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# TRANSLATION

## MEASUREMENT OF BASE PRESSURE IN FREE FLIGHT

By

G. I. Mishin

## FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

WRIGHT-PATTERSON AIR FORCE BASE

OHIO

# UNEDITED ROUGH DRAFT TRANSLATION

## MEASUREMENT OF BASE PRESSURE IN FREE FLIGHT

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English Pages: 7

SOURCE: Izvestiya AN SSSR. Otdeleniye Tekhnicheskikh Nauk. Mekhanika i Mashinostroyeniye (Russian), Nr. 6, 1963, pp 116-118

S/0179-063-000-006

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Date 18 Sept. 19 64

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# MEASUREMENT OF BASE PRESSURE IN FREE FLIGHT

G. I. Mishin

In addition to experiments in wind tunnels the measurement of base pressure is of great interest.

The dependence of base pressure on the Mach number M on cylindrical bodies having the front section in the shape of a hemisphere in the range of M numbers from 1.32 to 2.91 and on the Reynolds number $R_L$ (varying proportionally to the velocity) from $0.9 \cdot 10^6$ to $2.0 \cdot 10^6$ was investigated on a modernized ballistic unit [1]. The experiments were carried out with respect to a method using the deflection of a rubber diaphragm placed in the bottom of the model and sealing off a small cavity filled with air at 1 atm and the temperature of the ambient medium. Figure 1 shows the dimensions and design of the model. The thin, elastic, rubber diaphragm 1 was fastened under little tension to the outer side of the inner cylinder by glue and tape 2.

Preceding the experiments, the models were fastened to a special holder and placed in a vacuum chamber for calibration. Calibration amounts to photographing the deflection contour of the diaphragm d, at first for a sequential pressure reduction in the chamber p, and then in the reverse direction for a recovery of pressure to atmospheric pressure $p_\infty$, and of the last deflection measurements on comparator IZA-2. To increase calibration accuracy, the millimeter scale, by which the photography scale was controlled, was photographed simultaneously with the model. Such calibration in forward and reverse directions enabled us to establish the absence of the "fatigue" phenomenon of rubber during expansion and leakage of air from the cavity. If "fatigue" occurs, the points corresponding to the reverse course would be located lower than those corresponding to a forward course, and an opposite picture would be observed during air leakage from the cavity, while the difference should increase according to the approach of the chamber pressure to the atmosphere. Thus, as a result of calibration we obtained the dependence of rubber deflection on the difference of atmospheric pressure $p_\infty$ and chamber pressure $\underline{p}$ (hence, in the base section of the model).

$$\Delta p = p_\infty - p. \tag{1}$$

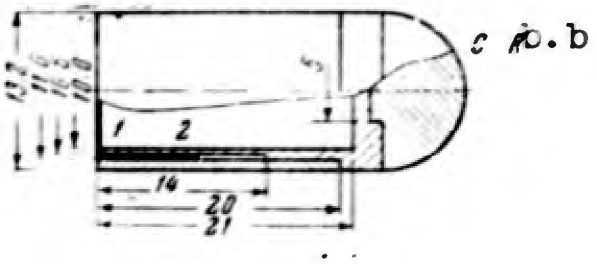

Fig.1

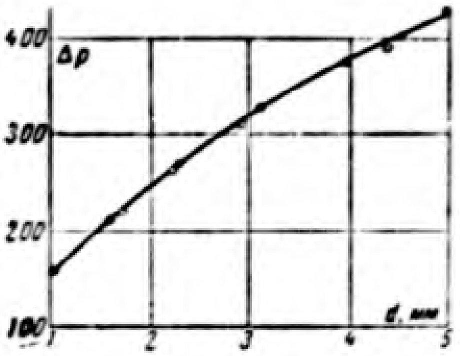

Fig.2

As an example, one of the calibration curves is shown in Fig.2, where the light points correspond to a pressure increase and the dark to a pressure decrease (here the pressure value, as throughout the article, is given in mm Hg.)

Systematic measurements showed that during rubber deflection less than the radius of the diaphram the "fatigue" phenomenon did not appear, the diaphragm assumed the form of a spherical segment. The latter case enables us to easily calculate the volume increase depending on the magnitude of diaphragm deflection and to correct the measured magnitude of deflection owing to the angle of attack.

During adiabatic gas expansion corresponding to the maximum permissible diaphragm deflection of approximately 5 mm (for the given model dimensions), gas heating should occur at the rate of ~ 10 deg$\cdot$ sec$^{-1}$. On this basis we can assume that calibration was conducted under conditions essentially fulfilling the isothermic process. The experiment lasted approximately 0.01 sec., therefore gas expansion in the working volume was assumed close to the adiabatic. With smaller diaphragm deflections this becomes even more correct. Thus, the difference between atmospheric pressure and base pressure

$$\Delta p^{0} = p_{\infty} - p^{0}, \tag{2}$$

which is the original intent, is the sum of the value $\Delta p$ (which corresponds to the given diaphragm deflection) and correction $\delta p$

$$\Delta p^{0} = \Delta p + \delta p . \tag{3}$$

If we designate the volume increase owing to deflection by $\Delta V$, then the correction for the difference of theromdynamic processes occuring during calibration and in the experiment can be calculated by the formula

$$\delta p = p_{\infty}\left[\frac{1}{1+\Delta V/V} - \frac{1}{(1+\Delta V/V)^{\gamma}}\right] \tag{4}$$

where V is the original volume; $\gamma$ is the relationship of specific heats. When filling the cavity with air, for which $\gamma = 1.4$, and taking into account that under the conditions of these experiments the relationship $\Delta V/V$ is small, Expression (4) was reduced to a more convenient expression for the calculations

$$\delta p = p_\infty \frac{1}{1+\Delta V/V}\left[0.4\,\frac{\Delta V}{V} - 0.28\left(\frac{\Delta V}{V}\right)^2 + 0.224\left(\frac{\Delta V}{V}\right)^3\right]. \qquad (5)$$

The correction value was about 8% of the value of pressure difference being measured; Fig. 3 shows the correction curve corresponding to $p_\infty = 760$ mm Hg. This curve was used practically in the entire range of possible change of the value of atmospheric pressure.

In the experiments we obtained a series of shadow photographs of the model along the trajectory in two mutually perpendicular planes, as a result of which we were able to determine the angles of attack. The first station of photography was located 2.5 m from the edge of the tube. In the photographs (in Fig. 4 M = 2.09) the shock waves and flow configurations are clearly visible in the base section. In order to eliminate additional errors, we measured the diaphragm deflection directly with respect to the negatives to within approximately ± 0.1 mm, which yields an error of ± 3% with a 3-mm deflection.

If the model traces with zero angle of attack, then the measurement of the diaphragm deflection by series photography indicates only a slight decrease of its value owing to a base pressure increase, which is due to an insignificant drop of the flight velocity. In the presence of even small oscillations during motion of the model there was a dependence of the value of the diaphragm deflection on the angle of attack, i. e., diaphragm tension was able to follow a rather rapid change of the base pressure. In experiments with near Mach numbers but with different amplitudes of angles of attack the values of the base pressure calculated with respect to the diaphragm deflection, which corresponded to zero angle of attack, practically coincided. This enabled us to assume that the relaxation and thermal processes during diaphragm tension in these experiments are negligibly small.

Since the diaphragm occupied only a section of the "stagnation" zone far from the "squeezed" flow region, then, as the experiment using holders in the wind tunnel indicates, it was not able to introduce noticeable distortions into the flow beyond the base of the model, which also was controlled by the measurements of streamline geometry.

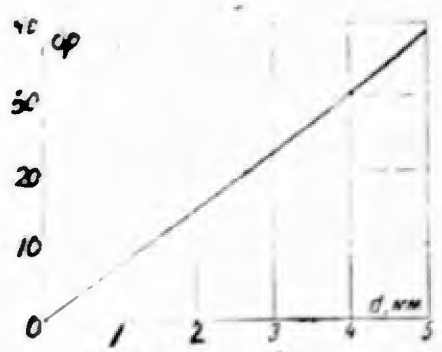

Figure 3.

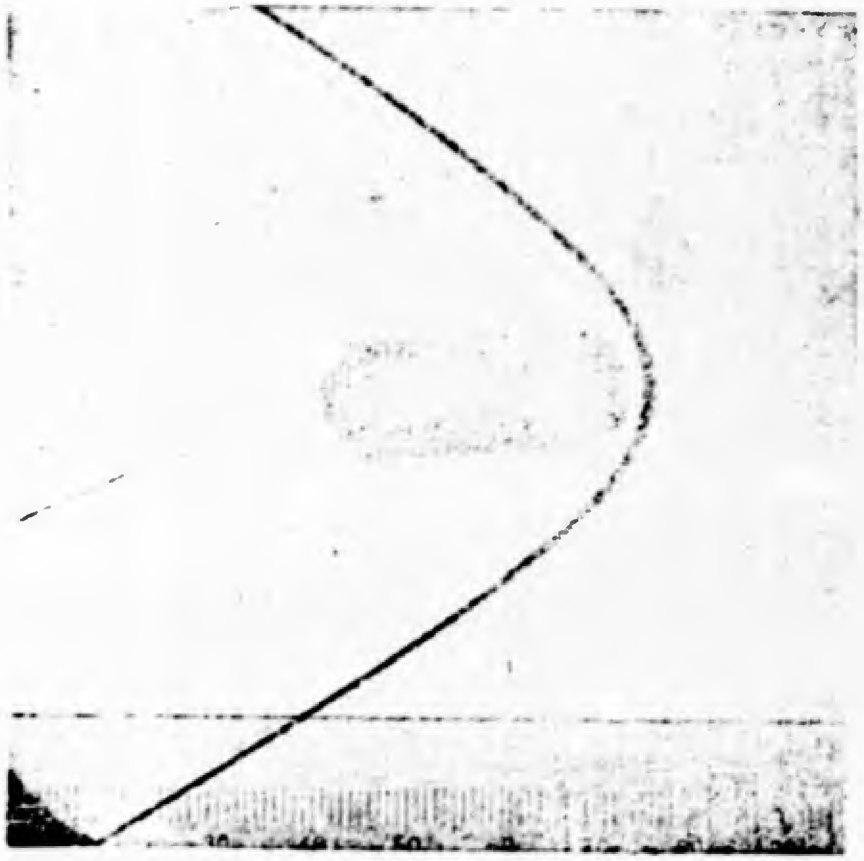

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Figure 4.

The data of each series were interpreted by the method of least squares, taking into the angle of attack into account

$$\Delta p^{\circ} = W_c + W_{\vartheta}^{=}\vartheta \qquad (6)$$

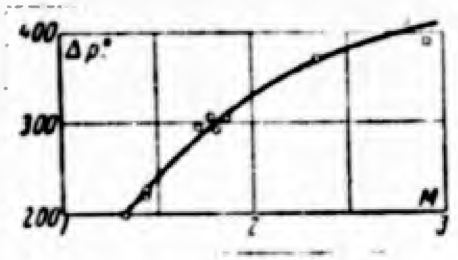

Fig. 5

Up to angles of attack of ~ $15^\circ$, the value of W$ in the investigated range of Mach number M was equal, on the average, to 8 mm Hg/deg. Under large angles of attack we observed a change of the streamline geometry of the model: breakaway occurred not from the base of the model, but from a lateral face. This was accompanied by a sharp base pressure increase as compared to a continuous streamline.

The results of the experiments corresponding to the zero angle of attack ($\Delta p^\circ = W_0$), are shown in Fig. 5.

Knowing $\Delta p^0$, it is not difficult to calculate the coefficient of base resistance $C_\chi^0$ which by definition is equal to

$$C_x^0 = \frac{\Delta p^\circ}{{}^1/_2 \rho u^2} \qquad (7)$$

Here p is gas density; u is the momentum of the model. The values of $C_\chi^0$ obtained by Formula (7) are designated by the points in Fig. 6. The broken curve corresponds to the calculation assuming that there is a constant pressure in the base region of the model equal to one-half of the atmospheric pressure, irrespective of the model velocity

$$C_\chi^0 = 1/\gamma M^2 \qquad (8)$$

The maximum deviation for the average curves $\Delta p^\circ$ (M) and $C_\chi^0$ (M) is approximately 3%. When estimating the accuracy of measurement results it follows to take into account that in each separate experiment the series of photographs was interpreted, each of which was measured with an error of ± 3% which lead to a substantial reduction of the error of determining $\Delta p^{o}$. The values p and u in these experiments were recorded with high accuracy, therefore, the measurement errors of $\Delta p^{o}$ and $C_x^{o}$ were approximately the same.

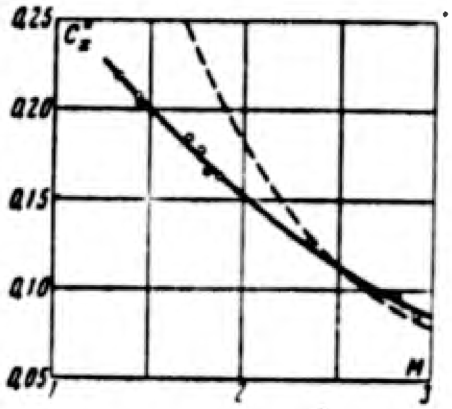

Fig. 6

Preliminary estimates enabled us to conclude that this measurement method will obviously be rather sensitive for the investigation of the effect of the relationship of specific heats on the coefficient of base resistance.

In conclusion, I would like to thank Yu. A Dunayev for his interest in the work and useful comments, and also B. A. Mosiyenko, L. A. Pchelovodov, A. A. Sokolov, and V. Yurevich, who took part in the experiments.

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