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RESEARCH MEMORANDUM

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EXPLORATORY ROCKET FLIGHT TESTS TO INVESTIGATE THE USE OF A FREELY SPINNING MONOPLANE TAIL FOR STABILIZING A BODY

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EXPLORATORY ROCKET FLIGHT TESTS TO INVESTIGATE THE USE OF A FREELY SPINNING MONOPLANE TAIL FOR STABILIZING A BODY

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SUMMARY

A brief experimental investigation has been conducted by the National Advisory Committee for Aeronautics to determine qualitatively the feasibility of stabilizing a body by the use of a freely spinning monoplane tail. A theoretical treatment appears in an analysis of the effect of rolling on stability presented in NACA TN 1627. Two models were flown, one with freely spinning fins twisted to approximately 5° at the tips and the other twisted to about half that amount. In addition to these two models, two test rockets were flown for comparison. One of the test rockets had a standard cruciform fin configuration, while the other had a single pair of fixed, opposed, untwisted fins. No fixed, twisted, monoplane fin vehicles were flown but the theoretical analysis indicated similar stability boundaries for this and the freely spinning fin configuration provided the rolling moment of inertia is not more than about 20 percent of the pitching moment of inertia. Observations by motion pictures and radar showed that the two models and the 4-fin test rocket all were stable in flight and had approximately zero-lift trajectories. The fixed 2-fin test rocket flew with a pronounced wobble (about $\pm 20^{\circ}$) which indicated an appreciable amount of instability.

INTRODUCTION

Among the problems encountered in the installation on aircraft of missiles, rockets, bombs, and jettisonable external stores is that of maintaining adequate clearance between the fins of such devices and the ground or the aircraft structure. It has been suggested that one possible solution to the clearance problem lay in using monoplane rather than the usual cruciform or triform fin arrangements. Stabilization of the missile, rocket, bomb, or store in free flight after release from the carrying aircraft would be achieved by forcing the fins (or body and fins) to rotate continuously about the longitudinal axis of the body.

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The rotation could be forced simply by building asymmetric twist into the fin assembly. An analytical study of the possibility of using rolling to stabilize a body that would normally be stable in either the pitch or the yaw plane but unstable in the other plane appears in reference 1, an analysis of the effects of rolling on the longitudinal stability of aircraft.

In order to obtain some experimental verification of the effects of rolling in stabilizing bodies that would normally be stable in only one plane, some simple noninstrumented bodies were flown at the Langley Pilotless Aircraft Research Station at Wallops Island, Va. Observations of these tests are reported herein.

SYMBOLS

$C_D = \frac{\text{Drag}}{qS}$

S	maximum body cross-sectional area, sq ft
q	dynamic pressure, lb/sq ft
M	Mach number
R	Reynolds number based on maximum body diameter
ω_θ^2	pitch frequency parameter, $\left(\frac{\omega_y}{p}\right)^2$
ω_ψ^2	yaw frequency parameter, $\left(\frac{\omega_z}{p}\right)^2$
p	rate of roll, rps
ω_y	pitch frequency, $\frac{1}{2\pi}\sqrt{\frac{-C_{m_\alpha}57.3qSd}{I_y}}$, cps
ω_z	yaw frequency, $\frac{1}{2\pi}\sqrt{\frac{C_{n_\beta}57.3qSd}{I_z}}$, cps
C_{m_α}	variation of pitching-moment coefficient with angle of attack, per deg
C_{n_β}	variation of yawing-moment coefficient with angle of sideslip, per deg

I_y	moment of inertia in pitch, slug-ft^2
I_z	moment of inertia in yaw, slug-ft^2
d	maximum body diameter, ft

MODELS

The models used in the investigation are shown in figures 1 and 2. The basic body and fin shapes were the same as those used in the investigation reported in reference 2. The flat-plate fins and a portion of the body skin approximately equal in length to the fin root chord were mounted on ball bearings and were free to rotate relative to the rest of the body. The fins were twisted to produce clockwise roll as viewed from the rear. The only difference between models 1 and 2 was in the amount of fin twist, approximately 5° at the tip for model 1 and about half that amount for model 2. (See fig. 3.) Preflight estimates showed that these deflections would produce roll rates about $2\frac{1}{2}$ and $1\frac{1}{4}$ times the natural pitch frequency of models 1 and 2, respectively. Both models were powered with motors from standard 3.25-inch Mark 7 rockets. Information on the weights, center of gravity, and moments of inertia of the models is given in table I.

In addition to the two models, two aircraft rockets were also flown. (See fig. 4.) Rocket 1 was a standard 3.25-inch Mark 7, Mod. 0, rocket with a 3.5-inch Mark 8 rocket head, a standard cruciform fin assembly, and launching lugbands. Rocket 2 was identical to rocket 1 except that two opposite fins were removed and a monoplane fin assembly resulted. (See fig. 4.) The only twist present in the rocket fins was that resulting from standard construction tolerances.

TESTS

The models were flown at the Pilotless Aircraft Research Station at Wallops Island, Va.

Model velocity and position data were measured by radar. Reynolds numbers, Mach numbers, and drag coefficients were obtained from these data and radiosonde atmospheric data by the methods outlined in reference 2.

Visual and photographic observation with 16-millimeter color motion pictures (taken at 125 frames per second) were the only means used to obtain stability information since the models carried no internal instrumentation.

In order to obtain some more nearly quantitative information on the stability of the models and rockets, the apparent pitch angles were measured from the motion pictures. It was possible to measure these angles for about $1\frac{1}{2}$ seconds of the test flights but beyond this time the model image on the film became too small to allow measurement. Errors introduced by the camera not remaining horizontal and the film not remaining parallel to the flight path during tracking should appear only as a very low frequency distortion of the mean pitch angle.

For the models, which were coated with bright orange-yellow lacquer, it was also possible to note the angular position of the fins well enough to define a time history of fin rotation. Graphical differentiation of this fin-rotation time history provided data for an approximate time history of fin-rolling velocity for the first two seconds of the flights.

For the rockets, which were coated with a dull aluminum lacquer, it was not possible to define the fin position in enough pictures to obtain a rolling-velocity time history.

All models and rockets were launched from rail launchers. Elevation angles and other pertinent information are listed in the following table:

Flight	Launcher		Wind	
	Elevation, deg	Azimuth (approximate), deg	Direction	Velocity, mph
Model 1	30	145	ESE	5
Model 2	30	145	SE	5-8
Rocket 1	20	145	W	10-12
Rocket 2	30	145	WNW	10-15

The flight Reynolds numbers are shown as functions of Mach number in figure 5.

RESULTS AND DISCUSSION

General Flight Behavior

Radar data.- The flight paths and Mach numbers of the models and rockets, as obtained from the position and velocity radar data, are shown in figures 6 and 7. In general, the position radar will not depict deviations from the mean flight path of less than ±200 feet; thus, from the radar data of figure 6, the only indication of a major difference between the two models or the two rockets is the much shorter range (higher average drag thereby being indicated) for rocket 2 (nontwisted monoplane fins). A higher average drag for rocket 2 is also indicated by the greater deceleration evident for this rocket in figure 7.

Visual and photographic observation.- Observation of the actual flights and study of the motion-picture film indicated that models 1 and 2 and rocket 1 all were stable in flight and had approximately zero-lift trajectories. Rocket 2 (nontwisted monoplane fins) flew with a pronounced wobble, which indicated an appreciable amount of instability.

Pitch angles.- Apparent pitch angles measured from the motion pictures are presented in figures 6 and 8. These data show that both models and both rockets flew with almost continual oscillation in pitch (and probably also in yaw). The amplitudes of the oscillations were about the same, $\pm 1^{\circ}$ or 2°, for the two models and the standard rocket; for the rocket with nontwisted monoplane fins the oscillation increased in amplitude with time and reached a value of about $\pm 20^{\circ}$ at about 1.3 seconds after firing.

Rolling velocity.- The rolling velocity data for models 1 and 2 are presented in figure 9. Also shown in figure 9 are rolling velocities estimated from measured fin-twist angles, strip theory (ref. 3), and measured velocity data (fig. 7). The measured rolling velocities are generally higher than the estimated velocities. Part of the difference is probably due to aeroelastic effects on the thin magnesium fins and part may be a result of errors inherent in the approximate method by which the rolling velocities were determined.

As noted in the section entitled "TESTS," the fin positions could not be defined well enough to determine rolling velocity data for the rockets. For rocket 2, however, when the motion pictures of the flight were projected at 16 frames per second (1/8 speed) it appeared that the rocket was oscillating in pitch, roll, and yaw in such a manner that the rear end of the rocket was describing a circular motion with the plane of the fins remaining tangent to the circle so that the fins were horizontal at the maximum and minimum pitch angles and vertical when the apparent pitch angle was equal to the mean flight-path angle.

Thus, the roll rate in revolutions per second would be equal to the apparent pitch frequency in cycles per second for rocket 2. An inspection of the data in figures 8 and 9 disclosed no such systematic relationship between pitch and roll frequencies for models 1 and 2. The quality of the data, however, is not sufficiently high to conclude definitely that there was no systematic relationship.

Estimated Stability

Models as flown.- Estimates of lift and moment coefficients for models 1 and 2 were used in conjunction with measured moments of inertia and center-of-gravity locations to calculate the pitch and yaw natural frequencies. These calculated values of natural frequency and measured values of rolling frequency were combined to provide values of ω_θ^2 and ω_ψ^2 for use with the charts of reference 1. These values of ω_θ^2 and ω_ψ^2, which are shown in figure 10, were such that both models should have been stable according to figure 3 of reference 1. In these calculations the models were considered to have zero roll inertia since only the fins and a small portion of the body was rolling and the greater part of the model mass was not rolling.

Effects of changes.- As an illustration of the effects of various geometric changes on the estimated stability, the values of ω_θ^2 and ω_ψ^2 for $M = 1.3$, $t = 1$ second (from fig. 10) have been plotted in figure 11 on an enlarged plot of part of figure 3 of reference 1.

By using the characteristics of model 2 as a base, points have been plotted on figure 11 to show the calculated effects of variations in fin size, center-of-gravity location, and fin rolling velocity on the values of ω_θ^2 and ω_ψ^2 and thus, on the stability of the model. The amounts by which various characteristics of model 2 could be changed and still have stability as indicated by figure 11 are given in the following table:

Item	Range of change from model 2 without reaching instability
Center of gravity	$1\frac{1}{4}$ diam. ahead or $1\frac{3}{4}$ diam. back
Fin size	$\frac{1}{2}$ to $1\frac{1}{3}$ times original area
Rolling velocity	$\frac{3}{4}$ to ∞ times original value

Thus, the indications are that appreciable variations induced by such things as errors in estimating stability derivatives, manufacturing tolerances, and variations in load (such as fuel) probably can be tolerated in a particular missile, bomb, or external store without critical losses in the stabilizing effect of freely rolling fins.

Freely rolling fins rather than fins fixed to the body were employed in the present tests in order to approach the zero rolling-moment-of-inertia case analyzed in reference 1. In the analysis presented in reference 1, however, the effect of roll inertia was considered by utilizing various values for the ratio of moments of inertia about the roll and pitch axes. This analysis showed that increasing the rolling moment of inertia to 20 percent of the pitching moment of inertia (more than equivalent to fixing the fins to cause body rotation) would not appreciably change the stability boundaries for monoplane fins, that is, for positive values of ω_θ^2 and negative values of ω_ψ^2.

Drag Data

Models.- Drag coefficients obtained from the flight of models 1 and 2 are presented in figure 12. For comparison there are also presented in figure 12 the drag coefficients of similar models having no fins and cruciform fins from reference 2. The data for models 1 and 2 are in fair agreement. At subsonic speeds the drag coefficients for models 1 and 2 (2-fin panels) are about halfway between those for the finless and cruciform (4-fin) models as might be expected from simple fin-area considerations. At transonic and low supersonic speeds, however, models 1 and 2 appear to have about the same drag as the finless model. One possible explanation for this drag phenomenon is that there may be a favorable interference effect of the rotating-fin assembly on the body base pressures.

Rockets.- Drag coefficients obtained from the flights of rockets 1 and 2 are presented in figure 13. The most apparent item to be noted in figure 13 is the large difference in drag between the two rockets. The actual values of the drag coefficients for rocket 2 are probably meaningless in themselves and serve only to emphasize the high average drag of a body flying at large angles of attack and sideslip.

Additional Research Required

The results obtained from the present investigation represent qualitative data only. Further tests would be required with internally instrumented models to obtain quantitative static and dynamic stability data. It is believed that the results presented herein prove the practicability of providing stability by the use of a rotating, monoplane tail (either with or without body rotation), but various details need

more complete investigation. Among the items requiring more study are (a) launching or releasing monoplane fin bodies from aircraft, (b) effects of rolling moment of inertia (fixed or free fins) on the launching or release, and (c) quantitative data on static and dynamic stability and thus the dispersion after launching or release.

CONCLUDING REMARKS

Results of the tests reported herein indicate that two models having freely spinning monoplane fins and a standard rocket with cruciform fins all were stable in flight and had approximately zero-lift trajectories. A fixed, nonrotating monoplane fin test rocket flew with a pronounced wobble (approximately $\pm 20^{\circ}$) which indicated an appreciable amount of instability.

Data from the monoplane fin test rocket indicated approximately equal roll and pitch frequencies but the quality of the data from the two models and the cruciform fin test rocket was not sufficient to show whether a similar relationship existed for these vehicles.

Rolling velocities for the two models were appreciably greater than theory indicated and a large part of this difference is believed to be attributable to aeroelastic effects.

Computed effects of various changes to the model configuration show that fairly large changes can probably be tolerated in fin size, roll rate, and center-of-gravity position without critical losses in the stabilizing effect of the freely rolling fins.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va.

REFERENCES

1. Phillips, William H.: Effect of Steady Rolling on Longitudinal and Directional Stability. NACA TN 1627, 1948.

2. Hart, Roger G.: Effects of Stabilizing Fins and a Rear-Support Sting on the Base Pressures of a Body of Revolution in Free Flight at Mach Numbers from 0.7 to 1.3. NACA RM L52E06, 1952.

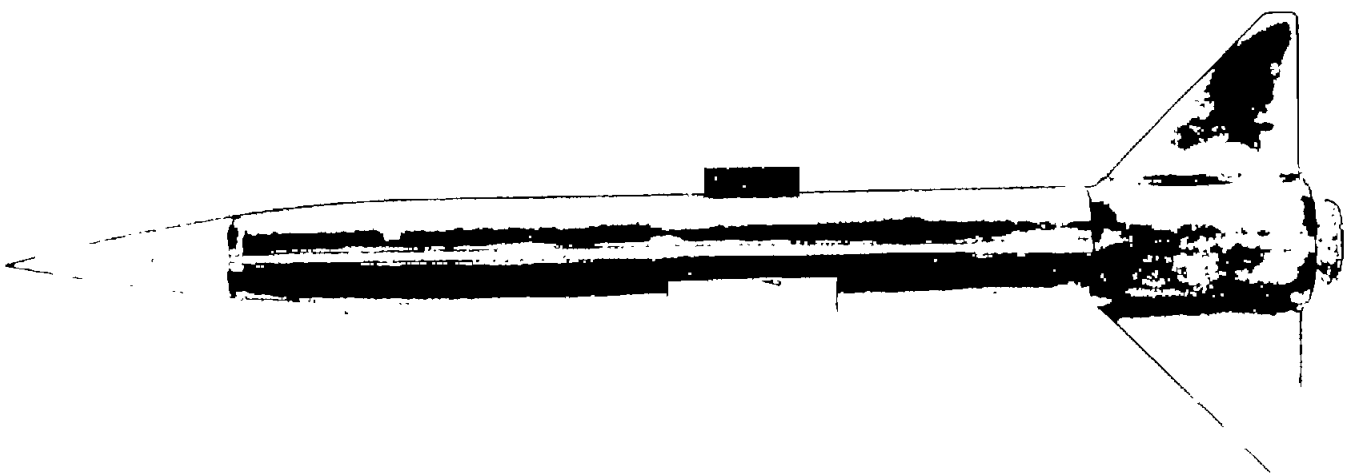
3. Strass, H. Kurt, and Marley, Edward T.: Rolling Effectiveness of All-Movable Wings at Small Angles of Incidence at Mach Numbers from 0.6 to 1.6. NACA RM L51H03, 1951.

TABLE I

PHYSICAL CHARACTERISTICS OF MODELS

[All the quantities (except fin inertia) varied approximately linearly with time between the loaded and empty values during rocket burning.]

	Loaded	Empty
Model 1		
Weight, lb.	41.06	31.68
Center-of-gravity position, behind nose, in . . .	32.88	33.09
Moment of inertia (pitch or yaw), slug-ft^2 . . .	2.215	2.022
Body plus fin rolling moment of inertia, slug-ft^2	0.0224	0.0208
Model 2		
Weight, lb	40.69	31.31
Center-of-gravity position, behind nose, in . . .	32.75	33.03
Moment of inertia (pitch or yaw), slug-ft^2 . . .	2.230	2.035
Body plus fin rolling moment of inertia, slug-ft^2	0.0223	0.0207
Fin rolling moment of inertia, Model 1, slug-ft^2	0.0065	
Fin rolling moment of inertia, Model 2, slug-ft^2	0.0065	



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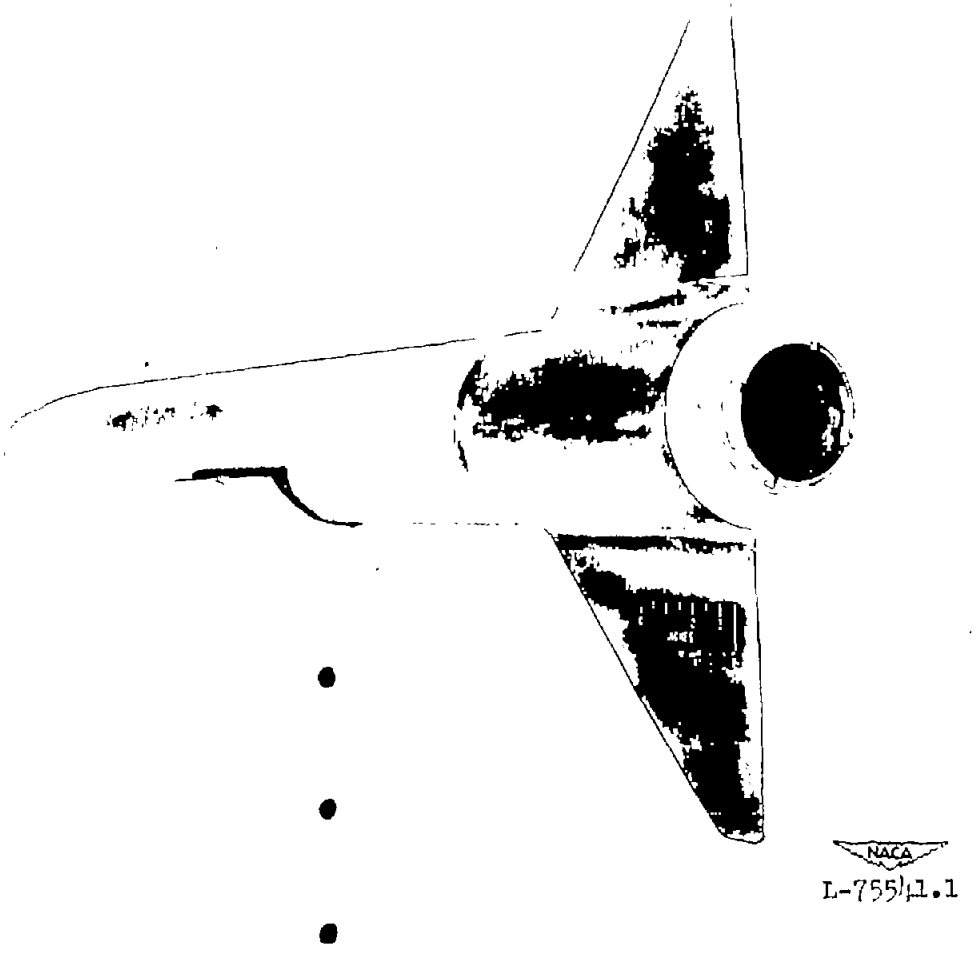
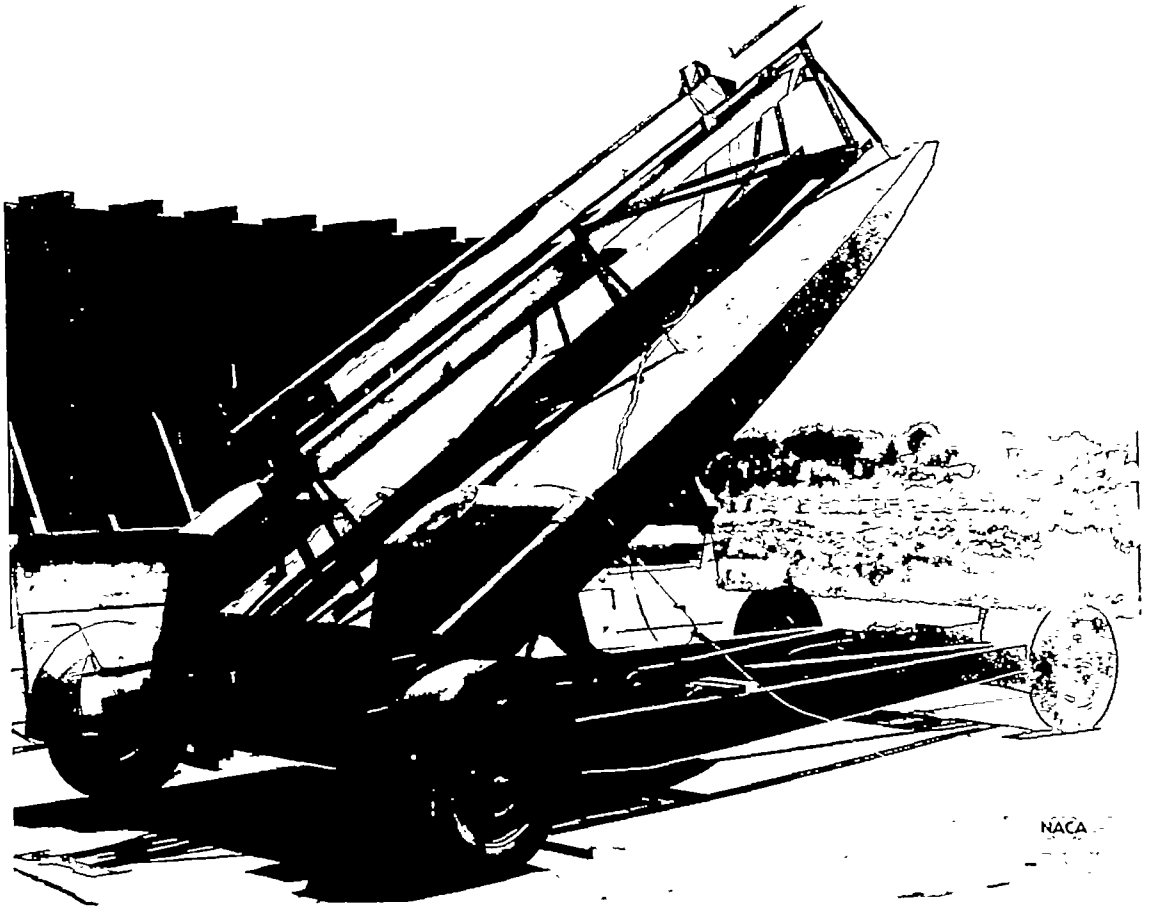
(a) Side view.

Figure 1.- Photographs of one of the models.



(b) Three-quarter rear view.

Figure 1.- Continued.



(c) Model on the launcher.

Figure 1.- Concluded.

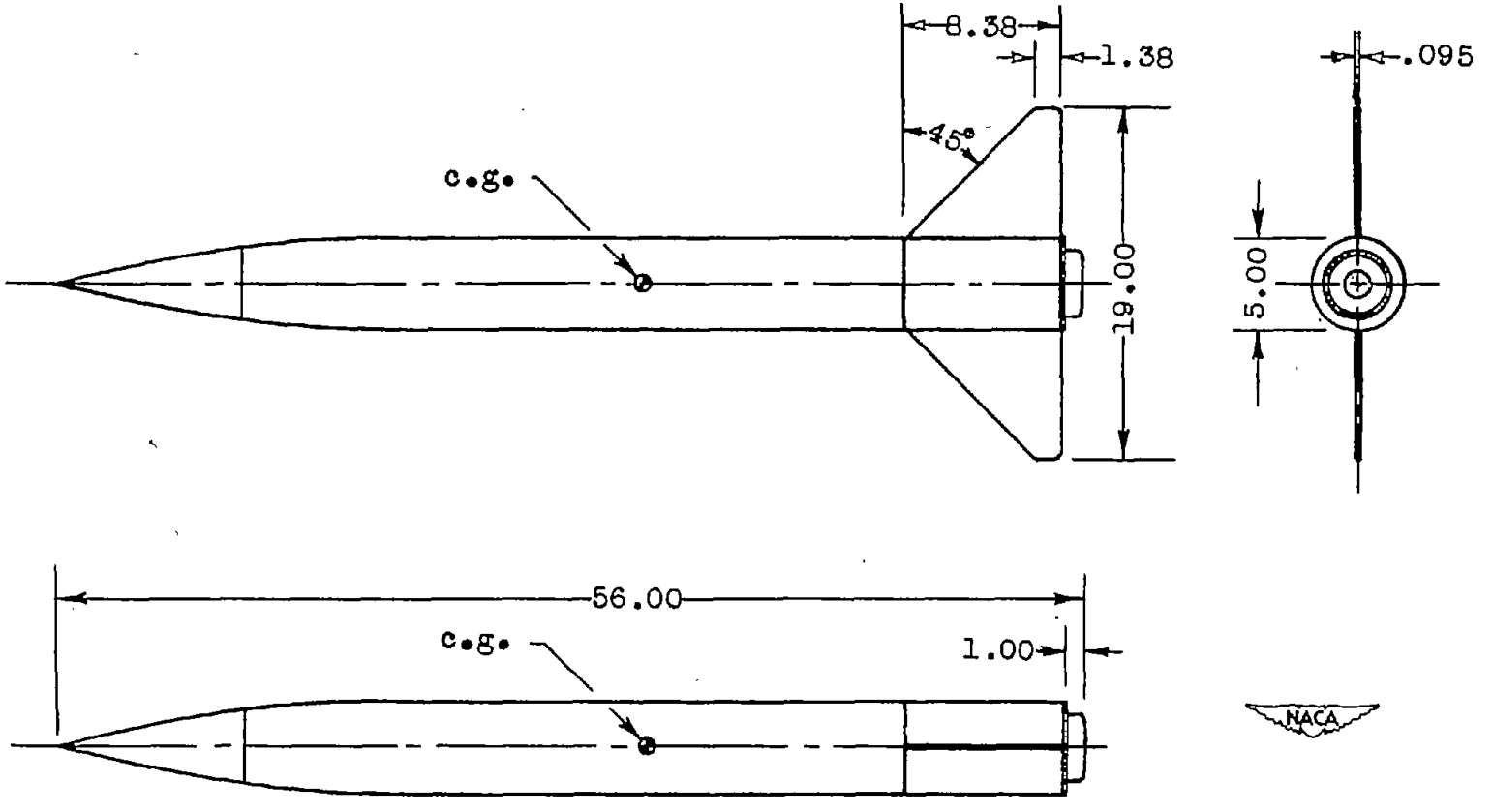


Figure 2.- Three-view drawing of monoplane, rotating fin model. All linear dimensions are in inches.

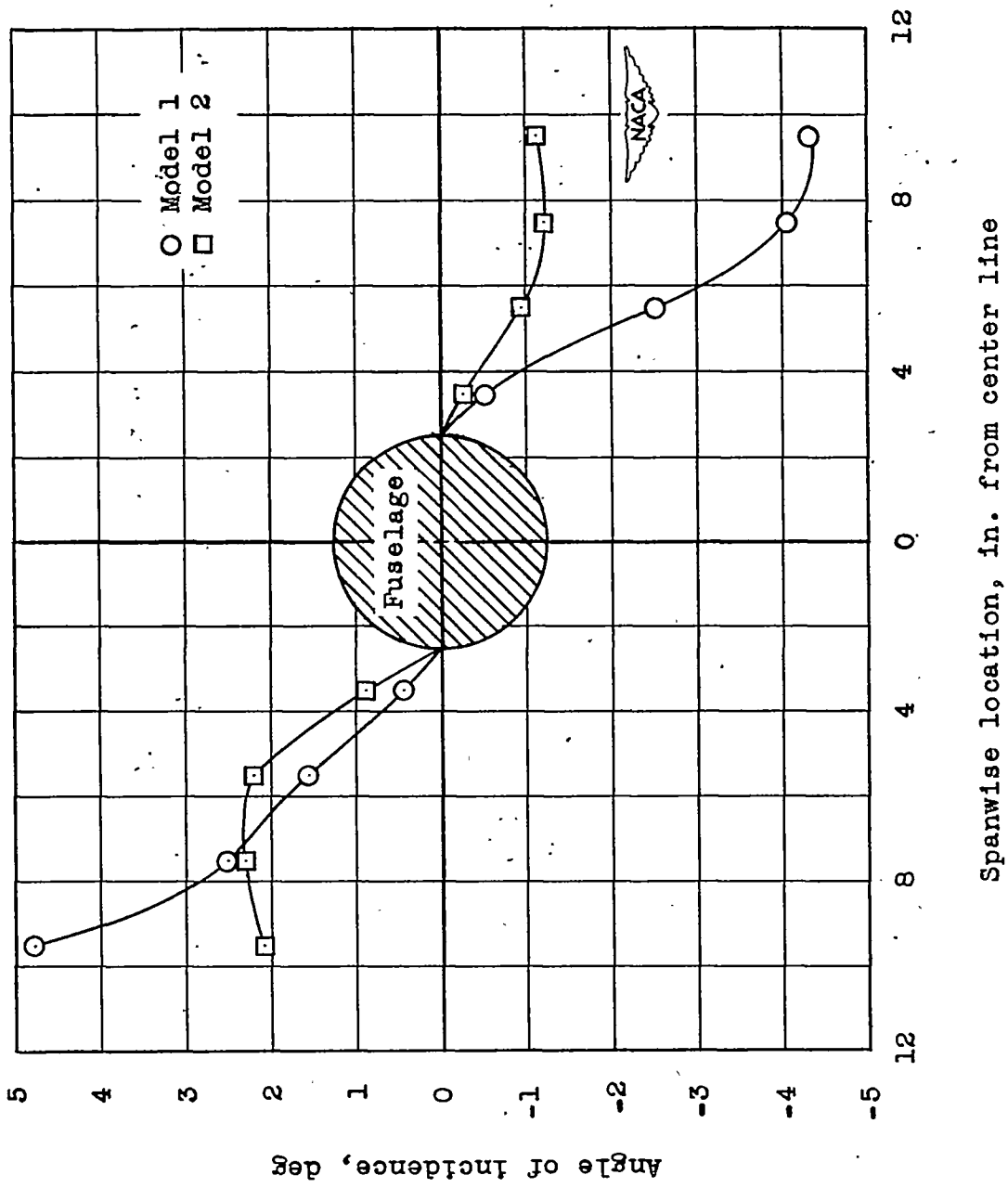


Figure 3.- Fin twist along the span looking from the rear.

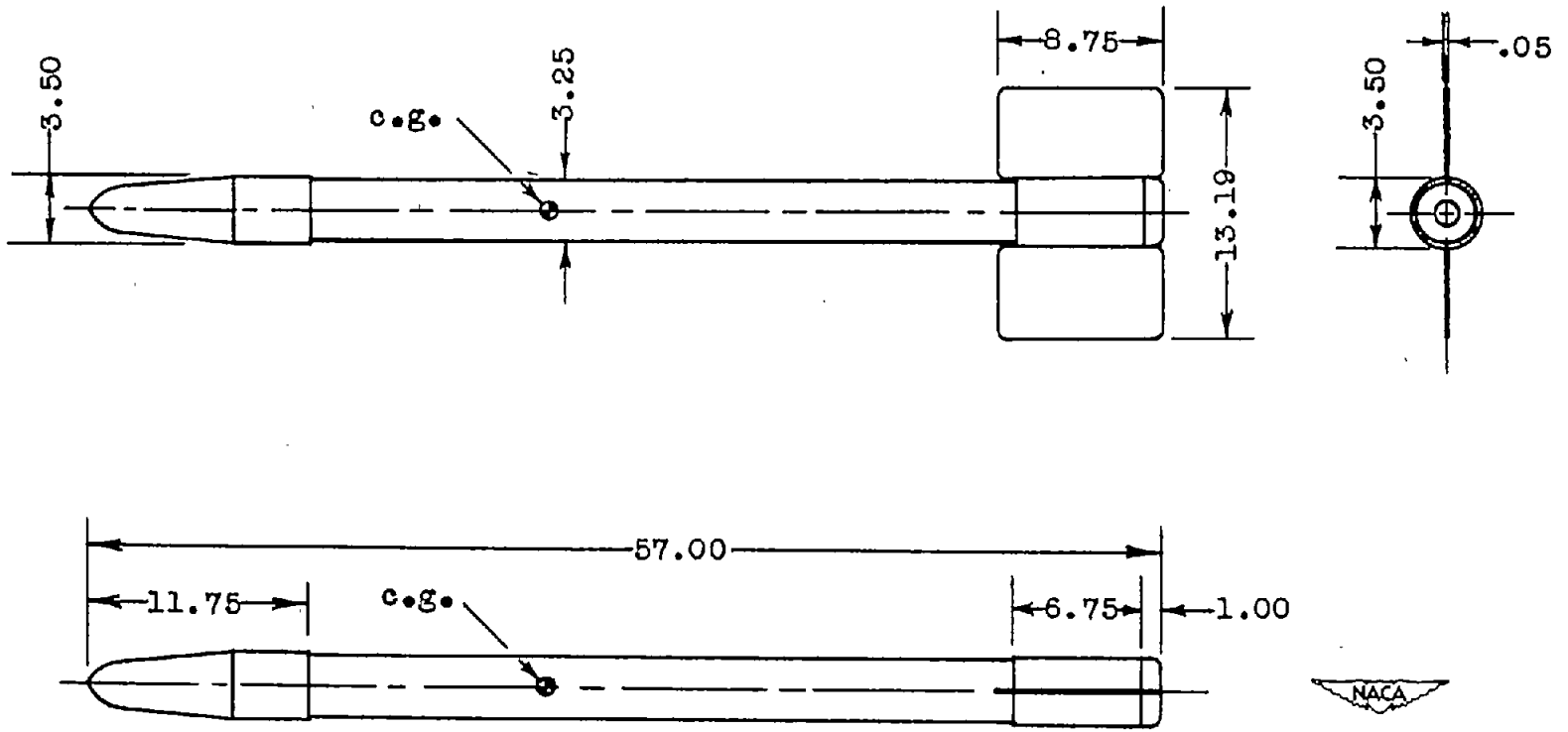


Figure 4.- Three-view drawing of the untwisted, monoplane fin test rocket. All dimensions are in inches.

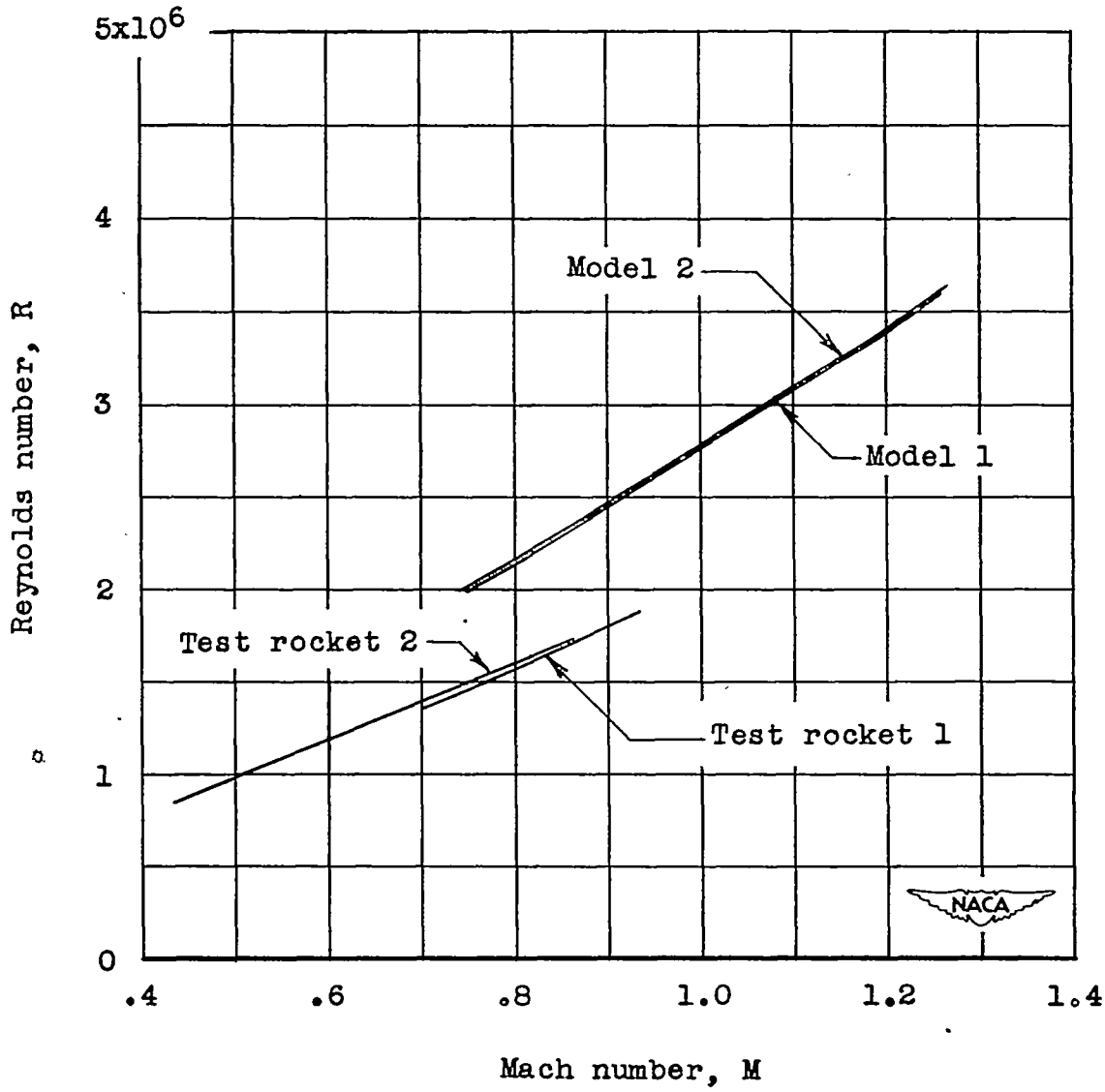
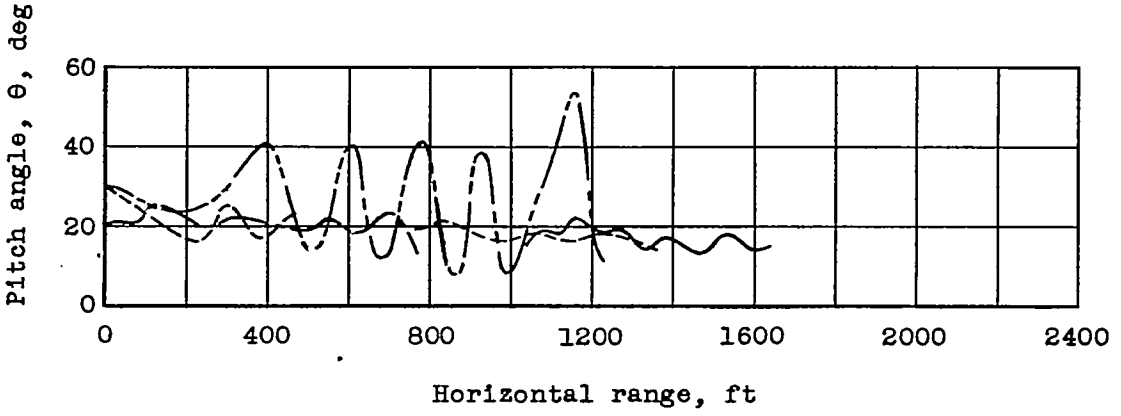
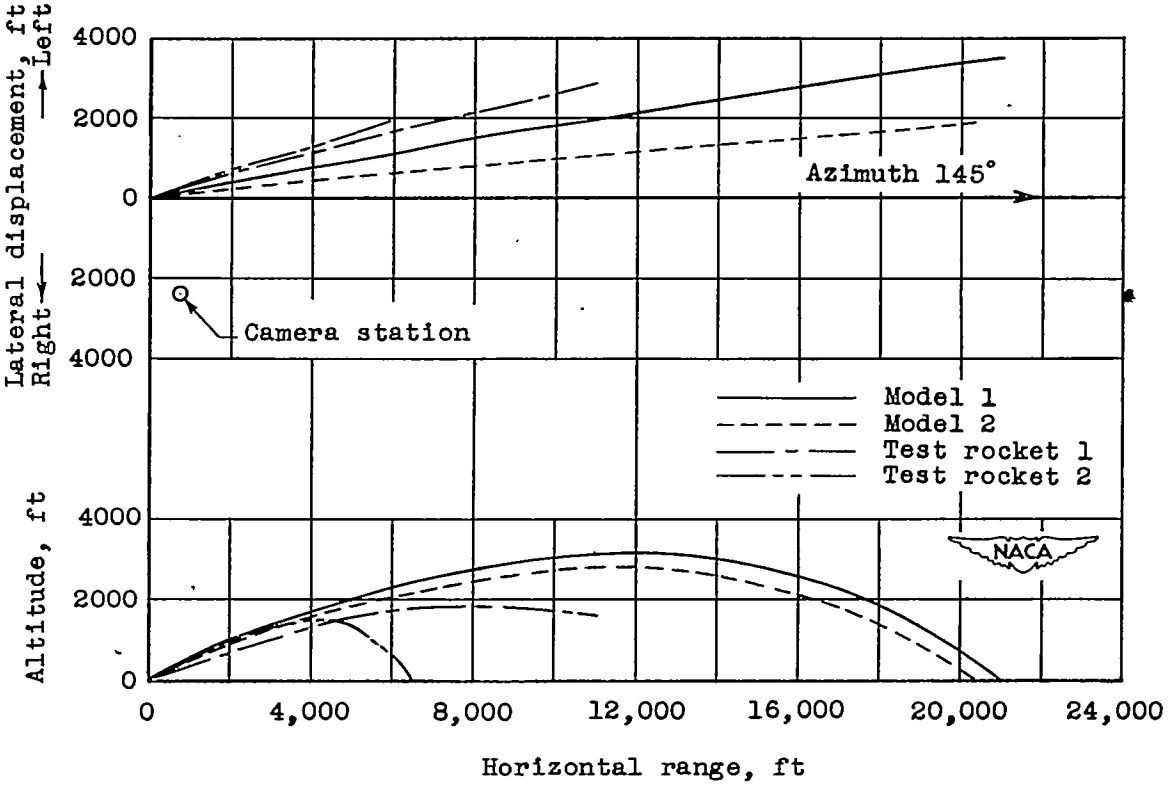


Figure 5.- Reynolds number based on maximum body diameter as a function of Mach number.



(a) Apparent pitch angle.



(b) Flight-path data.

Figure 6.- Flight-path information from each of the test vehicles.

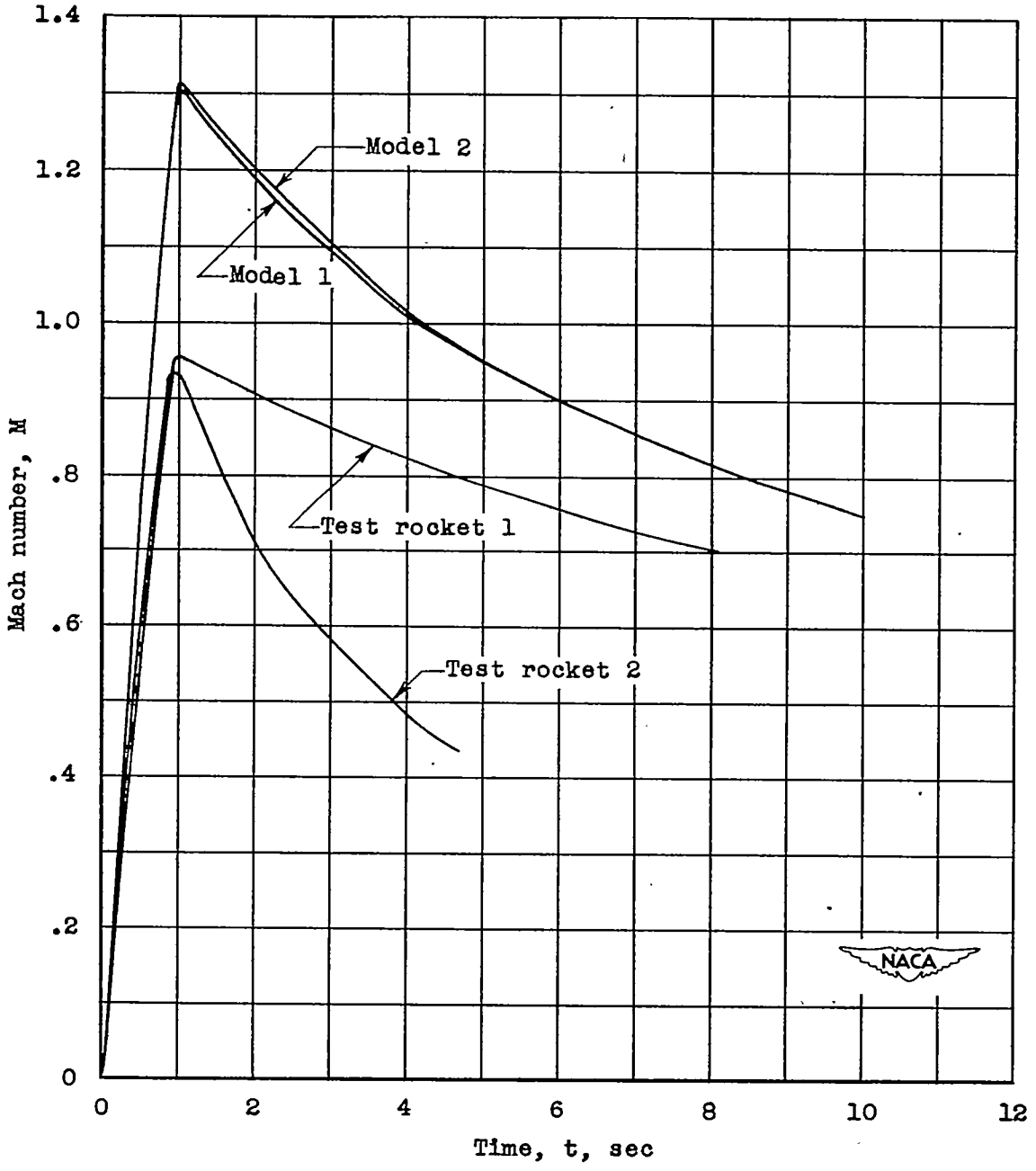


Figure 7.- Variation of Mach number with time for all the test vehicles.

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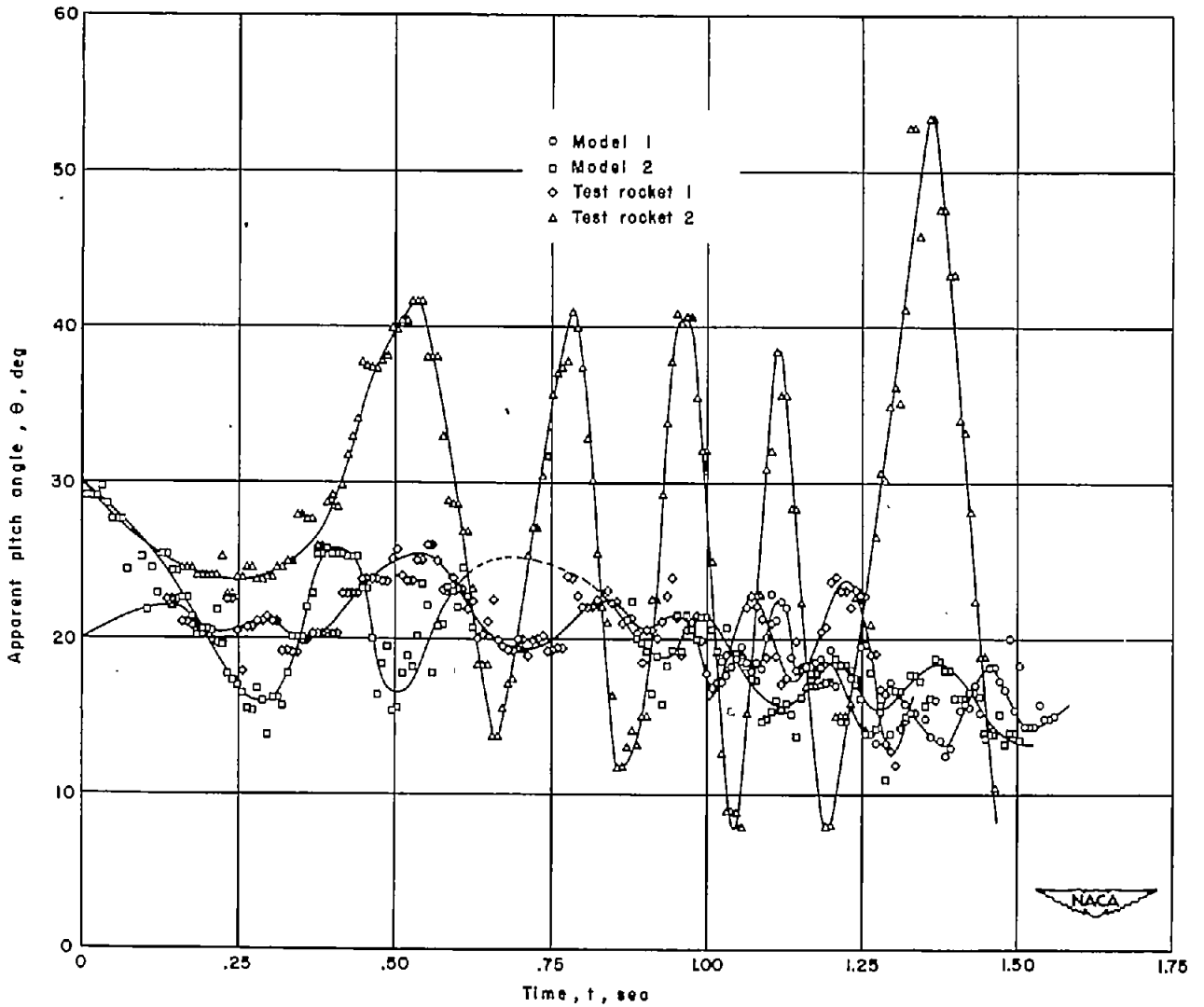

Figure 8.- Apparent pitch angles for all the test vehicles varying with time.

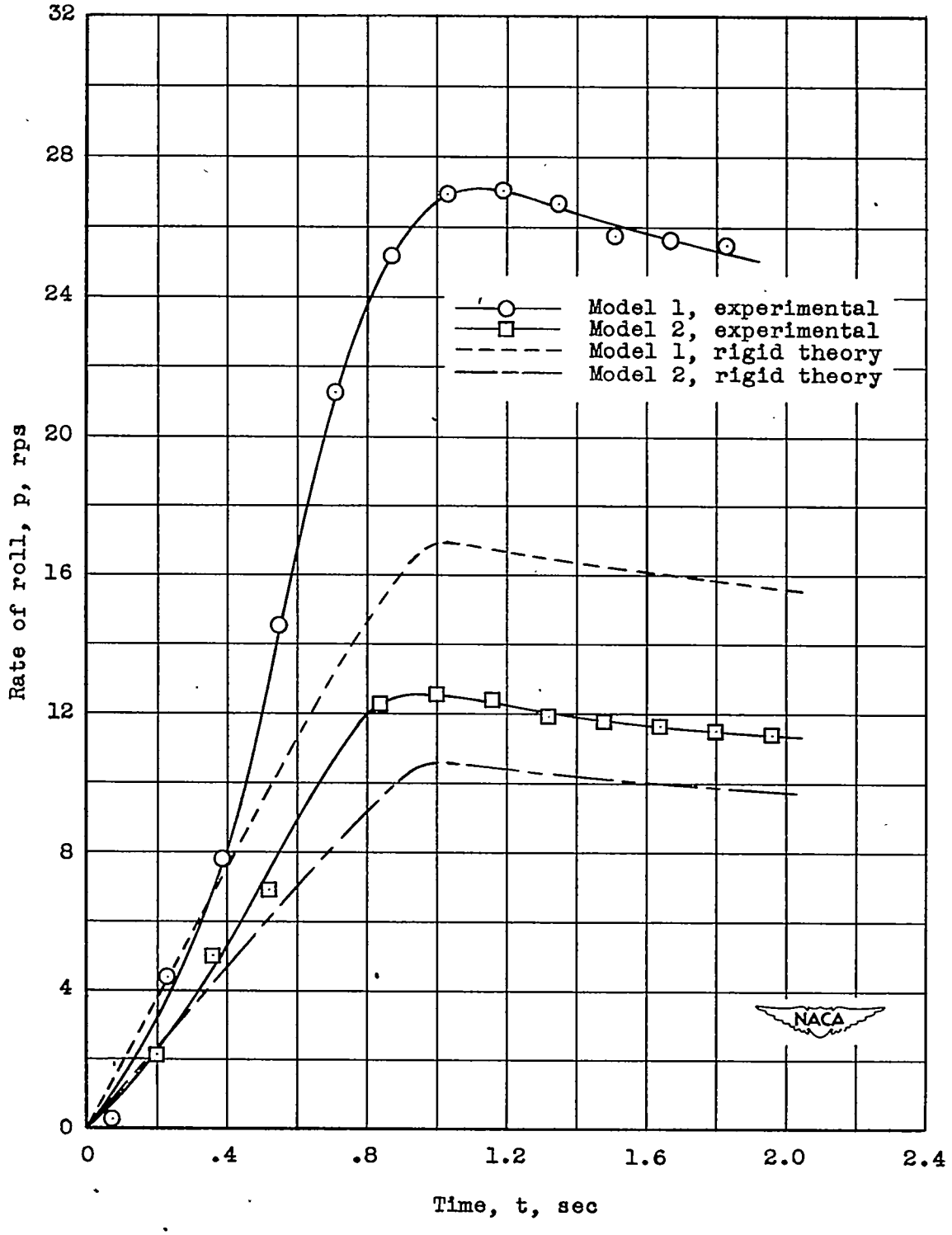

Figure 9.- Experimental and theoretical rates of roll for the two models as functions of time.

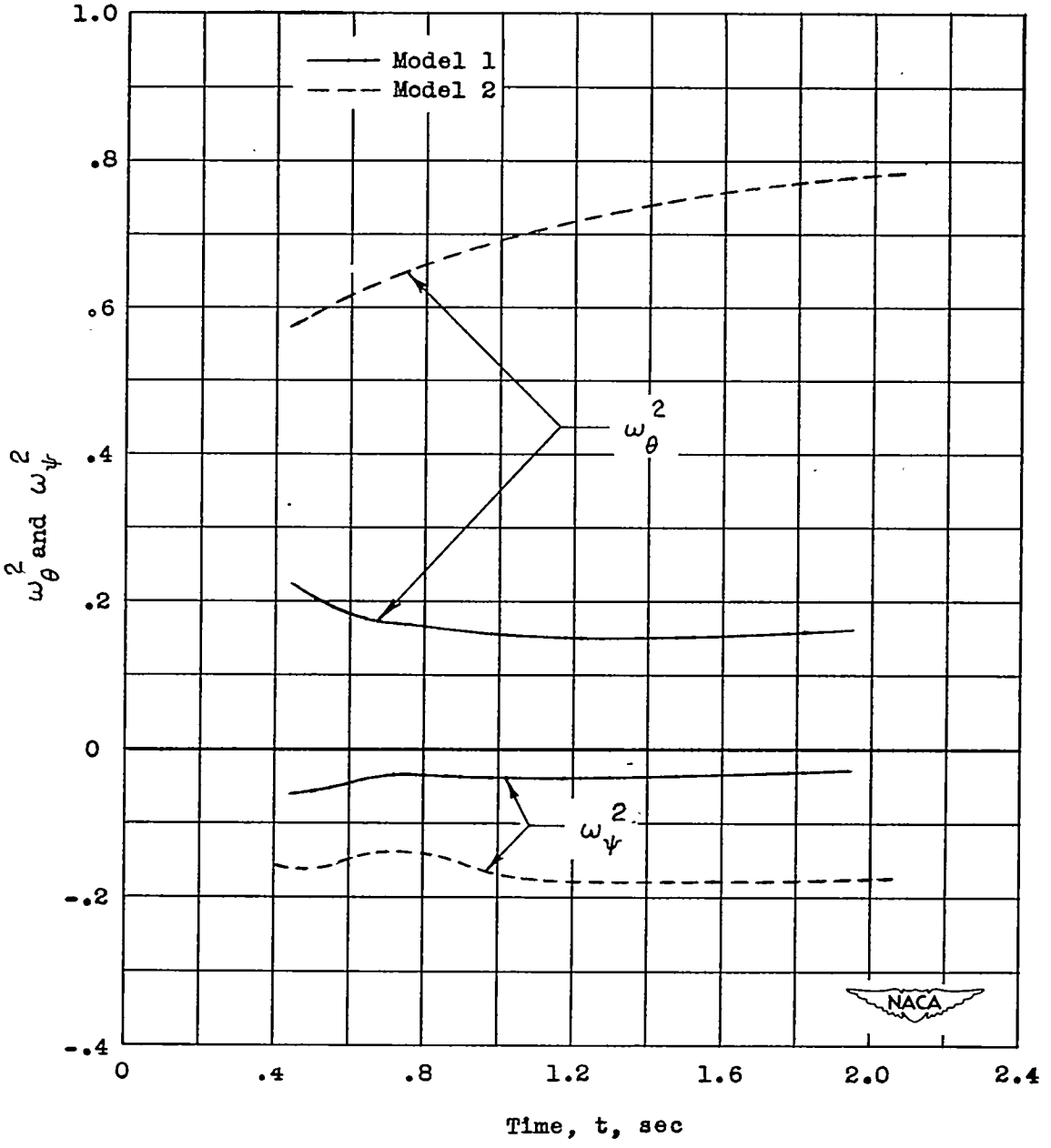

Figure 10.- Frequency parameters for models 1 and 2 for use with charts of reference 1.

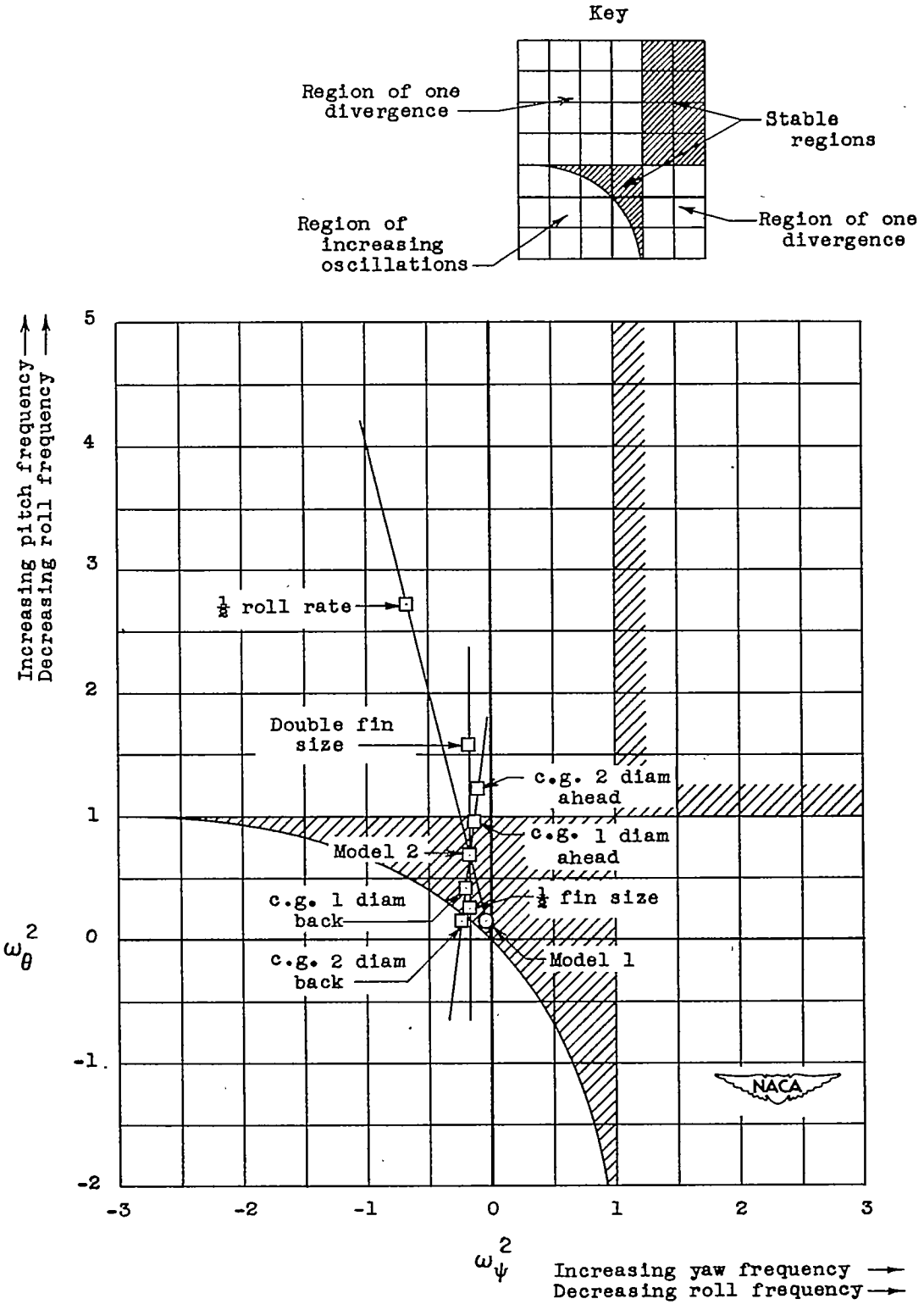

Figure 11.- Stability chart from reference 1 showing the effects of various changes to model 2.

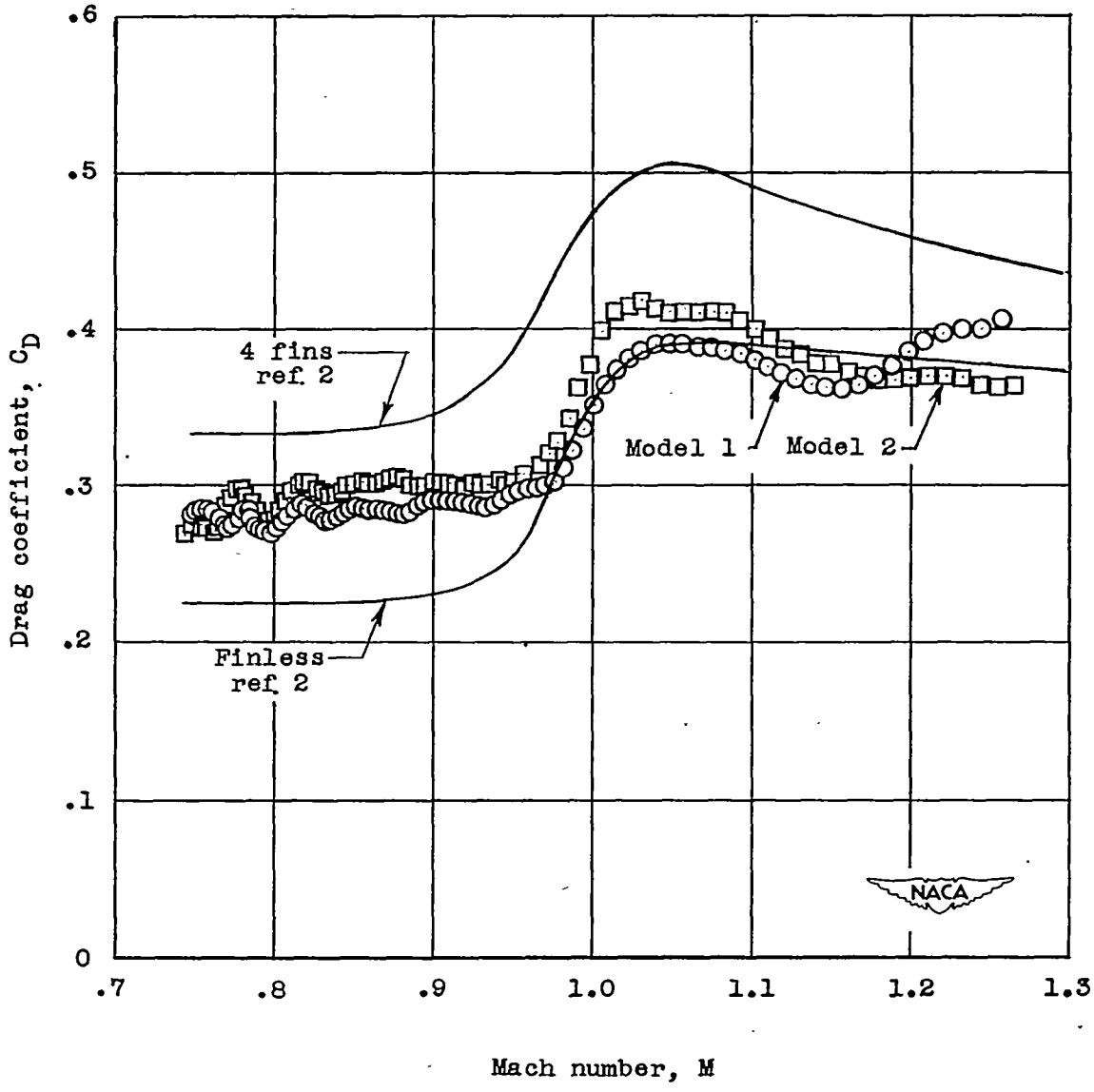

Figure 12.- Drag coefficient as a function of Mach number for the two monoplane models, a four-fin model and a finless model.

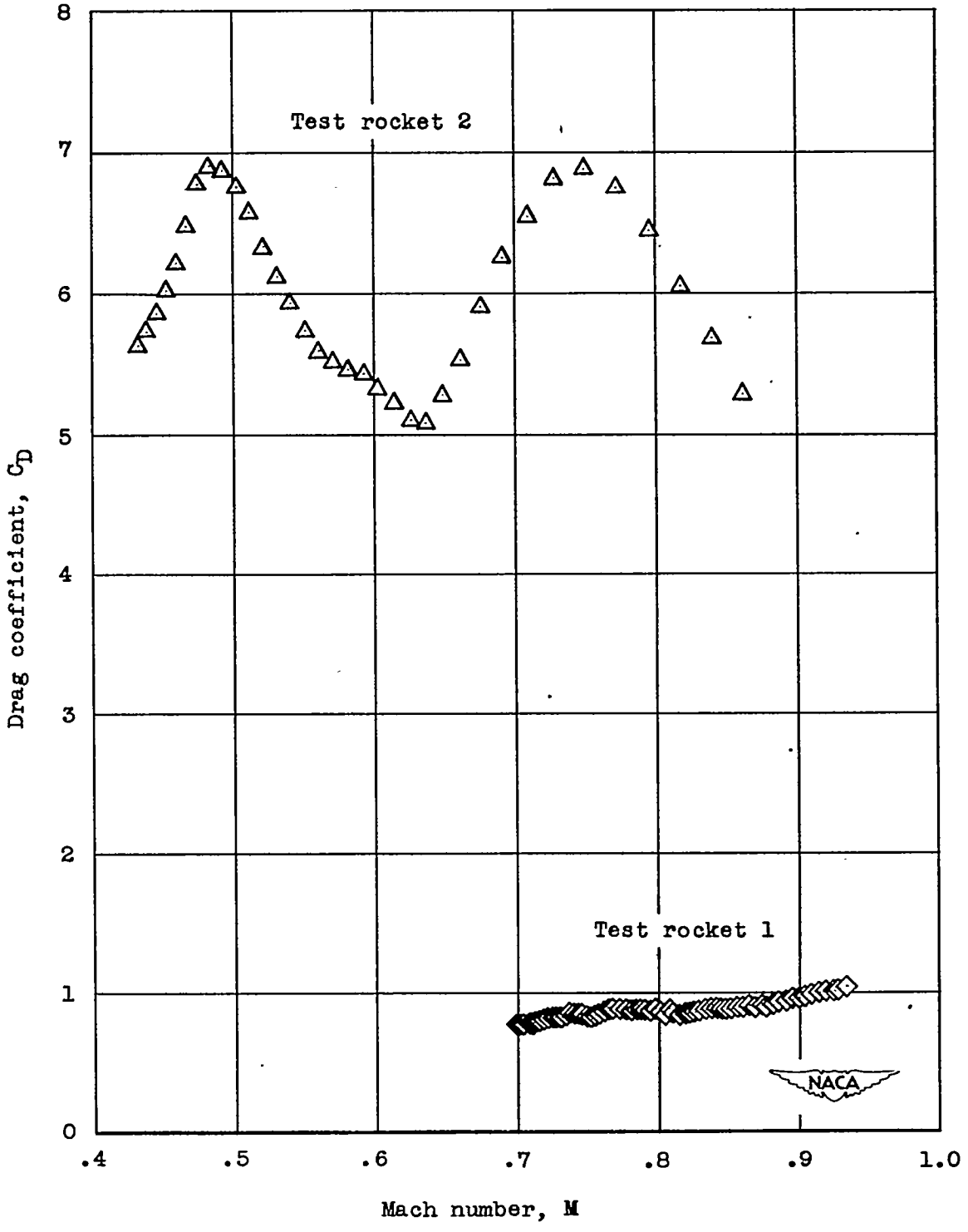

Figure 13.- Drag coefficient as a function of Mach number for the two test rockets.

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