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RESEARCH MEMORANDUM

FLOW COEFFICIENTS FOR ORIFICES IN BASE OF TRANSPIRATION-COOLED TURBINE ROTOR BLADE

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

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SUMMARY

Orifices in the base of transpiration-cooled turbine blades are desirable and necessary for properly distributing and regulating the flow to the porous shell. Because of differences in orifice shape neither theoretical nor standard experimental flow coefficients for orifices or flow nozzles can be used for computing the pressure drop - flow relations. Static tests on a segment of a transpiration-cooled turbine rotor blade with a wire-cloth shell were therefore conducted to determine the flow coefficients associated with some representative metering orifices; average flow coefficients from 0.96 to 0.79 were obtained for orifice diameters from 0.031 to 0.102 inch.

INTRODUCTION

In the transpiration cooling of turbine blades, orifices in the blade base to meter the cooling air allow a porous shell of constant chordwise permeability to be used and yet enable the proper chordwise coolant distribution to be obtained (refs. 1 and 2). In addition to these desirable characteristics, the orifice, by its flow and pressure drop relation, also greatly diminishes the undesirable overcooling of a constant chordwise permeability shell that is an otherwise necessary evil when the engine must operate over a range of altitude conditions (ref. 3).

Orifices in the blade base serve to distribute and to regulate the amount of flow to a particular compartment of the blade. It is desirable to take a large pressure drop across the orifice to compensate for altitude effects, but this drop should be commensurate with available cooling-air pressures. For a given flow through the porous shell of the blade (which determines the heat transferred to the blade) the required coolant-supply pressure is dependent on the permeability characteristics of the shell and the flow coefficient of the metering orifice or flow nozzle. When the shell permeability and orifice area are specified, the required supply pressure varies inversely as the flow coefficient.

Because of the many possible variations in shape of the orifices used in turbine blades compared with usual orifice shapes, standard values of the flow coefficient cannot be used a priori. For metering orifices whose thickness is different from that usually encountered, the flow coefficients varied from 0.78 to 0.87 (ref. 2).

In the rotor blade reported in reference 1, which used a wire-cloth shell, the orifices in the base were not in the form of a plate. Differences in flow coefficient due to a change from a sintered to a wire-cloth material would be expected to be small but the differences resulting from the change in shapes of the metering devices might be significant. To determine the flow coefficients associated with this type of metering orifice, a segment of the rotor blade was bench tested and the results are presented herein.

SYMBOLS

The following symbols are used in this report:

A	flow area
B	flow coefficient for orifice or flow nozzle
d	flow diameter
g	acceleration due to gravity
h_B	pressure drop through orifice
p	static pressure
R	gas constant
Re	Reynolds number, $Wd_n/A_n\mu$
T	temperature
v	velocity out of porous sheet
W	weight flow
μ	absolute viscosity
ρ	density

Subscripts:

a cooling air or porous surface through which air is passing

g gas (herein corresponds to atmosphere)

n orifice (or flow nozzle)

o for reference temperature of 518.4° R

APPARATUS AND PROCEDURE

A schematic diagram of the test equipment used for determining the pressure-drop characteristics of the orifices in series with wire cloth is shown in figure 1. The present apparatus is similar to that described in reference 4 except for some differences in the upstream pressure station and the test section. The pressure tap shown in figure 1 is in a region where the maximum velocity is less than 40 feet per second, so that it may be considered a total pressure.

The test section was an enlarged segment adapted from the transpiration-cooled blade reported in reference 1 and is shown in figure 2. It consisted of a 20-by-200-mesh wire cloth calendered to 0.0205-inch thickness and silver-soldered to the brass frame containing three orifices. (Permeability characteristics of the cloth with this thickness reduction (33.2 percent) are given in ref. 5 and reproduced on fig. 3.) The orifices were fittings that simulated the air-flow-passage size in the base of the aforementioned turbine blade and were made with exit-flow diameters of 0.031, 0.050, and 0.102 inch. A set consisting of three orifices, all of the same size, were screwed into the frame (fig. 2). After the flexible tubing was attached to the fittings, air was passed through the apparatus.

CALCULATION METHOD

Because calculation of the flow coefficients from the measured data was desired, the equations relating the weight flow of air and pressure drop are solved for the flow coefficient. These equations, given in references 2 and 3, then yield, for subsonic flow,

$$B = \rho_a v_a \frac{A_a}{A_n} \sqrt{\frac{R}{2g} \frac{T_{a,n}}{h_B(p_a - h_B)}} \qquad (1)$$

and, for supercritical pressure drops ($h_B = 0.472\ p_a$),

$$B = \frac{\rho_a v_a}{0.484 p_a} \frac{A_a}{A_n} \sqrt{\frac{2g}{RT_{a,n}}} \qquad (2)$$

When the specific weight flow $\rho_a v_a$ and the discharge pressure p_g are known, $p_a - h_B$ can be obtained from the 20-by-200-mesh curve given in figure 3. (For this case the p_a in the ordinate is actually $p_a - h_B$.) Since p_a is measured, the pressure drop through the orifice or flow nozzle h_B can be calculated.

RESULTS AND DISCUSSION

The experimental pressure-drop characteristics for the simulated transpiration-cooled turbine rotor blade are given in figure 3. A set of data are shown for each orifice size. The average of the flow coefficients for each orifice are 0.956, 0.865, and 0.788 for orifice diameters of 0.031, 0.050, and 0.102 inch, respectively. The pseudo-analytical curves using experimental flow coefficients are in very good agreement for the two smaller orifices, indicating that the flow coefficient is effectively constant over the range of weight flows investigated. Greater variations between the calculated curve and the experimental data for the 0.102-inch-diameter orifice are indicated. The reason for this discrepancy may be discerned with the aid of figure 4.

In figure 4, the flow coefficient B is plotted against the orifice Reynolds number Re. (Similar plots are used to present data from standard orifices, e.g., ref. 6, p. 60.) The vertical bars indicate the Reynolds number corresponding to $h_B \geq 0.472 p_a$, that is, supercritical pressure drops. For larger Reynolds numbers, the flow coefficient is essentially constant for a given orifice diameter. The average values of the flow coefficient for the two smaller orifices are not markedly different from the specific values. For the largest orifice (0.102-in. diameter), however, the coefficient varies from 0.68 at the low Reynolds number to 0.86 for a Reynolds number greater than the value for supercritical pressure drop. This large variation is probably due to the diameter of the orifice being almost as large as the 0.12-inch diameter of the fitting (fig. 2) and explains the discrepancies between calculated and experimental results noted on figure 3. With this orifice diameter, the flow is more akin to pipe flow and, hence, the flow coefficient is dependent on the Reynolds number for Reynolds numbers less than critical. It may be noted that the trend of flow coefficient with orifice size is the same as that observed in reference 2.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, December 11, 1953

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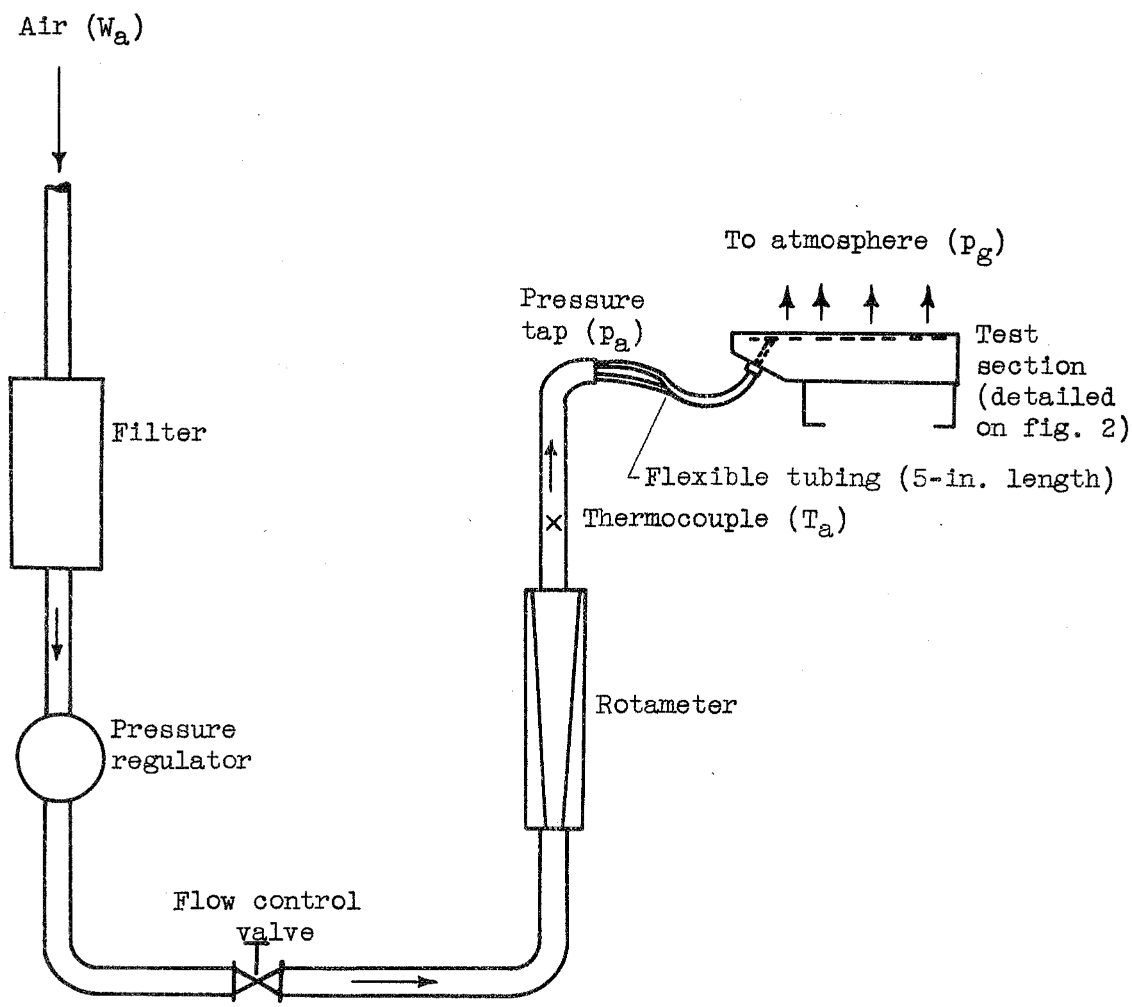

Figure 1. - Schematic diagram of test equipment for air-flow measurement.

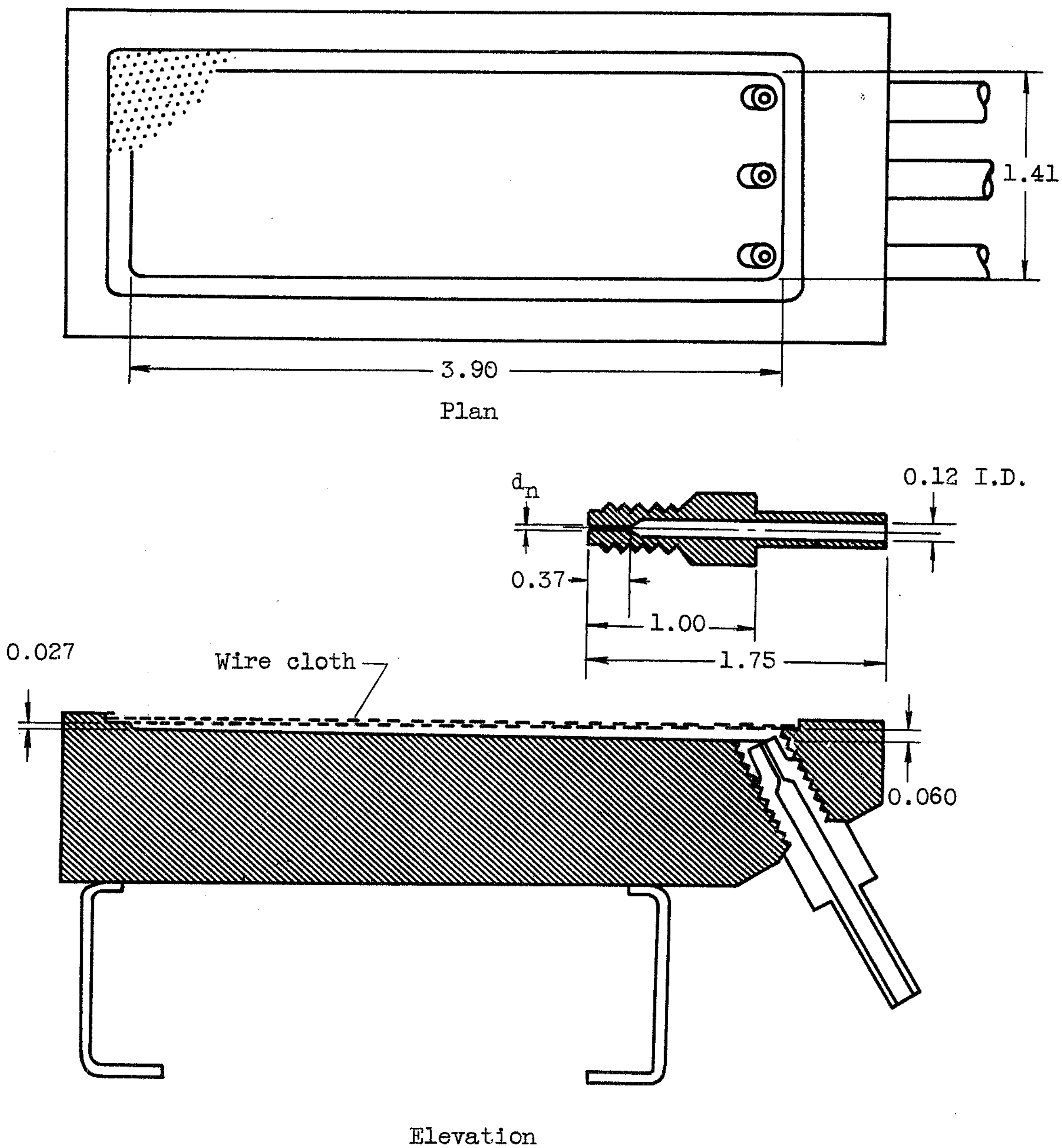

Figure 2. - Test section for flow coefficient determination. (All dimensions are in inches.)

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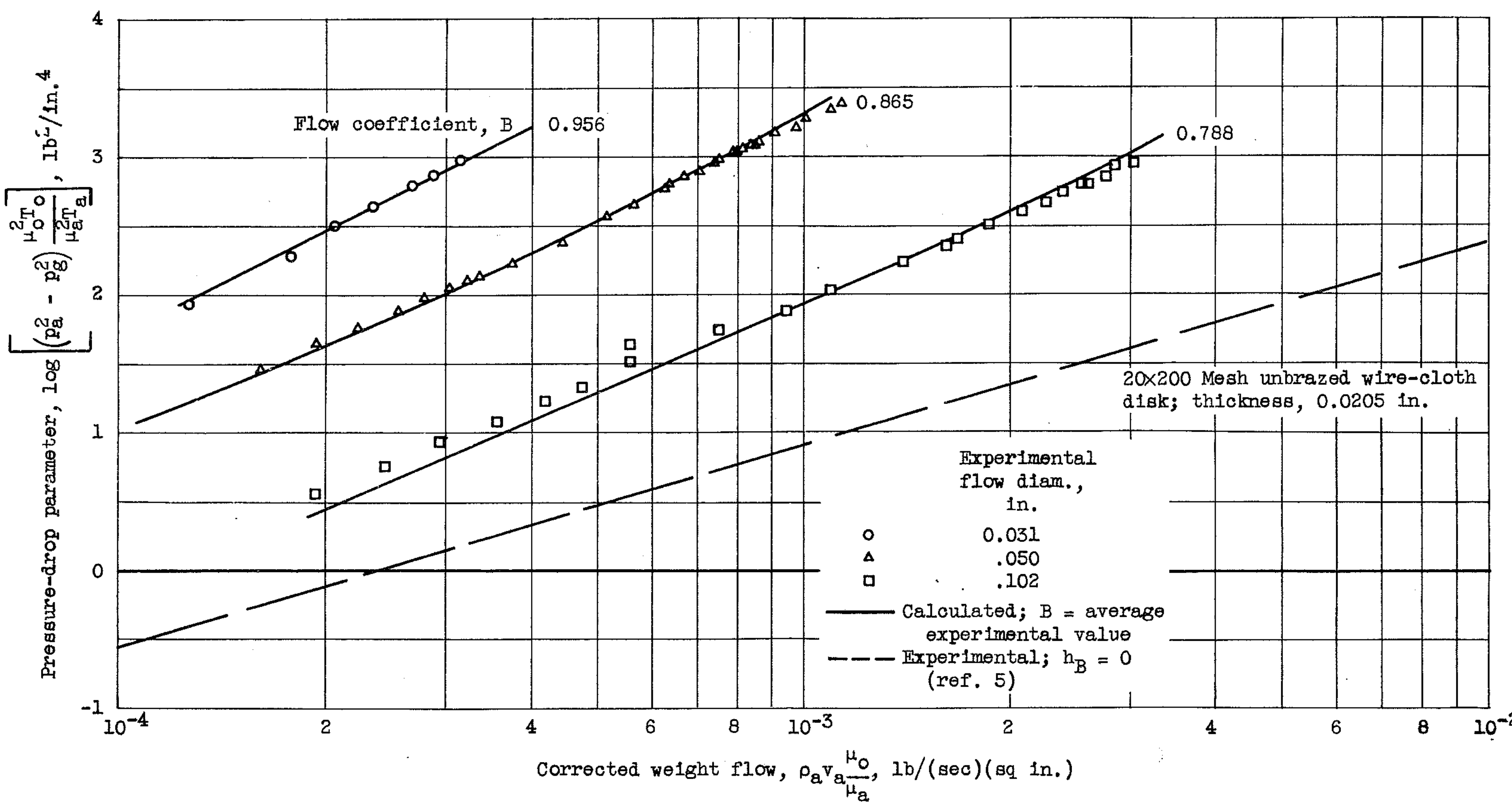

Figure 3. - Pressure-drop characteristics for orifices in series with wire cloth.

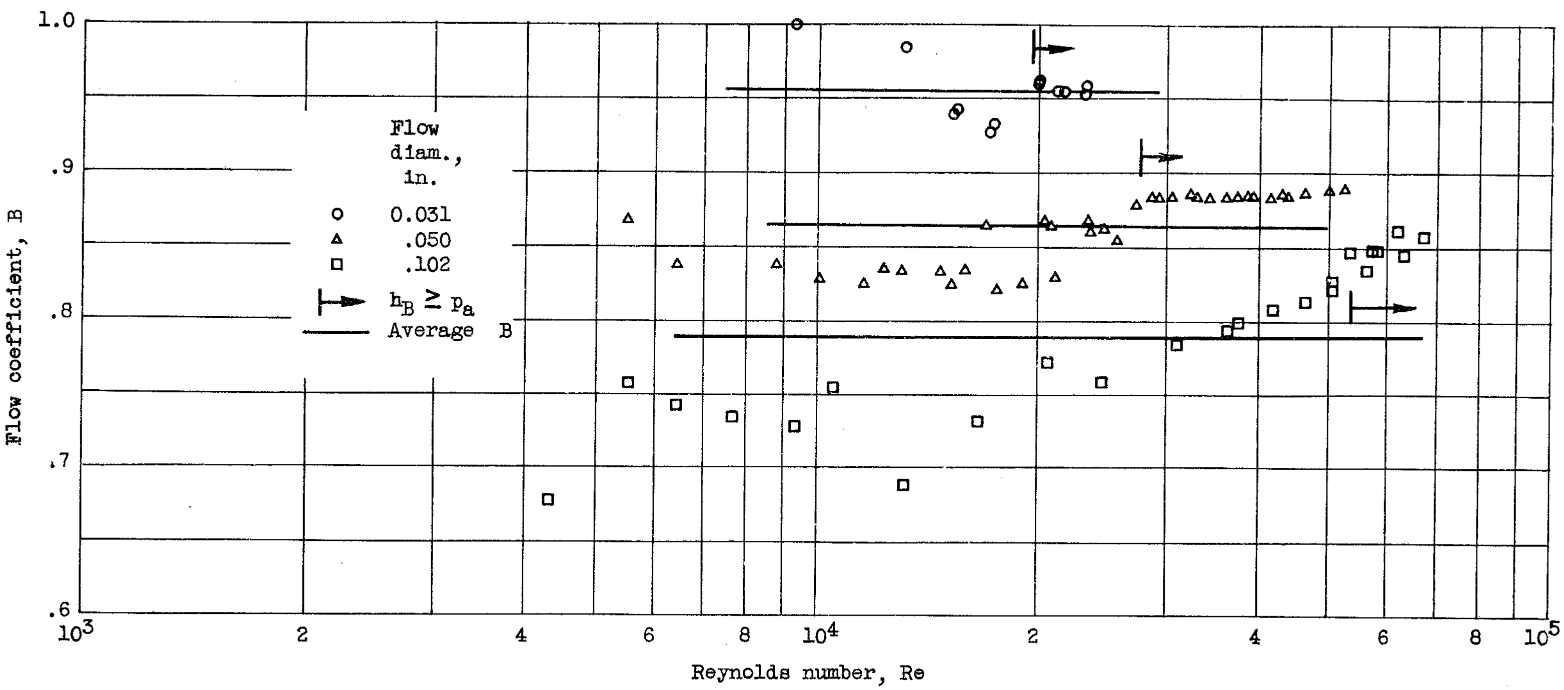

Figure 4. - Flow coefficients as function of orifice Reynolds number.

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Abstract

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