NASA MEMO 10-19-58L

NASA

MEMORANDUM

NASA MEMO 10-19-58L

STATIC INVESTIGATION OF PADDLE VANE OSCILLATING IN JET OF 1,300-POUND-THRUST ROCKET MOTOR

By Wade E. Lanford

Langley Research Center
Langley Field, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON

November 1958

Declassified April 12, 1961

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA MEMO 10-19-58L

STATIC INVESTIGATION OF PADDLE VANE OSCILLATING IN JET OF 1,300-POUND-THRUST ROCKET MOTOR*

By Wade E. Lanford

SUMMARY

The results of a static investigation conducted to measure the normal forces on the entire jet-vane assembly and the hinge moments on the jet vane produced by a paddle vane oscillating in the jet of a 1,300-pound-thrust rocket motor are presented for vane-deflection angles from -5° to 25°.

A maximum average normal force of 71 pounds with a corresponding value for maximum average hinge moment of 228 inch-pounds was obtained with the maximum area of jet vane immersed at a jet-vane angle of 25°.

A decrease in thrust caused by immersion of the jet vane varied from a maximum loss of about 38 pounds, or approximately 3 percent at maximum jet-vane angle of 25°, to zero loss at jet-vane angles less than approximately 10°.

INTRODUCTION

The problem of missile and airplane control under conditions where aerodynamic forces are inadequate such as at low speeds or at high altitudes has directed attention to the possibility of control by deflection of the jet used for propulsion. Movable vanes totally immersed in the thrusting jet, swiveling rocket nozzles, swiveling of the entire rocket motor, partial immersion of fixed vanes, nozzle flow separation induced by spoilers or air injection, and paddle vanes have all been used with varying degrees of success in producing control forces by deflecting the jet used for propulsion. Swiveling rocket nozzles and totally immersed vanes appear to have more of the desirable features and fewer of the objectionable features than the other systems and are, therefore, the most popular. However, paddle vanes have the advantage of

*Title, Unclassified.

not causing any loss in thrust when the control forces are zero, which is not the case with immersed jet controls. Because of simplicity and relatively low weight requirements, the paddle vane appears attractive for use on small missiles obtaining propulsion from solid-fuel rocket motors. Paddle vanes would be especially suitable for use on a small missile propelled by a solid-fuel rocket motor of short thrust duration: the paddle vanes would provide nonaerodynamic control that is needed immediately after launch when high initial control forces would be needed for executing rapid turns, and they would provide aerodynamic control for the remaining unpowered flight to the target.

Research was conducted to provide data on the normal force and hinge moment as functions of jet-vane angle or some performance parameter of the propelling rocket motor such as thrust, nozzle-exit pressure, or dynamic pressure at the nozzle exit. Results obtained from tests of paddle vanes of fixed deflection immersed in the jet of a solid-fuel rocket motor having a large variation in thrust are presented in reference 1.

A program to obtain research data from flight tests of a research missile incorporating a body of square cross section and utilizing paddle vanes for both nonaerodynamic and aerodynamic control in the manner previously mentioned was undertaken (ref. 2). Data previously obtained on paddle-type jet vanes were felt to be insufficient for use in designing the research missile because the data had been obtained from vanes that remained stationary during the test and were fitted to a rocket motor smaller than the one to be employed in the research missile; also, it was felt that data obtained under dynamic conditions from a test of jet vanes preferably fitted to a rocket motor identical to the one employed on the research missile would be needed to aid in the design of the research missile. The jet-vane pulsing mechanism and rocket motor used in this test, conducted by the Langley Pilotless Aircraft Research Division of the National Aeronautics and Space Administration, covered the range of conditions under which the jet vanes used on the flight models were to operate.

SYMBOLS

The direction and location of forces and moments are shown in figure 1.

A cross-sectional area of nozzle, sq in.

C_h hinge-moment coefficient, $\frac{M_h}{qS_{max}c}$

$C_{h_\delta} = \frac{dC_h}{d\delta}$

C_N normal-force coefficient, $\frac{F_N}{qS_{max}}$

$C_{N_\delta} = \frac{dC_N}{d\delta}$

c vane chord, distance from jet-vane hinge axis to jet-vane trailing edge (see fig. 1), 3.31 in.

d distance from center of pressure to vane hinge axis, $\frac{M_h \cos \delta}{cF_N}$, percent chord

F_N normal force, positive upward, measured in a direction perpendicular to hinge axis and center line of rocket motor, lb

l distance from centroid of impinged area of jet vane to jet-vane hinge axis, in.

M Mach number

M_h hinge moment, positive normal force produces a positive hinge moment, in-lb

m moment area, Sl, $in.^3$

p static pressure, lb/sq in. abs.

q dynamic pressure, $\frac{\gamma}{2} pM^2$, lb/sq in.

S vane surface area immersed in imaginary cone formed by extension of interior surface of rocket nozzle (see figs. 1 and 2), sq in.

T thrust, lb

t time, sec

γ ratio of specific heats, 1.25

δ angle made by vane surface and longitudinal axis of rocket motor, positive when vane is immersed into jet, deg

functions of jet-vane angle (fig. 6) are presented for the third cycle in which complete data were obtained (t = 1.14 seconds to

4

Subscripts:

t = 1.40 seconds). The axis for pitching moment and hinge moment is shown in figure 1. Complete data were not obtained in the first cycle after firing because oscillations in the strain-gage beam measuring pitch and normal force made the oscillograph traces unreadable. Data for the third cycle were chosen for presentation because they were obtained for the portion of the test in which the thrust was nearly constant.

The maximum surface area S_{max} of the jet vane immersed in the imaginary cone formed by extending the rocket nozzle, the instantaneous dynamic pressure q_e at the nozzle exit, and the vane chord which was the distance from the hinge axis of the vane to the trailing edge of the vane were used in computing normal-force and hinge-moment coefficients as functions of jet-vane angle. Dynamic pressure for small nozzle-divergence angles was computed by the following formula:

$$q_e = \frac{1}{2} \gamma p_e {M_e}^2$$

For reduction of data presented in this report, q_e was needed for only 1 cycle of the jet-vane oscillation. Chamber pressure p_c from which exit pressure p_e was computed was 361 pounds per square inch during the entire oscillation and, thus, only one value of p_e was needed. This value of p_e was calculated by multiplying the value of p_c obtained in the test by 0.0304, the ratio of p_e/p_c calculated by means of the following equation given in reference 3:

$$\frac{A_e}{A_t} = \left(\frac{2}{\gamma + 1}\right)^{\frac{1}{\gamma-1}} \left(\frac{\gamma - 1}{\gamma + 1}\right)^{\frac{1}{2}} \left(\frac{p_c}{p_e}\right)^{\frac{1}{\gamma}} \left[1 - \left(\frac{p_e}{p_c}\right)^{\frac{\gamma-1}{\gamma}}\right]^{-\frac{1}{2}}$$

The values of γ and M_e which were previously presented were considered to be constant throughout the test. Dynamic pressure at the exit q_e was computed to be 56.0 pounds per square inch.

The distance from center of pressure to vane hinge axis d was computed by the equation

$$d = \frac{M_h \cos \delta}{cF_N}$$

where all of the normal force of the jet-vane test assembly was assumed to be derived from forces of the deflected jet vane, and the center of pressure of the entire vane assembly was the center of pressure of the vane.

The accuracy of experimental data is within the following limits:

Jet-vane angle, deg	±0.1
Jet-vane hinge moment, in-lb	±1
Normal force, lb	±2.4
Thrust, lb	±4.0
Pitching moment, in-lb	±22
Chamber pressure, lb/sq in.	±2

RESULTS AND DISCUSSION

Performance of Rocket Motor

The performance of the rocket motor was affected by a decrease in thrust when the vane was in the rocket jet. The maximum decrease in thrust for each cycle, about 38 pounds or approximately 3 percent, occurred when the jet vane was at maximum deflection in the jet. (See fig. 5.) Loss in thrust decreased from the maximum at maximum jet-vane-deflection angle as the jet-vane angle decreased to a value of approximately 10°, below which there was no loss in thrust.

Jet Characteristics

Since the angle that a line tangent to the jet flow (see fig. 1) just after it leaves the nozzle exit is a function of the ratio p_c/p_a, the area immersed in the jet is also a function of the ratio p_c/p_a. As p_c/p_a increases, the expansion angle increases. Thus, as the ratio p_c/p_a is increased, the force acting on the vane at a particular deflection angle increases because of the increase in immersed area and of the angle at which the jet impinges on the vane. Ambient pressure is a function of altitude and, therefore, the force acting on a paddle jet vane would be a function of altitude. At an exit pressure of 10.7 pounds per square inch, the calculated exit pressure during the oscillation for which data are presented, the vane would enter the boundary at 14°. Hinge moment and normal force changed at approximately 13° and thus indicated that the vane entered the jet at this deflection angle.

Aerodynamic Characteristics of Vane Assembly

When the vane started to enter the jet, hinge moment, normal force, and pitching moment started to increase at approximately the same jet-vane deflection angle, about 14°. (See fig. 6.) Maximum values of normal force, pitching moment, and hinge moment were, respectively, 71 pounds, 2,560 inch-pounds, and 228 inch-pounds. A comparison of the hinge moment, normal force, and pitching moment obtained when the vane was entering the jet with the values obtained at the corresponding deflections when the vane was emerging from the jet showed that for angles greater than 15° the hinge moment was greater when the vane was emerging from the jet. Below this angle the hinge moment was negative or very small while the vane was emerging from the jet and was zero or positive while the vane was entering the jet. Normal force and pitching moment of the whole assembly were larger when the vane was emerging from the jet than when the vane was entering the jet. At large deflection angles it is believed that almost all the normal force and moments resulted from the oscillating jet vane. From a consideration of the hinge-moment data, which were the only data obtained that were dependent only on the forces applied to the pulsed-jet vane, it appears that the jet flow remains attached to the oscillating jet vane as it emerges from the jet; this result is possibly due to an aspiration effect which induces flow around the jet and tends to reduce the static pressure on part or on all of the lower side of the oscillating vane and on the upper side of the fixed vane.

Pitching-moment data were of insufficient accuracy to be used in computing the center of pressure. A more accurate computation of the center of pressure was obtained by using hinge-moment data where it was assumed that most of the normal force was obtained from aerodynamic forces acting on the jet vane. Figure 7 indicates that the vane center of pressure begins to move forward as the vane enters the jet and continues to move forward until the vane has moved out of the jet. The center of pressure was near the trailing edge of the vane as it was entering the jet; however, at maximum-deflection angle the center of pressure was near the centroid of the area of the vane immersed in the jet, approximately 88 percent of the chord. Because the forces and moments on the vane were small as it entered or left the jet, the center of pressure was not as accurate at these deflections as it was at the maximum-deflection angles.

For deflections between 14° and 17°, as the vane was entering or leaving the jet, the normal-force coefficient and the hinge-moment coefficients varied nonlinearly with vane deflection (fig. 7). However, for deflections greater than about 17°, these variations were linear and the values of C_{N_δ} and C_{h_δ} were approximately 0.043 and 0.044 per degree, respectively. Maximum values obtained for C_N and C_h for $\delta = 25^\circ$ were 0.385 and 0.380, respectively.

SUMMARY OF RESULTS

From a static investigation of a paddle vane oscillating in the jet of a 1,300-pound-thrust rocket motor, the following results are presented:

1. Maximum normal force of 71 pounds with a corresponding value for hinge moment of 228 inch-pounds was obtained with the maximum area of jet vane immersed in the jet at an angle of 25°.

2. Loss of thrust caused by a maximum jet-vane deflection angle of 25° was about 38 pounds, or about 3 percent.

3. The jet remained attached to the oscillating vane as the vane emerged from the jet after moving past the angle at which the vane contacted the jet when entering it.

4. The center of pressure moves forward with an increase in jet-vane angle while the vane is entering the jet and continues to move forward with a decrease in jet-vane angle while the vane is moving out of the jet. The center of pressure for the maximum deflection angle was approximately at 88 percent of the chord.

5. The average value of the slope of normal-force coefficient as a function of jet-vane angle along the part of the curve that is fairly linear is 0.043 per degree. The corresponding value of the slope of hinge moment as a function of jet-vane angle along the part of the curve that is fairly linear is 0.044 per degree.

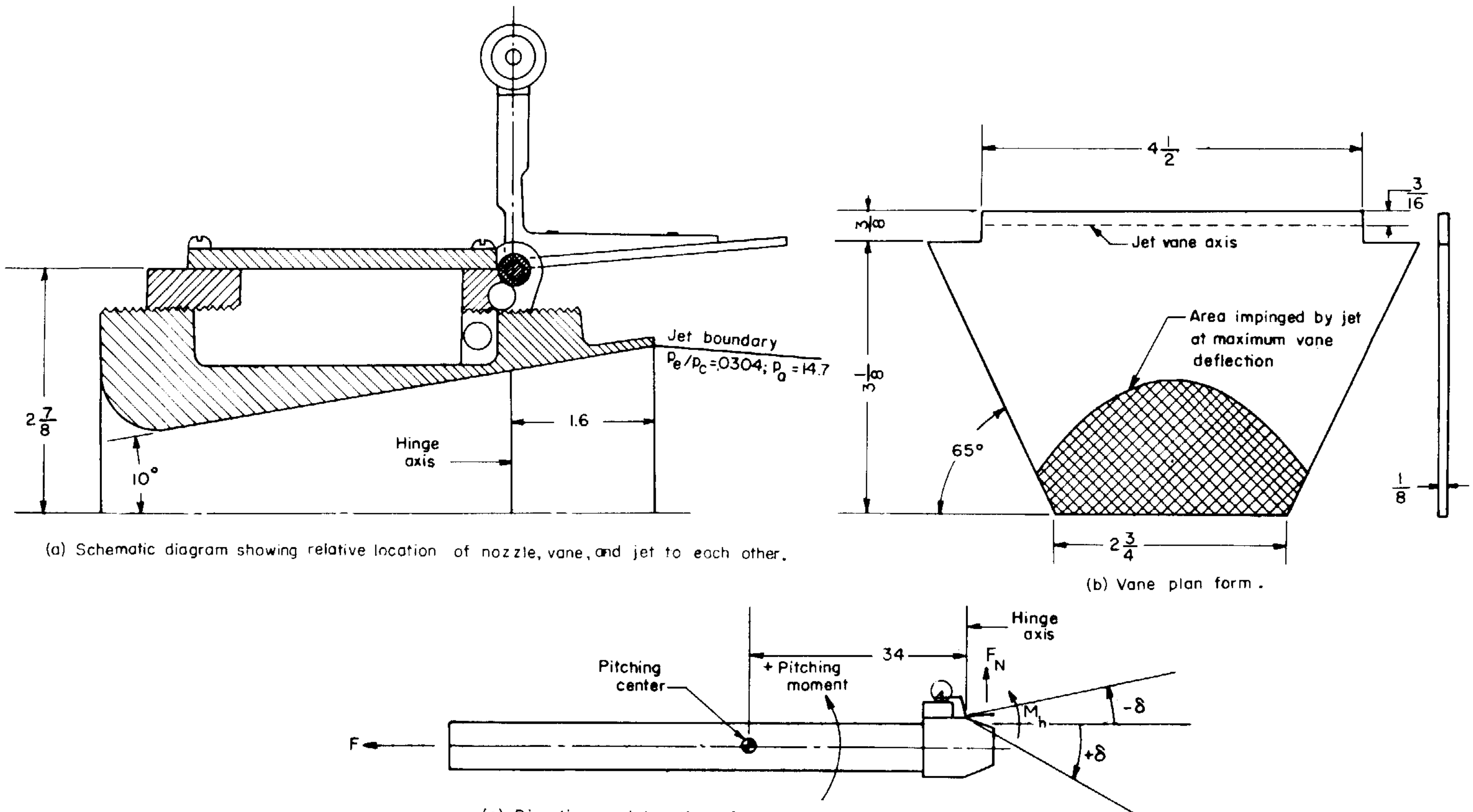
Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., August 20, 1958.

REFERENCES

1. Bond, Aleck C.: Experimental Investigation of a Flat-Plate Paddle Jet Vane Operating on a Rocket Jet. NACA RM L50I20, 1950.

2. Henning, Allen B., Wineman, Andrew R., and Rainey, Robert W.: Some Data on Body and Jet Reaction Controls. NACA RM L56L17, 1957.

3. Anon.: Rocket Fundamentals. OSRD No. 3992, ABL-SR4, NDRC, Div. 3, Sec. H, 1944.



(a) Schematic diagram showing relative location of nozzle, vane, and jet to each other.

(b) Vane plan form.

(c) Direction and location of moments and forces.

Figure 1.- Details of jet-vane oscillating mechanism. All dimensions are in inches.

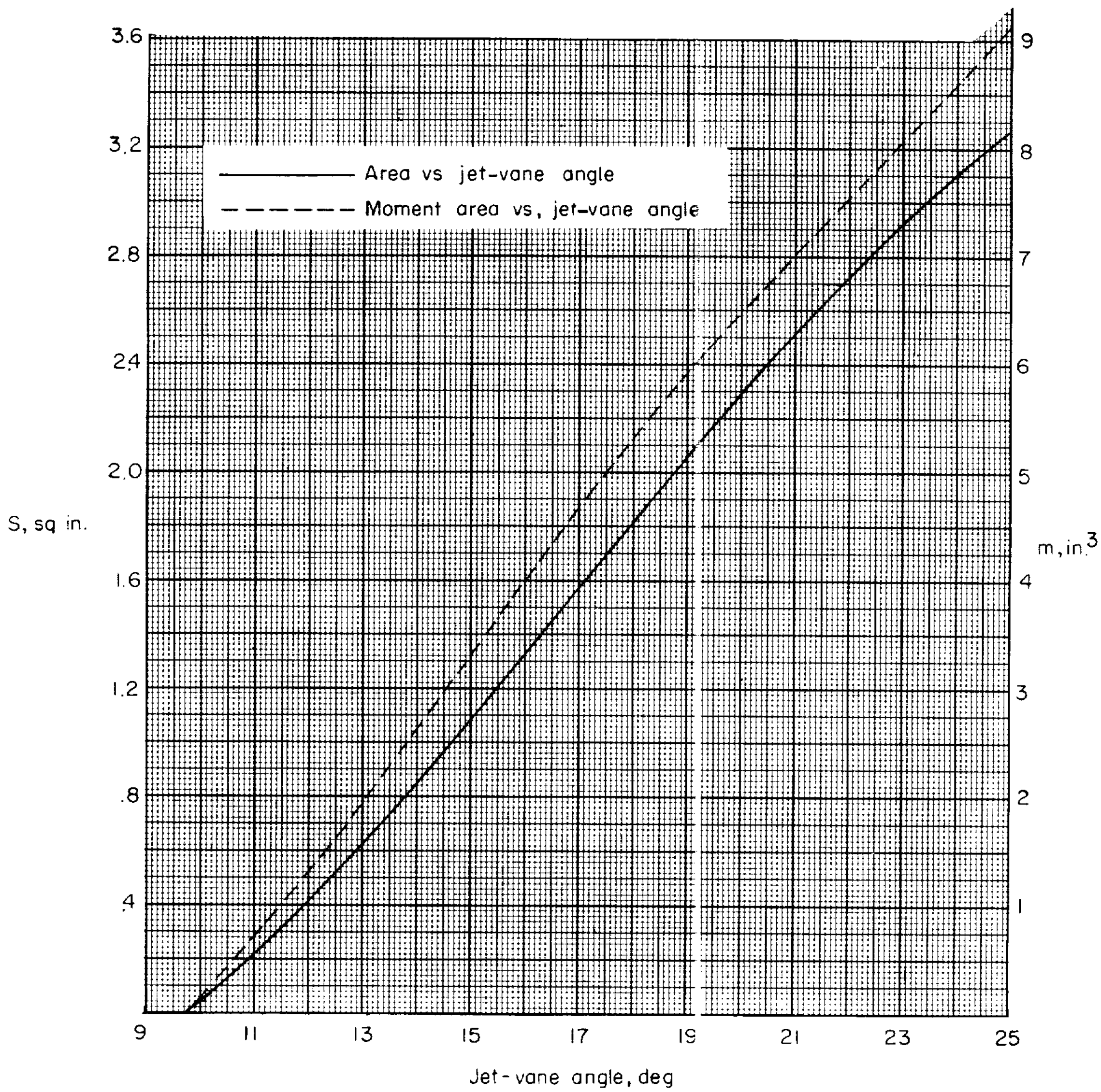
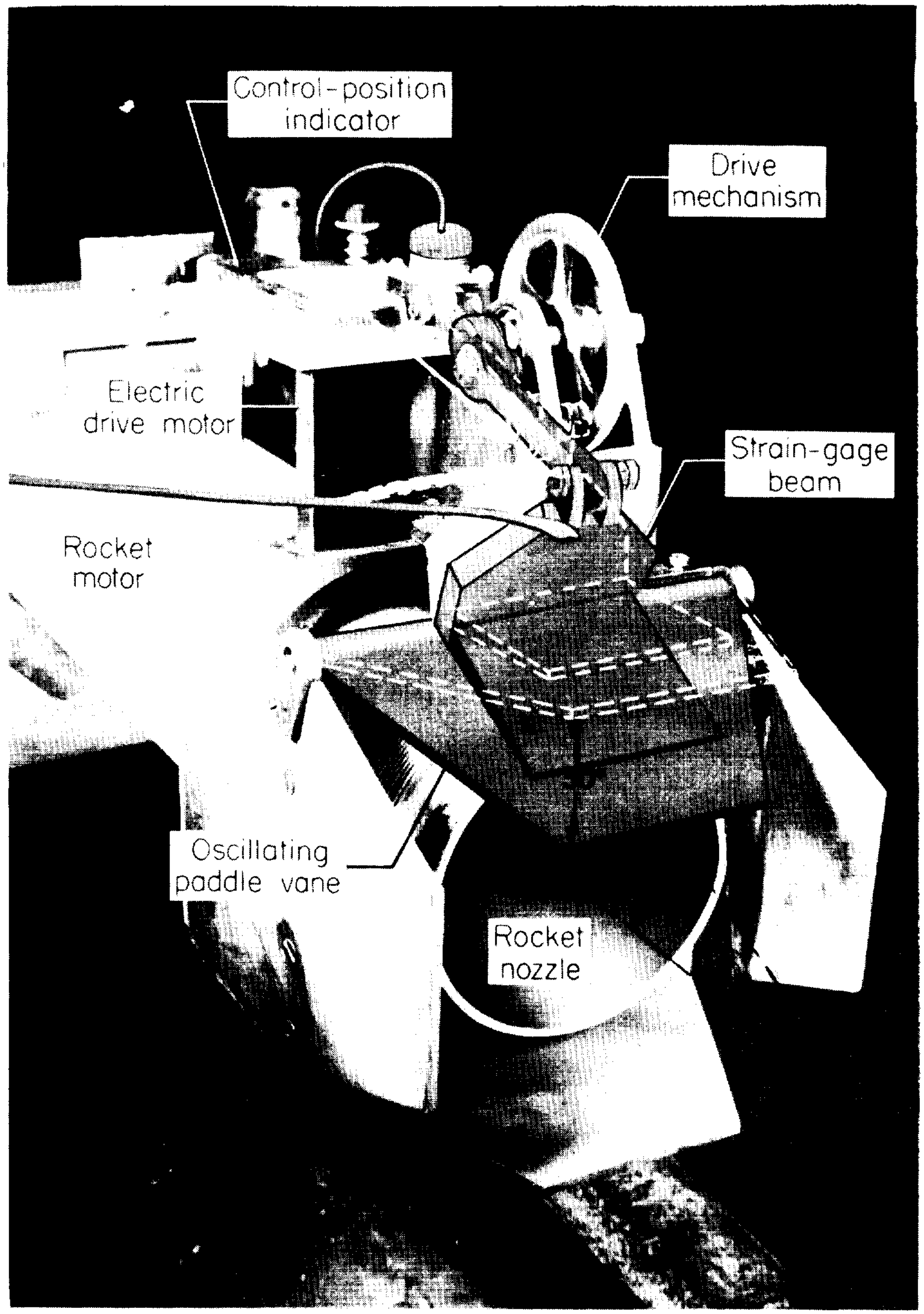


Figure 2.- Immersed area of jet vane and moment area of jet vane as functions of jet-vane angle.



L-58-341.1

Figure 3.- Jet-vane test assembly showing components and illustrating maximum and minimum jet-vane angles.

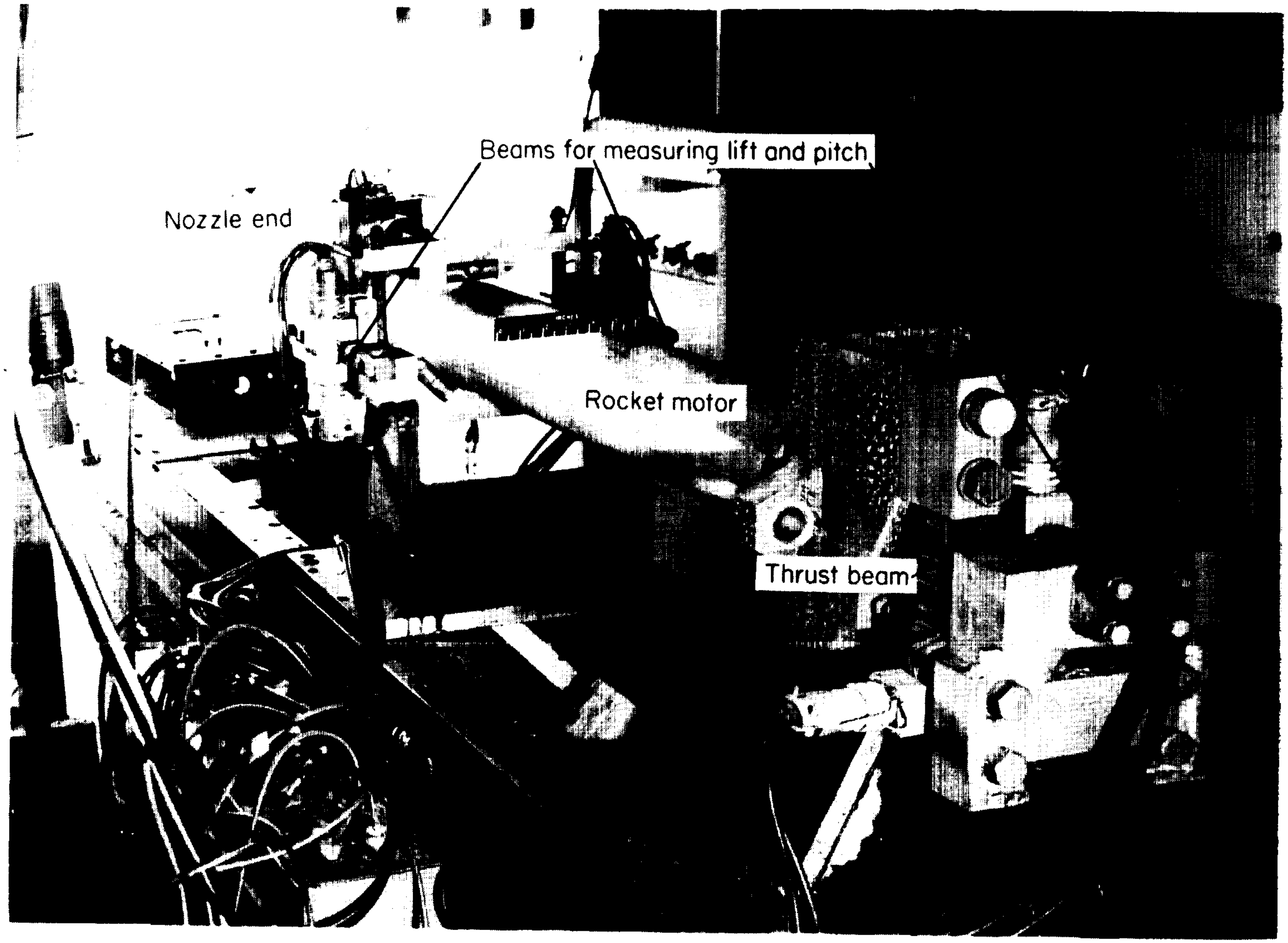
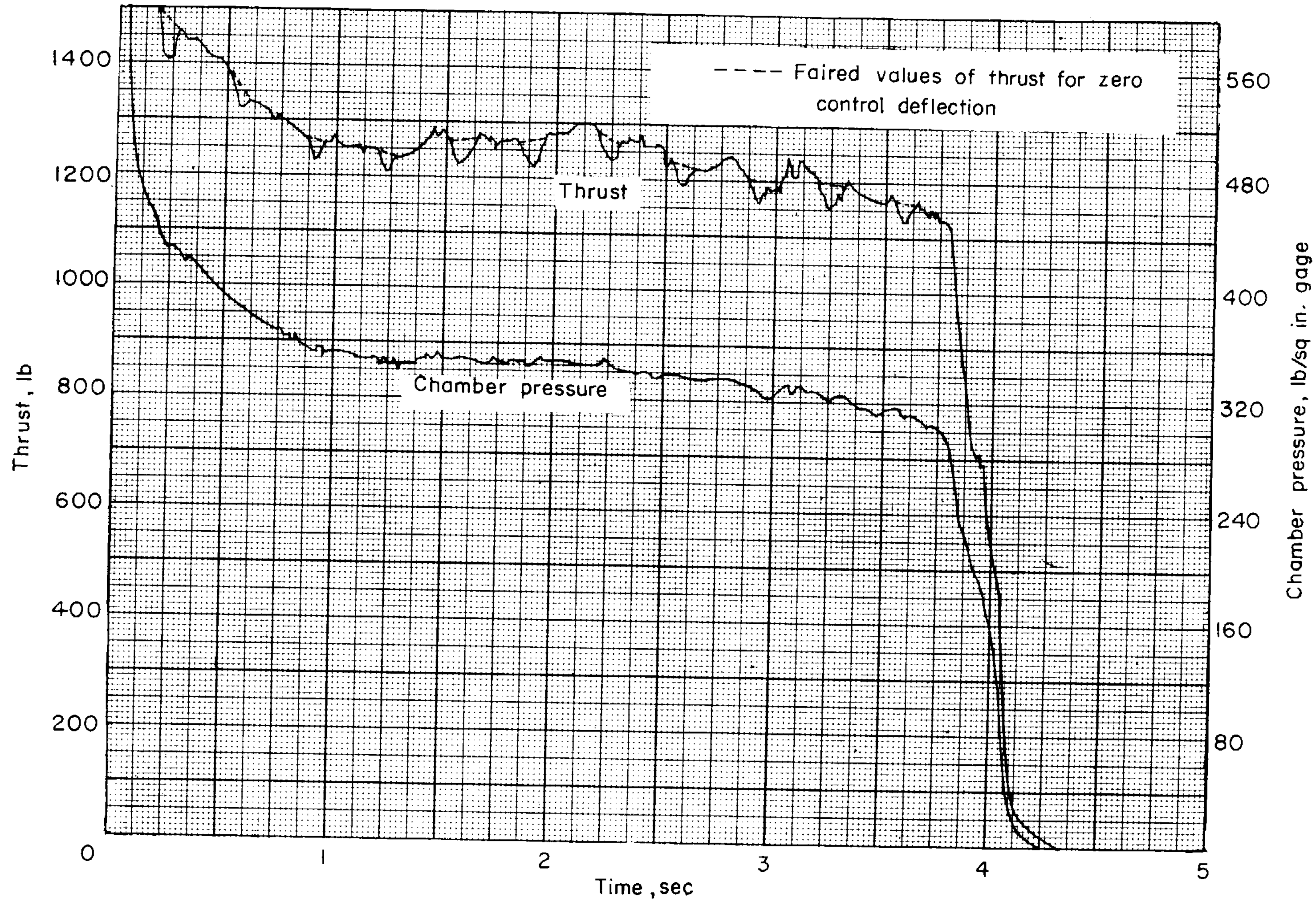
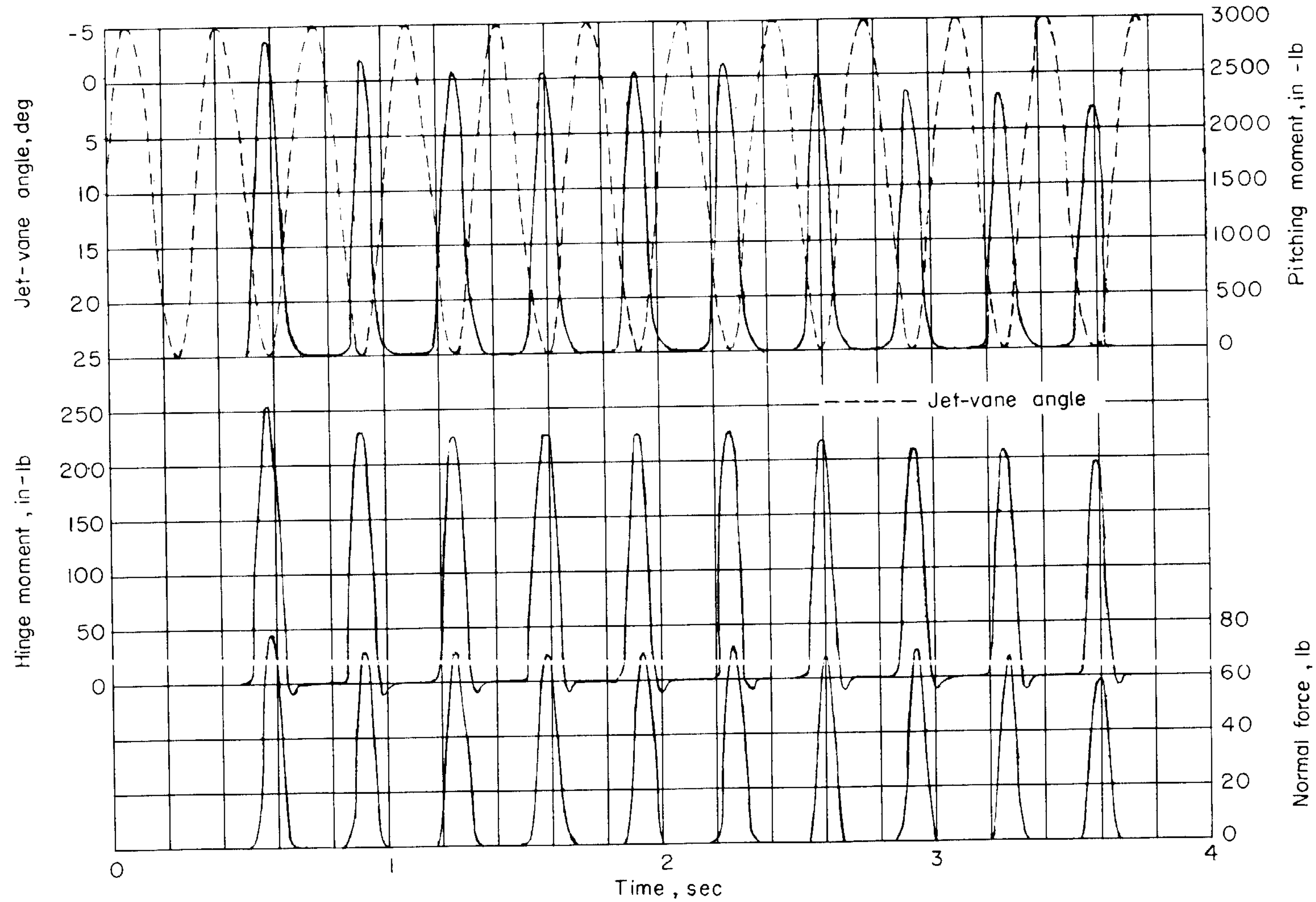


Figure 4.- Thrust stand used for test. L-57-3568.1



(a) Thrust and chamber pressure plotted against time.

Figure 5.- Time histories of measured data of test.



(b) Jet-vane deflection, hinge moment, pitching moment, and normal force as a function of time.

Figure 5.- Concluded.

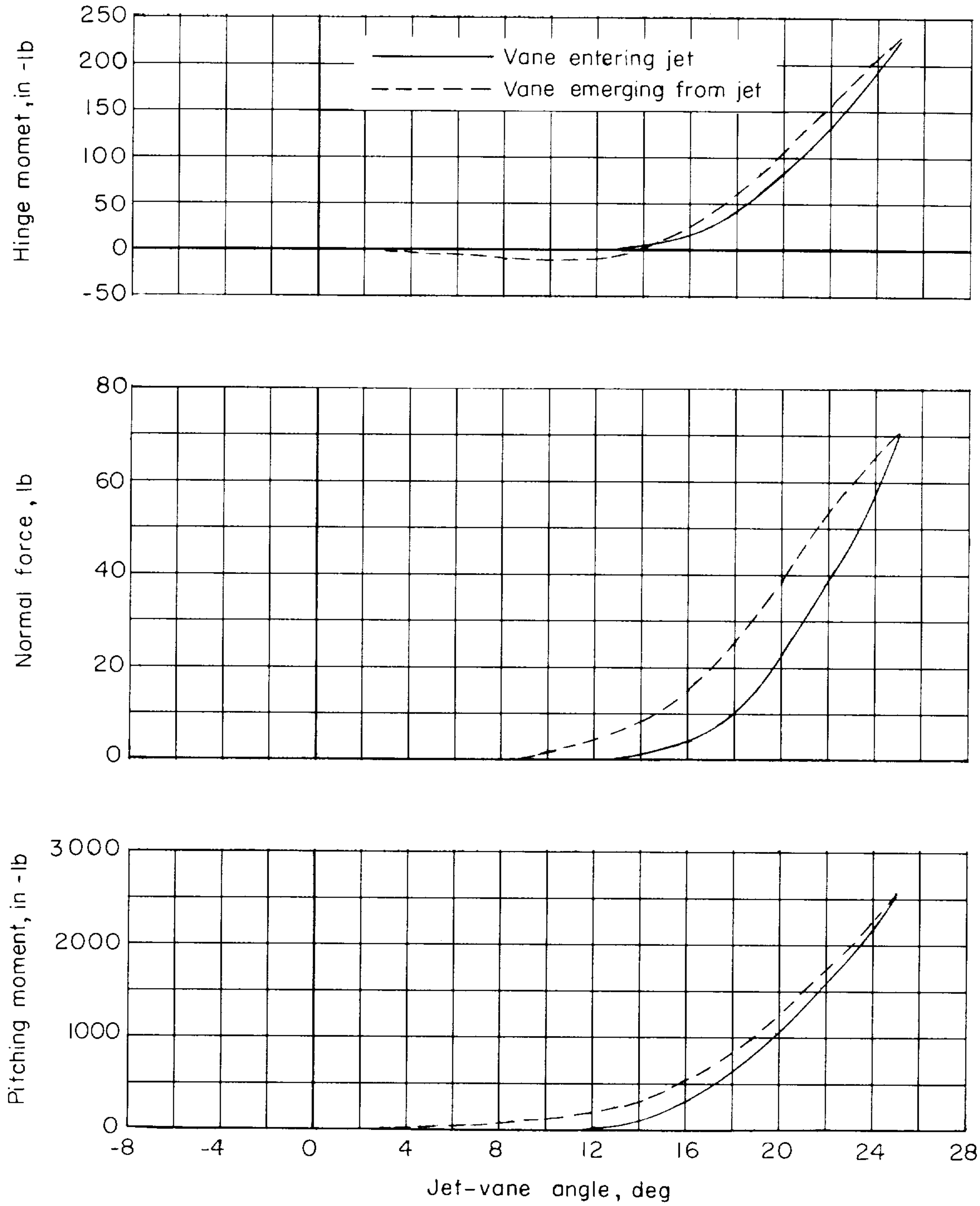


Figure 6.- Hinge moment, normal force, and pitching moment as functions of jet-vane angle.

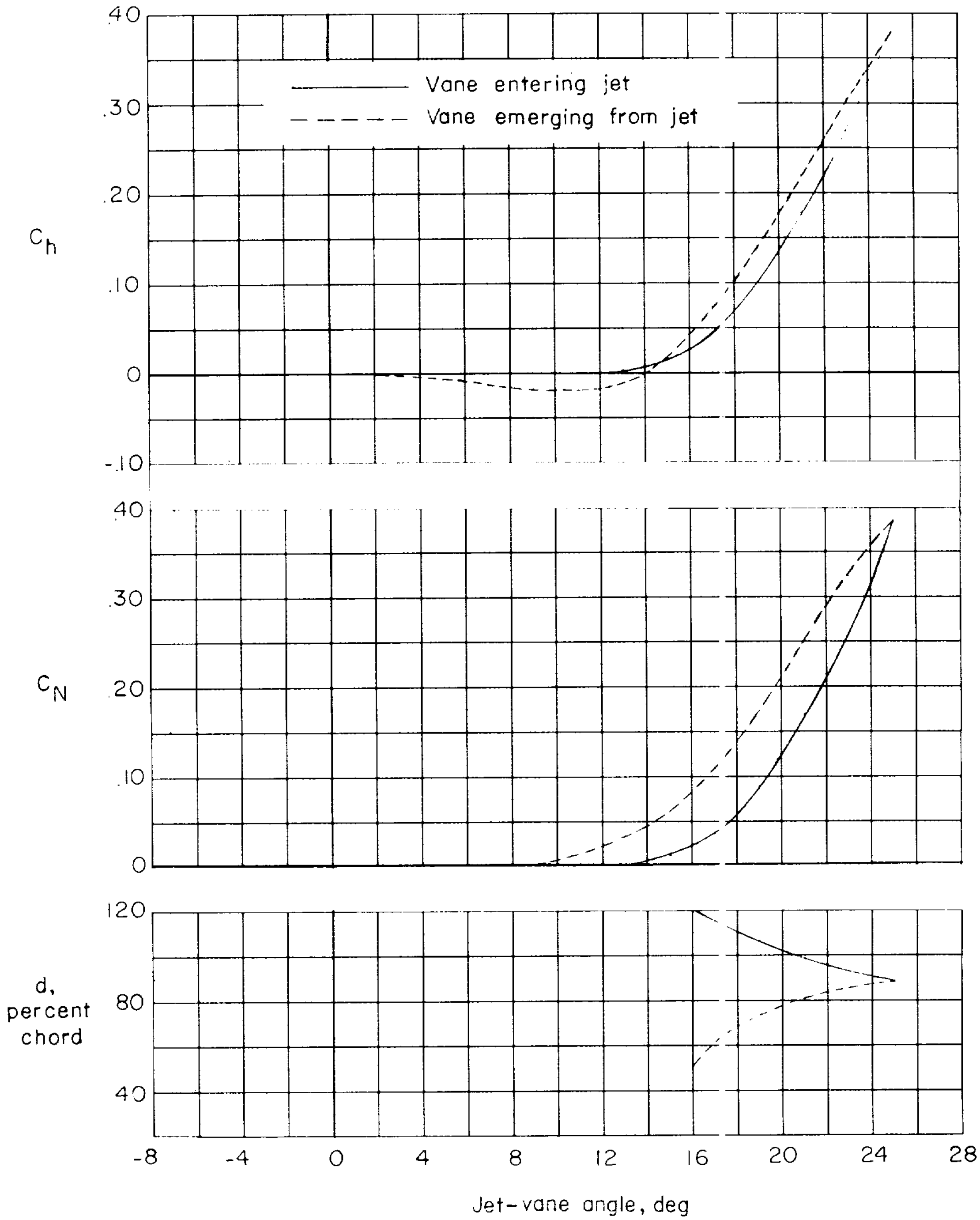


Figure 7.- Hinge-moment coefficient, normal-force coefficient, and distance from center of pressure to vane hinge axis as functions of jet-vane angle.