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# GAS CROSSFLOW EFFECTS ON AIRFLOW THROUGH A WIRE-FORM TRANSPIRATION-COOLING MATERIAL

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16. Abstract

An experimental analysis was conducted to determine the effects of gas stream flow parallel to the discharging surface on the flow characteristics of a wire-form porous material. Flow data were obtained over a range of transpiration airflow rates from 0.129 to 0.695 g/sec-cm$^2$ ($1.83\times10^{-3}$ to $9.88\times10^{-3}$ lb/sec-in.$^2$) and external gas stream Mach numbers from 0 to 0.46. The conclusion was drawn that the flow characteristics of the wire cloth were not significantly affected by the external gas flows.

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# GAS CROSSFLOW EFFECTS ON AIRFLOW THROUGH A WIRE-FORM TRANSPIRATION-COOLING MATERIAL

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## SUMMARY

In transpiration-cooled airfoils used in aircraft gas turbines, the discharge air from vanes and blades mixes with the gas stream flowing through the channels formed by adjoining airfoils. A study was made to determine the effects of the outside gas flow on the flow characteristics of a wire-form porous material. Experimental flow data were obtained in a bench-type facility with airflow rates through the porous material from 0.129 to 0.695 g/sec-cm$^2$ ($1.83\times10^{-3}$ to $9.88\times10^{-3}$ lb/sec-in.$^2$) and external air stream Mach numbers from 0 to 0.46. It was concluded that, within the range of test conditions investigated, the porous-material flow characteristics were not affected by external airflow parallel to the discharge surface.

## INTRODUCTION

An experimental analysis was conducted to evaluate the effects of gas flow over the outside surface of a transpiration-cooling material on the flow characteristics of the air transpiring through the porous wall.

This study is the third in a series undertaken by the NASA Lewis Research Center to develop methods for predicting coolant airflow distributions in a transpiration-cooled gas-turbine blade or vane. In the first of these studies (ref. 1), the flow characteristics of both wire-form and laminate-form porous materials used for transpiration cooling were correlated with geometrical parameters for these materials. It was demonstrated that these correlations could be successfully applied to predict flow rates with air temperatures up to 722 K (840$^\circ$ F) and with porous sheet curvatures as high as 0.25 cm (0.10 in.). The flow correlations derived for the wire-form porous material were used in a subsequent study (ref. 2), in which an analysis was developed for predicting airflow rates and pressure distributions in the coolant distribution passages of a transpiration-cooled vane and the discharge flow rates from the porous airfoil shell. The analytical model was verified by the good agreement between flow rate and pressure predictions and experimental data obtained from cold-flow tests on a transpiration-cooled vane with the use of a bench-type flow facility. However, the vane cold-flow tests did not completely determine how well the airflow distribution could be predicted in the transpiration-cooled vane, because these tests were not conducted with gas flowing along the airfoil surfaces, as would be the case in actual engine operation. In references 3 and 4, tests were conducted on perforated plates under normal- and parallel-flow conditions with free-stream Mach numbers from 0.2 to 1.3. The flow data from these tests indicated that the parallel-flow condition reduced the normal flow through the perforated plates for a given pressure drop. Therefore, a distinct possibility existed that the flow characteristics of the transpiration-cooled material in an engine environment could be substantially different from those determined from cold-flow tests in a static environment. The likelihood of this effect occurring increases as the thickness of the porous material is reduced, because the internal passages in the porous material tend to behave more like small orifices, as in the perforated plates tested in references 3 and 4.

The purpose of this investigation was to determine if gas flow parallel to a porous transpiration-cooled surface affects the flow characteristics of the porous material and to analyze these effects if they are significant. Experimental data were obtained from cold-flow tests in a bench-type facility with gas-stream flow parallel to the airflow discharge surface of a flat, porous specimen. Measurements of the airflow through the wire-form porous specimen were taken over a range of specific flow rates from 0.129 to 0.695 g/sec-cm$^2$ ($1.83\times10^{-3}$ to $9.88\times10^{-3}$ lb/sec-in.$^2$). Flow data were compared for free-stream Mach numbers from 0 to 0.46. The porous material was of the same type and geometry as the material used for the airfoil of the transpiration-cooled vane studied in reference 2. The thickness of thes material, 0.061 cm (0.024 in.), was considered the practical minimum for a transpiration-cooled airfoil because of structural considerations such as resistance to impact by foreign objects. Therefore, if the external gas stream was found to have no effect on the flow characteristics of this material, it probably would not affect the flow characteristics of any transpiration-cooled vane or blade.

## APPARATUS AND PROCEDURE

### Test Specimen

The porous specimen shown in figure 1 was fabricated from Poroloy, a wire-wound material manufactured by the Bendix Corporation; this material was also used in the

2.79 cm by 2.79 cm (1.1 in. by 1.1 in.) because of the presence of a weld-affected zone around the edges.

## Flow Test Apparatus and Procedure

The flow facility is shown in figure 2, and the system and associated instrumentation are illustrated in figure 3. Secondary air at 86.2 $N/cm^2$ (125 psig) was supplied to the test specimen through a filter, two pressure regulators in series, a calibrated nozzle mass flowmeter, and a plenum chamber. Airflow parallel to the specimen discharge surface was ambient air drawn through a tunnel by means of a vacuum system. The free-stream Mach number in the tunnel was determined by measuring the total and static

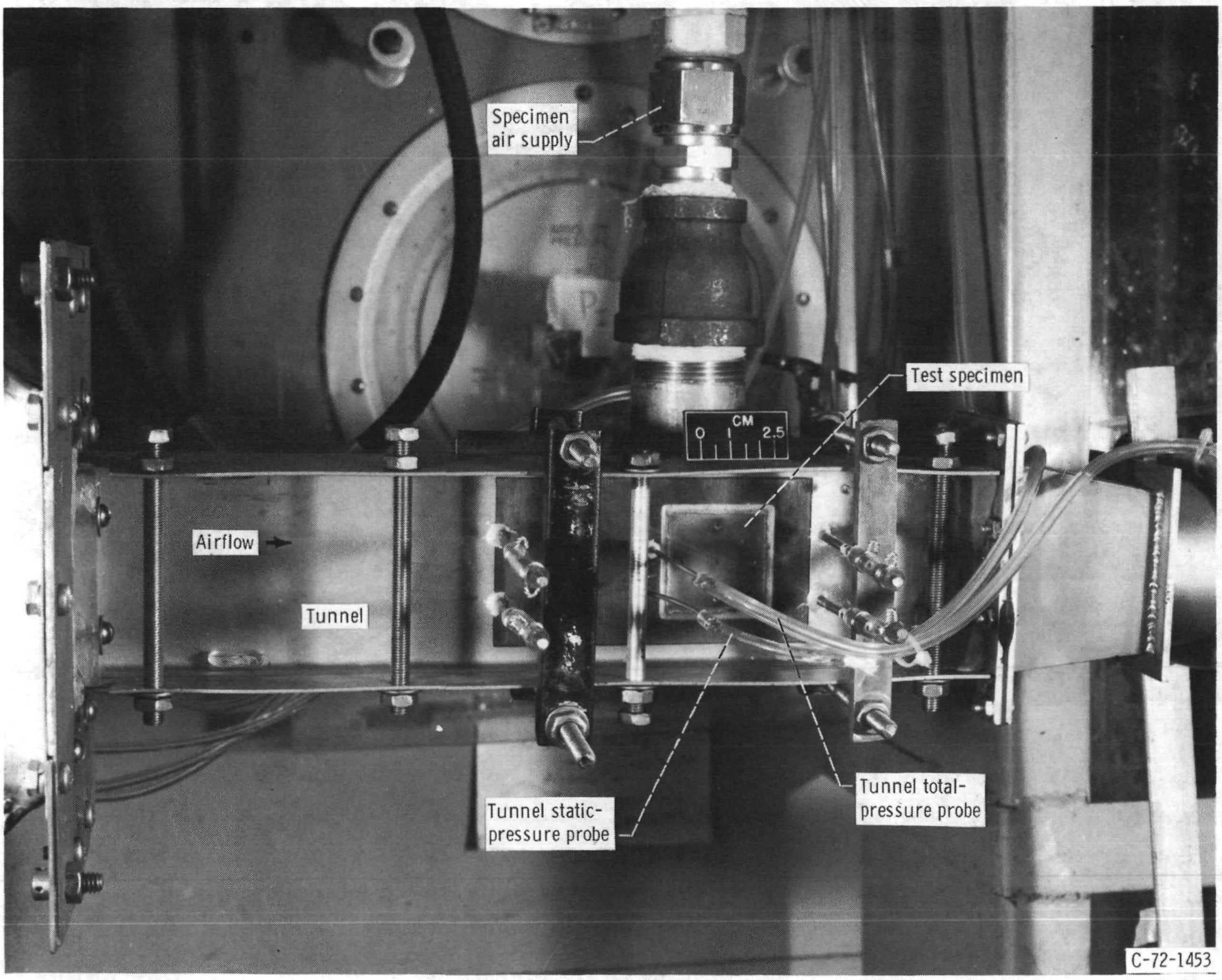
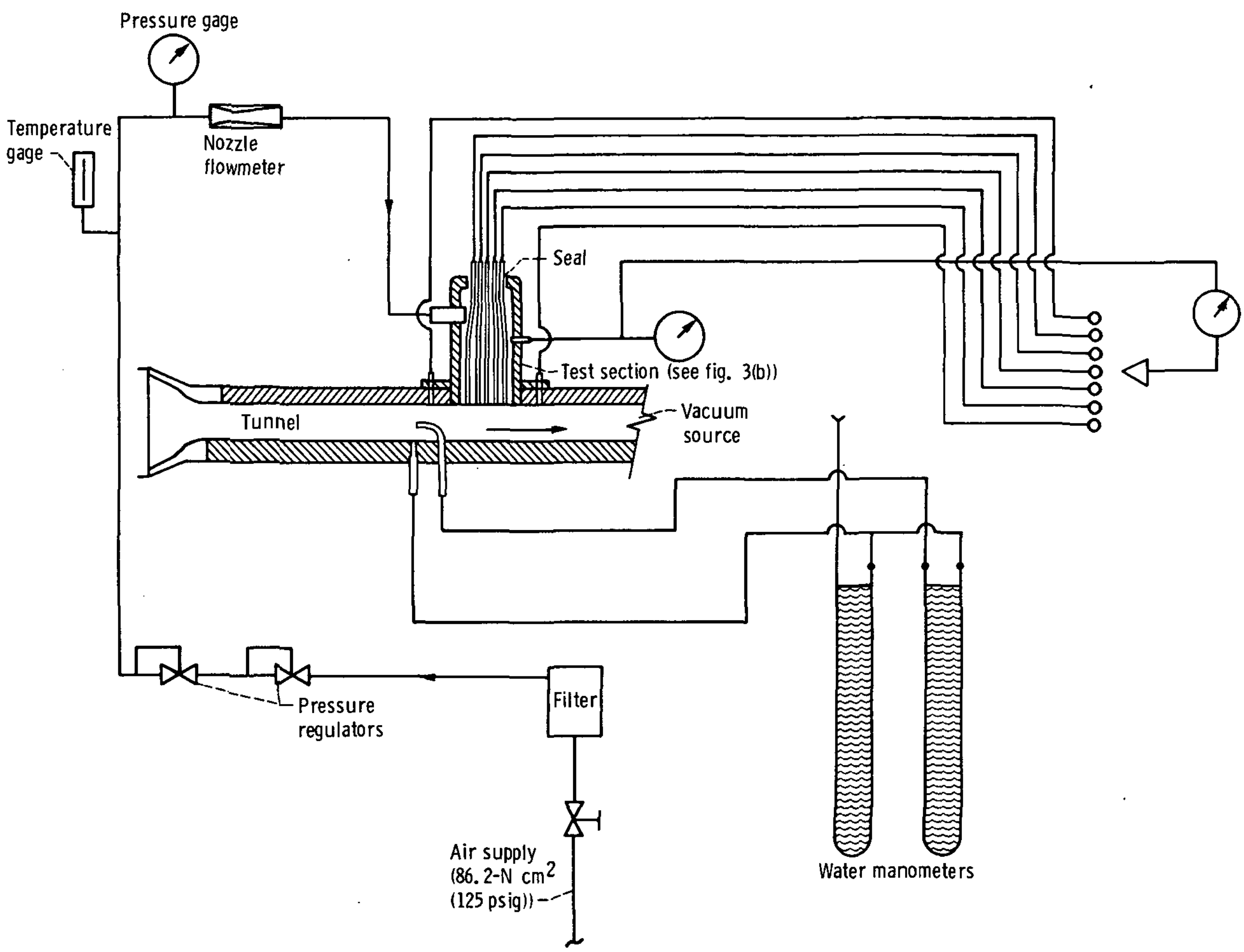
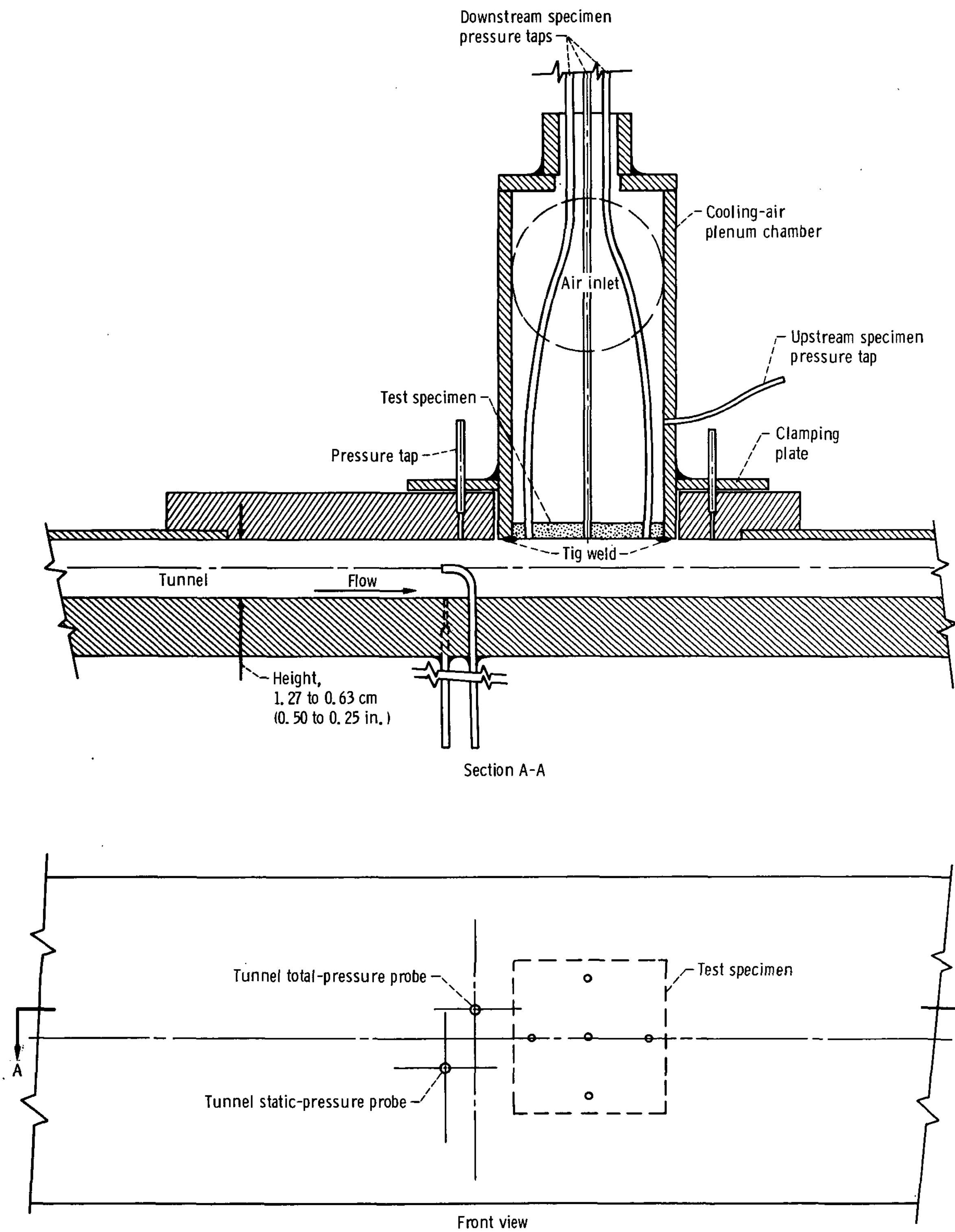



Figure 2. - Test facility.




(a) Test setup.

Figure 3. - Flow test apparatus.




(b) Test section.

Figure 3. - Concluded.

tunnel pressures with water manometers accurate to ±0.13 cm (0.05 in.) of water.

The flow rates through the test specimen were controlled by the pressure regulators and measured by the nozzle flowmeter, with an assumed system minimum accuracy of ±2 percent of the measured value. The specimen upstream static pressure was obtained by measuring the pressure in the cooling-air plenum, while the downstream static pressure was obtained by measuring the differences between the plenum pressure and a series of pressures across the downstream side of the specimen and subtracting the average difference from the plenum pressure. The pressure gages were of the Bourdon type, with accuracies of ±0.25 percent of full scale. Initially, tests were conducted at zero Mach number, with the specimen removed from the tunnel and the airflow through the specimen being exhausted into the atmosphere. Tests were then conducted with the specimen installed in the tunnel, at a free-stream Mach number of 0.40. In an attempt to increase the gas-stream Mach number, the tunnel height was decreased from 1.27 cm (0.50 in.) to 0.63 cm (0.25 in.); this was the minimum practical height to which the tunnel could be reduced and resulted in only a slight increase in free-stream Mach number from 0.40 to 0.46. The airflow rates through the porous specimen were progressively increased by varying the pressure difference across the specimen from 4 to 24 $N/cm^2$ (6 to 35 psi). The Poroloy specimen discharge pressure varied from 9.9 $N/cm^2$ (14.4 psia) for atmospheric discharge tests to 8.6 $N/cm^2$ (12.5 psia) during the tests with a free-stream Mach number of 0.46.

## RESULTS AND DISCUSSION

The experimental flow data are correlated in figure 4 in terms of the parameter $(P_1^2 - P_2^2)g/2\mu RT\tau G$ as a function of $G/\mu$. These parameters were derived from the so-called Green equation for fluid flow through a porous medium, which was originally presented in reference 6. This equation can be presented in a modified form as

$$\frac{\left(P_1^2 - P_2^2\right)g}{2\mu RT\tau G} = \alpha + \beta\left(\frac{G}{\mu}\right) \tag{1}$$

where the symbols are defined in the appendix. It is apparent that the left side of equation (1) is a linear function of $G/\mu$. The flow resistances or characteristics of the porous material, $\alpha$ and $\beta$, are the intercept and slope, respectively, of the line.

Experimental results for the condition with airflow discharging into the atmosphere (zero Mach number) and for tunnel free-stream Mach numbers from 0.40 to 0.46 are compared in figure 4. A straight-line curve fit was drawn through the data points repre-

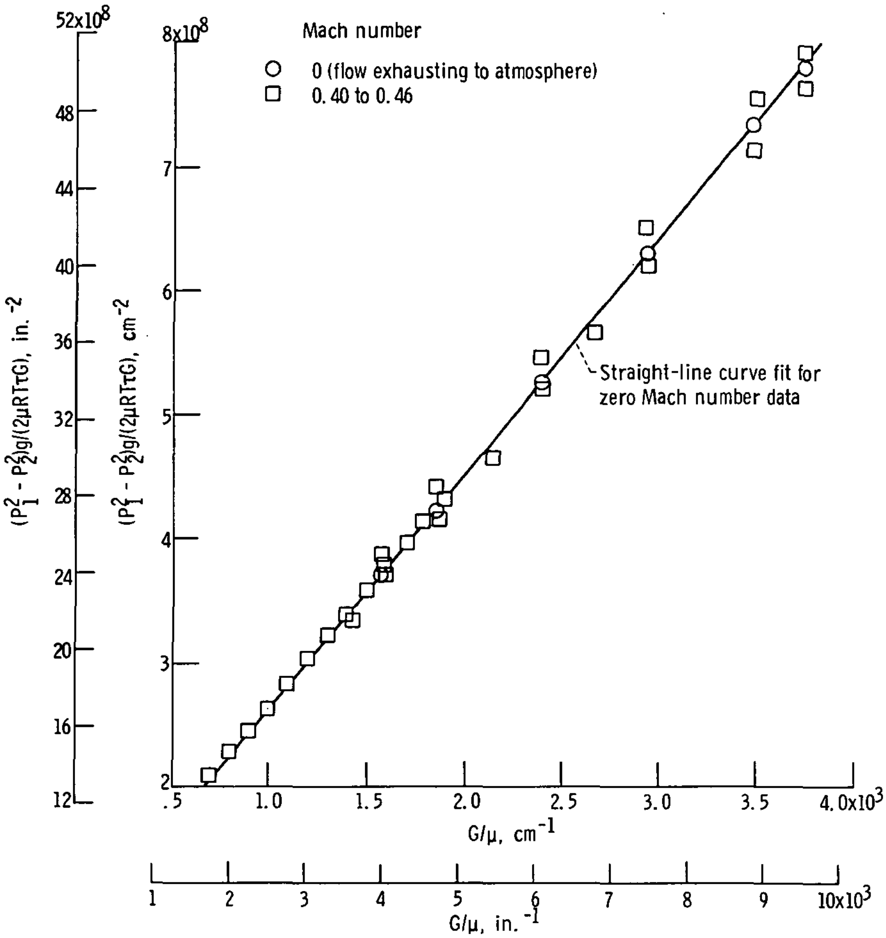



Figure 4. - Effect of external gas-stream Mach numbers up to 0.46 on Poroloy specimen flow characteristics.

senting zero Mach number. The external gas flow data scattered around both sides of this base line with a maximum deviation of 4 percent.

The excellent correlation shown in figure 4 between test results for external gas stream flow and test results for transpiring airflow exhausting to the atmosphere demonstrated that there was no significant effect of gas-stream crossflow on the Poroloy flow characteristics up to a free-stream Mach number of 0.46. The linearity of the data in figure 4 also confirmed that even with gas-stream flow across the discharge surface, the transpiration flow obeys the standard flow relation for a porous material as defined by the Green equation.

## SUMMARY OF RESULTS

This investigation of parallel gas cross-flow effects on flow through a wire-form transpiration-cooling material yielded the following results:

1. In comparison with tests performed under static ambient conditions, gas stream flow up to a Mach number of 0.46 across the discharge surface of the porous material has no significant effect on the flow characteristics of the material.

2. Transpiration coolant flow combined with external gas cross flow obeys the standard flow relation for a porous medium as defined by the Green equation.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, October 18, 1972,
501-24.

# APPENDIX - SYMBOLS

| | |
|---|---|
| G | airflow rate per unit area |
| g | universal gravitational constant |
| $P_1$ | upstream static pressure |
| $P_2$ | downstream static pressure |
| R | gas constant |
| T | static temperature |
| $\alpha$ | viscous resistance coefficient |
| $\beta$ | inertial resistance coefficient |
| $\mu$ | viscosity |
| $\tau$ | specimen thickness |

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