"INFLUENCE OF INJECTION ON SURFACE
PRESSURE COEFFICIENTS FOR AN
AEROFOIL MODEL"

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A B S T R A C T

This paper gives some lights about the change in surface
pressure coefficients for an aerofoil model due to the normal
and tangential injection at the leading edge of the test model.
Effects of accelerated and decelerated main flows ($\vartheta = \pm\ 3^{\circ}$)
also had been investigated with and without injection. In all
cases of flow types, the injection through a row of normal holes
gives a high absolute values of surface pressure coefficient
only near the leading edge. But tangential injection gives mo-
derate increase in absolute value of surface pressure coeffi-
cient along the aerofoil surface. The greater injection para-
meter, the bigger change in pressure coefficient and the bigger
absolute value of pressure coefficient.

NOMENCLATURE

B	injection parameter, (u_2/u_∞)
c	aerofoil chord length, mm
c_p	surface pressure coefficient $= (p - p_\infty)/\frac{1}{2}\rho u_\infty^2$
p	surface pressure, N/m^2
p_∞	mainstream static pressure, N/m^2
s	aerofoil surface length in flow direction, mm
t	aerofoil thickness, mm
u_2	secondary air velocity, m/sec
u_∞	mainstream velocity, m/sec
x	coordinates in aerofoil direction
x_p	chordwise surface distance, mm
$\bar{x}$	non-dimensional length $= x_p/s$
y	coordinate normal to aerofoil chord direction

1- Introduction

The continuous increase in specific power and thermal efficiency of a modern gas turbine has led to high turbine inlet temperature while maintaining the skin of the blades at relatively low temperature for long life expectancy. This low temperature can be obtained by injecting a coolant flow through holes distributed along the surface of the structure.

Injection technique has been widely employed in the modern technology specially in cooling of combustion chambers [1], gas turbine blades [2], and for drag reduction in aircraft applications [3] which is important in improving the aerodynamic performance.

The present work gives an experimental study about the effects of the injection in boundary layer on the surface pressure coefficients for aerofoil immersed in a mainstream flow. Due to the complexity of the aerodynamical process of injection in the boundary layer [4], the prime object of the present experiments was to obtain a better understanding for the change in the surface pressure coefficients due to the injection techniques with negative and positive pressure gradient for an aerofoil test model.

2- Apparatus And Operating Conditions

The present investigation is carried out in an open wind tunnel which provides the test surface with a uniform stream at controlled velocities. These velocities range between 15 to 30 m/sec. The tunnel is illustrated in Fig.1.

The test section of the wind tunnel is 300 x 300 mm in cross-section. A photograph for the test model and test section describing the different parts is given in Fig.2.

The aerofoil is symmetrical with total length of 155 mm and a maximum thickness of 20 mm. Major dimensions of the test model are shown in Fig.3a. 12 surface pressure taps for measuring the pressure distribution were arranged on the aerofoil surface.

The test model supported horizontally at the center of the test section on a steel spindle through a divided angle as shown in Fig.3b. This is to examine the effects of the accelerated flow effects at different angles of inclination.

The secondary air is supplied by a reciprocating compressor, plenium tank, regulating valve and metering orifice. The compressed air passes through a needel valve, thin caliberated orifice for measuring the injectant flow rate, and an air distributer that can make a uniform film formation.

The injected air is introduced to the leading edge of the aerofoil model through a different two injection models Fig.3c. One of them to examine the effects of the normal injection and the other for tangential injection. The injection holes have 2.5 mm diameter. Sketches of the injection models configurations are given in Fig.3-d.
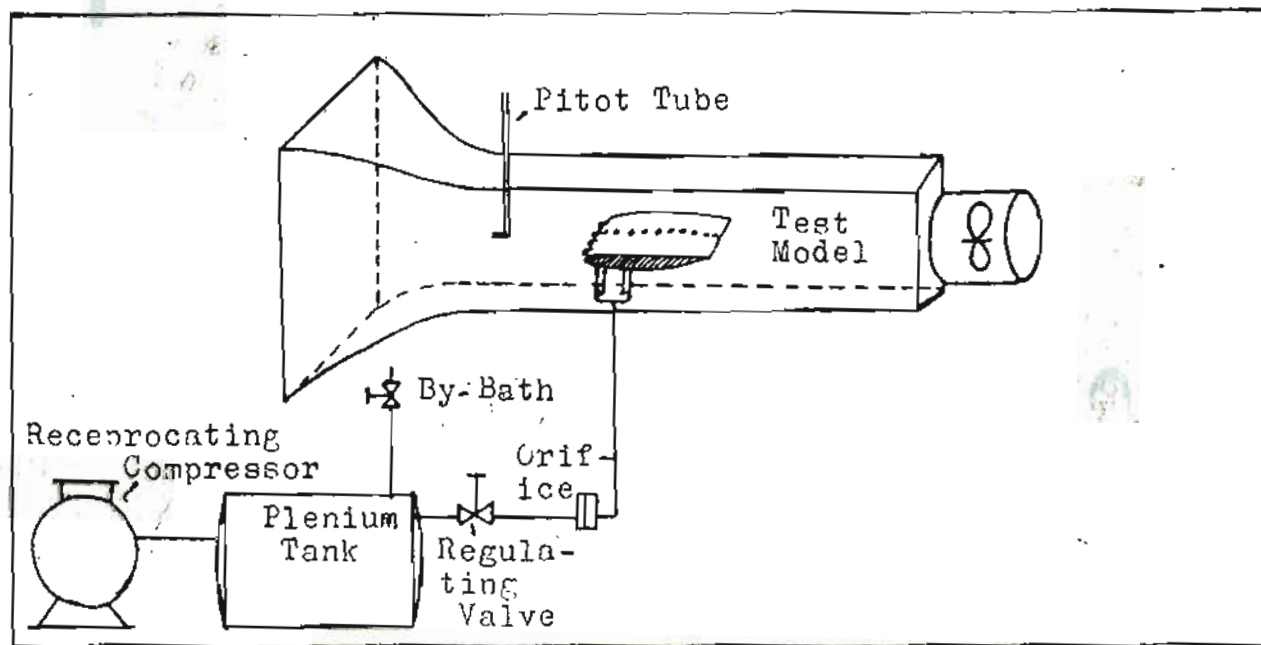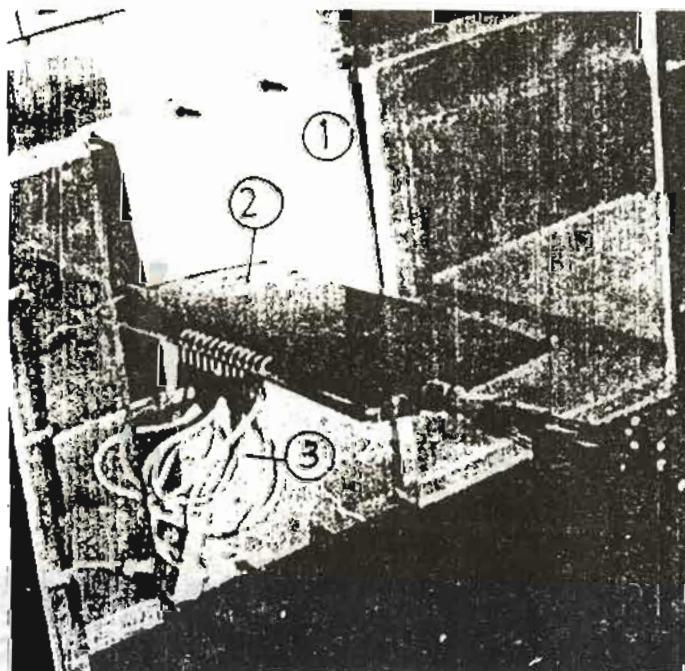
FIG. 1 SCHEMATIC DIAGRAM OF TEST APPARATUS.

FIG. 2 A PHOTOGRAPH FOR THE TEST MODEL AND TEST
       SECTION;
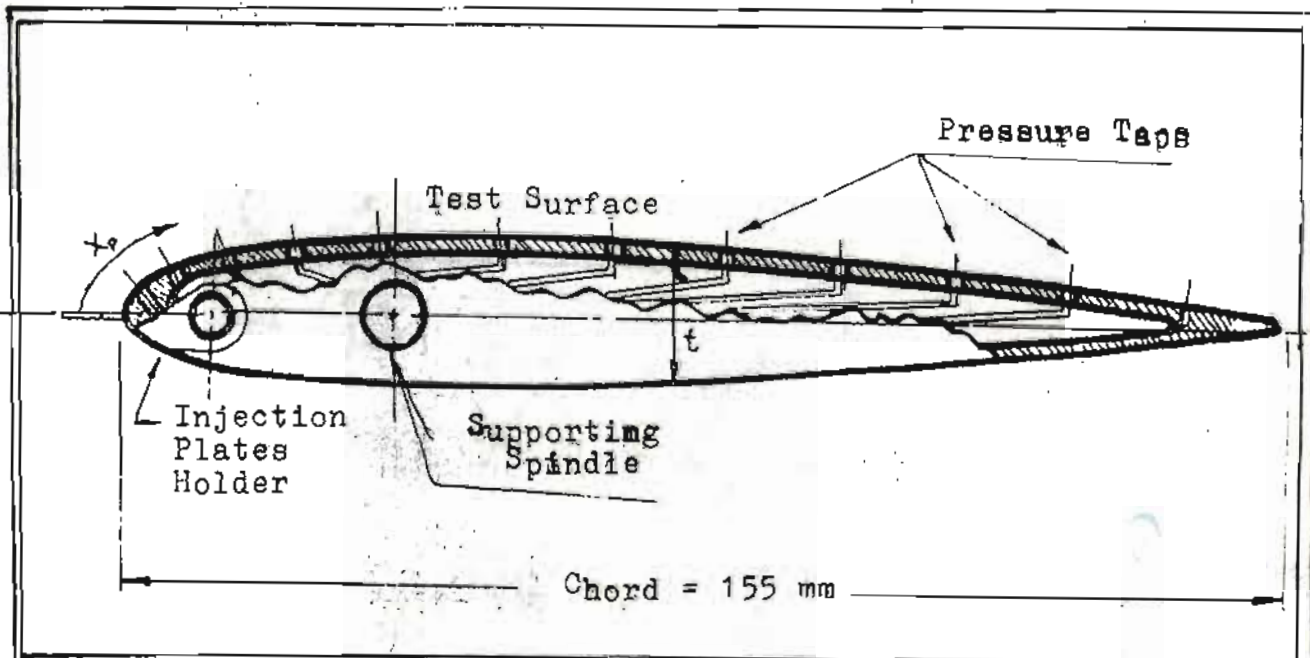   1- Test section, 2- Test model,
    3- Air Distributer.

Pressure Taps

Test Surface

Injection
Plates
Holder

Supporting
Spindle

t

Chord = 155 mm

FIG. 3a BASIC TEST MODEL CONFIGURATION

Test Model

Pressure Taps

Injection
Tubes

Pressure
Measuring
Tubes

Air Distributer

Secondary
Air
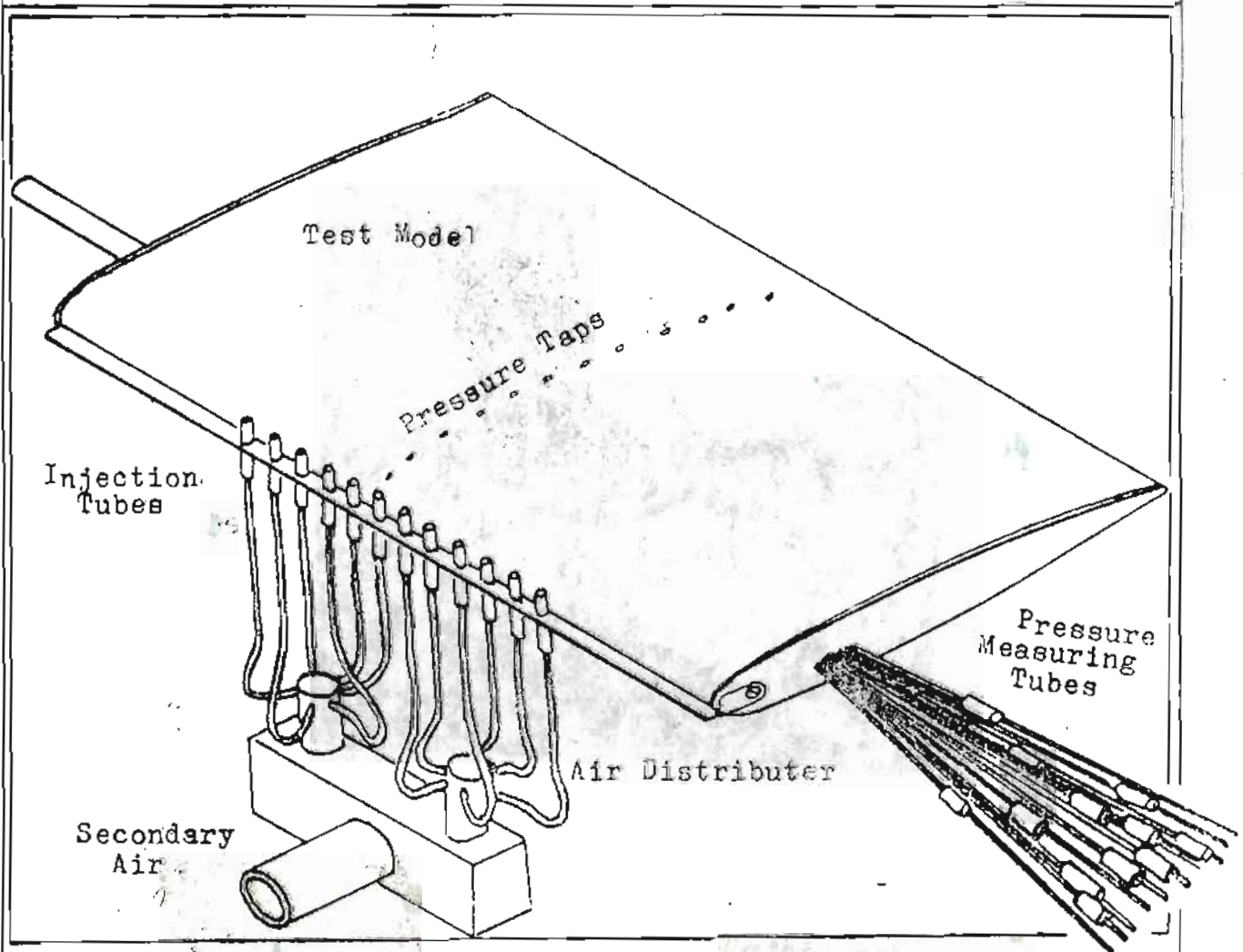
FIG. 3b TEST MODEL ASSEMBLY

u_2 secondary flow   x chordwise direction

u_∞ main flow   y normal direction

z spanwise direction

(Tangential Injection)   (Normal Injection)
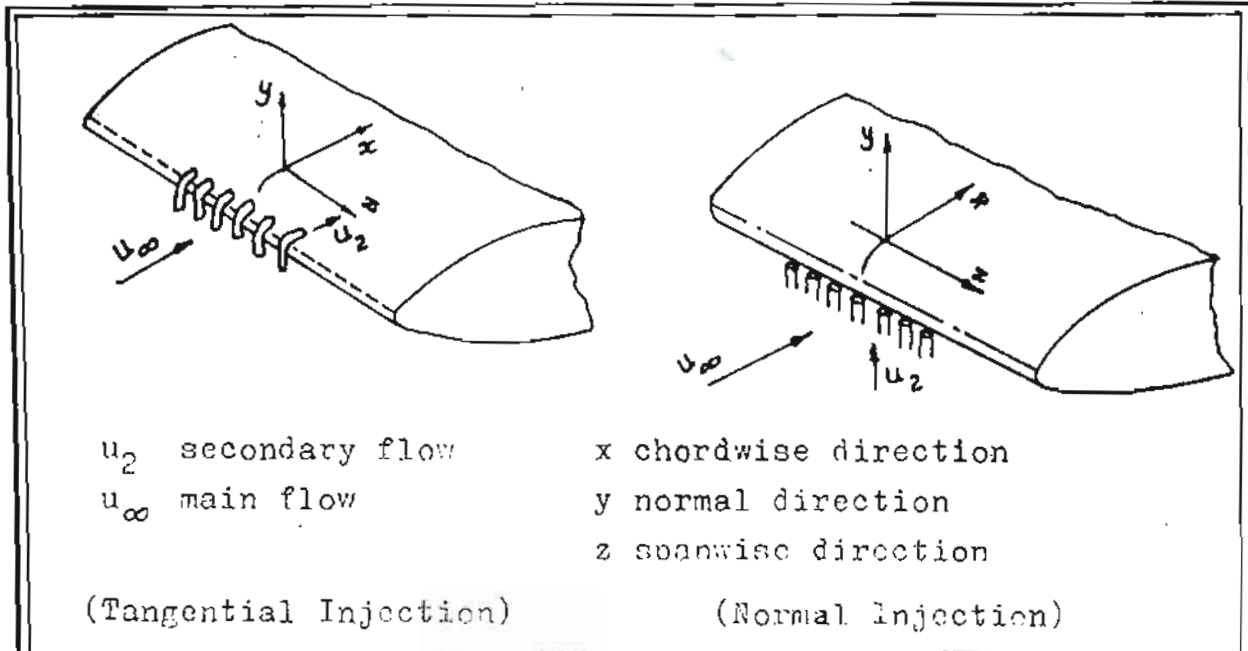
FIG. 3c   COORDINATES DEFINITIONS FOR DIFFERENT INJECTION
TYPES

Section At
A - A

Section At
B - B

d = 2.5 mm
D = 4.4 mm
P = 3 D
W = 3 D

Tangential Injection Edge   Normal Injection Edge
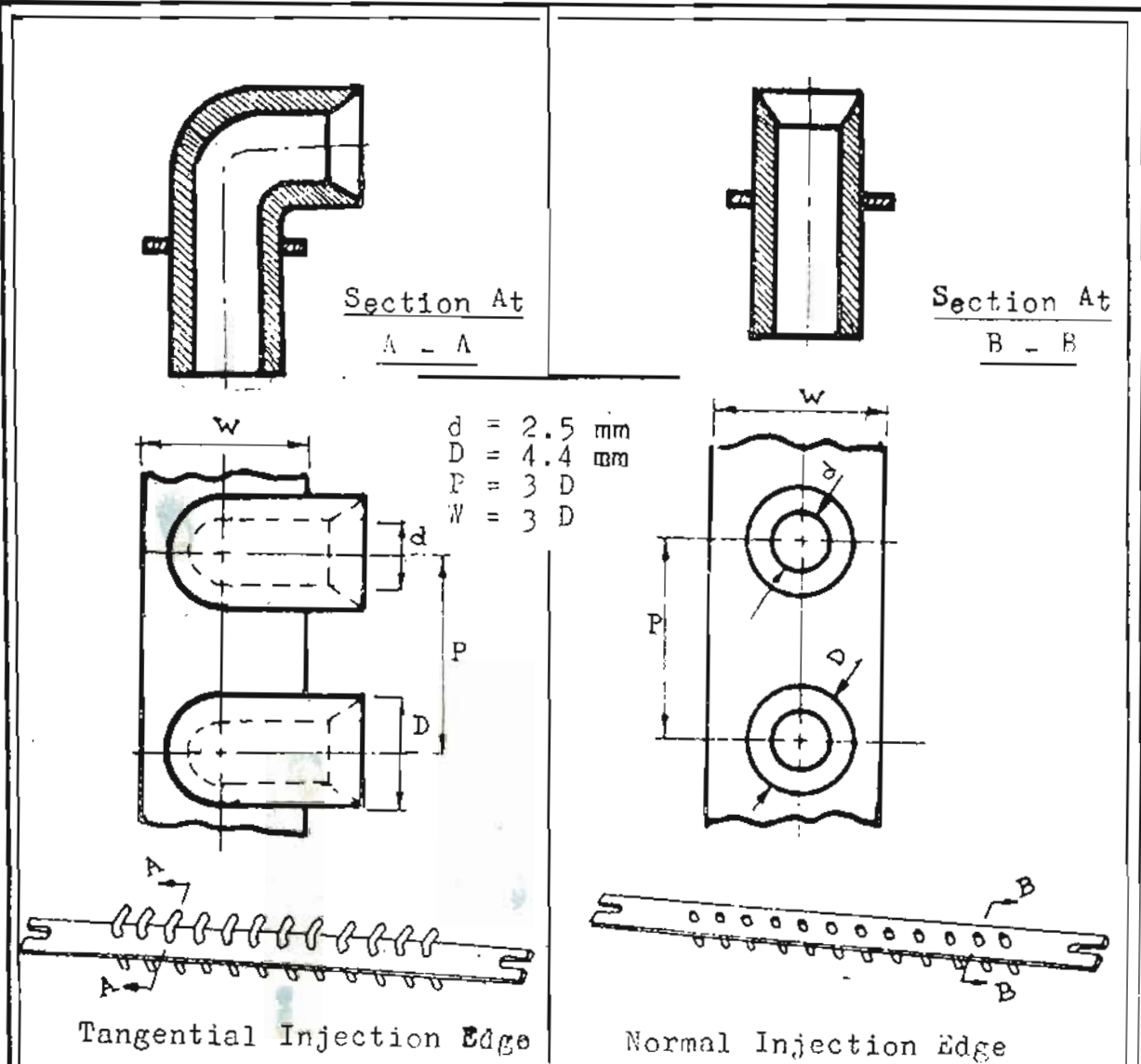
FIG. 3d   INJECTION EDGES CONFIGURATIONS

3- Controling Parameters

The surface pressure coefficient can be obtained by applying Bernoulli equation between a point in free stream and any point at aerofoil surface. It is given by the following relation [5]:

$$c_p = (p - p_\infty)/\frac{1}{2}\,\rho_\infty\,u_\infty^2$$

where:

- p : pressure on aerofoil surface
- p_∞ : mainstream pressure
- u_∞ : mainstream velocity
- ρ_∞ : mainstream density

For a given value of u_∞ the pressure difference can be measured and c_p can be evaluated.

4- Test Results And Discussion

The results obtained from experiments of the present work are reported as follows:

4-1 Normal Injection

In this case the air mainstream flows around the band of the jets. This interaction between the normal jets and the mainstream induces a low pressure condition immediately after jets in downstream direction. This is clear from the tuft study for normal injection on flat plate Fig.4,[6].

FIG. 4   TUFT STUDY
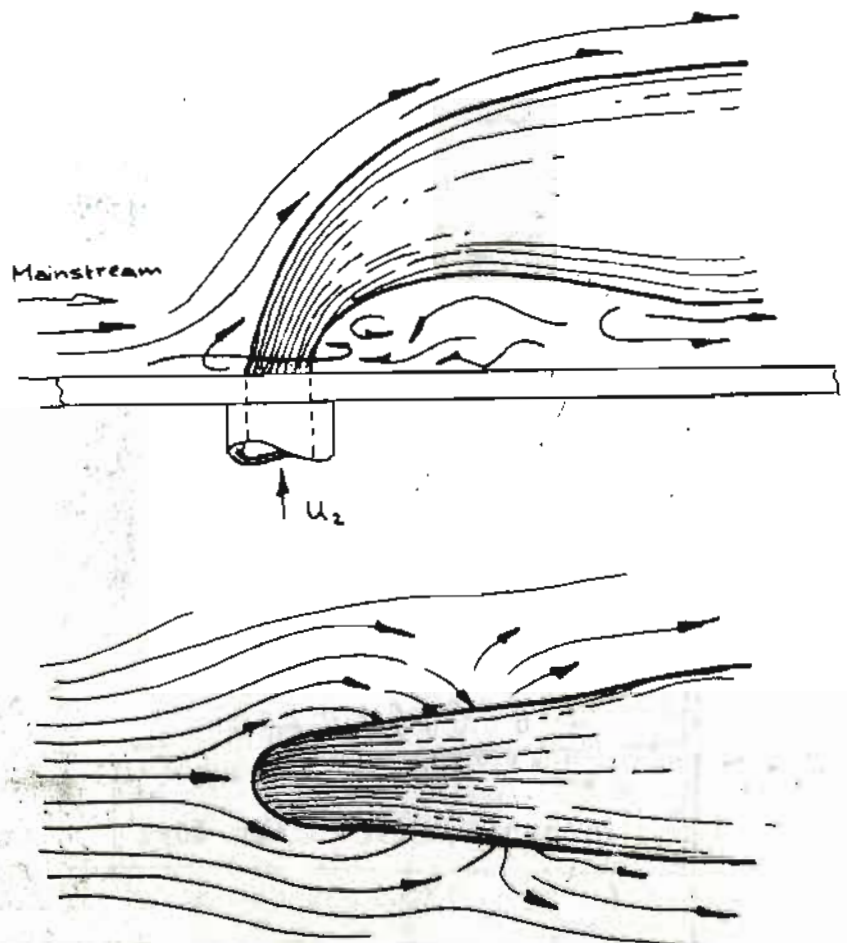
Increasing the injection parameter (β) increase the absolute value of the surface pressure coefficient only at the leading edge region (for $-3^\circ \leqslant \vartheta \leqslant +3^\circ$). This is due to normal injection which has own effects near the injection region [6].

For the case of zero angle of inclination, Fig.5, the effect of injection extend to a chordwise distance $\bar{x} = 0.6$. Maximum absolute value of surface pressure coefficient $\simeq 2.5$ occurs with injection parameter equal to 1.0. The absolute value of the surface pressure coefficient decreases with increasing the distance from the leading edge and with decreasing the injection parameter (β). The effect of injection on the surface pressure coefficient for the accelerated flow is smaller than in the foregoing two cases.

Also, for the same injection parameter the decelrated flow Fig.6 has more effect on the surface pressure coefficient value than zero incidence case. For $\beta = 1.0$, the maximum absolute value of surface pressure coefficient is ≈ 3. The effect of injection in that case extends to a distance nearly 0.4 of the aerofoil surface length.

The surface pressure coefficient in the case of accelerated flow ($\vartheta = +3^\circ$) is given in Fig.7 for different injection parameters.

4.2 Tangential Injection

The tangential injection has an effect not only near the leading edge region but over the whole aeroforl surface. As indicated in Figs. 8 - 10 the change in the surface pressure coefficient extend along the chordwise distance with a moderate rate, specially for the decelerated flow.
In this case the secondary flow moves uniformaly parallel and remains closer to the aerofoil surface. Thus the tangential injection insures a moderate increase in the surface pressure coefficient along the aerofoil chordwise for the constant, accelerated, and decelerated flows as indicated in Figs.8 - 10. Increasing the injection parameter β increase the absolute value of the surface pressure coefficients.

The present study is in agreement with the previous visualization study [6].

5- Conclusions

From the present study it is seen that the tangential injection is preferable than normal injection. It has an effect on the value of the surface pressure coefficient on the whole aerofoil surface.
From another point of view, the tangential injection has a reaction force against the drag force, while the normal injection has a reaction force against the lift force.
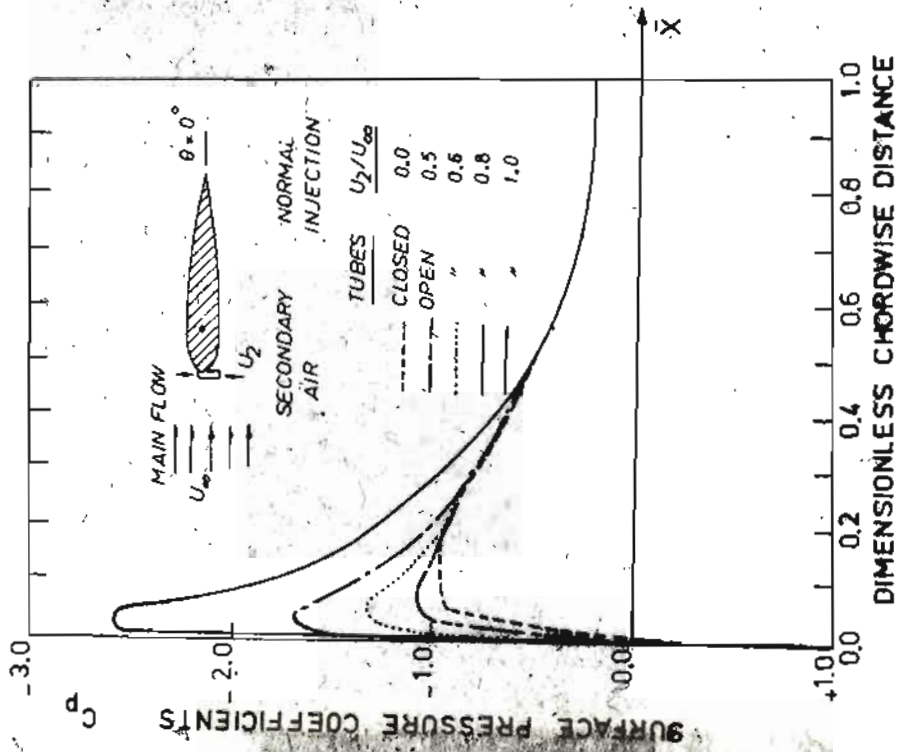
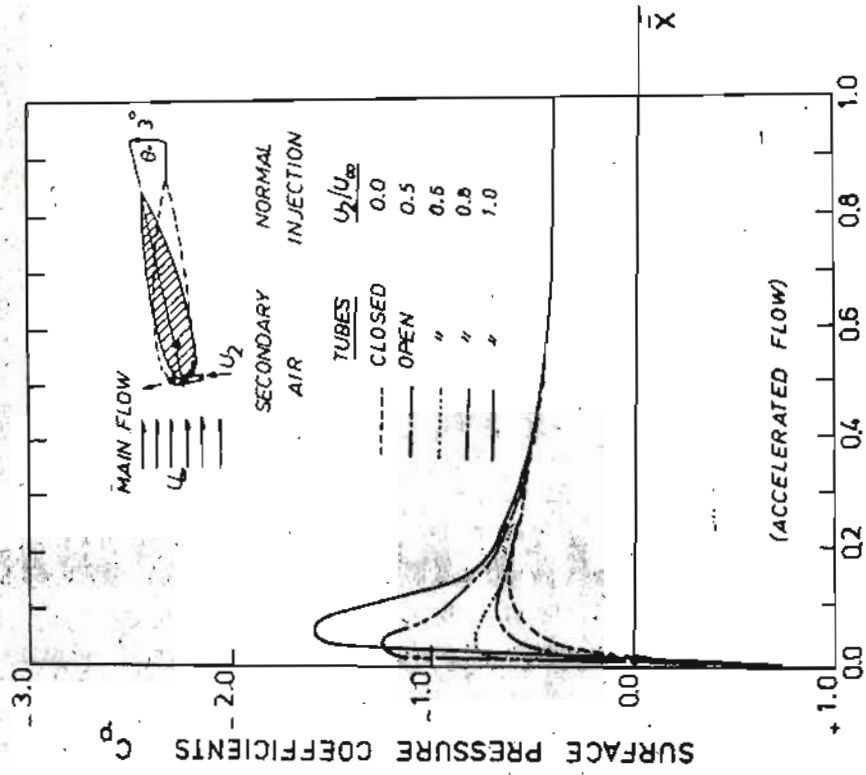FIG. 6 CHORDWISE DISTRIBUTIONS OF SURFACE
PRESSURE COEFFICIENTS

FIG. 5 CHORDWISE DISTRIBUTIONS OF SURFACE
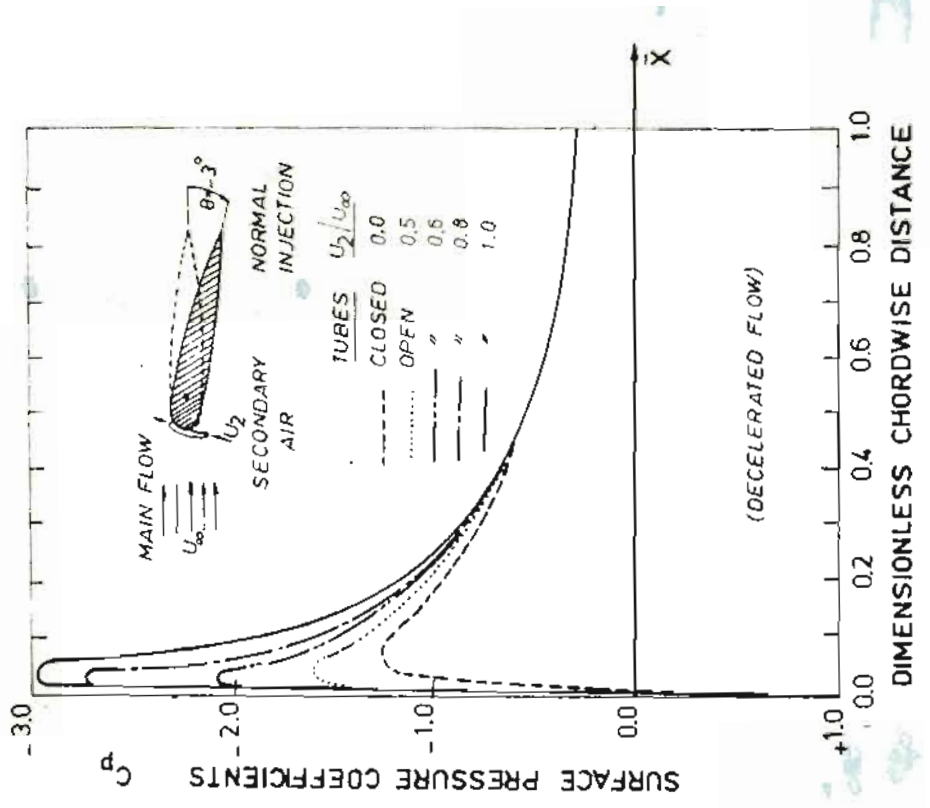PRESSURE COEFFICIENTS

FIG. 8 CHORDWISE DISTRIBUTIONS OF SURFACE
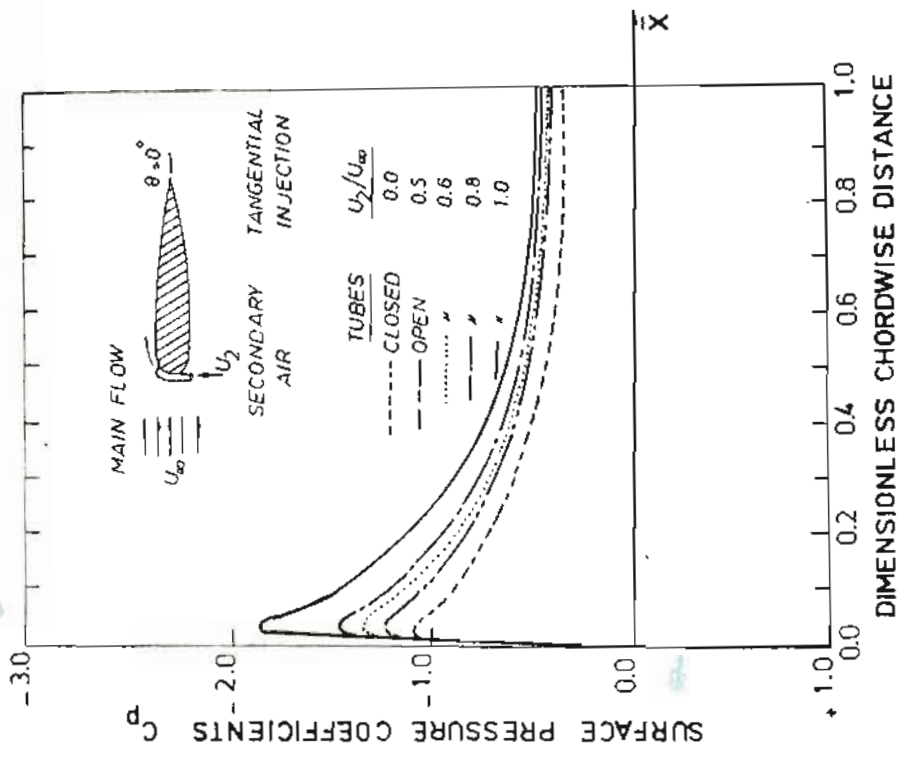PRESSURE COEFFICIENTS

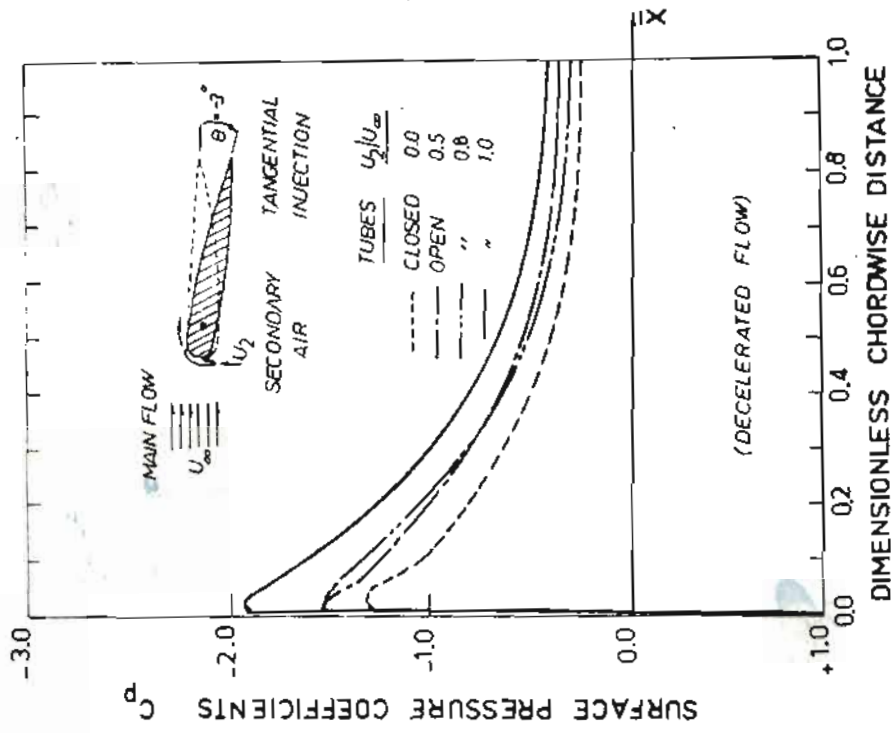FIG.7 CHORDWISE DISTRIBUTIONS OF SURFACE
PRESSURE COEFFICIENTS

FIG.10 CHORDWISE DISTRIBUTIONS OF SURFACE
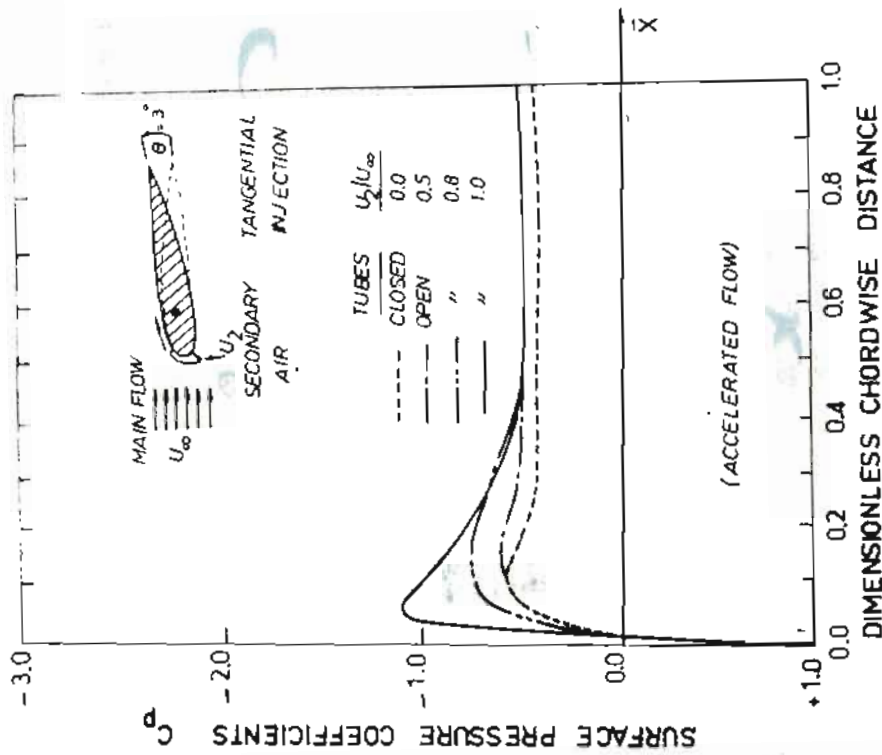PRESSURE COEFFICIENTS

FIG.9 CHORDWISE DISTRIBUTIONS OF SURFACE
PRESSURE COEFFICIENTS

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