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FLIGHT INVESTIGATION OF A V/STOL TRANSPORT MODEL HAVING SIX WING-MOUNTED LIFT FANS

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16. Abstract

The investigation consisted of free-flight model tests in hovering and forward flight through the transition speed range up to the speed where conversion would be made to wing-borne flight. Dynamic lateral-directional stability characteristics of the model were also calculated to explain the flight-test results. The model was flyable without artificial stabilization but, in general, angular rate damping was required to make the flight characteristics satisfactory.

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SUMMARY

An investigation has been made in the Langley full-scale tunnel to study the stability and control characteristics of a model of a transport-type V/STOL airplane having six lift fans arranged spanwise in the wing. The investigation included hovering flight out of ground effect and forward flight through the transition speed range up to the speed at which conversion could be made to wing-borne flight. The dynamic lateral-directional stability characteristics of the model for some flight conditions were also calculated to explain the results of the flight tests.

The results of the hovering-flight tests out of ground effect showed that the control-fixed motions of the model without artificial stabilization consisted of unstable oscillations in pitch and roll. The use of artificial rate damping in pitch and roll stabilized the unstable pitching and rolling motions. In forward flight, the model was dynamically stable when the flap was undeflected. When the flap was deflected, no longitudinal instability was encountered, but an unstable Dutch roll oscillation was experienced at angles of attack below 0°. The Dutch roll motion could be stabilized by the use of artificial roll-rate damping.

INTRODUCTION

Lift-fan configurations are of considerable interest for possible application as future V/STOL transport airplanes. Large-scale wind-tunnel investigations of a number of different lift-fan configurations have been made at the NASA Ames Research Center to determine static aerodynamic characteristics; and the results of some of these investigations have been published in references 1 and 2. The NASA Langley Research Center is extending this research to determine the dynamic stability and control characteristics of a similar series of configurations.

The particular configuration studied herein had six lift fans arranged spanwise in a relatively straight wing. The investigation consisted of free-flight tests in the Langley full-scale tunnel to determine the dynamic stability and control characteristics in hovering and transition flight. The forward-flight speeds investigated covered the fan-powered flight range between hovering and the speed at which conversion could be made to wing-borne flight. The conversion maneuver was not investigated but a few flights were made with the fans covered to check the characteristics of the model when flying as a conventional airplane. The results of the free-flight investigation were mainly qualitative and consisted of pilots' observations and opinions of the behavior of the model. The lateral-directional dynamic stability characteristics of the model were also calculated at several trim conditions to explain the results of the flight tests. An extensive force-test investigation of this model was performed previously to define the aerodynamic characteristics of the model; and the results are presented in reference 3.

SYMBOLS

Values are given in both SI and U.S. Customary Units. The measurements and calculations were made in U.S. Customary Units. All forces and moments are referred to the body-axis system.

A,B,C,D,E — coefficients defined in appendix A

c — wing chord, m (ft)

$\bar{c}$ — mean aerodynamic chord, m (ft)

$C_{1/2}$ — cycles required for oscillation to damp to one-half amplitude

C_2 — cycles required for oscillation to double amplitude

C_L — lift coefficient, L/qS

F_Y — side force, N (lb)

g — acceleration due to gravity

I_X — moment of inertia about X body axis, kg-m^2 (slug-ft^2)

I_Y — moment of inertia about Y body axis, kg-m^2 (slug-ft^2)

I_Z — moment of inertia about Z body axis, kg-m^2 (slug-ft^2)

$j = \sqrt{-1}$

L	lift, N (lb)
M_X	rolling moment, m-N (ft-lb)
M_Z	yawing moment, m-N (ft-lb)
m	mass, kg (slugs)
P	period of oscillation, sec
p	rolling velocity, rad/sec
q	dynamic pressure, $\frac{1}{2}\rho V_o{}^2$, N/m^2 (lb/ft^2)
r	yawing velocity, rad/sec
S	wing area, m^2 (ft^2)
s	Laplace operator, $\sigma + j\omega$, 1/sec
$T_{1/2}$	time required for a mode of motion to damp to one-half amplitude, sec
$\frac{1}{T_{1/2}}$	damping parameter, per sec
T_2	time required for a mode of motion to double amplitude, sec
V_o	trim velocity, m/sec (ft/sec)
v	perturbation velocity along Y body axis, m/sec (ft/sec)
X,Y,Z	coordinate axes
α	angle of attack, deg or rad
α_p	angle of attack of principal axis, $\alpha + \eta$, deg or rad
β	angle of sideslip, deg or rad

β_V fan exit-vane angle, measured rearward from fan axis, deg

δ_f flap deflection, deg or rad

ζ ratio of damping present in oscillatory mode of motion to value required for critical damping

η angle of principal axis with respect to body axis, deg or rad

ϕ angle of bank, deg or rad

ρ air density, kg/m^3 (slugs/ft^3)

σ real part of root of characteristic equation, 1/sec

ω imaginary part of root of characteristic equation, rad/sec

ω_n undamped natural frequency of oscillatory mode, rad/sec

Dimensional stability derivatives:

$$Y_V = \frac{1}{m}\frac{\partial F_Y}{\partial v}$$

$$L_p = \frac{1}{I_X}\frac{\partial M_X}{\partial \alpha} \qquad N_p = \frac{1}{I_Z}\frac{\partial M_Z}{\partial p} \qquad Y_p = \frac{1}{m}\frac{\partial F_Y}{\partial p}$$

$$L_r = \frac{1}{I_X}\frac{\partial M_X}{\partial r} \qquad N_r = \frac{1}{I_Z}\frac{\partial M_Z}{\partial r} \qquad Y_r = \frac{1}{m}\frac{\partial F_Y}{\partial r}$$

$$L_\beta = \frac{1}{I_X}\frac{\partial M_X}{\partial \beta} \qquad N_\beta = \frac{1}{I_Z}\frac{\partial M_Z}{\partial \beta}$$

APPARATUS AND TESTS

Model

General characteristics.- Photographs of the model used in the investigation are shown as figure 1, and a three-view drawing of the model is shown in figure 2. A list of the mass and geometric characteristics of the model is presented in table I. The six lift fans mounted in the wing were powered by turbine blades fixed around the circumference of the rotor and were driven by compressed air. Each fan (the direction of fan rotation is indicated in fig. 2) was provided with a set of louver-type vanes mounted across the fan exits as shown in figure 3. The vanes were operated remotely and were used to direct the fan slipstream for forward propulsion through the transition speed range. The wing trailing edge could be removed and replaced by an alternate trailing edge having a full-span single-slotted flap as shown in figure 3. When the undeflected trailing edge was in place, an aileron surface was present.

Controls.- For this investigation, jet-reaction controls were used about the three-body axes of the model for attitude control, and height control was obtained by changing the fan speed. Jets at the wing tips gave roll control and jets at the tail gave yaw and pitch control.

The maximum jet-reaction control moments available and the accelerations produced by these moments were

Axis	Control moment		Acceleration
	m-N	ft-lb	rad/sec^2
Pitch	25.5	18.8	1.9
Roll	14.0	10.3	1.5
Yaw	21.0	15.5	1.1

The ailerons, when mounted, and the rudder were interconnected to the roll and yaw control jets so that the aerodynamic surfaces operated to give a combination control whenever a control input was made by the pilot (even in hovering flight).

The jet-reaction controls were operated by flicker-type (full-on or full-off) pneumatic mechanisms which were remotely operated by the pilots by means of solenoid-operated valves. Each actuator had a motor-driven trimmer which was electrically operated by the pilots so that controls could be rapidly trimmed independently of the flicker controls. The horizontal-tail incidence angle could be changed remotely by the pitch pilot and was considered to be the primary pitch trimming device.

Both the roll control and the pitch control were connected to a stability-augmentation device. The devices consisted of roll-rate-sensitive and pitch-rate-sensitive gyroscopes that provided signals to servomechanisms connected to the roll control and pitch control which moved the controls to oppose a rolling or pitching motion.

Test Equipment and Setup

The test setup for the free-flight tests made in the Langley full-scale tunnel is shown in figure 4. The model was flown without restraint in the 9- by 18-m (30- by 60-ft) open-throat test section of the tunnel and was remotely controlled about all three axes by human pilots. The pilots who controlled the model about its roll and yaw axes were located in an enclosure at the rear of the test section where they could best view the lateral-directional motions of the model. The pitch pilot, model power operator, and safety-cable operator were stationed at the side of the test section. Pneumatic and electric power and control signals were supplied to the model through the flexible trailing cable which was made up of wires and light plastic tubes. This trailing cable also incorporated a 0.318-cm (1/8-in.) steel cable that passed through a pulley above the test section. This cable was used as a safety cable to catch the model if an uncontrollable motion or mechanical failure occurred. The reasons for using this model flight technique in which the piloting duties are divided, in preference to the conventional single-pilot technique, is explained in detail in reference 4. In the tests made with the fans covered (conventional airplane configuration), the two pilots were used with one pilot controlling both roll and yaw and the other controlling pitch.

As a typical flight began, the model hung from the safety cable with zero tunnel airspeed. The tunnel drive motors were then started and the particular airspeed was established. The compressed-air power to the model fans was then increased and adjustment was made to the fan-exit vanes until the model was in equilibrium flight at the desired attitude and airspeed.

Tests

The investigation consisted of free-flight tests to determine the dynamic stability and control characteristics of the model during hovering flight out of ground effect and in fan-powered forward flight up to a speed of about 19.2 m/sec (63 ft/sec). This speed was approximately that at which conversion to wing-borne flight would be made. The conversion maneuver was not investigated because of the model mechanical limitations but a few flights were made with the fans covered to check the characteristics of the conventional airplane configuration. Propulsion for these conventional-flight tests was supplied by thrust from a compressed-air jet exhausting at the rear of the fuselage. The results of all tests were mainly qualitative and consisted of pilot's observations of and opinions on the behavior of the model. Motion pictures were made of all flights for further study.

The hovering tests out of ground effect were performed by hovering the model at a height of 4.6 to 6.1 m (15 to 20 ft) above the groundboard in the tunnel test section. In these tests the uncontrolled pitching and rolling motions and the ease with which these motions could be stopped after they had been allowed to develop were examined.

Forward-flight tests were made at various fixed airspeeds to determine the stability and control characteristics of the model in the fan-powered flight range.

CALCULATIONS

The lateral-directional dynamic stability characteristics of the model were calculated to explain the free-flight results. The linearized equations of motion used are presented in the appendix. The aerodynamic static data used in the calculations were based on the results of wind-tunnel tests presented in reference 3, and the dynamic derivatives were taken from forced-oscillation tests; these data are given in table II. The results of the calculations are presented in terms of the period of an oscillation P and the damping parameter $\frac{1}{T_{1/2}}$. Positive values of $\frac{1}{T_{1/2}}$ denote stable modes of motion, whereas negative values of this parameter denote unstable modes of motion. The calculated results are given in table III.

RESULTS AND DISCUSSION

A motion-picture film supplement (L-1096) has been prepared and is available on loan. A request card and a description of the film will be found at the back of this paper.

Hovering Flight

In hovering flight out of ground effect and without artificial stabilization, the model had unstable control-fixed motions in both pitch and roll. Figure 5 shows time histories of typical pitch and roll motions which were obtained from motion-picture records of flight tests in which the pilot held the control in a neutral position and allowed the motion to develop. In spite of the fact that the model had unstable control-fixed pitching and rolling motions, the pilots felt that the model was fairly easy to control because the period was sufficiently long. They could control the motions easily, and the model could be flown fairly smoothly and could be maneuvered easily from one place to another. Although the model was easy to control without artificial stabilization, the pilots were aware of some disturbances from the slight random fluctuations in the recirculating fan slipstream in the area where the tests were made. No measurements except qualitative observations of persons standing in the test area have been made with this, or any other model, to determine the gustiness of the air in the test area. From such observations, however, it seems that the velocity changes involved in the disturbances are probably small compared with those that would be encountered outdoors on a gusty day, but they might have been more frequent than outdoor gust disturbances.

Hovering-flight tests were also made to study the effect of increased damping in roll and pitch on the hovering-flight characteristics of the model. In these tests the addition of artificial rate damping completely stabilized the model so that it no longer had unstable oscillations. The use of artificial stabilization also reduced the response to the random disturbances to the point that the pilot effort to control the pitching and rolling motions was almost limited to making corrections to changes in trim.

The model had about neutral stability in yaw during hovering flights, and the only yaw control inputs required were those needed to keep the model properly oriented with respect to the various pilots. The yaw pilot had no difficulty in maintaining a constant heading during the hovering tests.

Forward Flight

The forward-flight tests were made in the steady-level-flight condition for the flight range from hovering to about 19.2 m/sec (63 ft/sec) $(C_L = 1.3)$. This speed corresponds approximately to the point at which conversion to wing-borne flight would be made. The relation between the speeds used in the tests and the exit-vane deflection angles is shown in figure 6.

Test flights in the transition range were made for both the flap-undeflected and flap-deflected configurations because no attempt was made to determine optimum points in the transition for the flaps to be deflected or undeflected. In general, the longitudinal stability characteristics of the model seemed to be independent of flap configuration, but the lateral-directional characteristics deteriorated when the flap was deflected.

Longitudinal stability.- The basic stability of the model throughout the fan-powered flight range was determined during constant-airspeed flight tests with no artificial stabilization. The pitch pilot experienced no difficulty with longitudinal stability or control at any point in the transition speed range for either flap configuration.

During the flights in the conventional flight mode with the fans inoperative and covered, the pitch pilot found that the model flew well and he had no trouble with the longitudinal stability.

Lateral-directional stability.- With flap undeflected, the model flew quite well and was fairly easy to control in roll even though the roll control was considered to be weak. The fans provided a high degree of damping in roll so that the pilot expressed the opinion that the rolling motion was well damped. Tests with the roll damper in operation showed that the added damping served to reduce the pilot workload even though it was not actually needed for smooth flying.

With flap deflected, the model was continually being disturbed by apparent flow separation on the flaps. This flow problem with the flaps deflected, which had been noted in the tests of references 2 and 3, has been attributed to blockage of the flap by the fan exhaust. The continual disturbance of the model made the roll pilot's task much more difficult and the problem was compounded by the somewhat weak control but relatively smooth flights could be made without artificial stabilization with close attention to the control.

Although the roll problem just discussed was important, the most serious lateral-directional problem was an unstable Dutch roll oscillation encountered at angles of attack below 0° with flaps deflected. At 14.3 m/sec (47 ft/sec), $\beta_V = 20^{\circ}$, the Dutch roll motion was so unstable that the roll pilot lost control at $\alpha = -5^{\circ}$. At the highest speed tested, 19.2 m/sec (63 ft/sec), $\beta_V = 45^{\circ}$, the roll pilot was able to retain control but expressed the opinion that at slightly negative angles of attack the Dutch roll motion was "very lightly damped and appears almost unstable." At an angle of attack of 0°, however, the Dutch roll motion of the model was definitely stable. Tests with the roll damper in operation showed that artificial damping completely stabilized the model so that no further difficulty was experienced by the roll pilot. In order to determine the cause of the unstable Dutch roll motion at $\alpha = -5^{\circ}$, calculations were made of the dynamic lateral-directional characteristics. The results of the calculations are presented in table III and figures 7 to 9.

The results presented in figure 7 show the characteristics of the lateral-directional oscillation for $\alpha = 0^{\circ}$ at the various exit vane angles investigated. (The data presented for $\beta_V = 0^{\circ}$ are based on the flight results presented in fig. 5(b).) The results indicate that as β_V increases (trim airspeed increases), the unstable oscillation of hovering flight becomes less unstable and finally becomes dynamically stable at about $\beta_V = 40^{\circ}$. It should be noted that the calculations indicate that with $\alpha = 0^{\circ}$ the Dutch roll oscillation at $\beta_V = 45^{\circ}$ should be stable; this result is in agreement with free-flight results. The effects of angle of attack on the Dutch roll characteristics for $\beta_V = 45^{\circ}$ are presented in figure 8. The results show that when the angle of attack is changed from 0° to -5°, the Dutch roll becomes unstable ($T_{1/2} = -2.81$ sec), as was found in the flight tests. Additional calculations were made for $\alpha = -5^{\circ}$ to determine which parameters caused the degradation in stability. For these calculations, the values of various parameters at $\alpha = -5^{\circ}$ were changed to equal those at $\alpha = 0^{\circ}$. These changes included alining the principal longitudinal axis with the flight path (α_p). As can be seen in figure 8, changes in a number of parameters, including α_p, L_β, N_β, and N_r, caused the unstable Dutch roll motion.

The effects of artificial rate damping were calculated by assuming arbitrary increases in the damping-in-roll derivative L_p. The results presented in figure 9 show that the unstable oscillation could be made stable if the damping in roll was increased by a factor of about 2.5. This result tends to be in agreement with the free-flight test results.

The model had a high degree of directional stability and it was found that during most of the tests, no yaw control was needed for smooth easy flights. During the flap-deflected tests, it was found that not only was yaw control not needed to control random yawing motions, but also yaw control inputs were detrimental in that rolling motions which caused severe difficulties for the roll pilot were induced. No artificial stabilization was used in yaw at any time during the entire investigation.

When the flight tests were made in the conventional flight mode with the fans inoperative and covered (flap undeflected), the rudder and the roll control were connected electrically and operated as a coordinated control by one pilot. The model was easy to control in this condition and showed no problems with either static or dynamic lateral-directional stability.

Application of Results to Full-Scale Aircraft

There have been about 10 cases in which flight tests on V/STOL models in the wind tunnel such as the present series can be compared with flight tests of a full-scale airplane of the same configuration. On the basis of this experience, it is possible to interpret some of the qualitative pilot evaluation of the handling qualities of the model in terms of its significance to a full-scale airplane. The stability characteristics such as period and damping, of course, simply scale according to conventional scaling relations based on similar Froude number and relative density factor.

The fact that the pilots of the model found it to be easy to fly in hovering flight in spite of the oscillatory instabilities in both pitch and roll is considered to indicate that a full-scale airplane would be easy to control in visual flight. Experience has shown, however, that a high degree of automatic stabilization is required for hovering flight on instruments. The pilot would not be expected to be aware of the fact that the model had unstable oscillations because the period of the oscillation is so long that he would sense the initial divergence and correct for it before it became apparent that the initial divergence would arrest itself and develop into an oscillation.

For the transition-flight range, the longitudinal stability was about as good as that of any V/STOL model previously tested and would be expected to be satisfactory for visual flight. The unstable Dutch roll motion experienced with flap deflected at $\alpha = -5^{\circ}$ would be unacceptable and would have to be corrected in order for the airplane to be considered acceptable, even for visual flight. Since full-scale test experience has shown that no V/STOL airplane tested to date has had sufficient damping for flight on instruments, it can be assumed that the present configuration would also require substantial artificial stabilization for precision tasks such as final approach on instruments and thus a stabilization system would be available when needed to stabilize the Dutch roll motion.

SUMMARY OF RESULTS

Free-flight model tests of a V/STOL transport-type airplane with six wing-mounted lift fans yielded the following results:

1. Hovering-flight tests out of ground effect showed that the basic control-fixed flight characteristics without artificial stabilization were unstable oscillations in pitch and roll. The period of the oscillation was fairly long, however, so that the initial rate of divergence was low, and the model was reasonably easy to control in spite of the instability.

2. No difficulty was experienced with longitudinal stability or control at any point in the transition speed range for either flap configuration.

3. With flap deflected, the model had an unstable Dutch roll oscillation at angles of attack below 0° over the entire transition speed range. The Dutch roll motion was overcome by the use of artificial roll-rate damping.

4. The model had a high degree of directional stability through the transition speed range and very few yaw control inputs were needed for most forward-flight test conditions.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., February 13, 1971.

APPENDIX A

LATERAL-DIRECTIONAL EQUATIONS OF MOTION

The linearized, small-perturbation lateral-directional equations of motion used were:

Side force:

$$\left(s - Y_v\right)\beta + \left(-sY_p - \frac{g}{V_o}\right)\phi + \left(-Y_r + 1\right)r = 0 \tag{A1}$$

Rolling moment:

$$-L_\beta\beta + \left(s^2 - sL_p\right)\phi - L_r r = 0 \tag{A2}$$

Yawing moment:

$$-N_\beta\beta - sN_p\phi + \left(s - N_r\right)r = 0 \tag{A3}$$

where $\beta = \frac{v}{V_o}$.

For nontrivial solutions, s must be a root of the characteristic equation

$$As^4 + Bs^3 + Cs^2 + Ds + E = 0 \tag{A4}$$

where

$$A = 1$$

$$B = -Y_v - L_p - N_r$$

$$C = N_\beta + L_pN_r - L_rN_p + Y_v\left(L_p + N_r\right) - L_\beta Y_p - N_\beta Y_r$$

$$D = L_\beta N_p - L_pN_\beta - Y_v\left(L_pN_r - L_rN_p\right) - \frac{g}{V_o} L_\beta - L_\beta\left(Y_rN_p - N_rY_p\right)$$
$$+ N_\beta\left(Y_rL_p - L_rY_p\right)$$

$$E = \frac{g}{V_o}\left(L_\beta N_r - L_rN_\beta\right)$$

The damping and period of a mode of motion, in seconds, are given by the equations $T_{1/2} = -\frac{0.693}{\sigma}$ and $P = \frac{2\pi}{\omega}$, respectively, where σ and ω are the real and imaginary parts of the roots of the stability equation. Additional stability characteristics may be obtained by the following relations:

$$\left.\begin{aligned} C_{1/2} &= \frac{T_{1/2}}{P} \\ \omega_n &= \sqrt{\sigma^2 + \omega^2} \\ \zeta &= -\frac{\sigma}{\omega_n} \end{aligned}\right\} \tag{A5}$$

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TABLE I.- MASS AND GEOMETRIC CHARACTERISTICS OF THE MODEL

Weight	378 N (85 lb)
Moment of inertia:	
I_X	9.37 kg-m^2 (6.91 slug-ft^2)
I_Y	13.59 kg-m^2 (10.02 slug-ft^2)
I_Z	18.48 kg-m^2 (13.63 slug-ft^2)
Fuselage:	
Length	223.5 cm (7.33 ft)
Cross-sectional area, maximum	1244.9 cm^2 (1.34 ft^2)
Wing:	
Area	12 866.6 cm^2 (13.85 ft^2)
Span	228.1 cm (7.48 ft)
Aspect ratio	4.05
Mean aerodynamic chord	57.6 cm (1.89 ft)
Tip chord	42.4 cm (1.39 ft)
Root chord	70.7 cm (2.32 ft)
Taper ratio	0.60
Dihedral angle	0°
Thickness ratio	0.15
Airfoil section	NACA CYH
Aileron, each:	
Chord, percent wing chord	20
Area	343.7 cm^2 (0.37 ft^2)
Flap, each:	
Type	Single slotted
Chord, percent wing chord	30
Span	Full
Fans:	
Diameter	20.3 cm (0.667 ft)
Exit-vane chord	2.8 cm (0.092 ft)
Number of vanes	9
Vertical tail:	
Area	1932.3 cm^2 (2.08 ft^2)
Span	48.8 cm (1.60 ft)
Aspect ratio	1.23
Root chord	49.7 cm (1.63 ft)
Tip chord	29.9 cm (0.98 ft)
Airfoil section	NACA 0012
Rudder:	
Chord	8.8 cm (0.29 ft)
Span	46.3 cm (1.52 ft)
Tail length, center of gravity to 0.25 mean aerodynamic chord	94.5 cm (3.10 ft)
Horizontal tail:	
Area	3864.6 cm^2 (4.16 ft^2)
Span	147.2 cm (4.83 ft)
Aspect ratio	5.60
Root chord	35.7 cm (1.17 ft)
Tip chord	16.8 cm (0.55 ft)
Taper ratio	0.47
Dihedral angle	0°
Pivot position	0.39 root chord
Airfoil section	NACA 0012
Elevator each:	
Root chord	10.7 cm (0.35 ft)
Tip chord	6.4 cm (0.21 ft)
Span	56.7 cm (1.86 ft)
Tail length, center of gravity to 0.25 mean aerodynamic chord	104.5 cm (3.43 ft)

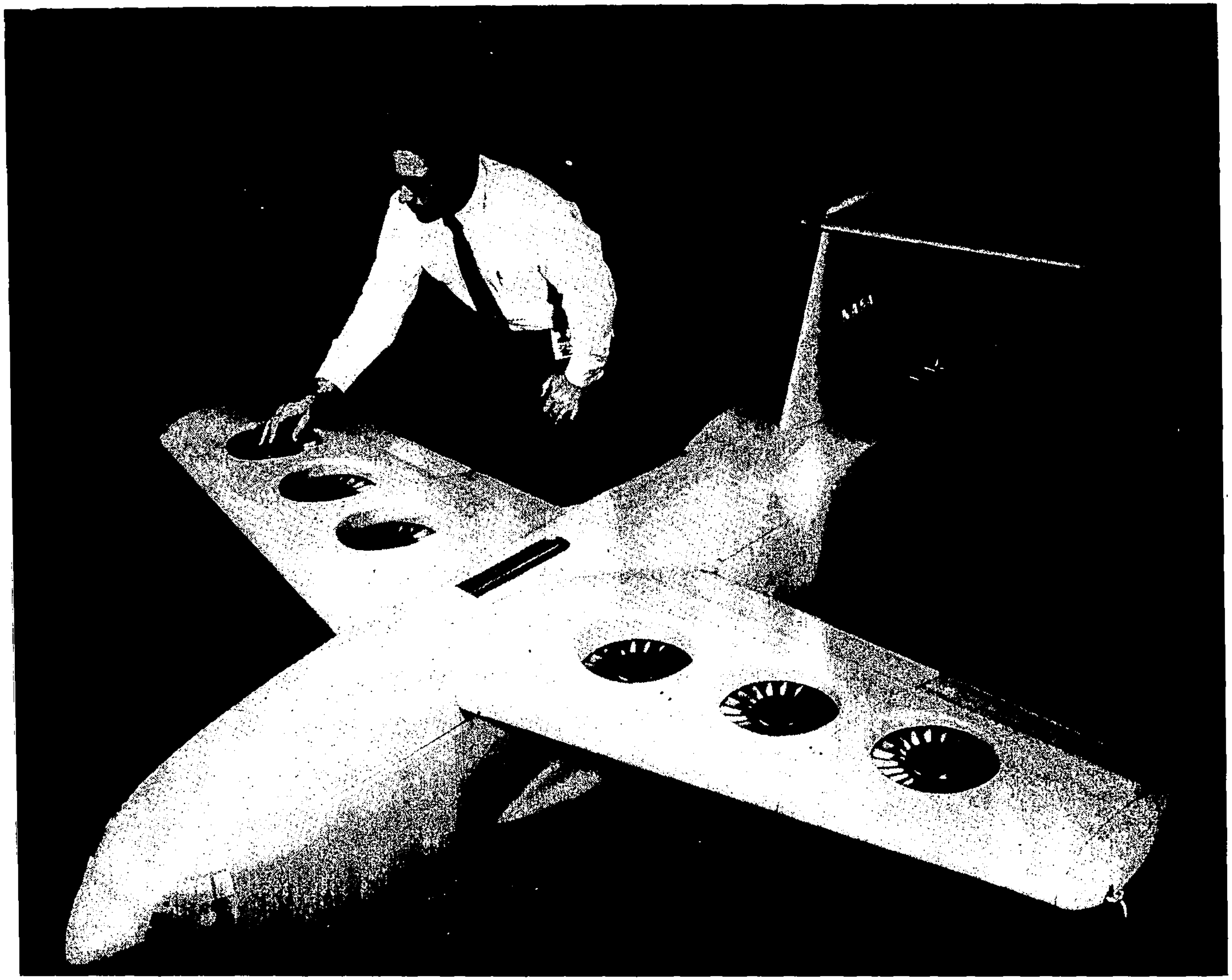
TABLE II.- LATERAL-DIRECTIONAL STABILITY DERIVATIVES

β_v, deg	α, deg	V_o		Y_v, per sec	Y_p		Y_r		L_β, per sec^2	L_p, per sec	L_r, per sec	N_β, per sec^2	N_p, per sec	N_r, per sec
		m/sec	ft/sec		m/sec	ft/sec	m/sec	ft/sec						
20	0	12.80	42.0	-0.50	0	0	0	0	-13.89	-1.35	0.95	3.58	-0.23	-0.50
30	0	15.85	52.0	-.43	0	0	0	0	-16.04	-1.53	1.18	4.92	-.25	-.64
45	0	17.40	57.1	-.53	0	0	0	0	-15.00	-1.71	1.45	7.28	-.14	-.46
45	5	15.76	51.7	-.39	0	0	0	0	-16.94	-1.76	1.55	5.41	-.26	-.65
45	-5	19.35	63.5	-.50	0	0	0	0	-15.00	-1.71	1.45	7.28	-.14	-.46
90 (Cruise)	0	30.48	100.0	-.60	0	0	0	0	-25.24	-3.16	-2.83	133.36	-.27	-.54

TABLE III.- SUMMARY OF CALCULATED LATERAL-DIRECTIONAL DYNAMIC STABILITY CHARACTERISTICS

β_v, deg	α, deg	Mode	σ	ω	$T_{1/2}$, sec	P, sec	$C_{1/2}$ (*)	ω_n	ζ (*)
20	0	Oscillatory	0.283	±2.559	-2.45	2.455	-1.00	2.57	-0.11
		Aperiodic	-2.764	0	.25				
		Aperiodic	-.147	0	4.71				
30	0	Oscillatory	.151	±2.757	-4.60	2.279	-.50	2.76	-.05
		Aperiodic	-2.764	0	.25				
		Aperiodic	-.129	0	5.39				
45	0	Oscillatory	-.081	±3.038	8.57	2.068	.24	3.04	.026
		Aperiodic	-2.630	0	.26				
		Aperiodic	.083	0	-8.37				
45	5	Oscillatory	-.028	±3.017	25.00	2.082	.08	3.02	.009
		Aperiodic	-2.704	0	.25				
		Aperiodic	-.034	0	20.30				
45	-5	Oscillatory	.246	±3.030	-2.81	2.073	-.74	3.04	-.081
		Aperiodic	3.262	0	.21				
		Aperiodic	-.025	0	27.62				
90 (Cruise)	0	Oscillatory	-5.287	±11.627	1.31	.540	.41	11.64	.045
		Aperiodic	-3.489	0	.20				
		Aperiodic	.248	0	-2.80				

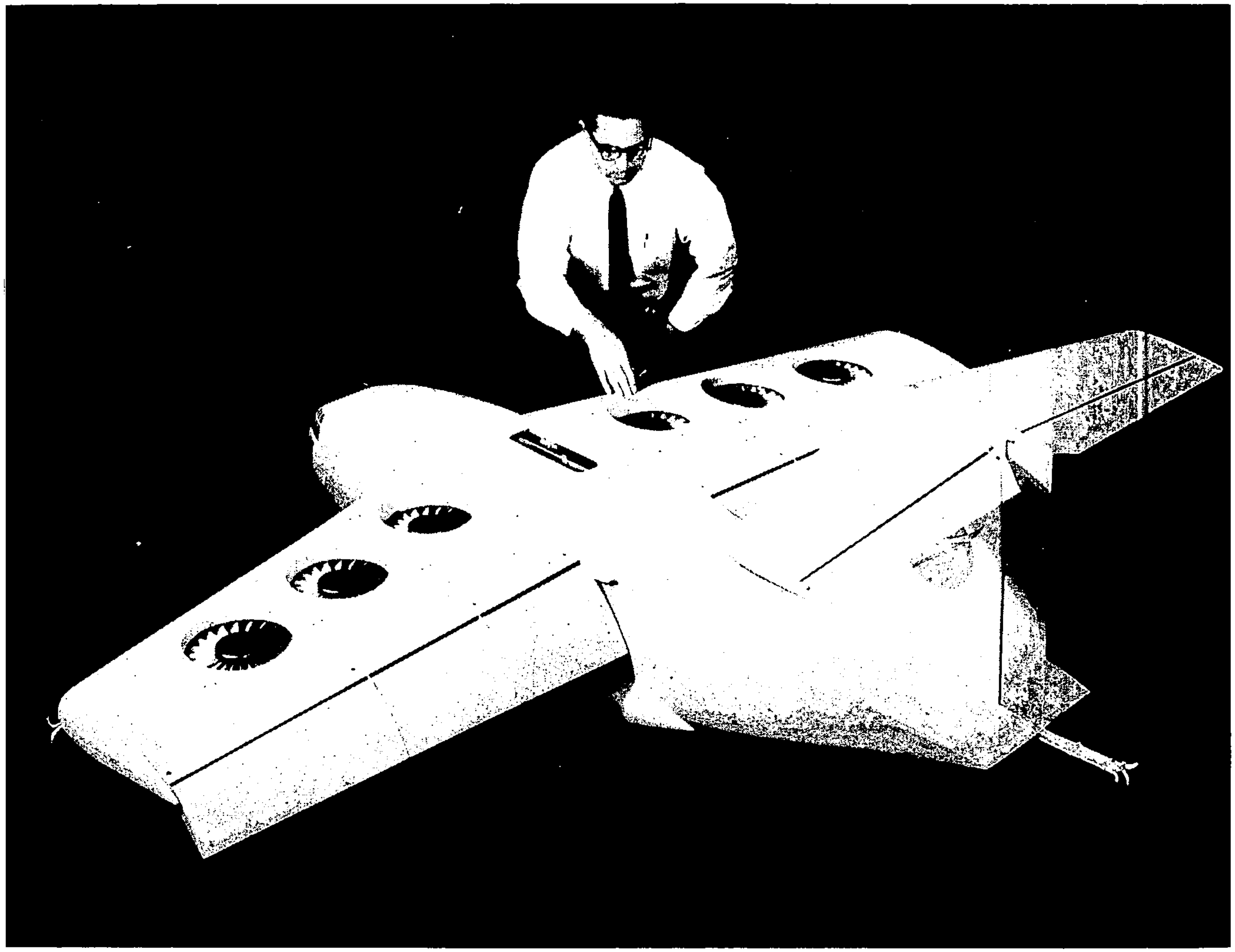
*Negative signs indicate unstable modes of motion. For example, if $T_{1/2} = -2.45$, then $T_2 = 2.45$; or if $C_{1/2} = -1.00$, then $C_2 = 1.00$.



L-67-7852

(a) Three-quarter front view.

Figure 1.- Photographs of model.



L-67-7853

(b) Three-quarter rear view.

Figure 1.- Concluded.

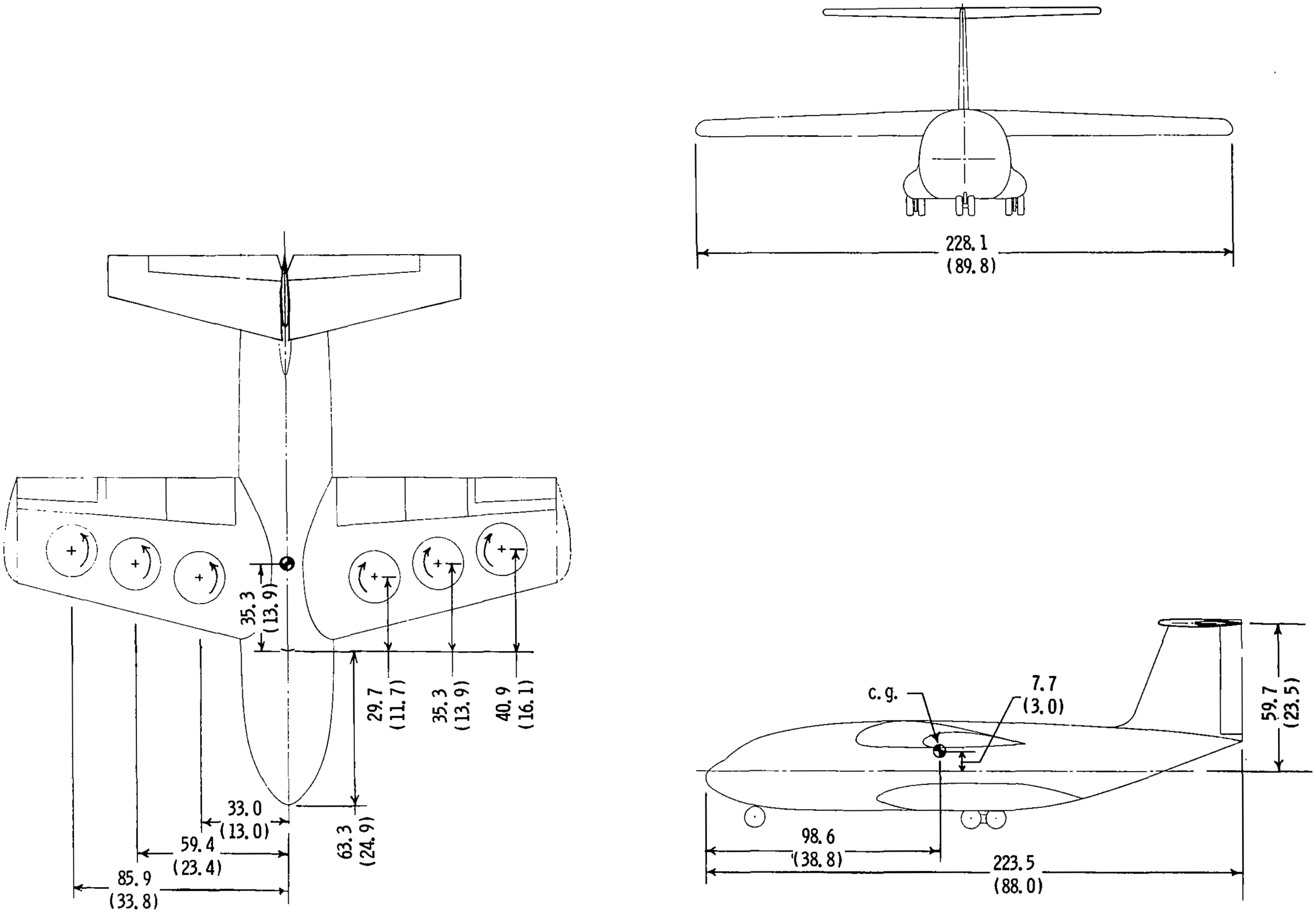


Figure 2.- Sketch of model. Dimensions are given first in centimeters and parenthetically in inches.

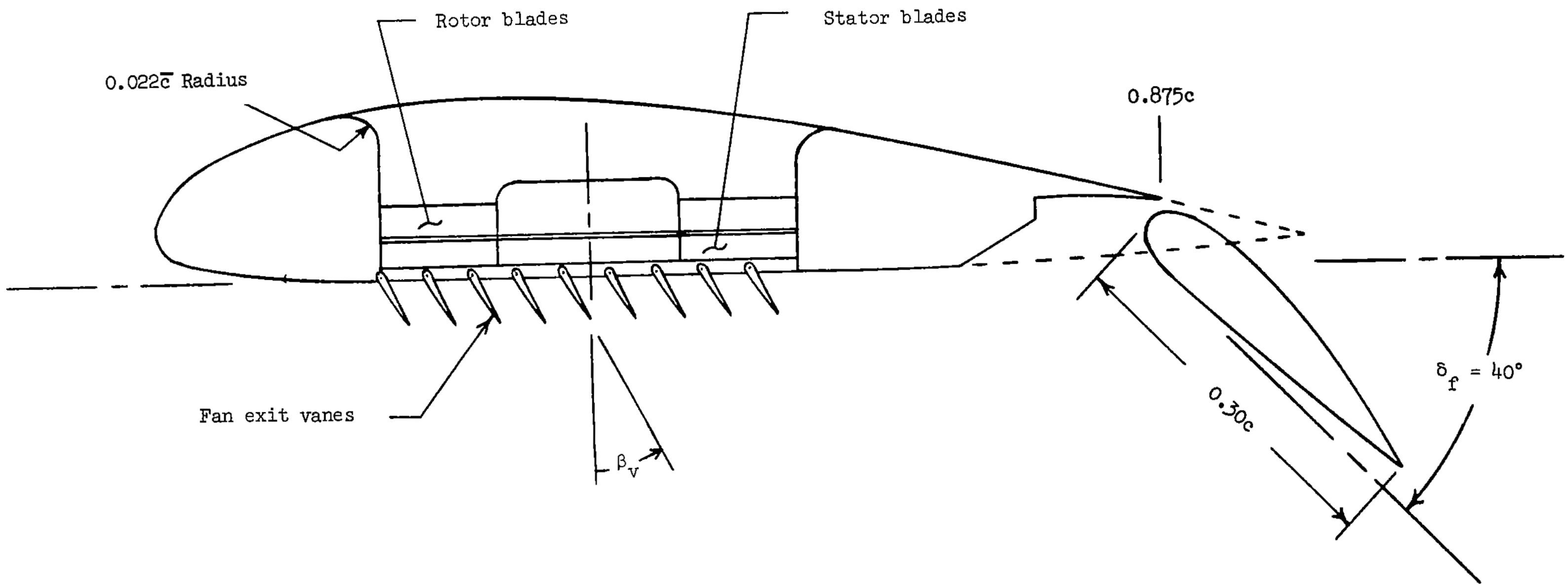


Figure 3.- Typical section through wing and fan showing position of fan and fan exit vanes.

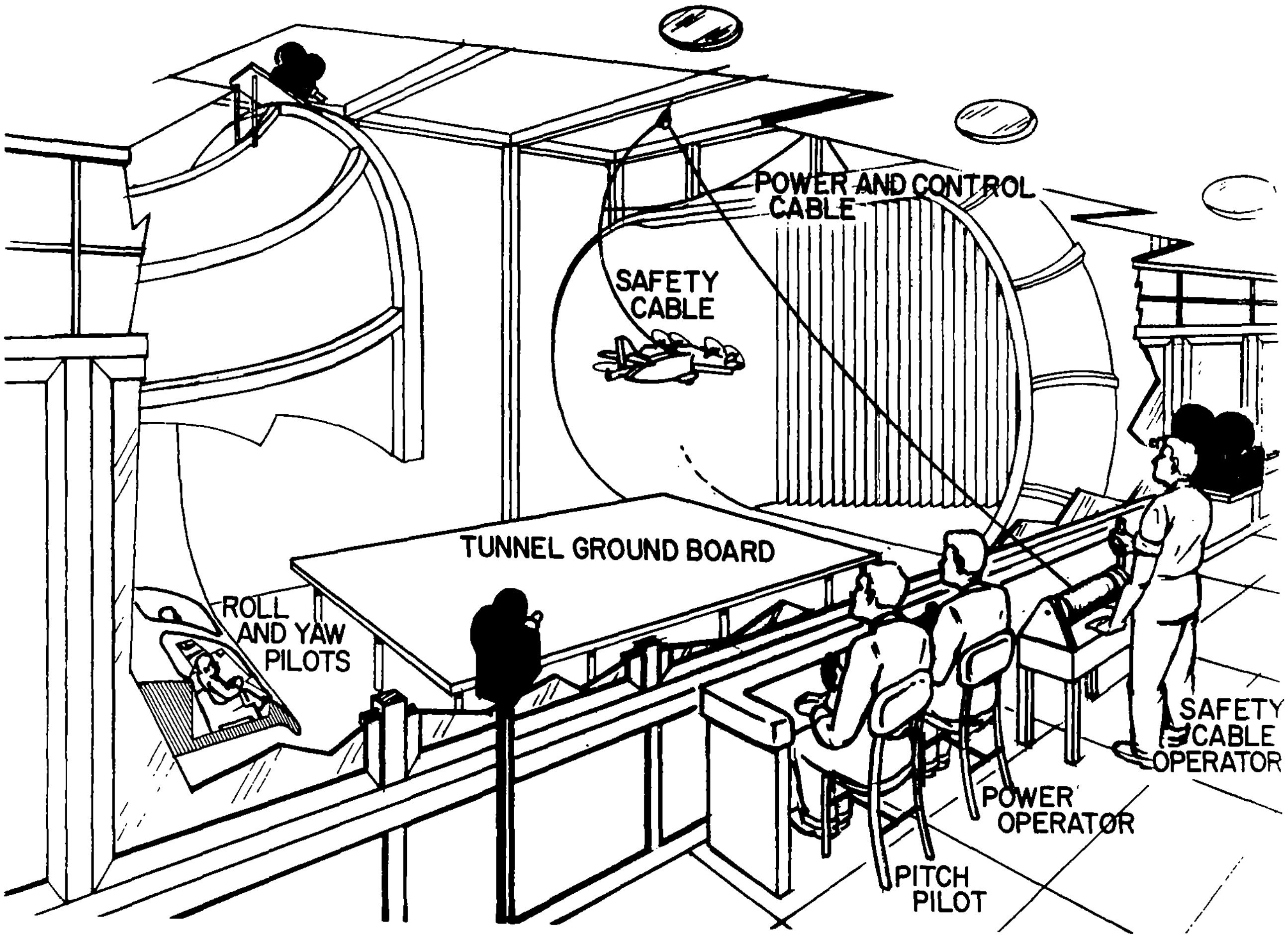


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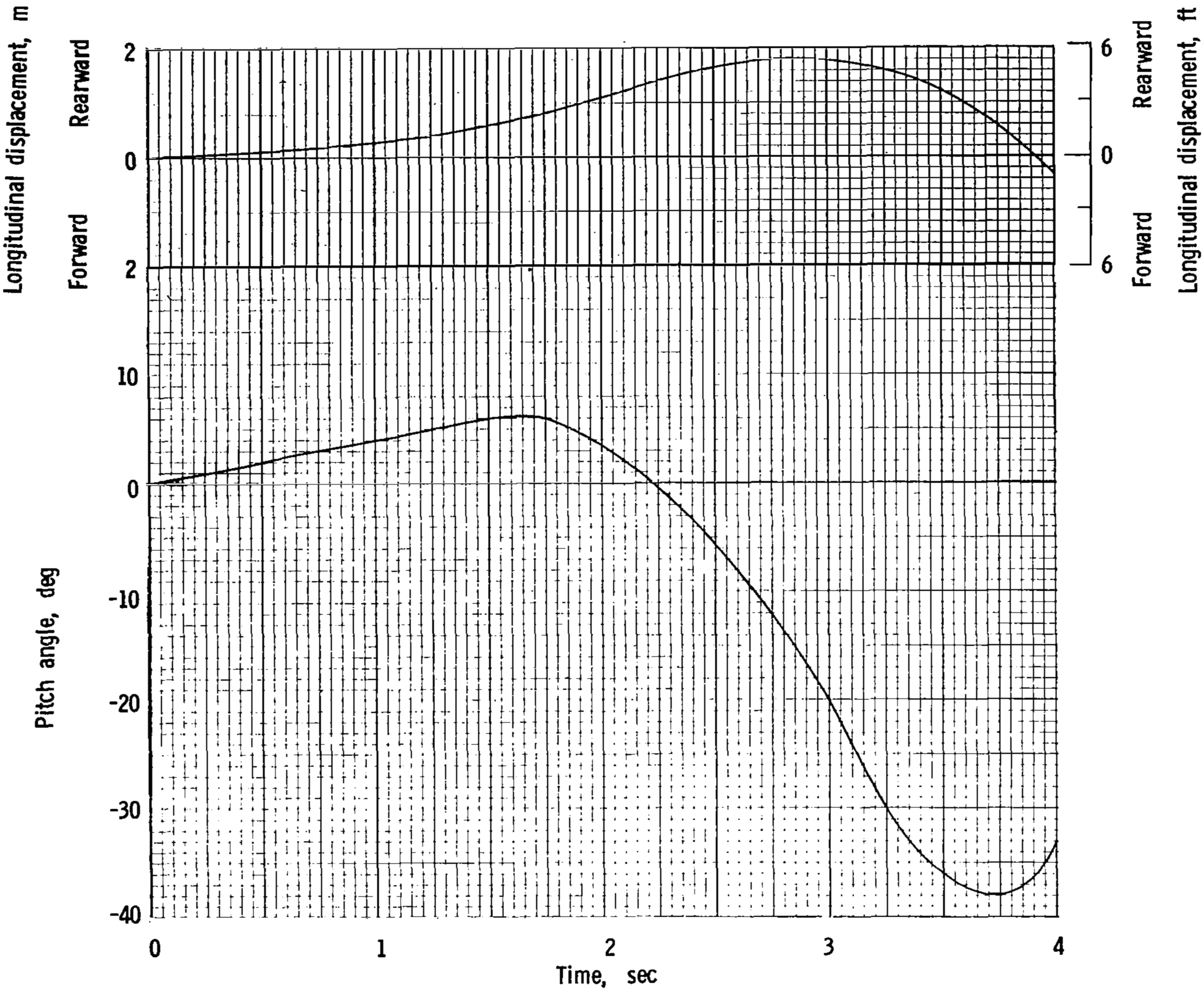
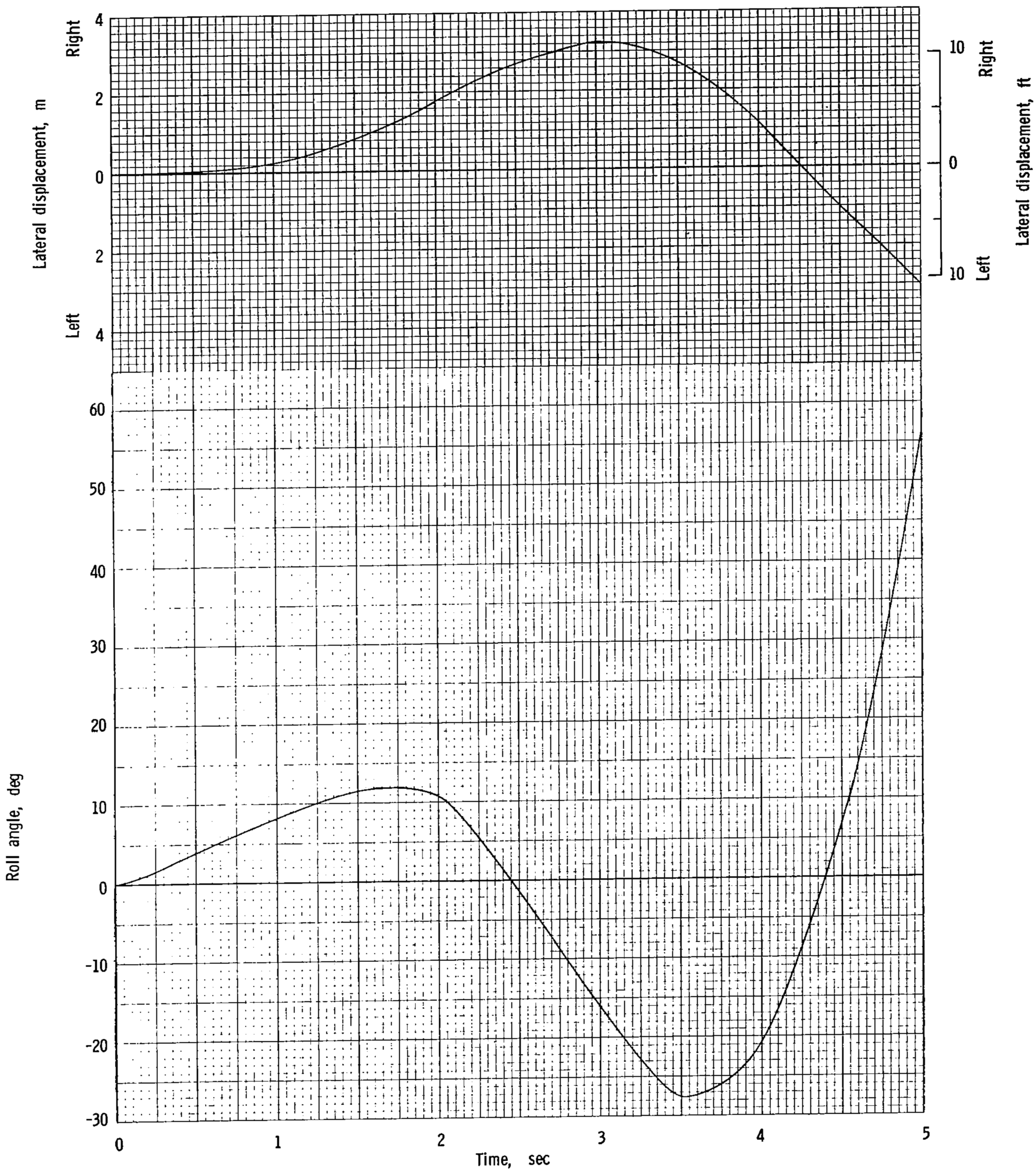
Figure 4.- Test setup for flight tests in the Langley full-scale tunnel.



(a) Longitudinal.

Figure 5.- Typical control-fixed motions of model in hovering flight.



(b) Lateral.

Figure 5.- Concluded.

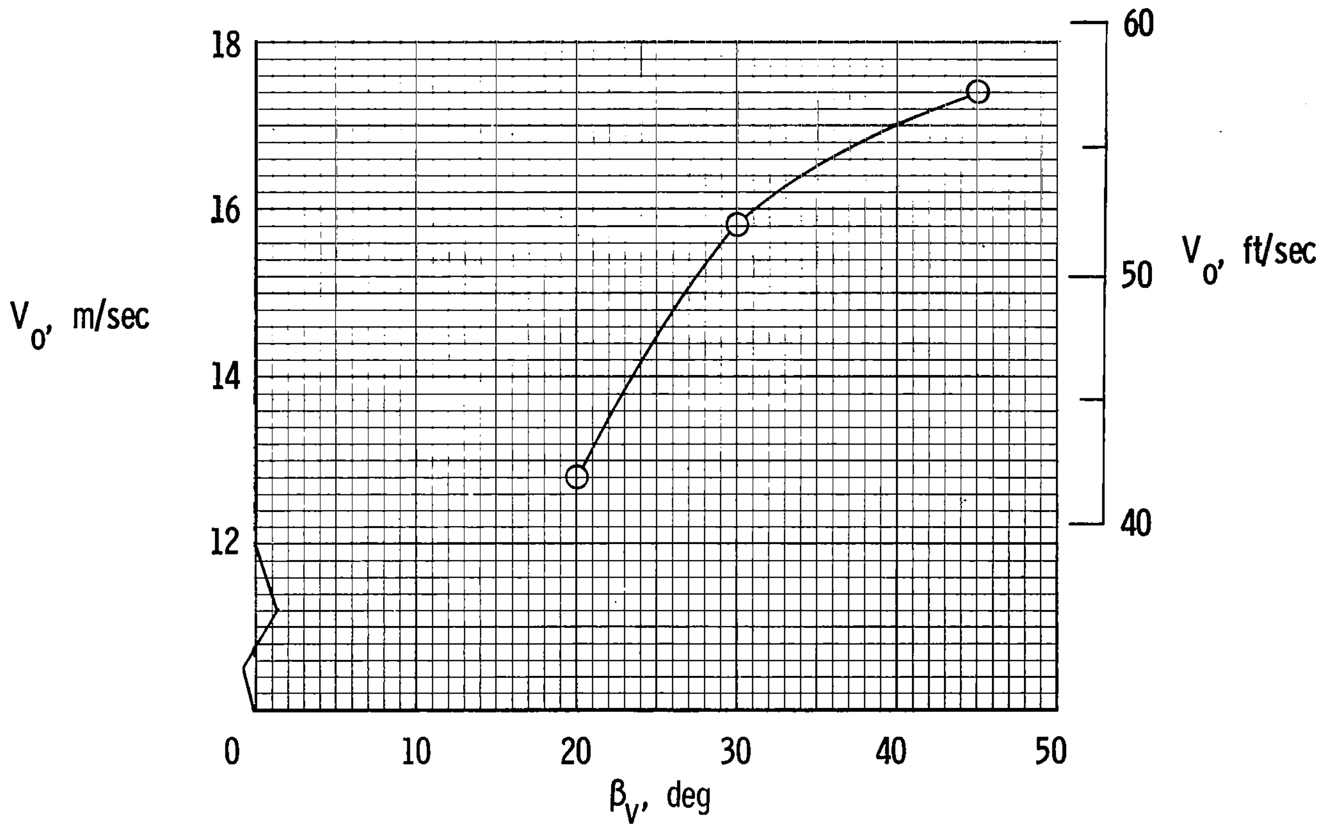


Figure 6.- Variation of trim speed with fan exit-vane angle. $\alpha = 0^{\circ}$; $\delta_f = 40^{\circ}$.

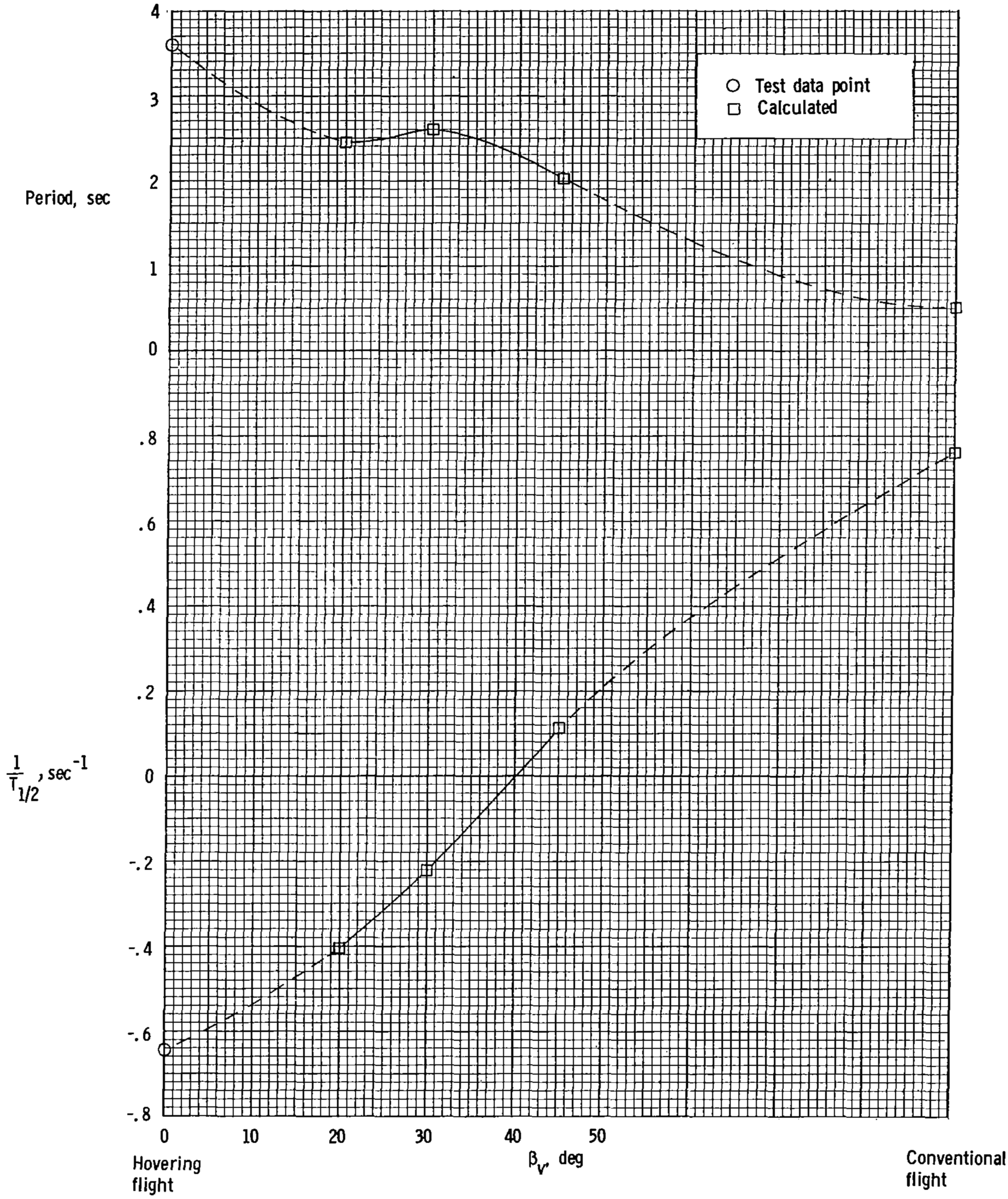


Figure 7.- Calculated characteristics of the lateral directional oscillation. $\alpha = 0^{\circ}$; $\delta_f = 40^{\circ}$.

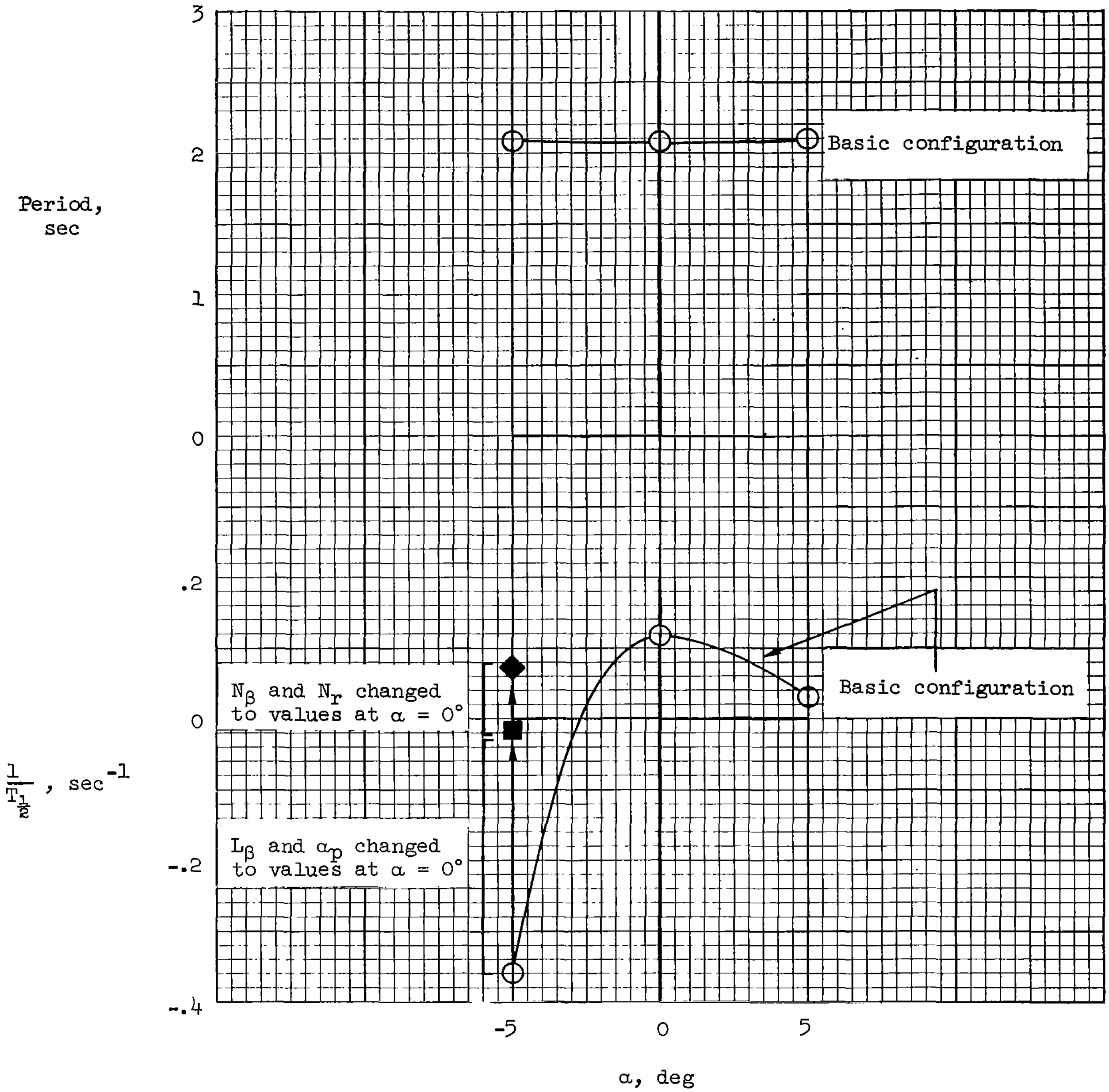


Figure 8.- Effect of angle of attack on the characteristics of the lateral-directional oscillation. $\delta_f = 40^o$; $\beta_v = 45^o$.

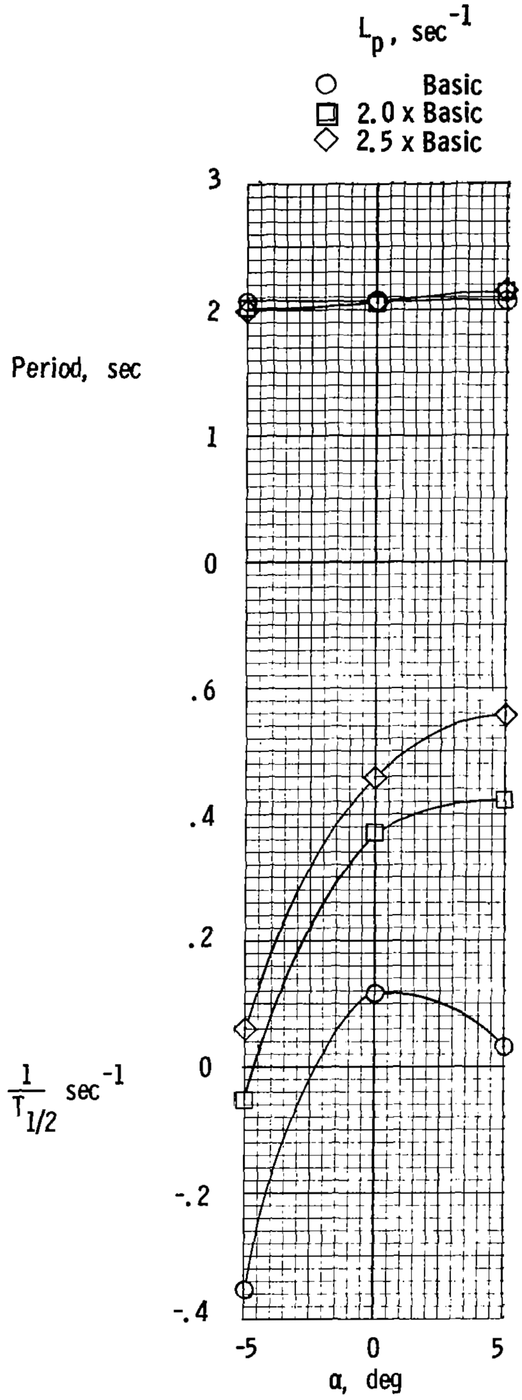


Figure 9.- Effect of angle of attack on the calculated lateral oscillation. $\delta_f = 40^\circ$; $\beta_v = 45^\circ$.

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