Hence the line $T_m = 0{\cdot}5$ separates the thermally developing and developed regions.

The effectiveness is plotted in Fig. 4 against the dimensionless distance along the flow direction. It is seen that it rapidly approaches its limiting value of unity for small Prandtl numbers. From the same figure it can be noted that the influence of $\beta$ is significant compared to that of Prandtl number by observing the curves 6 and 7 which are plotted for $Pr = 1$. It is found that the effectiveness is a weak function of $\alpha$ as was observed for dimensionless mean temperature.


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# FILM COOLING IN ADVERSE PRESSURE GRADIENTS

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NOMENCLATURE

- $E$, the film effectiveness, wall–main stream temperature difference/wall–main stream temperature difference at injection slot [dimensionless];
- $X$, the distance downstream of the slot [in];
- $S$, the height of the slot opening [in];
- $M$, the ratio of the mass velocities, the coolant's divided by the main stream's [dimensionless];
- $A$, dimensionless factor accounting for the effects of geometry, turbulence and boundary layers;
- $\theta$, momentum thickness of the main stream at the slot location [in].

IN THIS brief note, film cooling will refer to the process of injecting a gas along a wall, through discrete openings, to shield the wall from a high temperature gas stream. A "film" of gas persists for a distance downstream of injection, its effect gradually eroded by mixing with the main stream. Figure 1 gives an idea of the geometry involved.

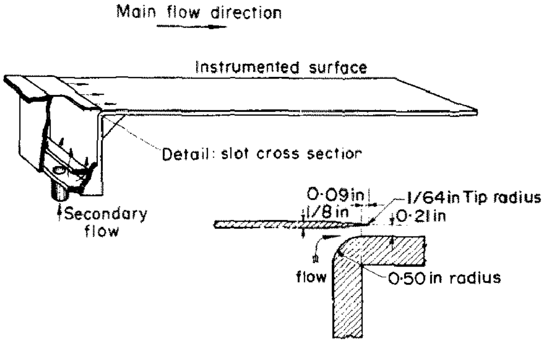


FIG. 1. The film cooling injection system.

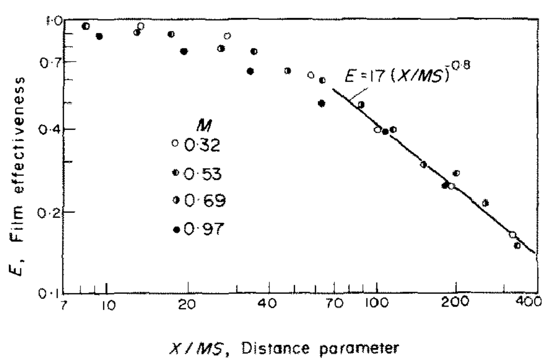


FIG. 2. Experimental results without pressure gradient.

The process can insulate effectively in high heat flux situations, and has also been proposed to control boundary layer separation in an adverse pressure gradient. Hypersonic airbreathing engines could use these traits, to name a possible application.

Pai and Whitelaw [1] presented the important step of an analytical method (a computer solution of the boundary-layer equations with a mixing length concept) for the prediction of film cooling effectiveness. The method predicts a quite small effect for adverse pressure gradients. Escudier and Whitelaw [2] found experimentally a small pressure gradient effect for the introduction of coolant through a porous plug rather than a slot. Several experimental studies with favorable pressure gradients present a not entirely consistent view, but an indication that the effect is also small.

Experiments were performed to investigate film cooling with adverse pressure gradients, in which air at moderate pressure, temperature and velocity flows through a duct of rectangular cross section. The inside vertical dimension is constant; the inside horizontal dimension is variable. Slots

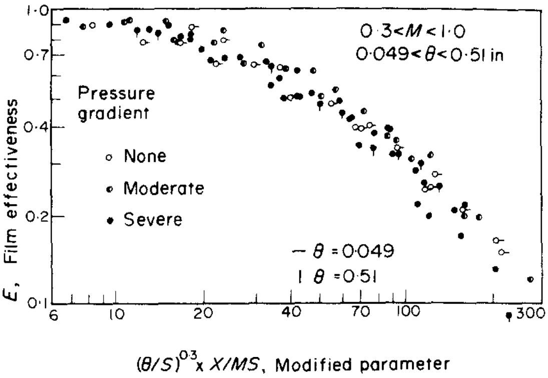


FIG. 3. Film cooling results with the boundary layer accounted for.

milled into the upper and lower walls allow insertion of a plane wall at angles of 0, 7 and 15° with the entering flow direction, such that the flow approximates a two-dimensional divergent flow with adverse pressure gradient. The angled wall contains the film cooling injector (streamwise position variable) described in Fig. 1, wall temperature and static pressure sensors and insulation on its backface to make the wall adiabatic.

The experimental results will be presented in terms of; $E$, $X$, $S$ and $M$. Many experimenters have used plots of the dimensionless quantities $E$ against $X/NS$ to bring their data together. For large $X/MS$, their data take the form $E = A(X/MS)^{-4/5}$, where the factor $A$ accounts for effects of geometry, turbulence and boundary layers and is usually near 20. This study, for the case without pressure gradient, yields an $A$ of near 17, as Fig. 2 shows. Reference [3] reports the data and test setup in detail.

An adverse pressure gradient affects the thickness of the boundary layer in the main stream. The experimental results of this paper agree with the general trend of a drop in effectiveness with a thicker boundary layer, shown in several studies. Figure 3 presents the data in terms of $(\theta/S)^{0.3}X/MS$. The correlation shows no discernible effect of pressure gradient at all. These data represent, in some cases, flows up to boundary-layer separation, so that correction to $E$ is probably not needed for adverse pressure gradients, once boundary layer is accounted for.

These results are valid for low speed flow. A recent paper [4] presents the supersonic case as apart, in that the adverse pressure gradient increased effectiveness strongly. The reason for the difference is unclear. Many applications of the process are at high speed; further study is in order.

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# INSTABILITES AU COURS DE LA CONTRACTION DE BULLES DE VAPEUR NON SPHERIQUES

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NOMENCLATURE

$k$, conductibilité thermique [g cm/s$^3$ °C];
$L$, chaleur latente de vaporisation [erg/g];
$P_{v(T_w)}$, pression saturante à la température $T_w$ [dyn/cm$^2$];
$P_\infty(t)$, pression loin de la bulle;
$R$, rayon de la bulle [cm];
$R_0$, rayon initial [cm];
$t$, temps [s];
$T_w$, température à l'interface (liquide et vapeur) [°C];
$T_\infty$, température de la masse liquide [°C];
$\alpha$, diffusivité thermique [cm$^2$/s];
$\rho$, masse volumique du liquide [g/cm$^3$];
$\rho_v(T_w)$, masse volumique de la vapeur à la température $T_w$ [g/cm$^3$];

Les points représentent les dérivées par rapport au temps.

## 1. INTRODUCTION

DE NOMBREUSES études [2–6] ont été consacrées à la contraction de bulles de vapeur soumises à des pressurisations ou à des sous-refroidissements rapides. Toutefois, le plus souvent ces études n'ont traité que de la décroissance de bulles supposées sphériques en permanence et de ce fait il existe peu de données sur le maintien de la forme sphérique pendant la contraction. Plesset et Mitchell [1] ont étudié théoriquement la stabilité d'une bulle soumise à une variation de pression et ont conclu qu'une petite déformation de la forme sphérique n'est pas amplifiée tant que le rayon adimensionnel, rapport rayon sur rayon initial, est inférieur à 0,2.

Du point de vue expérimental on doit noter des résultats contradictoires. Ainsi, pour des sous refroidissements supérieurs à 20°C, Florschuetz et Chao [2] ont obtenu des bulles initialement sphériques qui se déforment et se brisent en cours de contraction. Au contraire, Board et Kimpton [3] opérant à des sous refroidissements supérieurs n'ont constaté de déformation des bulles qu'immédiatement avant d'atteindre le rayon minimum qui précède une expansion de la bulle.

Par ailleurs, dans le cas de bulles non sphériques en ascension dans un liquide en ébullition les chercheurs ont toujours étudié la variation du rayon de la sphère de même volume sans mentionner d'éventuelles instabilités ou ruptures, ni des différences de comportement suivant la forme initiale de la bulle.