57888E-02
 .00000E 00      .00000E 00       .10000E 01       .00000E 00       .00000E 00       .00000E 00       .00000E 00       .00000E 00
-.18630E-01      -.38108E-02      -.76095E 00      .00000E 00       -.10046E 00      -.11842E 02      .22269E 02       -.97522E 02
-.47799E-02      -.40296E-02      -.61995E 00      .00000E 00       -.18509E-01      -.10041E 02      -.62585E 01      .51033E 00
 .00000E 00      .00000E 00       .00000E 00       .00000E 00       .00000E 00       .10000E 01       .00000E 00       .38939E-01
 .12932E-01      -.48546E-02      -.38949E 00      .00000E 00       .39914E-01       -.15047E 01      -.82866E 00      -.35350E 01

      G MATRIX IS

DELTA E          DELTA C          DELTA A          DELTA P

-.19116E 01      .52986E 00       -.28399E-02      .29578E-01
-.64652E-01      -.97768E 01      .62042E-01       -.23584E-02
 .36041E 00      .80767E-02       -.41254E-04      -.34468E-02
 .00000E 00      .00000E 00       .00000E 00       .00000E 00
-.20741E 00      -.82411E-01      .16555E 01       -.11828E 01
-.30068E-01      -.39061E-01      .10458E 01       -.29983E 00
 .00000E 00      .00000E 00       .00000E 00       .00000E 00
 .19421E 00      .36836E-01       .13848E 00       .86572E 00
IBP= 0
```

TABLE 12.- CONTINUED

CONFIGURATION L31

```
F MATRIX IS

     U               W                Q              THETA             V                P                PHI              R

-.81365E-02     .14165E-01      .74030E 00     -.32176E 02      .67018E-03     -.89745E 00      .17026E-01      .11407E 01
-.14654E-01    -.13206E 01      .10896E 03     -.12529E 01     -.24858E-01     -.29242E 01     -.31133E 00     -.45763E-01
-.15201E-03     .10482E-04     -.10178E 01      .00000E 00      .23129E-04      .14367E 00      .23714E-03      .57955E-02
 .00000E 00     .00000E 00      .10000E 01      .00000E 00      .00000E 00      .00000E 00      .00000E 00      .00000E 00
-.18479E-01    -.38131E-02     -.76096E 00      .00000E 00     -.11060E 00     -.11842E 02      .22269E 02     -.97522E 02
-.46421E-02    -.40320E-02     -.61994E 00      .00000E 00     -.21079E-01     -.10041E 02     -.62585E 01      .51033E 00
 .00000E 00     .00000E 00      .00000E 00      .00000E 00      .00000E 00      .10000E 01      .00000E 00      .38939E-01
 .13043E-01    -.48570E-02     -.38948E 00      .00000E 00      .47335E-01     -.15047E 01     -.82865E 00     -.35350E 01

 G MATRIX IS

  DELTA E        DELTA C          DELTA A         DELTA P

-.19117E 01     .52981E 00     -.28399E-02      .29529E-01
-.54652E 01    -.97770E 01      .51885E-01     -.22012E-02
 .36041E 00     .80859E-02     -.38323E-04     -.34450E-02
 .00000E 00     .00000E 00      .00000E 00      .00000E 00
-.20743E 00    -.82436E-01      .16555E 01     -.11828E 01
-.30079E-01    -.39079E-01      .10458E 01     -.29983E 00
 .00000E 00     .00000E 00      .00000E 00      .00000E 00
 .19422E 00     .36825E-01      .13847E 00      .86571E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L32

```
      F MATRIX IS
          U              W              Q           THETA             V              P              PHI            R

  -.66959E-02     .14155E-01     .74021E 00    -.32176E 02     .66821E-03    -.89745E 00     .16970E-01     .11408E 01
  -.10566E-01    -.13207E 01     .10896E 03    -.12529E 01    -.24795E-01    -.29244E 01    -.31133E 00    -.45943E-01
  -.42300E-03     .12556E-04    -.10178E 01     .00000E 00     .22971E-04     .14365E 00     .24644E-03     .57926E-02
   .00000E 00     .00000E 00     .10000E 01     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00
  -.18384E-01    -.38081E-02    -.76098E 00     .00000E 00    -.11060E 00    -.11842E 02     .22269E 02    -.97522E 02
  -.45585E-02    -.40274E-02    -.61997E 00     .00000E 00    -.21079E-01    -.10041E 02    -.62586E 01     .51034E 00
   .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .10000E 01     .00000E 00     .38939E-01
   .13107E-01    -.48534E-02    -.38951E 00     .00000E 00     .47335E-01    -.15047E 01    -.82866E 00    -.35350E 01
       G MATRIX IS
      DELTA E        DELTA C           DELTA A        DELTA P

  -.19116E 01     .52988E 00    -.28399E-02     .29578E-01
  -.54653E 01    -.97768E 01     .52042E-01    -.23584E-02
   .36040E 00     .80740E-02    -.41028E-04    -.34468E-02
   .00000E 00     .00000E 00     .00000E 00     .00000E 00
  -.20738E 00    -.82423E-01     .16555E 01    -.11828E 01
  -.30050E-01    -.39070E-01     .10458E 01    -.29983E 00
   .00000E 00     .00000E 00     .00000E 00     .00000E 00
   .19421E 00     .36827E-01     .13848E 00     .86572E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L33S

```
     F MATRIX IS

     U              W                Q                THETA            V                P                PHI              R

 -.66440E-01     .14559E 00      .73053E 00     -.31751E 02      .66230E-03     -.88561E 00      .16723E-01      .11256E 01
 -.18083E 00    -.94596E 00      .10893E 03     -.38217E-01     -.24883E-01     -.28904E 01     -.31179E 00     -.88824E-01
  .10823E-01    -.24730E-01     -.10159E 01     -.80104E-01      .24687E-04      .14144E 00      .29070E-03      .86443E-02
  .00000E 00     .00000E 00      .10000E 01      .00000E 00      .00000E 00      .00000E 00      .00000E 00      .00000E 00
 -.22137E-01     .44370E-02     -.76201E 00      .46096E-01     -.11060E 00     -.11841E 02      .22269E 02     -.97524E 02
 -.80247E-02     .35939E-02     -.62008E 00      .66803E-02     -.21079E-01     -.10041E 02     -.62585E 01      .51010E 00
  .00000E 00     .00000E 00      .00000E 00      .00000E 00      .00000E 00      .10000E 01      .00000E 00      .38939E-01
  .10240E-01     .14566E-02     -.38847E 00     -.43167E-01      .47335E-01     -.15059E 01     -.82863E 00     -.35334E 01

      G MATRIX IS

   DELTA E        DELTA C            DELTA A          DELTA P

 -.18865E 01     .52284E 00     -.27830E-02      .29149E-01
 -.53930E 01    -.97970E 01      .52148E-01     -.33163E-02
  .35565E 00     .94014E-02     -.49853E-04     -.33715E-02
  .00000E 00     .00000E 00      .00000E 00      .00000E 00
 -.20466E 00    -.83218E-01      .16555E 01     -.11829E 01
 -.29660E-01    -.39204E-01      .10458E 01     -.29983E 00
  .00000E 00     .00000E 00      .00000E 00      .00000E 00
  .19166E 00     .37534E-01      .13847E 00      .86575E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L33U

```
     F MATRIX IS

     U              W                 Q                THETA              V                 P                 PHI              R

-.71716E-01     .15716E 00       .78854E 00      -.34272E 02      .71489E-03      -.95594E 00      .18051E-01      .12150E 01
-.19592E 00    -.91290E 00       .10910E 03      -.72466E 01     -.24732E-01      -.30914E 01     -.30799E 00      .16672E 00
 .11818E-01    -.26910E-01      -.10269E 01       .39527E 00      .14771E-04       .15470E 00      .40316E-04     -.82082E-02
 .00000E 00     .00000E 00       .10000E 01       .00000E 00      .00000E 00       .00000E 00      .00000E 00      .00000E 00
-.22709E-01     .56914E-02      -.75571E 00      -.22746E 00     -.11060E 00      -.11849E 02      .22269E 02     -.97514E 02
-.81076E-02     .37757E-02      -.61917E 00      -.32964E-01     -.21078E-01      -.10042E 02     -.62585E 01      .51150E 00
 .00000E 00     .00000E 00       .00000E 00       .00000E 00      .00000E 00       .10000E 01      .00000E 00      .38939E-01
 .10777E-01     .28188E-03      -.39436E 00       .21301E 00      .47330E-01      -.14987E 01     -.82876E 00     -.35425E 01
      G MATRIX IS

   DELTA E        DELTA C           DELTA A          DELTA P

-.20363E 01     .56436E 00      -.30040E-02       .31464E-01
-.58213E 01    -.96783E 01       .51517E-01       .33014E-02
 .38390E 00     .15735E-02      -.81856E-05      -.38079E-02
 .00000E 00     .00000E 00       .00000E 00       .00000E 00
-.22092E 00    -.78713E-01       .16555E 01      -.11826E 01
-.32016E-01    -.38552E-01       .10458E 01      -.29979E 00
 .00000E 00     .00000E 00       .00000E 00       .00000E 00
 .20688E 00     .33316E-01       .13849E 00       .86552E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L34S

```
 F MATRIX IS

     U            W             Q            THETA          V             P             PHI          R

-.38166E-01   .14464E 00    .72571E 00   -.31542E 02    .65217E-03   -.87979E 00    .16647E-01    .11182E 01
-.10027E 00  -.94869E 00    .10892E 03    .55722E 00   -.24911E-01   -.28738E 01   -.31229E 00   -.10993E 00
 .55010E-02  -.24550E-01   -.10150E 01   -.11937E 00    .26521E-04    .14034E 00    .30763E-03    .10037E-01
 .00000E 00   .00000E 00    .10000E 01    .00000E 00    .00000E 00    .00000E 00    .00000E 00    .00000E 00
-.20350E-01   .43327E-02   -.76251E 00    .68679E-01   -.11060E 00   -.11840E 02    .22269E 02   -.97525E 02
-.63974E-02   .35786E-02   -.62015E 00    .99506E-02   -.21077E-01   -.10041E 02   -.62585E 01    .50999E 00
 .00000E 00   .00000E 00    .00000E 00    .00000E 00    .00000E 00    .10000E 01    .00000E 00    .38939E-01
 .11555E-01   .15540E-02   -.38798E 00   -.64321E-01    .47337E-01   -.15064E 01   -.82861E 00   -.35327E 01
  G MATRIX IS

  DELTA E      DELTA C       DELTA A      DELTA P

-.18741E 01   .51937E 00   -.27744E-02    .28958E-01
-.53578E 01  -.98068E 01    .52201E-01   -.38629E-02
 .35332E 00   .10054E-01   -.51527E-04   -.33357E-02
 .00000E 00   .00000E 00    .00000E 00    .00000E 00
-.20329E 00  -.83555E-01    .16555E 01   -.11829E 01
-.29453E-01  -.39231E-01    .10458E 01   -.29984E 00
 .00000E 00   .00000E 00    .00000E 00    .00000E 00
 .19039E 00   .37899E-01    .13846E 00    .86578E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L34U

```
F MATRIX IS

   U             W              Q              THETA           V              P              PHI            R

-.40969E-01    .15526E 00    .77900E 00   -.33859E 02    .70006E-03   -.94439E 00    .17869E-01    .12003E 01
-.10829E 00   -.91832E 00    .10907E 03   -.60641E 01   -.24774E-01   -.30584E 01   -.30879E 00    .12480E 00
 .60294E-02   -.26553E-01   -.10251E 01    .31728E 00    .17493E-04    .15252E 00    .77185E-04   -.54426E-02
 .00000E 00    .00000E 00    .10000E 01    .00000E 00    .00000E 00    .00000E 00    .00000E 00    .00000E 00
-.20654E-01    .54847E-02   -.75673E 00   -.18255E 00   -.11060E 00   -.11847E 02    .22269E 02   -.97516E 02
-.64414E-02    .37456E-02   -.61931E 00   -.26449E-01   -.21077E-01   -.10042E 02   -.62585E 01    .51128E 00
 .00000E 00    .00000E 00    .00000E 00    .00000E 00    .00000E 00    .10000E 01    .00000E 00    .38939E-01
 .11840E-01    .47504E-03   -.39339E 00    .17097E 00    .47332E-01   -.14999E 01   -.82873E 00   -.35410E 01

  G MATRIX IS

 DELTA E       DELTA C          DELTA A        DELTA P

-.20117E 01    .55750E 00   -.29781E-02    .31084E-01
-.57512E 01   -.96977E 01    .51619E-01    .22158E-02
 .37927E 00    .28642E-02   -.13121E-04   -.37365E-02
 .00000E 00    .00000E 00    .00000E 00    .00000E 00
-.21821E 00   -.79419E-01    .16555E 01   -.11827E 01
-.31616E-01   -.38632E-01    .10458E 01   -.29980E 00
 .00000E 00    .00000E 00    .00000E 00    .00000E 00
 .20437E 00    .34025E-01    .13848E 00    .86557E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L35

```
     F MATRIX IS

       U              W              Q            THETA            V              P             PHI             R

 -.10547E-01     .14755E 00     .74027E 00   -.32176E 02     .66920E-03   -.89746E 00     .17015E-01     .11407E 01
 -.21524E-01    -.94039E 00     .10896E 03   -.12529E 01    -.24873E-01   -.29246E 01    -.31133E 00    -.45583E-01
  .30176E-03    -.25098E-01    -.10178E 01    .00000E 00     .23242E-04    .14367E 00     .23843E-03     .57942E-02
  .00000E 00     .00000E 00     .10000E 01    .00000E 00     .00000E 00    .00000E 00     .00000E 00     .00000E 00
 -.18632E-01     .46481E-02    -.76096E 00    .00000E 00    -.11060E 00   -.11842E 02     .22269E 02    -.97522E 02
 -.47795E-02     .36250E-02    -.61994E 00    .00000E 00    -.21078E-01   -.10041E 02    -.62585E 01     .51033E 00
  .00000E 00     .00000E 00     .00000E 00    .00000E 00     .00000E 00    .10000E 01     .00000E 00     .38939E-01
  .12934E-01     .12600E-02    -.38947E 00    .00000E 00     .47335E-01   -.15047E 01    -.82866E 00    -.35350E 01

      G MATRIX IS

    DELTA E        DELTA C        DELTA A       DELTA P

 -.19117E 01     .52982E 00    -.28301E-02    .29529E-01
 -.54653E 01    -.97771E 01     .51885E-01   -.22012E-02
  .36041E 00     .80853E-02    -.40127E-04   -.34450E-02
  .00000E 00     .00000E 00     .00000E 00    .00000E 00
 -.20742E 00    -.82436E-01     .16555E 01   -.11828E 01
 -.30065E-01    -.39076E-01     .10458E 01   -.29982E 00
  .00000E 00     .00000E 00     .00000E 00    .00000E 00
  .19423E 00     .36834E-01     .13847E 00    .86571E 00
```

TABLE 12.- CONTINUED

CONFIGURATION L36

```
     F MATRIX IS

     U              W               Q              THETA            V              P              PHI             R


-.10061E-01     .14755E 00     .74020E 00    -.32176E 02     .66821E-03    -.89750E 00     .16970E-01     .11408E 01
-.20219E-01    -.94042E 00     .10896E 03    -.12529E 01    -.24795E-01    -.29236E 01    -.31133E 00    -.45943E-01
 .21080E-03    -.25099E-01    -.10178E 01     .00000E 00     .22971E-04     .14365E 00     .24644E-03     .57934E-02
 .00000E 00     .00000E 00     .10000E 01     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00
-.18594E-01     .46503E-02    -.76096E 00     .00000E 00    -.11060E 00    -.11842E 02     .22269E 02    -.97522E 02
-.47494E-02     .36264E-02    -.61995E 00     .00000E 00    -.21079E-01    -.10041E 02    -.62585E 01     .51033E 00
 .00000E 00     .00000E 00     .00000E 00     .00000E 00     .00000E 00     .10000E 01     .00000E 00     .38939E-01
 .12953E-01     .12601E-02    -.38949E 00     .00000E 00     .47334E-01    -.15047E 01    -.82866E 00    -.35350E 01
      G MATRIX IS

    DELTA E        DELTA C          DELTA A        DELTA P


-.19116E 01     .52988E 00    -.28399E-02     .29578E-01
-.54652E 01    -.97768E 01     .52042E-01    -.23584E-02
 .36040E 00     .80738E-02    -.41705E-04    -.34468E-02
 .00000E 00     .00000E 00     .00000E 00     .00000E 00
-.20740E 00    -.82429E-01     .16555E 01    -.11828E 01
-.30055E-01    -.39070E-01     .10458E 01    -.29983E 00
 .00000E 00     .00000E 00     .00000E 00     .00000E 00
 .19422E 00     .36839E-01     .13847E 00     .86572E 00
```

TABLE 12.- CONCLUDED

CONFIGURATION L37

```
      F MATRIX IS

        U              W                Q             THETA             V                P                PHI              R

-.28645E-02     .14754E 00      .74026E 00     -.32176E 02      .66526E-03     -.89744E 00      .16947E-01      .11408E 01
 .31445E-03    -.94040E 00      .10896E 03     -.12529E 01     -.24795E-01     -.29237E 01     -.31133E 00     -.46844E-01
-.11439E-02    -.25097E-01     -.10178E 01      .00000E 00      .23152E-04      .14366E 00      .24980E-03      .57968E-02
 .00000E 00     .00000E 00      .10000E 01      .00000E 00      .00000E 00      .00000E 00      .00000E 00      .00000E 00
-.18146E-01     .46507E-02     -.76092E 00      .00000E 00     -.11060E 00     -.11842E 02      .22269E 02     -.97522E 02
-.43397E-02     .36260E-02     -.61991E 00      .00000E 00     -.21079E-01     -.10041E 02     -.62585E 01      .51032E 00
 .00900E 00     .00000E 00      .00000E 00      .00000E 00      .00000E 00      .10000E 01      .00000E 00      .38939E-01
 .13286E-01     .12588E-02     -.38946E 00      .00000E 00      .47333E-01     -.15047E 01     -.82866E 00     -.35350E 01

       G MATRIX IS

     DELTA E        DELTA C          DELTA A         DELTA P

-.19116E 01     .52981E 00     -.28301E-02      .29529E-01
-.54653E 01    -.97771E 01      .51885E-01     -.22012E-02
 .36040E 00     .80866E-02     -.40577E-04     -.34452E-02
 .00000E 00     .00000E 00      .00000E 00      .00000E 00
-.20740E 00    -.82400E-01      .16555E 01     -.11828E 01
-.30061E-01    -.39049E-01      .10458E 01     -.29983E 00
 .00000E 00     .00000E 00      .00000E 00      .00000E 00
 .19421E 00     .36847E-01      .13848E 00      .86572E 00
```

TABLE 13.- LONGITUDINAL EIGENVALUES AND TRANSFER FUNCTION NUMERATORS

	L01S	L03
$\Delta(S)$	(2.93)(1.34)(0.10;0.34)	(3.00)(1.34)(0.16;0.056)
$N^{u}_{\delta ES}$	-1.8(0.15;2.46)(1.41)	-1.9(0.15;2.46)(1.41)
$N^{w}_{\delta ES}$	-5.2(-6.17)(0;0.06)	-5.4(-6.17)(0.036;0.039)
$N^{\theta}_{\delta ES}$	0.34(1.32)(0.009)	0.36(1.32)(0.0085)
$N^{u}_{\delta C}$	0.5(3.24)(1.15)(-0.17)	0.53(3.24)(1.15)(-0.17)
$N^{w}_{\delta C}$	-9.84(2.80)(0.07;0.35)	-9.78(2.90)(0.11;0.069)
$N^{\theta}_{\delta C}$	0.012(1.51)(0.50)	0.008(0.025)(1.52)
	L01U	L04
$\Delta(S)$	(3.24)(1.35)(-0.13;0.34)	(3.02)(1.34)(0.74)(-0.63)
$N^{u}_{\delta ES}$	-1.99(0.15;2.45)(1.41)	As per L03
$N^{w}_{\delta ES}$	-5.7(-6.17)(0.073;0.053)	
$N^{\theta}_{\delta ES}$	0.37(1.32)(0.045)	
$N^{u}_{\delta C}$	0.55(3.20)(1.13)(-0.17)	
$N^{w}_{\delta C}$	-9.84(3.26)(-0.16;0.34)	0.53(3.23)(1.14)(-0.17)
$N^{\theta}_{\delta C}$	0.012(0.61)(1.5)	0.008(1.53)(-0.017)
	L02S	L05
$\Delta(S)$	(2.96)(1.34)(0.10;0.24)	(3.01)(1.34)(0.13)(-0.11)
$N^{u}_{\delta ES}$	-1.86(0.15;2.46)(1.41)	As per L03
$N^{w}_{\delta ES}$	-5.3(-6.17)(0.0092;0.052)	
$N^{\theta}_{\delta ES}$	0.35(1.32)(0.0087)	
$N^{u}_{\delta C}$	0.52(3.24)(1.15)(-0.17)	
$N^{w}_{\delta C}$	-9.84(2.84)(0.077;0.25)	0.53(3.23)(1.14)(-0.17)
$N^{\theta}_{\delta C}$	0.012(1.50)(0.26)	0.008(1.51)(-0.072)
	L02U	L06S
$\Delta(S)$	(3.26)(1.35)(-0.21;0.24)	(0.79;2.50)(0.10;0.27)
$N^{u}_{\delta ES}$	-2.01(0.15;2.46)(1.41)	-1.86(0.15;2.43)(1.32)
$N^{w}_{\delta ES}$	-0.58(-6.17)(0.016;0.050)	-5.3(-6.17)(-0.029;0.075)
$N^{\theta}_{\delta ES}$	0.38(1.32)(0.0088)	0.35(1.31)(0.0099)
$N^{u}_{\delta C}$	0.56(3.24)(1.15)(-0.17)	0.52(-1.71)(0.54;2.99)
$N^{w}_{\delta C}$	-9.7(3.26)(-0.26;0.24)	-9.82(2.89(0.03;0.34)
$N^{\theta}_{\delta C}$	0.029(0.55)(4.77)	0.011(23.11)(0.035)

TABLE 13.- CONTINUED

	L06U	L09
$\Delta(S)$	(0.83;2.60)(-0.17;0.28)	(0.79;2.52)(0.066)(-0.063)
$N^{u}_{\delta ES}$	-2.1(0.15;2.43)(1.31)	As per L08
$N^{w}_{\delta ES}$	-6.0(-6.17)(0.34;0.012)	
$N^{\theta}_{\delta ES}$	0.40(1.30)(0.0082)	
$N^{u}_{\delta C}$	0.58(-1.71)(0.54;2.99)	
$N^{w}_{\delta C}$	-9.63(3.55)(-0.29;0.33)	-9.78(2.92)(0.098)(-0.086)
$N^{\theta}_{\delta C}$	-0.0015(-173.0)(0.038)	0.008(30.3)(0.0076)

	L07S	L10
$\Delta(S)$	(0.79;2.51)(0.11;0.20)	(0.79;2.52)(0.10)(-0.10)
$N^{u}_{\delta ES}$	-1.87(0.15;2.43)(1.31)	As per L08
$N^{w}_{\delta ES}$	-5.3(-6.17)(0.017;0.050)	
$N^{\theta}_{\delta ES}$	0.35(1.30)(0.0088)	
$N^{u}_{\delta C}$	0.52(-1.71)(0.54;2.99)	
$N^{w}_{\delta C}$	-9.81(2.86)(0.06;0.25)	-9.78(2.92)(0.15)(-0.13)
$N^{\theta}_{\delta C}$	0.01(23.76)(0.023)	0.008(30.3)(0.0053)

	L07U	L11
$\Delta(S)$	(0.82;2.60)(-0.24;0.20)	(1.97)(1.50)(0.22)(0.72)
$N^{u}_{\delta ES}$	-2.1(0.15;2.43)(1.31)	-1.91(0.15;2.43)(1.42)
$N^{w}_{\delta ES}$	-6.0(0.051;0.039)(6.17)	-5.5(-6.17)(0.018;0.076)
$N^{\theta}_{\delta ES}$	0.39(1.30)(0.0085)	0.36(1.33)(0.0098)
$N^{u}_{\delta C}$	0.58(-1.71)(0.54;2.99)	0.53(2.05)(1.62)(0.63)
$N^{w}_{\delta C}$	-9.64(3.47)(-0.36;0.24)	-9.78(1.96)(0.22)(0.76)
$N^{\theta}_{\delta C}$	-0.077(236.0)(0.024)	0.008(1.89)(0.56)

	L08	L12
$\Delta(S)$	(0.79;2.52)(0.15;0.057)	(1.83)(1.55)(0.84)(0.10)
$N^{u}_{\delta ES}$	-1.9(0.15;2.43)(1.31)	As per L11
$N^{w}_{\delta ES}$	-5.4(-6.17)(0.066;0.031)	
$N^{\theta}_{\delta ES}$	0.36(1.30)(0.0083)	
$N^{u}_{\delta C}$	0.52(-1.71)(0.54;2.99)	
$N^{w}_{\delta C}$	-9.79(2.88)(0.18;0.070)	-9.78(1.74)(1.13)(0.11)
$N^{\theta}_{\delta C}$	0.009(27.0)(0.010)	0.008(1.70)(0.35)

TABLE 13.- CONTINUED

	L13	L17
Δ(S)	(1.64)(1.64)(1.06)(0.013)	(3.02)(0.97;0.056)(1.34)
$N^{u}_{\delta ES}$	As per L11	As per L16
$N^{w}_{\delta ES}$		
$N^{\theta}_{\delta ES}$		
$N^{u}_{\delta C}$		
$N^{w}_{\delta C}$	-9.78(1.48)(1.48)(0.015)	-9.78(2.93)(0.87;0.061)
$N^{\theta}_{\delta C}$	0.008(1.55)(0.026)	0.008(1.55)(0.13)
	L14	**L18**
Δ(S)	(1.64)(1.64)(1.08)(0.0028)	(3.01)(0.19)(1.34)(-0.075)
$N^{u}_{\delta ES}$	As per L11	As per L16
$N^{w}_{\delta ES}$		
$N^{\theta}_{\delta ES}$		
$N^{u}_{\delta C}$		
$N^{w}_{\delta C}$	-9.78 (1.50)(1.50)(0.0059)	-9.78(2.91)(0.19)(-0.074)
$N^{\theta}_{\delta C}$	0.008(1.53)(-0.017)	0.008(1.51)(0.031)
	L15	**L19**
Δ(S)	(1.63)(1.63)(1.12)(-0.015)	(3.01)(1.34)(0.17)(-0.062)
$N^{u}_{\delta ES}$	As per L11	As per L16
$N^{w}_{\delta ES}$		
$N^{\theta}_{\delta ES}$		
$N^{u}_{\delta C}$		
$N^{w}_{\delta C}$	-9.78(1.52)(1.52)(-0.011)	-9.78(2.92)(0.18)(-0.061)
$N^{\theta}_{\delta C}$	0.008(1.50)(-0.094)	0.008(1.52)(0.051)
	L16	**L20**
Δ(S)	(3.06)(0.19;0.24)(1.34)	(0.79;2.53)(0.29;0.20)
$N^{u}_{\delta ES}$	-1.91(0.15;2.46)(1.41)	-1.91(1.31)(0.15;2.43)
$N^{w}_{\delta ES}$	-5.47(-6.17)(0.082)(0.019)	-5.47(-6.17(0.11)(-0.0043)
$N^{\theta}_{\delta ES}$	0.36(1.32)(0.11)	0.36(1.30)(0.11)
$N^{u}_{\delta C}$	0.53(3.24)(1.15)(-0.17)	0.53(-1.71)(0.54;2.99)
$N^{w}_{\delta C}$	-9.78(2.99)(0.17;0.25)	-9.78(2.99)(0.16;0.25)
$N^{\theta}_{\delta C}$	0.008(1.71)(0.49)	0.008(30.77)(0.12)

TABLE 13.- CONTINUED

	L21	L26
$\Delta(S)$	(0.79;2.53)(0.053)(0.053)	(1.63)(1.63)(1.12)(0.082)
$N^{u}_{\delta ES}$	As per L20	As per L16
$N^{w}_{\delta ES}$		
$N^{\theta}_{\delta ES}$		
$N^{u}_{\delta C}$		
$N^{w}_{\delta C}$	-9.78(2.93)(0.79;0.66)	-9.78(1.50)(1.50)(0.082)
$N^{\theta}_{\delta C}$	0.008(30.4)(0.11)	0.008(1.50)(0.0087)

	L22	L28S
$\Delta(S)$	(0.79;2.53)(0.17)(-0.064)	(1.30)(1.03(0.10;0.59)
$N^{u}_{\delta ES}$	As per L20	-1.78(0.18;2.46)(1.40)
$N^{w}_{\delta ES}$		-5.1(-6.17)(0.003;0.060)
$N^{\theta}_{\delta ES}$		0.34(1.32(0.009)
$N^{u}_{\delta C}$		0.49(3.94)(0.95;1.32)
$N^{w}_{\delta C}$	-9.78(2.91)(0.20)(-0.088)	-9.88(0.032;0.61)(0.88)
$N^{\theta}_{\delta C}$	0.008(30.3)(0.11)	0.015(1.39)(0.36)

	L24	L28U
$\Delta(S)$	(1.84)(1.53)(0.22)(0.79)	(1.27)(1.27)(-0.086;0.54)
$N^{u}_{\delta ES}$	As per L16	-1.87(0.18;2.46)(1.41)
$N^{w}_{\delta ES}$		-5.3(-6.17)(-0.018;0.069)
$N^{\theta}_{\delta ES}$		0.35(1.32)(0.0096)
$N^{u}_{\delta C}$	0.53(2.04)(1.64)(0.63)	0.52(0.39)(0.95;1.31)
$N^{w}_{\delta C}$	-9.78(1.78)(1.02)(0.22)	-9.81(1.15)(-0.14;0.55)
$N^{\theta}_{\delta C}$	0.008(1.71)(0.49)	0.01(1.64)(0.53)

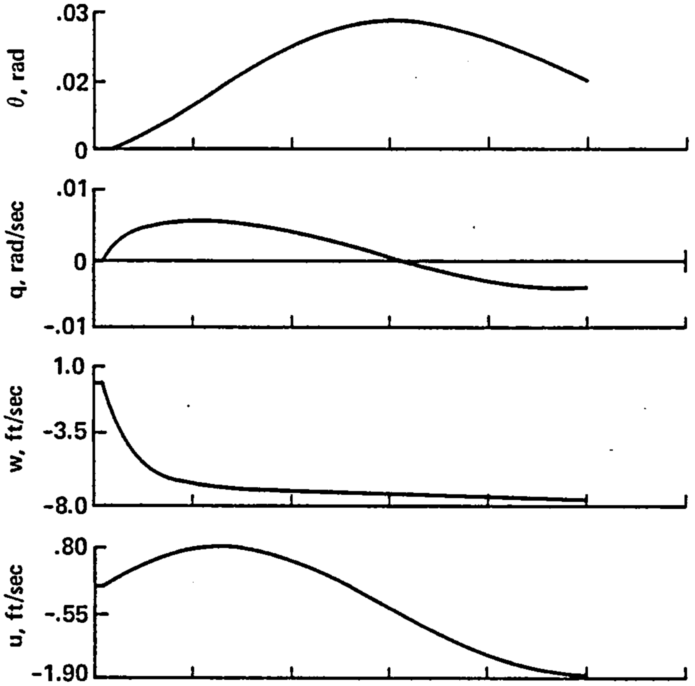
	L25	L29S
$\Delta(S)$	(1.64)(1.64)(1.06)(0.11)	(1.27)(1.07)(0.096;0.42)
$N^{u}_{\delta ES}$	As per L24	-1.84(0.18;2.46)(1.40)
$N^{w}_{\delta ES}$		-5.3(-6.17)(0.023;0.048)
$N^{\theta}_{\delta ES}$		0.35(1.32)(0.0088)
$N^{u}_{\delta C}$		0.51(0.39)(0.95;1.32)
$N^{w}_{\delta C}$	-9.78(0.99;1.47)(0.12)	-9.84(0.037;0.44)(0.88)
$N^{\theta}_{\delta C}$	0.008(1.55)(0.13)	0.012(1.44)(0.23)

TABLE 13.- CONTINUED

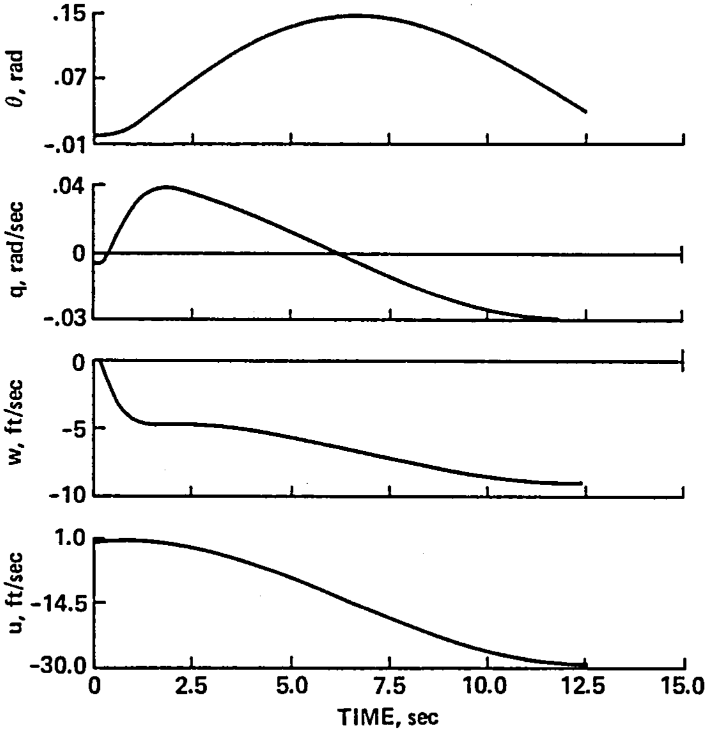
	L29U	L33S
Δ(S)	(1.26)(1.26)(-0.11;0.40)	(0.52;1.91)(0.098;0.36)
$N_{\delta ES}^{u}$	-1.90(1.41)(0.18;2.46)	-1.89(0.18;2.43)(1.32)
$N_{\delta ES}^{w}$	-5.4(-6.17)(-0.012;0.063)	-5.4(-6.17)(-0.0087;0.065)
$N_{\delta ES}^{\theta}$	0.36(1.32)(0.0093)	0.36(1.31)(0.0094)
$N_{\delta C}^{u}$	0.53(0.39)(0.95;1.32)	0.52(-2.57)(0.39;2.42)
$N_{\delta C}^{w}$	-9.78(1.12)(-0.16;0.41)	-9.80(1.19)(-0.17;0.54)
$N_{\delta C}^{\theta}$	0.0085(1.66)(0.33)	0.0094(26.5)(0.036)
	L30	L33U
Δ(S)	(1.21)(1.21)(0.11;0.095)	(0.55;1.93)(-0.14;0.40)
$N_{\delta ES}^{u}$	-1.91(0.17;2.46)(1.42)	-2.04(0.18;2.43)(1.32)
$N_{\delta ES}^{w}$	-5.5(-6.17)(0.023;0.043)	-5.8(-6.18)(-0.020;0.070)
$N_{\delta ES}^{\theta}$	0.36(1.33)(0.0087)	0.38(1.31)(0.0097)
$N_{\delta C}^{u}$	0.53(0.39)(0.95;1.31)	0.56(-2.57)(0.39;2.42)
$N_{\delta C}^{w}$	-9.78(0.97)(-0.058;0.12)	-9.68(1.55)(-0.43;0.50)
$N_{\delta C}^{\theta}$	0.0081(1.55)(0.026)	0.0016(166.0)(0.037)
	L31	L34S
Δ(S)	(0.079)(-0.064)(1.20)(1.20)	(0.51;1.91)(0.13;0.26)
$N_{\delta ES}^{u}$	As per L30	-1.87(0.18;2.43)(1.32)
$N_{\delta ES}^{w}$		-5.4(-6.18)(-0.018;0.065)
$N_{\delta ES}^{\theta}$		0.35(1.31)(0.0094)
$N_{\delta C}^{u}$		0.52(-2.57)(0.39;2.42)
$N_{\delta C}^{w}$	-9.78 (0.96)(0.057)(-0.050)	-9.81(1.04)(-0.064;0.42)
$N_{\delta C}^{\theta}$	0.0081(1.54)(-0.0005)	0.01(24.4)(0.023)
	L32	L34U
Δ(S)	(1.20(1.20)(0.13)(-0.11)	(0.54;1.94)(-0.17;0.27)
$N_{\delta ES}^{u}$	As per L30	-2.0(0.18;2.43)(1.32)
$N_{\delta ES}^{w}$		-5.8(6.17)(-0.018;0.065)
$N_{\delta ES}^{\theta}$		0.38(1.31)(0.0094)
$N_{\delta C}^{u}$		0.56(-2.57)(0.39;2.42)
$N_{\delta C}^{w}$	0.53(0.39)(0.95;1.32)	-9.70(1.40)(-0.44;0.37)
$N_{\delta C}^{\theta}$	0.0081(1.53(-0.017)	0.003(90.0)(0.024)

TABLE 13.- CONCLUDED

	L35	
$\Delta(S)$	(0.52;1.93)(0.13;0.075)	
$N^{u}_{\delta ES}$	-1.91(0.18;2.43)(1.32)	
$N^{w}_{\delta ES}$	-5.5(-6.17)(-0.014;0.059)	
$N^{\theta}_{\delta ES}$	0.36(1.31)(0.0091)	
$N^{u}_{\delta C}$	0.53(-2.57)(0.39;2.42)	
$N^{w}_{\delta C}$	-9.78(0.99)(0.0013;0.10)	
$N^{\theta}_{\delta C}$	0.0081(30.0)(0.010)	
	L36	
$\Delta(S)$	(0.52;1.93)(0.012;0.070)	
$N^{u}_{\delta ES}$	As per L35	
$N^{w}_{\delta ES}$		
$N^{\theta}_{\delta ES}$		
$N^{u}_{\delta C}$		
$N^{w}_{\delta C}$	-9.78(1.0)(0.045;0.077)	
$N^{\theta}_{\delta C}$	0.0081(30.0)(0.01)	
	L37	
$\Delta(S)$	(0.51;1.93)(0.10)(-0.11)	
$N^{u}_{\delta ES}$	As per L35	
$N^{w}_{\delta ES}$		
$N^{\theta}_{\delta ES}$		
$N^{u}_{\delta C}$		
$N^{w}_{\delta C}$	-9.78(9.17)(-0.17)	
$N^{\theta}_{\delta C}$	0.0081(30.0)(0.0068)	

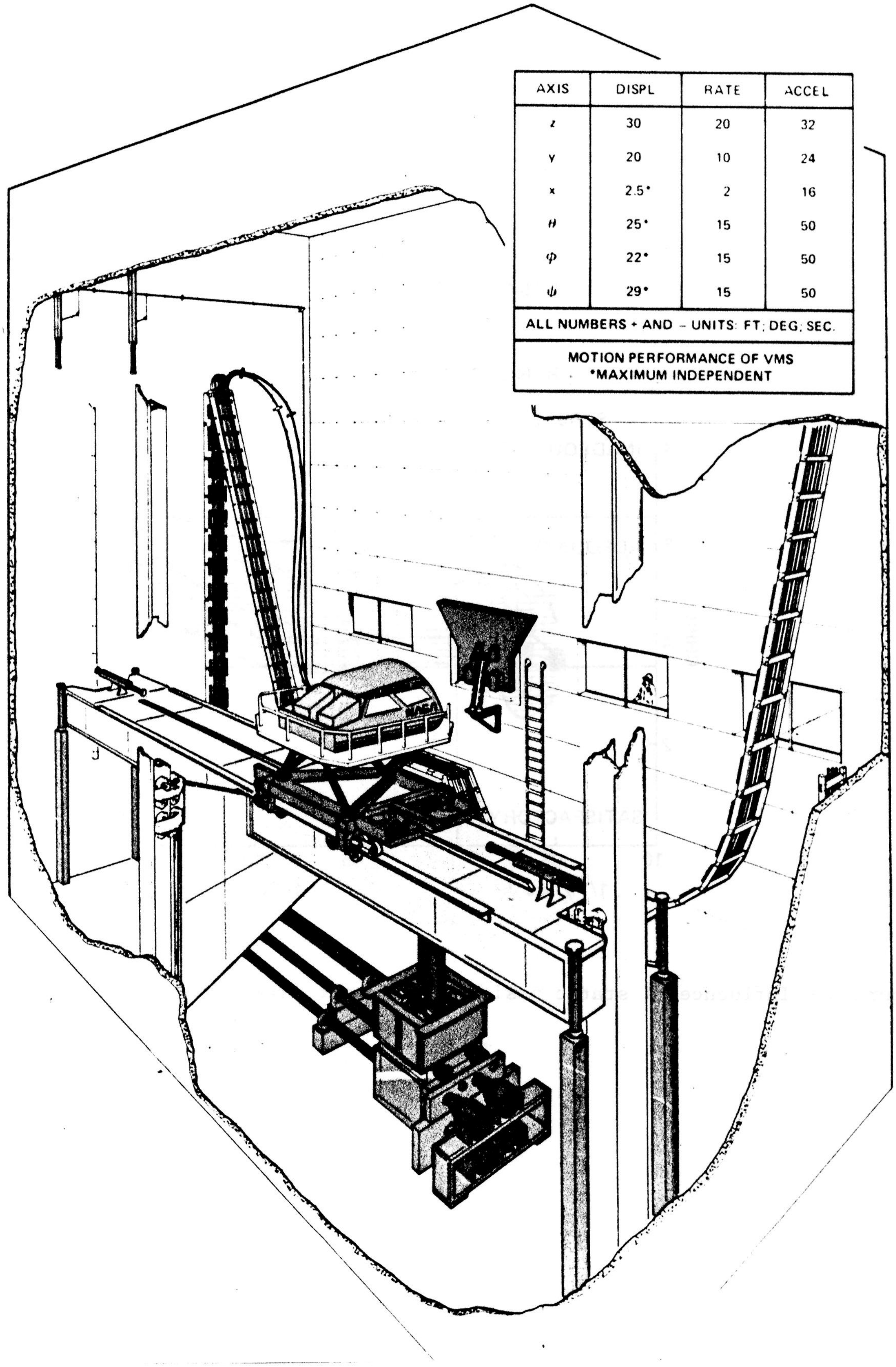


(a) $M_w = 0.$



(b) $M_w = -0.025$

Figure 1.- Stable-gradient responses to 1-in. collective step.



AXIS	DISPL	RATE	ACCEL
z	30	20	32
y	20	10	24
x	2.5*	2	16
θ	25*	15	50
φ	22*	15	50
ψ	29*	15	50

ALL NUMBERS + AND − UNITS: FT; DEG; SEC.

MOTION PERFORMANCE OF VMS
*MAXIMUM INDEPENDENT

Figure 2.- Motion Performance of VMS.

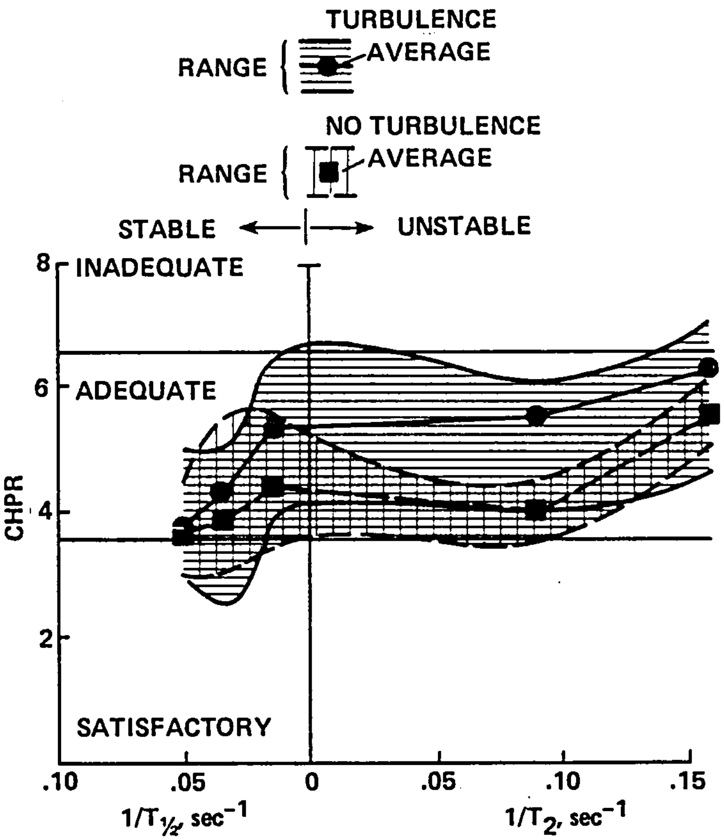
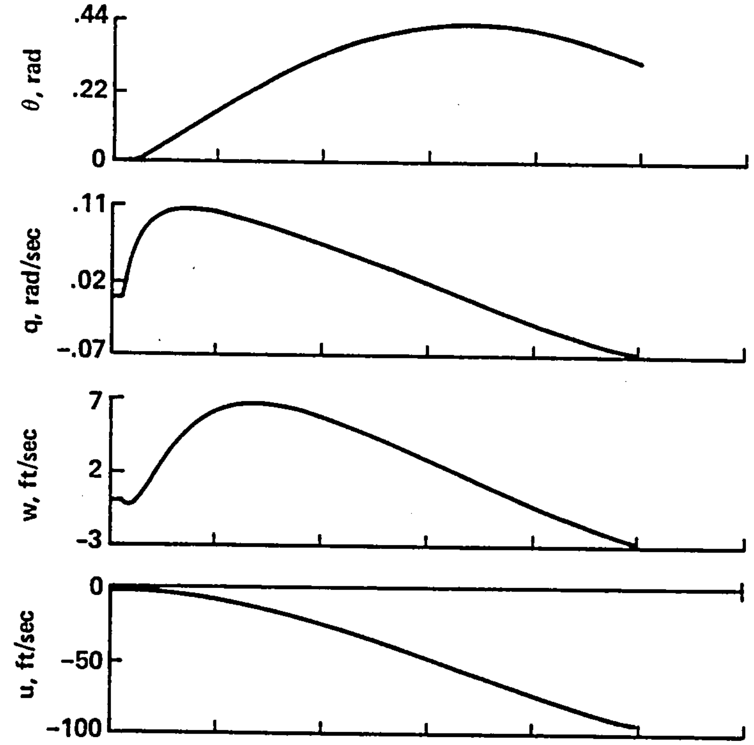
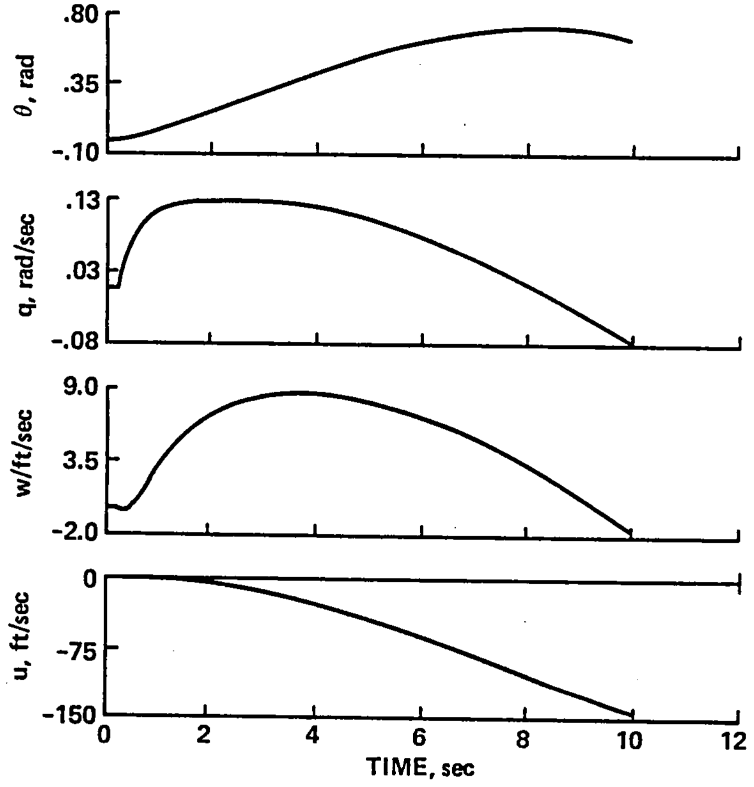


Figure 3.- Influence of static position gradient: high M_q, low drag damping, $M_w = 0$.

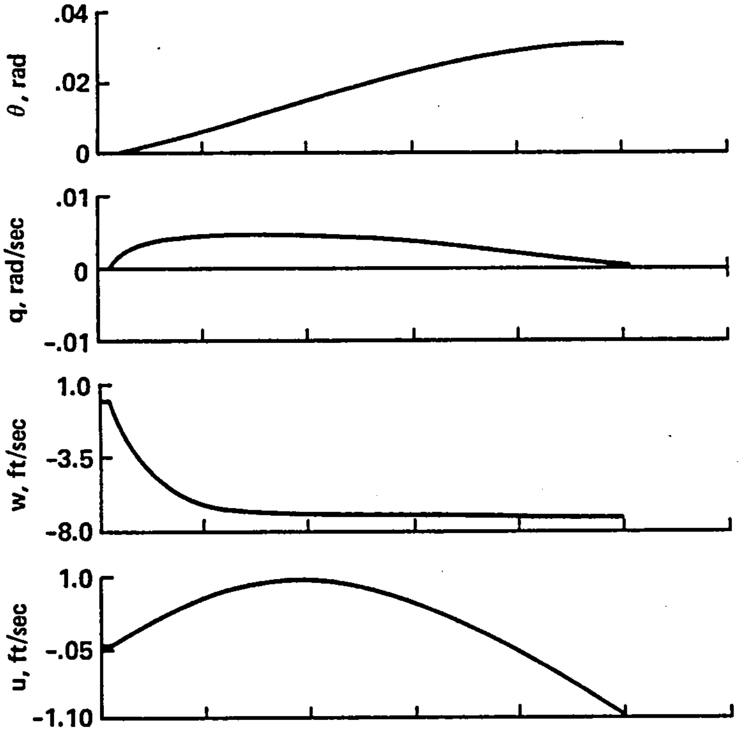


(a) STABLE PHUGOID

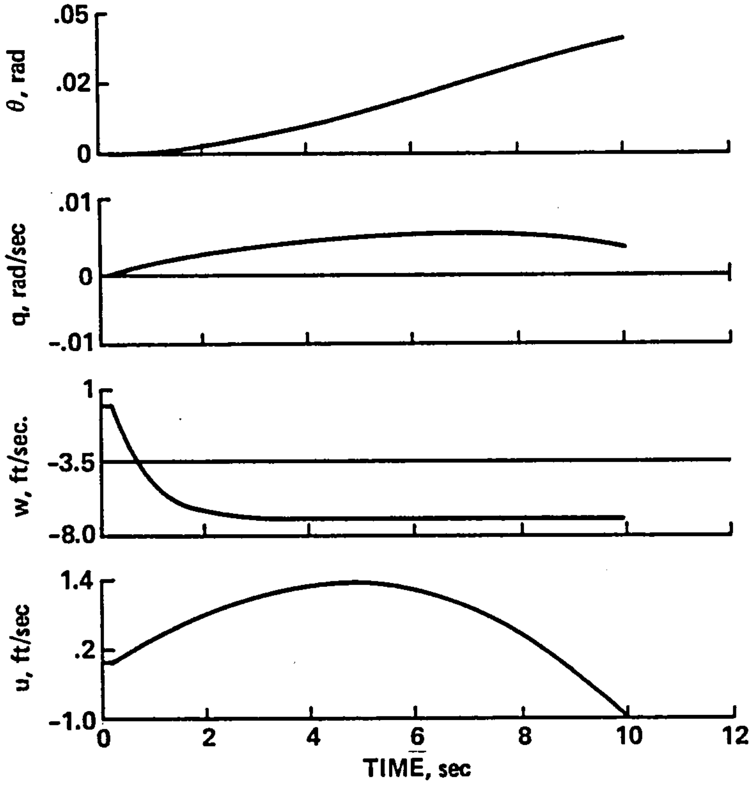


(b) UNSTABLE PHUGOID.

Figure 4.- Responses to longitudinal cyclic step, $M_w = 0$, configuration L02S.

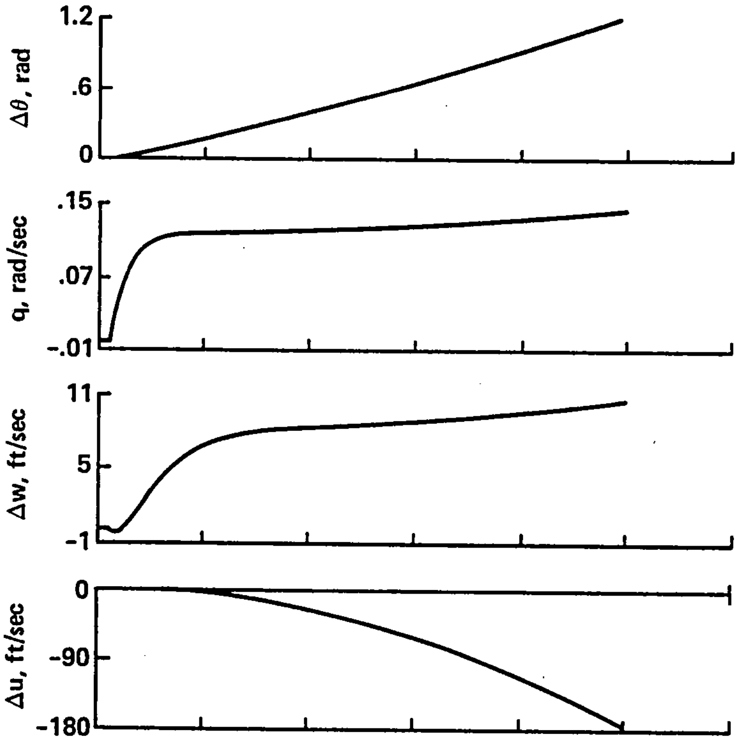


(a) STABLE PHUGOID.

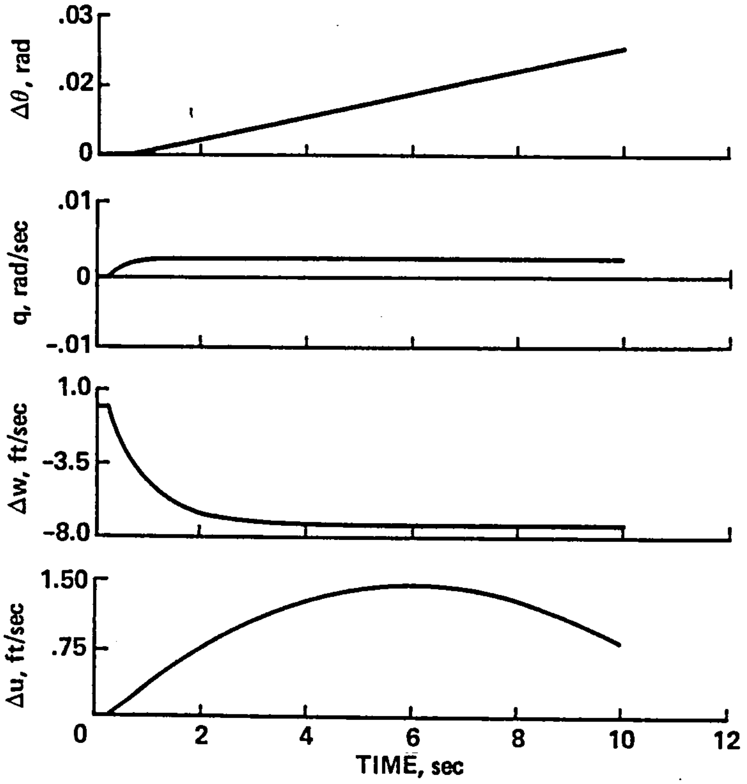


(b) UNSTABLE PHUGOID.

Figure 5.- Responses to collective step, M_w = 0, configuration L02S.



(a) LONGITUDINAL CYCLIC STEP.



(b) COLLECTIVE STEP.

Figure 6.- Responses to cyclic and collective steps, $M_w = 0$, unstable aperiodic: configuration L04.

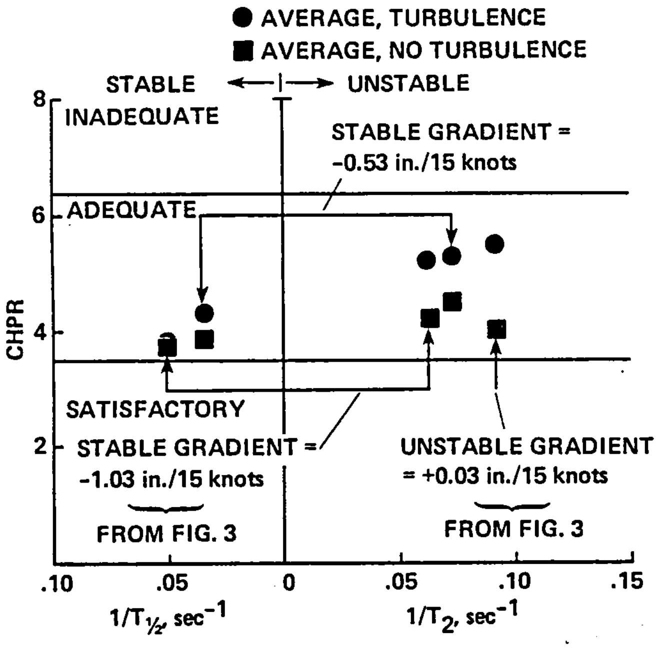


Figure 7.- Influence of long-term oscillation damping (high M_q, low drag damping, $M_w = 0$).

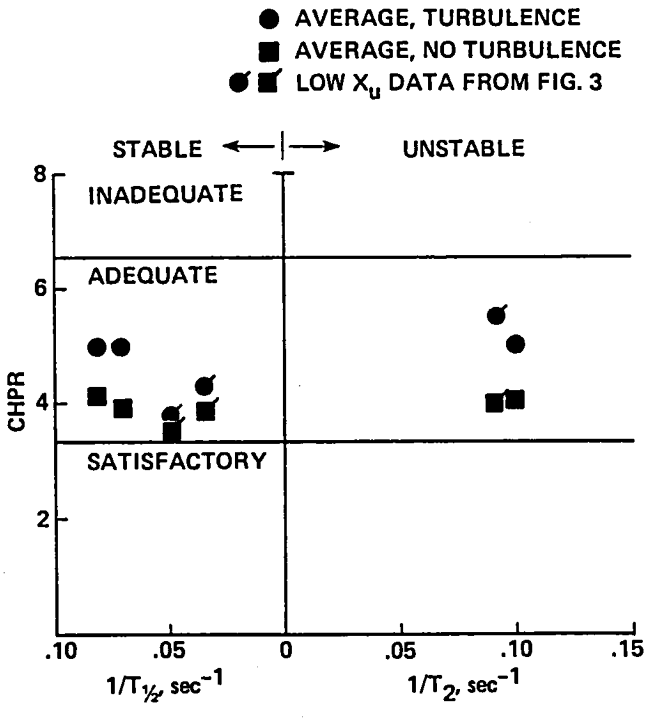


Figure 8.- Influence of high drag damping ($M_w = 0$, high M_q).

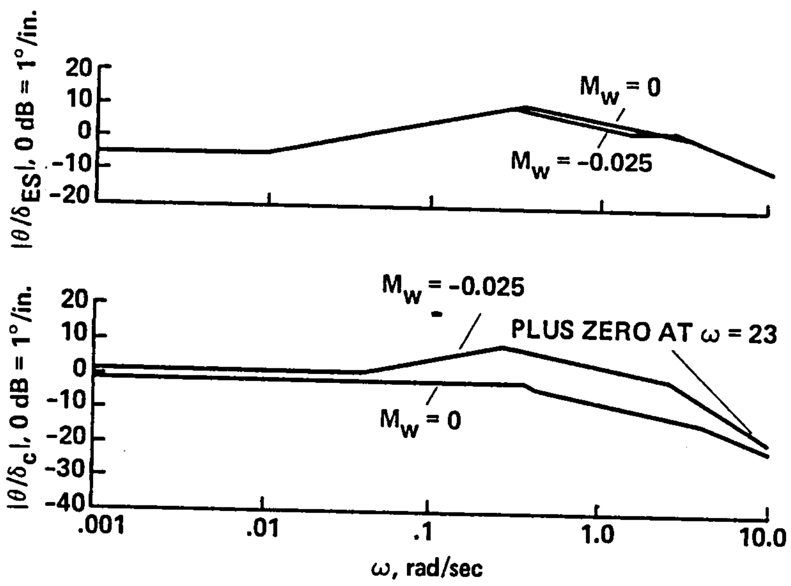


Figure 9.- Pitch attitude response to longitudinal cyclic and collective for $M_w = 0$ and $M_w = -0.025$.

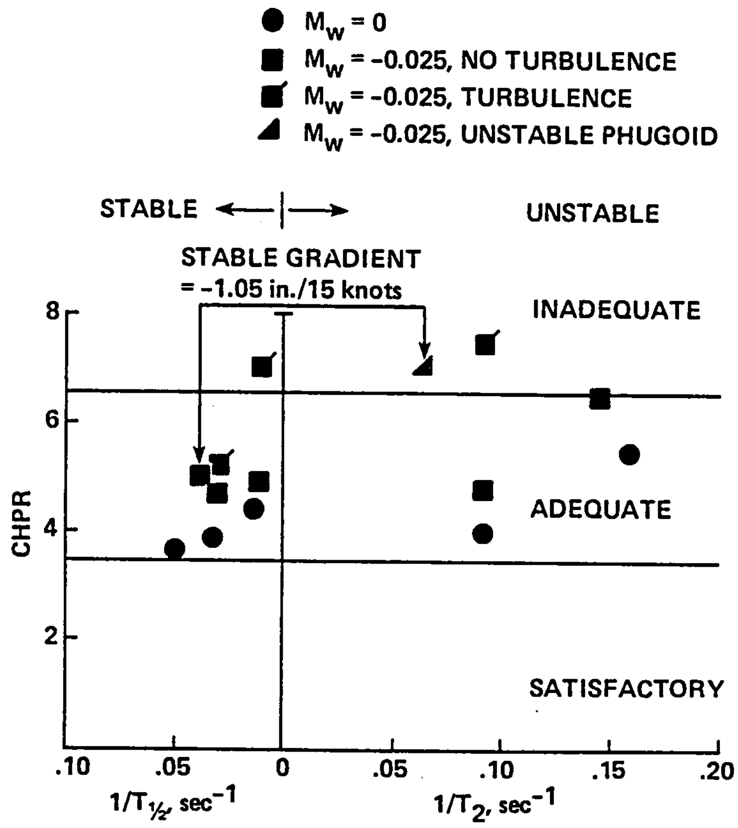


Figure 10.- Influence of $M_w = -0.025$ (low drag damping, high pitch-rate damping).

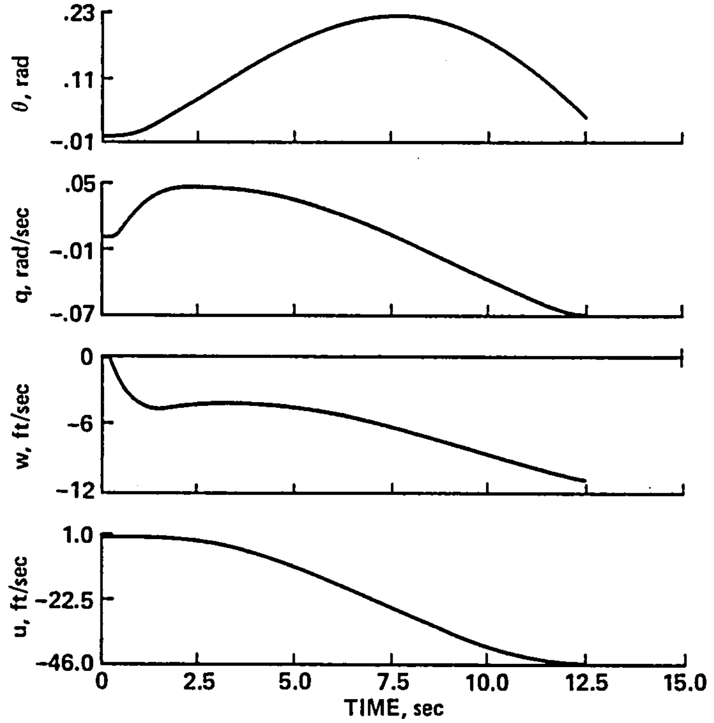


Figure 11.- Response to collective step, unstable phugoid, M_w = -0.025 (low drag damping, high pitch-rate damping).

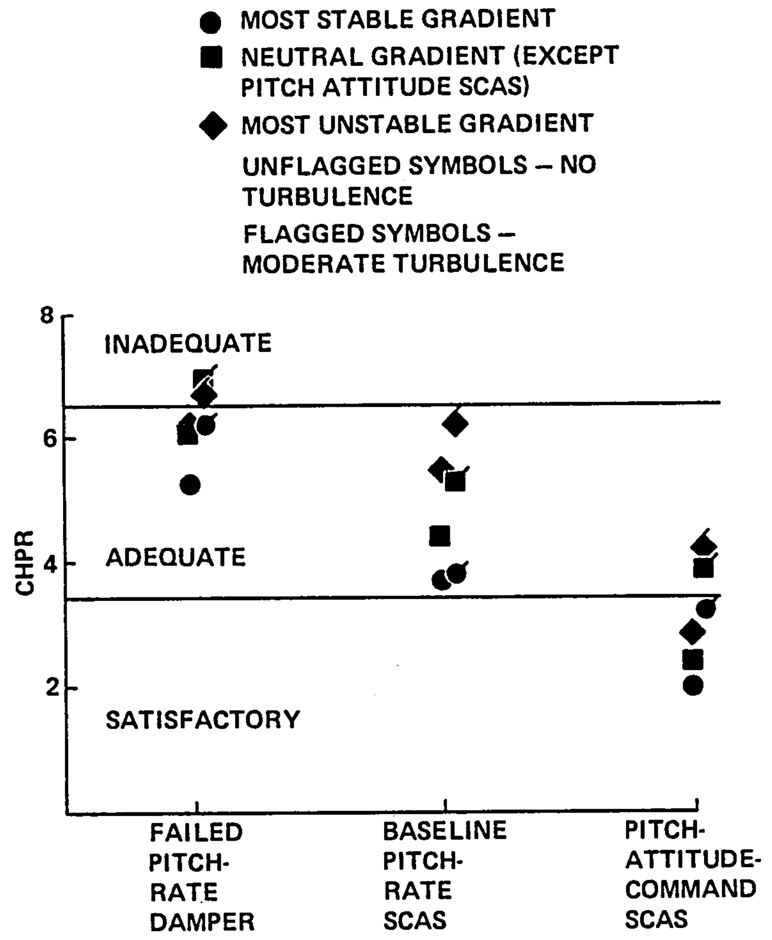


Figure 12.- Influence of SCAS.

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16. Abstract

A ground-simulation experiment was conducted to investigate the direct and interactive influences of several longitudinal static and dynamic stability parameters on helicopter flying qualities during terminal-area operations in instrument conditions. Variations that were examined included five levels of static control-position gradients ranging from stable to unstable; two levels of dynamic stability for the long-period oscillation; two levels of the steady-state pitch speed gradient; two levels of angle-of-attack stability and pitch-rate damping; and two levels of stability and control augmentation. These variations were examined initially in calm air and then in simulated light-to-moderate turbulence and wind shear. Five pilots performed a total of 223 evaluations of these parameters for a representative microwave landing system precision approach task conducted in a dual-pilot crew-loading situation. Pilot ratings indicated (1) that the system is clearly adequate for the IMC approach in calm air for neutral and slightly unstable static control-position gradients but that adding turbulence causes a significant degradation in system performance; (2) that high angle-of-attack stability has an adverse effect because of pitch-to-rate of descent coupling; and (3) that the steady-state pitch-speed gradient has a minimal influence.

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