Sidewall Boundary-Layer Influence on Shock Wave/Turbulent Boundary-Layer Interactions

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Nomenclature

$G1, G2$ = shock generator #1, #2
M = Mach number
P = pressure
Re_∞ = freestream unit Reynolds number
Re_{δ_0*} = Reynolds number based on δ_0*
S, R = separation, reattachment
T = temperature
W = test surface span
x = axial coordinate
x_i = shock intercept with test surface in the absence of any boundary layer
$y*$ = vertical coordinate of sonic line
α = shock generator angle of attack
δ = boundary-layer thickness
$\delta*$ = displacement thickness
θ = momentum thickness

Subscripts
O, F = at start, end, of the interaction pressure rise
t = tunnel stagnation value, upstream of nozzle
w = wall

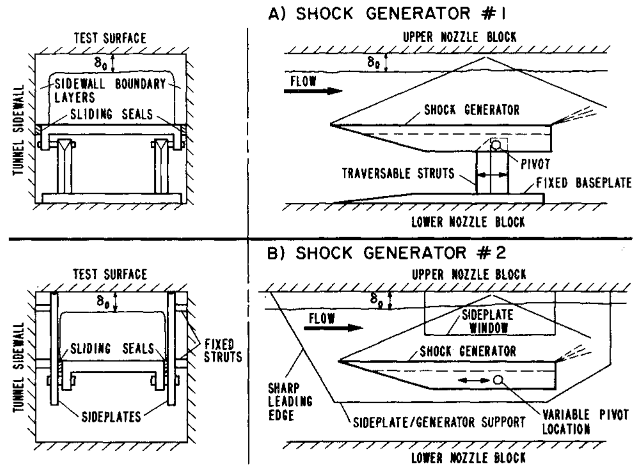

Fig. 1 Shock generator schematics.

Theme

THE objective of this research was to experimentally investigate the interactions between incident oblique shock waves and turbulent boundary layers. Interaction regions were created by impinging full-span, externally generated, shock waves on a nozzle wall boundary layer. Two distinct shock generators were used; the first completely spanned the channel, while the second spanned the distance between two side plates mounted to the channel side walls. A comparison of interaction data obtained with and without large-scale sidewall effects shows that isolating the main interaction, through the use of sideplates, lowers the incipient separation pressure level, while it subsequently reduces the scale of the interaction region for separated flows.

Contents

A recent survey article by Green[1] serves to outline the unresolved aspects of this phenomenon. One long standing controversy[2] has focused on the scale of the interaction region as a function of the over-all pressure rise across it. Hammitt[3] demonstrated that experimental configuration is an important variable in shock wave/boundary-layer interactions, but the mechanism whereby configuration exerts its influence was not discovered. During phase I of the present investigation,[4] details of this mechanism were uncovered; results generated under phase II show to what extent sidewall effects influence a shock wave/boundary-layer interaction flowfield.

All tests were conducted in the 20.32 cm by 20.32 cm asymmetric, variable Mach number, supersonic tunnel of the NASA Ames Unitary system. Test conditions were: $M_0 = 2.9$, $P_t = 6.80$ atm, $T_t = 291°K$, $(T_w/T_t) \simeq 1$, and $Re_\infty = 5.73 \times 10^7$/m. Schematics of the two shock generators are shown in Fig. 1.

Tunnel-empty measurements showed the test boundary layer to be spanwise uniform, with $\delta_0 = 1.694$ cm, $\delta_0* = 0.388$ cm, and $\theta_0 = 0.0817$ cm; no spanwise or axial pressure gradients were measured in the absence of an impinging shock wave (sideplates were installed for $G2$ tunnel-empty tests). The ratio (W/δ_0) was 12 for $G1$ and 9 for $G2$; however, the ratio of uniform flow span-to-δ_0 remained essentially constant at 9, since the sideplates were positioned to cut off the original sidewall boundary layers. Both the sidewall and sideplate boundary layers were those which developed naturally, and they were not deliberately altered in any manner.

For unseparated interactions, $G1$ and $G2$ yielded similar results. Wall pressure distributions and oil-flow patterns were in mutual agreement, both showing the existence of inflow, or flow convergence, near shock impingement. Sonic-line locations on centerline, Fig. 2 (obtained from independent traverses of pitot and static probes) were unaffected by the addition of sideplates, so long as the test boundary layer remained attached.

Incipient separation, in both cases, was found to be a symmetric/three-dimensional phenomenon. Regions of reverse flow were first observed near the channel corners; then, for each incremental increase in shock strength, these reverse flow regions spread laterally, until they merged at the channel centerline. (Despite the fact that the original sidewall boundary layers were

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Index categories: Boundary Layers and Convective Heat Transfer—Turbulent; Nozzle and Channel Flow; Jets, Wakes, and Viscid-Inviscid Flow Interactions.

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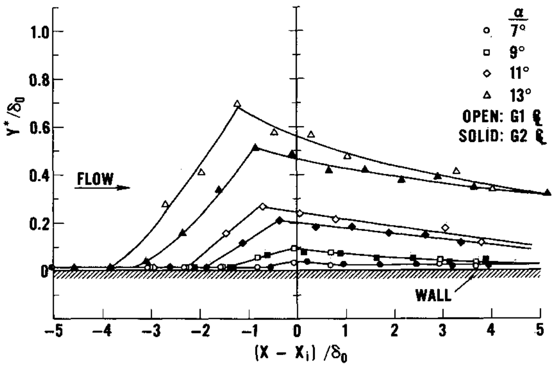

Fig. 2 Sonic-line locations.

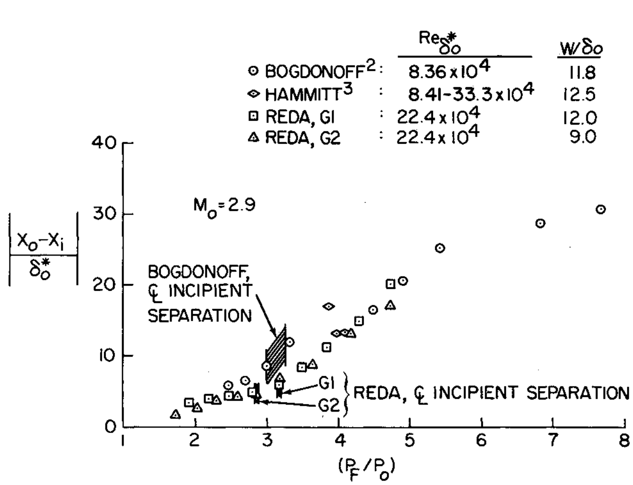

Fig. 4 Upstream influence vs over-all pressure rise.

cut off with the $G2$ configuration, large-scale corner boundary layers must still have developed.) Although incipient separation occurred at a somewhat lower over-all pressure level for $G2$, both $G1$ and $G2$ data were found to fall within the bounds of available incipient separation correlations.

Principal differences between $G1$ and $G2$ flowfields were observed for those shock strengths sufficient to create separated flow regions which completely spanned the test surface and were of some finite axial dimension, the order of $1/2\delta_0$ or greater. For such flows, both $G1$ and $G2$ wall pressure distributions tended towards spanwise uniformity; however, oil-flow patterns within the separated flow regions revealed marked differences, attributed to varying degrees of lateral inflow from the sidewall and corner regions. Direct comparisons of $G1$ and $G2$ sonic-line locations, Fig. 2, and wall pressure distributions, Fig. 3, for such well-separated flows, clearly showed that isolating the main interaction with sideplates substantially reduced the scale of the interaction region.

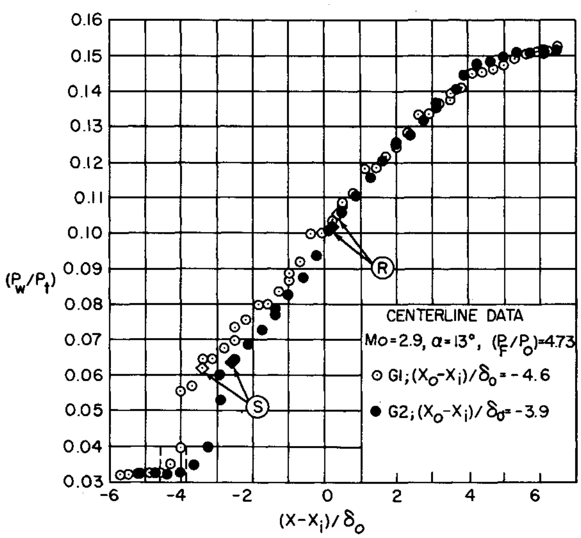

Fig. 3 Surface static pressure distributions, $\alpha = 13.0°$.

Figure 4 shows a comparison of present data with the results of Refs. 2 and 3, for upstream influence vs over-all pressure rise. Note that all of these interactions were generated on nozzle wall boundary layers, in rectangular facilities of similar (W/δ_0) ratios. Data for the isolated interactions fall along the lower limit of available data.

In summary, combined results of this investigation have shown both how, and to what extent, sidewall boundary layers influence mean flowfield behavior through various strength shock wave/turbulent boundary-layer interactions.

References

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