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TECHNICAL NOTE

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EFFECTS OF CONTROL-FEEL CONFIGURATION ON AIRPLANE LONGITUDINAL CONTROL RESPONSE

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SUMMARY

A general study of longitudinal control feel was made with a transonic fighter-type airplane equipped with a control-feel system which was adjustable in flight. The control-feel system provided a feel component with individual gain control in proportion to each of five quantities: stick deflection, stick rate, airplane normal acceleration, pitching acceleration, and pitching velocity. A number of feel configurations were investigated in flight and analytically. These feel configurations had feel components in various amounts from various combinations of these five sources. The results contained herein are all for an airplane center-of-gravity position at approximately 25 percent of the mean aerodynamic chord, a Mach number of 0.85, and an altitude of 28,000 feet.

Results are presented as time histories, as plots of the variation of peak force per g with input duration, and as frequency-response plots. A number of frequency-response plots are included to illustrate the effects of choice of feel sources and gains. The results illustrate the desirability of balancing a normal-acceleration feel component with a pitching-acceleration feel component. Pitching-velocity feel is shown to be useful for shaping control-system frequency response. The results suggest the desirability of designing a control-feel system to a large extent by means of frequency-response analysis in order to keep the shapes of the frequency-response curves within desirable limits.

INTRODUCTION

With irreversible power-actuated control systems, the control feel becomes independent of the aerodynamic hinge-moment characteristics of the control surface. Therefore, the control-feel characteristics can be tailored to a large extent as desired. A number of investigations such as were reported in references 1 to 5 have been made to determine what constitutes desirable longitudinal control-feel characteristics.

This research project at the Langley Research Center of the National Aeronautics and Space Administration has been concerned with a more general investigation of longitudinal control-feel characteristics.

Reference 6 describes a variable longitudinal control-feel system which was installed in a fighter-type airplane at the Langley Research Center. With this system it was possible to have components of control feel proportional to normal acceleration, pitching acceleration, pitching velocity, stick position, and stick rate. Presented herein are the results of measurements of varied control-feel characteristics obtained with this variable control-feel system. Comparative analytical results are also presented.

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SYMBOLS

F	stick force, lb
δ	stick deflection, in.
$\dot{\delta}$	stick rate, in./sec
$\ddot{\delta}$	stick acceleration, in./sec^2
i	stabilizer incidence, deg
$\dot{\theta}$	airplane pitching velocity, radians/sec
$\ddot{\theta}$	airplane pitching acceleration, radians/sec^2
a_n	normal acceleration, g units
ω	circular frequency, radians/sec
K	gain factor
$j = \sqrt{-1}$	
ϕ	phase angle, deg
Δt	input time interval, sec
$F_a(j\omega)$	standard level of feel component proportional to normal acceleration, lb
$F_{\dot{\theta}}(j\omega)$	standard level of feel component proportional to pitching velocity, lb

$F_{\ddot{\theta}}(j\omega)$ standard level of feel component proportional to pitching acceleration, lb

$F_{\delta}(j\omega)$ standard level of feel component proportional to stick deflection, lb

$F_{\dot{\delta}}(j\omega)$ standard level of feel component proportional to stick rate, lb

DESCRIPTION OF APPARATUS

Airplane and Longitudinal Control System

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This investigation of control-feel characteristics was conducted with the use of a transonic fighter airplane which had an irreversible power-actuated control system. Figure 1 is a photograph of the test airplane. The production control system and control-feel system for this airplane are described in detail in references 6 and 7, and some of the aerodynamic characteristics of the test airplane are given in reference 8. The production longitudinal control-feel system consisted of dual bob weights mounted ahead of the control stick and in the tail section, an eddy-current damper attached to the stick, and a cam-driven centering spring with a steep nonlinear gradient through neutral. For most of this flight-test program the devices which normally produced the longitudinal feel were removed except for the centering spring. This centering spring was retained with a modified cam which provided a force gradient of $3\frac{3}{4}$ pounds per inch of the stick deflection as shown in figure 2. The modified centering spring was used to provide longitudinal control feel during take-off and landing and to serve in general as a reversion system for the variable electrohydraulic control-feel system.

The longitudinal control system was linked by push-pull rods and had a negligible amount of lost motion. The control friction was approximately $1\frac{1}{2}$ pounds measured at the stick grip. This value was increased to just under 2 pounds with the electrohydraulic feel system installed. The gearing between stick and stabilizer was 0.9 inch per degree for the normal flight range. The moment of inertia of that part of the control system located ahead of the servo valve, taken about the stick pivot, was found to be 0.8 slug-foot^2 with the bob weights installed and 0.5 slug-foot^2 with the bob weights removed.

Variable Control-Feel System

An electrohydraulic longitudinal control-feel system was installed in the test airplane which made it possible for the pilot to vary in flight the amount of control force from five component sources. The five sources were stick position, stick rate, airplane normal acceleration, pitching acceleration, and pitching velocity. A block diagram of the variable control-feel system is presented in figure 3. It should be noted that zero spring feel was obtained by electronic canceling of the $3\frac{3}{4}$-pound-per-inch mechanical spring. This variable-feel system is described in more detail in reference 6.

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The maximum feel-servo outputs measured at the stick grip are listed in the following table:

Servo output proportional to -	Maximum magnitude of output
Normal acceleration	±8 lb/g
Pitching acceleration	±50 lb/radian/sec^2
Pitching velocity	±120 lb/radian/sec
Stick deflection	±10 lb/in.
Stick rate	±2.5 lb/in./sec

For this investigation, the variable control-feel system provided 17 test feel configurations, designated feel configurations A to Q. The combination of feel components is given for each of these 17 configurations in table I. In this table the amounts of feel from the various components are given in percent of the standard level. Thus, stick centering of $3\frac{3}{4}$ pounds per inch, stick-rate damping of 1.0 pound per inch per second, normal-acceleration feel of 3 pounds per g, and pitching-acceleration feel of 7 pounds per radian per second per second were the 100-percent levels. The 100-percent level for pitch-rate feel was selected as 20 pounds per radian per second to make this component approximately equal to the pitching-acceleration component at a circular frequency of 3 radians per second. This frequency was the short-period resonant frequency for the test airplane for the test operating conditions (altitude of 28,000 feet at a Mach number of 0.85).

INSTRUMENTS

The set of standard NASA recording instruments used in this investigation had been installed in the test airplane for other purposes; as a result, the sensitivity of the force and deflection recorders was lower than would be desired. There follows a tabulation of the quantities recorded and the approximate instrument sensitivities:

Recorded quantity	Approximate sensitivity per inch of trace deflection
Stick force	60 lb
Stick position	9.5 in.
Stabilizer deflection	12 deg
Normal acceleration	1.5g
Pitching acceleration	0.8 radian/sec^2
Pitching velocity	0.5 radian/sec
Airspeed	100 knots
Altitude	6,000 feet

The response of these instruments was essentially flat over twice the frequency range of interest in this investigation (0 to 10 cps).

PRESENTATION OF RESULTS

The measured and calculated longitudinal control characteristics of the test airplane with various control-feel configurations are presented by means of three types of plots. These plots include maneuver time histories, variation of peak force per g with input duration, and frequency-response plots of transfer functions related to control feel. The standard test conditions were a Mach number of 0.85 at an altitude of 28,000 feet, and the airplane center of gravity at 25 percent of the mean aerodynamic chord. Figure 4 presents time histories of pull-up and hold maneuvers for a number of feel configurations. Figure 5 presents time histories of turns, in which the pilot attempted to increase the normal acceleration in steps of $\frac{1}{2}$ g, with the same feel configurations. All but three of the pairs of maneuvers in figures 4 and 5 were performed by the same pilot.

The variation of peak force per g with input duration was determined from triangular manual control force inputs of varying duration. These results are presented for the more significant feel configurations in figure 6. The effect of various feel configurations on the dynamic characteristics of the test airplane is presented in terms of frequency response in figures 7 to 19. The frequency-response data were obtained from triangular control inputs with a duration of 1 second or less by the methods of references 9 and 10. The calculated points on figure 6 were also obtained from procedures described in references 9 and 10. The transfer functions shown in the figures are: the control-system response $i/F(j\omega)$, and the airplane response functions $\dot{\theta}/F(j\omega)$ and $a_n/F(j\omega)$. The frequency range of the data usually extends to 15 or 20 radians per second, values which exceed the short-period frequency of the airplane and also exceed the effective frequency range of the human pilot. The results with the spring feel alone (configuration G) extend above a frequency of 30 radians per second and indicate a control-system resonance at a frequency of 30 radians per second (fig. 13).

Presented in table I is an index to the figures, where for each feel configuration the figures containing results for that feel configuration are listed. Because the test program was terminated during a redirection of the research effort, the test configurations covered were somewhat random and do not represent a systematic coverage of possible combinations. However, enough data were obtained to give examples of the dynamic effects of feel from the five sources investigated.

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DISCUSSION OF RESULTS

Previous flying-qualities measurements on the test airplane permitted evaluation of the production feel configuration by several pilots. The production feel characteristics were considered by the pilots to be very satisfactory. The airplane was characterized as being easy to get used to. However, the control forces were classed as being heavier than the optimum for a fighter-type airplane. The flight-test program was too brief to obtain detailed assessment by the pilots of the various feel configurations. However, regardless of the force level involved, the pilots always downrated the feel characteristics when any of the four feel sources in the production feel configuration were omitted. But none of the feel combinations tested were considered to be intolerable.

The longitudinal control-feel configuration which was designated as "standard feel" for the present investigation was equivalent to the production feel configuration, with a linearized $3\frac{3}{4}$-pound-per-inch stick centering gradient and a slightly reduced control-system moment of inertia. It was determined analytically that variation of the control-system moment of inertia from 0 to 1.6 slug-feet^2, twice the normal value, did not appreciably affect the response of the control system at frequencies up to 3 cycles per second.

Maneuver Time Histories

The maneuver time histories of stabilizer deflection and normal acceleration (figs. 4 and 5) indicate that with standard feel (configuration A) the pilot maneuvered confidently and, as a result, consistently overshot moderately when attempting to induce step increments of acceleration. Within approximately 2 seconds from the start of the control input, the normal acceleration was stabilized at approximately the desired higher level. These maneuvers were performed with similar results for either pull-up or turn for several of the other test feel configurations, namely, 50 percent feel (configuration K), standard feel with the spring centering eliminated (configuration D), and standard feel with the force per g eliminated (configuration C). For three feel combinations in which the stick damping and/or the response feel were reduced (configurations F, G, and L), hunting about the desired acceleration level persisted for a full cycle longer during the pull-up maneuvers.

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When normal-acceleration feel was used in the absence of pitching-acceleration feel (configuration B) the time histories show a cautious gradual buildup of acceleration without the requested step increments. By means of this cautious technique the pilot maintained close control of acceleration for a feel configuration which is shown by the frequency-response data to have low damping.

The time history for configuration O shows another example of a feel configuration with low damping (flown by a less experienced pilot) (fig. 5). In this case, negative pitching-velocity feel component was the destabilizing element. The turn maneuver exhibited continual hunting about the desired acceleration level. In contrast, configuration N, which includes a strong positive pitching-velocity feel component, was flown with more confident inputs and less oscillatory response.

Variation of Peak Force Per g With Input Duration

A military handling-qualities requirement which was set up in the late 1940's specified that the ratio of peak force to peak acceleration in sudden pull-ups should never be less than the steady force per g. The purpose of this requirement was largely to avoid control-feel characteristics which permitted a delay in control force buildup after control deflection. This delay in buildup can occur, for example, when the component of force due to normal acceleration is the predominant one. The data of figure 6 indicate that the standard feel system (configuration A), the spring and damper feel (configuration F), or the centering spring feel alone (configuration G) all produced a progressive adequate buildup of peak force per g with the abruptness of a triangular control input for input durations of 1 second or less.

Examination of calculated and measured time histories showed that the buildup of normal acceleration was too slow to influence the peak force in these maneuvers until the input duration exceeded 1 second. For the more abrupt maneuvers, lag in airplane response and in the control system caused the pitching acceleration to peak at about the same time as the peak in stick deflection. However, even without this lag, the contribution of pitching-acceleration feel would be only about 1 or 2 pounds per g for input durations of less than 1 second. Therefore, as shown by comparison of figures 6(b) and 6(c), it is evident that reasonable amounts of response feel will not contribute effectively to the desired buildup of longitudinal control force for abrupt control inputs.

It should be noted that usually this military control-feel requirement is not strictly satisfied. There is usually a slight dip in the L
curve of peak force per g at a time interval which is apparently related 1
to the airplane short-period mode. Such a dip is not very apparent in 6
the data of figure 6, but was more so for similar data obtained for the 4
production airplane, which covered input intervals up to 8 seconds. In 1
that case the minimum value of peak force per g occurred at an input interval of about 2 seconds. The value at 2 seconds was about 15 percent lower than the value at 8 seconds. This slight dip in peak force per g is related to the short-period pitching mode of the airplane. This characteristic is illustrated much more adequately by a frequency-response plot.

Frequency Response as Influenced

by Control-Feel Configuration

Frequency-response plots such as those of figures 7 to 19 further illustrate the difference in dynamic characteristics of the test airplane and its control system with various feel configurations. The response characteristics of the control system in terms of the function $i/F(j\omega)$ are markedly different for the several feel configurations. The overall significance of the differences in the response of the airframe with various feel configurations is shown by the airplane response functions $\dot{\theta}/F(j\omega)$ or $a_n/F(j\omega)$. The discussion will be concerned primarily with the shape of the frequency-response curves. Adjustment in force level, which might be desirable in some cases, could be made by changing all the feel-component gains in the same proportion.

Consider first the control-system characteristics as indicated by the response function $i/F(j\omega)$. Feel configurations which result in excessive peak magnification of i/F because of coupling with the airplane response in the short-period mode are undesirable or intolerable. The peak magnification of i/F with the acceptable standard feel (fig. 7) was only about 30 percent greater than the steady value. The frequency response of a simple spring-and-dashpot feel system is also shown to be acceptable by the data of figure 12. The frequency-response plots of i/F, such as those of configurations D and E (figs. 10 and 11), indicate that the peak amplitude magnification was increased moderately by removing either the spring centering or the stick-rate damping from the standard feel configuration. It is interesting to note the calculated frequency response of the standard feel configuration with the stick-rate damping removed. The characteristics of this configuration (fig. 11) may be acceptable over the calculated frequency range. The peak magnification of i/F is only 1.6 in response to the airplane short-period mode. However, with this arrangement the feel component proportional to pitching acceleration could possibly stimulate the control-system mode (at $\omega \approx 30$ radians per second).

Excessive peaking occurred as the preponderance of normal-acceleration feel component over pitching-acceleration feel component was increased progressively in configurations B, J, and P (figs. 8, 16, and 18, respectively). For example, the calculated peak magnification of i/F for configuration P, which had the force per g component doubled with the force per $\ddot{\theta}$ cut in half, was about 30 compared with a value of about 1.3 for the standard feel configuration. The corresponding stabilizing effect of removing normal-acceleration feel from the standard feel configuration is shown in figure 9. Comparison of the data of figures 9 and 12 shows that pitching-acceleration feel attenuates the response between $\omega = 1.5$ and 9 radians per second.

Addition of a force component due to pitching velocity to the standard feel system, as in the calculated results for configuration M (fig. 17), replaced the peak at $\omega = 3$ radians per second with a dip for i/F and reduced the peak magnification of a_n/F. A measurement of the stabilizing influence of pitching-velocity feel at the frequency of the short-period mode can be obtained by comparing the data for configuration I in figure 15 with the data of configuration Q, figure 19, which does not include pitching-velocity feel.

For two of the feel configurations shown, that is, for configuration G (spring feel alone) and configuration H (three-way response feel), the response quantity i/F continues to increase with increasing frequency instead of becoming attenuated at frequencies above the short-period mode. (See figs. 13 and 14.) However, the airplane response quantity a_n/i decreases rapidly enough with increasing frequency to tend to keep the variation of a_n/F with frequency acceptable. This type of control-system characteristic, which makes the stick force lighter the faster the stick is cycled, is undesirable because it not only does not satisfy the handling-qualities requirements but also may endanger the control-system structure.

The significance of the frequency-response data can be further illustrated by constructing vector or phase diagrams at frequencies of particular interest such as at the frequency of the short-period airplane mode. Figure 20(a) is such a diagram obtained from the frequency-response data of figure 7 for the standard feel configuration. The diagram shows the required pilot force input vector $\mathbf{F}$, the several feel-component vectors, and the phasing of δ, i, and $\dot{\theta}$ at a frequency of 3 radians per second.

The influence of the response-feel components on the dynamic behavior of the control system can be deduced from the phase diagram. Pitching acceleration tends to be in phase with stick rate at the frequency of the airplane short-period mode. Therefore pitching-acceleration feel supplies damping to the control system at this fre- L
quency. Normal-acceleration feel is feeding a maximum amount of energy 1
into the oscillation of the control system at or near this frequency. 6
At this frequency, $\dot{\theta}$ is still approximately in phase with stabilizer 4
deflection. At or near $\omega = 3$ radians per second, addition of a 1
pitching-velocity feel component is equivalent to increasing the spring centering, or stick-deflection feel component. As was shown in the frequency-response data of figures 15 and 17, addition of pitching-velocity feel gradually attenuates the control-system response as the frequency approaches $\omega = 3$ radians per second and thereby reduces, or even inverts, the peak magnification of the forced oscillation in pitch of the airplane at the short-period mode.

A second phase diagram, figure 20(b), for a somewhat higher frequency (6 radians per second) shows a considerably altered situation. In this case the pitching-acceleration and normal-acceleration feel components in line with $\dot{\delta}$ are negligible, so that response feel from these sources no longer has a direct effect on the damping of the control system. At this frequency the pitching-velocity feel component becomes fully effective at feeding energy into the oscillation of the control system, but there is no airplane resonance to be excited by the increased amplitude of control motion per unit force input. This effect was apparent on the frequency-response plots of figure 15 for ω from about 5 to 10 radians per second.

CONCLUDING REMARKS

An investigation of longitudinal control-feel characteristics has been made with a transonic fighter airplane equipped with a variable control-feel system. Measured and calculated results were presented to show the effects of using control feel from several sources or combinations of sources in various proportions. The component feel sources considered were stick deflection (spring feel), stick rate, airplane normal acceleration, pitching acceleration, and pitch rate.

All feel configurations considered approximately satisfied the military dynamic control-feel requirement which specifies that the peak force per g encountered during abrupt pitch maneuvers should not fall below the steady force per g. However, an analysis based on this requirement was found to give insufficient indication of lightly damped oscillatory modes such as occur with unbalanced response feel.

The frequency response of each of the control-feel configurations tested was determined as a supplement to the transient peak force per g characteristics to define better the oscillatory behavior of the longitudinal control system. Frequency-response plots for a number of control-feel configurations were presented. These examples give an indication of how the feel sources used and the gains used influence the frequency response of the control system and the airplane. These data show that in a response-feel system normal-acceleration feel has a strong tendency to destabilize the short-period mode and therefore must be balanced by another feel component. Pitching-acceleration feel, which is found to produce an inadequate buildup of transient control force in abrupt maneuvers, is shown to be well suited for dynamic balancing of the normal-acceleration feel component during an oscillation. Pitching-velocity feel is also demonstrated to be useful for obtaining flatter frequency response of the control system.

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The results presented indicate the value of frequency-response analysis in the design of a longitudinal control-feel system. From such analysis the choice of feel components and gains can be made to shape the frequency-response curves within safe and desirable limits.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., June 30, 1961.

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TABLE I.- TEST FEEL CONFIGURATIONS AND INDEX OF FIGURES

Configuration (a)	Feel component, percent of standard level, proportional to -					Maneuver time history presented in figures -	Measured and calculated peak force per g presented in figure -	Frequency-response plots presented in figure - Measured	Frequency-response plots presented in figure - Calculated
	a_n	$\dot{\theta}$	$\ddot{\theta}$	δ	$\dot{\delta}$				
A	100	0	100	100	100	4 and 5	6	7	7
B	100	0	0	100	100	4 and 5		8	8
C	0	0	100	100	100	4 and 5		9	9
D	100	0	100	0	100	4 and 5			10
E	100	0	100	100	0				11
F	0	0	0	100	100	4 and 5	6	12	12
G	0	0	0	100	0	4 and 5	6	13	13
H	100	100	100	0	0				14
I	100	100	100	25	50			15	15
J	200	0	100	25	50			16	
K	50	0	50	50	50	4 and 5			
L	50	0	50	100	25	4 and 5			
M	100	100	100	100	100				17
[b]N	100	500	100	100	100	4 and 5			
[c]O	100	-125	100	100	100	4 and 5			
P	200	0	50	100	100				18
Q	100	0	100	25	50				19

[a]Control-system moment of inertia was 0.5 slug-ft^2 except for configuration N.

[b]With bob weights and eddy-current damper, moment of inertia equal to 0.8 slug-ft^2.

[c]With eddy-current damper.

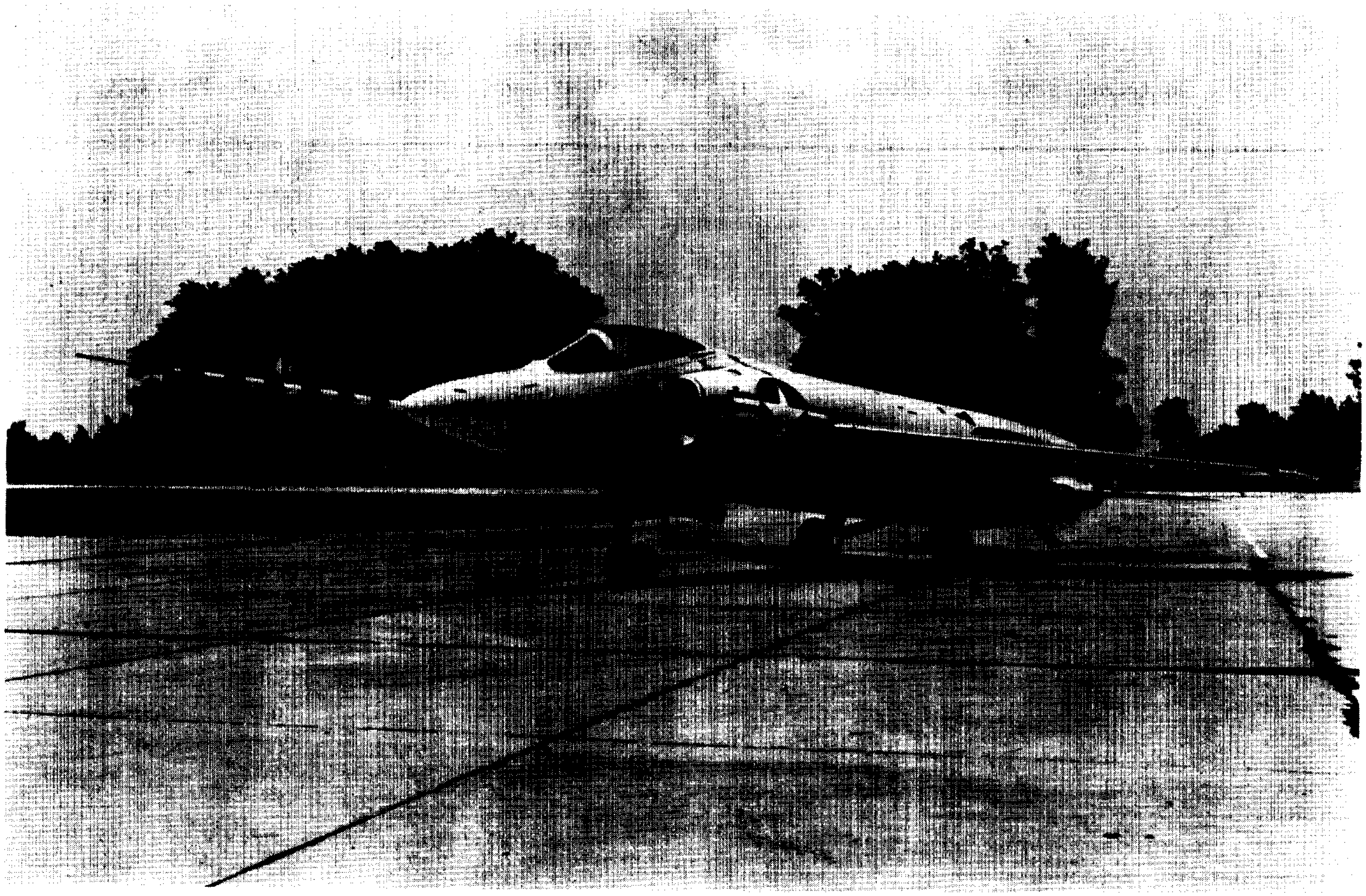


Figure 1.- Photograph of test airplane. L-57-2254

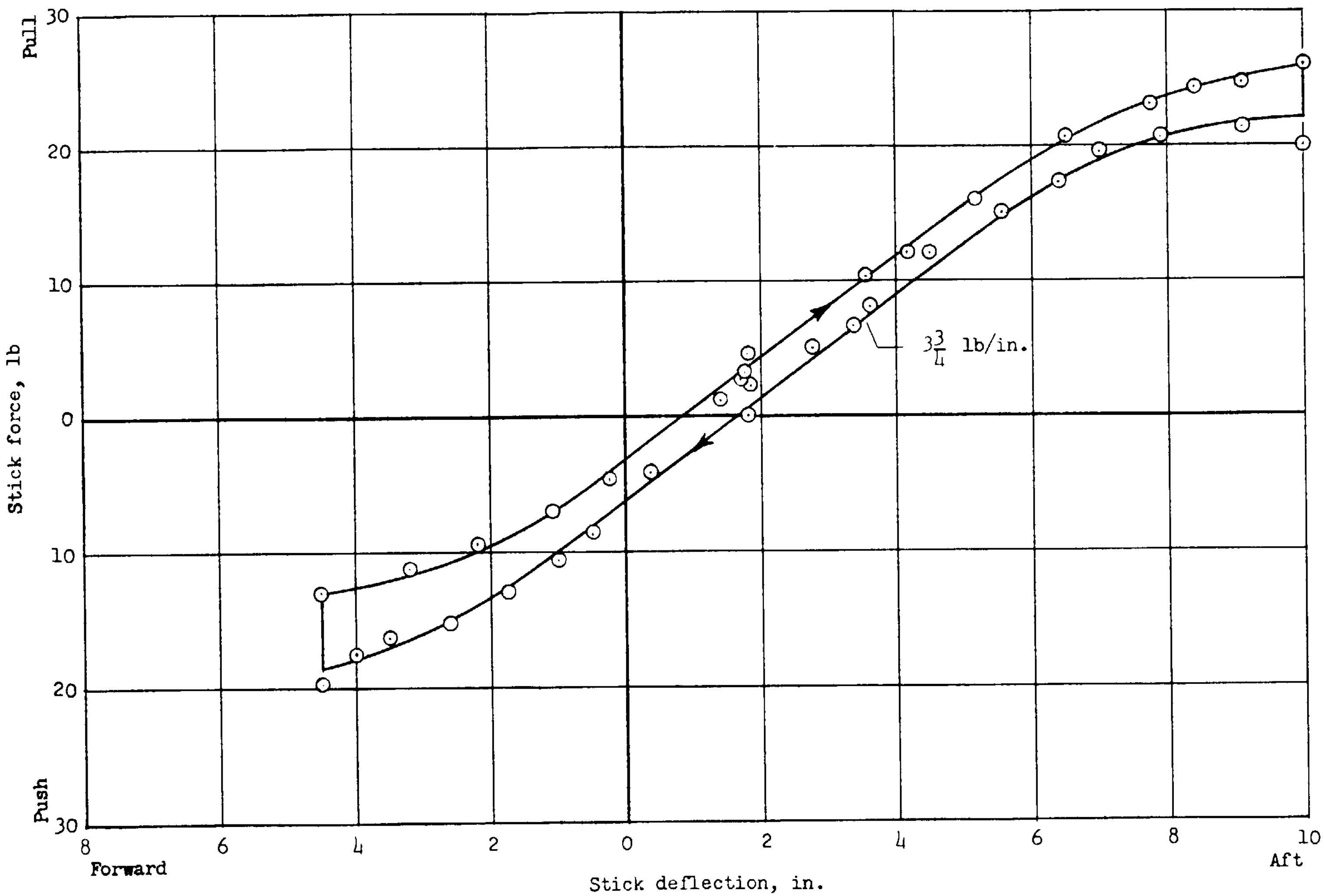


Figure 2.- Modified-cam mechanical-spring force gradient as used with the variable electro-hydraulic feel system. (Trim point can be varied by pilot.)

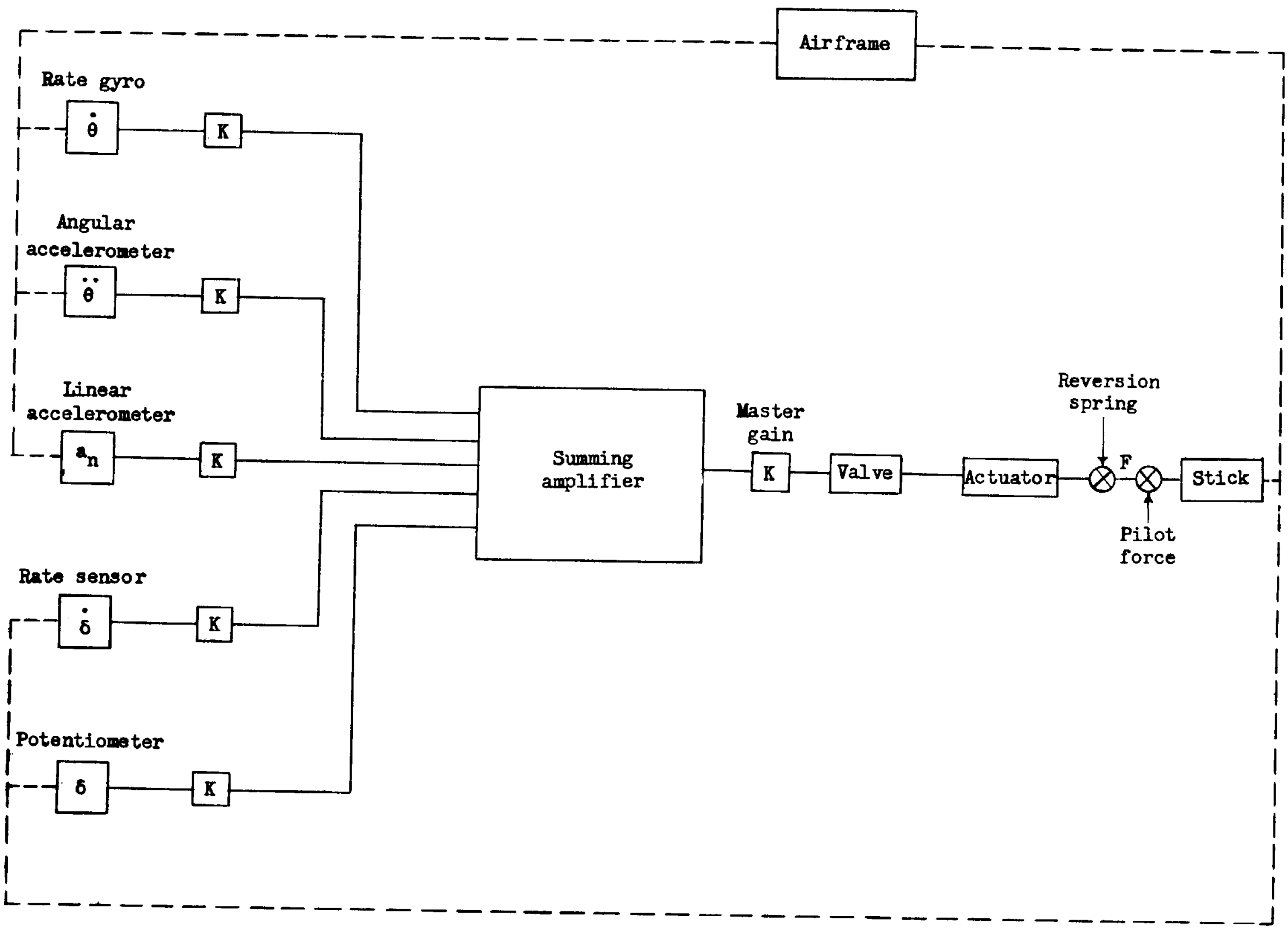


Figure 3.- Block diagram of variable control-feel system.

L-1641

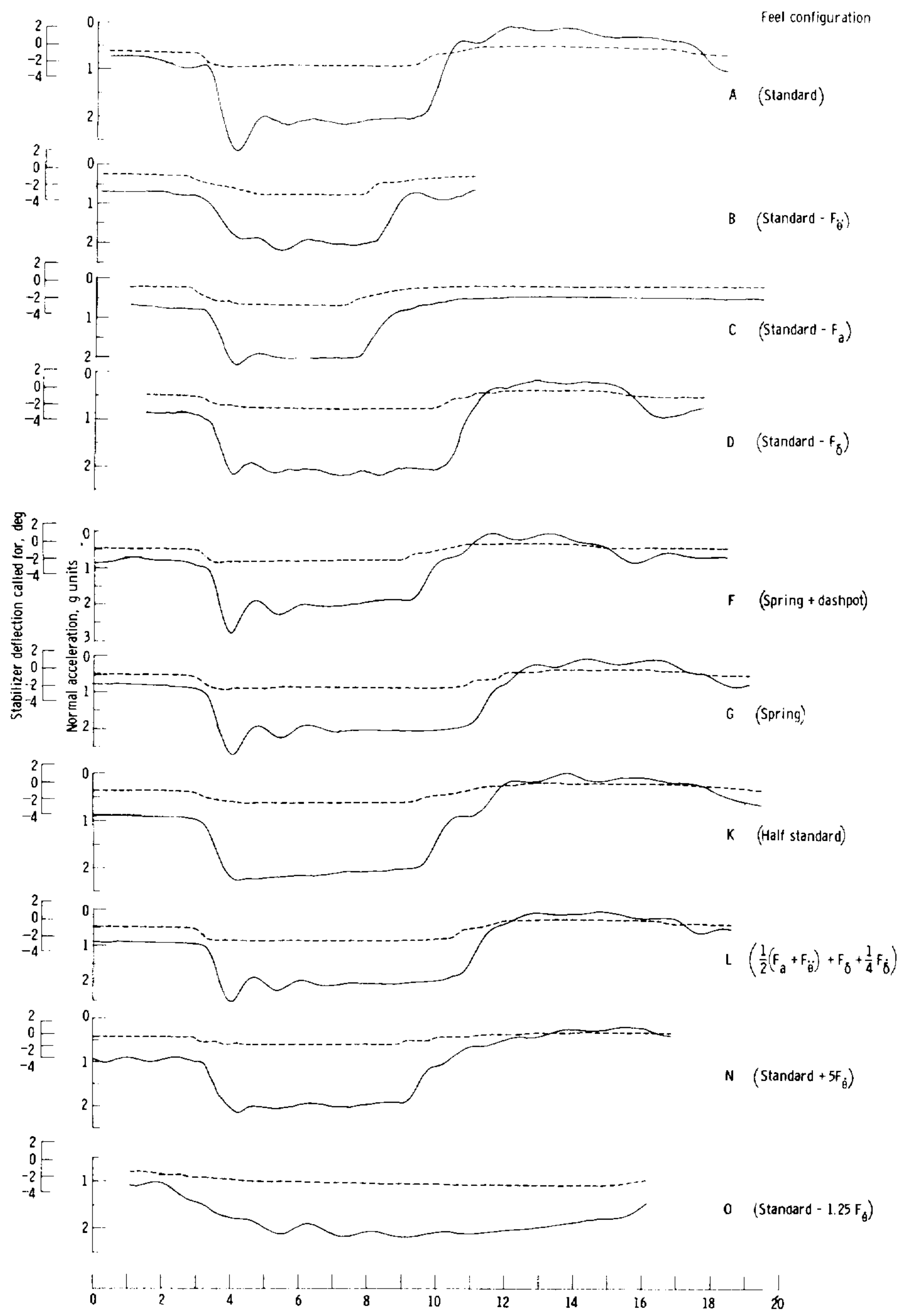


Figure 4.- Time histories obtained by tracing the instrument records from longitudinal pull-up and hold maneuvers with various control-feel configurations. (Normal acceleration is represented by the solid line and stabilizer deflection by the dashed line.)

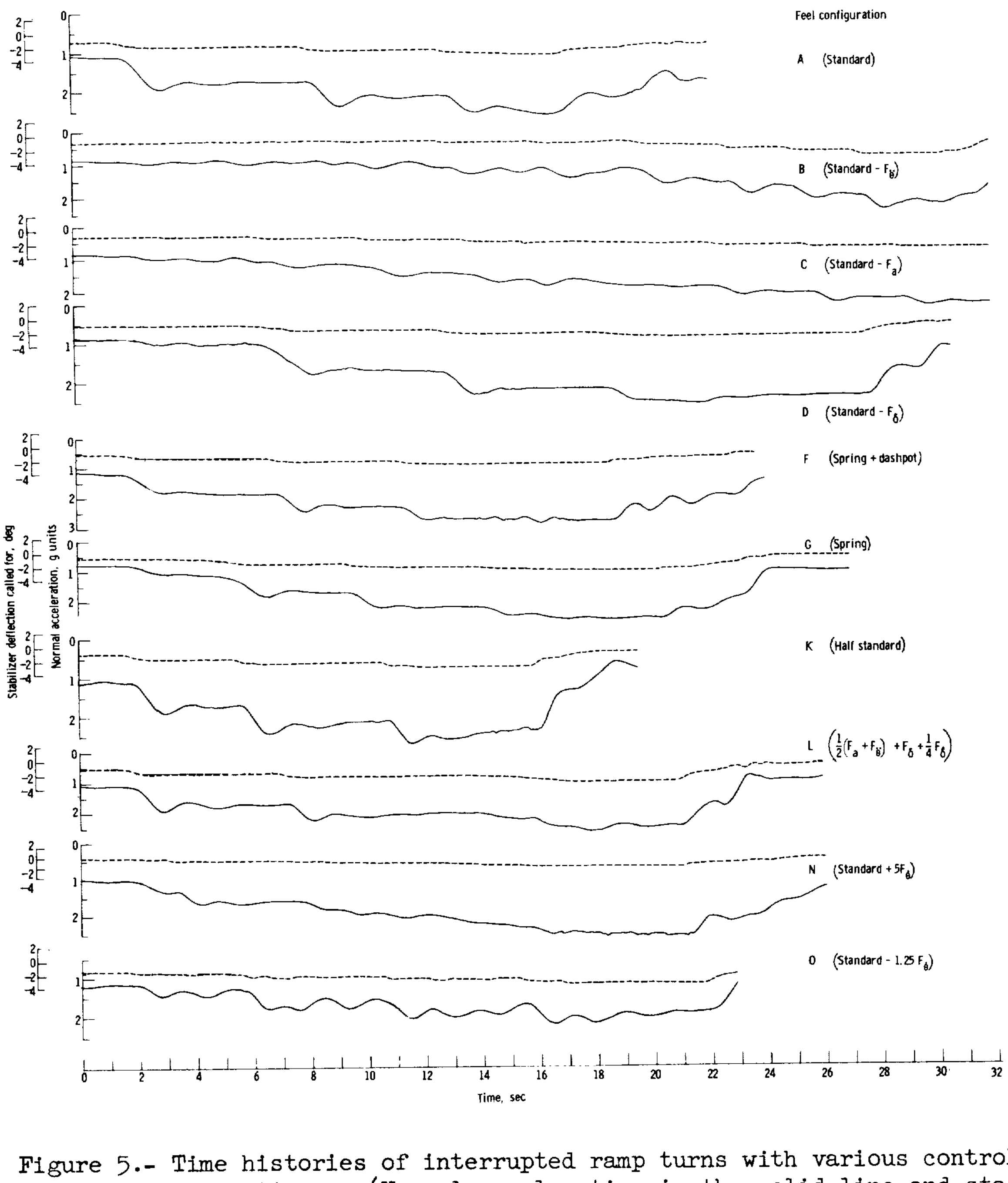
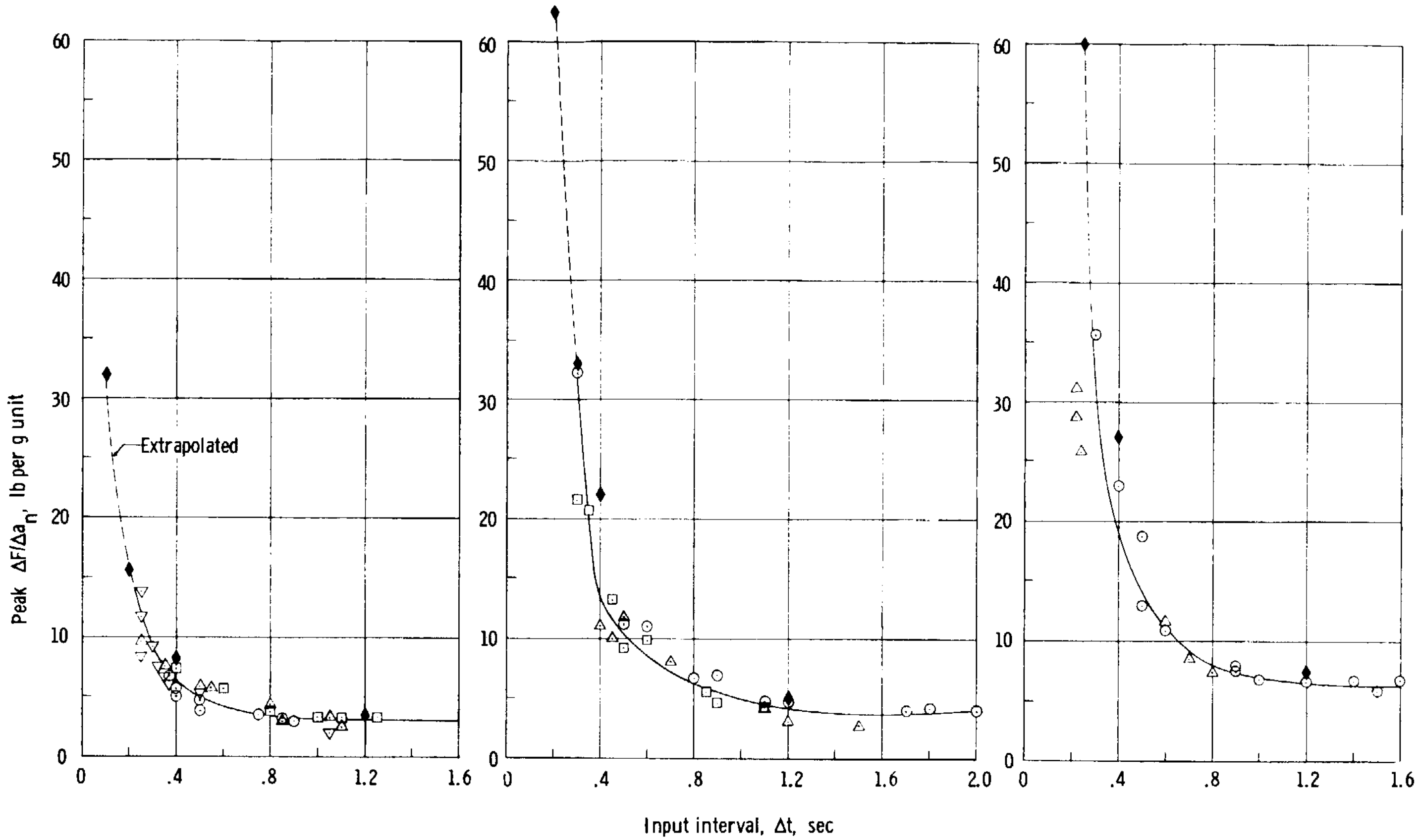


Figure 5.- Time histories of interrupted ramp turns with various control-feel configurations. (Normal acceleration is the solid line and stabilizer deflection is the dashed line.)

L-1641



(a) Spring feel (configuration G); $\Delta F/\Delta a_n = 4$ lb/g for steady turn.

(b) Spring plus damper (configuration F); $\Delta F/\Delta a_n = 4$ lb/g for steady turn.

(c) Standard feel (configuration A); $\Delta F/\Delta a_n = 7$ lb/g for steady turn.

Figure 6.- Variation of peak force per g with input duration for several feel configurations. (Solid symbols represent calculated points; various open symbols each represent a different flight.)

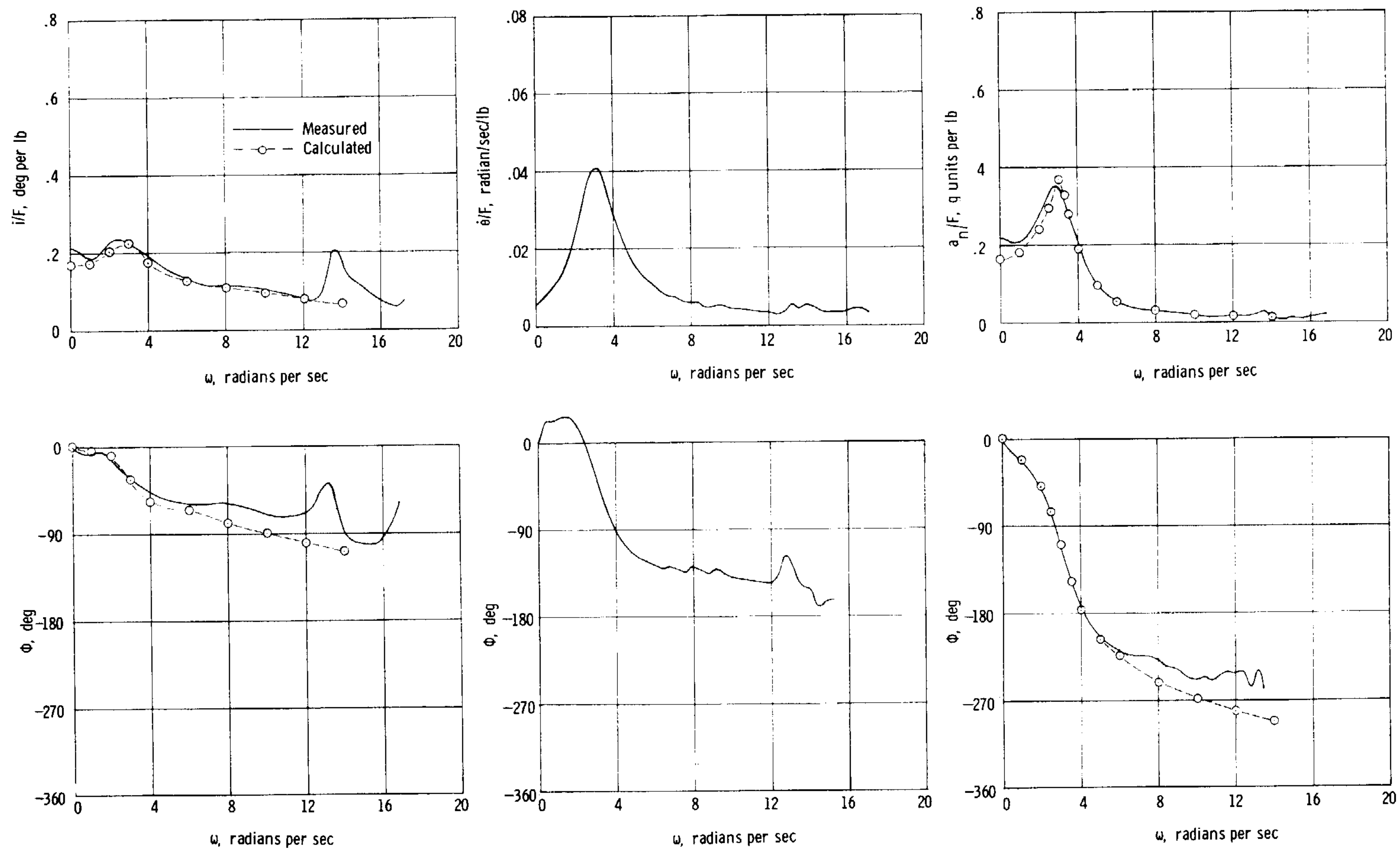


Figure 7.- Comparison of measured and calculated frequency responses with the standard longitudinal control-feel configuration. (Configuration A, standard.)

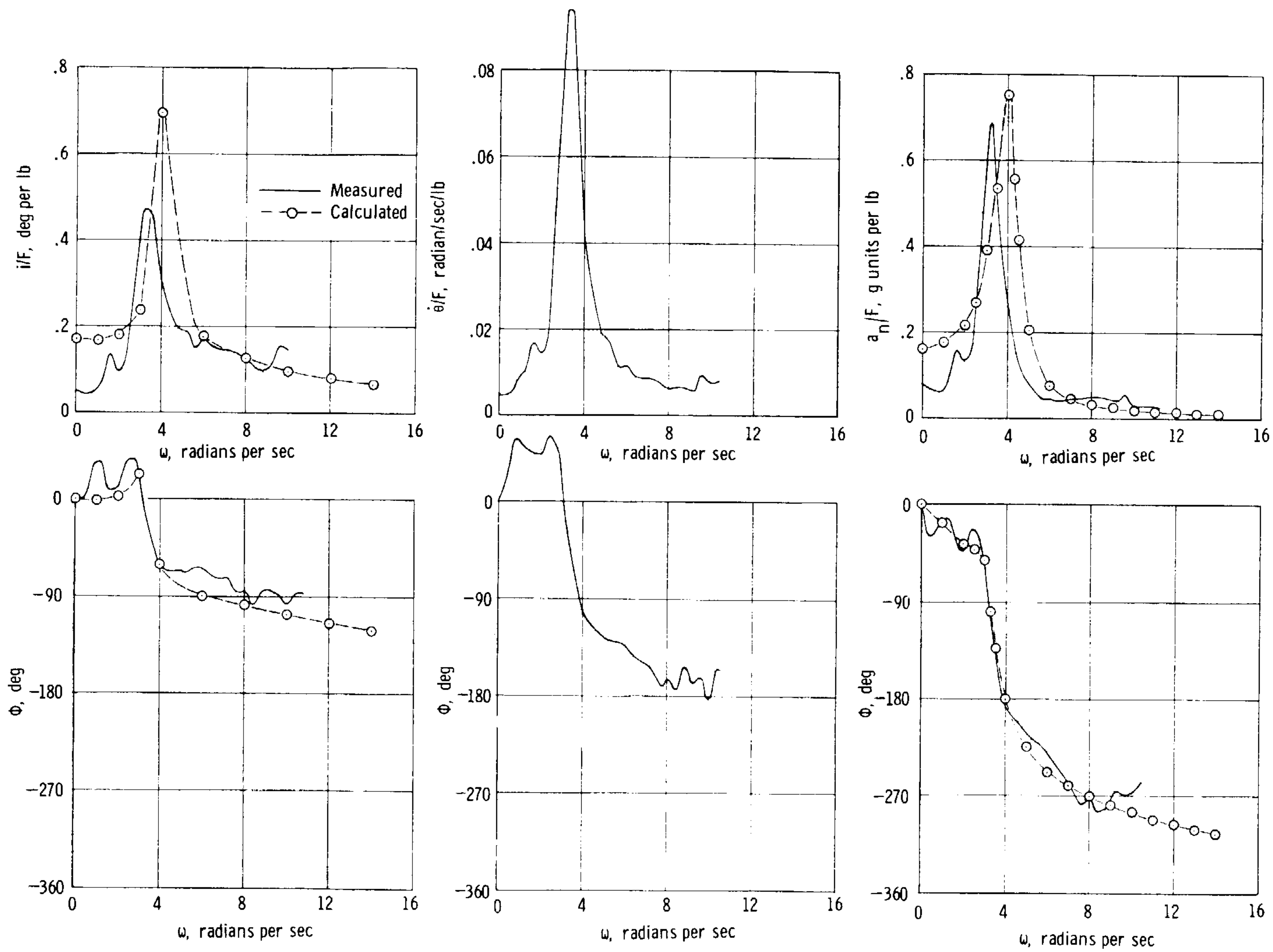


Figure 8.- Comparison of measured and calculated frequency responses with pitching acceleration feel omitted from the standard feel configuration. (Configuration B, standard - $F_{\ddot{\theta}}$.)

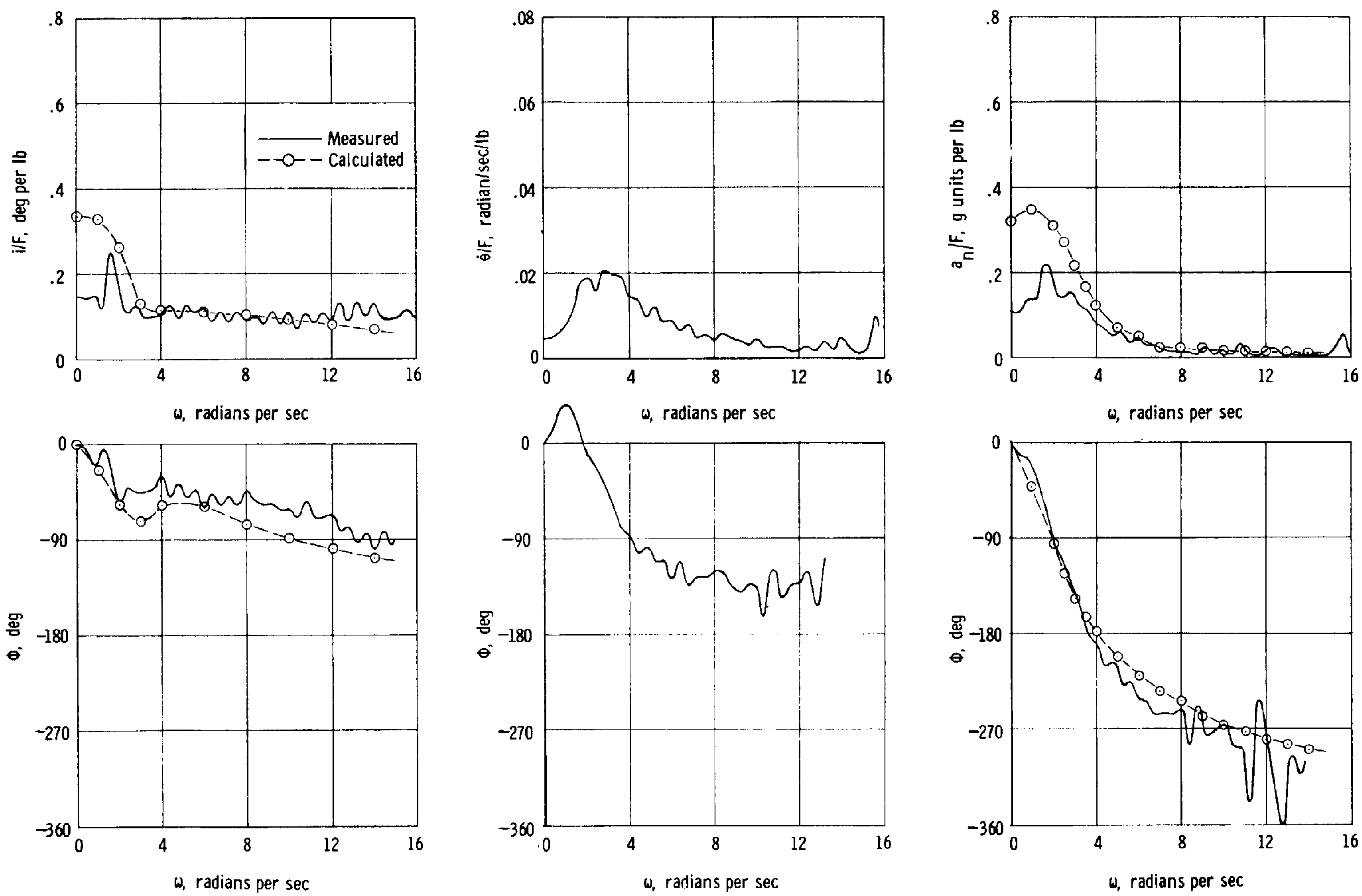


Figure 9.- Comparison of measured and calculated frequency responses with the force component proportional to normal acceleration omitted from the standard feel configuration. (Configuration C, standard - F_a.)

L-1641

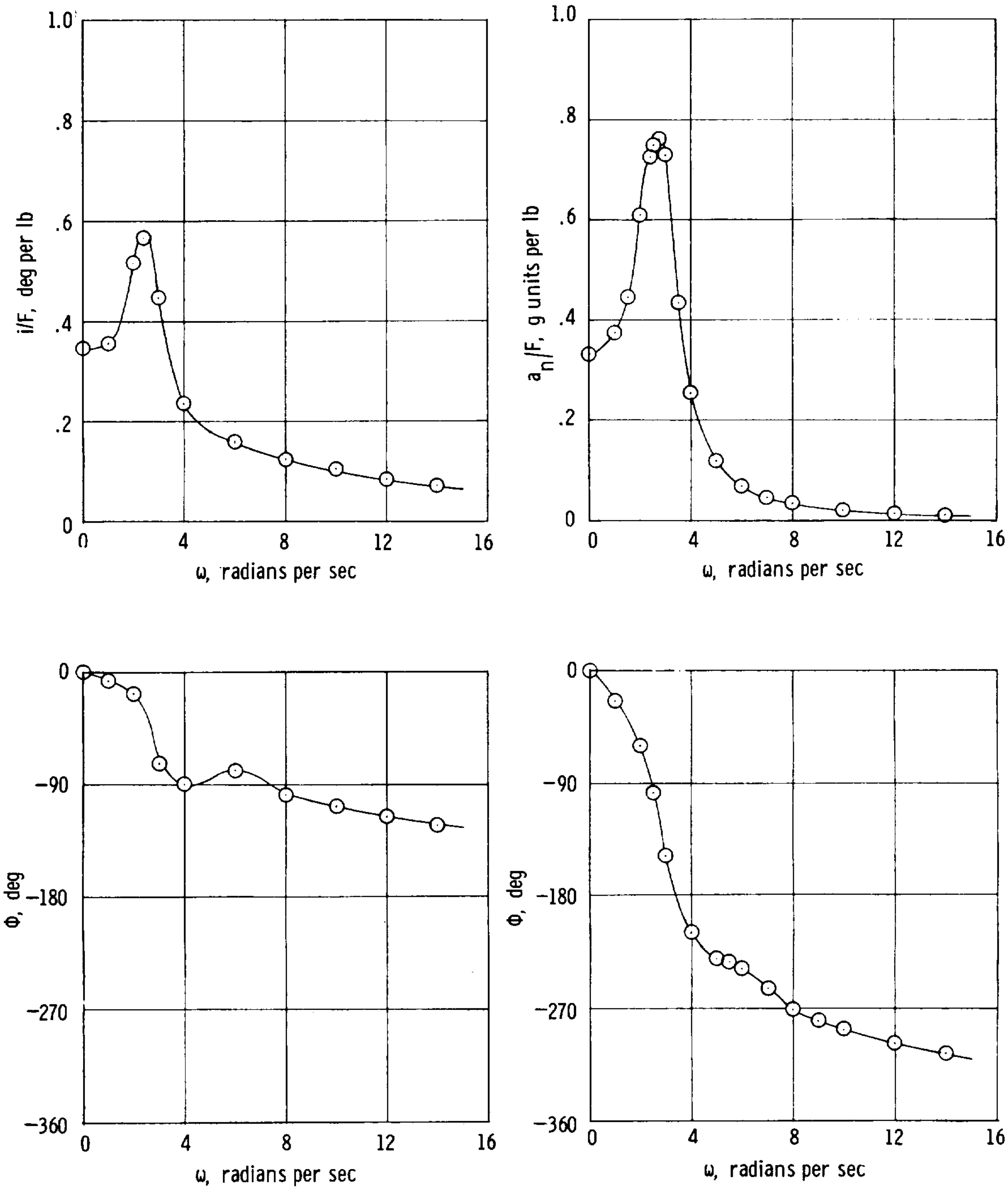


Figure 10.- Calculated frequency responses with spring feel omitted from the standard feel configuration. (Configuration D, standard - F_δ.)

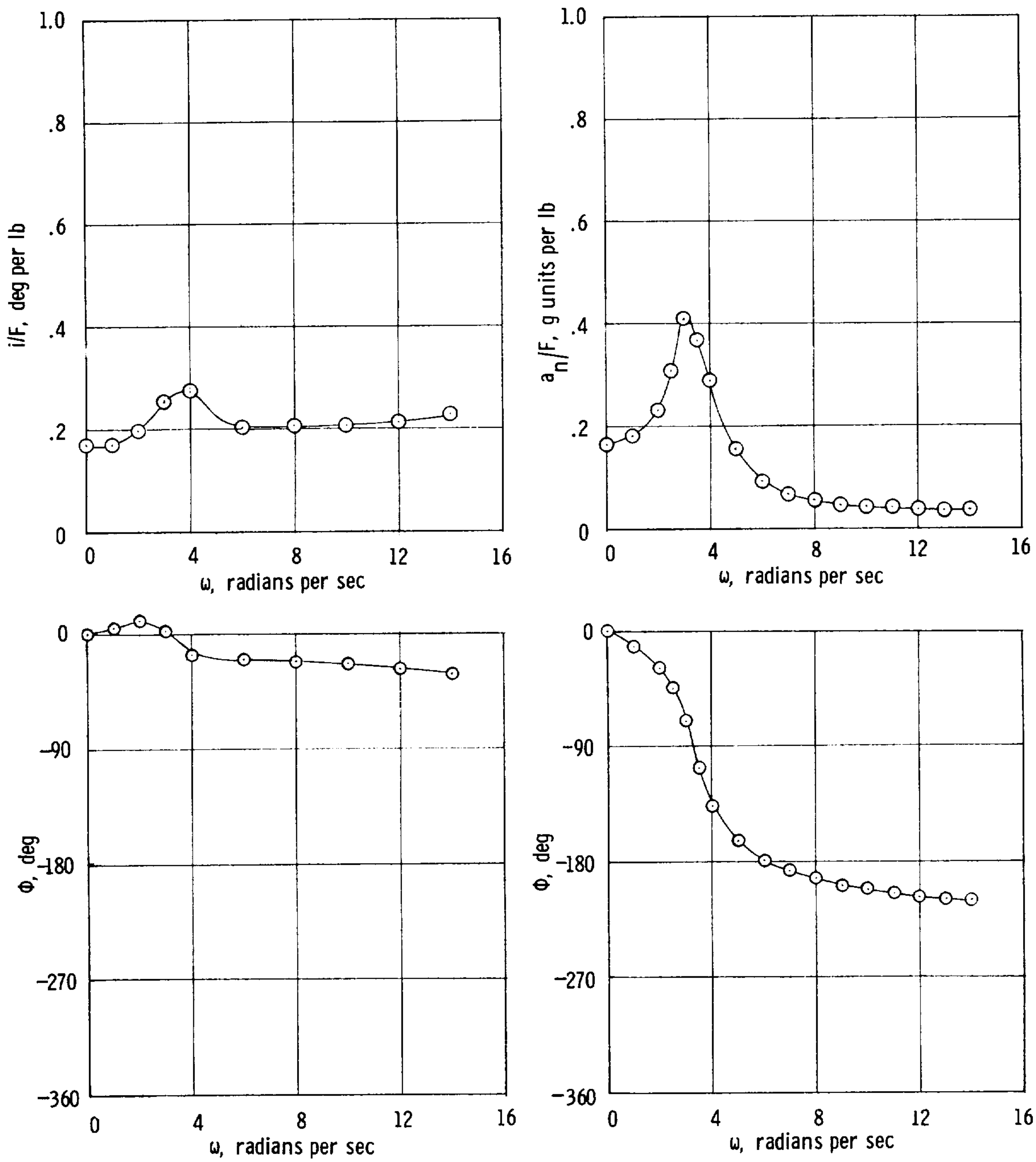


Figure 11.- Calculated frequency responses with stick-rate damping omitted from the standard feel configuration. (Configuration E, standard - $F_{\dot{\delta}}$.)

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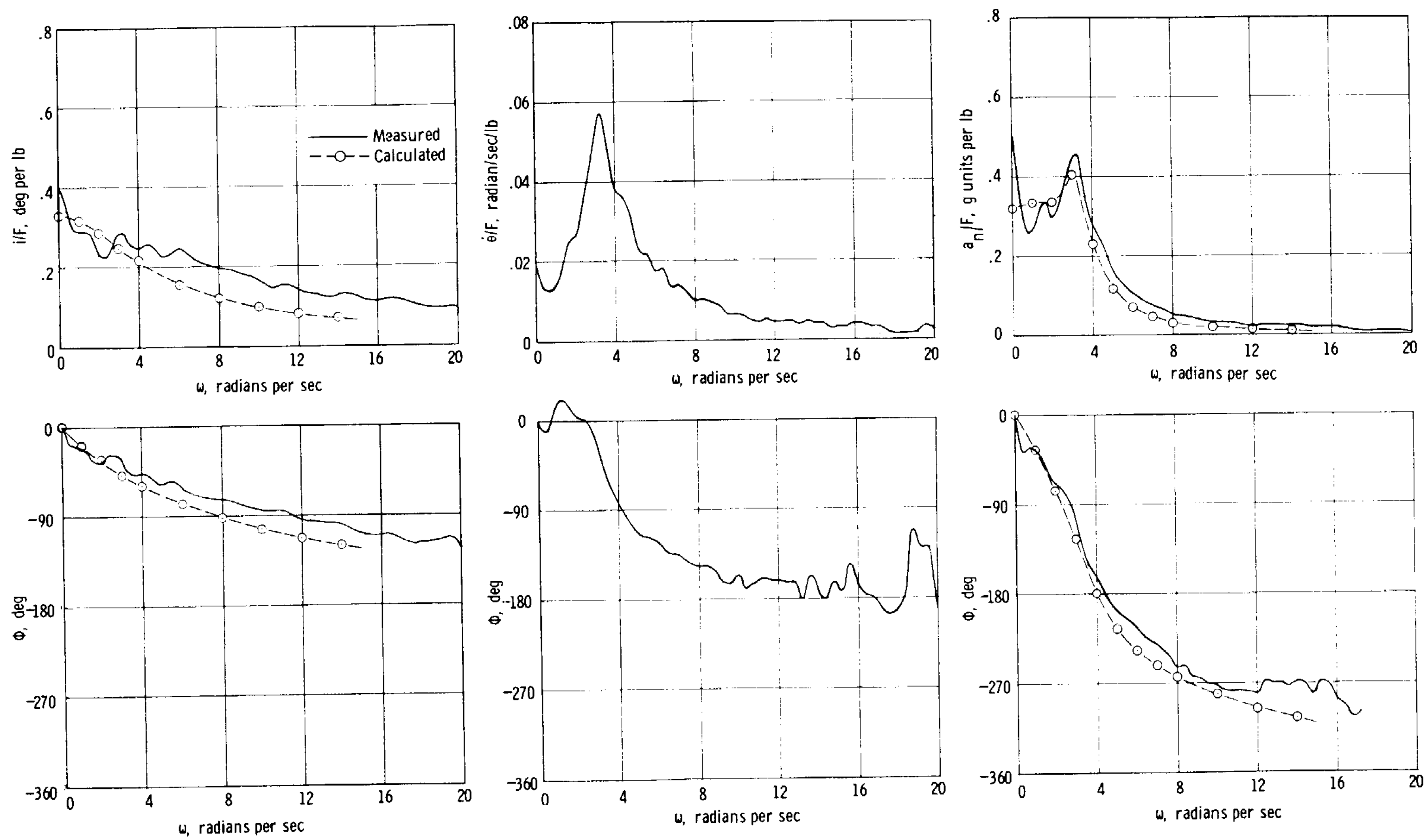

Figure 12.- Comparison of measured and calculated frequency responses with a feel configuration consisting of spring centering plus stick-rate damping. (Configuration F, spring + dashpot.)

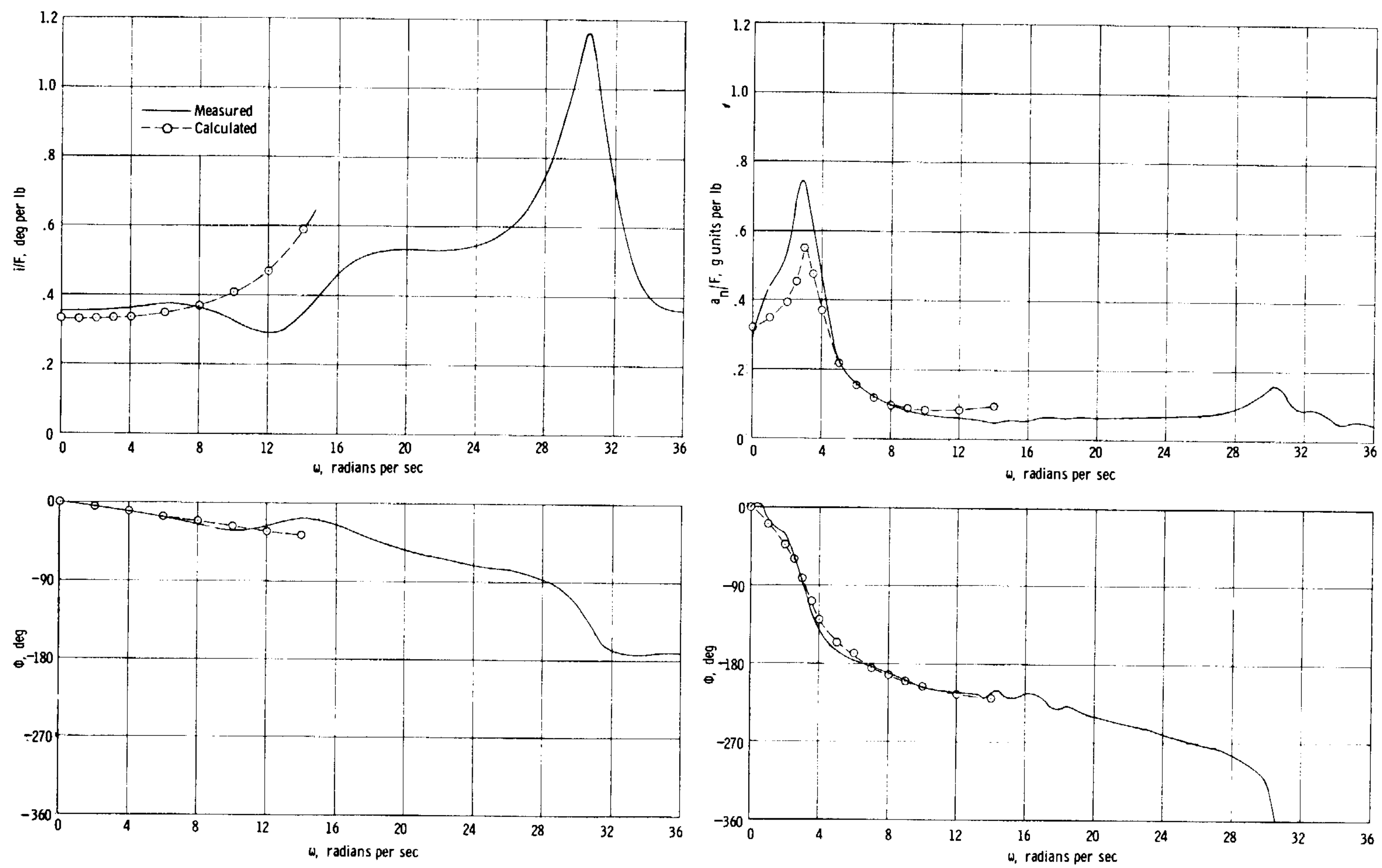

Figure 13.- Comparison of measured and calculated frequency responses with spring feel alone. (Configuration G, spring.)

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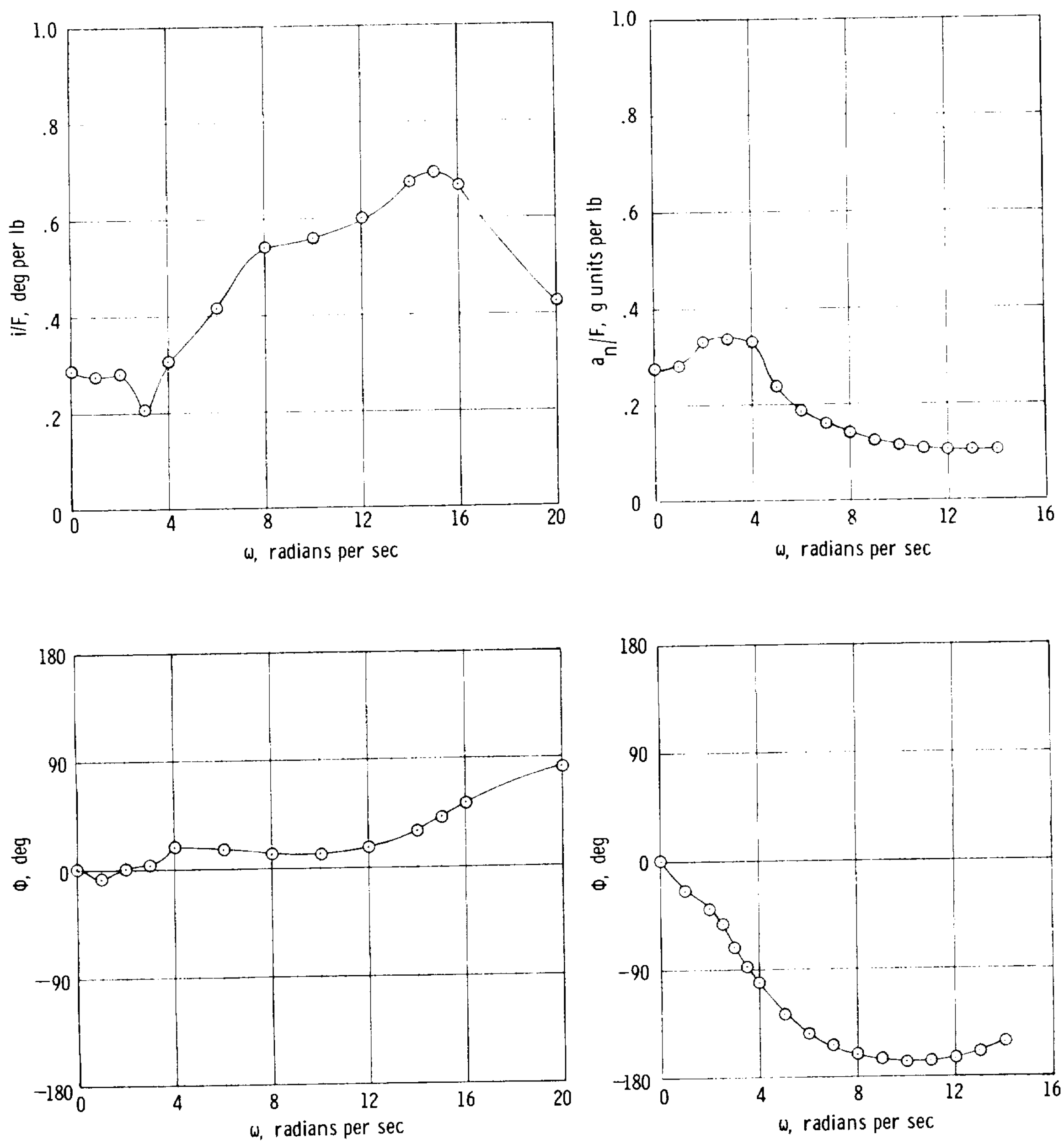

Figure 14.- Calculated frequency responses with a response feel system having feel components proportional to normal acceleration, pitching acceleration, and pitching velocity. (Configuration H, $F_a + F_{\dot{\theta}} + F_{\ddot{\theta}}$.)

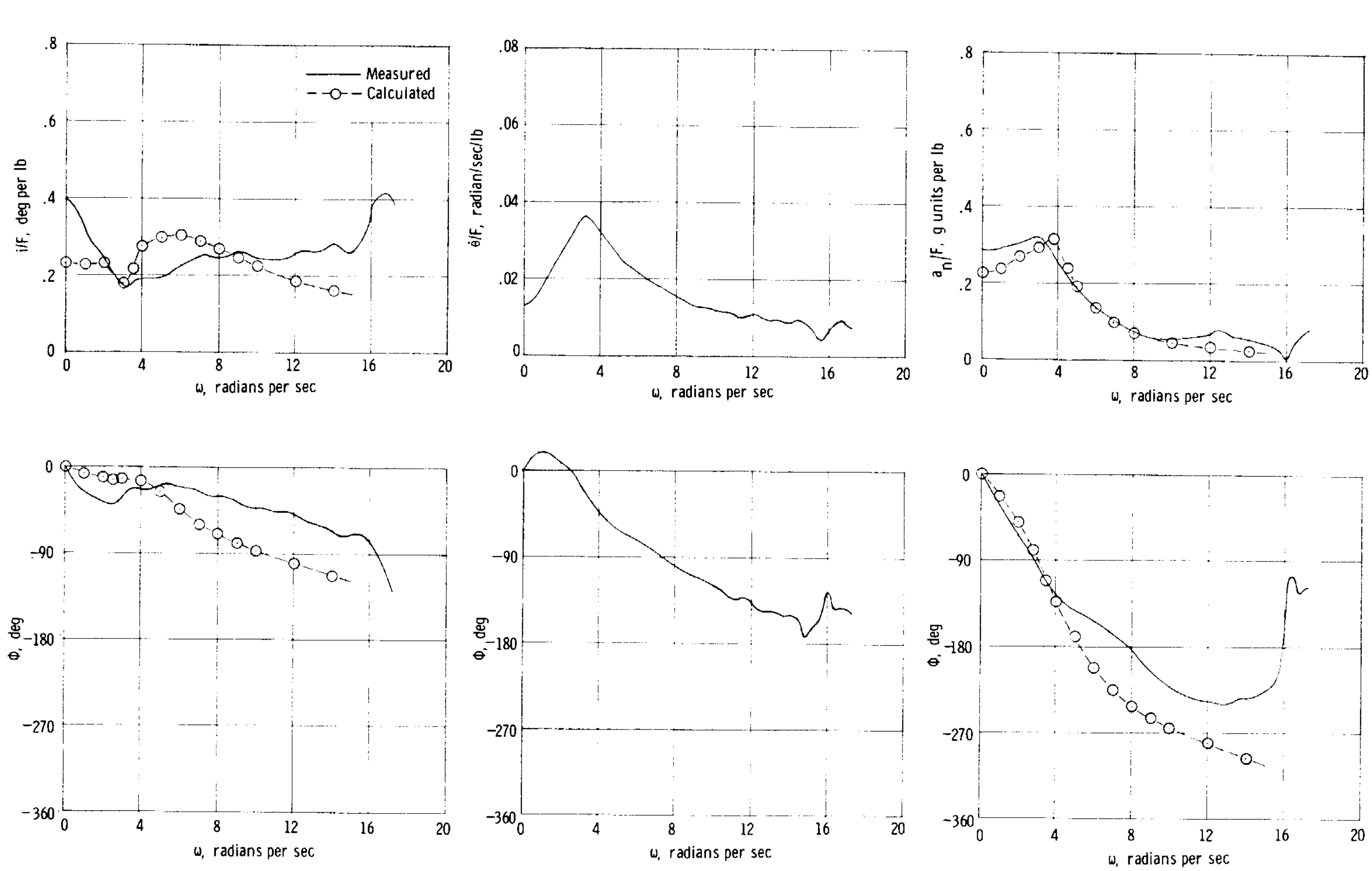

Figure 15.- Comparison of measured and calculated frequency responses with three-way response feel plus small amounts of spring centering and stick-rate damping. $\left(\text{Configuration I, } F_a + F_{\dot{\theta}} + F_{\ddot{\theta}} + \frac{1}{4}F_{\delta} + \frac{1}{2}F_{\dot{\delta}}.\right)$

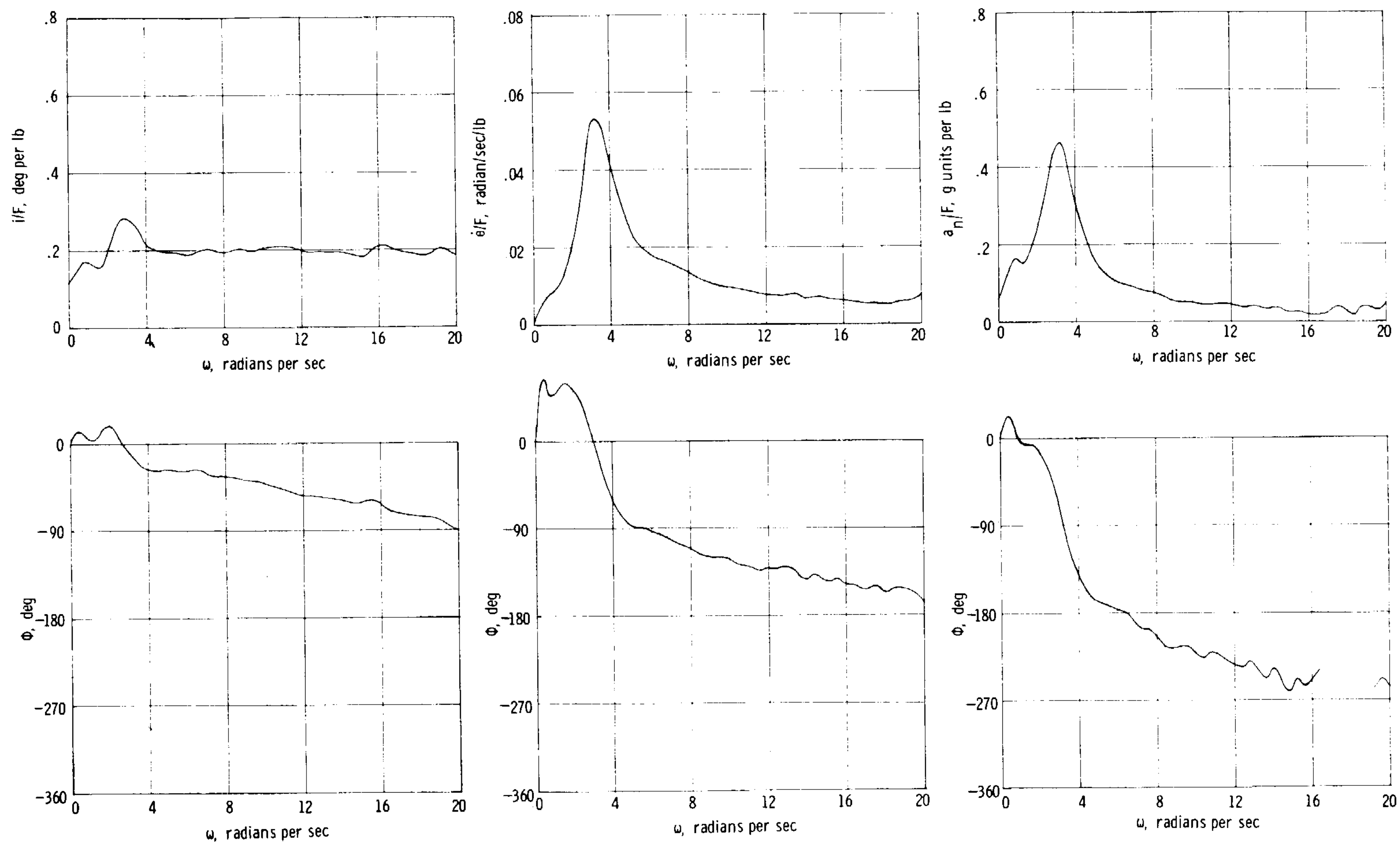

Figure 16.- Measured frequency responses for configuration J. $\left(2F_a + F_{\ddot{\theta}} + \frac{1}{4}F_{\delta} + \frac{1}{2}F_{\dot{\delta}}.\right)$

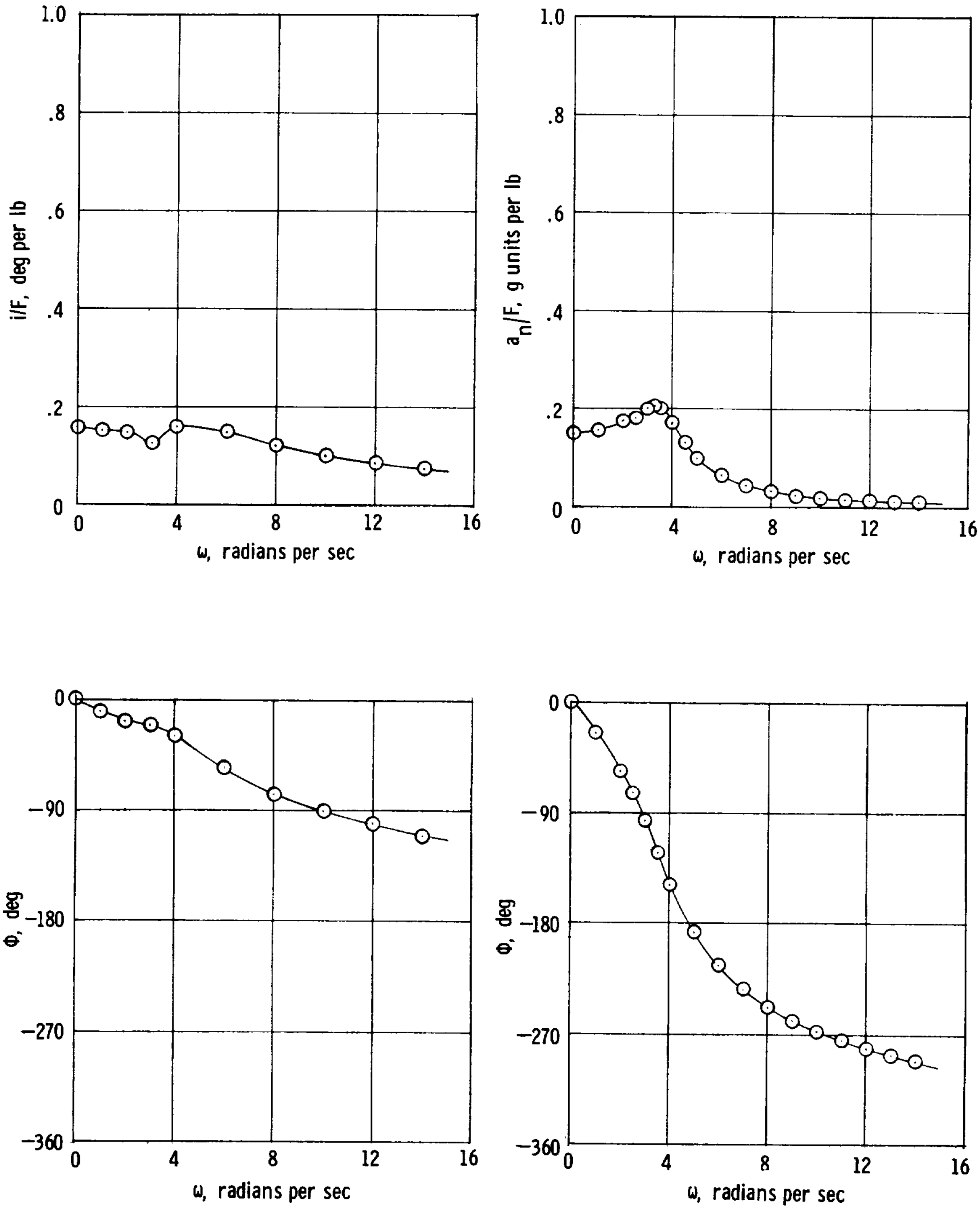

Figure 17.- Calculated frequency responses with a feel component proportional to pitching velocity added to the standard longitudinal feel configuration. (Configuration M, standard + $F_{\dot{\theta}}$.)

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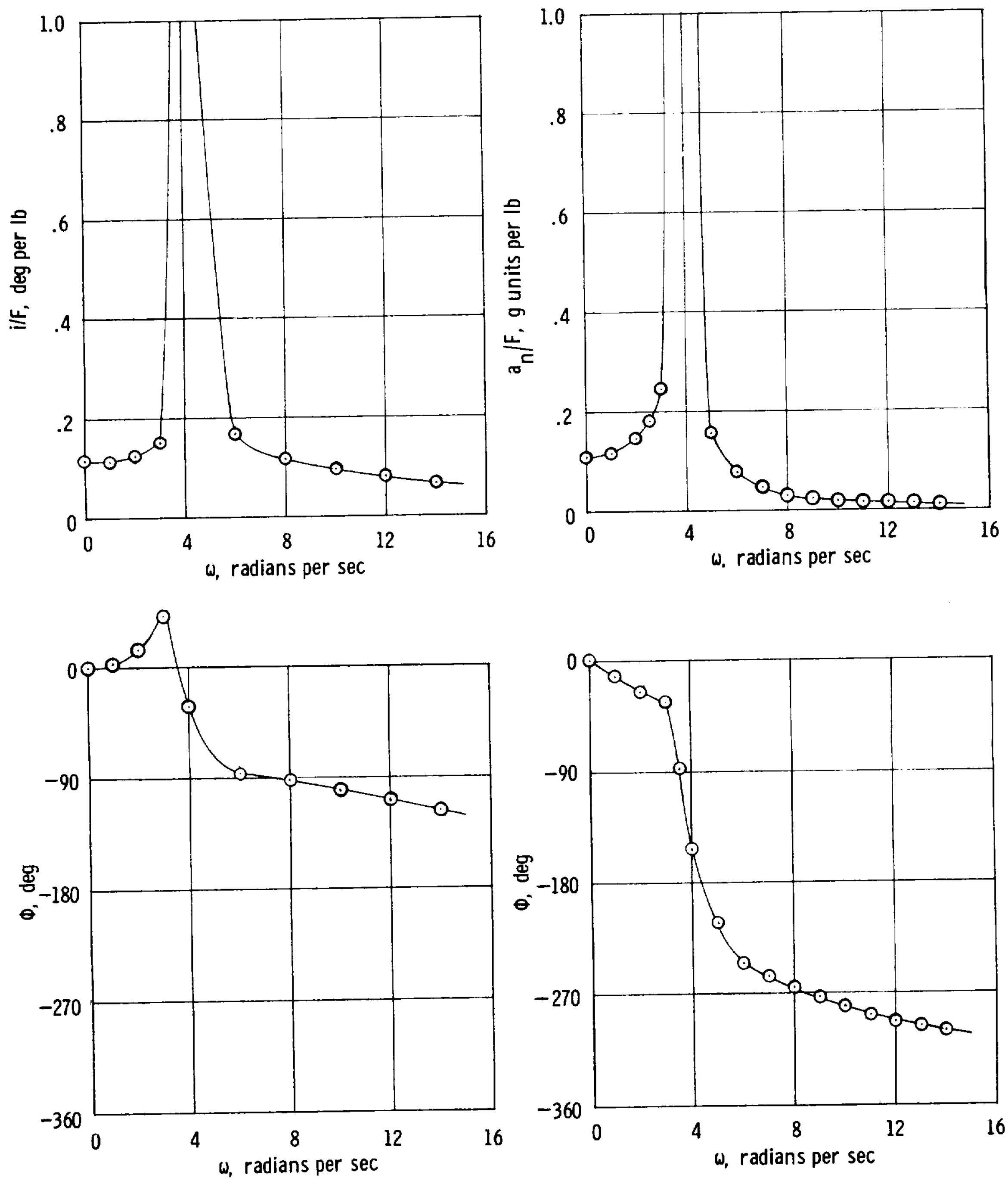

Figure 18.- Calculated frequency responses for configuration P.
$\left(2F_a + \frac{1}{2}F_{\ddot{\theta}} + F_{\delta} + F_{\dot{\delta}}.\right)$

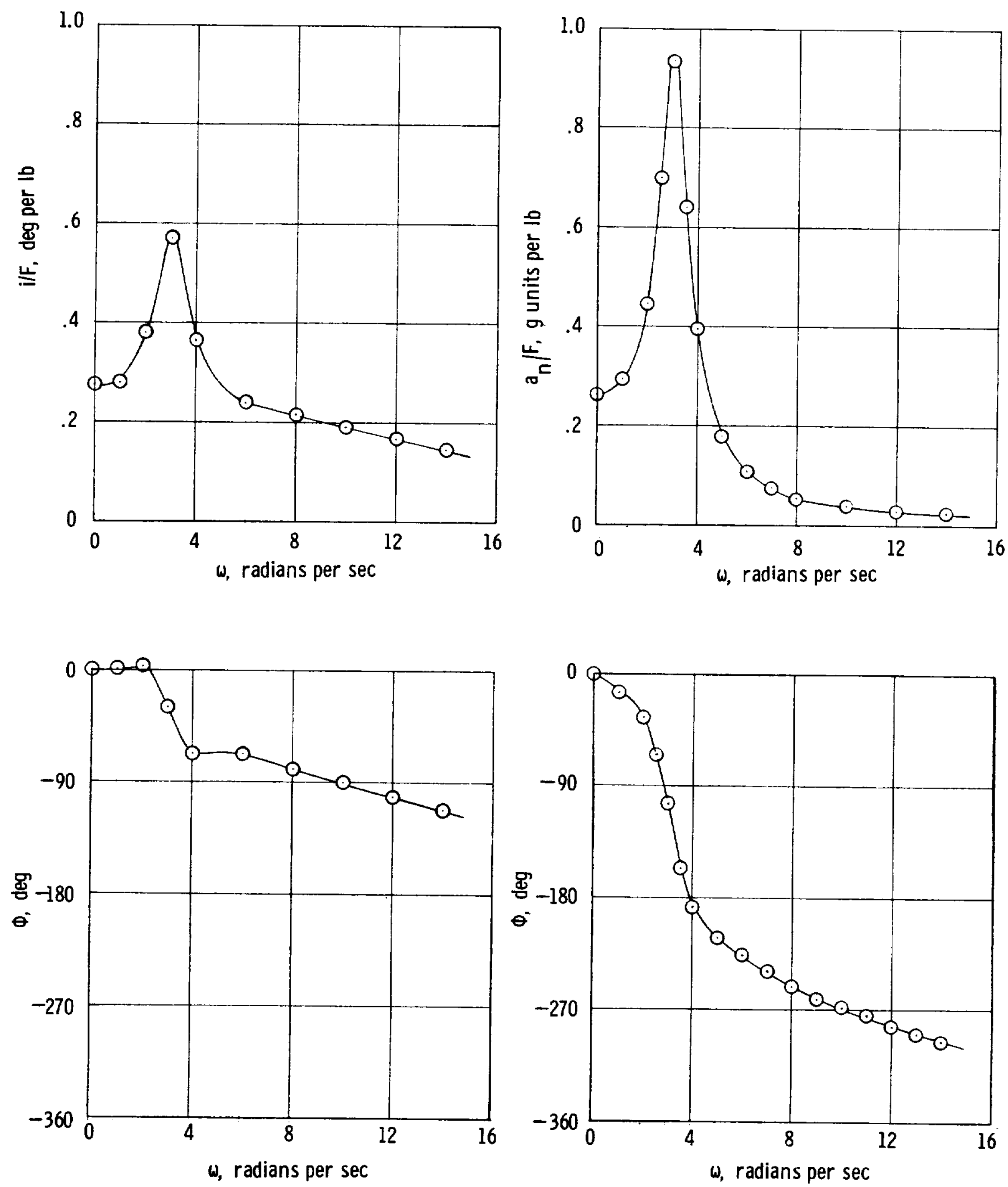

Figure 19.- Calculated frequency responses for configuration Q.
$\left(F_a + F_{\ddot{\theta}} + \frac{1}{4}F_\delta + \frac{1}{2}F_{\dot{\delta}}.\right)$

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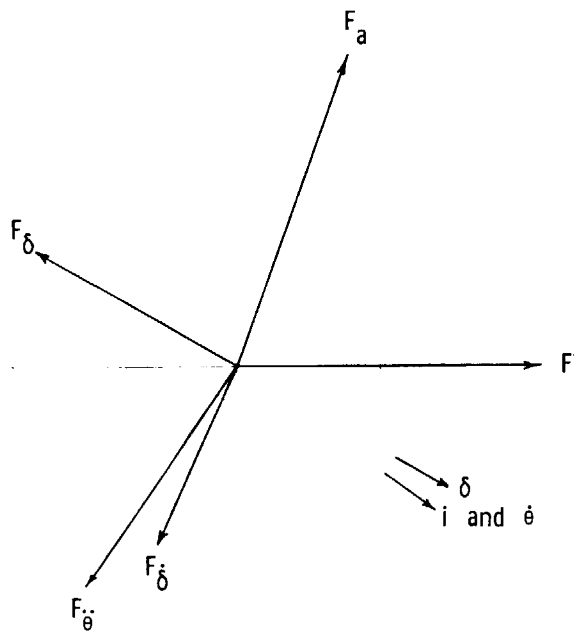
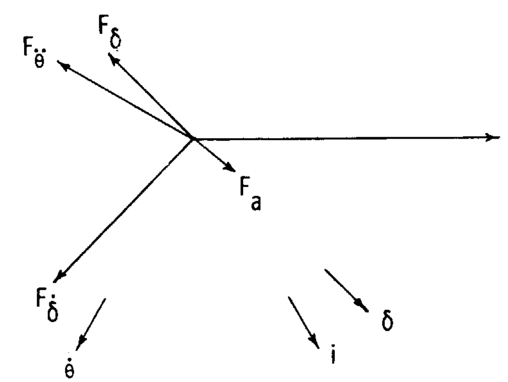


(a) ω = 3 radians/sec.



(b) ω = 6 radians/sec.

Figure 20.- Vector and phase diagrams for the standard feel configuration at two frequencies.

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NASA TN D-912
National Aeronautics and Space Administration.
EFFECTS OF CONTROL-FEEL CONFIGURATION ON AIRPLANE LONGITUDINAL CONTROL RESPONSE. Harold L. Crane and Robert W. Sommer. October 1961. 33p. OTS price, $1.00.
(NASA TECHNICAL NOTE D-912)

A control-feel system, which was adjustable in flight, provided control feel as a function of any combination of stick deflection, stick rate, airplane normal acceleration, pitching acceleration, and pitching velocity. The dynamic effects of using varied feel sources in various ratios were measured and/or calculated. Frequency-response plots are presented to illustrate the dynamic effects of feel from the several sources and combinations thereof. The investigation was conducted at a Mach number of 0.85 and an altitude of 28,000 feet.

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