NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL MEMORANDUM 1328

CONCERNING THE FLOW ABOUT RING-SHAPED COWLINGS

PART VIII - FURTHER MEASUREMENTS ON ANNULAR PROFILES

By Dietrich Küchemann and Johanna Weber

Translation of ZWB Forschungsbericht Nr. 1236/8, March 25, 1943.

Washington
February 1952

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL MEMORANDUM 1328

CONCERNING THE FLOW ABOUT RING-SHAPED COWLINGS

PART VIII - FURTHER MEASUREMENTS ON ANNULAR PROFILES*

By Dietrich Küchemann and Johanna Weber

ABSTRACT:

The measurements of part V (reference 1) of this series of reports, which concerned comparatively long ring profiles, are supplemented by measurements on shorter rings as they are used for shrouded propellers and cowlings of ring-shaped radiators. Mass-flow coefficients and profile drags are given. Furthermore, it has to be determined how far the potential theory describes the flow phenomenon with sufficient accuracy and whether the present theory for the calculation of thin annular profiles yields useful profile forms and is suitable for determination of the mass flow for thick profiles.

OUTLINE:

I. STATEMENT OF THE PROBLEM

The measurements on annular profiles given in the present report serve as a supplement for part V (reference 1). However, whereas in part V (reference 1) the annular profiles had a relatively great length l referred to the ring diameter $2r_o$, namely $l/2r_o = 2$, shorter profiles

---

*Über die Strömung an ringförmigen Verkleidungen. VIII Mitteilung: Weitere Messungen an Ringprofilen. Zentrale für wissenschaftliches Berichtswesen der Luftfahrtforschung des Generalluftzeugmeisters (ZWB) Berlin-Adlershof, Forschungsbericht Nr. 1236/8, Göttingen, March 25, 1943.

will be investigated now as they are used for shrouded propellers (compare part VII (reference 2)) and as cowlings of annular radiators. For both purposes of application, a profile form is desired for several operating conditions, preferably for start and climb, with the smallest possible profile drag and the greatest possible increase of the mass flow. The annular profile alone was to be investigated first for a preliminary clarification of these problems. In particular, the question was to be treated as to how far the existing theory of thin annular profiles (part III (reference 3)) enables the development of usable profile forms and permits predetermination of the mass flow.

II. THE ANNULAR PROFILES INVESTIGATED

According to the calculation method given in part III (reference 3), the mean camber lines of four profiles with different (negative) circulation and of equal length ($l/2r_o = 0.5$) were determined. The annular profiles 5 and 6, as well as 7 and 8, have, in every case, the same total circulation and are distinguished only by the facts that 5 and 7 have a curved mean camber line, while 6 and 8 have an additional S-curvature. The calculation parameters c_ν of part III (reference 3) have the values:

	(Camber)	(S-curvature)
Annular profile 5	$c_2 = -0.05$	$c_3 = 0$
Annular profile 6	$c_2 = -0.05$	$c_3 = -0.05$
Annular profile 7	$c_2 = -0.10$	$c_3 = 0$
Annular profile 8	$c_2 = -0.10$	$c_3 = -0.10$

The theoretical coefficients c_r of the radial force which correspond to c_a for two-dimensional profiles are $c_r = -0.5$ for the annular profiles 5 and 6, and $c_r = -1.1$ for the annular profiles 7 and 8. The influence of the finite profile thickness has, so far, not been treated theoretically. We were therefore obliged to assume a thickness distribution and to superimpose it on the mean camber lines. The modification to the mass flow thereby produced may be calculated in first approximation according to the continuity equation which proved to be satisfactory for the profiles investigated in part V (reference 1), however, a certain error is connected with this assumption which takes effect particularly in the determination of the radial-force coefficient c_r, as has been shown in part I (reference 4). The influence of the thickness manifests itself in making the c_r-values negatively larger than those resulting for the mean camber line.

We used the same thickness distribution for all annular profiles (see fig. 1) as in part V (reference 1) with a maximum thickness of 20 percent of the profile length at 35 percent of the length counted from the leading edge. The profile forms produced by superposition of this thickness distribution along the mean camber lines may also be seen from figure 1.

Aside from these four annular profiles, a further shorter one ($l/2r_o = 0.25$) was investigated which has a curved mean camber line with S-curvature and is related to the annular profile 6. The pertaining data are:

Annular profile 9 $c_2 = -0.05$ $c_3 = -0.05$

The theoretical coefficient of the radial force also is $c_r = -0.5$.

III. THE METHOD OF MEASUREMENT

The rings were turned from wood and had the dimensions shown on figure 2. They were attached with a sting to the drag balance as described in part V (reference 1). The profile drag, W, was measured for various free-stream velocities v_o and plotted against a Reynolds number, formed with the profile length l, $Re = v_o \frac{l}{\nu}$ in the form of a coefficient

$$c_w = W \Big/ \frac{\rho}{2} {v_o}^2 F_M$$

with F_M signifying the generating surface of the annular profile which is identical with the surface area of the wing that is obtained by cutting open the annular profile and developing it into a plane. Thus, Re and c_w may be compared directly with the values customary for two-dimensional wings.

The mass flow was determined by a survey at the exit area of the wing. The total-pressure measurement shows the regions where kinetic energy of the flow is lost and thus forms a supplement of the drag measurements.

IV. RESULTS

The theoretical mean velocities $\overline{v_{ith}}$ in the narrowest inner cross section F_i and the corresponding measured values $\overline{v}_i$ are indicated in the following table:

Annular profile	F_A/F_i	$\overline{v_{ith}}/v_o$	$\overline{v_i}/v_o$	$\overline{v}_A/v_o$
5	1.34	1.44	1.35	1.01
6	1.39	1.44	1.37	0.99
7	1.42	1.70	1.46	1.03
8	1.54	1.70	1.40	0.91
9	1.17	1.22	1.21	1.04

The deviations between the theoretical and the measured values are seen to be slight in most cases. The theoretical presuppositions are satisfied best for the annular profiles 5, 6, and 9 where insignificant losses in mass flow occur. For the annular profiles 7 and 8, the theoretical value of the circulation obviously is too large and does not materialize in practice; this phenomenon was thoroughly discussed in part V (reference 1).

The numerical table gives the ratio between the exit area F_A and the smallest inner area F_i and, additionally, the mean measured velocity $\overline{v}_A$ in the exit plane. It may be erroneously assumed that approximately the undisturbed external pressure p_o and hence the undisturbed free-stream velocity v_o prevail in the plane of the exit which would justify a calculation of the flow on annular profiles under this presupposition in a simple one-dimensional manner. However, the measurements of the velocity distribution in the exit plane do not confirm this assumption, as is shown by the measured results indicated in figure 3. First, one recognizes that the boundary layer on the inside of the annular profile brings on a loss of flow. The limit of the range where the total pressure does not reach the full undisturbed value is characterized by a dashed line. In the entire adjoining inner space, however, there prevails according to the measurements preeminently a negative static pressure and therewith a velocity increased compared to v_o. This fact, also to be expected theoretically (see part 7 (reference 2)), is what causes the increase of the mass flow mentioned. The fact that in some cases this velocity increase is on the average exactly cancelled by the reduction in velocity in the boundary layer, is incidental.

The theoretical value of the increase of the mass flow was not attained for annular profiles 7 and 8 (fig. 3). This discrepency is caused by the relatively large regions with energy loss; one may speak of distinct separation phenomena particularly for profile 8. The measured drag coefficients for all profiles are plotted in figure 4. The c_w values lie, for the annular profiles 5, 6, and 9, in a range which is usable for the practical application of such rings. Moreover, a noticeable dependence of the c_w value on the characteristic Reynolds number appears so that one may assume even lower drags in practical applications such as shrouded propellers because of the increase in Re. In general, the drags are in a range which lies only slightly above the one customary for two-dimensional profiles of corresponding thickness and circulation. A certain increase of the profile drag due to the influence of the ring is to be expected as was shown in part V (reference 1).

V. APPLICATION OF THE RESULTS

The measurements, which are to be valued as spot checks for clarification of the properties of annular profiles, show that a noteworthy increase of the mass flow by a negative circulation is possible for relatively short annular profiles without the profile drag becoming excessive. One may expect, particularly for shrouded propellers, a further increase of the effectiveness and an increase in static thrust over those so far attained for short profiles since the additional velocity $\delta_o = \bar{v}_i/v_o - 1$ caused by the present rings was considerably increased compared to the value of $\delta_o = 0.12$ in part VII (reference 2). For ring-shaped radiators it will in many cases be possible to design the cowling of the radiator so that the mass flow in climb need not be increased by more than 30 to 40 percent by auxiliary means such as small additional profile drags on the ring. This is particularly conceivable in the case of drum radiators. If one assumes, for instance, that the mass-flow coefficient for such an arrangement (that is, the ratio between the mean velocity v_K at the radiator and the flight velocity v_o) is to be modified by the cowling between $v_K/v_o = 0.1$ (high-speed flight) and 0.28 (climb), one would have to attempt, by suitable shaping of the hub and the cooling block, to make $v_K/v_o = 0.2$ without cowling. The cowling then has the function of either reducing this mass-flow coefficient to one-half (for high-speed flight) or to increase it to 1.4 times its value (for climb) which, in an appropriate design, ought to be possible by flaps without much additional drag. However, any increase in the mass-flow coefficient caused by the ring by more than about 40 percent (at the $l/2r_o$ proportions considered here), is accompanied by very considerable additional drags since the flow then certainly will separate at the ring. (See measurements, particularly those of part V (reference 1).

The measurements show further that a usable annular profile may be designed according to the methods of part III (reference 3) where the influence of the thickness of the ring on the mass flow is taken into consideration with sufficient accuracy by the continuity condition. The magnitude of the circulation up to which the flow at the profile does not separate also may be estimated from the existing measurements. For the design of a propeller shroud, one has to consider, additionally, the slipstream and the influence of the propeller hub; this is discussed in more detail in part VII (reference 2). Analogous requirements apply to cowlings of ring-shaped radiators.

VI. SYNOPSIS

The profile properties of annular profiles as they are used for shrouded propellers, cowlings of ring-shaped radiators, and similar flow problems had been investigated for comparatively long profiles; in the present report, the profile properties are clarified for shorter profiles as well, in a first survey. All measurements are made on four different annular profiles with $l/2r_o = 0.5$ and on one with $l/2r_o = 0.25$ with respect to the increase of the mass flow by the circulation about the ring and to the profile drags appearing. It is found that the theory yields useful profile forms and that, moreover, the air quantity flowing through may, by means of the present approximation theory, be determined beforehand with sufficient accuracy up to certain values of circulation, the magnitude of which can be estimated. The profile drags in the nonseparated flow region are insignificantly larger than the corresponding values for two-dimensional wings. For the rings with $l/2r_o = 0.5$, it was shown that the mean velocity in the narrowest inner cross section can be about 30 to 40 percent higher than the free-stream velocity without the profile drag becoming excessive. For the shorter profile with $l/2r_o = 0.25$, the increase of the mass flow is correspondingly smaller and amounts, at the most, to about 20 to 25 percent. The conclusions to be drawn from these results as to the application of annular profiles for shrouded propellers and ring-shaped radiators are briefly discussed.

Translated by Mary L. Mahler
National Advisory Committee
for Aeronautics

REFERENCES

1. Küchemann, Dietrich, and Weber, Johanna: Über die Strömung an ringförmigen Verkleidungen. V. Mitteilung. Forschungsbericht Nr. 1236/5, 1942. (Available as Tech. Intelligence Trans. F-TS-620-RE, AAF, Air Materiel Command, Wright Field.)

2. Küchemann, Dietrich, and Weber, Johanna: Über die Strömung an ringförmigen Verkleidungen. VII. Mitteilung. Forschungsbericht Nr. 1236/7, 1942. (Available as ATI 27053, Air Materiel Command.)

3. Küchemann, Dietrich, and Weber, Johanna: Über die Strömung an ringförmigen Verkleidungen. III. Mitteilung. Forschungsbericht Nr. 1236/3, 1941. (Available as Tech. Intelligence Trans. F-TS-683, AAF, Air Materiel Command, Wright Field.)

4. Küchemann, D.: Über die Strömung an ringförmigen Verkleidungen endlicher Dicke. I. Mitteilung. Forschungsbericht Nr. 1236, 1940. (Available as NACA TM 1325.)

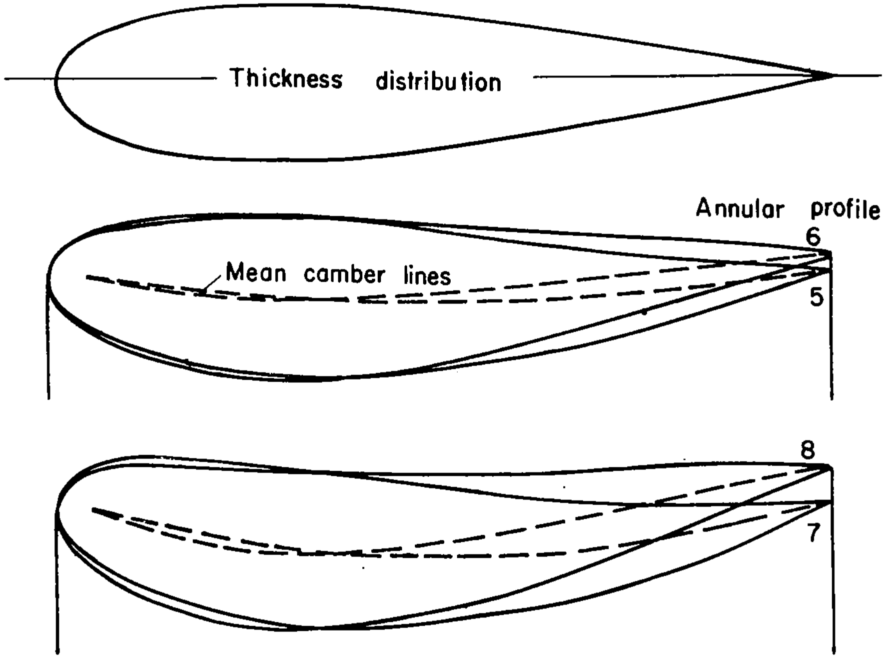

Figure 1.- The thickness distribution used and the profile forms thus originating.

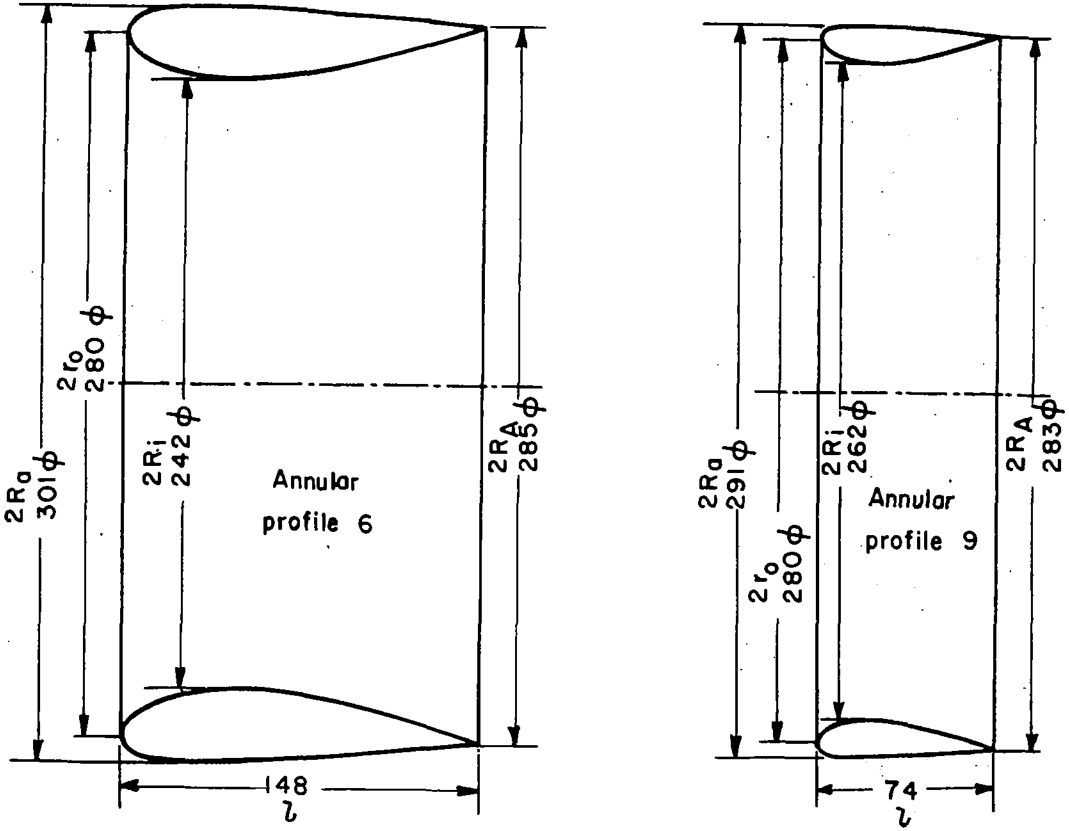

Figure 2.- Two of the annular profiles investigated. Dimensions in mm.

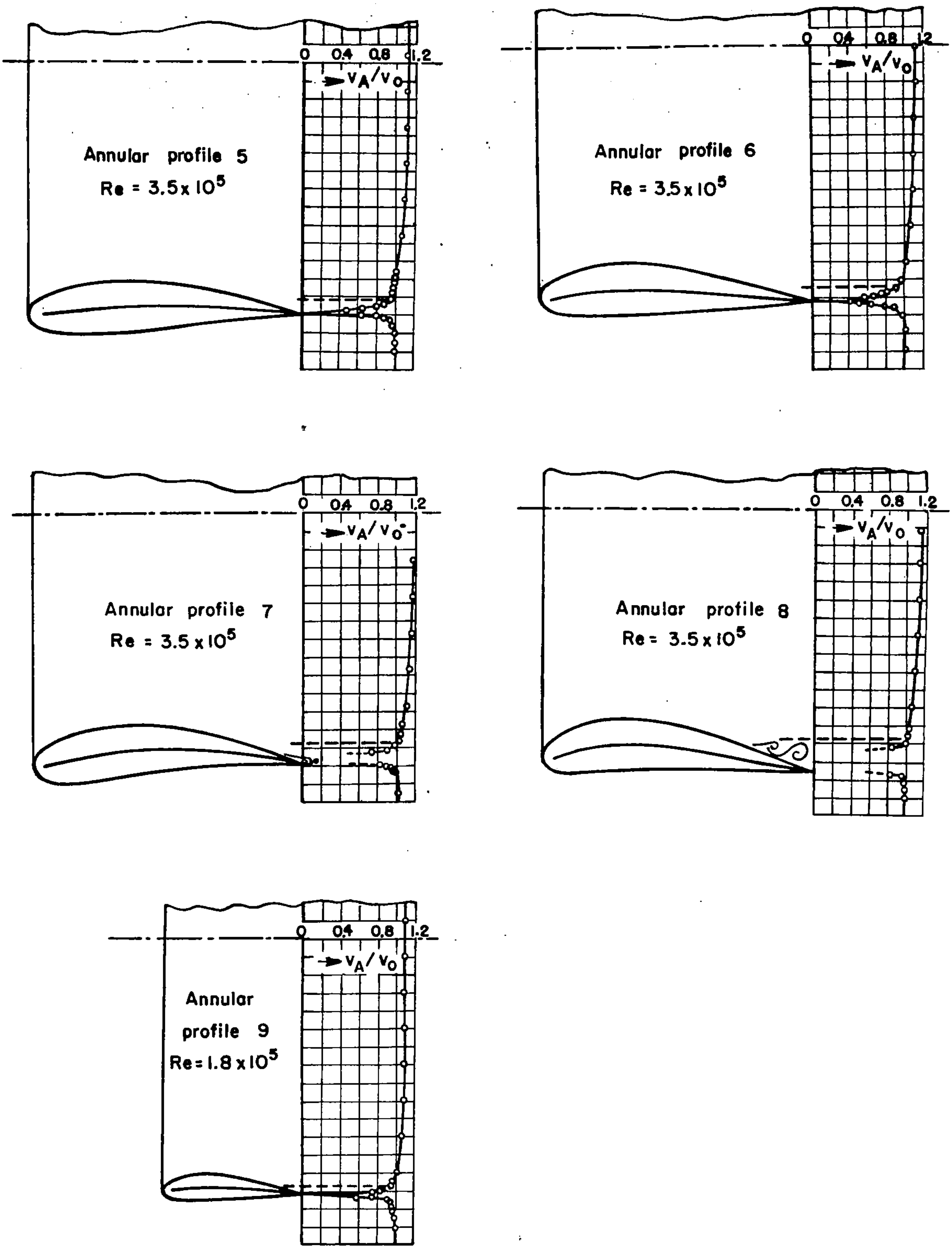

Figure 3.- Measured velocity distributions in the ring exit plane.

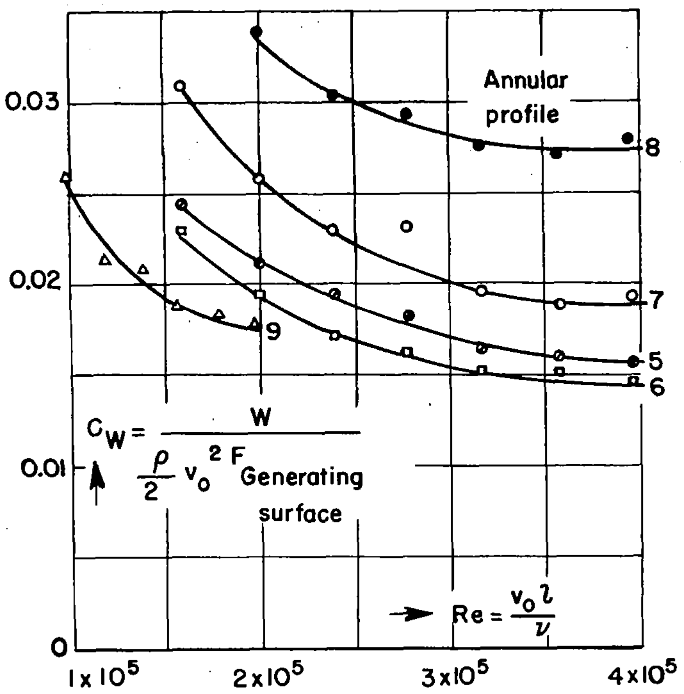

Figure 4.- Drag coefficients of the rings investigated as functions of the characteristic Reynolds number.

NACA-Langley - 2-18-52 - 1000