No 4

TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 956

CORRECTIONS ON THE THERMOMETER READING IN AN AIR STREAM

By H. J. Van der Maas and S. Wynia

Nationaal Luchtvaartlaboratorium
Amsterdam, 1939

Washington
October 1940

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL MEMORANDUM NO. 956

CORRECTIONS ON THE THERMOMETER READING IN AN AIR STREAM*

By H. J. Van der Maas and S. Wynia

. . .

NOTATION

v true flow velocity

v_w true flight velocity

p pressure

q dynamic pressure

ρ density

ρ_o density at ground in standard atmosphere

c_p specific heat at constant pressure

c_v specific heat at constant volume

$K = c_p/c_v$

g acceleration of gravity

R gas constant

T absolute temperature

A mechanical equivalent of heat

μ viscosity

λ heat transfer coefficient

θ temperature

θ_a thermometer reading

H altitude

m mass

---

*"Correctie voor stuwing en wrijving op thermometeraanwijzingen." Nationaal Luchtvaartlaboratorium, Amsterdam, No. 8, 1939. Report V 834, pp. 28-33.

I. INTRODUCTION

To obtain reliable results from observations during flight tests, the external air temperatures must usually be known - often to an accuracy of a tenth of a degree Centigrade. For this purpose, the N.L.L. (Nationaal Luchtvaartlaboratorium) employs a special type of thermometer, namely, the so-called "distance thermometer." The latter generally consists of a mercury bulb which, by a long, flexible capillary, is connected to the dial located in the pilot's cockpit, while the measuring body is located in the air stream outside the airplane. A sun shield serves to screen the instrument from the direct rays of the sun. Figure 1 shows two thermometers constructed in accordance with this principle. The only difference is in the shape of the sun shield.

Instead of mercury thermometers it is, naturally, also possible to use, for example, electrical-resistance thermometers for the measurement of the temperature. Both systems possess typical advantages and disadvantages. The most important advantage of electrical thermometers, as compared with mercury thermometers, is their considerably smaller time lag. Their disadvantages are mainly associated with the sensitive galvanometer required for accurate measurements and which must be suitable for use on an airplane. It is not our intention in this article to go further into this matter. At the present time, the N.L.L. is giving consideration to a partial replacement of mercury by electrical thermometers for temperature measurements in flight tests. In this report the discussion will be restricted to the distance thermometers mentioned above, which have been found very useful.

The difficulty is that the reading of such thermometers may for various reasons differ - in some cases considerably - from the true outside air temperature. In the first place, there naturally occur instrumental errors, which can be found by calibration. We wish to point out here that this correction, which offers no difficulty, will be entirely left out of consideration, so that in the following, wherever we speak of thermometer reading, it is assumed that the instrumental correction has been made.

A second error is caused by the changed flow velocity in the neighborhood of the measuring body. Even without the use of a sun shield (which strongly affects the flow pattern and flow velocity, there exists in every case on the surface of the body, at least one stagnation point. Since, wherever (strictly speaking, in a potential flow) there is a decrease in the flow velocity there is, according to Bernoulli's law, an increase in the pressure; every decrease in velocity is associated with an approximately adiabatic compression and, hence, a temperature rise. The latter may amount to several degrees Centigrade for large changes in velocity.

Furthermore, there is formed on the surface of the measuring body, a boundary layer within which the internal friction (viscosity) of the air plays an important part. Since the energy of the friction is converted into heat, the temperature in the boundary layer of the measuring body rises, especially at the points where the flow velocity outside the boundary layer is large. The corrections to be made for the two last-named effects of adiabatic compression and friction, and which have variously been investigated - also by the N.L.L. (Report A, reference 1) - will, in the present paper, be determined by a new method.

In addition to the above-mentioned errors, one more important source of error may be mentioned, namely, that due to time lag. The mercury thermometers of the type described have a large heat capacity; on account of this fact, together with the limited heat transfer, the thermometer reading lags behind the change in temperature of the surroundings. Some observations in regard to this lag error will be made in the appendix.

Summarizing, it is necessary to apply a threefold correction (in addition to the already applied instrumental correction) to each thermometer reading:

1. A correction for adiabatic compression.

2. A correction for friction.

3. A correction for time lag.

Finally, it is to be observed that all the measurements considered in this report were made with one of the two distance thermometers shown in figure 1. They are manufactured by Negretti and Zambra, and are distinguished by the notation NZI, with the "old" type of sun shield (fig. 1A), and NZII, with the "new" type of sun shield (fig. 1B).

II. CORRECTIONS FOR ADIABATIC COMPRESSION AND FRICTION

1. General

The temperature effect associated with the retarding of an air stream has long been known. The first investigations in this field were carried out by Kelvin and Joule, who were able to show good agreement between theory and experiment. Since then, various investigators have concerned themselves with problems of a more or less similar nature. We may mention here the work of Pohlhausen (reference 2), Edmond Brun (reference 3), and other investigations by the N.L.L. (reference 1), limiting ourselves to those publications of which use was made in the present report.

For a detailed historical review, we may point to the work of Edmond Brun (reference 3). All experiments with which we are familiar, however, are incomplete in one respect, namely, that the air density, on which, in general, the temperature may also depend, was not considered. In laboratory and wind-tunnel measurements, the investigation of the part played by the air density meets with difficulties which may be avoided if a method is found that makes use of flight tests. Such a method has been developed by the N.L.L., and an additional means was thus provided for investigations in this field. Before going into a description of the method, however, it is desirable to consider the effects to be expected from the theoretical viewpoint - having regard particularly to the finding of practically suitable correction formulas for thermometer readings.

2. Temperature Change Associated with Adiabatic Compression

Part of the simple treatment given below has already appeared in older reports (reference 1). Since no account was taken of the effect of air density, we repeat the theory in more complete form.

Under the assumptions that:

a) the flow is steady and free from rotation,

b) the internal friction may be neglected,

c) no external forces are acting,

d) compression takes place adiabatically, the pressure and density being connected by the known formula for ideal gases, p/ρ^K = const.

the equation of Bernoulli with compressibility taken into account, is:

$$\frac{v_1^2}{2} + \frac{K}{K-1}\frac{p_1}{\rho_1} = \frac{v_2^2}{2} + \frac{K}{K-1}\frac{p_2}{\rho_2} \qquad (1)$$

where the subscripts $_1$ and $_2$ denote two arbitrary points in the field of flow. For ideal gases, we have, in addition

$$\frac{p}{\rho} = g\,R\,T \qquad c_p - c_v = \frac{R}{A} \qquad (2)$$

From equations (1) and (2), there is obtained:

$$T_2 - T_1 = \frac{K-1}{K}\,\frac{v_1^2 - v_2^2}{2g\,R} = \frac{1}{2g\,A\,c_p}\,(v_1^2 - v_2^2) \qquad (3)$$

This expression may also directly be found from the energy equation:

$$\tfrac{1}{2}\,m\,(v_1^2 - v_2^2) = A\,mg\,c_p\,(T_2 - T_1)$$

which states that the kinetic energy is completely converted into heat.

Thus it is found that the temperature rise through the adiabatic compression depends entirely on the velocity change and not on the density. It is possible to construct a thermometer so that its mercury bulb is practically all located at a stagnation point; for example, by making the dimensions of the bulb as small as possible and mounting it at the center of a circular disk which is set up at right angles to the flow direction. For such a "stagnation point thermometer" the correction would be given by (3) with $v_2 = 0$. Moreover, practically no flow occurs in the direct neighborhood of the mercury bulb, so that the effect of the friction is inappreciable and no correction need be made for it. (See reports A.322, A.342, and A.479.

With the thermometer types employed on airplanes, however, corrections must be made both for adiabatic compression and friction.

3. Temperature Change Associated with Friction

The correction which must be applied on account of the frictional heat developed in the boundary layer of the thermometer body, can be approximately computed in only a single simplified case. In general, this boundary layer is partly laminar and partly turbulent. In a turbulent boundary layer, the velocity distribution is nonuniform; as a result of this fact, the temperature distribution due to the liberated frictional heat is not capable of simple computation.

For the case of a steady potential flow along a flat wall with laminar boundary layer, Pohlhausen (reference 2) has computed at what temperature difference between the wall and the gas (or fluid) the heat exchange between boundary layer and wall is zero. It is found that this temperature difference may be written in the form:

$$\Delta T = \frac{1}{8} \beta \frac{v^2}{g A c_p} \tag{4}$$

where β is a constant that may be considered as dependent only on the kind of gas. For air, β approximately equals 3.6.

The formula thus obtained:

$$\Delta T = 0.45 \frac{v^2}{g A c_p} \tag{5}$$

can be applied to a "plate thermometer" - that is, a thermometer whose mercury bulb is in the form of a thin, flat plate, for which the boundary layer is assumed to be laminar.

From formula (5) it follows that the temperature change due to friction likewise does not depend on the density, but only on the square of the velocity.

4. With $g = 9.81 \frac{m}{s^2}$ $A = 427 \frac{kgm}{cal}$; $c_p = 0.241 \frac{cal}{kg\ ^\circ C}$

the theoretically derived correction formulas for the two extreme cases become:

1) for the stagnation-point thermometer (case where friction is neglected) from (3)

$$\Delta_1\theta = -0.5 \times 10^{-3} v^2 \quad (\Delta\theta \text{ in } {}^\circ C, \; v \text{ in m/s}) \qquad (6)$$

2) for the plate thermometer (only friction without adiabatic compression)

$$\Delta_2\theta = -0.45 \times 10^{-3} v^2 \quad (\Delta\theta \text{ in } {}^\circ C, \; v \text{ in m/s}) \qquad (7)$$

where v is the undisturbed flow velocity.

To the above may be added:

2a) plate thermometer with turbulent boundary layer:

$$\Delta_3\theta = \text{unknown}$$

$\Delta_1\theta$ and $\Delta_2\theta$ are approximately of the same magnitude. On the basis of laboratory measurements (E. Brun, reference 3), it may be expected that $\Delta_3\theta$ is also of the same order of magnitude.

In the case of a thermometer of arbitrary construction, the above three separately considered effects, in general, occur together. On the basis of the formulas found for $\Delta_1\theta$ and $\Delta_2\theta$, it is necessary, with the aid of experiment, to investigate as to whether the total correction is also with sufficient accuracy proportional to the square of the velocity - for which must be taken the true flight velocity v_W. There remains, however, the question whether the correction formula, which in this case may be written

$$\Delta\theta = -c_1 v_W^2 = -c \frac{\rho_o}{\rho} q \qquad (8)$$

may be extrapolated beyond the region for which it was experimentally established.

For a thermometer of the type NZI, the investigation was completely carried out (see section IV), and it appears that up to dynamic pressures of 600 kg/m² the error may, in fact, with good approximation, be computed by a formula of type (8).

5. It is of interest to add to the above consideration the following remarks which concern the practical applica-

tion of the correction formula.

In the formula there occurs the undisturbed flow velocity v_w, namely, the velocity at a point where it is not disturbed by the thermometer. When a thermometer is mounted at a certain place on an airplane, however, there are two causes of disturbance - i.e., the airplane and the thermometer. The question now is: Which velocity is to be substituted for v_w in the formula?

The above difficulty may, to a large extent, be removed by mounting the thermometer at a point where the flow velocity as far as possible is equal to the flight velocity, and then also substitute the actual velocity for v_w. If this is not done, an error will be made in the correction formula.

We wish to determine the order of magnitude of this error, assuming that the correction formula is of form (8). Let

v_w be the true flight velocity

v_t the flow velocity in the neighborhood of the thermometer be at a point where the disturbance by the thermometer itself may be neglected

$q_t = \frac{1}{2} \rho v_t^2$

θ be the true temperature of the air

θ_t the true temperature at the point where v_t is taken

θ_a the reading of the thermometer

According to (8), we may now write:

$$\theta_t - \theta_a = - c \frac{\rho_o}{\rho} q_t \qquad (9)$$

Furthermore, θ_t deviates from θ, because to each change in velocity there corresponds an adiabatic compression. That this velocity change is largely caused by the airplane, is of no concern here. There is then also obtained from (3)

$$\theta - \theta_t = - \frac{1}{2g\,A \cdot c_p} (v_w{}^2 - v_t{}^2)$$

$$= - c' \frac{\rho_o}{\rho} (q - q_t) \qquad (10)$$

and the required total correction from (9) and (10) is

$$\Delta\,\theta = \theta - \theta_a = - c' \frac{\rho_o}{\rho} q - (c - c') \frac{\rho_o}{\rho} q_t \qquad (11)$$

Direct, but actually erroneous application of (8) would give:

$$\Delta\,\theta = - c \frac{\rho_o}{\rho} q$$

Now c practically never differs from c' (because the correction constants for friction alone and compression alone are approximately equal (see (6) and (7)), so it may be expected that the correction constants for a combination of both effects is also approximately of the same magnitude, as appears to be the case. An extreme assumption, for example, is: $\frac{4}{5}$ c = c'. Equation (11) then becomes:

$$\Delta\,\theta = - \frac{4}{5} c \frac{\rho_o}{\rho} q - \frac{1}{5} c \frac{\rho_o}{\rho} q_t$$

The error made in the direct application of (8) is thus - if it is assumed that q_t lies between the limits 0 and 2q - at most, 20 percent. It is naturally desirable, especially for accurate measurements, to choose carefully a suitable mounting for the thermometer.

III. EXPERIMENTAL INVESTIGATION

1. The tests to be carried out must not only give the value of the constant occurring in the formula, but must also give the form of the latter, and it is particularly necessary to check the dependence on the air density.

Before going into the experimental method of the N.L.L.

which utilizes flight tests, we wish to recapitulate the results already obtained from wind-tunnel tests, referring to a previous report (reference 1) for more details. In these tests the reading of the thermometer is compared with the reading of a stagnation-point thermometer, to which the theoretical correction (6) was applied. For the NZI thermometer, the following result was obtained:

$$\Delta \theta = - 0.010 \, q \quad (\Delta \theta \text{ in } {}^\circ C, \quad q \text{ in kg/m}^2)$$

so that from formula (8)

$$c = 0.010 \, \frac{{}^\circ C \, m^2}{kg}$$

2. In seeking to obtain the desired result through flight-test measurements a serious difficulty is encountered, namely, the considerable inertia of the usual thermometer, which causes an error in the reading that is not known with sufficient accuracy. This error might be eliminated by using steady thermometer readings over a long period - such readings being obtained during flight through an isothermal layer of the atmosphere. This has the disadvantage that uniformity of atmospheric conditions, over which there is no control, must be assumed. Furthermore, even in the most favorable cases, the structure of the atmosphere is never entirely uniform.

Two methods may be considered that might lead to useful results:

1. A direct method, in which as favorable atmospheric conditions as possible are awaited, during which as accurate measurements as possible are made with apparatus especially developed for this purpose (for example, stagnation-point thermometer as basic instrument).

2. A method by which it is sought to obtain reliable results exclusively through the corresponding readings of the thermometer to be investigated, the speedometer, and the altimeter. For this purpose no special apparatus is required but as will appear, good results are possible only if sufficiently comprehensive data are available. The latter can be gathered in the course of a large number of flights.

The N.L.L. chose the latter method, which has the advantage that it can be conveniently carried out while the reliability of the results can always be improved through systematic extension of the data. In this manner, difficulties which are bound up with the construction of specially suitable apparatus, are also avoided.

The required measurements were made by the N.L.L. during performance tests on various aircraft. In these tests the temperature is always determined with a distance thermometer of the NZI type or NZII type (usually the former), so that sufficient data can be gathered.

3. The method employed by the N.L.L. will be further explained in what follows. During performance measurements horizontal flights are carried out at various constant speeds; for example, to determine the relation between the velocity and the rotational speed. When such a series of flights is carried out in an isothermal layer of the atmosphere, the thermometer readings - provided care is taken during the flights that these readings are recorded after they have become steady - can be used for the required purpose. It is then always possible, from the relation existing between speed, altitude, and thermometer reading, to establish the applicability of the assumed correction formula (8) and also the value of the constant.

Since it is not possible during the test to check whether or not the aircraft remains in an isothermal layer - this will be the case only under very favorable atmospheric conditions - all measurements must subsequently be sorted according to the following criterion:

The readings obtained during flights at equal altitude with different constant dynamic speeds, show a regular increase at large dynamic pressures. When a series of at least three observations satisfy this criterion, it may be assumed that the flight under consideration is, at least approximately, carried out under the desired conditions.

In this connection, it is of interest to point out that, since the flights were conducted on various aircraft, small deviations may arise as a result of varying location of the thermometer on the airplane, even though as favorable location as possible is always chosen. (See also I, 5.)

IV. ANALYSIS OF THE RESULTS

The data contained in the unpublished reports (V.660, V.718, V.771, and V.1051) include a series of observations which satisfy the above criterion (III,3). These data are taken over and worked up in the table at the end of this report. Figure 2 gives the corresponding curves. All observations are carried out with the thermometer type NZI except the last two series taken from report V.1051, which were obtained with a thermometer type NZII.

From the above-mentioned curves, which give the thermometer readings as a function of the dynamic pressure, $(d\theta_a/dq)_H$ is obtained. From (8),

$$\left(\frac{d\theta_a}{dq}\right)_H = c \frac{\rho_o}{\rho_H}$$

The table below gives the results:

Report	Dynamic pressure in mm of water	Altitude in SA*		Values of $\left(\frac{d\theta_a}{dq}\right)_H = c \frac{\rho_o}{\rho_H}$	
		pressure	density		
V.660	295-595	380	375	0.0083	Thermometer NZI
V.718	130-325	1670	1690	.0096	
V.771-I	150-260	5070	5040	.0135	
V.771-II	95-320	3590	3550	.0145	
V.771-IV	95-230	5070	5040	.0143	
V.771-V	95-305	3620	3570	.0123	
V.771-VI	95-315	2590	2430	.0105	
V.1051	150-600	3200	-	0.00965	Thermometer NZII
V.1051	250-600	1000	-	,00675	

*SA = standard atmosphere.

The curves on figure 2b give the values of $(d\theta_a/dq)_H$ as a function of the altitude. There is also shown the curve which is obtained by substituting in (8) for c the value 0.008 °C m²/kg or $c_1 = 0.5\ 10^{-3}$ °C s²/m².

The seven points experimentally found for the NZI thermometer, with the exception of one, appear to fit the curve with small scatter. The value $c = 0.010\ ^{\circ}C\ m^2/kg$ (III,1) obtained from the tunnel tests, is somewhat larger. These measurements, however, were all made at smaller speeds (up to 30 m/s).

Although it is still very desirable to extend the available experimental data, the conclusion may be drawn from the above results that the correction formula to be applied to the thermometer readings - at least, for a thermometer of this type - may, in fact, with good approximation be of the form (8). For this thermometer (type NZI), $c = 0.008\ ^{\circ}C\ m^2/kg$, or $c_1 = 0.5\ 10^{-3}\ ^{\circ}C\ s^2/m^2$. The correction agrees approximately with that theoretically determined for the stagnation-point thermometer.

The two points found for the thermometer NZII are naturally not sufficient for basing any conclusions. It appears probable, however, that the value of the correction constant of this thermometer must be chosen smaller; for example, $c = 0.0065^{\circ}\ C\ m^2/kg$.

The accuracy of the results as already observed, on account of the many possible disturbances and sources of error, is closely connected with the number of suitable measurement results. With the method described, however, good accuracy is attainable as appears from the cases considered above.

V. SUMMARY

A method is described for checking a correction formula, based partly on theoretical considerations, for adiabatic compression and friction in flight tests and determining the value of the constant. The formula is:

$$\Delta\ \theta_a = -\ c\ \frac{\rho_o}{\rho}\ q$$

where, for a thermometer of the type NZI

$$c = 0.008\ \frac{^{\circ}C\ m^2}{kg}$$

For practical application, the formula can also be written:

$$\Delta\ \theta_a = -\ 3.86 \times 10^{-5}\ \frac{\rho_o}{\rho}\ v_q^2$$

where v_q is the dynamic velocity in km/h.

Some values obtained are given in the table below.

	Correction in °C			
Dynamic velocity, km/h	100	200	300	400
Altitude: 0 m	-0.39	-1.54	-3.48	-6.17
" 3000 m	-.52	-2.08	-4.68	-8.32
" 6000 m	-.72	-2.87	-6.45	-11.5
" 9000 m	-1.01	-4.06	-9.12	-16.2

For good accuracy, comprehensive observation data are necessary. The results obtained appear reliable.

VI. APPENDIX

Time Lag of a Thermometer

The thermometer reading θ_a gives the averaged mercury temperature. If the temperature of the surroundings (θ) differs from the above, the reading changes. To a first approximation it may be assumed that the change in the reading per unit time is proportional to the instantaneous temperature difference:

$$\frac{d\theta_a}{dt} = k\ (\theta - \theta_a)$$

or

$$\Delta\ \theta = \frac{1}{k}\ \frac{d\theta_a}{dt}$$

The value of k must also depend on the speed of the air flow in which the thermometer is placed, especially at small flow velocities. The correction constant $k' = 1/k$ can also be obtained from observations during flight tests. For this purpose, there is first determined by level flights the temperature distribution in the atmosphere. Again, the requirement of extremely uniform temperature distribution must be met, so that the level flights take place in an isothermal layer, and the time-lag error can thus be eliminated. These level flights are then followed by diving or climbing flights. From the relations between time, altitude, and thermometer reading, the value of the correction constant can be found since the change of temperature with altitude is known.

It is desirable to carry out all the flights with the same velocity, so as to exclude the corrections for adiabatic compression and friction from the computation. Only if this correction is accurately known, may this rule be considered superfluous.

The investigation on this subject has not been completed and will be continued with the object of publishing more detailed data. The not accurately known dependence of k' on the speed, and hence also on the location at which the thermometer is mounted, are disturbing factors for this investigation.

REFERENCES

1. Reports of the N.L.L.:

A.322 - De aanwijzing van thermometers in bewegende lucht I (2-4-32). Gepubliceerd in De Ingenieur 29-12-32, no. 45.

A.479 - De aanwijzing van thermometers in bewegende lucht II (20-4-34). (Unpublished)

A.484 - De aanwijzing van thermometers in bewegende lucht III (16-4-34). (Unpublished)

V.675 - Vliegproeven betreffende de aanwijzing van afstandsthermometers (13-3-34). (Unpublished)

2. Pohlhausen, E.: Der Wärmeaustausch zwischen festen Körpern und Flüssigkeiten. Z.f.a.M.M., Bd. I, 1921, S. 115.

3. Brun, Edmond: Phénomenès thermiques provoqués par le déplacement relatif d'un solide dans un fluide. Publications scientifiques et techniques du Ministère de l'Air, no. 63, 1935; and no. 112, 1937.

Translation by S. Reiss,
National Advisory Committee
for Aeronautics.

Data and Analysis of Results of Level Flights for the Determination of the Temperature Correction on the Thermometer Reading

Dynamic velocity Vq in km/h	Dynamic pressure q in mm H_2O	Standard altitude in m	Temperature θ_a in °C[a]	Temperature for H = 380 m[b]	$\left(\frac{d\theta_a}{dq}\right)_H$ taken from figure 2	Remarks
300	433	370	5.8	5.7		
298	428	400	5.3	5.4		
321	497	350	5.9	5.6		Airplane 1
350	591	425	6.2	6.5		
321	497	350	6.0	5.8		
320	493	410	5.8	6.0	0.0083	11-24-33
280	378	375	5.1	5.1		
258	321	390	5.0	5.0		Thermometer
244	287	385	4.0	4.0		NZI
207	208	350	3.8	3.6		
293	414	380	5.2	5.2		
259	324	1670	+8.2	-		Airplane 2
237	271	1670	+7.7	-		
217[b]	228	1675	+7.3		0.0096	10-1-34
188[b]	172	1670	+6.8	-		Thermometer
167[b]	136	1670	+6.3	-		NZI
231	258	5075	-15.8	-		Airplane 3
205	203	5070	-16.5	-	0.0135	
178	153	5080	-17.3	-	Flight I	4-26-35
140 142	94.5 97.5	3595	-8.5	-		
174	146	3590	-8.1 -7.8	-		
234	264	3595	-6.0	-	0.0145	Thermometer NZI
256.5 255.5	318 315	3585	-5.0	-	Flight II	
140	94.5	5080	-17.8	-		
160	124	5075	-17.3	-		
178 179	153 155	5075	-16.9		0.0143	Airplane 3
219	231	5070	-15.8	-	Flight IV	

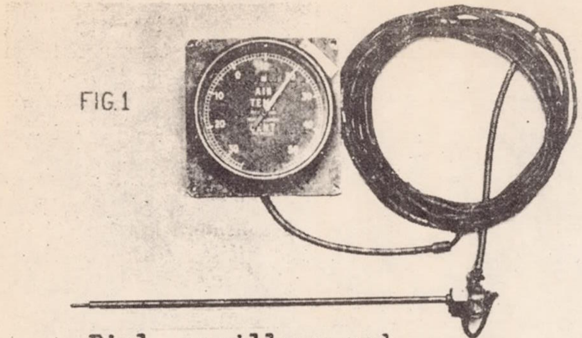
For a and b, see footnotes, p. 17.

Data and Analysis of Results of Level Flights for the Determination of the Temperature Correction on the Thermometer Reading (Continued)

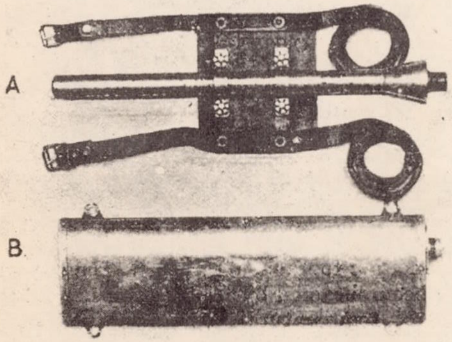
Dynamic velocity Vq in km/h	Dynamic pressure q in mm H_2O	Standard altitude in m	Temperature θ_a in °C[a]	Temperature for H = 380 m[b]	$\left(\frac{d\theta_a}{dq}\right)_H$ taken from figure 2	Remarks
140	94[b]	3605	-8.9	-		
164[b]	131	3625	-8.0	-	0.0125	5-2-35
195[b]	184	3605	-7.8	-		Thermometer
250	304	3635	-6.8	-	Flight V	NZI
142	97[b]	2590	-4.8	-		
179	155	2590	-4.3	-		
217[b]	229	2560	-3.3	-	0.0105	
239[b]	278	2590	-3.1	-		
254[b]	313	2540	-2.7	-	Flight VI	
353	600	3210	-7.6	-		Airplane 4
320	492[b]	3210	-9.0	-		
301[b]	438	3200	-9.0	-		
264[b]	337	3185	-9.9	-	0.00965	1-19-38
246	291[b]	3215	-10.9			Thermometer
221[b]	236[b]	3215	-11.5			NZII
178[b]	153	3205	-12.2			
356	610	1005	3.5	-		
336[b]	545	1000	3.0	-		
307[b]	455	1000	2.4	-	0.00675	
260[b]	327	995	1.5[b]	-		
228	250[b]	970	.9			

[a]Corrected for instrumental error.

[b]Only measurements of 11-24-33 were corrected to the same altitude. For the other measurements this was not necessary, since they were carried out at approximately equal altitude. In this correction, it is assumed $\frac{d\theta}{dH} = -0.0065$.



Dial, capillary and mercury bulb.



Sun shields.

Figure 1.- Distance thermometer.

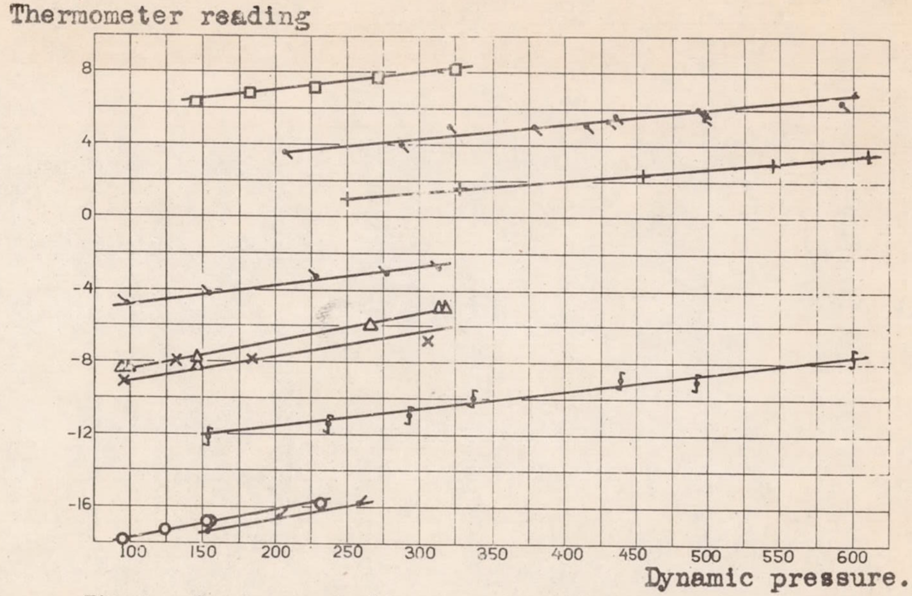


Fig. 2a. Instrumentally corrected thermometer reading as function of dynamic pressure.

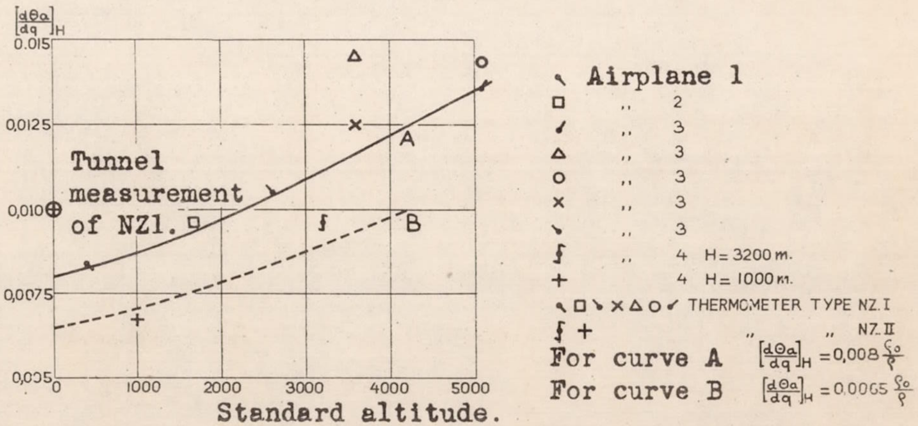


Fig. 2b. $\left|\frac{d\,\theta a}{dq}\right|_H$ as function of altitude in standard atmosphere.