# NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

## TECHNICAL MEMORANDUM 1327

CONCERNING THE FLOW ABOUT RING-SHAPED COWLINGS

PART VI - FURTHER MEASUREMENTS ON INLET DEVICES

By Dietrich Küchemann and Johanna Weber

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ABSTRACT:

The present report presents as a supplement to the fourth report
(FB 1236/4) in the series of investigations concerning the flow about
ring-shaped cowlings further wind-tunnel measurements on inlet devices
which are to show the influence of the radius of the nose of the cowling
on the flow conditions.  Moreover, a simple rule for the design of such
arrangements, containing a hub in the interior, is suggested.

OUTLINE:

I. PRELIMINARY REMARKS

The present report deals with further wind-tunnel measurements on
inlet devices as a supplement to reference 1 of a series concerning flow
about ring-shaped cowlings.  In the previous measurements a few problems
had remained open.  The influence of nose radius and nose form of the
cowling had not been treated in detail; it was to be investigated more
closely in a new test series.  The results of the new test series are
presented herein.  Furthermore, a simple method of design will be described
and examined.

All cowlings investigated before had the same radius of curvature
$\rho_N = 0.067 R_a$.[1]  Due to this small nose radius, minor local separation

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*"Über die Strömung an ringförmigen Verkleidungen.  VI. Mitteilung:
Weitere Messungen an Einlaufgeräten."  Zentrale für wissenschaftliches
Berichtswesen der Luftfahrtforschung des Generalluftzeugmeisters (ZWB)
Berlin-Adlershof, Forschungsbericht Nr. 1236/6, Göttingen, March 30, 1942.
    [1]The designations are the same as in reference 1.

phenomena had occurred at the inside of the inlet for several cowlings, particularly for static conditions. It was assumed that a larger nose radius would cause still smaller losses in the flow in the interior. Thus $\rho_N = 0.095R_a$ was chosen for the new cowling 5. For the sake of a better survey of the influence of nose radius and nose form, the nose part of cowling 5 was changed further (cowlings 6 and 7; compare fig. 10) so that the effect of smaller nose radii, $\rho_N = 0.040R_a$ and $\rho_N = 0.014R_a$ could be found.

The previous measurements had proved the importance of having no increase in the cross sections of the interior for avoidance of flow losses. Thus the problem consists in finding an arrangement where the outside possesses in high-speed flight the low incremental velocities desired and where the cross sections interior does not increase. In application the interior is always filled partly or entirely, for instance, by a hub or a radiator (radial engine). For solution of the flow problem, the displacement bodies may be replaced by singularities. One can, however, considerably facilitate the solution by making use of the fact following from the measurements that the flow on the outside depends primarily on the mass flow (position of the stagnation point) not on the conditions in the interior, so that the shaping of the inner space may be treated independently of the outside. The installation of radiators has already been investigated in this respect.[2] The case of a hub built into the interior will be discussed below.

For a flow about a hub, the difficulty in establishing, for instance, a constant cross-sectional variation lies mainly in determining the "flow cross sections" themselves, especially in the range where the hub begins. We consider for this purpose the free stream about the hub which is represented in figure 1 for the simplest case of the three-dimensional half body (single source). (Differently shaped hubs may be replaced by suitable source-sink-arrangements; for a single body, this does not require a large expenditure in calculation.) The pressure distributions on the stream lines (fig. 1) show that in the region between lines I and III a pressure drop prevails, that is, that the flow cross sections in this region narrow. Upstream from line I and downstream from line III a widening results. If one of these stream lines is made the inside wall of the cowling, as shown in an example in figure 2, the assumption is permissible that the flow does not separate at this wall; however, if one wants to obtain a constant or a continuously narrowing cross section, only minor changes from the suggested interior are necessary which can easily be made.

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[2]Compare D. Kuchemann and J. Weber: The installation of radiators. To be published shortly as a FB.

## II. RESULTS

## 1. A Cowling with Large Nose Radius                          .

Cowling 5 (fig. 3) was calculated as an infinitely long annular body without hub, producing a velocity ratio $U_i/U_0 = 0.3$ ($Q/\pi R_a^2 U_0 = 0.16$). The pertaining mean camber line resulted from a vortex distribution constant along the length. The distribution surface and stream surface of the total flow were made to coincide with the aid of an iteration method. By superposition of an annular source flow, the contour drawn in figure 3 resulted. (The calculation method will be described in detail in a report to be published shortly.) The hub 1 present was placed in the interior, and the inside of the cowling was changed as indicated above. It had to be taken into consideration that the hub does not have exactly the shape of a half body. We were striving for a uniform decrease of the cross sections in order to avoid flow losses in the interior. In the presence of the hub, the velocity ratio $U_i/U_0$ for which the flow approaching the cowling is smooth will be different from 0.3. We obtain the same mass flow $Q/\pi R_a^2 U_0 = 0.16$ as for the empty cowling if we have for the new arrangement 51 (compare the numerical table) the velocity ratio $U_i/U_0 = 0.85$ at $x = 2.5R_a$.

Numerical Table

| $x/R_a$ | 0 | 0.05 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 |
|---|---|---|---|---|---|---|---|
| $r/R_a$ outside | 0.600 | 0.695 | 0.728 | 0.772 | 0.802 | 0.826 | 0.845 |
| $r/R_a$ inside | 0.600 | 0.516 | 0.503 | 0.501 | 0.515 | 0.539 | 0.565 |

| $x/R_a$ | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 | 1.1 | 1.2 |
|---|---|---|---|---|---|---|---|
| $r/R_a$ outside | 0.863 | 0.879 | 0.892 | 0.903 | 0.913 | 0.922 | 0.931 |
| $r/R_a$ inside | 0.593 | 0.621 | 0.645 | 0.665 | 0.682 | 0.696 | 0.708 |

| $x/R_a$ | 1.3 | 1.4 | 1.5 | 2.0 | 2.5 | 3.0 |
|---|---|---|---|---|---|---|
| $r/R_a$ outside | 0.939 | 0.946 | 0.953 | 0.978 | 0.992 | 1.000 |
| $r/R_a$ inside | 0.718 | 0.726 | 0.733 | 0.758 | 0.776 | 0.821 |

In figure 4 the measured[3] and the calculated wall velocity distributions for the design conditions are compared with each other. One recognizes a good agreement on the outside and one can see, in particular that the theory reproduces the maximum incremental velocity with sufficient accuracy. In the present case, the maximum incremental velocity is 22 percent. Minor deviations of theory and measurement in the range $0.1 \leq x/R_a \leq 0.3$ are caused by an inaccuracy in the manufacture of the model. Since the inner space is considerably changed by the addition of the hub, the measured wall-velocity distribution on the inside now differs from the one calculated theoretically (without hub). However the desired velocity distribution on the inside increasing now only slightly, is reached very quickly. The velocity at the hub wall also follows this trend, that is, the velocity distribution over the flow cross section is for $x \geq 0.5R_a$ practically constant. Therewith the rule suggested for the design has proved usable, even in this case where the variation of the interior is a considerable one.

The wall pressure distributions for nonsmooth entrance are plotted in figures 5 and 6. Figure 7 shows the pressure distributions for static conditions. The comparison with cowling 1 is of special interest; cowling 1 differs from cowling 5 chiefly in the nose radius. (Compare fig. 3.) The influence on the incremental velocities on the outside is only slight. (Compare fig. 8.) In the pressure distributions for static conditions, however, a considerable difference is noticeable (fig. 7). In spite of the somewhat smaller entrance cross section in cowling 5, the minimum pressure peak on the inside is now not nearly as high. The local flow separation in the front part of the interior for cowling 1 is hardly ascertainable now for cowling 5. (Compare also fig. 13.) In reference 1 the quantity $Q_w/Q_{th}$ was used for characterizing the quality of the flow about the body. This quantity represents the ratio between actual and potentially theoretical mass flow. It must, however, be taken into account that the unavoidable wall friction layer is of more importance for small than for larger flow cross sections. Thus the displacement thickness of the boundary layer occupies a larger part of the cross section for arrangement 51 than for arrangement 11. For our model dimensions the quantity $Q_w/Q_{th}$ is therefore no unequivocal criterion of quality which must be considered, for instance, in the comparison of the values indicated in figures 7 and 13.

In figure 9 the axial forces obtained by integration from the wall pressure distributions are compared with the theoretical values (compare reference 1); however, the number of pressure test points in the rear part of the interior was not sufficient for obtaining reliable results in all cases. This deficiency becomes, however, noticeable to a noteworthy extent only for larger mass flows ($U_i > U_o$). For smaller mass flow, the agreement between measurement and theory is quite

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[3]The measurements were performed as described in reference 1.

satisfactory.  It is shown that the assumption made for the theoretical division of the axial forces into hub thrust and cowling thrust, namely that the hub is located very far within the cowling, is usable even in our case.

The behavior in case of oblique flow is practically not changed compared to arrangement 11 so that it need not be discussed in more detail.

## 2. Cowlings with Various Nose Shapes

The cowlings 6 and 7, the form of which can be seen from figure 10, were made by putting a wooden ring on cowling 5.  Since the purpose of these measurements only is to give a survey, the test points in front were omitted.  First, it is shown that the incremental velocities on the outside probably are reduced with smaller nose radii (fig. 11).  For zero mass flow, on the other hand, there results, for arrangement 71, a local region of separation at the nose as demonstrated by the boundary-layer measurement on the outside (fig. 12); however, the flow conditions in the interior deteriorate considerably in case of larger mass flows (stagnation point on the outside), particularly for static conditions. Flow observations, with the aid of tufts, showed that, for arrangements 61 and 71, the flow on the inside separated directly behind the nose.  This behavior is found again in the velocity distributions over an inner cross section (fig. 13).  In the comparison of the arrangements 51, 61, and 71, the values of $Q_w/Q_{th}$ give a clue concerning the flow losses.  Figure 13 shows furthermore, by comparison of the arrangements 51 and 4 empty, that for 51 also the losses are limited to wall friction, hence, it follows that for arrangements where a hub is directly behind the entrance, the selected radius of curvature is sufficient to guarantee a flow without losses even for static conditions.

## III. SUMMARY

Whereas the annular bodies investigated in reference 1 had the same nose radius, this report offers a series of measurements on inlet devices with various nose shapes.  The measurements show that it is possible, by suitable selection of nose radius and nose shape, to attain for arrangements with a hub in the interior a flow completely without losses (aside from the wall friction) even for static conditions. A pointed nose considerably deteriorates the flow conditions inside the cowling for large mass flows.

Further, it is suggested to simplify the design of arrangements with hub by treating the shaping of the interior independently of the exterior.

The walls of the inner space are to be formed so that the flow cross sections remain constant or decrease slightly, respectively. For solution of this problem, the flow pattern of the hub body alone is used. The usability of the suggested rule for design is confirmed by the results of the measurements.

The incremental velocities on the outside in high-speed flight are sufficiently small and are, for smooth entrance, well reproduced by the theory.


Translated by Mary L. Mahler
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REFERENCES

1. Küchemann, Dietrich, and Weber, Johanna:  Über due Strömung an
      ringförmigen Verkleidungen.  IV. Mittleilung:  Windkanalmessungen
      an Einlaufgeraten.  Forschungsbericht Nr. 1236/4, 1941.  (Available
      as ATI 50545, Air Materiel Command.)
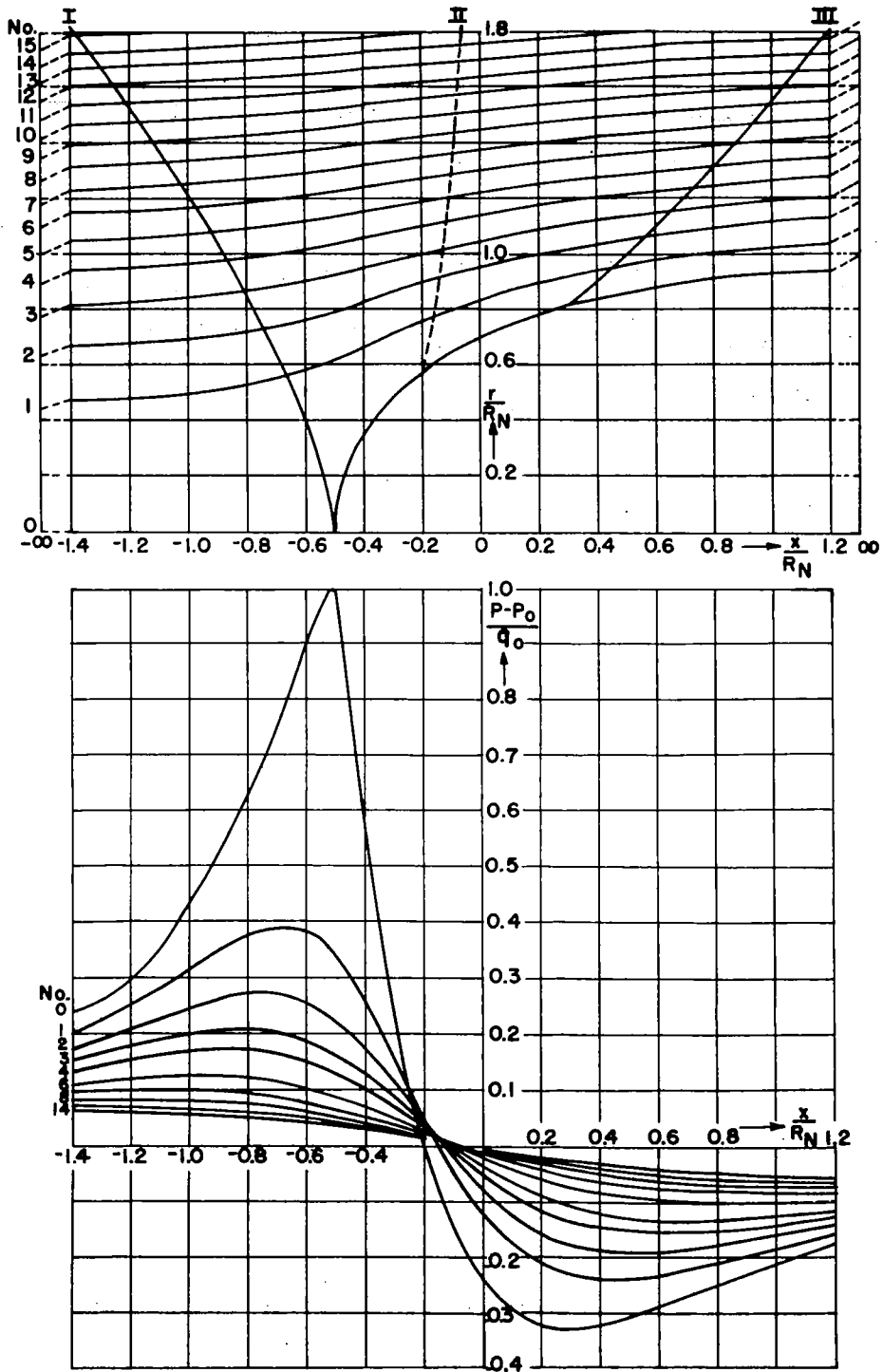
Figure 1.- Streamline pattern of the flow about the three-dimensional half body and pressure distribution on the streamlines.  Line I:  Beginning of the pressure drop on the streamlines;  line II:  $p = p_0$;  line III:  end of the region of pressure drop.
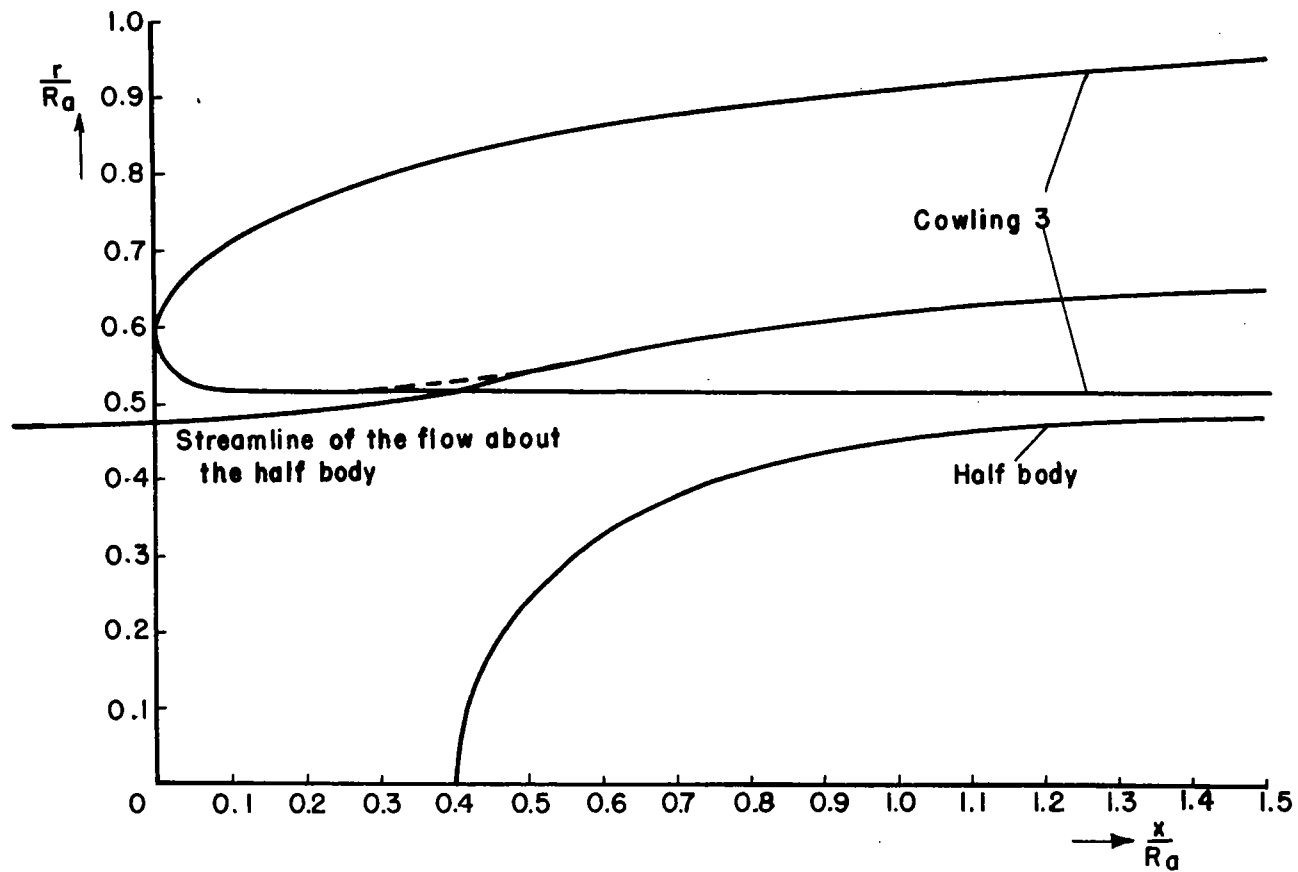
Figure 2.- Concerning the shaping of the interior.
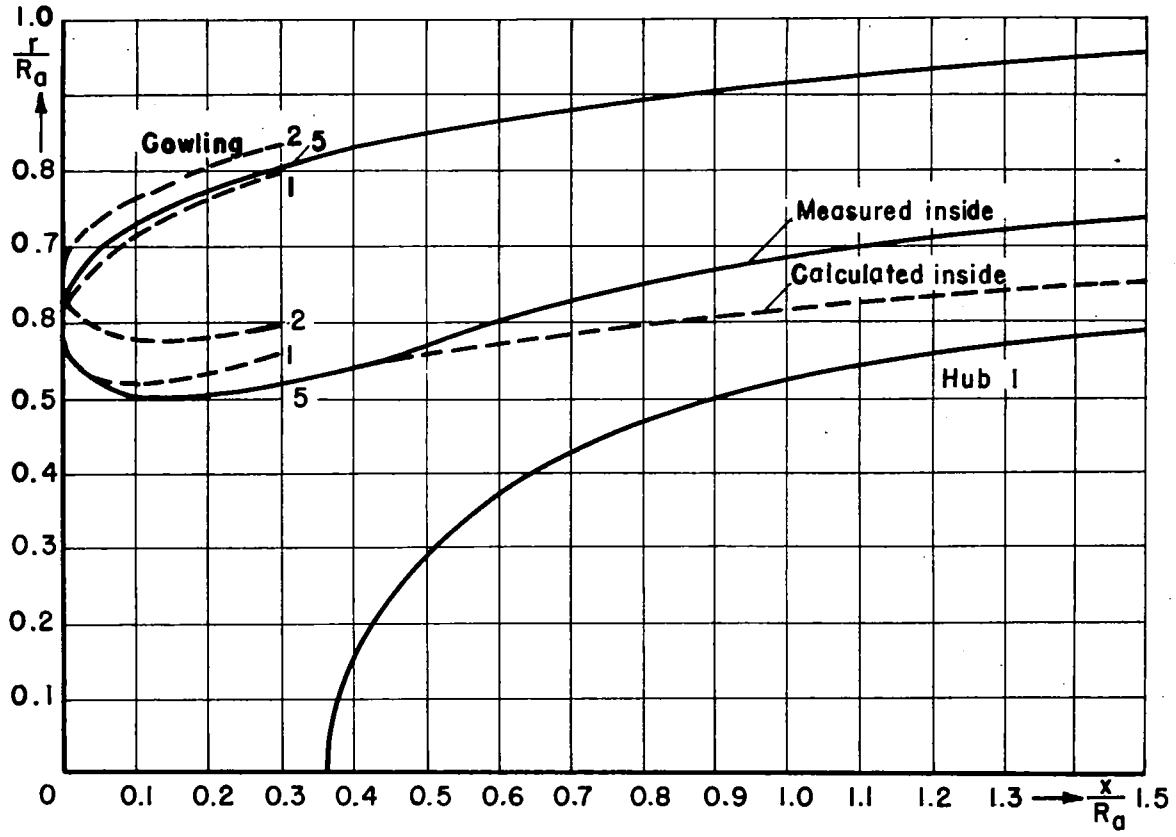
Figure 3.- Comparison of the measured and calculated arrangements.
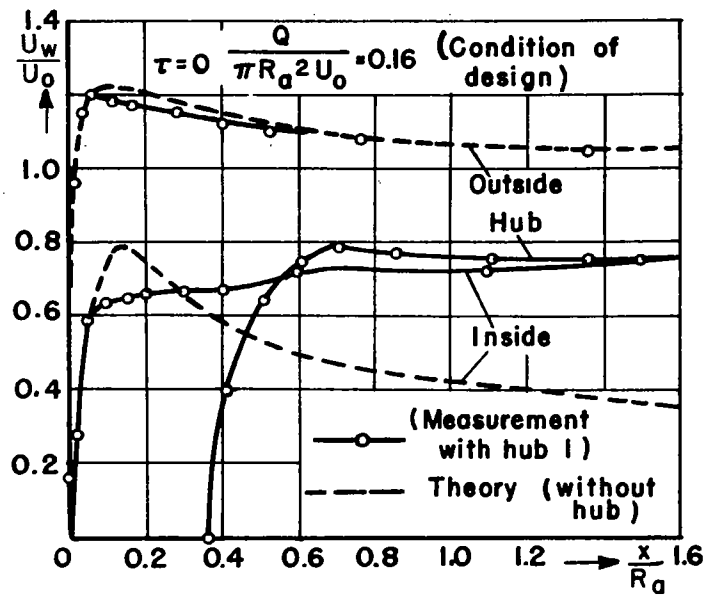
Figure 4.- Measured and calculated velocity distributions for smooth
entrance for arrangement 51.
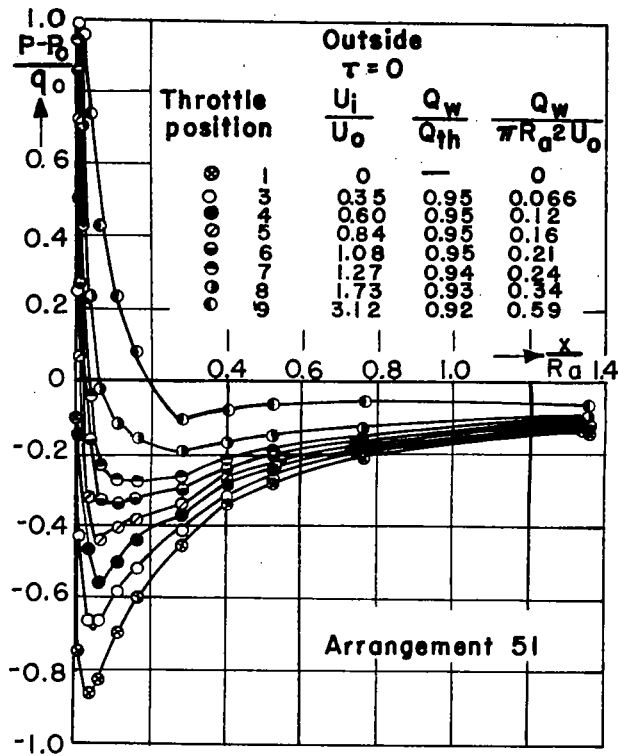
Figure 5.- Pressure distributions on the outside for various operating conditions ($U_i$ measured at $x = 2.5R_a$).
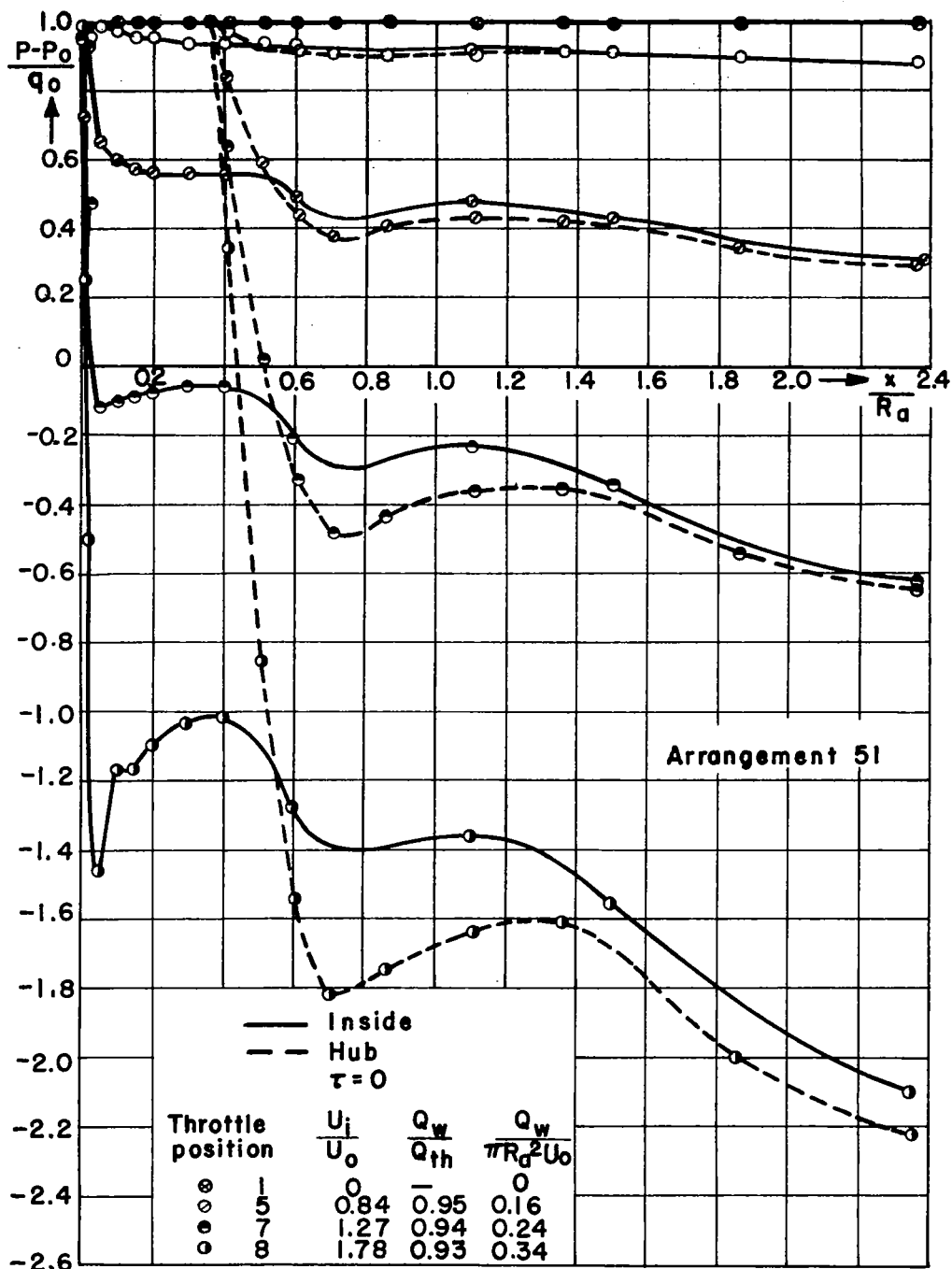
Figure 6.-   Pressure distributions on inside and hub for various operating
conditions.
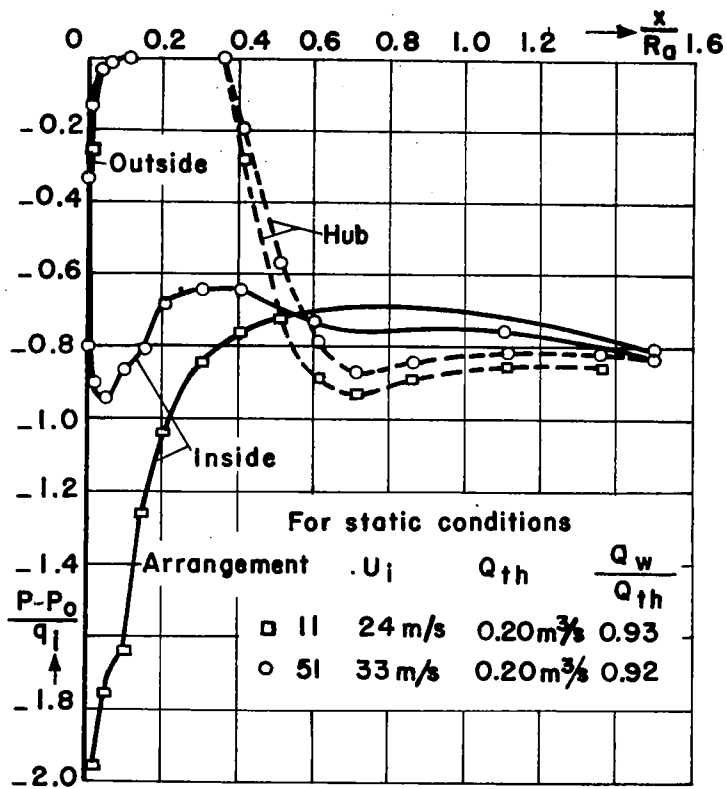
Figure 7.- Wall pressure distributions for static conditions. Comparison of two cowlings with different nose radii; compare figure 3.
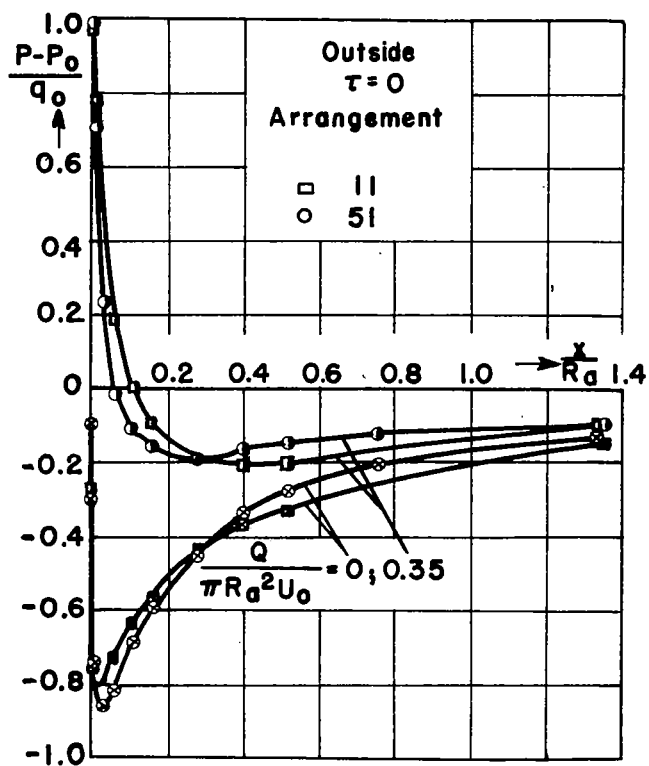
Figure 8.-   Influence of the nose radius on the pressure distributions on
the outside.
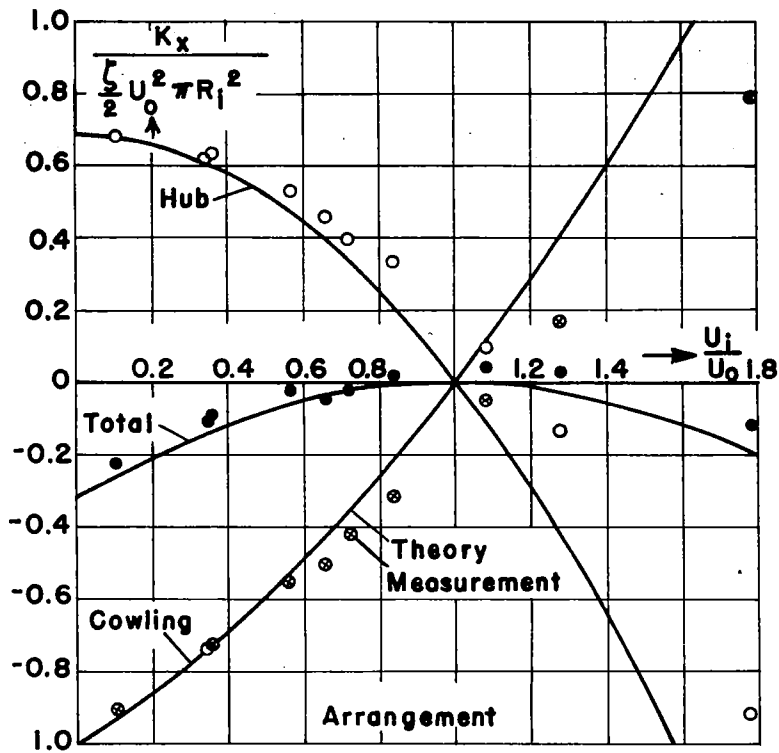
Figure 9.- Measured and calculated axial forces.
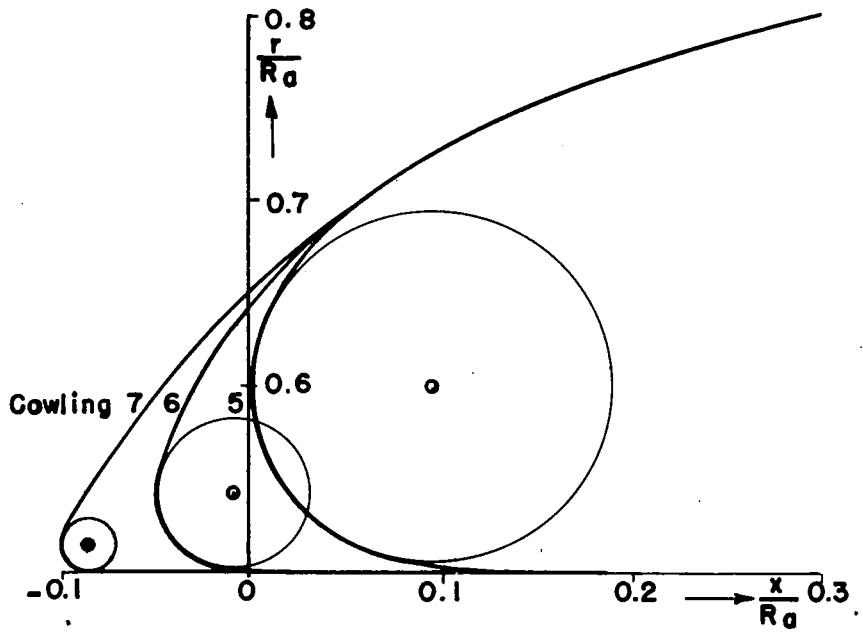
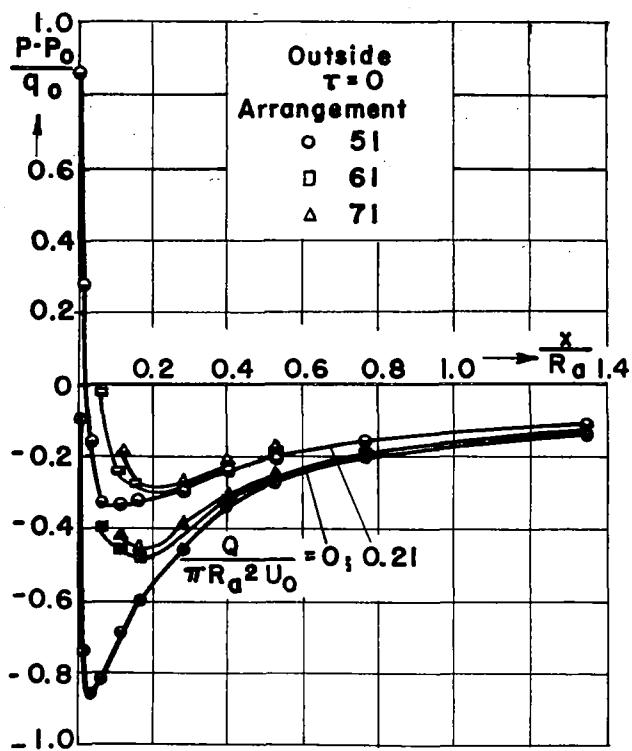Figure 10.- Cowlings 6 and 7 as modifications of the nose part of cowling 5.

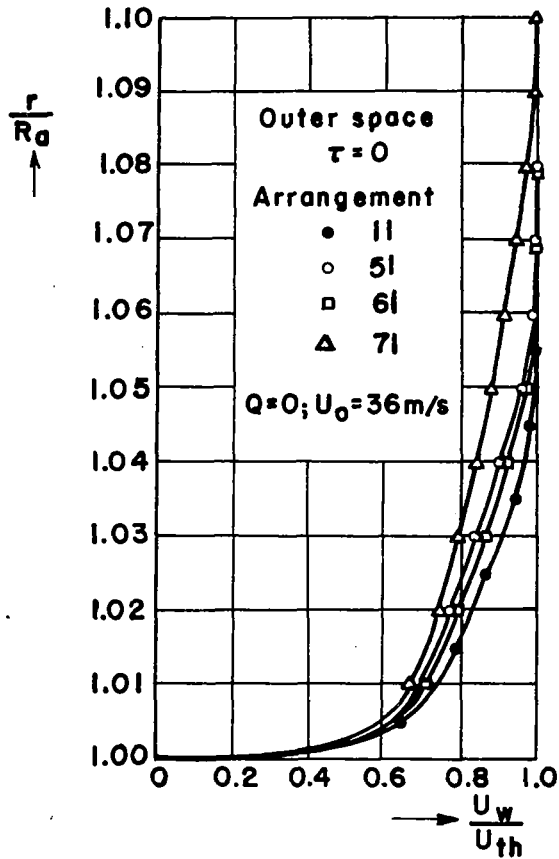Figure 11.- Influence of the nose form on the pressure distributions on the outside.

Figure 12.-  Velocity profiles in the outer space for various arrangements
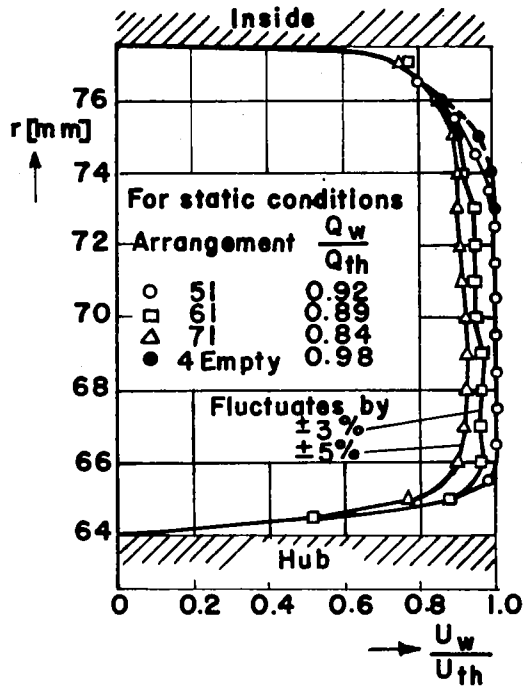at $x = 2.5R_a$ for mass flow zero.

Figure 13.-   Velocity profiles in the inner space for various arrangements
at  x = 2.5R$_a$  for static conditions.