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RESEARCH MEMORANDUM

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FREE-FLIGHT INVESTIGATION OF 16-INCH-DIAMETER SUPERSONIC RAM-JET UNIT

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RESEARCH MEMORANDUM

FREE-FLIGHT INVESTIGATION OF 16-INCH-DIAMETER SUPERSONIC RAM-JET UNIT

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SUMMARY

In order to determine the performance of ram-jet units in flight at supersonic speeds and to study methods for improving the performance, an investigation of a series of 16-inch-diameter ram-jet engines is being conducted in free flight. Supersonic flight speeds are obtained by releasing the unit from an airplane at an altitude of approximately 30,000 feet and allowing the engine thrust and the force of gravity to accelerate the unit.

During the first flight, a Mach number of 1.42 was reached. At this condition, the thrust coefficient exceeded the drag coefficient by 0.20. Partial failure of the telemetering equipment prevented a complete evaluation of the engine performance.

INTRODUCTION

Theoretical calculations have indicated that high thrust coefficients and low specific fuel consumption may be obtained with ram-jet units at supersonic flight speeds (reference 1); however, very little experimental performance data are available at these speeds. In order to measure the actual performance of ram-jet units and to study methods of improving the performance, an investigation of ram-jet units is being conducted in free flight. The method used to attain supersonic flight is to release the engine from an airplane at approximately 30,000 feet altitude and to allow the engine thrust and the force of gravity to accelerate the ram-jet unit. These flight experiments are being conducted over the Atlantic Ocean near Wallops Island, Virginia.

The first ram-jet unit to be investigated was designed for efficient diffuser operation at free-stream Mach numbers from 1.33 to 1.80 with a maximum combustion-chamber velocity of

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approximately 165 feet per second. Other engines are being designed for higher flight Mach numbers and combustion-chamber velocities.

The results obtained in the first flight are discussed herein. Failure of part of the telemetering equipment during the flight prevented a complete evaluation of the engine performance. Sufficient data were obtained, however, to determine the difference between the thrust and the drag of the engine at Mach numbers between 0.80 and 1.42.

APPARATUS AND INSTRUMENTATION

A photograph of the first supersonic 16-inch ram-jet unit investigated (designated model 16-A-1) is shown in figure 1 and a schematic cross-sectional view of the unit is presented in figure 2. The inlet diameter is 8 inches, the outlet diameter is $11\frac{1}{8}$ inches, and the over-all length excluding the telemetering antenna is $164\frac{1}{4}$ inches. The gross weight is 520 pounds. A single oblique shock-type diffuser with no internal contraction ratio is used. A central body (figs. 2 and 3) located within the diffuser contains an eight-channel telemetering transmitter, a fuel system, and a tubular tank in which nitrogen is stored at a pressure of 3000 pounds per square inch. A schematic drawing of the fuel system is shown in figure 4. The fuel-flow regulator controls the flow of nitrogen into the fuel tank in order to give a fuel pressure approximately four times the absolute free-stream total pressure throughout the flight. In order to maintain fairly high fuel pressures at low flow rates, fuel was injected into the combustion chamber by three separate systems of spray nozzles. Spring-loaded pressure reducing valves shut off the fuel flow in the second and third spray systems at fuel pressures below 50 and 100 pounds per square inch gage, respectively. The fuel used was 73-octane gasoline (AN-F-23A). A ducted-airfoil-type flame holder with intermediate gutters (fig. 5) was chosen for the ram-jet unit on the basis of results from preliminary ground investigations. Combustion was initiated by two electrically ignited flares mounted upstream of the flame holder.

The following data were transmitted by the telemetering unit:

1. Axial acceleration

2. Free-stream total pressure

3. Free-stream static pressure

4. Static pressure in diffuser, $4\frac{5}{8}$ inches downstream of air inlet

5. Dynamic pressure in diffuser, 65 inches downstream of air inlet

6. Total pressure at end of diffuser

7. Static pressure at engine-exhaust outlet

8. Pressure drop across orifice-type fuel flow meter

Because of the location of the static orifices on the antenna, the free-stream static-pressure measurements will be somewhat in error at subsonic speeds unless the diffuser-inlet velocity is approximately equal to flight velocity.

The total pressure at the end of the diffuser was measured by eight total-pressure tubes, which were connected to a common manifold in order to obtain a pressure that was approximately the average of the total pressures at the eight positions. The dynamic pressure in the diffuser was measured with eight total-pressure tubes and two static-pressure tubes, which were connected in such a way as to obtain an average dynamic pressure. A sharp-edged orifice, 0.85 inch in diameter, was used to measure fuel flow.

Radar equipment and phototheodolite equipment were used to obtain a time history of the position of the engine with respect to a point on the ground during the flight.

CALCULATION PROCEDURE

The velocity and the Mach number of the engine during flight were calculated from radar and phototheodolite records and from free-stream total- and static-pressure and ambient-air temperature measurements. Ambient-air temperature was obtained from an atmospheric survey made with the airplane immediately after the release of the ram-jet unit.

Failure of several channels of the telemetering equipment to operate satisfactorily prevented a complete evaluation of engine performance. The accelerometer readings, dynamic pressure in the diffuser, total pressure at the combustion-chamber inlet, and the fuel flow were not obtained. Without these pressure and fuel-flow readings, the engine thrust, external drag, diffuser efficiency, and combustion efficiency could not be obtained. The acceleration could be obtained, however, by differentiating the velocity-time curve; from this acceleration, the net force on the unit could be determined. The net thrust (ram-jet thrust minus external drag) was obtained by subtracting the component of the acceleration of gravity in the direction of motion from the calculated axial acceleration and multiplying the result by the mass of the ram-jet unit.

Because of incomplete radar records and the inaccuracy of the free-stream total-pressure data at low pressures, velocity and acceleration data are not presented for the first 25 seconds of the flight.

RESULTS AND DISCUSSION

A plot of the telemeter data recorded by the two ground stations during the flight is shown in figure 6. The tailed points indicate data received by telemetering station 2. The telemeter records are continuous and the data were read at 1-second intervals if possible. Blank sections of the curves indicate that no signal or an indistinct signal was received during that part of the flight. The static pressure recorded immediately before impact was 14.7 pounds per square inch, which coincides with the barometric pressure at sea level at that time.

High values of the static pressure inside the diffuser (fig. 6) indicated internal subsonic flow throughout the flight. Fairly good diffuser-pressure recovery would thus be expected. The static pressure at the engine outlet (fig. 6) is approximately equal to the ambient-air pressure during the first 40 seconds of the flight. At 40 seconds, the engine-outlet static pressure diverges sharply from the ambient-air pressure, which indicates that choking has been attained in the nozzle. The choking occurred at a free-stream Mach number of approximately 1.25.

The variation of altitude with time after release is shown in figure 7. The altitude was determined from free-stream static pressure and the atmospheric survey made by the launching plane.

The variation of flight velocities from both telemeter data and radar records with time after release is shown in figure 8. The velocities determined by the two methods agree satisfactorily even at subsonic speeds. No radar records were obtained prior to 24 seconds or during the last $2\frac{1}{2}$ seconds of the flight.

The variation of flight Mach number, axial acceleration (not including the acceleration of gravity), and the difference between the thrust coefficient (ram-jet thrust per free-stream dynamic pressure per combustion-chamber area) and the drag coefficient (external drag per free-stream dynamic pressure per combustion-chamber area) with time after release for the last 20 seconds of the flight is shown in figure 9. The Mach number was 1.42 at the end of the flight, which was 43.7 seconds after release. The net acceleration attained a maximum value of 1.72 times the acceleration of gravity and the difference between the thrust coefficient and the drag coefficient was 0.20 at a Mach number of 1.42. The drag exceeded the thrust until a Mach number of approximately 0.87 was reached. The low values of the thrust coefficient minus the drag coefficient in the range from 25 to 28 seconds is attributed to a low fuel-flow rate. The lean fuel-air ratio is believed to have been caused by imperfect fuel-regulator action at the low free-stream total pressures. Intermittent traces of fuel flow on the telemeter record tend to confirm this belief. The low acceleration during the first part of the flight prevented the ram-jet unit from reaching a higher Mach number before reaching the water.

SUMMARY OF RESULTS

From limited data obtained during a free-flight investigation of a supersonic 16-inch-diameter ram-jet unit, the following results were observed:

1. A maximum free-stream Mach number of 1.42 was attained during the flight.

2. The thrust coefficient exceeded the drag coefficient by 0.20 at a Mach number of 1.42.

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National Advisory Committee for Aeronautics,
Cleveland, Ohio.

REFERENCE

1. Cleveland Laboratory Staff: Performance and Results of Application of Various Types of Aircraft-Propulsion System. NACA TN No. 1349, 1947.

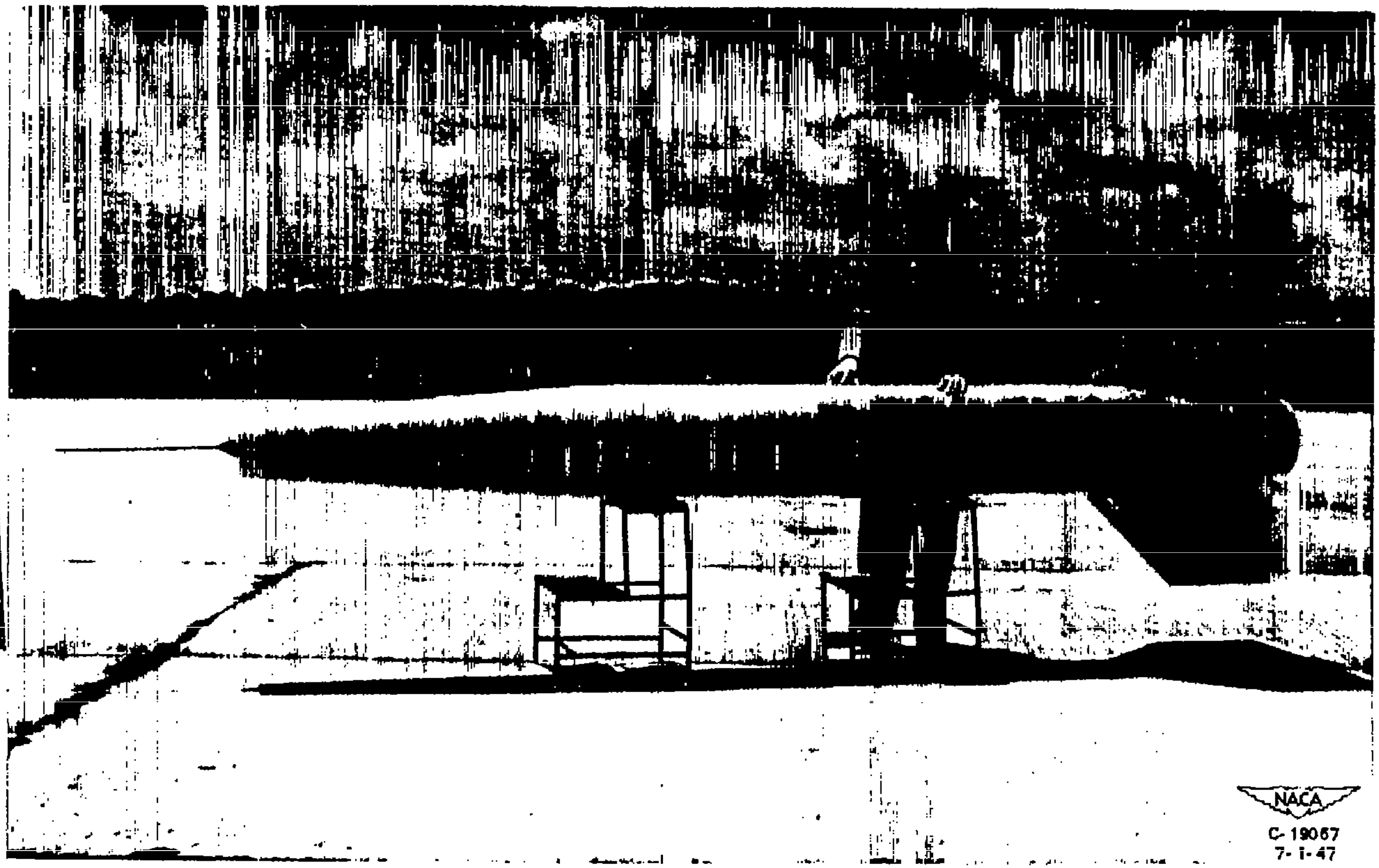
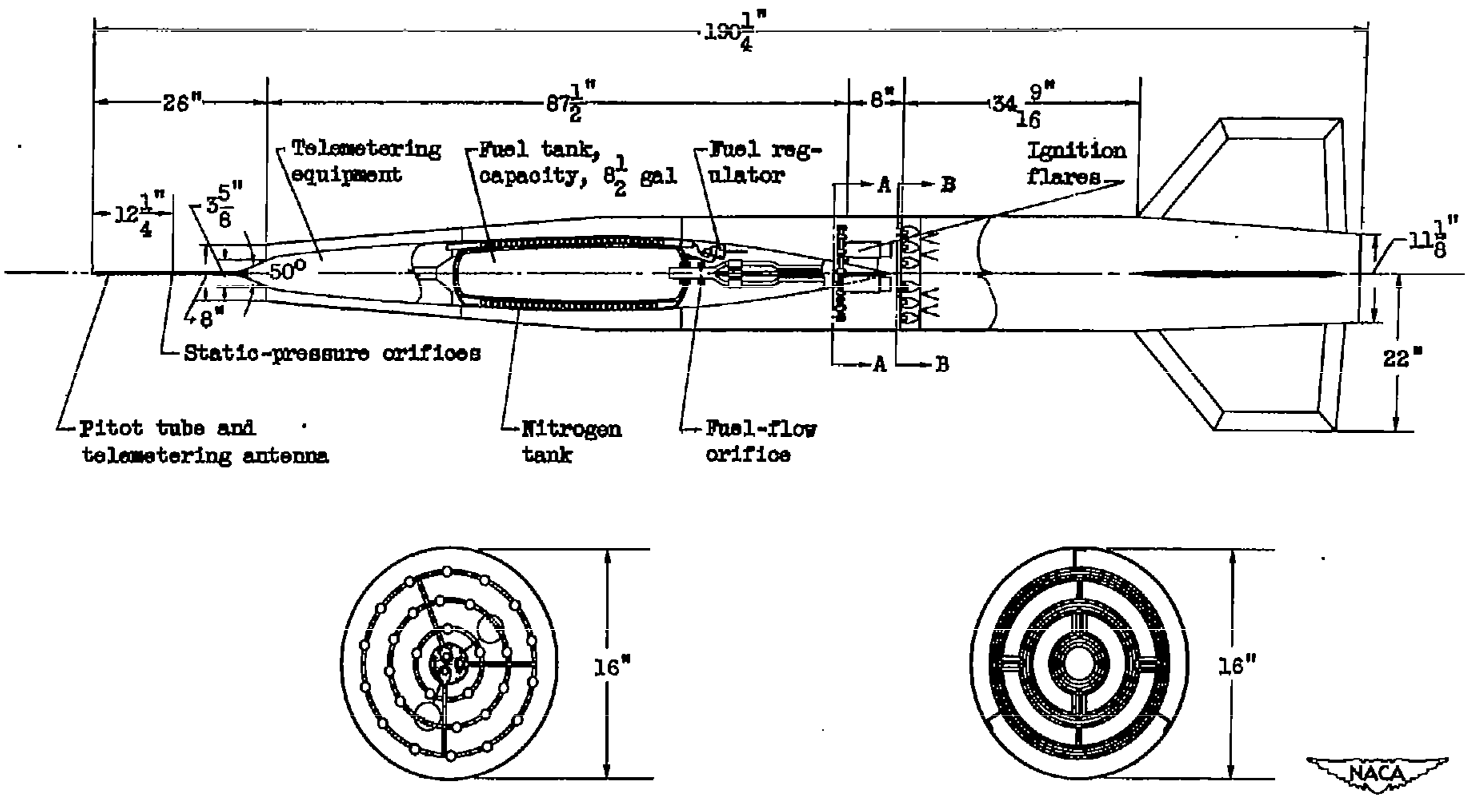


Figure 1. - Supersonic 16-inch ram-jet unit model 16-A-1.



Section A-A, fuel injector

Section B-B, flame holder

Figure 2. - Schematic cross-sectional view of supersonic 16-inch ram-jet unit, model 16-A-1.

Figure 3. - Central body of supersonic 16-inch ram-jet unit, model 16-A-1.

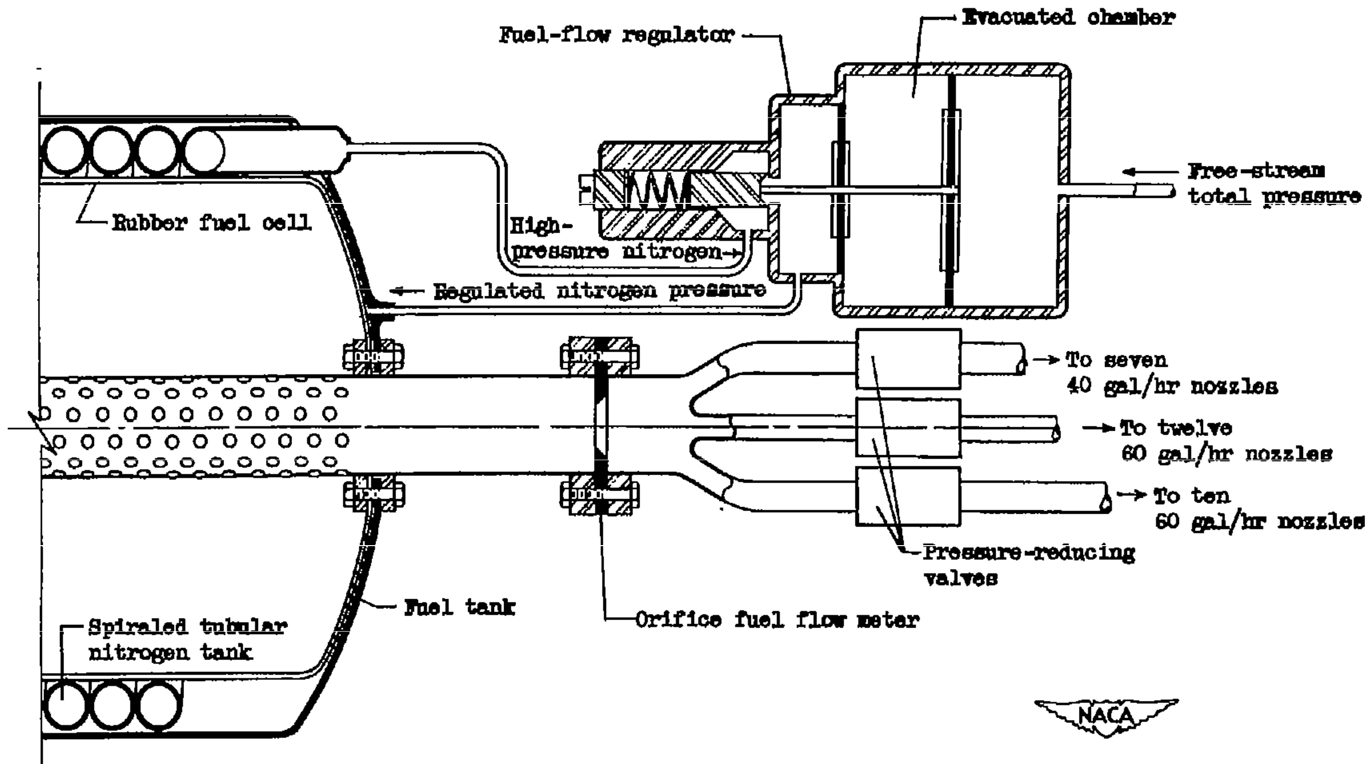
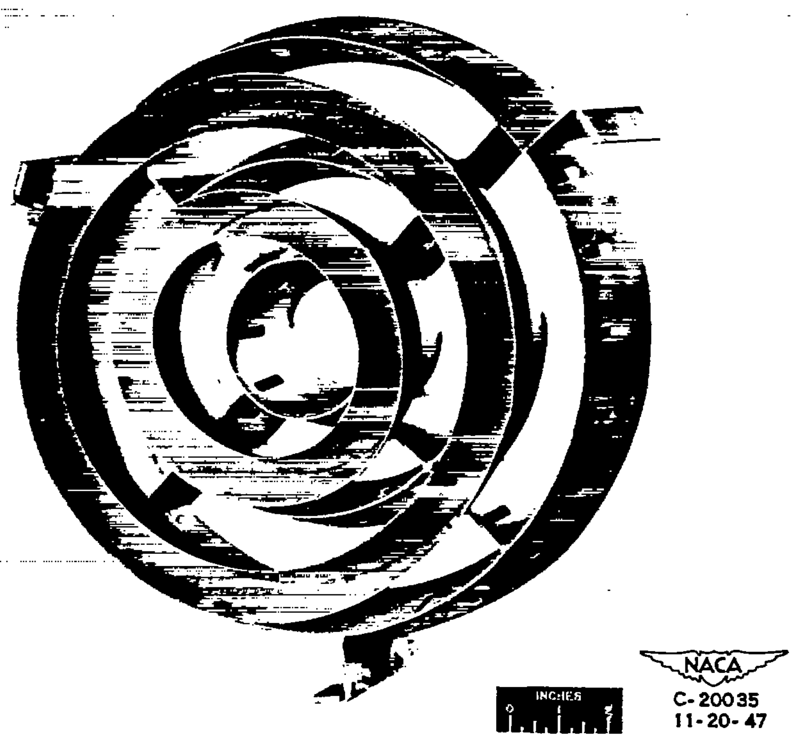


Figure 4. - Schematic drawing of fuel system for supersonic 16-inch ram-jet unit, model 16-A-1.

(a) Three-quarter front view.



(b) Three-quarter rear view.

Figure 5. - Flame holder for supersonic 16-inch ram-jet unit. model 16-A-1.

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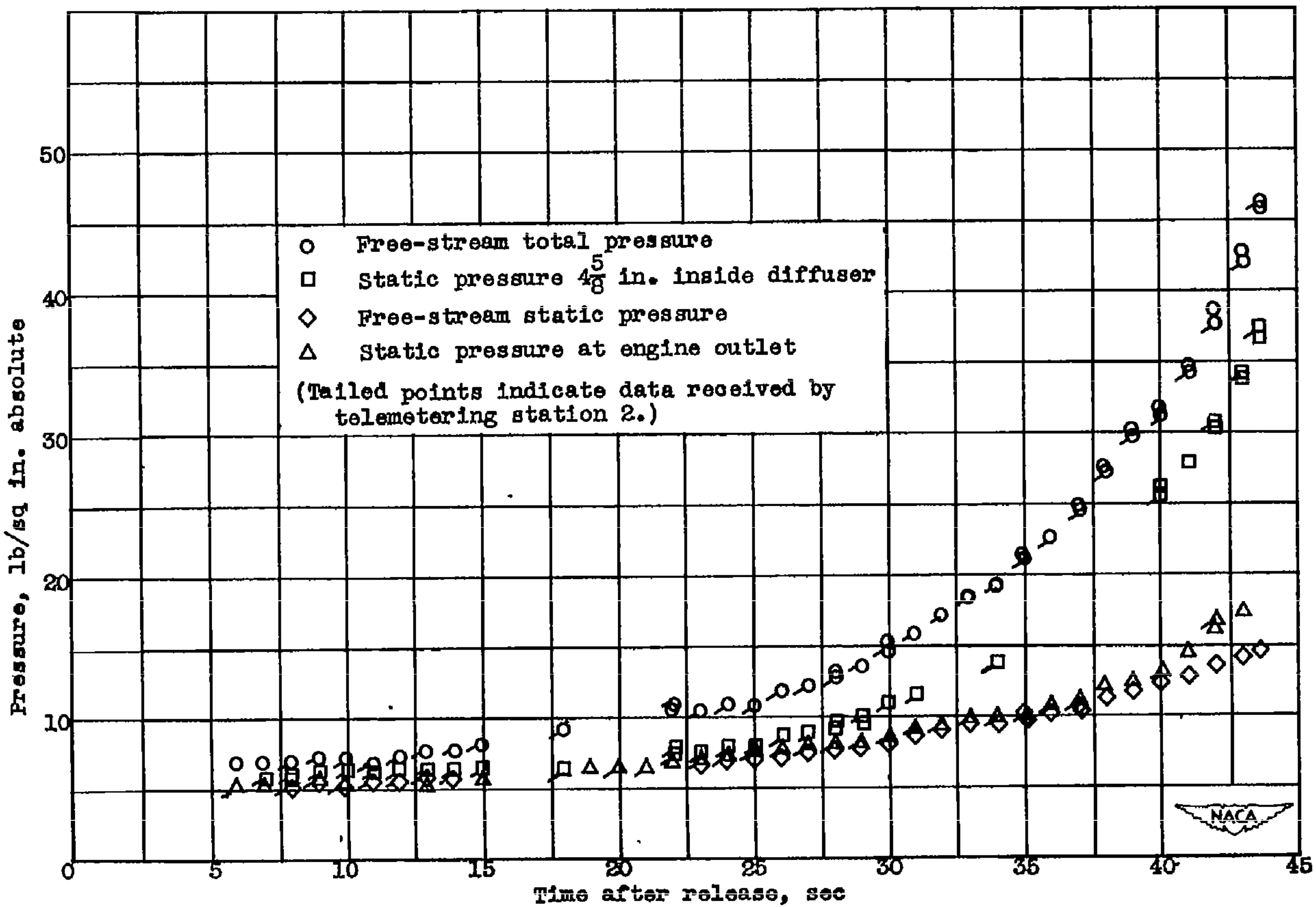

Figure 6. - Telemeter data recorded during flight of supersonic 16-inch ram-jet unit, model 16-A-1.

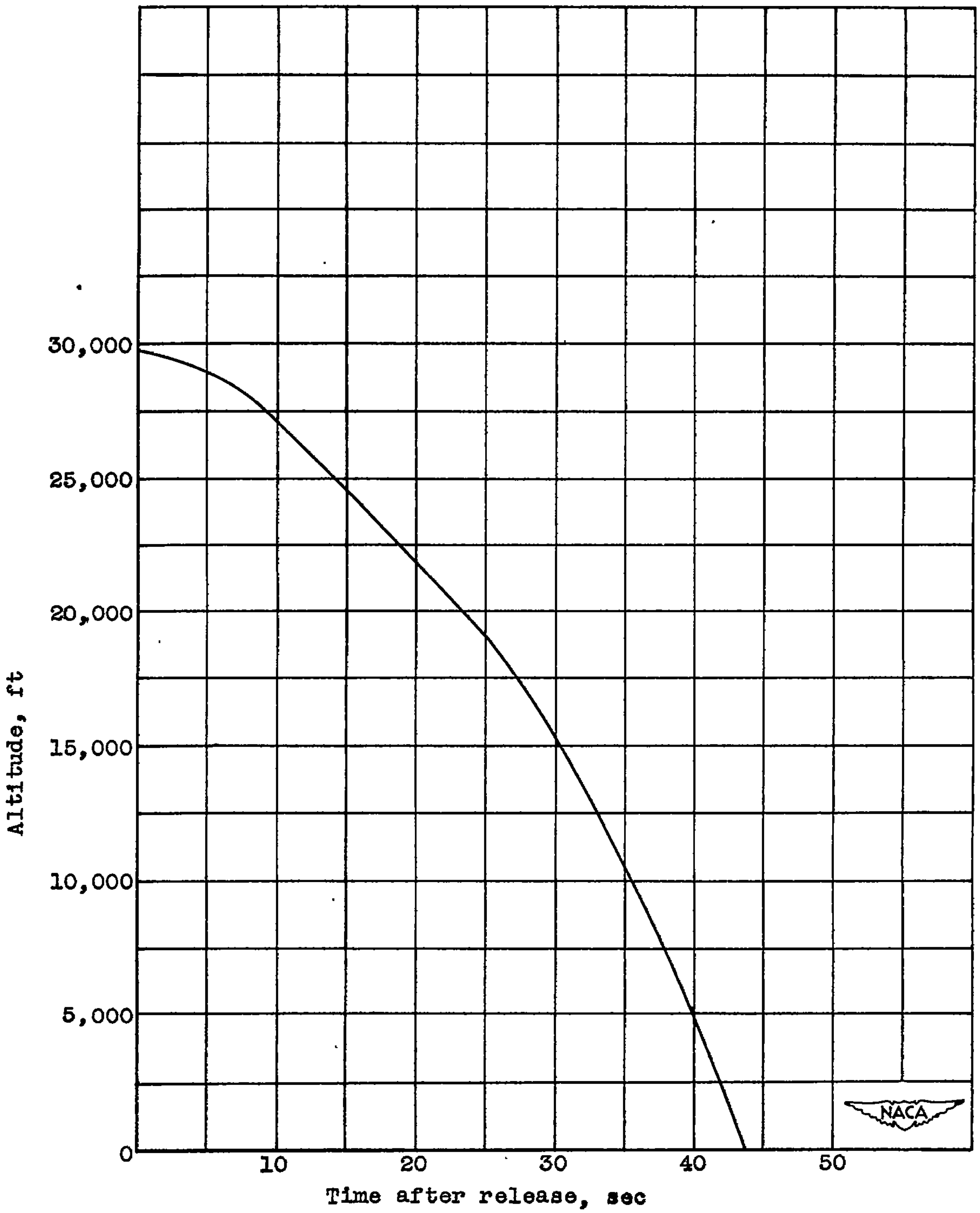

Figure 7. - Variation of altitude with time after release of supersonic 16-inch ram-jet unit, model 16-A-1.

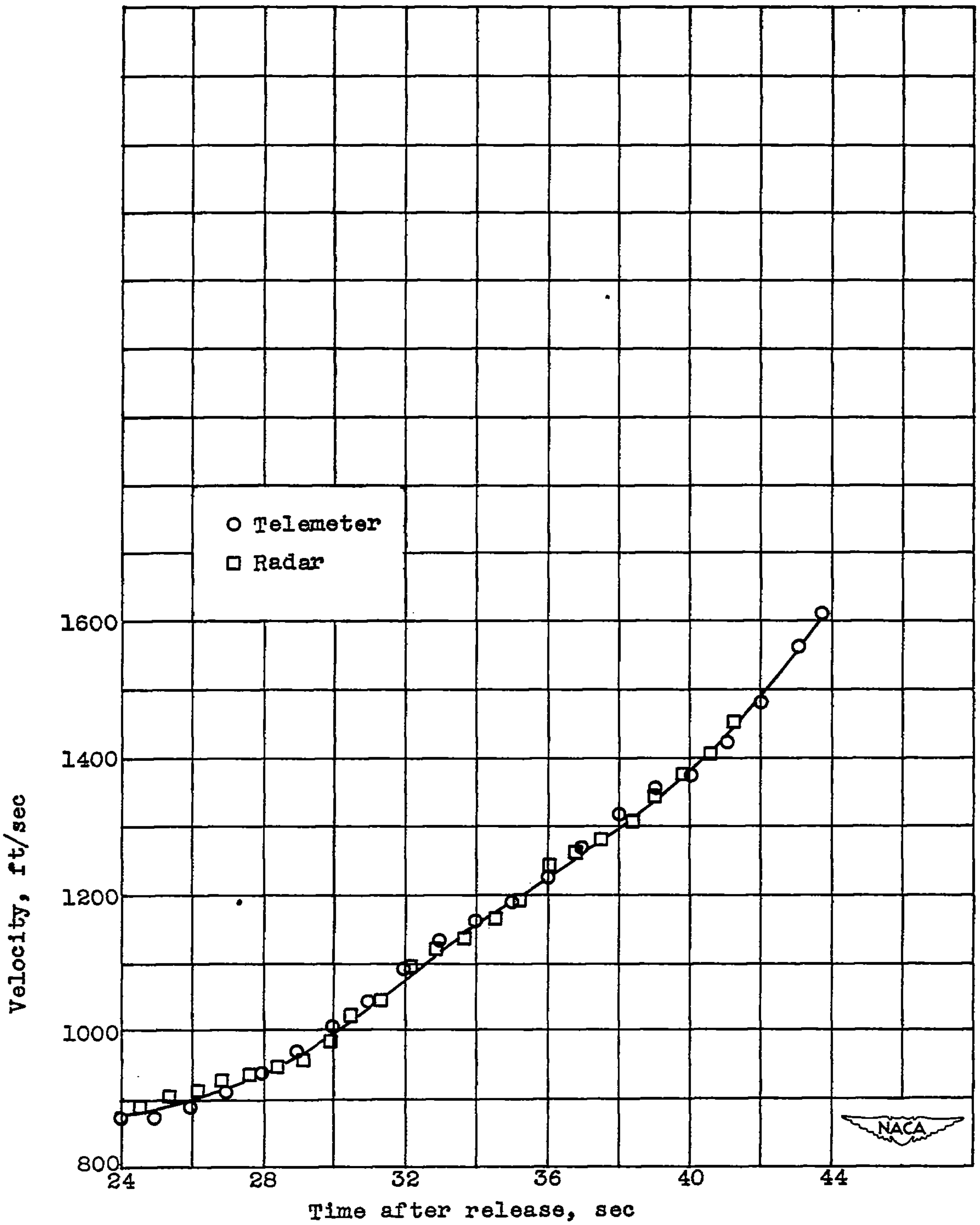

Figure 8. - Variation of velocities from telemeter and radar data with time after release of supersonic 16-inch ram-jet unit, model 16-A-1.

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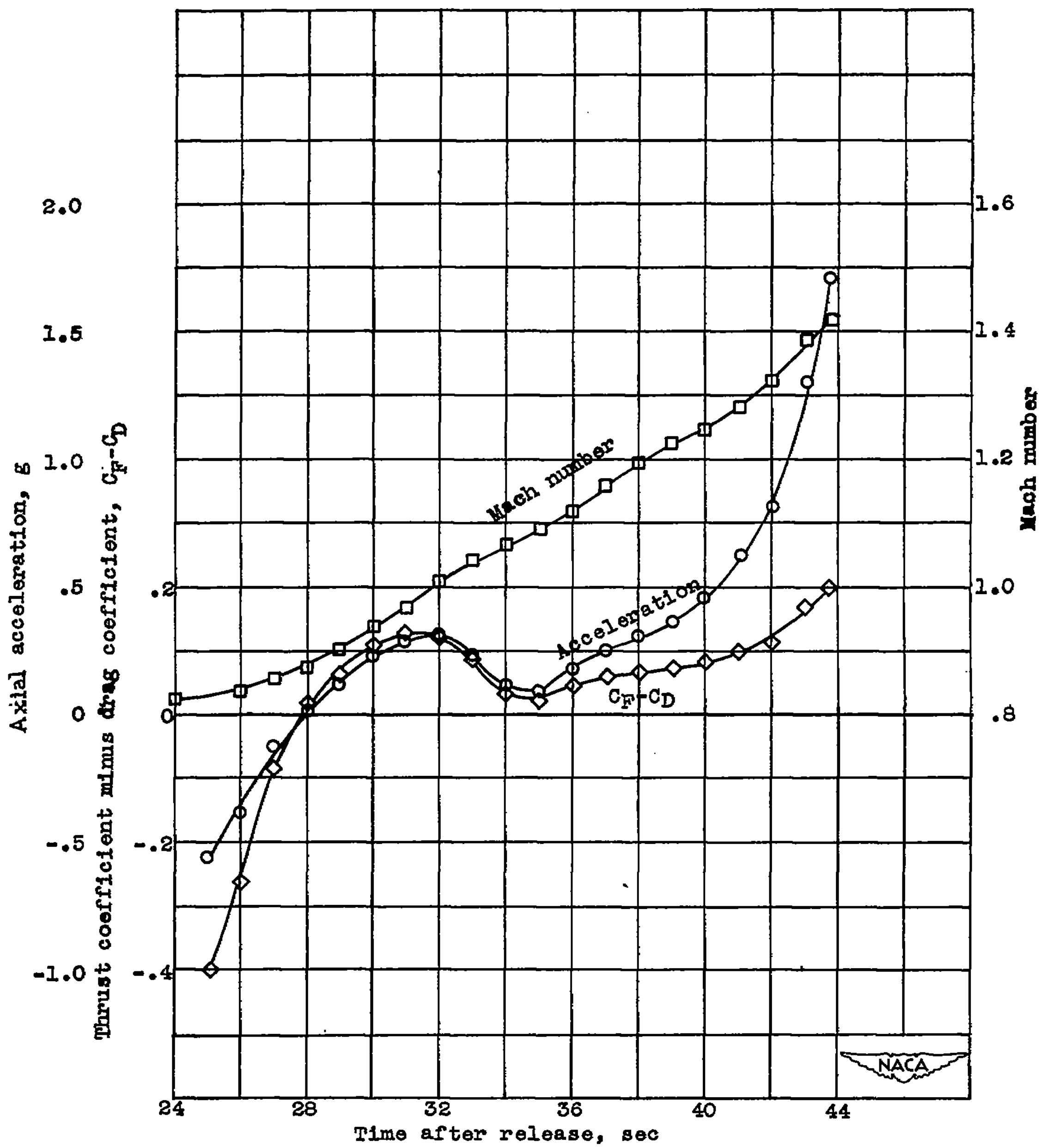

Figure 9. - Variation of axial acceleration, Mach number, and thrust coefficient minus drag coefficient with time after release of supersonic 16-inch ram-jet unit, model 16-A-1.