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RESEARCH MEMORANDUM

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FLIGHT TEST OF A SOLID-FUEL RAM JET WITH THE INTERNAL SURFACE OF THE COMBUSTOR AIR COOLED

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Langley Aeronautical Laboratory
Langley Field, Va.

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FLIGHT TEST OF A SOLID-FUEL RAM JET WITH THE INTERNAL SURFACE OF THE COMBUSTOR AIR COOLED

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SUMMARY

A flight investigation has been made of a rocket-launched solid-fuel ram-jet engine designed to bypass cooling air around the fuel charge. The internally cooled combustor averted combustor burn-out during the flight test. After the boost period, the model accelerated from a Mach number of 1.91 and an altitude of 3,900 feet to a Mach number of 2.94 and an altitude of 19,700 feet in 8.1 seconds. Maximum values of acceleration (8.8g) and air specific impulse (163 seconds) were obtained with a maximum value of gross thrust coefficient of 0.70. The overall fuel specific impulse was 416 seconds.

INTRODUCTION

The National Advisory Committee for Aeronautics is conducting a program to develop new high-energy fuels for use in ram-jet applications. As a part of this program, the Langley Pilotless Aircraft Research Division obtained preflight and flight performance data on solid metallic type fuels (refs. 1 to 3). However, the problem of ram-jet combustor-wall burn-out, particularly experienced with the radial burning solid fuel (refs. 1 and 2) prevented full utilization of the fuel potential.

Observation of the preflight tests (ref. 2) led one to conclude that the combustion chamber wall first burned through immediately downstream of the fuel charge. In an effort to cool the initial portion of the combustor from the intense heat generated by the burning fuels, a portion of the air entering the ram jet was bypassed around the fuel charge.

Preliminary ground tests indicated that the "air bypass" engine might be a solution to the problem and that a flight test of the configuration would be in order. The results of the flight test on the "air bypass" engine are presented in this paper. The flight test was made at the Langley Pilotless Aircraft Research Station at Wallops Island, Va.

SYMBOLS

p	static pressure, lb/sq in. abs
T	static temperature, °R
A	maximum stream tube area, sq ft
M	free-stream Mach number
t	time measured from take-off, sec
g	acceleration of gravity, 32.2 ft/sec^2
C_D	external drag coefficient, based on combustion-chamber area
C_{T_n}	net thrust coefficient, based on combustion-chamber area
C_{T_g}	gross thrust coefficient, based on combustion-chamber area
S_a	sonic air specific impulse, $\frac{\text{lb of jet thrust}}{\text{lb of air/sec}}$
T_s	stagnation temperature, °R
ϕM	ratio of jet impulse at exit to jet impulse at sonic station
γ	ratio of specific heats of air

APPARATUS AND METHODS

Model

The model, which incorporated a conical shock entrance diffuser designed for a Mach number of 2.13, is shown as a sketch and photograph in figures 1(a) and 1(b), respectively. The area ratio of the combined supersonic and subsonic diffuser was 0.458 based on the area at the entrance lip and the combustion-chamber area. The inner body was attached to the diffuser wall with cruciform struts. The model was 62.00 inches long with a 7-inch-diameter combustion chamber, upon which four fins, each with an area of 0.416 square foot, were mounted. Four sheetmetal separator strips, welded to the combustor shell, centered the fuel charge in the model. An exit nozzle having contraction and expansion ratios equal to 0.852, when referenced to the combustion-chamber area, was attached at the rearward end of the combustor.

The combustor was constructed of 0.093 Inconel sheet. The exit nozzle and stabilizing fins were stainless steel. The remainder of the model was constructed of mild steel. The empty model weight was 59.4 pounds.

Fuel

The radial-burning magnesium-base solid-fuel charge was essentially similar to that reported in reference 1. In the present instance, however, the charge was molded under a higher pressure of 6,000 pounds per square inch and incorporated an inhibitor at the leading edge of the fuel charge. A photograph of the fuel in place in the model is shown as figure 1(c). The composition of the charge was as follows:

Magnesium, atomized, percent	82
Sodium nitrate, percent	10
Rubber cement	6
Stearic acid	2

The fuel charge was $21\frac{1}{2}$ inches in length and had inside and outside diameters of $4\frac{1}{4}$ inches and $6\frac{1}{4}$ inches, respectively. An igniter ring made up of barium nitrate, atomized magnesium, and nitrocellulose cement was located at the upstream end of the fuel charge. The ingiter ring was fired with two 5-delay electric squibs buried in a black-powder—cement mix. Preflight tests of the fuel indicated that a cellulose-acetate inhibitor installed so as to shield the leading edge of the fuel charge from the ignition shock would prevent irregular erosion of the fuel charge and subsequent fuel break-up. Accordingly, a 1/8-inch-thick annulus ring was located between the igniter and the fuel charge and a 1/16-inch wall tube, 1 inch long, was cemented into place on the inside diameter of the charge immediately downstream of the igniter. The 18.4-pound fuel charge was cemented into an 0.047-inch-wall steel liner having a weight of 6.2 pounds giving a total model take-off weight of 84 pounds. The fuel charge was positioned in the model with a retaining ring at the downstream end.

Booster Rocket and Adapter

A JATO 3.5-DS-5700 rocket motor was used to accelerate the ram jet to supersonic speed. A cast-magnesium alloy coupling fastened to the rocket motor and fitted internally in the ram-jet exit nozzle attached the ram jet to the booster. This coupling was designed to block only 10 percent of the nozzle exit area during the boost period. Four fins, each with an area of $1\frac{1}{4}$ square feet, were mounted at the rear end of the rocket motor and provided stability of the combination during the boost period. A photograph of the ram jet and coupled booster in place on the launcher prior to firing is shown as figure 2.

Measurements

The velocity of the model in flight was measured with a CW Doppler radar. The position of the model in space was determined with NACA modified SCR 584 tracking radar. High-speed manually operated tracking cameras provided information on the behavior of the model during the rocket-boost period and the ram-jet powered portion of the flight.

Upon completion of the flight test, a radiosonde balloon was released to obtain the pressure, temperature, and altitude relationship. The wind-velocity—altitude relationship was obtained by tracking the balloon with a rawinsonde. The variation of static pressure p and static temperature T, obtained from the radiosonde data, with altitude is presented in figure 3.

RESULTS AND DISCUSSION

The variation of maximum stream-tube area, used in determining the weight flow of air, with free-stream Mach number is presented in figure 4. These data were determined using the one-dimensional-flow analysis that is described in reference 4.

The altitude and horizontal range coordinates, as obtained from SCR 584 data, are presented in figure 5 up to the point where radar contact was lost. The altitude-time data are also presented for the powered portion of the flight. The pertinent events and the times at which they occurred in flight are noted in figure 5.

The flight Mach number M of the ram jet is presented in figure 6 as a function of flight time. Velocity data determined by the CW Doppler velocemeter were used in these calculations after appropriate corrections for wind velocities at the various altitudes were made. The model separated from the rocket booster at $M = 1.98$ and decelerated until ram-jet ignition occurred at $M = 1.91$. The data show a peak value of $M = 2.94$ obtained at the time of 11.8 seconds. During this period, maximum values of longitudinal acceleration of 8.8g were calculated from the data. This peak Mach number is somewhat higher than the value of $M = 2.73$ (fig. 6) obtained in the flight test of a similar radial burning fuel mounted in an engine without "air bypass" (ref. 1). The Reynolds number, based on body length, varied between 66×10^6 and 62×10^6 during the powered portion of the flight. Combustion-chamber burn-through, previously experienced with the radial-burning-fuel charges in ground tests (ref. 2) and in flight tests (refs. 1 and 5), did not occur in preflight or flight tests of this configuration.

The net thrust coefficient C_{T_n} and the gross thrust coefficient C_{T_g} of the ram-jet engine is presented in figure 7 as a function of Mach number. The net thrust was obtained from the longitudinal acceleration data (obtained from CW Doppler radar set) and the mass of the ram jet (with appropriate corrections for changing mass with fuel consumption). The gross thrust coefficient was obtained from the net thrust coefficient and the computed external drag coefficient C_D also presented in figure 7. The fuel rate was considered constant over the elapsed time of 8.5 seconds during ram jet operation. The external-drag coefficient C_D was estimated from theoretical friction drag (ref. 6) and pressure drag on the engine (ref. 7), two-dimensional pressure drag on the fins, and experimental values of additive drag of the inlet below design Mach number as obtained from the data of reference 8. The drag coefficients, which are roughly 25 percent higher than those reported in reference 1, are believed to be more representative values. A maximum value of $C_T = 0.70$ was calculated at $M = 2.67$ for these data.

A time history of the air specific impulse S_a delivered by the ram jet is presented in figure 8. The values of S_a, at the sonic section of the exit nozzle, were obtained by adding the gross thrust to the total momentum of the ram-jet entrance air and dividing by the weight flow of air and the thrust function ϕM (ref. 9). The value of ϕM was calculated with $\gamma = 1.20$. A maximum value of $S_a = 163$ was calculated from the data at the time of 10 seconds at $M = 2.68$. The calculated values of free-stream stagnation temperatures T_s also presented in figure 8 indicate a maximum value of $T_s = 1,220$ was reached at $t = 11.7$ which occurs at $M = 2.94$.

The total fuel load of 18.38 pounds was assumed to have been expended between the times of 3.7 and 12.2 seconds to produce a gross impulse of 7,645 pound-seconds. The ratio of these values demonstrates that an overall value of fuel specific impulse of 416 seconds was obtained. This value may be compared with the value of 412 seconds obtained with this type fuel in an engine not featuring air bypass around the fuel charge (ref. 1).

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 9, 1956.

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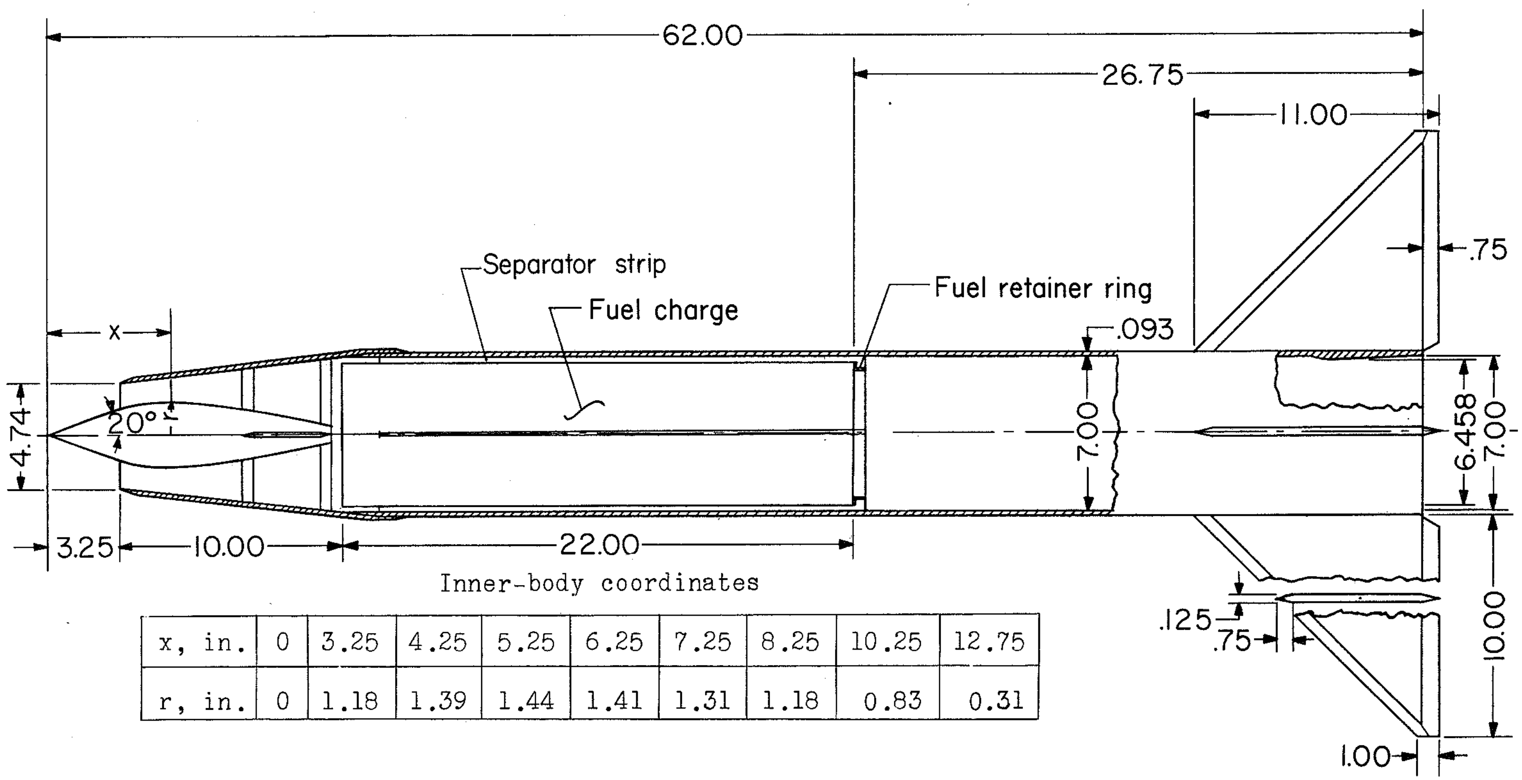
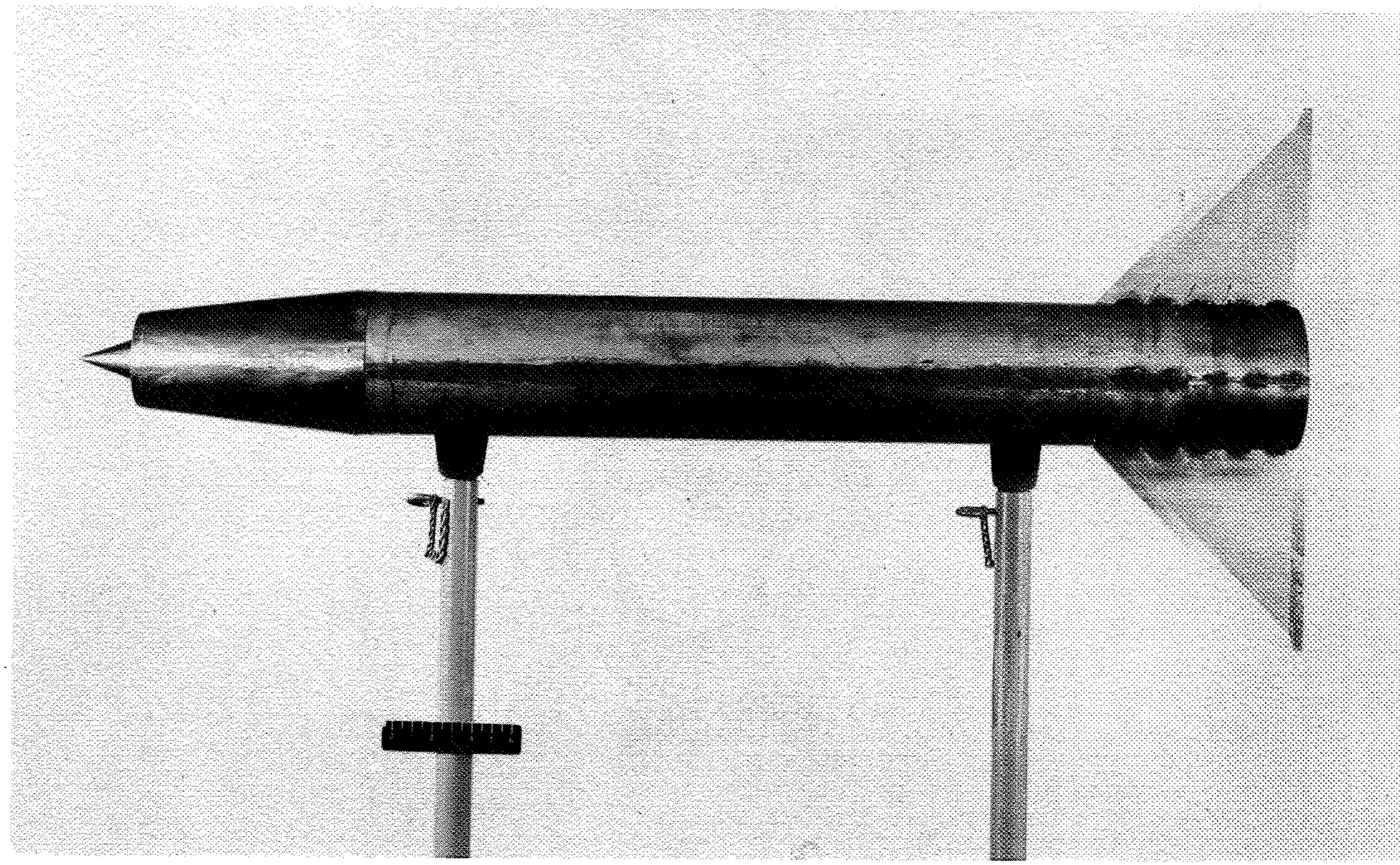


Inner-body coordinates

x, in.	0	3.25	4.25	5.25	6.25	7.25	8.25	10.25	12.75
r, in.	0	1.18	1.39	1.44	1.41	1.31	1.18	0.83	0.31

(a) Sketch of model. All dimensions are in inches.

Figure 1.- The solid-fuel ram jet.



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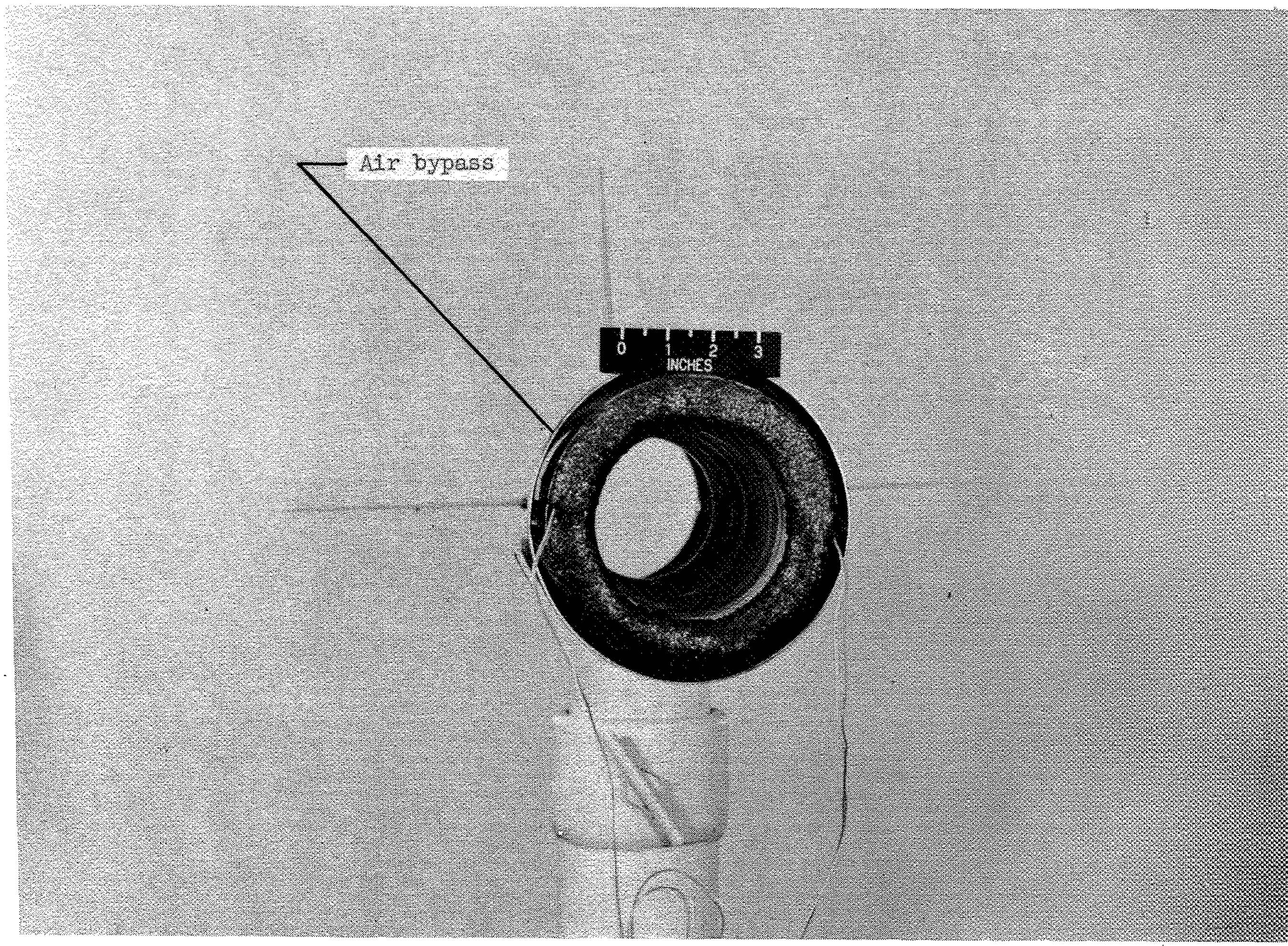
(b) Photograph of model.

Figure 1.- Continued.



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(c) Front view of solid-fuel charge mounted in combustor.

Figure 1.- Concluded.

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Figure 2.- The test model and booster in the launching attitude.

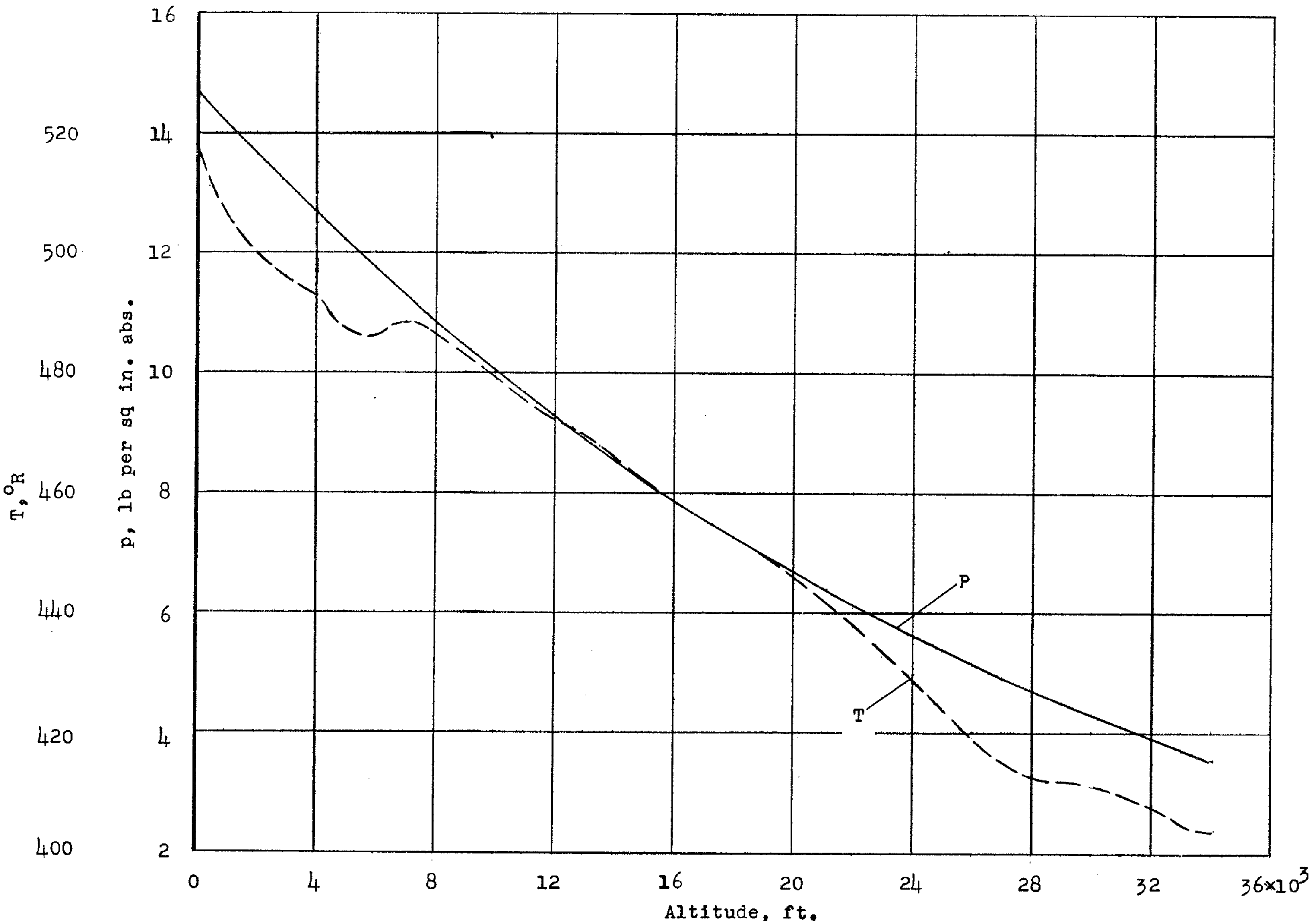

Figure 3.- The variation of ambient pressure and temperature with altitude.

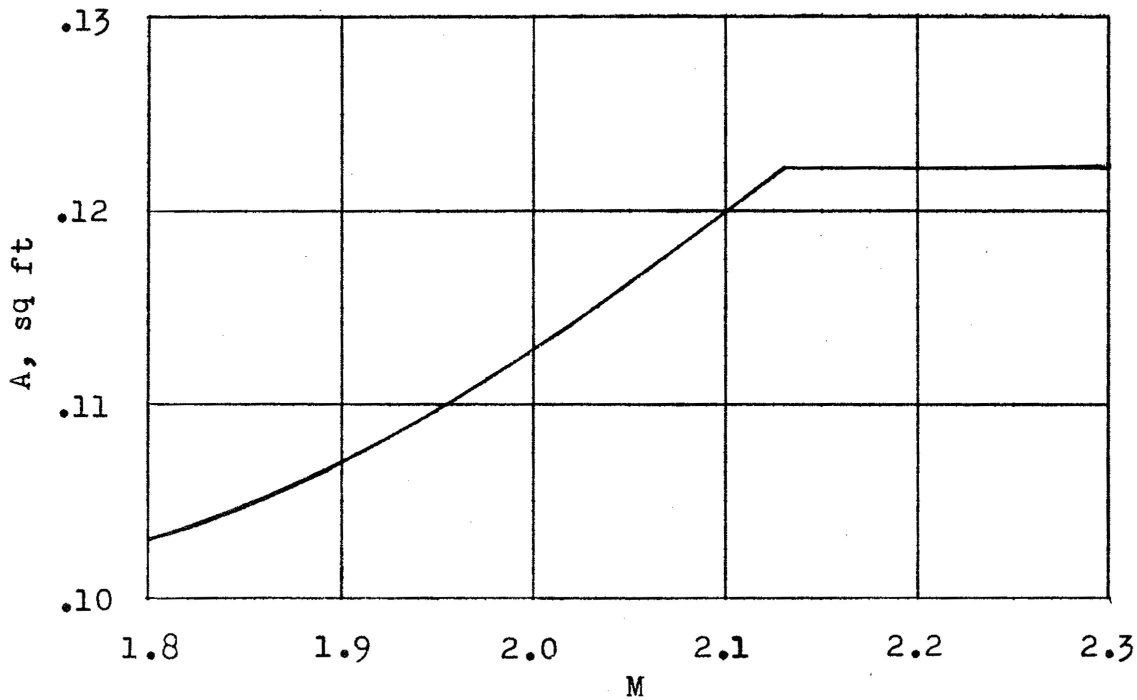

Figure 4.- The variation of maximum stream tube area with flight Mach number as determined from the methods presented in reference 4.

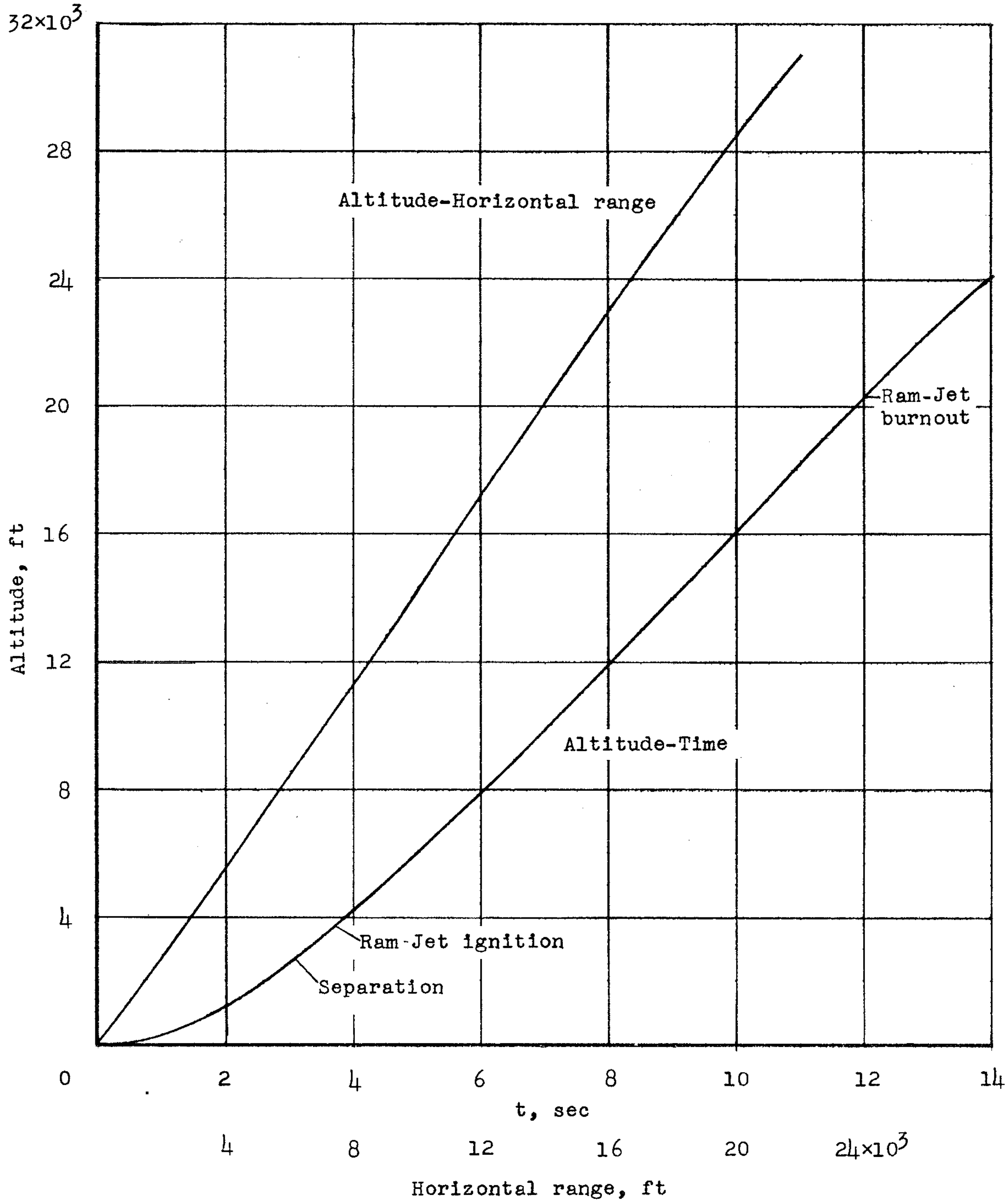

Figure 5.- The variation of altitude with horizontal range and flight time.

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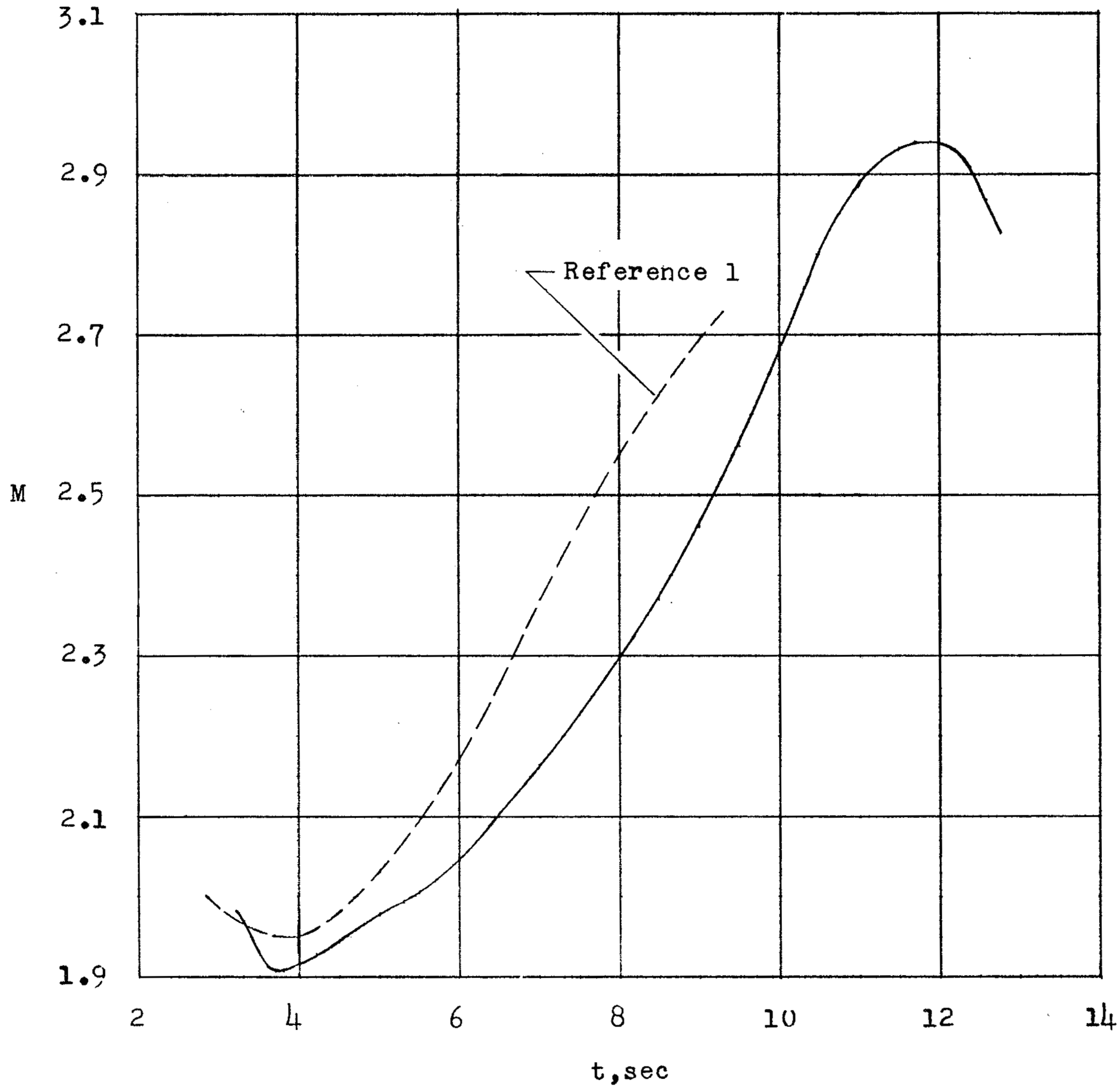

Figure 6.- The flight Mach number against time.

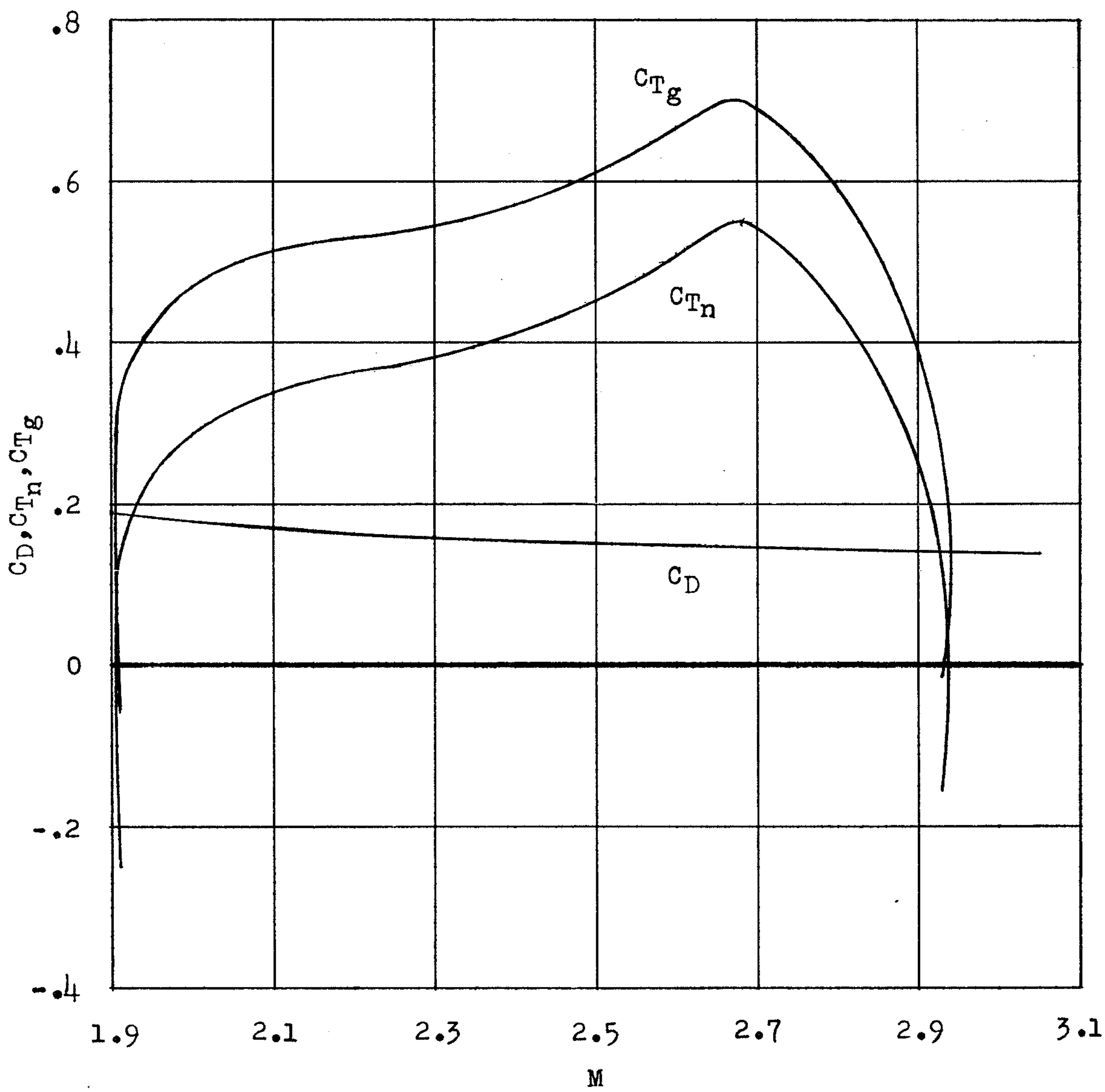

Figure 7.- The variation of gross thrust and drag coefficients with flight Mach number.

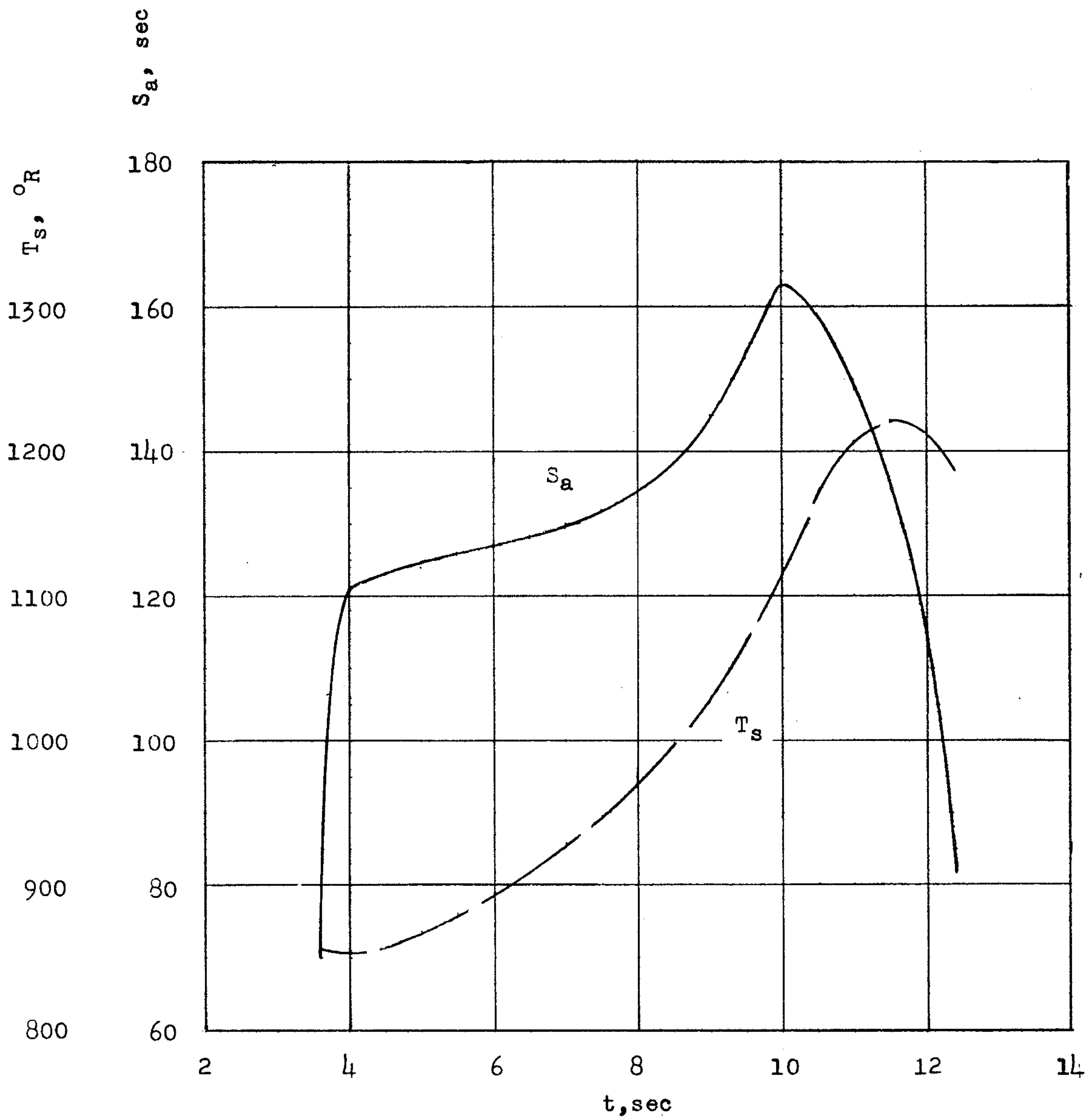

Figure 8.- The computed air specific impulse and stagnation temperature plotted against flight time.