TECHNICAL MEMORANDUMS

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EFFECT OF VISCOSITY IN SPEED MEASUREMENTS WITH DOUBLE-THROAT VENTURI TUBES*

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The present experiments are an extension of the investigations which were published in 1929.** That publication, however, did not embrace the question of viscosity effect. In order to clarify this effect some experiments were made in the Göttingen low-pressure tunnel with the same Bruhn double-throat Venturi tube (fig. 1), which was used in the preceding experiments. This type of tunnel makes it possible to vary the pressure and thereby the density within wide limits and consequently, to examine the viscosity effect. Unfortunately, the lack of automatic control of pressure and temperature made it impossible to maintain the density ρ constant in the test section. This, however, did not impair the results because pressure and temperature were determined at different periods. It merely has a slightly disturbing effect on the clearness of the representation when the direct test points are considered.

Multiplication factor K.- If p_a is the pressure, v_a the speed, and ρ_a the density in the test section of the wind tunnel (in the outside space, respectively), and p_i, v_i, and ρ_i represent the corresponding quantities in the test section of the multi-throat Venturi, we have

$$p_a - p_i = K \frac{\rho_a}{2} v_a^2.$$

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*"Einfluss der Zähigkeit bei Geschwindigkeitsmessungen mit Staudruckmultiplikatoren. (Bruhnsche Venturi-Doppeldüse.)" From Zeitschrift für Flugtechnik und Motorluftschiffahrt, June 15, 1931, pp. 321-323, published by R. Oldenbourg, Munich and Berlin.

**H. Peters, "Über den Gültigkeitsbereich der Staudruckmessung mit Staudruckmultiplikatoren," Zeitschrift für Flugtechnik und Motorluftschiffahrt, Feb. 28, 1929.

Factor K is directly affected by the shape and performance of the instrument. Moreover, an effect of the Reynolds Number $R = \frac{v\,d\,\rho}{\mu}$, that is, of the viscosity $\frac{\rho}{\mu} = f\,(p,t)$ and the ratio $\frac{v}{a}$ (a = velocity of sound) is to be expected. The characteristic cross section of the double-throat Venturi is its narrowest section, hence it is quite natural to refer the Reynolds Number to this section.

$$R = \frac{v_i\,d_i\,\rho_i}{\mu}$$

Hereby it is profitable to choose the dynamic viscosity μ conformably to the temperature in the wind stream, i.e., in outer space. Now it is seen that in this Venturi tube the factor K as function of R is independent of the ratio $\frac{v}{a}$ up to a point where the velocity of sound in the narrowest section, that is, $v_i = a$, is reached. This independence becomes readily apparent in Figure 2, which renders the measured K values as function of R. Upon attaining the velocity of sound in the narrowest section, the passing mass, that is, $v_i\,\rho_i$, remains constant according to the dynamics of gases. Consequently, the Reynolds Number no longer changes in spite of the rise in speed v.

But for practical purposes the dependence of factor K on the pressure difference $p_a - p_i$ is of primary interest, and for that reason the dependence $K = f\,(p_a - p_i)$ must be reduced from $K = f\,(R)$ and pressure p_a and temperature t be introduced as parameter. Figure 3 shows $K = f\,(p_a - p_i)$ for various pressures p_a (in kg/m²) and for temperatures $t = -40°$, $0°$, and $+40°C$.

The indicating instruments record for the greater part a speed $v = \sqrt{\frac{2}{\rho}\,\frac{p_a - p_i}{K}}$. Now if it be assumed that the setting of these instruments be such as to indicate correctly the speed v_o at a stated pressure p_o and temperature t_o, it would, at other pressures and temperatures, entail corrections of the order of

$$\frac{v_o}{v_o} = \sqrt{\frac{p_o}{p}\,\frac{T}{T_o}\,\frac{K_o}{K}}$$

T = absolute temperature. K_o and K are to be taken by equal pressure difference $p_a - p_i$ and conformably to p_o and t, and p and t, respectively. For example, at 8000 m, which is equivalent to a pressure $p \approx 3000$ kg/m² and a temperature $t \approx -40^\circ$, the instrument indicates a speed 80% too low, if at sea level it indicates correctly at $p_o = 10,000$ kg/m² and $t_o = 0^\circ$. But the Bruhn type tube does not enter into the question as navigation instrument; it merely serves to check the flight position. Hence it would be more appropriate to record the dynamic pressure $q = \frac{\rho}{2} v^2 = \frac{p_a - p_i}{K}$ rather than the speed. If the indicating instrument is likewise designed to yield a correct record of the dynamic pressure q_o at pressure p_o and temperature t_o, the correction to be effected for arbitrary pressures and arbitrary temperatures, is of the order of

$$\frac{q}{q_o} = \frac{K_o}{K}.$$

Thus, Figure 4 affords, for illustration, $\frac{q}{q_o} = f(q_o)$ for temperature $t = 0$ and various pressures p, where it was assumed that q_o is correctly indicated at $p_o = 10,000$ kg/m² and $t_o = 0^\circ$. It will be observed that $\frac{q}{q_o}$ is unaffected by q_o within the limits of exact measurement and interpretation, so that

$$\frac{q}{q_o} = f\ (p, t)$$

may be assumed. Figure 5 shows $\frac{q}{q_o} = f\ (p)$ at temperatures $t = -40^\circ$, 0°, and $+40^\circ$ which, applied to the same example as above, means that the instrument records the dynamic pressure 15% too low.

<u>Range of validity</u>.- In the previously published report it was shown that the pressure difference $p_a - p_i$ remained practically constant even by further rise in speed as soon as the velocity of sound in the narrowest section had been reached, thus making it impossible to determine the dynamic pressure from the pressure difference. The maximum dynamic pressure, still recorded, is computed at

$$q_{max} = \frac{1 - \lambda}{K} p_a,$$

where

$$\lambda = \left(\frac{p_i}{p_a}\right)_{crit} = \left(\frac{2}{\kappa + 1}\right)^{\frac{\kappa}{\kappa-1}} \left(1 + \frac{v_a^2}{2}\frac{\rho_a}{}\frac{1}{p_a}\frac{\kappa - 1}{\kappa}\right)^{\frac{\kappa}{\kappa-1}}$$ is

the critical pressure ratio.

Satisfactory agreement with these figures may be expected when the test section and the narrowest section coincide. But the test section of the investigated double-throat Venturi was slightly to the rear of the narrowest section and already in the enlarged section. The result is a higher pressure than in the narrowest section if the speed in the latter is below sound velocity (diffuser effect); but upon reaching sound velocity, further expansion in the section enlargement is possible, and the pressure in the test section may consequently become lower. However, this second expansion cannot continue indefinitely, because the pressure in the exit section of the diffuser is always higher than in the narrowest section. The result is a pressure shock in the diffuser. This shock may be straight or oblique and may, according to the dynamics of gases, travel from place to place, affected by the pressure in the exit section of the diffuser, by the boundary layer and the slightest changes in diffuser shape and surface conditions. This makes the reproducibility of the pressure shock on the same place very problematical even for the same nozzle. The pressure p_i in the test section now depends on the point at which the pressure shock occurs. Figure 6 shows the results of measuring $\frac{p_a - p_i}{p_a} = f(v_a)$ in the range of critical pressure ratio and the computed value $1 - \lambda = f(v_a)$ for the narrowest section. According to this it seems as if the pressure shock with respect to density ρ, or better, to the Reynolds Number roams over the test section, as if at large Reynolds Numbers the shock occurred back of the test section (hence, $\left(\frac{p_a - p_i}{p_a}\right)_{max} > 1 - \lambda$) and at small Reynolds Number in front of the test section directly aft of the narrowest section (hence, $\left(\frac{p_a - p_i}{p_a}\right)_{max} < 1 - \lambda$).

For practical purposes the working range is limited to

$$\left(\frac{p_a - p_i}{p_a}\right)_{max} \leqq 1 - \lambda \approx 0.45 \text{ to } 0.42$$

Figure 4 shows the limiting values for $1 - \lambda = 0.45$ and 0.42. Writing

$$q_{max} = (1 - \lambda) \frac{p_a}{K_o} \frac{K_o}{K} ,$$

$(1 - \lambda) \frac{p_a}{K_o}$ may be expressed as function of p_a (fig. 7), and from Figures 7 and 5, which donote $\frac{q}{q_o} = \frac{K_o}{K} = f(p_a)$, the maximum dynamic pressure q_{max}, still indicated by the multi-throat Venturi can be computed for different pressures and temperatures.

Translation by J. Vanier,
National Advisory Committee
for Aeronautics.

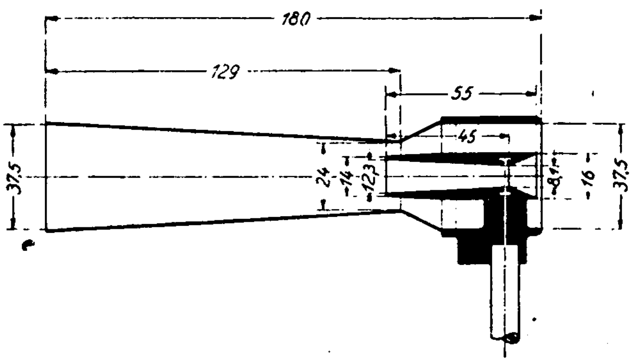

Fig.1,Bruhn double-throat venturi.

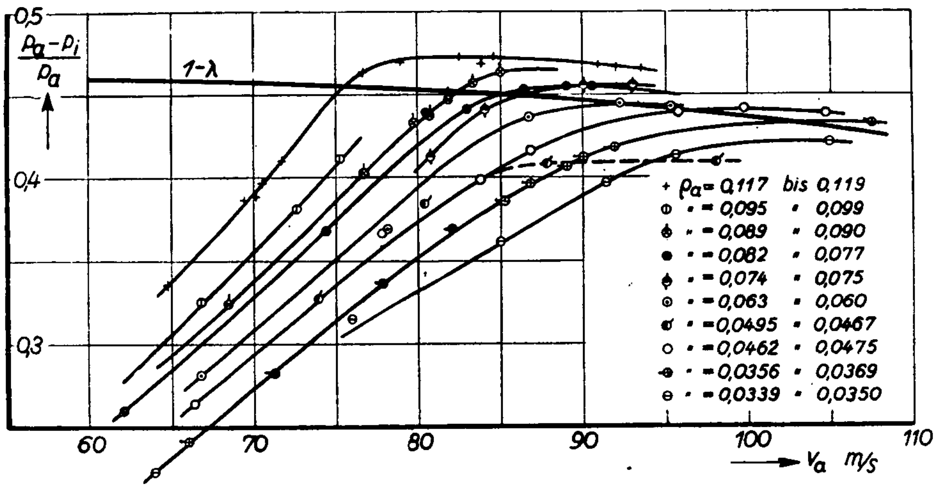

Fig. 6 Pressure difference with respect to the absolute pressure near the limit of validity plotted against speed v_a.

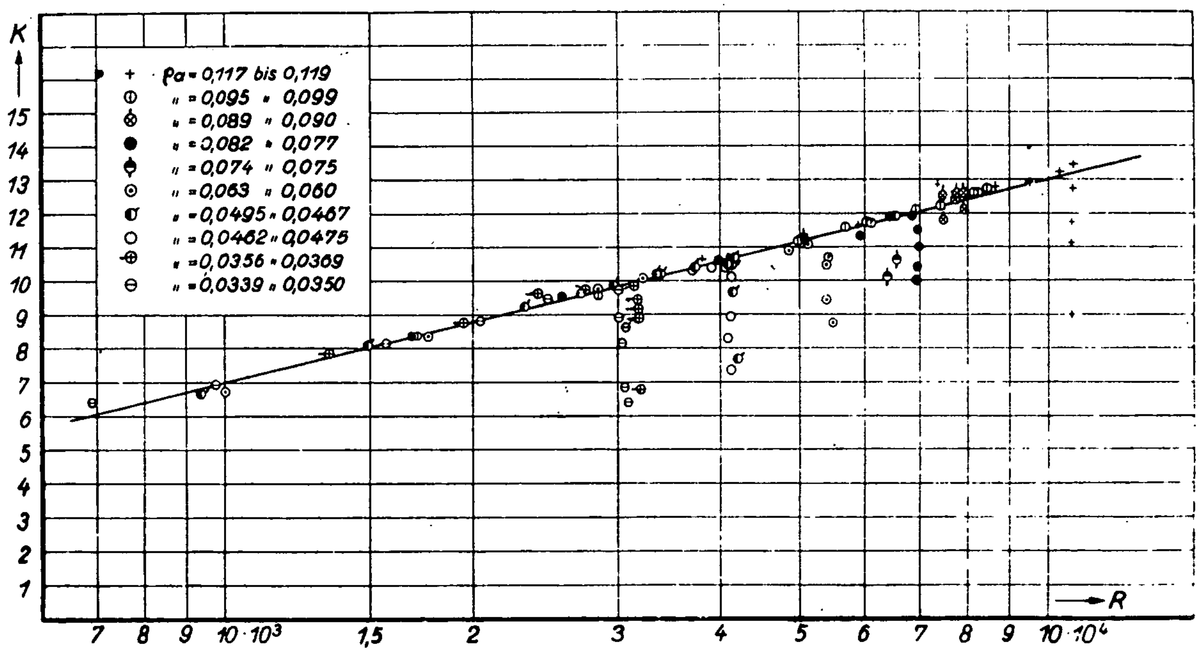

Fig. 2, Multiplication factor K as function of the Reynolds Number for different air densities.

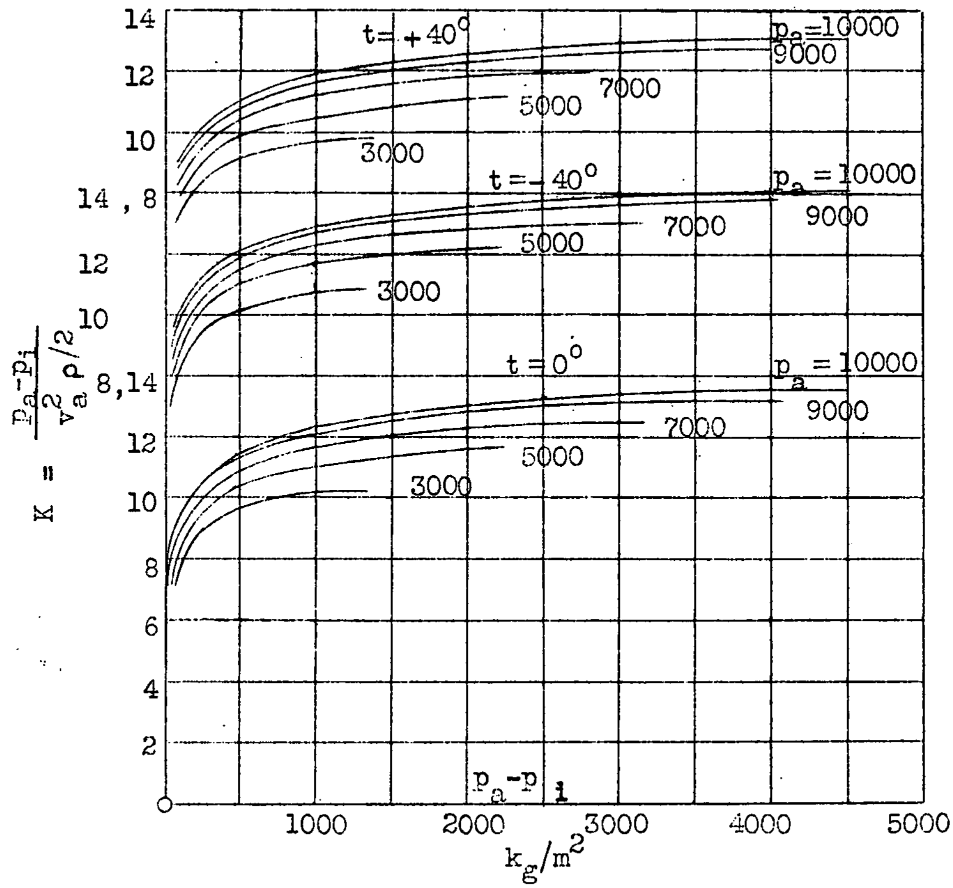

Fig.3, Multiplication factor K as function of the pressure difference for different pressures and temperatures.

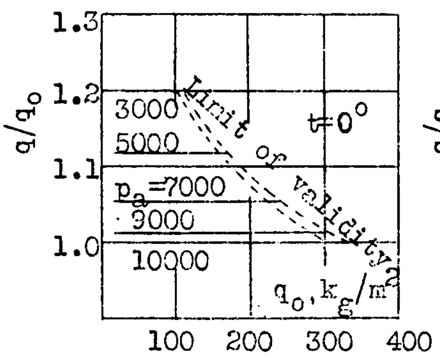

Fig.4, Amount of correction in q/q_o for different pressures.

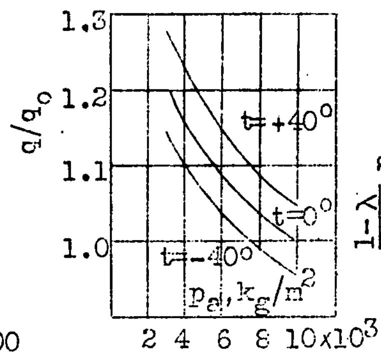

Fig.5, Amount of correction in q/q_o for different temperatures.

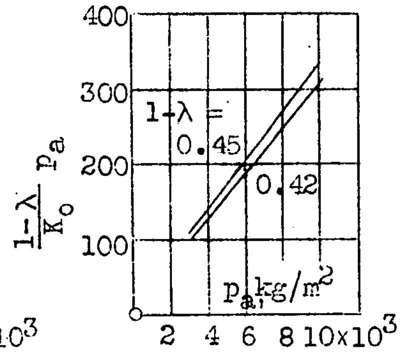

Fig.7, Limits of range of validity.