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EXTERNAL MEMORANDUM NO. 3

PROJECT MX-794
(AAF Contract W33-038 ac-14222)

Project "Wizard"

"Curves for the Calculation of the Order of Magnitude of Skin Heating Due to Friction of a Missile in Steady Flight in the Atmosphere"

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March 10, 1947

CONTENTS

Page

LIST OF ILLUSTRATIONS

INTRODUCTION

The importance of skin temperature on the structural design of Wizard missiles was realized in the early design stages, and work was started during the summer of 1946 to establish information concerning the feasibility of using light alloy metals. To the best of the writers' knowledge, the first investigation of this matter was made by Eber in 1939. In Reference 1 he concluded that the use of light alloy metals for the skin of the A-4 was out of the question. Experimental data on heat transfer coefficients were reported by the same author in 1941 (Reference 2), and subsequently used by Kraus and Hermann (Reference 3) to calculate the temperature of a missile in flight. Recently, several other reports have appeared on the subject of skin temperatures. Among these are the Fort Bliss report (Reference 4) which outlines a method of skin temperature calculation based on Eber's data, and the work of G. P. Wood (Reference 5) which uses subsonic heat transfer equations given in Reference 6.

Included on the Wizard program is an investigation of the strength of metals at temperatures likely to be encountered in flight. This report presents the results of skin temperature calculations based on the data of Eber, and forms a preliminary part of the skin strength investigation. It is intended to serve the dual purpose of providing the designer a means of making a rapid estimate of the order of magnitude of the skin equilibrium temperatures likely to be encountered in the high speed flight of a missile, and providing a point of departure for an experimental and theoretical study of skin heating effects.

The empirical data and the methods used have been stated in the references above, and are included in the appendix of this report for the sake of completeness.

SUMMARY

Curves are included on Figure 2 from which a conservative estimate of the skin temperature of a missile in steady flight may be made. Similar curves based on subsonic data are given on Figure 3. These represent a conservative upper limit case. By treating accelerated flight as a succession of steady states, the maximum skin temperature of a rocket at various instances during its accelerating phase can be calculated. This has been done for the typical flight shown on Figure 4. The results are given on Figure 5.

A discussion of the factors involved in skin heating and the assumptions made in calculating temperatures are also included. The influence of temperature lag is noted and an approximation to the magnitude of this effect is given. Recommendations are made for future investigations.

SYMBOLS

A = Surface area in sq ft

a = Local speed of sound in ft per sec

c_p = Specific heat at constant pressure in Btu per lb per degree Fahrenheit

c_v = Specific heat at constant volume in Btu per lb per degree Fahrenheit

g = Acceleration of gravity

$\bar{h}$ = Average heat transfer coefficient in Btu per sec per sq ft per degree Fahrenheit

h = Local heat transfer coefficient in Btu per sec per sq ft per degree Fahrenheit

H = Altitude in ft

K = Thermal conductivity in Btu per sec per sq ft per degree Fahrenheit

ℓ = Characteristic length in ft

M = Mach Number $\frac{v}{a}$

Nu = Nusselt Number $\frac{\ell h}{K}$

Pr = Prandtl Number $\frac{c_p \mu g}{K}$

Q = Quantity of heat in Btu

Re = Reynolds Number $\frac{\rho v \ell}{\mu}$

T = Temperature in degrees Rankine

T_{BL} = Boundary layer temperature

T_{amb} = Ambient temperature

T_{skin} = Skin temperature

T_{stag} = Stagnation temperature

t = Time in sec

v = Velocity in ft per sec

γ = Ratio of specific heats $\frac{c_p}{c_v}$

ϵ = Emissivity: ratio of emissive power of surface to that of black body

μ = Coefficient of viscosity in slug per ft sec

ρ = Mass density in slug per cu ft

σ = Stefan Boltzmann constant 17.3×10^{-10} in Btu per hr per sq ft per $^{\circ}R^4$

$^{\circ}F$ = Degrees Fahrenheit

$^{\circ}R$ = Degrees Rankine

USE OF THE DESIGN CHARTS

Figure 2 of this report may be used by the designer to estimate the order of magnitude of the skin equilibrium temperature. This is the temperature to which the skin will rise if the flight time at a given altitude and velocity is long enough for thermal equilibrium to be reached. Because a missile in powered flight is constantly accelerating, it will not remain at any given velocity and altitude long enough to reach the equilibrium value. Therefore, the actual body temperature will lag behind the value given on the chart. That is, the prediction is conservative as long as the body temperature is increasing. At some point during the ascending flight, the body temperature will reach a maximum and then start to decrease. The skin temperature will again lag behind the value given on the chart. Under these conditions, the prediction is unconservative. However, the actual temperature will not exceed the predicted maximum; for example, the peak shown on Figure 5.

Temperatures computed here are for a point near the nose, - the hottest part, - of the missile. Toward the rear, the temperatures will be lower.

As an approximation, in the computation of temperatures during accelerated flight, the path may be broken up into a series of steady flights. That is, over a short interval of time, the missile may be thought of as flying steadily at the average altitude for that interval.

The velocities and altitudes of a missile, launched at 12° from the vertical, during a typical flight are given in Figure 4. Suppose, for example, this flight is broken up into 2-second intervals and the temperature corresponding to the average velocity and altitude during each interval is read from Figure 2. For the interval from the 25th to the 27th second, the average velocity is found to be 4460 ft per sec and the average altitude to be 48,400 ft. Dividing the velocity by the speed of sound at 48,400 ft (from Figure 6), the Mach Number is found to be $M = 4.58$. The equilibrium temperature is found, from Figure 2, to be 1310 °F. Using the subsonic data of Figure 3 the temperature is found to be 1390 °F. Figure 5 shows the results of this process carried out from the time of launching to the time of burnout.

DISCUSSION

For a missile flying at high speed, the heat transfer to the skin is influenced by the heating of the boundary layer. Among the factors influencing the final temperature of the body, the following are regarded as most important:

(a) Heat exchange between the boundary layer and the body.

(b) Radiation from the body to space.

(c) Radiation received from the sun.

(d) Transfer of heat from the skin to the interior of the missile.

(e) In the case of a burning missile, heat transferred from the combustion chamber to the skin.

In this analysis, only the first two factors are considered. The heat radiated by the sun to a flat plate is about 0.11 Btu per sq ft per sec when an atmosphere is not present (Reference 7). This effect is small compared to the heat exchanged between the body and the boundary layer, and is therefore neglected in this analysis. Also, the heat transferred to the interior of the missile has been ignored, because a means for its determination has not been devised. This is a subject for future study.

If the missile is assumed to be in a state of steady flight under the above conditions, the skin will come to equilibrium at the temperature at which the heat radiated to space equals the heat transferred to the skin. In view of the neglect of factor (e), this analysis applies only to unfired missiles, or to that part of fired missiles which can be assumed to be insulated from combustion heat.

The quantity of heat radiated to space is given by the Stefan Boltzmann Law, which shows it to be a function of the temperature and the emissivity of the surface. The radiation of heat to space tends to reduce the skin temperature. It is desirable therefore to have the emissivity as high as possible. Because the emissivity can be made very high by proper preparation of the surface, an emissivity of unity has been assumed for this study.

The problem of heat transfer at high speeds between the boundary layer and the skin is not well understood. In Reference 8, the heat transfer problem for a laminar boundary layer has been treated. It has been generally assumed that the boundary layer on a body moving at supersonic speed is almost completely turbulent because of the high Reynold's Numbers involved. If this assumption is true the theoretical approach holds little promise at this time.

If the heat transfer coefficient (h) is dependent upon specific heat (c_p), thermal conductivity (K), velocity (v), viscosity (μ), density (ρ), sonic speed (a), and a characteristic length (ℓ), it can be shown by dimensional~~ess~~ considerations that the dimensionless combinations influencing the heat transfer process are the Nusselt Number $Nu = \frac{h\ell}{K}$, the Prandtl Number $Pr = \frac{c_p \mu g}{K}$, the Reynolds Number $Re = \frac{\rho v \ell}{\mu}$, and the Mach Number $M = \frac{v}{a}$.

$$Nu = f(Pr, Re, M)$$

In Reference 2, the form of this equation is determined for the case of the total heat transferred to the surface of a cone and consequently the cone angle is also involved. The dependence on cone angle is removed by basing the Reynolds Number on the free stream values downstream of the leading shock. The equation given is:

$$Nu = 0.0107 \, Re^{.82}$$

Prandtl's Number is not involved because its variation with temperature is small. The Mach Number is involved implicitly.

It is pointed out that skin temperature calculations in other reports follow the form of the equation given above, but they do not agree on the value of the coefficient. In general, calculations based on subsonic data use a value for the coefficient that is greater than 0.0107. At low speeds and altitudes where the radiation from the body is small, the influence of the coefficient is negligible. For high speeds and altitudes, its influence becomes more important. For example, at a Mach Number of six and an altitude of 100,000 ft, a change of 100% in the coefficient causes a change of 18% in the skin temperature. This point is illustrated further in the appendix.

In Reference 2, Eber reports the ten Bosch relation

$$Nu = 0.0331 \, Re^{.80}$$

which was computed from measurements of the heat transfer to a flat plate in subsonic flow. This is taken as representative of subsonic data, and has been used as a basis of temperature calculations for an upper limit case. Results of skin temperature computations using this value of the Nusselt Number are graphed on Figure 3.

The boundary layer temperature is less than the stagnation temperature because the air is not brought to rest isentropically. Experiments indicate that, on the average, 90% of the kinetic temperature is recovered. Then, considering the specific heats of air to be constant, the temperature in the boundary layer can be written:

$$T_{BL} = T_{amb}\left(1 + 0.9\,\frac{\gamma-1}{2}\,M^2\right)$$

The error introduced by considering the specific heat ratio to be a constant increases as the range between the static and stagnation values of the temperature increases. This subject is dealt with in Reference 9 where it is shown that at a Mach Number of six and sea level air the true value of $\frac{T_{stagnation}}{T_{ambient}}$ is about 10% less than the value predicted by the usual formula derived on the basis of constant γ. This means that treating γ as a constant leads to computed boundary layer temperatures that are too high.

Because of the uncertainty in the heat transfer coefficient computation, the influence of variable specific heat is neglected. Computations taking into account the effect of molecular dissociation and variable specific heat will be undertaken in the future if more accurate data on heat transfer coefficients becomes available. At present, it is believed that for Mach Numbers less than six and moderate altitudes this effect will be small.

Eber's experimental equation for the Nusselt Number has not been verified outside of the range of Reynolds Numbers between 2.5×10^5 and 1.6×10^6. The flight Reynolds Numbers based on a fixed length for missiles flying at altitudes between sea level and 100,000 ft and at Mach Numbers between two and six, have a much greater variation than those for which Eber's data has been verified. Then, if a fixed length is used, the formula must be extrapolated.

In this report Eber's data has not been extrapolated with regard to Reynolds Number. All computations are made for the Reynolds Number 1.6×10^6. It must be realized, then, in reading the graphs, that the temperature referred to is for that portion of the body lying ahead of the position for which $Re = 1.6 \times 10^6$. For flight at constant Mach Number and varying altitude or constant altitude and varying Mach Number, this would mean a quite large variation in the characteristic length. For the typical flight paths now being considered for Wizard missiles, however, both altitude and Mach Number increase together. As a result, the characteristic length varies within fairly close limits.

FUTURE INVESTIGATIONS

1. The flight period within the atmosphere of Wizard missiles will generally be of insufficient duration for thermal equilibrium to be reached. There are indications that the resulting temperature lag may be of real consequence in determining the maximum temperature to which the skin will rise. An approximate calculation of the lag for the missile flight path of Figure 4 has been made for a missile having 1/16" magnesium skin. The results are drawn on Figure 5.

The time necessary to reach equilibrium as a function of flight parameters and skin properties for the general case will be investigated.

2. The influence of variable specific heats and molecular dissociation will be studied.

3. For specific missiles, an attempt will be made to determine the heat loss to the interior of the missile.

4. Data is needed on the influence of Mach Number and Reynolds Number on local heat transfer coefficients for bodies of different shapes. The possibilities of utilizing wind tunnel and flight test techniques for the determination of local heat transfer coefficients will be investigated.

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2. Eber, "Experimentelle Untersuchung der Bremstemperature und des Wärmüberganges an einfachen Köpern bei Überschall geschwindigkeit", Peenemunde, Archive No. 66/57g.

3. Kraus-Herman, "The Magnitudes of Boundary Layer Temperatures, Heat Transfer Coefficients and Skin Temperatures of Vertically and Obliquely Launched A-4 Missiles and of the A-4b Glider". WVA Archive No. 66/167.

4. "The Calculation of the Skin Temperature of Rockets." Army Ordnance Research and Development Service, Sub-office (Rocket), Ft. Bliss, Texas. Tech. Report 17. November 1946.

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9. J. D. Schetzer and C. H. Lauretson, "Aerodynamic Relations with Variable Specific Heats". UMM-6, University of Michigan, Ann Arbor, Michigan. 1947. (To be released)

10. J. H. Keenan and G. Kaye, "Thermodynamic Properties of Air". John Wiley and Sons, Inc., New York. 1945.

APPENDIX

Boundary layer temperature versus Mach Number is plotted for various altitudes on Figure 1, from the approximate expression for the non-isentropic retardation of air.

$$T_{BL} = T_{amb}\left(1 + .9\,\frac{\gamma-1}{2}M^2\right)$$

The values of T_{amb} used are based upon the adopted standard atmosphere. The temperature between 35,000 ft and 100,000 ft is taken as 397°R. The influence of the temperature rise and Mach Number decrease in passing through the leading shock is neglected in the above equation for T_{BL}.

Heat Transferred Through the Boundary Layer

The rate of heat transfer between the boundary layer and the skin is found from the expression

$$\frac{\partial Q}{\partial t} = hA\,(T_{BL} - T_{skin}) \text{ Btu per sec} \qquad (1)$$

where the heat transfer coefficient is expressed by:

$$h = \frac{K\,Nu}{\ell} \qquad (2)$$

Using the data of Eber, (Reference 2), this becomes:

$$\bar{h} = \frac{K}{\ell}\,(0.0107)\,Re^{.82} \qquad (3a)$$

For the limit case, the subsonic data of ten Bosch is used. This leads to a heat transfer coefficient of the form:

$$\bar{h} = \frac{K}{\ell}\,(0.0331)\,Re^{.80} \qquad (3b)$$

The Reynolds Number is based upon free stream values downstream of the leading shock. The thermal conductivity is based upon the boundary layer temperature.

After multiplying and dividing Equation 3a by $\{c_p\,\mu\}_{BL}$ and rearranging terms, the heat transfer coefficient becomes:

$$\bar{h} = 0.0107\left\{\frac{c_p}{Pr}\right\}_{BL}\left\{\frac{\mu_{BL}}{\mu}\right\}\frac{\rho g v}{Re^{.18}} \qquad (4a)$$

Similarly, for the limit case,

$$\bar{h} = 0.0331 \left\{\frac{c_p}{Pr}\right\}_{BL} \left\{\frac{\mu_{BL}}{\mu}\right\} \frac{\rho g v}{Re^{.20}} \qquad (4b)$$

Equations 4a and 4b have been simplified by setting:

$$\left\{\frac{c_p}{Pr}\right\}_{BL} = 0.4$$

This represents an average value from the data in Reference 10 for boundary layer temperatures corresponding to Mach Numbers between zero and six. Furthermore, it has been assumed:

$$\frac{\mu_{BL}}{\mu} = \sqrt{\frac{T_{BL}}{T}}$$

The exponent on the temperature is actually about .76 at low temperatures and decreases as the temperature rises. At $T_{BL}/T = 6$, the exponent is .68 (Reference 10). The use of the above equation introduces a small error on the unconservative side.

Heat Radiated to Space

The heat radiated to space is given by the Stefan Boltzmann Equation:

$$\frac{\partial Q}{\partial t} = \frac{\sigma \epsilon}{3600} A T_{skin}^4 \text{ Btu per sec}$$

where $\sigma = \frac{17.3}{10^{10}}$ Btu per sq ft per hr per $^{\circ}R^4$.

Setting $\epsilon = 1$, the equation reduces to

$$\frac{\partial Q}{\partial t} = \frac{4.8}{10^{13}} A T_{skin}^4 \text{ Btu per sec} \qquad (5)$$

Equilibrium

Under the assumptions of this analysis, the body comes to equilibrium at the temperature for which the heat radiated to space equals the heat absorbed. Thermal equilibrium is expressed by equating the values of $\frac{\partial Q}{\partial t}$ from Equations 1 and 5.

$$\frac{4.8}{10^{13}} T_{skin}^4 = h(T_{BL} - T_{skin}) \qquad (6)$$

The solutions of Equation 6 are plotted on Figure 2 for the value of $\bar{h}$ given by Equation 4a. The solutions of 6 using $\bar{h}$ from 4b are plotted on Figure 3.

Influence of Errors in the Heat Transfer Coefficient on T_{skin}

Probably the most doubtful point in the calculation of skin temperatures is the heat transfer coefficient. The values used in current reports differ by a very large percentage. The value given by Eber which is used in this report in the form

$$\bar{h} = 0.0107 \left\{ \frac{c_p}{Pr} \right\}_{BL} \left\{ \frac{\mu_{BL}}{\mu} \right\} \frac{\rho g v}{Re^{.18}}$$

is regarded as a rough approximation in the present application, and though it is not possible to make a quantitative statement concerning its accuracy, it is felt that it would be unjustified to trust the formula within limits closer than 50%.

In the calculations of Figure 2, the following approximations were used:

(a) $\left\{ \frac{c_p}{Pr} \right\}_{BL} = 0.4$

(b) $\frac{\mu_{BL}}{\mu_{amb}} = \sqrt{\frac{T_{BL}}{T_{amb}}}$

(c) ρ v upstream of shock equals ρv downstream of shock.

These approximations lead to errors of much smaller magnitude than the accuracy of the heat transfer coefficient formula.

In the absence of radiation, the equilibrium temperature of the skin is simply equal to the temperature of the boundary layer and the heat transfer coefficient does not enter the problem.

At high temperatures, where radiation is important, the skin temperature stabilizes at a value less than the boundary layer temperature. The importance of the heat transfer coefficient in the calculation of T_{skin} increases as the difference between T_{BL} and T_{skin} increases. The decimal percent error in the skin temperature $\frac{\Delta T_{skin}}{T_{skin}}$ can be found approximately in terms of the decimal percent error in heat transfer coefficient $\frac{\Delta h}{h}$ by differerentiating Equation 6. This leads to the expression:

$$\frac{\partial T_{skin}}{\partial h} = \frac{T_{BL} - T_{skin}}{\frac{4h}{T_{skin}} (T_{BL} - T_{skin}) + h}$$

which is used in the expression

$$\frac{\Delta T_{skin}}{T_{skin}} = \frac{h}{T_{skin}} \cdot \frac{\partial T_{skin}}{\partial h} \cdot \frac{\Delta h}{h}$$

to give

$$\frac{\Delta T_{skin}}{T_{skin}} = \left[\frac{\left\{ \frac{T_{BL} - T_{skin}}{T_{skin}} \right\}}{4\left\{ \frac{T_{BL} - T_{skin}}{T_{skin}} \right\} + 1} \right] \frac{\Delta h}{h}$$

Using Figures 1 and 2 to find the value of $\frac{T_{BL} - T_{skin}}{T_{skin}}$, it is seen that at $M = 6$ and an altitude of 100,000 ft, the ratio is 0.61. This corresponds to a value of 0.18 for the coefficient of $\frac{\Delta h}{h}$. That is, a 50% error in h under these conditions leads to an error of 9% in the value of the skin temperature.

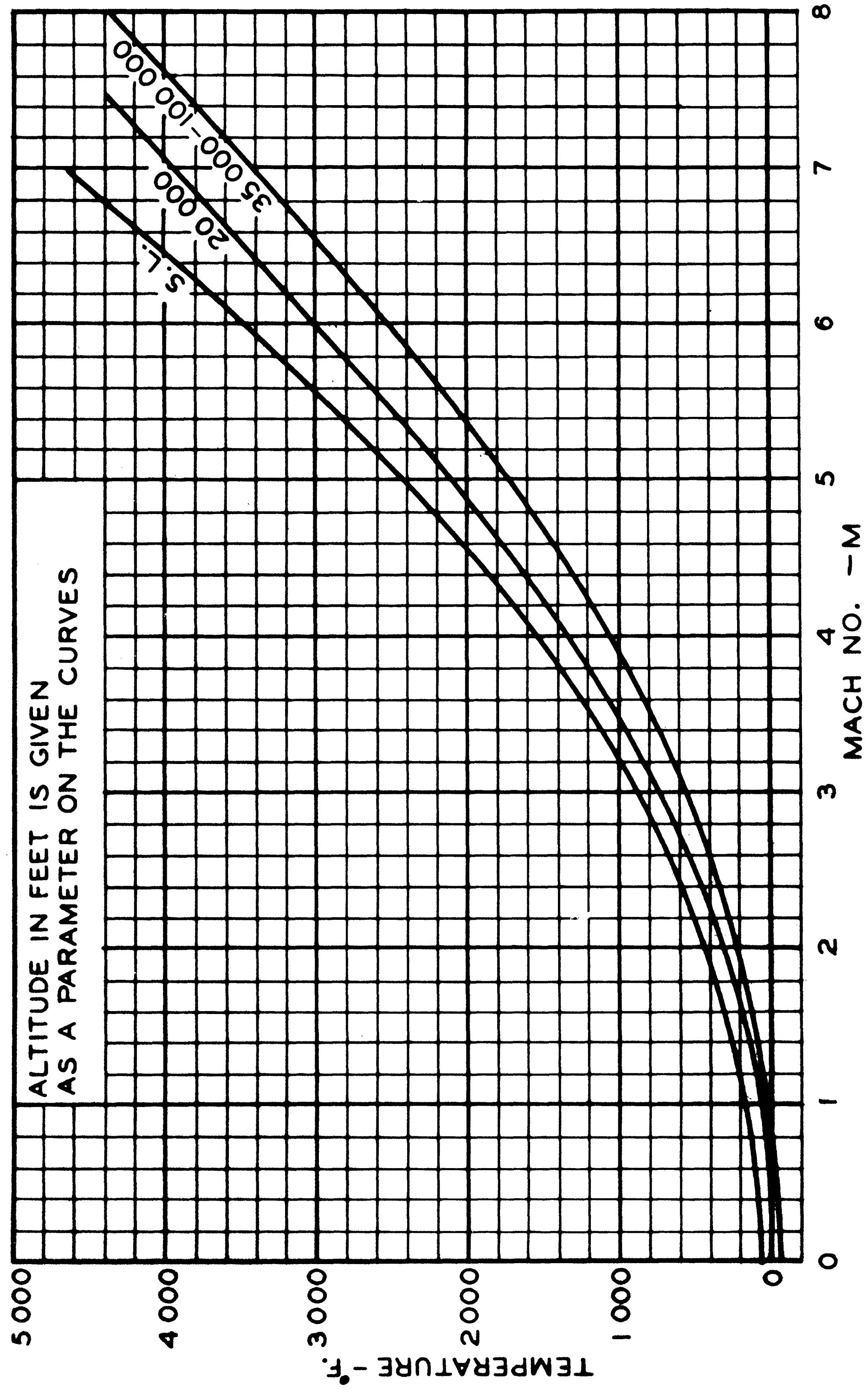

Figure 1

BOUNDARY LAYER TEMPERATURE

VS. MACH NUMBER

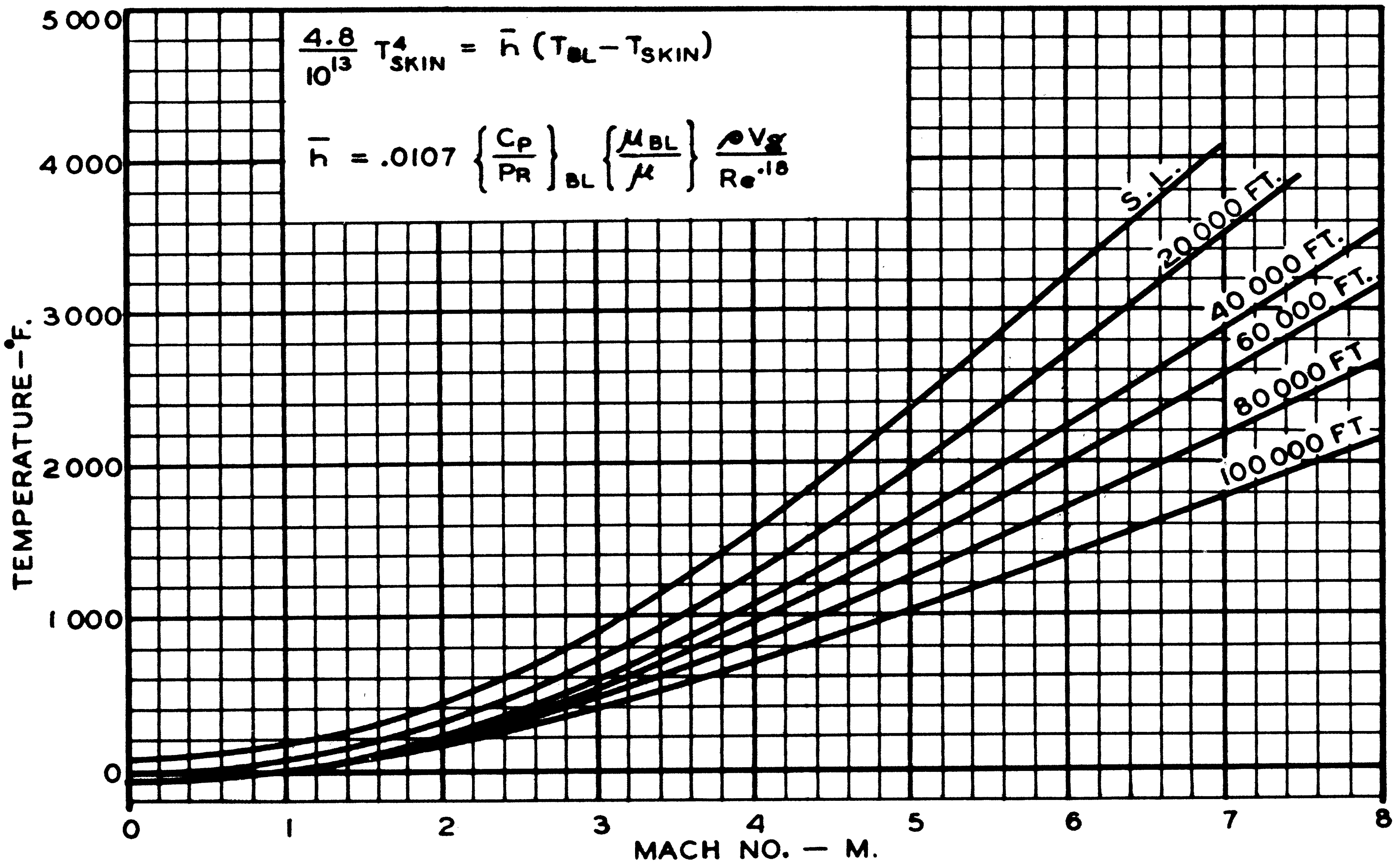

Figure 2

SKIN EQUILIBRIUM TEMPERATURE,

SUPERSONIC DATA

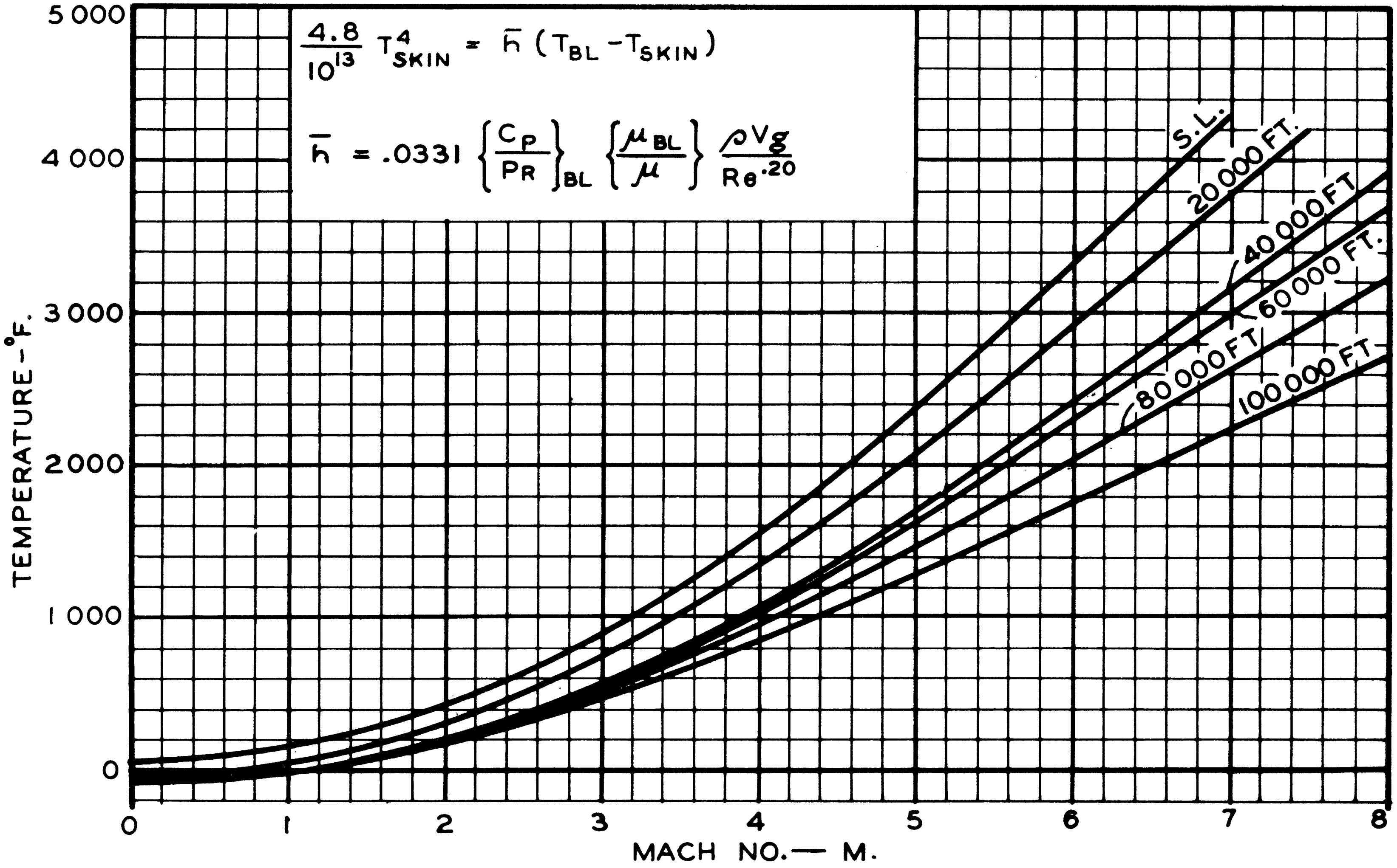

Figure 3

SKIN EQUILIBRIUM TEMPERATURE,

SUBSONIC DATA, - LIMIT CASE

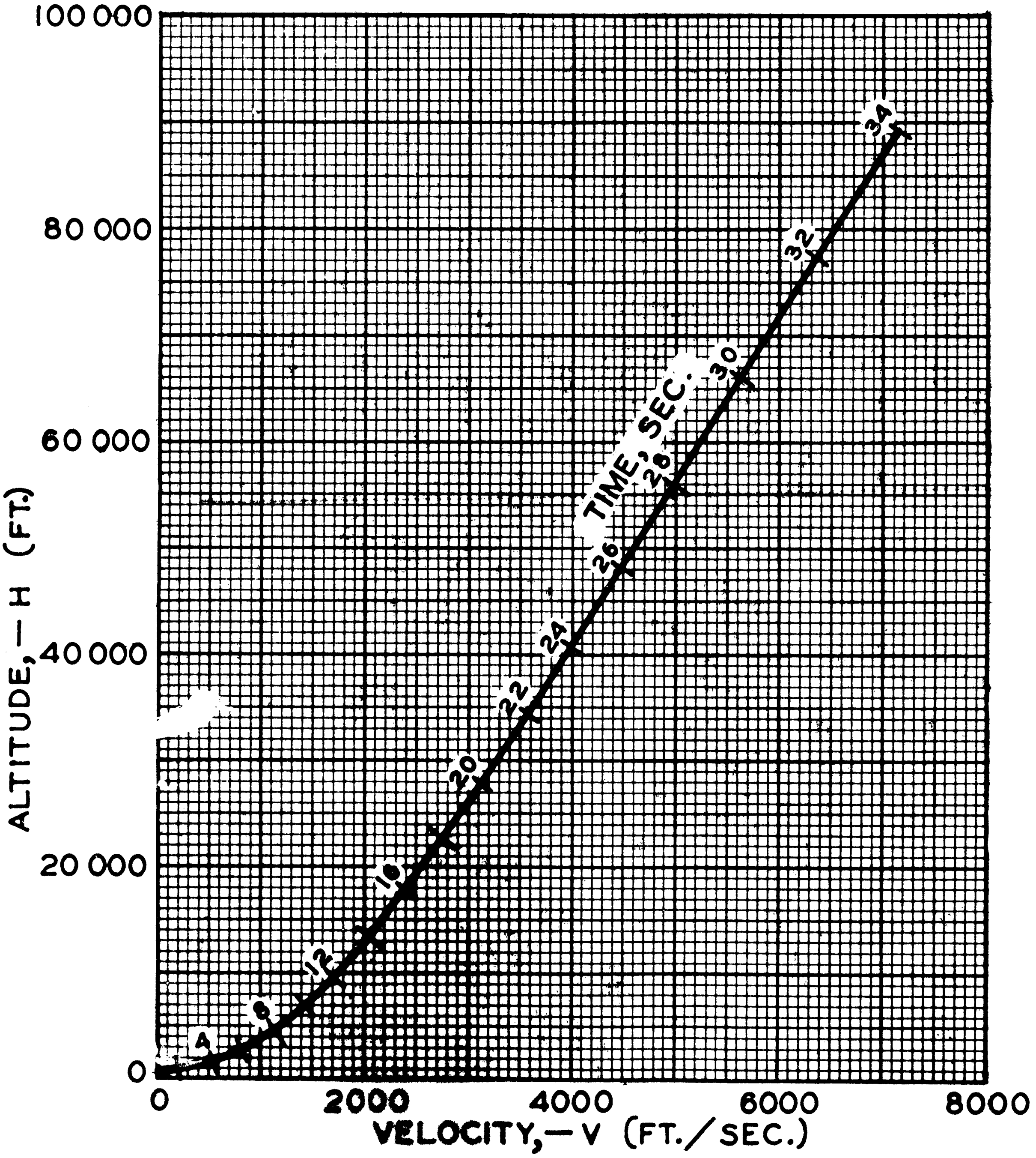

Figure 4

TYPICAL MISSILE FLIGHT

FOR SAMPLE PROBLEM

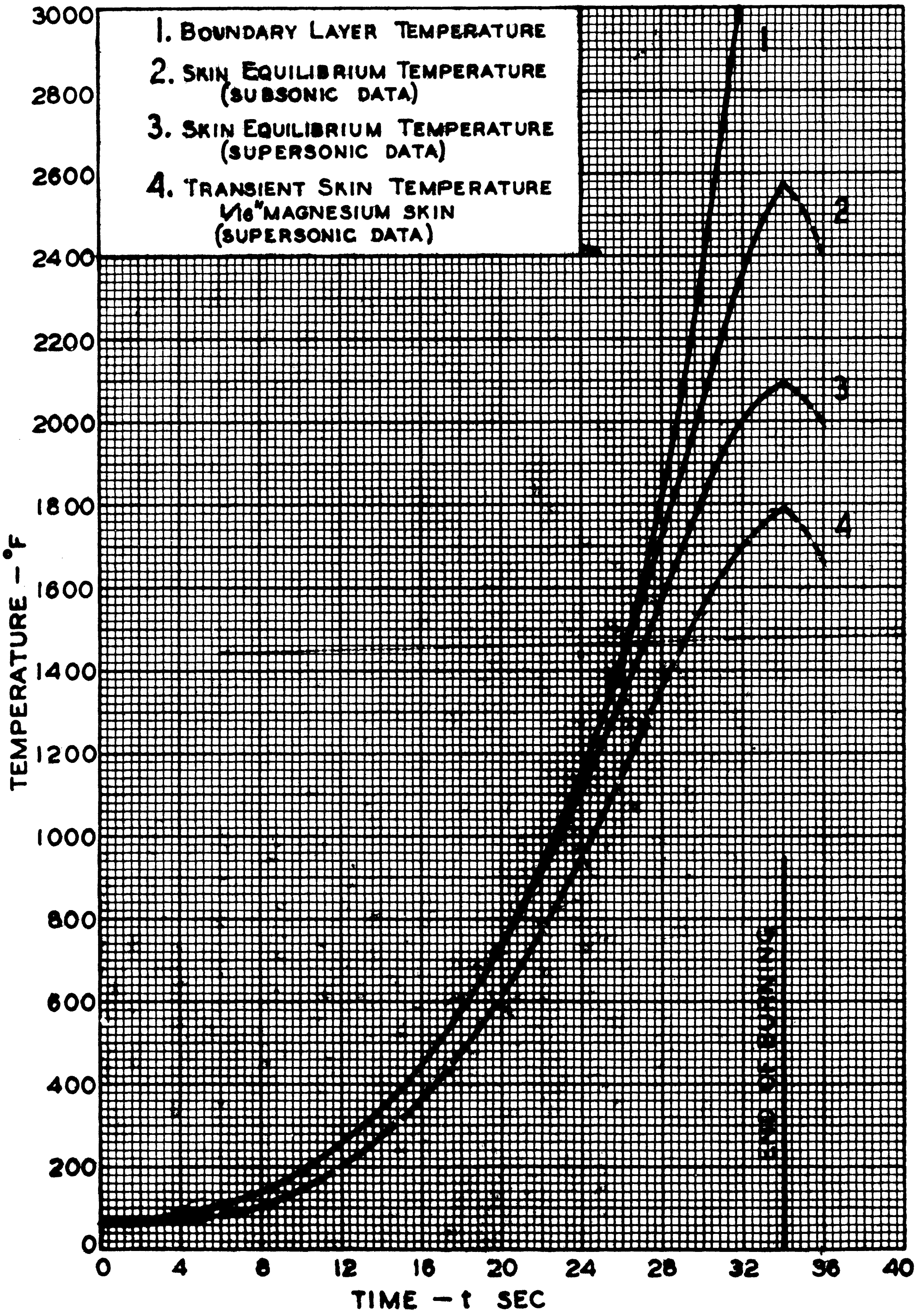

Figure 5

SKIN EQUILIBRIUM TEMPERATURE

FOR SAMPLE PROBLEM

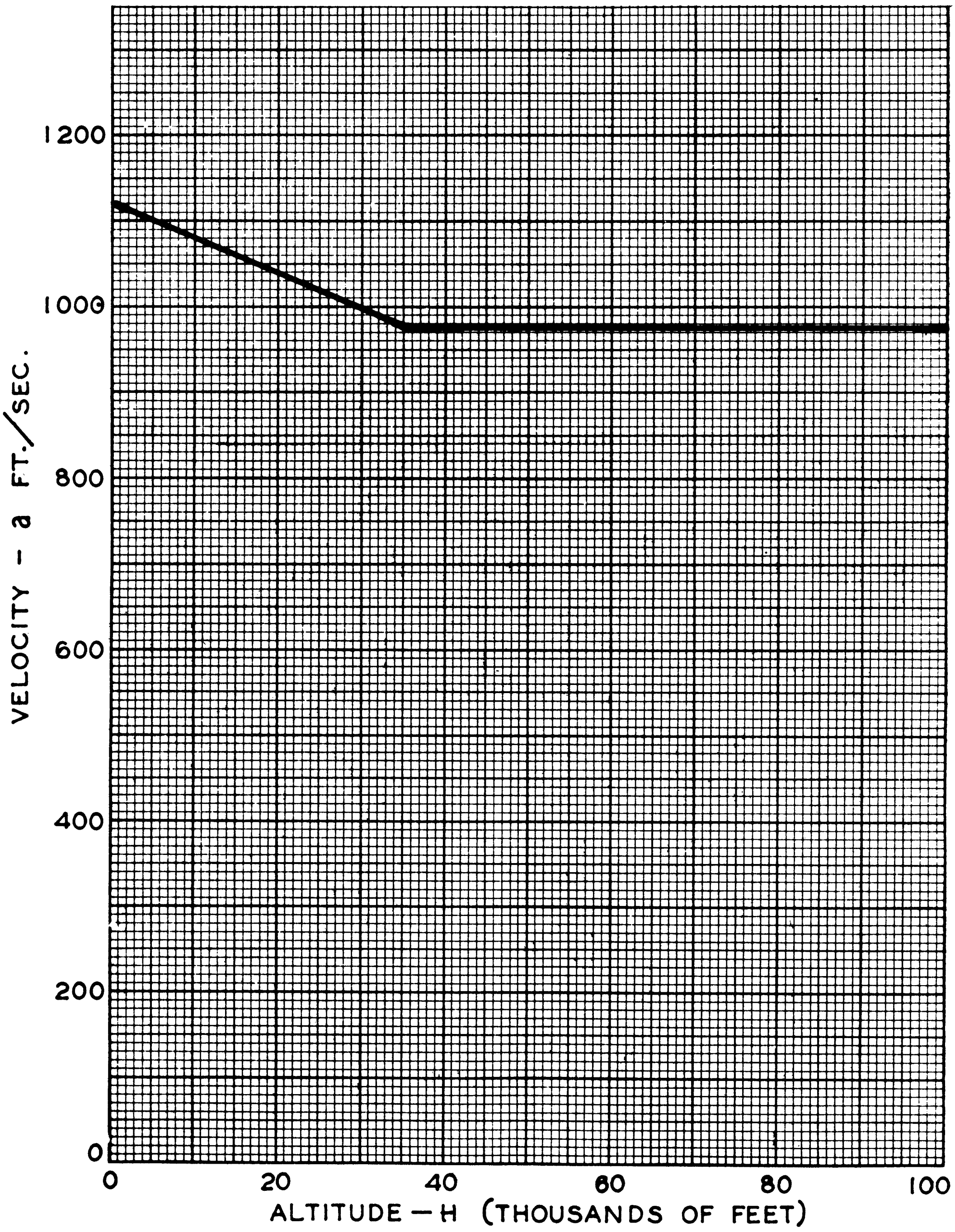

Figure 6

SPEED OF SOUND VS. ALTITUDE

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C-16	Eastman Kodak Company Navy Ordnance Division Rochester, New York Attention: Dr. Herbert Trotter	Naval Inspector of Ordnance Navy Ordnance Division Eastman Kodak Company 50 West Main Street Rochester 4, New York
C-17	Fairchild Engine & Airplane Corporation Pilotless Plane Division Farmingdale, Long Island, N.Y. Attention: Mr. J. A. Sloan	Representative-in-Charge Fairchild Engine & Airplane Corp. Pilotless Plane Division Farmingdale, Long Island, N. Y.
C-18	The Franklin Institute Laboratories for Research and Development Philadelphia, Pa. Attention: Mr. R. H. McClarren	Commanding Officer Naval Aircraft Modification Unit Johnsville, Pennsylvania

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C-24	Globe Corporation Aircraft Division Joliet, Illinois Attention: Mr. J. A. Weagle	Inspector of Naval Materiel 141 W. Jackson Blvd. Chicago 4, Illinois
C-25	Goodyear Aircraft Corp. Akron, Ohio Attention: Dr. Carl Arnstein	Bureau of Aeronautics Rep. Goodyear Aircraft Corp. Akron 15, Ohio
C-27	Grumman Aircraft Engineering Corporation Bethpage, Long Island, N.Y. Attention: Mr. William T. Schwendler	Bureau of Aeronautics Rep. Grumman Aircraft Engr. Corp. Bethpage, L.I., N. Y.
C-28	Hughes Aircraft Company Culver City, California Attention: Mr. R. E. Hopper Mr. D. H. Evans	Bureau of Aeronautics Rep. Douglas Aircraft Co. El Segundo, California
C-29 thru C-30	Jet Propulsion Laboratory California Institute of Technology	Officer-in-Charge Research & Development Service Suboffice (Rocket) California Institute of Technology Pasadena 4, California
C-31	Kaiser Fleetwings, Inc. Bristol, Pennsylvania Attention: Mr. Carl DeGanahl	Bureau of Aeronautics Rep. De Laval Steam Turbine Co. Trenton, N. J.
C-32	Kellex Corporation New York, New York	Inspector of Naval Materiel 90 Church Street New York 7, N. Y.
C-34 thru C-35	Chairman, MIT,GMC Project Meteor Office Massachusetts Institute of Technology Cambridge, Mass. Attention: Dr. H. G. Stever	Navy Ordnance Resident Technical Liaison Officer Massachusetts Institute of Technology Room 20-C-135 Cambridge 39, Mass.

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C-39	Princeton University Physics Department Princeton, New Jersey Attention: Dr. John A. Wheeler	Development Contract Officer Princeton University Princeton, New Jersey
C-40 thru C-42	Princeton University Princeton, New Jersey Attention: Project SQUID	Commanding Officer Branch Office Office of Naval Research 90 Church Street - Rm 1116 New York 7, New York
C-45	Ratheon Manufacturing Co. Waltham, Massachusetts Attention: Mr. R. C. Saunders	Inspector of Naval Materiel Park Square Building Boston 16, Mass.
C-48	S. W. Marshall Company Shoreham Building Washington, D. C.	Inspector of Naval Materiel 401 Water Street Baltimore 2, Maryland
C-49	Sperry Gyroscope Co., Inc. Great Neck, L.I., N. Y.	Inspector of Naval Materiel 90 Church Street New York 7, N.Y.
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C-51	United Aircraft Corp. Research Department East Hartford, Conn. Attention: Mr. John G. Lee	Bureau of Aeronautics Rep. United Aircraft Corp. Pratt & Whitney Aircraft Div. East Hartford 8, Conn.
C-53	University of Texas Defense Research Lab. Austin, Texas Attention: Dr. C. P. Boner	Development Contract Officer 500 East 24th Street Austin 12, Texas
C-54	Willys-Overland Motors, Inc. Maywood, California Attention: Mr. Joe Talley	Representative-in-Charge BuAer Consolidated-Vultee Aircraft Corp. Downey, Calif.

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DA-2	New Mexico School of Agriculture & Mechanic Arts State College, New Mexico Attention: Dr. Gardner Development Contract Officer	Development Contract Officer New Mexico School of Mines Albuquerque, New Mexico
DA-3	New York University Applied Mathematics Center New York, New York Attention: Mr. Richard Courant	Inspector of Naval Materiel 90 Church Street New York 7, New York
DA-4	Office of the Chief of Ordnance Research & Development Service Research & Materials Division Ballistics Branch The Pentagon Washington 25, D. C.	
DA-5	Polytechnic Institute of Brooklyn Brooklyn, New York Attention: Mr. R. P. Harrington	Inspector of Naval Materiel 90 Church Street New York 7, New York
DA-6	University of Minnesota Minneapolis, Minnesota Attention: Dr. Akerman	Inspector of Naval Materiel Northern Pump Co. Minneapolia, Minn.