TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 953

PRESSURE AND TEMPERATURE MEASUREMENT IN SUPERCHARGER INVESTIGATIONS

By A. Franz

Jahrbuch 1938 der Deutschen Luftfahrtforschung

Washington
September 1940

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL MEMORANDUM NO. 953

PRESSURE AND TEMPERATURE MEASUREMENT IN SUPERCHARGER INVESTIGATIONS*

By A. Franz

With the further development of the supercharger, requirements with regard to measuring accuracy increase while at the same time the conditions under which the measurements must be carried out become more difficult. The present paper is a contribution toward the improvement and refinement of the measuring methods. For pressure measurements some suggestions are made with regard to design and location of the measuring stations. The question of temperature measurement in rapid air flow is discussed, new instruments for the direct measurement of the temperature in the rapid air stream are described and the results obtained with the various instruments presented.

The more nearly the attainable limits are reached in the development of the supercharger the higher become the requirements that must be satisfied by the measurement procedure. Since the improvements which can be obtained by any method and which must be determined accurately naturally become smaller. At the same time the conditions under which the measurements must be carried out become much less favorable, as, for example, in pressure and temperature measurements for which the rise in the flow velocities have considerably increased these difficulties.

In the investigation of superchargers it is necessary to measure pressures, temperatures, air quantities, moments, and rotational speeds. In a series of publications on measuring procedure, rules for acceptance tests, etc.; in particular the directions for performance tests on superchargers published by the DVL, the important viewpoints for carrying out these measurements and the measuring instruments used are given in detail.

---

*"Messtechnische Fragen bei Laderuntersuchungen." Jahrbuch 1938 der deutschen Luftfahrtforschung, pp. II 215-218.

I. PRESSURE MEASUREMENT

By following the specifications mentioned above with regard to power and air quantity measurements, reliable results can be obtained. With regard to pressure measurements I should like to emphasize in addition, particularly for the case of large flow velocities, the importance of very accurate boring and arrangement of the measuring orifices. It is best to use several smooth orifices of 1 to 3 mm diameter uniformly distributed. The orifices are connected with each other so that the mean pressure of the cross section is measured. Care should be taken to see that the pipe at the position connecting to any orifice is smooth inside and has no roughness. In pipes of thin sheet such roughness easily arises through the welding of the short pipe connections. It is therefore better to solder them on since even small roughnesses can lead to considerable measuring errors. At very large flow velocities it is recommended that the measuring orifices of a cross section before being connected together should be individually connected to a manometer and the pressure readings compared at fixed operating conditions so that bad orifices may be excluded.

Great importance also is naturally to be attached to the location of the measuring cross section. Curvatures of the pipes in the neighborhood of the measuring stations which may give rise to rotational motion should absolutely be avoided.

On the suction side the measuring stations should be located close to the entrance to the intake pipes. Care should be taken particularly to maintain a sufficient distance from the suction side throttle to the measuring section since with too small a distance not only the admission to the impeller becomes unfavorable but the measurement is also in error since there is a pressure rise behind such a throttle if it is not closed. Figure 1 shows the pressure variation behind a diaphragm. For normal diaphragms a distance from the measuring point of at least eight times the pipe diameter should be chosen. In this respect the cross type diaphragms of the DVL are particularly advantageous.

With regard to the location of the measuring station in the pressure pipe the following may be said. It is usual to locate this station directly behind the exit from the pressure pipe. It is questionable, however, whether this gives correct results for the supercharger.

Figure 2 shows schematically a test set-up. As indicated, the pressure variation was measured in the pressure pipe. Such measurements were carried out with various superchargers and spirals and it was found that in all those cases after exit from the spiral into the unwidened pipe a further rise in the pressure took place. Figure 3 shows, for example, the results of such a measurement carried out with various discharge rates. This pressure rise is evidently due to the fact that at the exit from the spiral there is still a very nonuniform velocity distribution so that the kinetic energy of the air at this position is greater than that corresponding to the mean velocity. On equalizing the velocities the kinetic energy of motion is then converted into pressure. In determining the delivery head there is always substituted the kinetic energy corresponding to the mean velocity. Actually, however, the large kinetic energy contributions at the exit of the blower exist and should be taken into account.

It appears that it would be more correct to locate the pressure measurement station in the pressure pipe away from the spiral exit at the point at which the conversion into pressure is completed so that at least the portion of the kinetic energy at the blower exit which is actually converted into pressure energy in a straight pipe is taken into account.

II. TEMPERATURE MEASUREMENT

Through the simple measurement of the air temperatures at the inlet and outlet of a supercharger the internal delivery head, that is, the power taken up by the supercharger impeller, and the internal efficiency are determined. Accurate measurement of the temperature is therefore of great importance. A disadvantageous circumstance is that these temperature measurements must be carried out in a relatively rapid air stream.

As is known, the temperature T' measured with any apparatus in a rapid gas flow is higher than the true temperature T in the undisturbed stream on account of the flow retardation and surface friction effects. It lies between the total temperature T_{tot} of the air brought to rest and the true temperature T. To obtain T_{tot} and T a correction must be applied to the results obtained with the measuring instruments thus far employed.

The difference between the total and the static temperatures, assuming adiabatic compression is

$$T_{tot} - T = \frac{C^2}{2\,g\,\frac{\kappa}{\kappa - 1}\,R} = \frac{C^2}{2000}$$

where the temperature difference is in °C and the velocity C of the air stream is in m/s. For the temperature indicated by a measuring instrument, we can, as is known, set

$$T' = T + \alpha \frac{C^2}{2000}$$

where α is a correction coefficient which is less than 1.

For its mercury thermometers the DVL has found for α the experimental value 0.85. We have similarly determined the correction coefficient for our thermometer.

The test set-up is shown on figure 4. The measurements were carried out in the suction pipe and pressure pipe of the supercharger. Set-up 1 in the suction pipe has the advantage that T_{tot} can be directly measured in the air at rest before the inlet to the suction pipe. There is obtained:

$$\alpha = 1 - \frac{2000}{C^2}\,(T_{tot} - T')$$

The velocity C at the measuring point was determined with the aid of the continuity equation for which purpose there was measured the discharge and the pressure at the measuring station.

With test set-up 2 for carrying out the measurements in the pressure pipe a narrow pipe was used that passed over into a wider pipe through a diffuser. The temperatures and pressures were measured in the narrow and the wide portions.

Figure 5 shows the values obtained lying at about α = 0.5 and thus considerably below that found by the DVL. Since the scattering was very strong a very large number of tests in the suction and pressure pipes were conducted. The values on the average, however, clustered always about

0.5. We also injected oil and found that the presence of an oil mist in the air does not affect the result.

The dimensions and shape of the thermometer may be seen from figure 5. The shape of the thermometer is certainly of great importance although I believe the DVL employed similar thermometers so that the difference between the results obtained is not quite explainable.

On account of the importance of obtaining a reliable temperature measurement and on account of the large number of erroneous measurements that frequently arose and led to quite wrong conclusions systematic tests had long since been undertaken in order to obtain better results possibly by some other way.

With the aim of measuring directly the temperature in the retarded air stream there was first developed the apparatus shown in figure 6. A thermocouple is built into a streamline body so that the soldered juncture lies at the flow stagnation point if the direction of the flow is from the left. The forward portion of the streamline body in which the thermocouple is located is constructed of as good heat-insulating material as possible so that the results might not be impaired by heat conduction since at a small distance from the stagnation point there are already relatively high velocities and hence low temperatures.

The results obtained with this apparatus are good. The correction coefficient α lies on the average between 0.8 and 0.9. The reliability of the measurement is not yet satisfactory, however, particularly with very turbulent flows. In such flows with high cross velocities considerably smaller values were sometimes measured and this may be explained by the displacement of the stagnation point.

In order to avoid this difficulty the free stagnation principle was discarded and a through-flow apparatus developed in which a portion of the flow is branched off and flows through the body of the measuring apparatus. Figure 7 shows the fundamental features of the instrument. By means of a diffuser the flow through it is slowed down to quite small velocities and the temperature measured at the position of minimum velocity. The flow is retarded to such an extent that approximately the total temperature is obtained. The apparatus is relatively insensitive to cross flow the effect being only to reduce the discharge without altering the principle in any way,(fig. 7).

Figure 8 shows the construction of such apparatus. The one on the left is provided with a thermometer and the one on the right with a thermocouple. Great importance must naturally be attached to good heat insulation, particularly in the region of the inlet opening and the diffuser. The thermocouple is located at the end of the diffuser at the stagnation point of a small body projecting toward the diffuser.

The results obtained with the above apparatus are shown in figures 9 and 10. Figure 9 gives the values of the correction coefficient α obtained with the through-flow apparatus with thermometer. The values lie at about $\alpha = 0.9$. With the newer apparatus provided with thermocouple there was even measured, as shown in figure 10, the accurate temperature T_{tot} of the stagnation condition, the correction coefficient α for this apparatus being equal to 1.

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

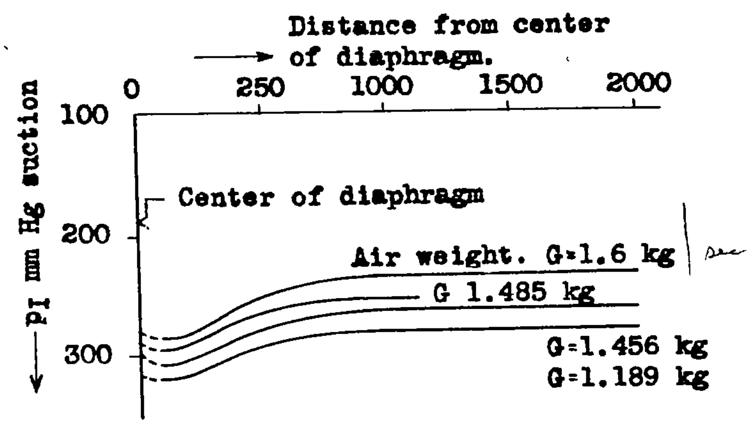


Figure 1.- Pressure variation behind diaphragm in suction pipe.

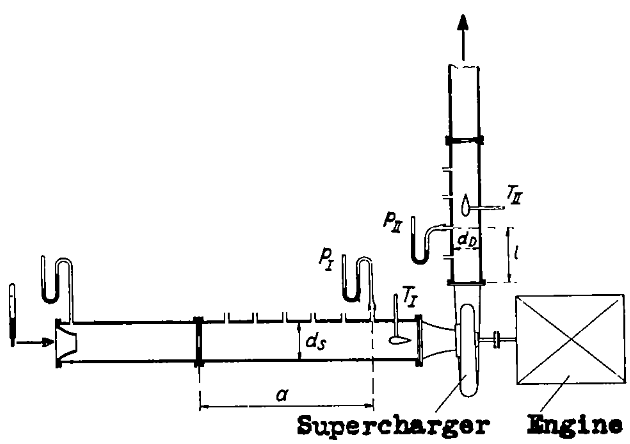


Figure 2.- Test set-up for the investigation of a supercharger.

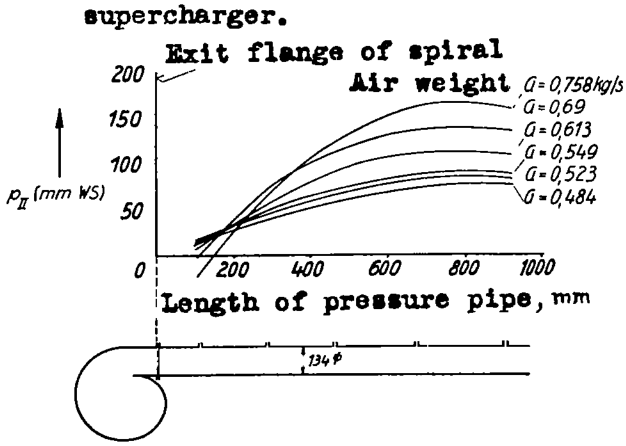


Figure 3.- Pressure variation in the pressure pipe.

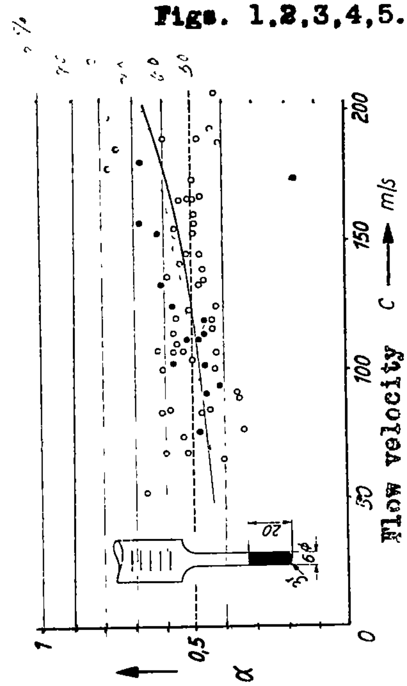


Figure 5.- Correction coefficient α for a mercury thermometer. $T' = T + \alpha \cdot C^2/2000$ for temperature measurement in a rapid air stream.

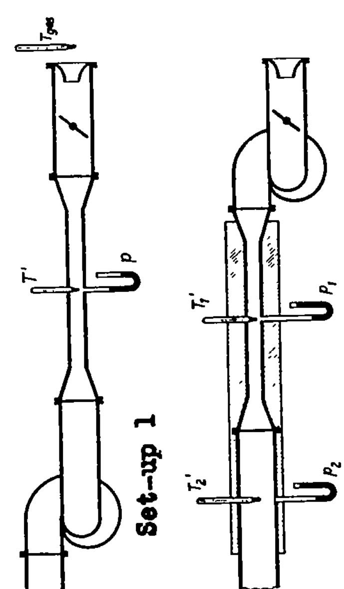


Figure 4.- Test set-up for the determination of the thermometer correction for the temperature measurement in a rapid air stream.

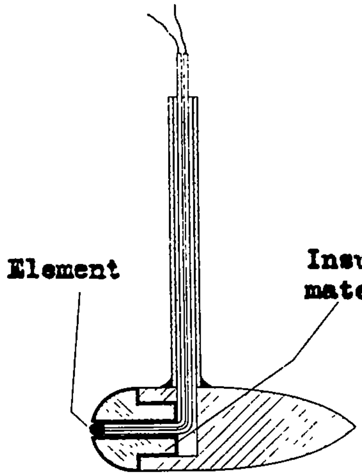


Figure 6.- Stagnation apparatus for temperature measurement.

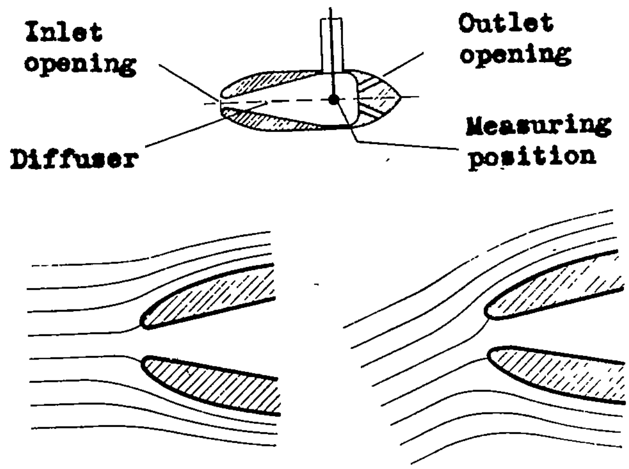


Figure 7.- Through-flow apparatus for temperature measurement in a rapid air stream.

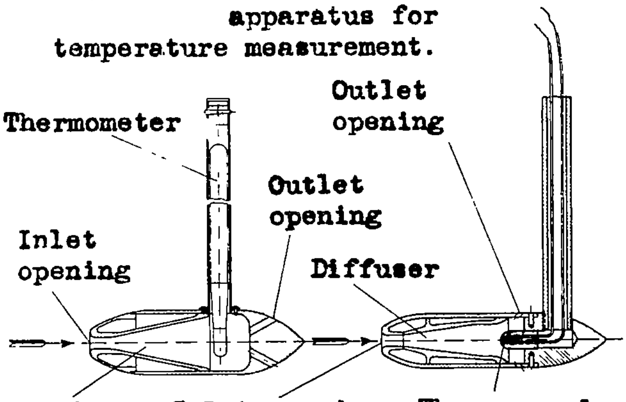


Figure 8.- Through-flow measuring apparatus for temperature measurement in rapid air stream.

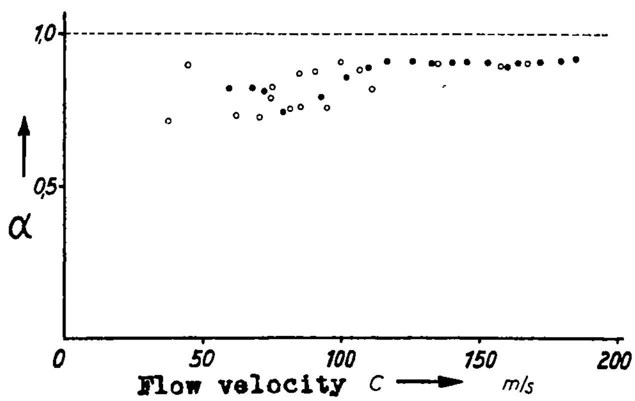
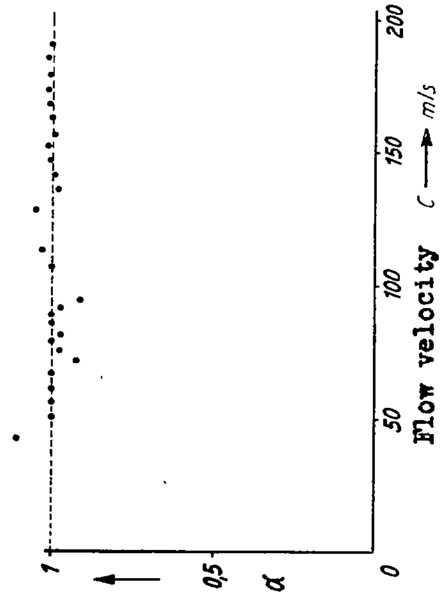


Figure 9.- Correction coefficient α for through-flow apparatus with thermometer for temperature measurement in a rapid air stream.

Figure 10.- Correction coefficient α for through-flow apparatus with ther~~mometer~~mocouple for temperature measurement in a rapid air stream.

See text



DO NOT REMOVE SLIP FROM MATERIAL

Delete your name from this slip when returning material to the library.

NAME	MS

NASA Langley (Rev. May 1988) RIAD N-75