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THE EFFECT OF SPINNER-BODY GAP ON THE PRESSURES AVAILABLE FOR COOLING IN THE NACA E-TYPE COWLING

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SUMMARY

Tests of a 1/3-scale model of an NACA E-type cowling were made in the 8-foot high-speed tunnel for the purpose of determining the effect of the gap between the skirt of the hollow spinner and the cowling proper on the pressures available for cooling. It was found that even a large gap (0.096 in. on the model) had no appreciable effect on the available cooling pressures.

INTRODUCTION

The NACA type-E cowling has a hollow spinner through which the engine cooling air is admitted. The propeller hub and blade shanks are covered by an inner spinner and fairings that also serve to provide blower action for the ground and climb cooling conditions. A principal characteristic of the cowling is its external shape, which permits the attainment of very high critical compressibility speeds, provided an inlet velocity of 0.4 free stream velocity or greater is maintained. The external lines of the cowling were obtained from nose shape B of reference 1. Models of this type of cowling were designed and tested in the investigations described in references 2 and 3. A photograph showing the general arrangement of the E-cowling spinner employed in the present tests is shown in figure 1.

Two general methods have been suggested for designing the spinner-body gap for the E cowling. In one method the gap is made very small and the flow passage is restricted by seals or labyrinths in order to reduce the air flow to a minimum. This design obviously presents manufacturing difficulties and the flow restrictions cause energy losses in the gap flow. In the second method the gap is designed as an aerodynamically efficient air outlet, shaped to make both the internal and external flow losses at the gap as small as possible. As no attempt is made to keep the gap size very small and no restrictions are placed in the path of the flow, this design is simple to manufacture. This second arrangement, however, has been questioned on the grounds that the presence of a relatively large unobstructed gap might adversely affect the pressures available for cooling in the main body of flow. The present investigation was therefore undertaken to determine the effect of gap size on the available cooling pressures.

The effects of gaps of two sizes on the pressures available for cooling were measured. For comparison the pressures available with gap sealed were also determined. The data are analyzed and discussed in some detail with the intention of clearing up several misconceptions that have existed regarding the effects of the gap.

SYMBOLS

A	area
H	total pressure
ΔH	loss in total pressure across spinner
V	velocity of air stream
n	propeller rotational speed
D	propeller diameter
ρ	air density
q	dynamic pressure $\left(\frac{1}{2}\rho V^2\right)$
C_T	thrust coefficient $\left(\frac{\text{thrust}}{\rho n^2 D^4}\right)$
Q	flow quantity

Subscripts:

0,1,2	stations in flow system shown in figure 2
g	condition with gap open
s	condition with gap sealed

FLOW RELATIONS

Figure 2 represents the streamlines of the flow entering the cowling for the gap-open and gap-sealed conditions. Inasmuch as the flow quantity required for engine cooling is the same for each case, the stream-tube area (A_0 on fig. 2) far ahead of the cowling corresponding only to the cooling-air flow must be the same for each gap condition. It is shown in reference 4 that the pressure built up at station 2 in front of the engine depends solely on the ratio A_0/A_2 for a given flight speed and diffuser loss. In the case of the present tests, this ratio is constant for all gap openings and the pressures available at station 2 will thus be the same regardless of gap size. Any effect of the gap on the pressure at station 2 must therefore arise from one of the following secondary considerations, which were neglected in the tests of reference 4.

1. The total flow quantity in the spinner is greater for the gap-open case because of the flow through the gap. The skin-friction and diffuser losses within the spinner will thus be somewhat greater with the gap open.

2. The suction of air through the gap could conceivably improve the diffuser efficiency of the spinner through a favorable boundary-layer control action.

The increased spinner-diffuser loss with the gap open (item 1) can be evaluated on the assumption that the spinner losses vary as the square of the flow quantity. That is,

$$\Delta H_g = \Delta H_s \left(\frac{Q_g}{Q_s}\right)^2 \qquad (1)$$

Effects due to suction of the boundary layer through the gap (item 2) can be evaluated only by experimental methods.

It is clear from the foregoing discussion that any adverse effect of the spinner gap on the available cooling pressures will be restricted to an increase in the skin-friction or separation losses in the spinner itself. Because the quantity of air passing through the gap is small in relation to the total flow, and because the skin-friction and separation losses in the spinner are usually also small, any adverse effect of the gap will obviously be very slight.

MODEL TESTS

The model employed in the tests was designed for preliminary testing of propellers at high forward speeds. In order that the propeller thrust at very high speeds be accurately measured, it was required that the body drag be low. As the critical speeds of conventional cowling forms are considerably below the maximum test speeds attainable, it was necessary to employ an E-type cowling. The interior design of the cowling was governed by the model propeller-hub dimensions and the motor installation. No attempt was made to simulate an air-cooled engine installation or to secure high efficiency for the internal flow. The blade-shank fairings, for example, were not streamline sections but terminated at the rear of the spinner where their thickness was 3½ inches. Figure 3 shows the general arrangement of the model and spinner. The external lines of the model were similar to the basic fuselage shape of the model tested in reference 2. The bulge on the bottom of the cowling shown in figure 3 represents additional space for ducting auxiliary air underneath the engine, as explained in reference 2.

The tests consisted of the measurement of pressures in a survey plane 1 inch behind the spinner. A 10-tube rake of static- and total-pressure tubes was employed. Tests were made with the gap sealed, with a 0.034-inch gap, and with a 0.096-inch gap. Runs were made with the spinner both stationary and rotating at a V/nD of 1.66 (based on the propeller diameter, 4 ft). In the runs with the spinner rotating, the gap-sealed condition was attained through the use of a lubricated leather seal. Additional data pertinent to the gap tests are tabulated as follows:

Test speed, V, miles per hour	125
Dynamic pressure, q, pounds per square foot	39.7
V/nD for rotating-spinner runs	1.66
Propeller diameter, D, feet	4
Inlet velocity ratio, V_1/V	0.85
Inlet area, A_1, square feet	0.367
Duct area at survey plane, square feet	0.557
$\Delta H/q$ (for $V/nD = 1.66$)	0.10

The V/nD of 1.66 for the rotating-spinner runs corresponds to the climb flight condition in which the spinner blades produce an appreciable thrust and thereby increase the duct pressure at the gap. The value of C_T (= thrust/$\rho n^2 D^4$) for the spinner was 0.0016 based on the 4-foot propeller diameter.

In the run with operating propeller, the increased pressure behind the propeller (due to the high thrust coefficient at which it was operating) reduced the amount of air flowing through the internal system. Thus, as indicated by equation (1), the spinner diffuser loss was correspondingly less than in previous runs. In order that a direct comparison with the other data could be made, the data with propeller operating were corrected by equation (1) to the same flow rate as the rate without propeller. The flow quantities were determined from duct-velocity data computed from the rake survey measurements.

A further correction was required for the propeller run because of the change in the angle of the flow impinging on the tubes of the survey rake. Owing to the reduced axial component of the duct velocity, the twist of the air leaving the blower was greater for the propeller run than for the runs without the propeller. This increased angularity affected the reading of both the total- and static-pressure tubes. The angle change was computed from the blower torque and the corresponding pressures were corrected by the use of calibration data for the tubes.

There was virtually no variation in the flow quantity passing through the cooling ducts for the several gap arrangements, and no corrections were required for any of the data except in the propeller run.

TEST RESULTS

The results are presented in table I as increments of the average total pressure at the survey plane. A positive increment indicates that the total pressure was greater with the gap open than with it closed. Table I shows that, for constant-flow quantity through the cooling-air duct, the net effect of the gap was to increase slightly the pressure available for cooling. Just the opposite effect might have been predicted in view of the fact that, with constant cooling-air flow, the flow quantity through the spinner is greater with the gap open than with the gap closed. It is clear that the flow through the gap must have a beneficial effect on the diffuser efficiency of the spinner which more than nullifies the increased skin-friction losses.

For the purpose of evaluating this favorable boundary-layer-control effect, the pressure-loss data were corrected to the condition of constant flow quantity through the spinner rather than through the cooling-air ducts. Equation (1) was used to accomplish this correction. The data so corrected should indicate the magnitude of the boundary-layer-control effect since, with constant-flow quantity in the spinner, the skin-firction and separation losses are identical for all gap conditions except for the suction action of the gaps. These results are also shown in table I. With the largest gap, the favorable effect amounts to about 25 percent of the over-all loss in total pressure through the spinner ($\Delta H = 0.10q$). This effect is great enough to warrant further investigation. In a spinner with larger area expansion ratios and larger diffuser losses, proportionately larger gains from the gap might be possible.

GAP DESIGN

Both the analytical considerations and the test results make it evident that there is no necessity for making the gap size very small. A gap 1/4-inch wide, full scale, can have no appreciable adverse effect and may have a slightly favorable effect.

The gap should be made so that the air may pass through it with a minimum of lost energy. An attempt to aline the outlet flow with the external-flow lines over the spinner should be made and the cowling lines near the gap should be slightly undercut below the basic contour in order to prevent a local peak in the pressure-distribution curve. Figure 4 shows a sketch of a suggested satisfactory gap shape.

When the spinner is being designed, the flow quantity will determine the inlet-area and blade-fairing details. It is obvious that the design flow quantity should be the sum of the air requirement of the engine and the flow through the gap.

CONCLUSIONS

The following conclusions are based on a conservative appraisal of the analysis and the test data:

1. The pressures available for cooling in the NACA E-type cowling cannot be adversely affected by the spinner-body gap except in that the skin-friction and separation losses in the spinner may be augmented by the increased flow rate in the spinner due to the presence of the gap.

2. No attempt need be made to make the gap size very small. A gap 0.096 inch wide on the model tested (about 1/4 in. full scale) had a slightly favorable effect on the available cooling pressures.

3. The gap should be designed to provide a flow passage of minimum aerodynamic loss. The joining of the internal and external flows should be effected without disturbing the external flow; that is, the cowling contour should be undercut slightly behind the gap.

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TABLE I

INCREMENTS IN TOTAL PRESSURE BEHIND SPINNER DUE TO EFFECTS OF GAP FLOW

Gap size (in.)	$\frac{H_g - H_s}{q}$	
	Spinner stationary V/nD = 0	Spinner rotating V/nD = 1.66
Constant flow quantity through cooling-air duct		
Sealed	0	0
0.034	.001	.006
.096	.006	.011
[a].096	----------	.018
Constant flow quantity through spinner		
Sealed	0	0
0.034	.006	.013
.096	.021	.029
[a].096	----------	.035

[a] With propeller.

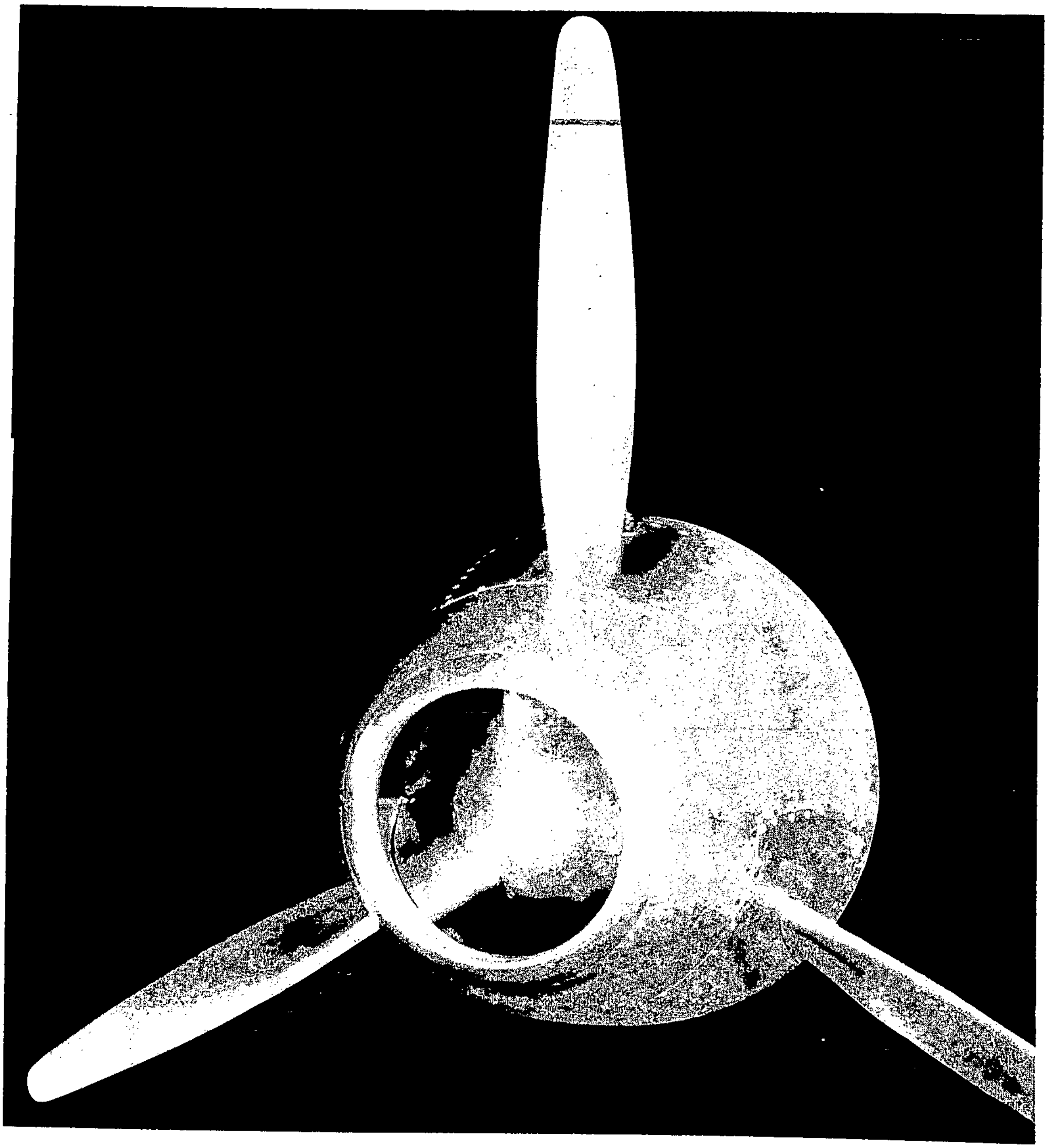

Figure 1.- NACA E-cowling spinner.

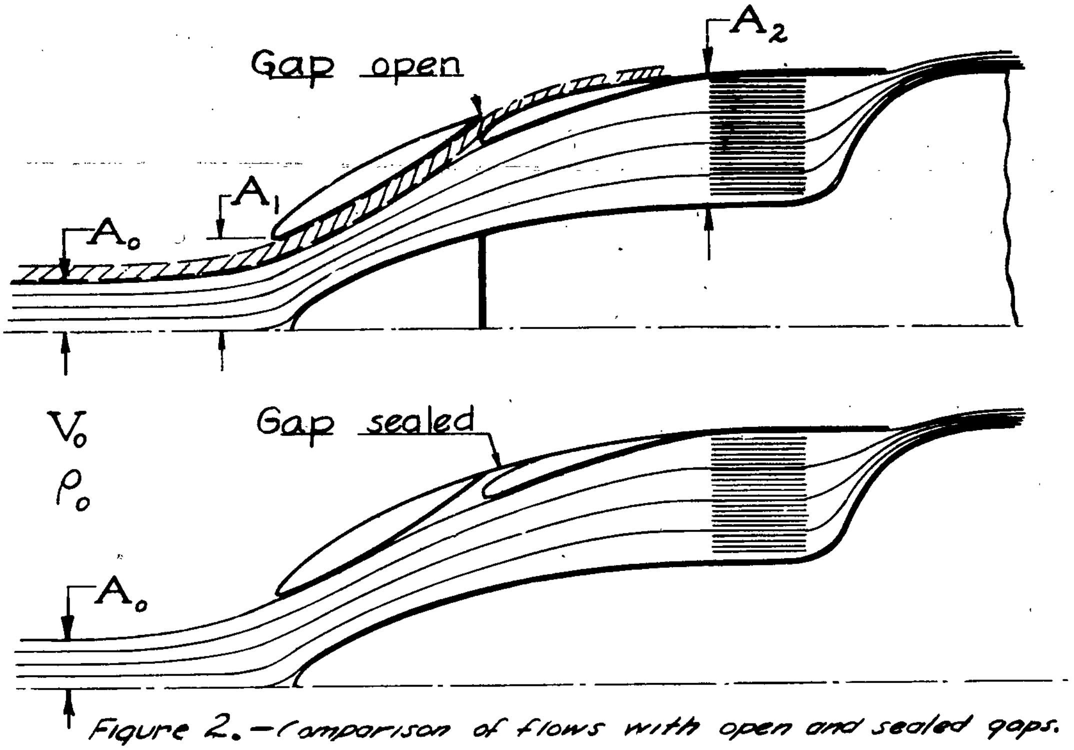

Figure 2.—Comparison of flows with open and sealed gaps.

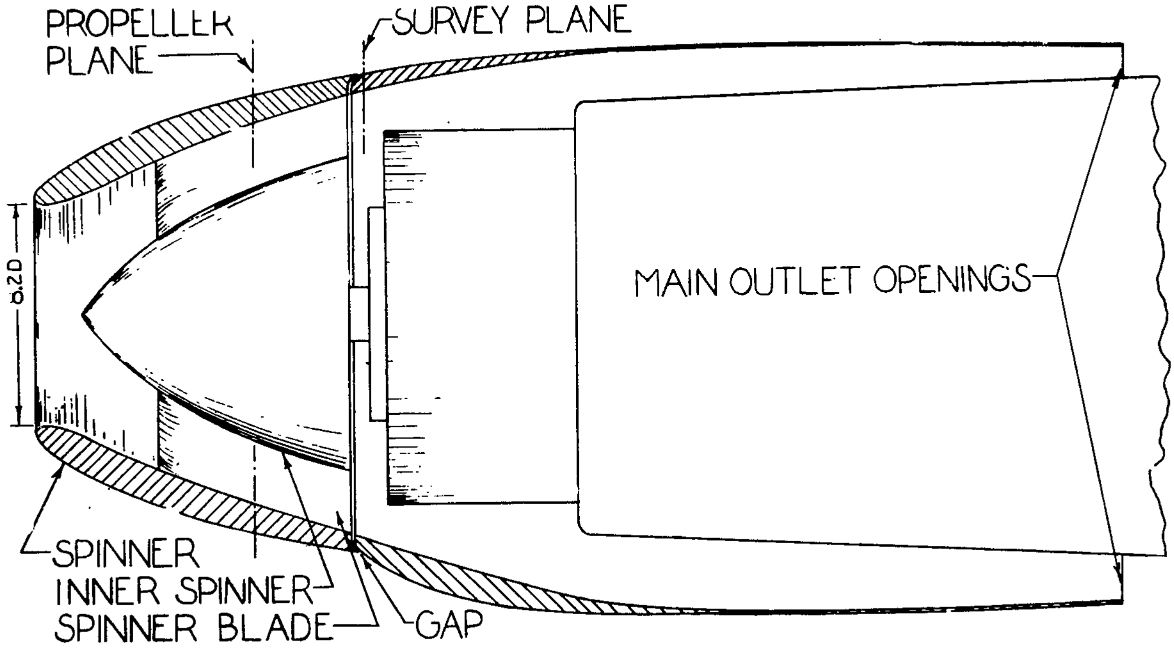

FIGURE 3.- MODEL ARRANGEMENT, SIDE VIEW.

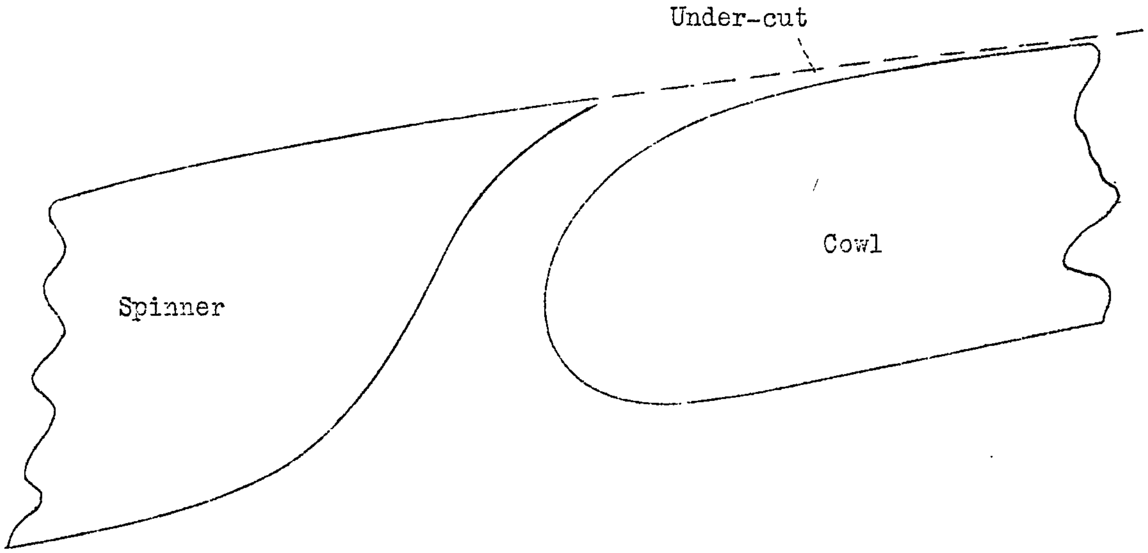

Figure 4.- Suggested gap profile.