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RESEARCH MEMORANDUM

PERFORMANCE MEASUREMENTS FROM A ROCKET-POWERED EXPLORATORY RESEARCH MISSILE FLOWN TO A MACH NUMBER OF 10.4

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NATIONAL ADVISORY COMMITTEE
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PERFORMANCE MEASUREMENTS FROM A ROCKET-POWERED EXPLORATORY RESEARCH MISSILE FLOWN TO A MACH NUMBER OF 10.4

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SUMMARY

As a step in the development of free-flight techniques to allow testing at hypersonic Mach numbers, a four-stage exploratory research missile has been successfully flight tested to a Mach number of 10.4. The Reynolds number at peak Mach number was 2×10^6 per foot of model length. The model length was 71 inches. A maximum temperature of 1220° F was measured on the model 26.6 inches back of the nose tip about one second after peak Mach number. The missile was estimated to have reached a maximum altitude of 219 statute miles.

INTRODUCTION

In recent months the Langley Laboratory has been developing its rocket test techniques to allow aerodynamic testing at hypersonic speeds. Several exploratory flight tests have been conducted to check the integrity of model and booster structures and instrumentation under the severe conditions encountered at hypersonic speeds. Initial tests were conducted with two-stage missiles which reached Mach numbers between 5 and 6. Subsequently, two three-stage models were flown to a Mach number of 6.9. Recently a four-stage exploratory research missile was flight tested to a Mach number of 10.4. The purpose of this report is to give a description of this missile and to present performance measurements obtained from this flight through peak Mach number. The variation of Mach number and Reynolds number with time and some skin temperature measurements are included. In order to expedite this presentation, no analysis of heating data is included. The missile was launched from the Langley Pilotless Aircraft Research Station at Wallops Island, Va., on October 14, 1954.

SYMBOLS

x	nose length from zero station
r	body radius
R	maximum cylindrical radius (3 in.)
L	length of model nose (30 in.)
P_T	total pressure behind normal shock
ΔP	differential pressure on wedge
A_L	longitudinal acceleration
A_n	normal acceleration
T	temperature, °F
M	Mach number, $\frac{\text{Velocity}}{\text{Velocity of sound}}$
R	Reynolds number, $\frac{\text{Density} \times \text{velocity} \times \text{length}}{\text{Viscosity}}$
P_o	static pressure
t	time, sec
h	altitude, ft
V	velocity, ft/sec

MODEL

A sketch of the model is shown in figure 1. A photograph of the model is shown as figure 2. The Von Kármán nose shape (ref. 1) is described by the equation

$$r = \frac{R}{\sqrt{\pi}}\sqrt{\varphi - \frac{1}{2}\sin 2\varphi}$$

where

$$\varphi = \cos^{-1}\left(1 - \frac{2X}{L}\right)$$

The fineness ratio of the nose was 5. The nose tip was modified by the addition of a wedge forward of station 1.96. The nose was followed by a 30-inch long, 6-inch diameter cylindrical section. Two small fins, which served as antennas, protruded from the cylindrical section at station 30. The rearward end of the model formed a flare of 10° half angle. The ratio of base diameter to cylinder diameter was 1.55.

The nose of the model to station 7.9 was of stainless steel and contained ballast consisting of lead and sintered tungsten slugs. Back of station 7.9, the model was fabricated from 0.032 inch-thick Inconel sheet. The instrumentation was housed in the nose of the model between stations 9 and 31. A radiation shield consisting of an inner nose skin (0.032 inch thick Inconel), placed 0.2 inch from the external skin, protected the instrumentation from extreme aerodynamic heating.

The antenna fins were made of solid molybdenum and were provided with a siliconized coating to protect the molybdenum from oxidation at high temperatures. A Thiokol T-55 rocket motor was housed in the cylindrical and flared sections of the model (fourth stage). Its characteristics are described in table I. The stabilizing flare was supported by balsa wood which fitted snugly between the rocket nozzle and the flare skin.

A photograph of the model and boosters on the launcher is presented in figure 3. The third stage consisted of a Thiokol T-40 rocket motor (see table I) housed in a cylindrical Inconel shell. It was stabilized by four hollow fins each fabricated from two 0.032 inch sheets of Inconel with supporting spars. Fairings, made of balsa covered by Inconel sheet, were placed between the fins of the third stage to reduce the drag of the combination. Both second and first stages used JATO M-5 rocket motors (see table I). The fins used on these two stages were constructed of mahoghany and balsa with aluminum overlays 1/8 inch thick.

The second and third stages were locked together to prevent premature separation. The lock was released at second stage burnout under pressure from the second-stage rocket chamber. The third and fourth stages were also locked together. This lock was broken by the blast of the firing of the fourth-stage rocket motor.

INSTRUMENTATION

Ground.- The velocity of the model during the first 28 seconds of the flight was obtained with a CW Doppler radar unit. A modified SCR 584 radar tracked the model for 34.5 seconds and provided slant range, azimuth, and elevation angle from which altitude, horizontal range, and model-flight-path angle may be calculated at a given time. A rawinsonde, balloon-launched near the time of flight, provided measurements of static pressure, static temperature, and balloon azimuth and elevation to an altitude of 85,000 feet. Wind velocity and direction were calculated from these data.

Internal.- The following quantities were measured by instruments in the model and telemetered to the ground receiving station.

Quantity	Location of instrument	Range	Purpose
P_t	Nose of wedge	15 to 75 lb/sq in.	Mach number
ΔP	Wedge	± 3 lb/sq in.	Angle of attack
A_L	Station 16	-11g to +25g	Thrust and drag
A_L	Station 16	-1g to +90g	Thrust
A_n	Station 16	± 10g	Normal force
T(thermocouple)	Station 25	0° F to 1800° F	Heat transfer
T(resistance wire)	Station 25	0° F to 1800° F	Heat transfer

Readable telemeter data were obtained from the instruments for 56 seconds with the exception of the total-pressure channel which failed just prior to peak Mach number and the resistance-wire temperature-measuring device which failed at about 35 seconds.

DATA REDUCTION

Mach number.- The CW Doppler radar unit afforded the variation of velocity with time from 2 to 28 seconds. Between 28 and 31 seconds, the low-range accelerometer readings, modified by subtracting the weight component, were integrated to provide velocity data. A similar method was used with the high-range accelerometer between 31 and 33.25 seconds at which time peak Mach number occurred. The velocities thus obtained were then used with values of the speed of sound to obtain Mach number. The speed of sound was calculated from static-temperature measurements obtained from the rawinsonde.

Total-pressure measurements in conjunction with static-pressure measurements afforded a Mach number measurement until 32.2 seconds of flight at which time the total-pressure instrument failed. The static pressure used was obtained from rawinsonde measurements. The Rayleigh pitot equation was used to calculate the Mach number from the pressure measurements. After 32.2 seconds of time, integrated accelerometer measurements were used to extend the data to 33.2 seconds.

The Mach number obtained from the several sets of measurements differs at the peak Mach number by 0.2. By considering the accuracy of all measurements involved, a peak Mach number (33.20 seconds) can be determined correct to ± 0.13. The accuracy with which the Mach number is known to 28 seconds is ± 0.01. This error increases between 28 and 33.20 seconds to the figure of ± 0.13 given above.

Reynolds number.- The Reynolds numbers based on body length were calculated by using velocities as obtained above in conjunction with density calculated from rawinsonde measurements. The viscosity was obtained by using rawinsonde static temperature measurements and standard tables.

FLIGHT TEST

The variation of velocity and altitude with flight time for the model, through peak velocity, is presented in figure 4. The velocity data presented was obtained from CW Doppler measurements for the first 28 seconds of flight and integrated accelerometer measurements to time of peak velocity. Between firings of the various stages, the model was allowed to decelerate. This is especially true between the first- and second-stage firings. The purpose of these coasting periods was to allow the model to coast through the lower, denser atmosphere at relatively low velocities and thereby reduce the maximum skin temperature. The coasting periods are indicated on the altitude-time plot by a broken line.

The variation of Mach number and Reynolds number with flight time for the model through peak Mach number is presented in figure 5. Four different symbols are used to indicate the instrumentation used to determine the Mach number at a given time. The solid line was obtained by considering the accuracies of all measurements concerned and its accuracy is believed to be better than that indicated by either symbol at a given time. Below 26 seconds there is essentially no disagreement between the measurements obtained in the two different ways.

Skin temperatures were measured at station 25 on the nose. (See fig. 1.) Measurements made at certain times are spotted on the plot of Mach number against time. A maximum skin temperature of 1220° F is indicated about one second after peak Mach number.

Reynolds numbers, based on body length, are seen to vary widely over the time for which data are presented. A peak Reynolds number occurs at second-stage burnout at which time the model was at a Mach number of 4.12.

At separation of the various stages, an oscillation occurred. In all cases both the normal-accelerometer and differential-pressure records show this oscillation to have been rapidly damped; thus, the model is shown to be both statically and dynamically stable in all stages.

The model is estimated to have reached a peak altitude of 219 statute miles. This estimate was obtained by assuming a drag-free, ballistic trajectory above an altitude of 140,000 feet.

CONCLUDING REMARKS

A four-stage research missile has been successfully flight tested to a Mach number of 10.4. This Mach number was attained at an altitude of 86,000 feet. The Reynolds number under these conditions was 2×10^6 per foot. The peak skin temperature measured during the flight 26.6 inches back of the nose tip was 1220° F and occurred about one second after the time of peak Mach number. The model is estimated to have reached a maximum altitude of 219 statute miles.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., December 28, 1954.

REFERENCE

1. Perkins, Edward W., and Jorgensen, Leland H.: Investigation of the Drag of Various Axially Symmetric Nose Shapes of Fineness Ratio 3 for Mach Numbers From 1.24 to 3.67. NACA RM A52H28, 1952.

TABLE I

CHARACTERISTICS OF ROCKET MOTORS USED IN TEST

Motor	Total weight, lb	Grain weight, lb	Total impulse, lb-sec	Specific impulse (overall), lb-sec/lb	Average thrust, lb	Burning time, sec
JATO M-5	1,180	740	139,500	117	42,300	3.3
Thickol T-40	132	102	18,600	141	2,900	6.31
Thickol T-55	46.0	33.6	7,150	155	4,800	1.33

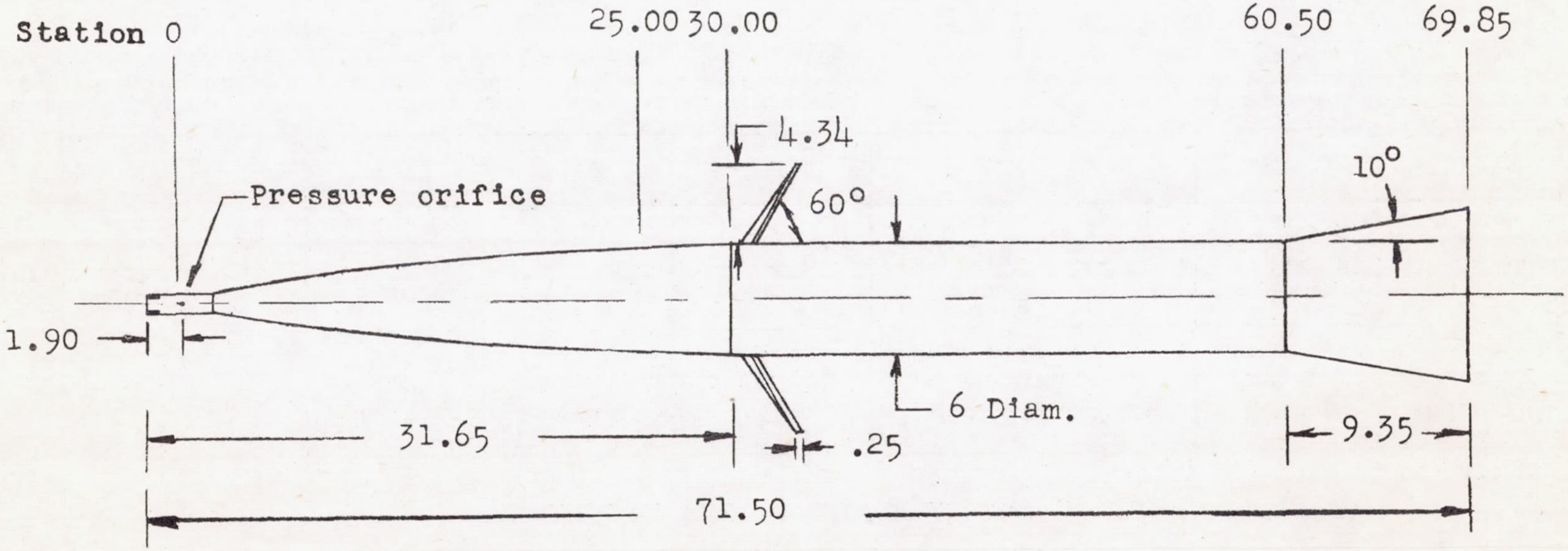

Figure 1.- Pertinent dimensions of test vehicle. All dimensions are in inches.

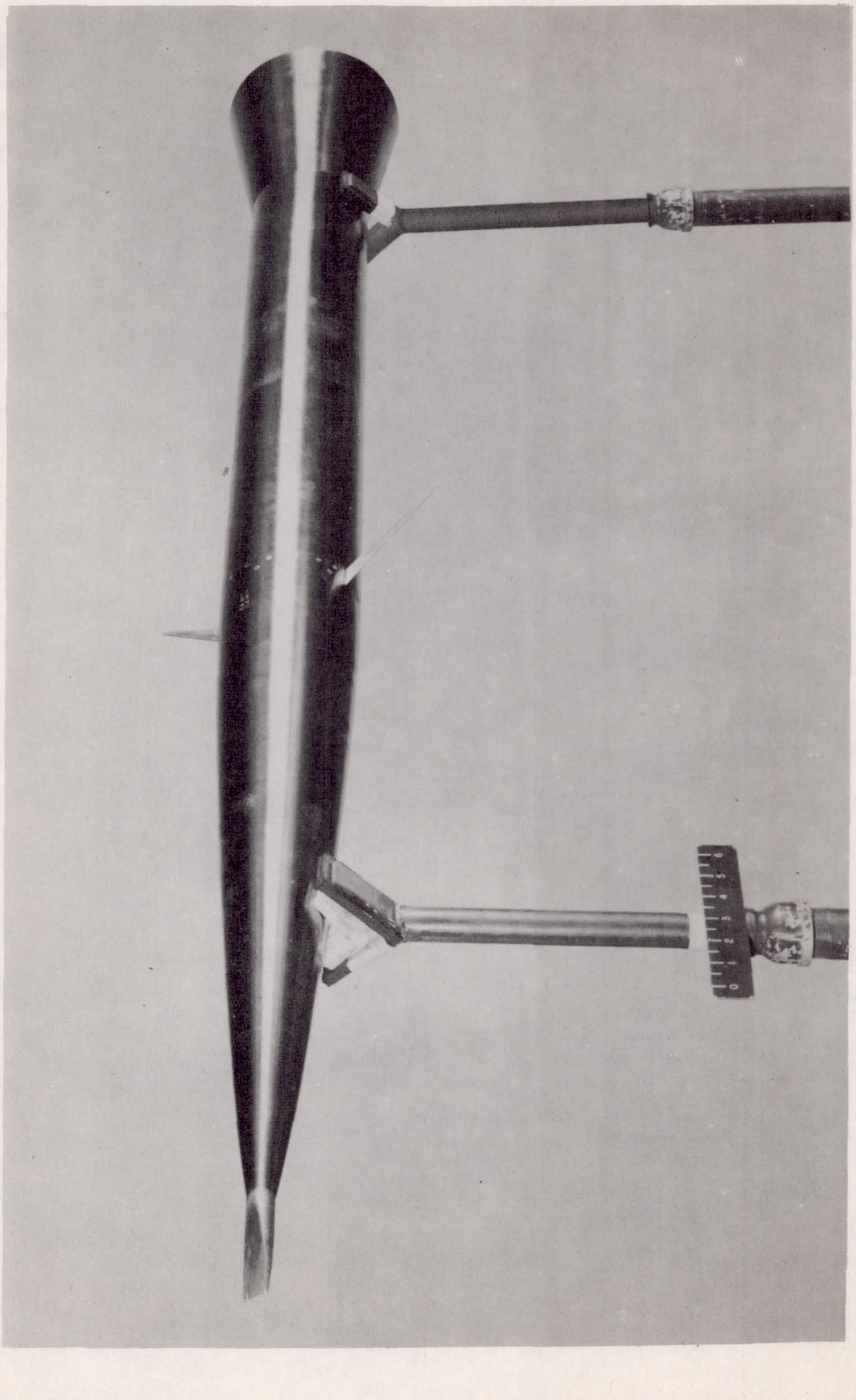

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Figure 2.- Three-quarter view of test vehicle.

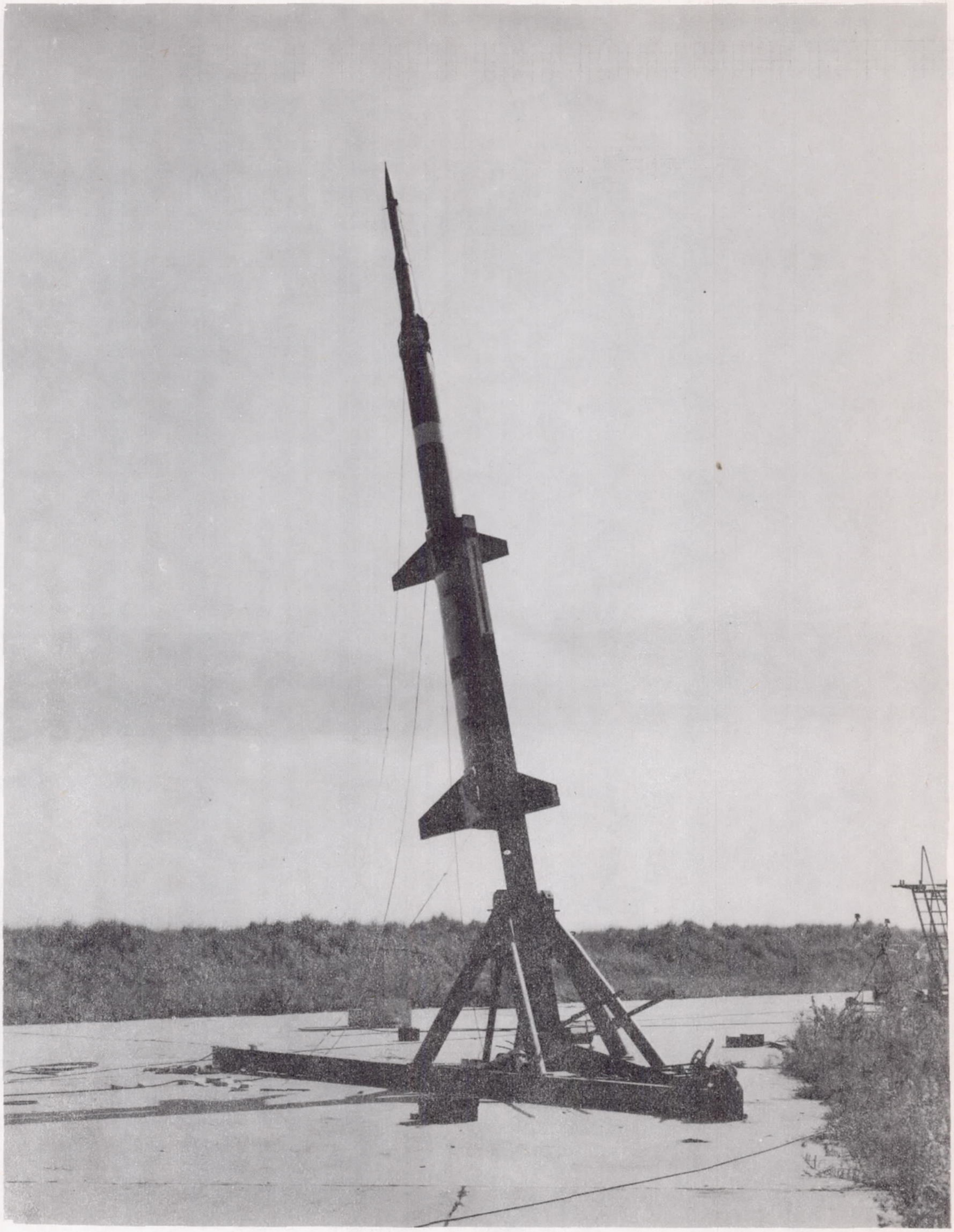

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Figure 3.- Photograph of test vehicle and boosters on launcher.

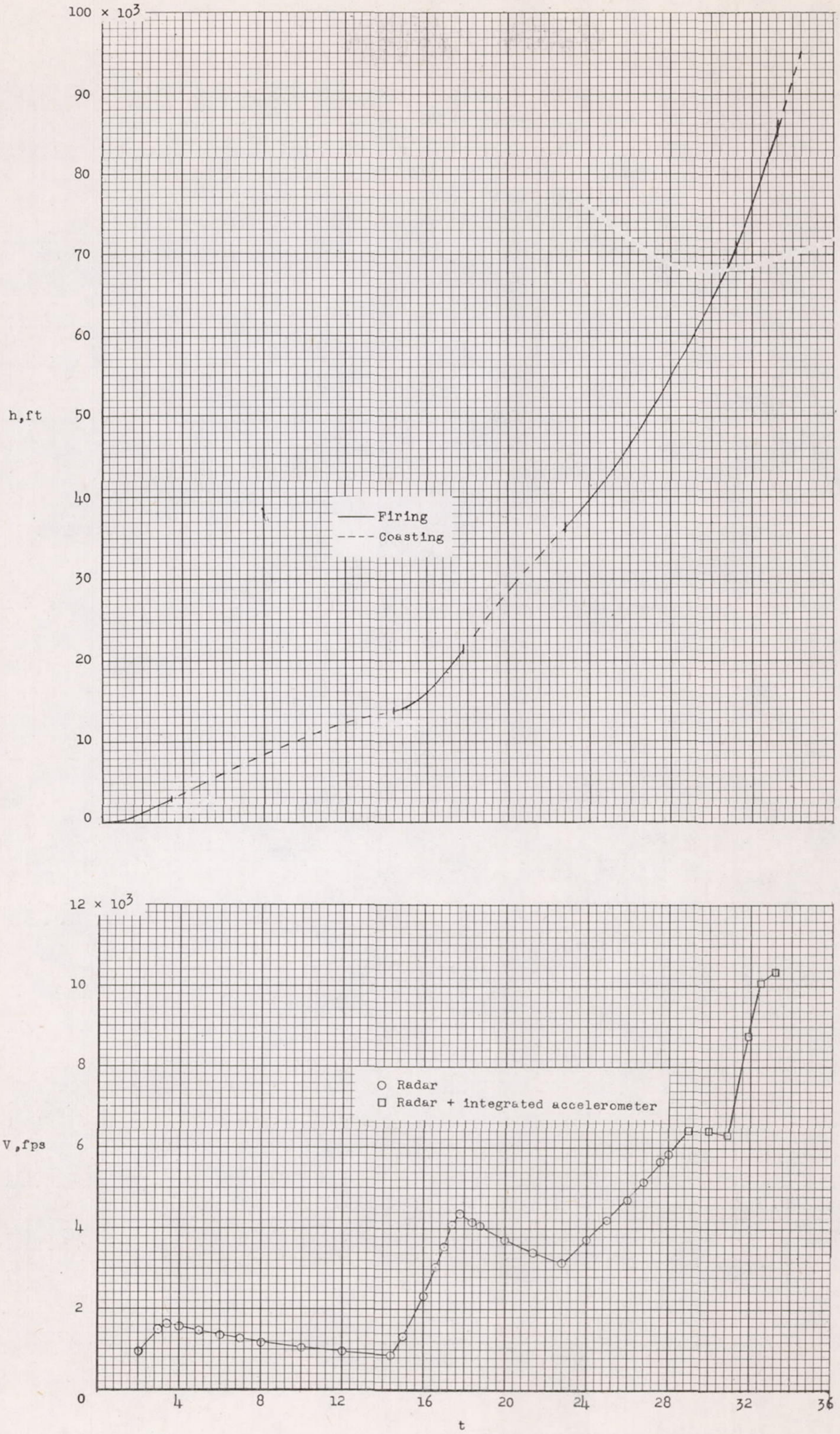

Figure 4.- Variation of measured altitude and velocity with time for test vehicle.

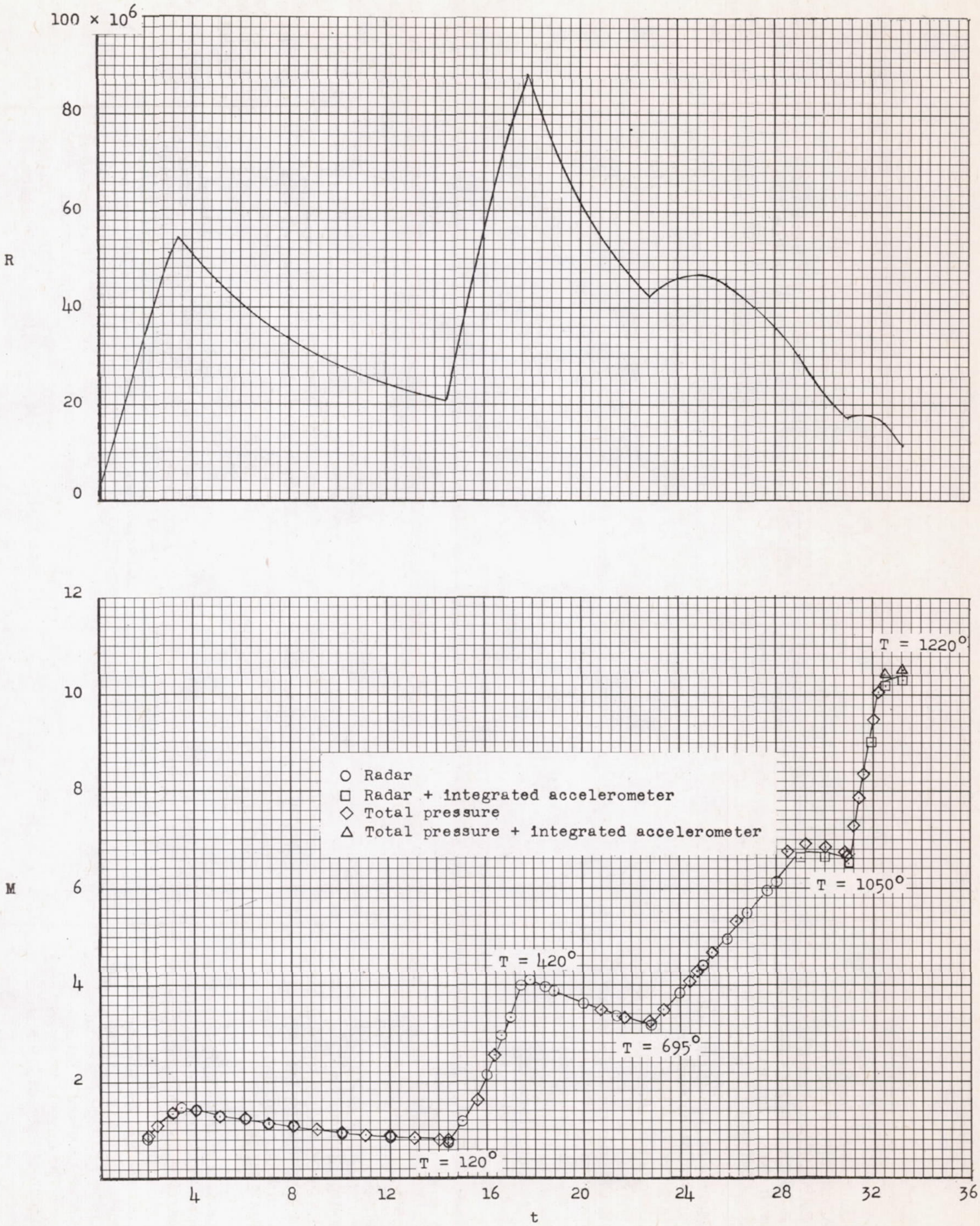

Figure 5.- Variation of Reynolds number (based on body length) and Mach number with time for test vehicle.