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A STUDY OF TRANSPIRATION FROM PERFORATED FLAT PLATE

BY

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ABSTRACT

This paper presents an experimental and analytical study for the transpiration through perforated plates. Water was used as the coolant to absorb heat by vaporization as it is drawn along the surface by the hot mainstream air.

The experiments were performed in a wind tunnel with test plates mounted at the center line of the test section. The rate of mass transfer during a data run was determined by direct weightings of the test elements before and after the run.

The object of this study was to provide a better understanding for the transpiration cooling and to set up a computer program in FORTRAN language encompassing the analytical treatment of transpiration cooling to help the researchers in this field.

NOMENECLATURE

M	Blowing ratio; $(\rho u)_{injection} / (\rho u)_{mainstream}$.
η	Film cooling effectiveness; $\Theta(X,Y,Z)/\Theta(X,O,O)$; (Mainstream Temperature - Surface Temperature) / (Mainstream Temperature - Injectant Temperature).
m_{sl}	Mass flow rate per slice
w_t	Total mass flow rate
u	Velocity
ρ	Density

INTRODUCTION

The overall efficiency of gas turbine engines can be improved considerablly by an increase of the maximum temperature of the thermodynamic cycle, i.e. the turbine inlet temperature operation at higher temperatures is possible if the blades are cooled down to the allowable temperatures which limited by the blade material [1 - 12]

One of the most promising techniques of cooling the outer surface of gas turbine blades, combustion chamber walls and flame tube surfaces is the transpiration cooling. In this method the wall is manufactured from a porous material. The coolant film on the hot gas side is, therefore continuously renewed and cooling effectiveness can be made to stay constant along the surface. In this process as it drawn along the surface by the mainstream. Substantially it is increased the effectiveness [13] .

Due to the strength problem, it is unlikely that porous material will be used but that a number of discrete holes will be machined into the surface of hollow blades filled with woven - steel wires. This will retain the mechanical strength of the structure and avoid blockage of pores which could occur with porous materials when used and also minimize the effects of oxidation.

The aim of this study was to provide a numerical approach for transpiration cooling in the absence and presence of different pressure gradients cases to simulate the main surfaces of combuster liners, flame tubes and turbine blades. Also, to set up a computer program for accelerating the calculations of the transpiration effectiveness to help the researchers in this field. Experiments have been performed to verify these predictions.

As recommended by Mayle (18) the laterally averaged film cooling effectiveness following injection through a row of holes is

$$\tilde{\eta}_v(X) = \frac{1}{Z}\int_{-P/2}^{P/2} \eta(X, Z)\,.\,dZ \qquad - - - - \tag{5}$$

where P is the distance between two adjacent holes centerlines and η (X, Z) is the film cooling effectiveness distribution for a row of holes. If there were no interaction between the jets along the row the lateral temperature distribution for a row of holes could be found by the principle of superposition, i. e summing up the contributions to the film cooling effectiveness from each individual hole in the row as seen in figure 8b.

If η_1 and η_2 are the film effectivenesses, from the individual first and second row of holes is given by

$$\tilde{\eta} = 1 - (1 - \eta_1)(1 - \eta_2)$$

for additional rows this becomes

$$\hat{\eta} = 1 - (1 - \eta_1)(1 - \eta_2)(1 - \eta_3)$$

or

$$\tilde{\eta} = 1 - EXP\left[\sum^{K} \ln(1 - \tilde{\eta}_K)\right] \qquad - - - \tag{6}$$

from equation (6), the average film cooling effectiveness at any location in the streamwise direction can be obtained without measuring the surface temperatures.

A COMPUTER PROGRAM FOR FULL COVERAGE FILM COOLED SURFACE :

A computer program 'MT 1' has been developed for predicting the average film cooling effectiveness including pressure gradients effect.

The program constructed with a main program and three subroutines:

Subroutine IINT for obtaining the average laterally film cooling effectiveness for each row of holes.
Subroutine DRIV for experimental data interpolation .
Subroutine INTEX for Lagrange technique (General case; intervals are not equal), this subroutine based on the analytical treatment reported in references (15, 16) .

The program is in FORTRAN IV language and is operational on PERKIN - ELMER 1625 system, 128K computer. Execution time for one run is typically less than 10 seconds.

Input :

For each run, (N) Number of locations in the streamwise direction at which the velocites has been measured, (EPPS = EPSS) the thermal diffusivity, (EM = EMM) blowing ratio, (UF = UFF) mainstream velocity. Further required geometry input is shown in figure 8c . Additional input quantities as the physical properties of the fluids must be given (obtained from reference 17).

Output :

For each run, the program output consists of a listing of the geometric variables and the calculated average film cooling effectiveness (ETN = average F.C.F.C. effectiveness upstream the injection row of holes, ETP = average F.C.F.C. effectiveness downs tream the row of injection holes.

NUMERICAL RESULTS

Analytical results for plates '1, 2', for fifferent blowing rates are shown in figures 10, 11 . Attention will now be return to the experimental results (figure 7 (a, b, c)).

For blowing rate equal 5×10^{-5} there is a good agreement between the experimental and analytical results obtained from the computer program, for the film cooling effectiveness up to X / D = 50. For X / D > 50 there are a little differences between the experimental and analytical results. The differences are due to the effects of the blowing rate 'M'. The experimental work was based on the actual value of 'M', but the analytical results were based on an average value across the stream wise direction. therefore some modifications in the analytical treatment must be done to encompassing the effects of the blowing rate on the film effectiveness. Fig 12 summarized the output of the computer program for plate '1', compared with the experimental results. For an economical scheme, a suggested holes geometry is predicted as follows:

coolant rate = 0.00005
spanwise pitch / hole diameter = 3.0
streamwise pitch / hole diameter = 1.6
F.effectiveness = 0.18 : 0.28

CONCLUSION

The present study provides a computer program in FORTRAN language designed for accelerating the numerical solution of the transpiration cooling technique to help the researchers in this field. The program encompassing the relation between the effectiveness, blowing rate, injection hole diameter, and hole spacing in the light of the full coverage film cooling studies.

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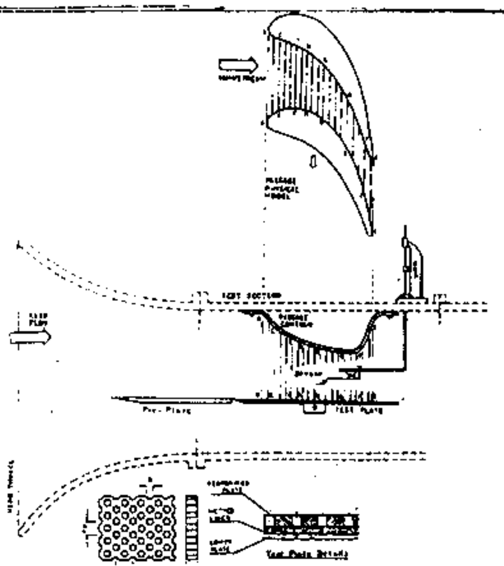
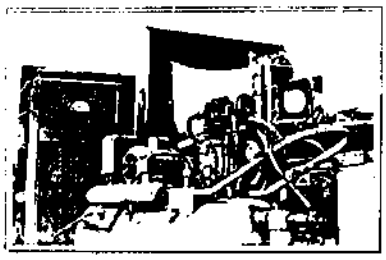


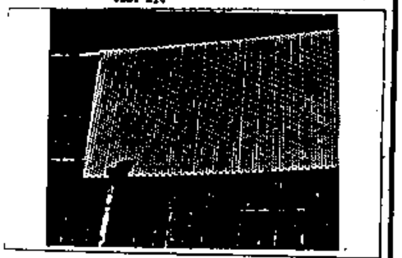
TABLE 1

	[illegible]	[illegible]	[illegible]	[illegible]
PLATE 1	9.0	5.0	3.0	3.0
PLATE 2	16.0	11.0	3.0	3.0

FIG. 1(b), SCHEMATIC DIAGRAMS OF THE TEST RIG AND THE TEST PLATES.



TEST RIG



TEST PLATE

FIG. 1(a) TEST RIG AND TEST PLATE

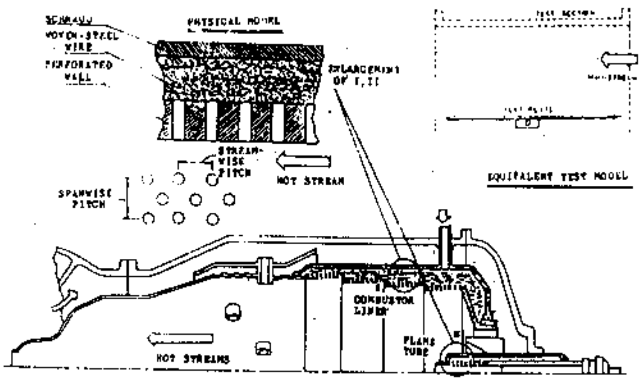


FIG. 2, SUGGESTED MODELS FOR COMBUSTOR WALL AND FLAME TUBE COOLED BY TRANSPIRATION.

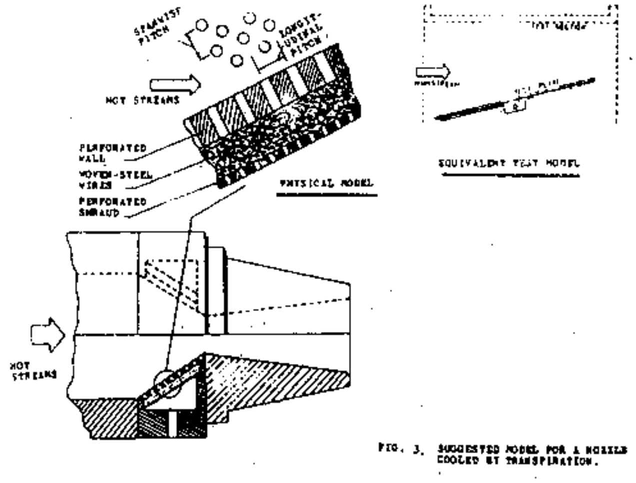


FIG. 3. SUGGESTED MODEL FOR A NOZZLE COOLED BY TRANSPIRATION.

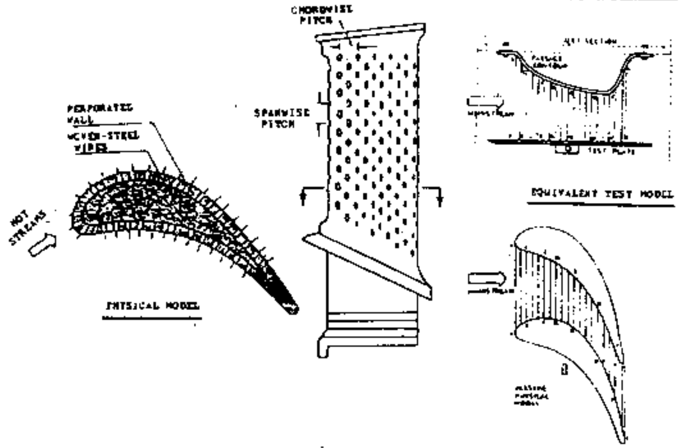


FIG. 4, SUGGESTED MODEL OF A TURBINE BLADE COOLED BY TRANSPIRATION.

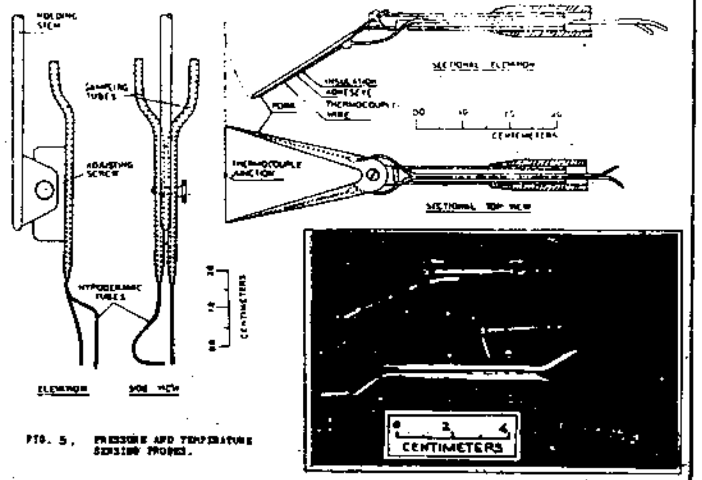
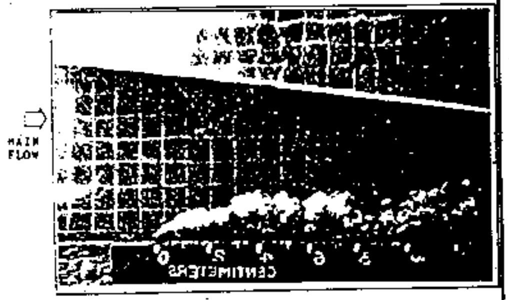


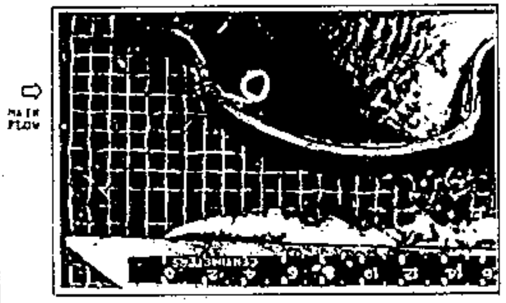
FIG. 5, PRESSURE AND TEMPERATURE SENSING PROBES.

A) ZERO PRESSURE GRADIENT.

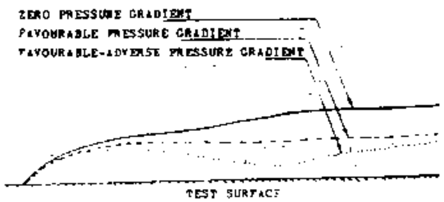


B) FAVOURABLE PRESSURE GRADIENT.

FIG. 6 VISUALIZATION STUDY FOR THE EFFECTS OF PRESSURE GRADIENTS ON FILM INJECTION.



C) FAVOURABLE -ADVERSE PRESSURE GRADIENT.



D) COMPARISON BETWEEN THE AVERAGE OUTER EDGE OF A FILM COOLED SURFACE IN ABSENCE AND PRESENCE OF PRESSURE GRADIENTS.

FIGURE 6 (CONTINUE).

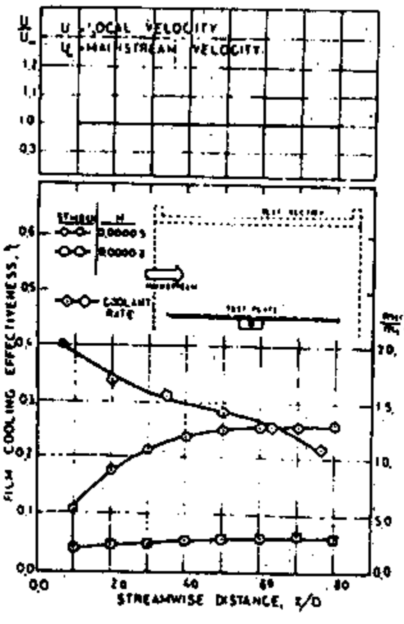


FIG. 7a, FILM COOLING EFFECTIVENESS

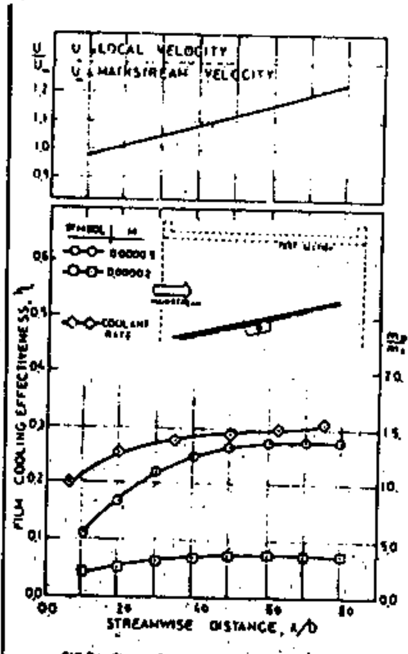


FIG. 7b, FILM COOLING EFFECTIVENESS

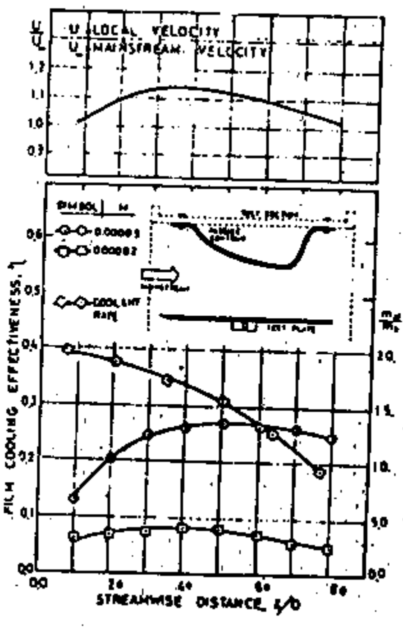


FIG. 7c, FILM COOLING EFFECTIVENESS

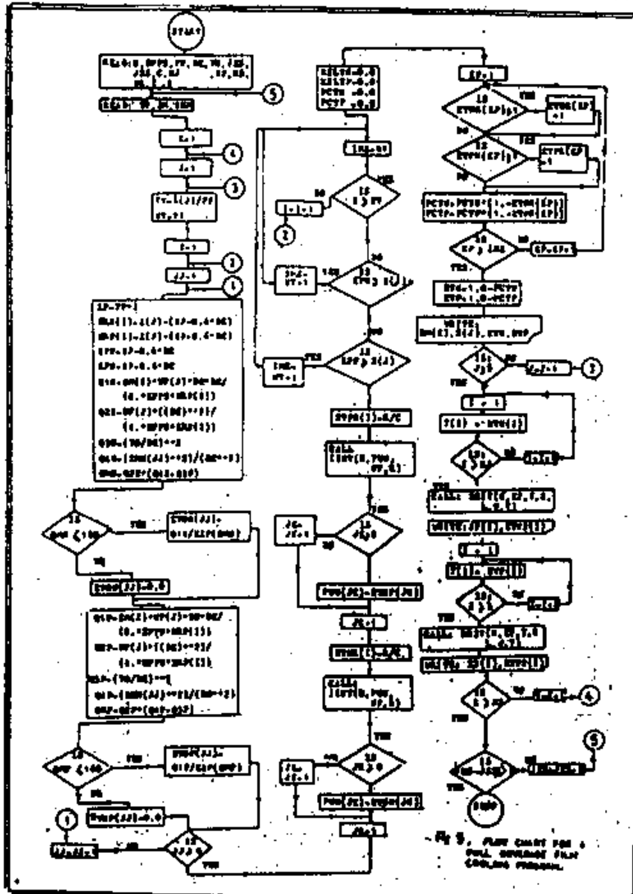


Fig 9. FLOW CHART FOR A FULL COVERAGE FILM COOLING PROGRAM.

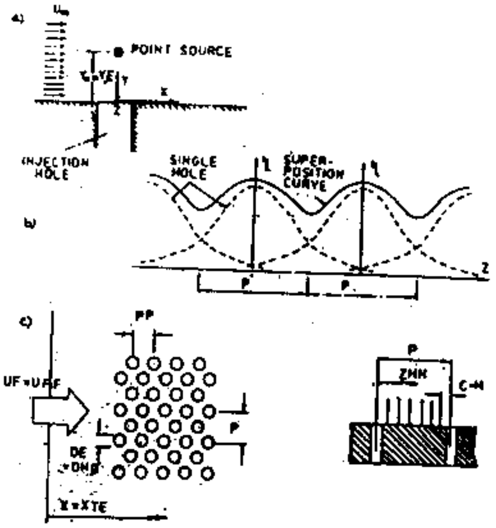


FIG. 8, COMPUTER PROGRAM GEOMETRY INPUT.

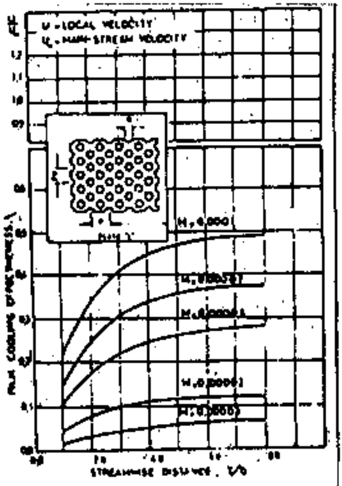


FIG. 10a, FILM COOLING EFFECTIVENESS (ACCORDING TO "MT 1" PROGRAM)

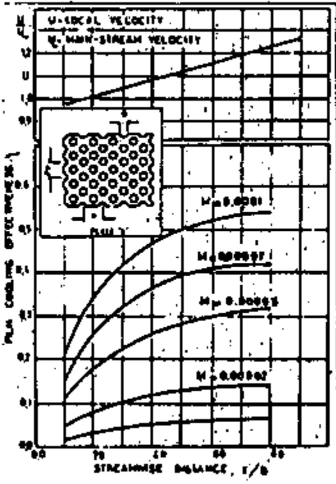


FIG. 10b, FILM COOLING EFFECTIVENESS (ACCORDING TO "MT 1" PROGRAM)

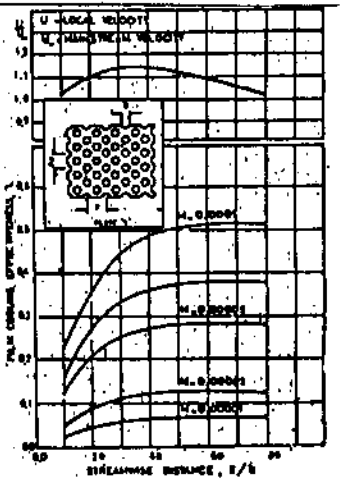


FIG. 10c, FILM COOLING EFFECTIVENESS (ACCORDING TO "MT 1" PROGRAM)

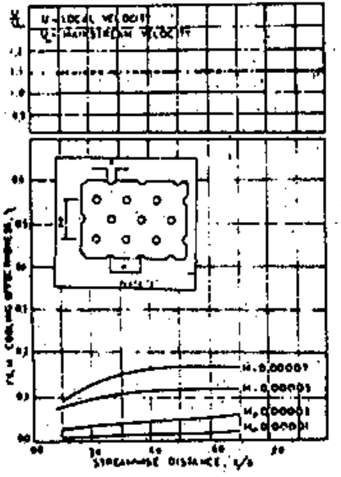


FIG. 11a, FILM COOLING EFFECTIVENESS (ACCORDING TO "MT 1" PROGRAM)

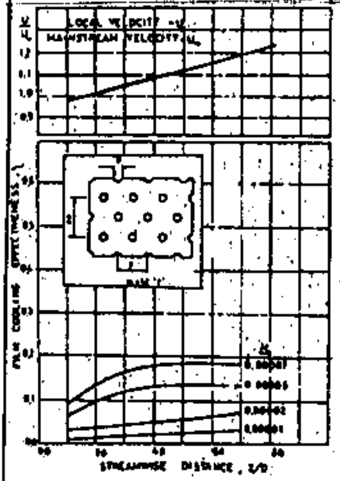


FIG. 11b, FILM COOLING EFFECTIVENESS (ACCORDING TO "MT 1" PROGRAM)

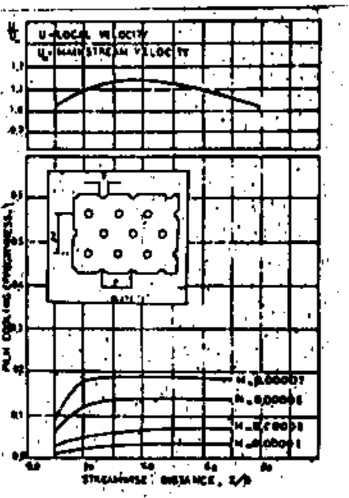


FIG. 11c, FILM COOLING EFFECTIVENESS (ACCORDING TO "MT 1" PROGRAM)

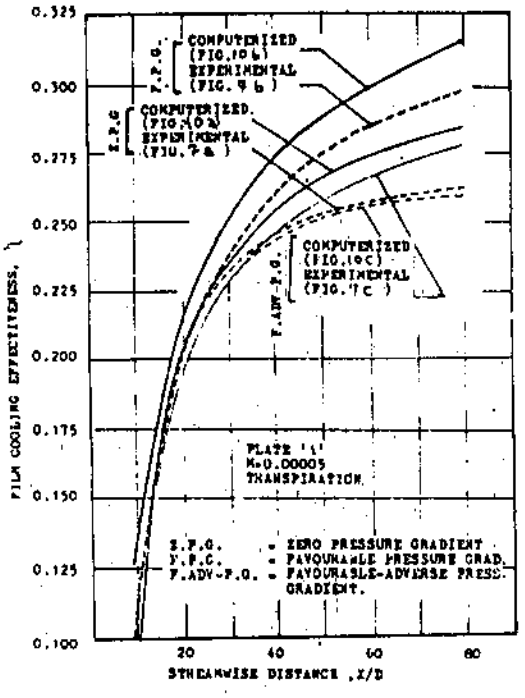


FIGURE 12 COMPARISON BETWEEN COMPUTERIZED AND EXPERIMENTAL VALUES OF THE FILM COOLING EFFECTIVENESS.