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Measurement of Aerodynamic Heating on the Nose of a Delta Aircraft at Speeds up to $M = 1{\cdot}65$

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Summary. This Report presents skin-temperature measurements recorded during a climb and level-flight acceleration at 40,000 feet, at speeds up to $M = 1 \cdot 65$. The temperatures were measured at 27 points on the skin of the aircraft nose, on a diaphragm forming part of the nose internal structure and inside the nose. Measurements were first made with the skin clean, and then with it painted. Comparison with estimates of boundary-layer temperature shows that during accelerations of about $0 \cdot 3$ M/minute the skin temperature lagged behind the estimated value by about 5°C, for the clean skin, and by about 9°C for the painted skin. The maximum skin temperature reached was about 100°C above ambient. Agreement between measured and calculated skin temperatures was good.

1. *Introduction.* Aerodynamic heating at supersonic speeds is an important problem in aircraft design. Allowance must be made for thermal effects on the structure; crew and equipment must be protected. Calculation of heating rates and skin temperatures may be made to predict the magnitude of the problem, but such theoretical work is usually based on tunnel or free-flight tests on flat plates or cones. It is important that these results be checked on a real aircraft and structure in flight, and this work has been started on the *Fairey Delta* 2. The present Report describes the temperature measurements made during climbs to, and supersonic runs at, 40,000 ft, on the nose skin of the aeroplane and on a diaphragm through the structure. The results are compared with calculations based on tunnel tests, and the agreement is found to be good.

2. *Aircraft.* The *Fairey Delta* 2 is a 60 deg delta, capable of supersonic speeds up to at least $M = 1 \cdot 70$, at 40,000 ft. It is powered by a Rolls-Royce RA28, fitted with reheat. The long pointed nose is a very prominent feature of the aeroplane, and it was used to position temperature pick-ups. The nose is essentially a thin cone, braced by a lattice of formers and longerons, which leaves panels of the cone free from internal structure.

3. *Instrumentation.* Skin temperatures were obtained using Standard Telephones thermistor elements Type M, having a very large negative temperature coefficient of resistance. The thermistors were set up in a simple electrical circuit (Fig. 1), so that the small changes of temperature which

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caused large alterations in thermistor resistance, were recorded as current variations through a galvanometer in a Hussenot recorder. In order to measure the temperature at 36 points, using one galvanometer, the circuit of each thermistor was sampled in such a way that all the temperatures were recorded within 2 seconds.

The thermistors were calibrated by the use of a combined oven/refrigerator over the range $-30°C$ to $+65°C$, before and after the flight tests. The calibrations have also been compared with an estimated calibration, obtained from a knowledge of the thermistor and galvanometer characteristics. A typical set of calibrations is shown in Fig. 1.

Temperatures were recorded at 27 positions on the aircraft skin (*see* Fig. 2), at 8 positions around a skin and diaphragm joint (*see* Fig. 3), and at one internal position to give air temperature. The thermistors were stuck to the aircraft skin using an Aluminium-loaded Araldite, and were installed in two ways, in one being mounted flush with the external skin, and in the other, being entirely internal. A sketch of each arrangement is shown in Figs. 4a and 4b respectively.

Except for the eight around the diaphragm joint, the thermistor positions were selected to be away from internal structure, so that easier comparison could be made with calculated temperatures, which are based on thin-shelled cone characteristics.

4. *Flight Test Technique.* 4.1. *Climb, Stabilised Speed, and Initial Acceleration.* The aircraft was climbed from 5,000 ft to 40,000 ft, and recordings of the skin temperature were taken every 5,000 ft. At 40,000 ft, height was maintained and the speed held at $M = 0 \cdot 95$ for about 3 minutes, and further temperatures recorded. After this stabilisation period, the aircraft reheat was lit, and at constant altitude, the aeroplane accelerated. Records were taken at intervals throughout the initial acceleration period, to determine the way in which the skin temperature began to lag behind the calculated boundary-layer temperature.

4.2. *Level-Flight Accelerations.* For the level-flight runs at altitude, the aircraft was stabilised for a few minutes around $M = 1 \cdot 0$, then reheat was lit, and records taken at every $0 \cdot 1$ Mach number increment throughout the acceleration and deceleration.

A run was made with the aircraft nose painted, for comparison with the clean condition. The painting consisted of one coat of etch primer (about one thousandth of an inch thick), and then one coat of cold-catalyst blue paint (2 to 3 thousandths of an inch thick).

5. *Results and Discussions.* The changes in temperature of the nose skin during acceleration and deceleration are shown in Fig. 5. The temperatures vary very little with axial position (apart from the region near the radio bay), or with type of mounting—'flush' or 'internal'. Accordingly, to show more clearly the variation of temperature and Mach number with time, the temperature history of one thermistor only is plotted in all the succeeding graphs. This thermistor position is the one indicated in Fig. 2.

5.1. *Climb, Stabilised Speed and Initial Acceleration.* In Fig. 6 the temperatures recorded during the climb are plotted and clearly show the lag of airframe temperature behind the calculated boundary-layer temperature, T_{w0}. The latter was obtained by using Meteorological Office data, and assuming a recovery factor of $0 \cdot 88$, (the recovery factor was interpolated from information given in Ref. 1). When the aircraft had remained at the stabilised speed for about 4 minutes, the measured skin temperature was very close to the calculated boundary-layer temperature. A stabilised condition was not maintained for long enough to show whether the temperature would settle precisely at the calculated value. When acceleration was resumed, initially at a rate of about $0 \cdot 3M$/minute, actual skin and internal air temperatures immediately lagged behind the boundary-layer values; the rapid cross-over from a positive lag as the temperature decreased in the climb to a negative lag as it increased in the initial acceleration indicates that the skin temperature had reduced to near the steady level-flight value.

5.2. *Level-Flight Acceleration.* Fig. 7 gives a temperature history for the representative thermistor, together with the corresponding Mach number variation. They show that skin temperature was lower than boundary-layer temperature (T_{w0}) by about 5°C throughout the acceleration, which was about $0 \cdot 2M$/minute. At the start of the deceleration, which was about $0 \cdot 5M$/minute, T_{w0} fell, but for a short time the skin temperature continued to rise, so that a cross-over point was obtained. Thereafter, as the aeroplane decelerated, skin temperature remained lagging behind, again by about 5°C.

The internal air temperature always had a large lag compared with T_{w0}.

The acceleration caused skin-temperature changes at the rate of 20°C/minute, and it will be noted that the maximum skin temperature achieved was about 100°C above ambient.

5.3. *Calculated Temperatures.* A comparison between measured skin temperatures and those calculated using the 'intermediate enthalpy' method[1] is presented in Fig. 8. In this method, heat-transfer coefficients were evaluated for various conditions during the run, and corresponding skin temperatures found using a step-by-step integration procedure. Agreement is seen to be good. Also shown in Fig. 8 is the calculated effect of a 10°C error in the assumed starting temperature of the run. The error is seen to be reduced to a negligible amount in about 30 seconds.

5.4. *Temperature Measurements after Painting the Aircraft Nose.* The effect on the temperature history of painting the aircraft nose is shown in Fig. 9. The difference between T_{w0} and the measured skin temperature is greater than for the clean aeroplane, indicating that the paint produces a significant insulation of the aircraft skin. The average lag of observed temperature behind T_{w0} is about 9°C. Once more the cross-over of temperatures is evident, as the aircraft decelerates.

5.5. *Temperatures Measured across a Diaphragm in the Nose.* The variations of temperature along the nose skin and diaphragm joint are shown in Figs. 10a and 10b. When the aircraft was accelerating, there was a progressive drop in temperature along the skin to the junction with the diaphragm, and a further drop of temperature towards the centre of the diaphragm. During the deceleration, the reverse gradually took place, so that at the lower speeds the diaphragm was warmer than the external skin. Thermistors G and H (*see* Fig. 3) became defective, and are not included in Figs. 10a and 10b.

6. *Conclusions.* The flight tests made to measure the variation of skin temperature with Mach numbers have shown that:

(i) The measurement of temperature up to the level achieved in the tests, can be made satisfactorily using electrically-switched thermistors.

(ii) The estimated thermistor calibration was in accurate agreement with the experimental calibration.

(iii) Both methods of thermistor attachment were satisfactory, but for ease of installation, the internally-mounted arrangement is preferable.

(iv) After stabilising speed, the skin temperature became very close to the calculated value after about 4 minutes.

(v) During the accelerations, the temperature of the skin lagged about 5°C behind estimated boundary-layer temperature for the clean condition, and about 9°C for the painted skin, for temperature changes of 20°C/minute.

(vi) In stabilised-flight conditions, the calculated boundary-layer temperature agreed well with the skin temperature measured. The maximum skin temperature was about 100°C above ambient.

LIST OF SYMBOLS

T_{w0}	Boundary-layer temperature at the surface
T_w	Skin temperature of aircraft
M	Free-stream Mach number
T_{ambient}	Air temperature at the time of tests

REFERENCE

No.	*Author*	*Title, etc.*
1	R. J. Monaghan	Formulae and approximations for aerodynamic heating rates in high speed flight. A.R.C. C.P.360. October, 1955.

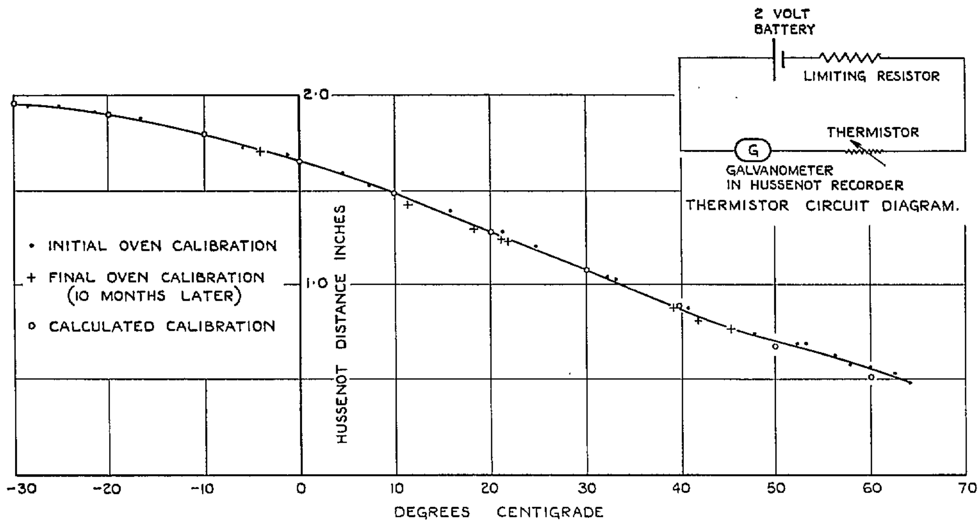


FIG. 1. Typical thermistor calibration.

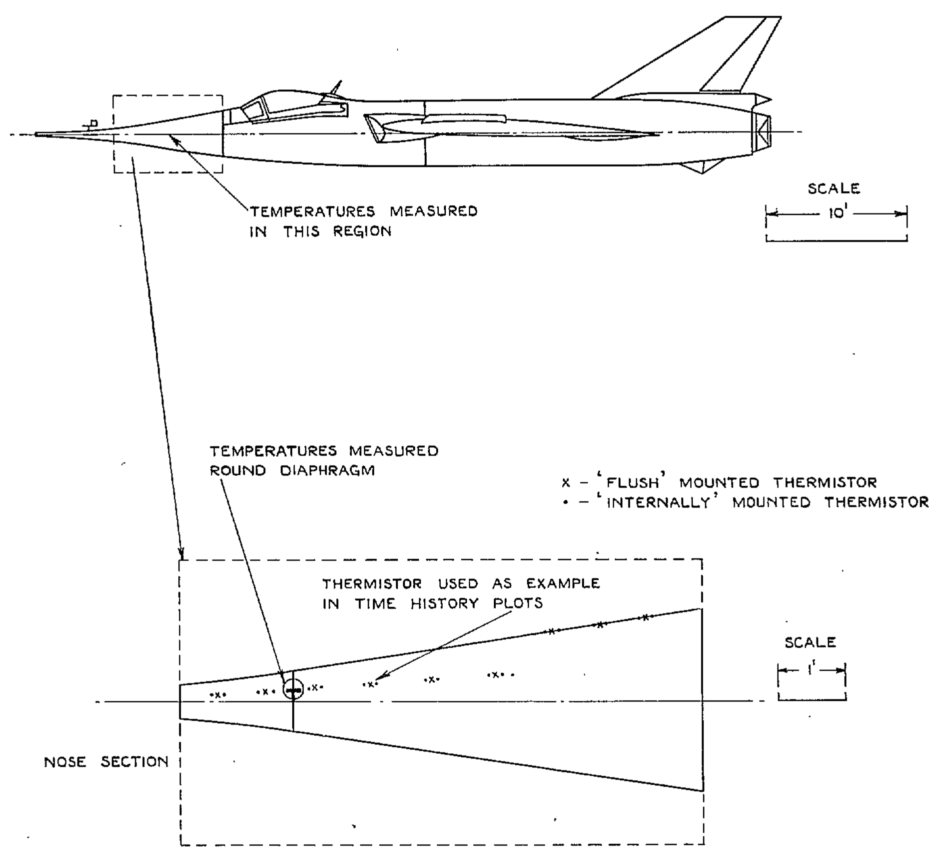
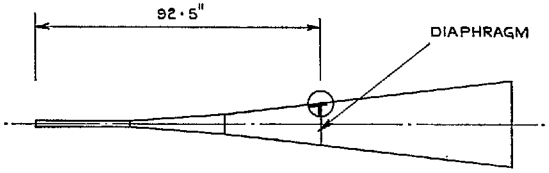


FIG. 2. Sketch of aircraft giving thermistor positions.



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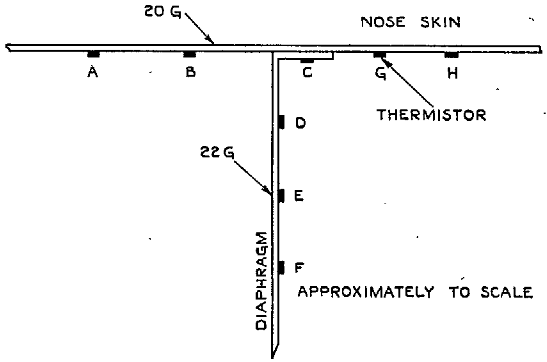

FIG. 3. Detail of thermistor positions around diaphragm/skin joint.

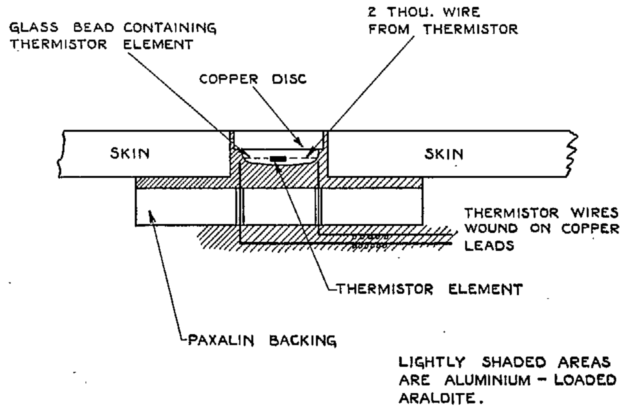

FIG. 4a. Sketch of 'flush' mounted thermistor.

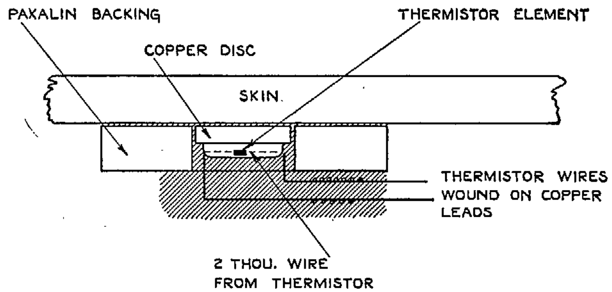

FIG. 4b. Sketch of 'internally' mounted thermistor.

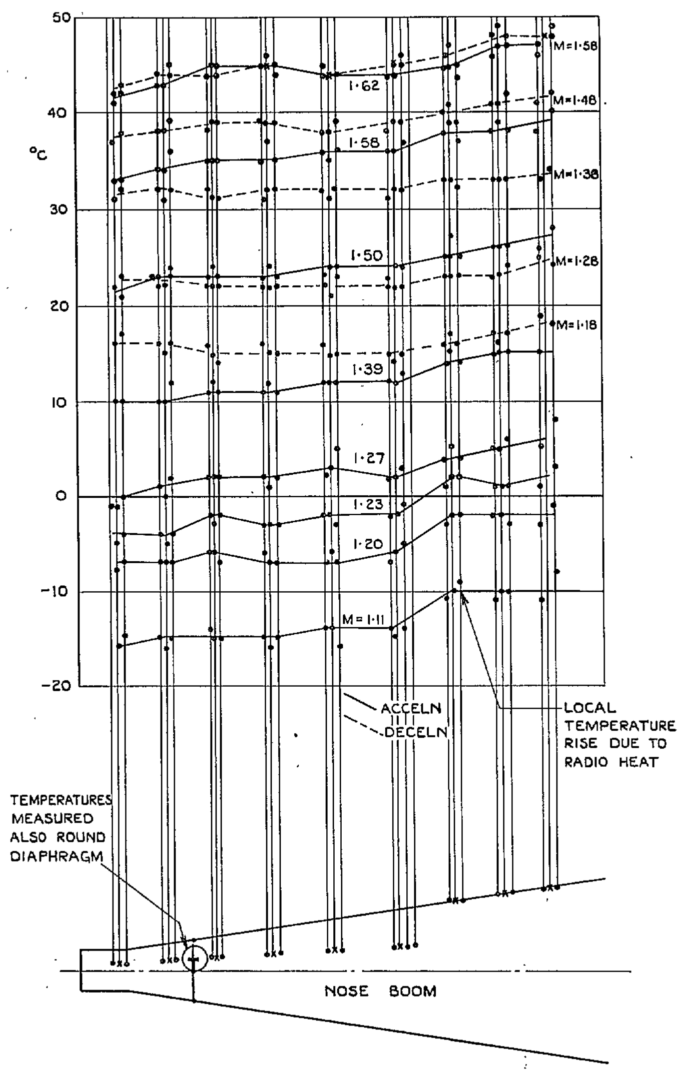

FIG. 5. Nose boom temperatures during level-flight acceleration and deceleration.

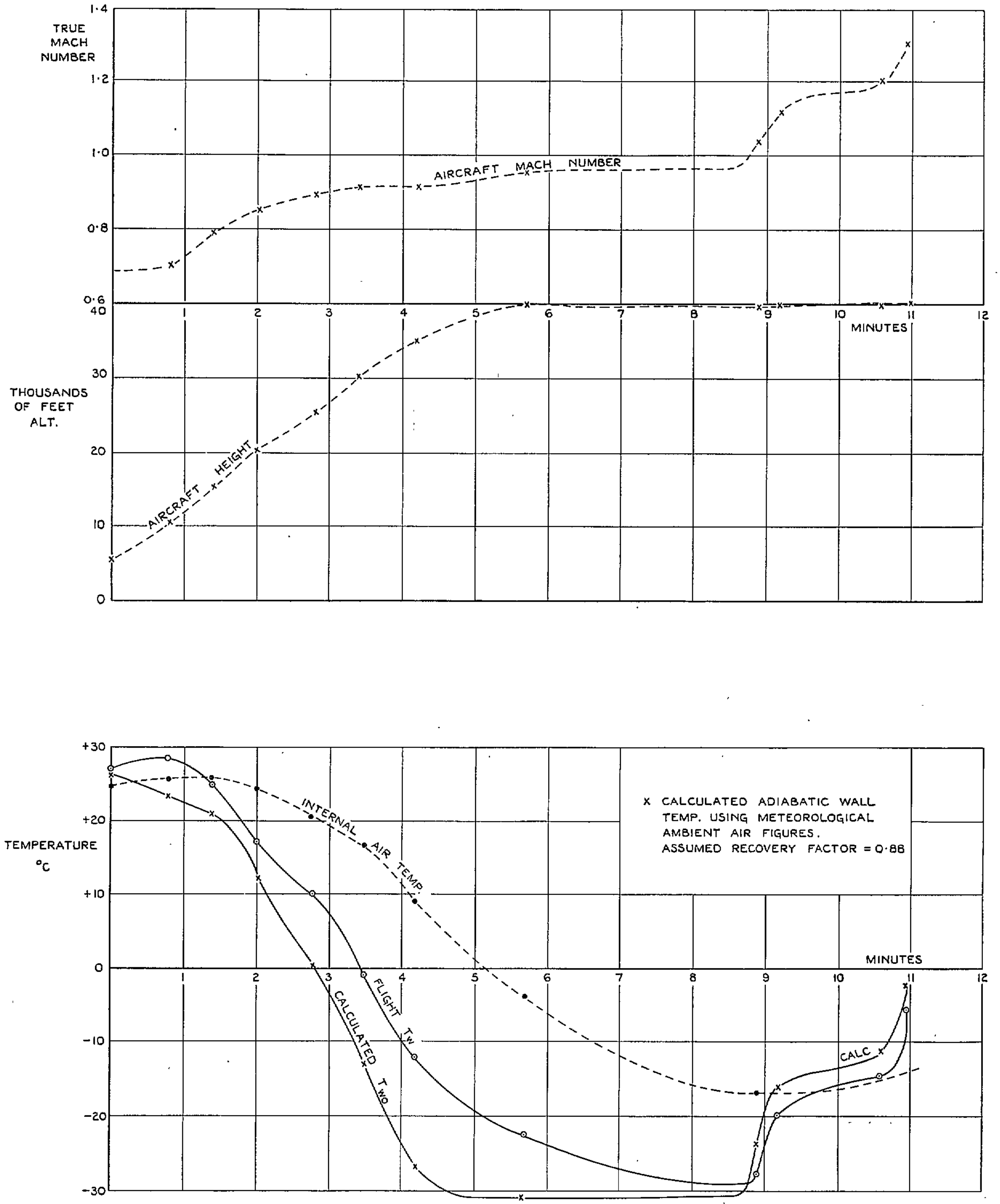

FIG. 6. Skin temperature during climb, stabilised speed and initial acceleration.

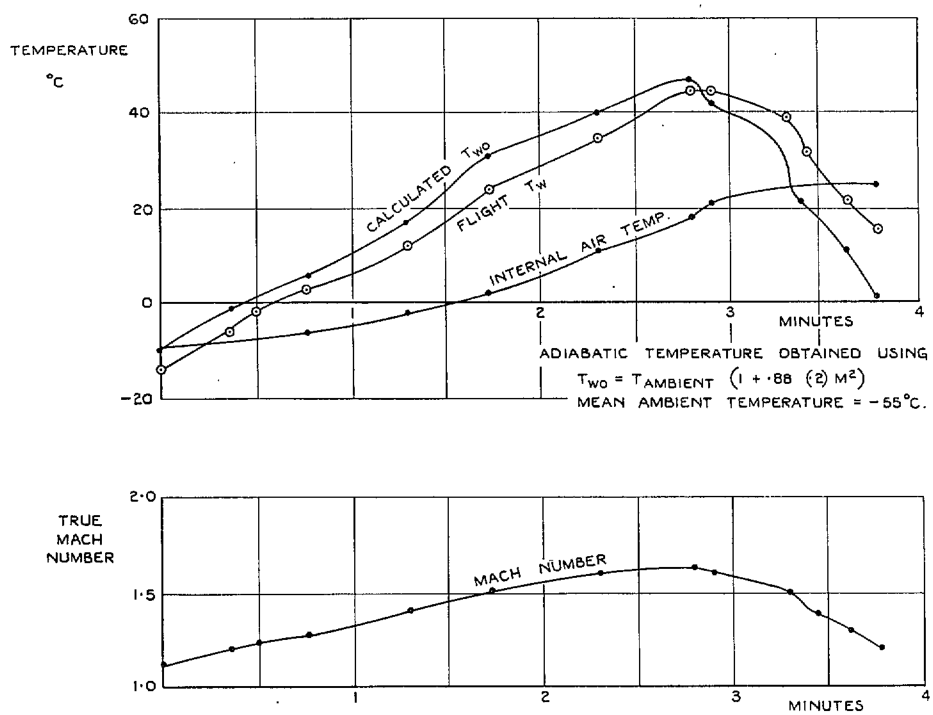

FIG. 7. Typical nose temperature history.

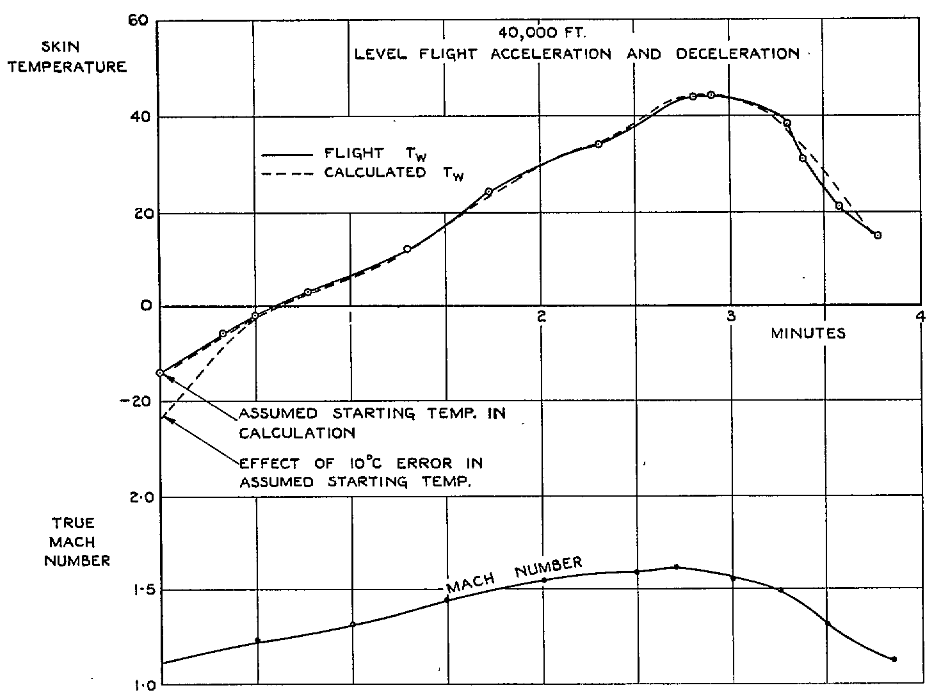

FIG. 8. Comparison of flight and calculated skin temperatures.

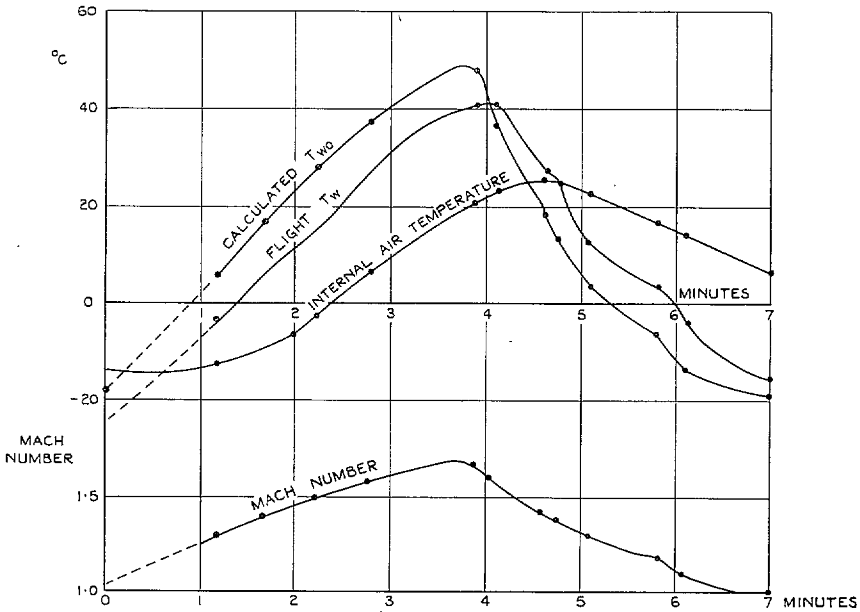

Fig. 9. Typical temperature history with aircraft nose painted.

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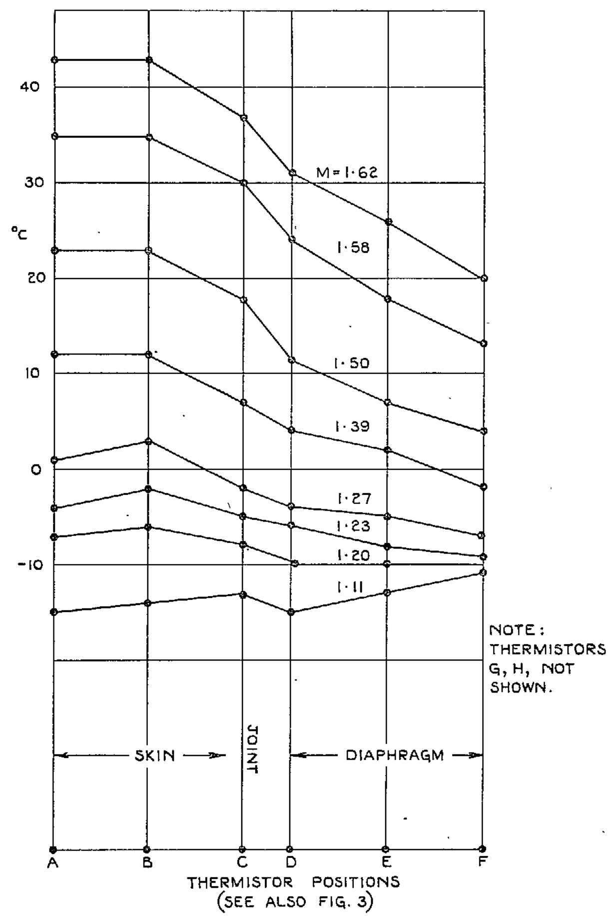

FIG. 10a. Temperatures of the skin and diaphragm during an acceleration.

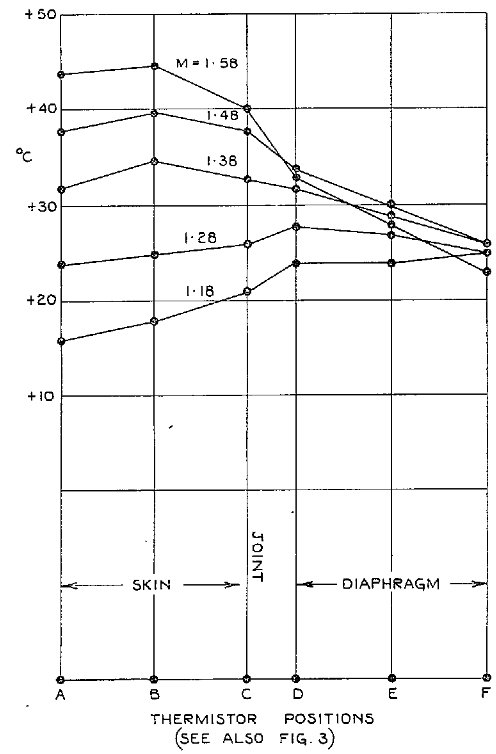

FIG. 10b. Temperatures of the skin and diaphragm during deceleration.

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