TRANSONIC WIND-TUNNEL WALL INTERFERENCE

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INTRODUCTION

The possibility of eliminating Reynolds number mismatch as a source of wind-tunnel testing error in the National Transonic Facility (NTF) places additional importance on the reduction of testing error due to other sources including wall interference. Accordingly, an expanded research program on wall interference in transonic wind-tunnel test sections was initiated at Langley Research Center in 1974. This paper will describe some progress under this program as well as its possible impact on NTF.

At the beginning of the program, the capability for assessing transonic tunnel wall interference was qualitative at best. The experimental approach, through carefully controlled comparative tests, was rarely accurate enough to produce definitive results. The theoretical approach suffered from inadequate knowledge of the slotted or perforated wall boundary conditions as well as the uncertainty of applying the classical linearized definition of the wall-induced velocity perturbation to the nonlinear transonic problem. As a result, the existing transonic test sections had been designed empirically, and wall interference was generally addressed only by imposing rule-of-thumb constraints on model size.

The adaptive-wall concept, which was receiving increasing attention at that time (see refs. 1 and 2) represented a departure from the traditional approach of applying wall-interference corrections to the wind-tunnel data. Instead, some property of the walls would be adjusted until a calculated interference-free criterion was satisfied for each tunnel data point. The Langley research program has been shaped by the belief that the most practical solution to the transonic wall-interference problem would involve a mixture of wall adjustment and data correction, and would require improved methods of expressing the wall-boundary conditions and of assessing the wall-induced velocity perturbation field.

SYMBOLS

a	slot spacing
C_p	pressure coefficient
K	parameter in slotted-wall boundary condition
M	Mach number

R	slot edge radius
u_w	wall-induced blockage velocity
v_w	wall-induced upwash velocity
V_R	tunnel reference velocity
x	longitudinal coordinate
y_M	vertical location of model
α	angle of attack
β	angle of sideslip
δ	slot width

SLOTTED-WALL BOUNDARY CONDITION

One accomplishment under the program is the clarification of the long-recognized discrepancy between the theoretically derived slotted-wall boundary conditions developed by Davis and Moore (ref. 3) and Chen and Mears (ref. 4). In the Chen and Mears method, the cross section of a slotted wall is represented by an intermittent series of doublet rods as illustrated in figure 1. For a particular doublet strength, the dividing streamline between the recirculating doublet flow and the general tunnel flow assumes the figure-eight shape illustrated, which has zero thickness halfway between slots. For a slot width of 2 percent of the slot spacing, the slot parameter K/a predicted by Chen and Mears is about 15 times that predicted by the Davis and Moore method. Chen and Mears, however, had mistakenly defined the slot width as the gap between doublet rod ends instead of the gap between dividing streamlines. By using the corrected slot width, the Chen and Mears value of the slot parameter is reduced to about three times the Davis and Moore value. Note, however, that even this so-called "zero thickness slat" has a generous radius of curvature adjacent to the slot in contrast to the Davis and Moore derivation which applies to a truly sharp-edged slot. In the Chen and Mears model, the slot edge radius of curvature can be varied by changing the doublet strength. The solid curves on figure 2 show the resulting slot parameter as a function of slot edge radius for several values of slot width. The corresponding Davis and Moore results, plotted at zero radius, now appear to be reasonably correlated with the corrected Chen and Mears results as indicated by the dashed portions of the curves. This work, reported in more detail in reference 5, has exposed the previously unrecognized importance of slot-edge curvature as a determining parameter in the slotted-wall boundary condition.

EXPERIMENTAL BOUNDARY VALUES

The work just described is aimed at improving the accuracy of the boundary condition used to represent slotted test-section walls in wall-interference analyses. In a completely different approach, the need for any such a priori statement of the wall boundary condition is eliminated by imposing instead the pressure distribution on or near the tunnel walls, measured during the actual wind-tunnel test, as boundary values to be matched in the wall-interference analysis. This principle has been embodied in a low-speed two-dimensional analysis method and is used to examine the wall interference in airfoil tests in a flexible-wall tunnel used in both a straight-wall mode and a self-streamlined or adaptive-wall mode. The straight-wall results are shown in figure 3 where the u and v components (blockage and upwash components, respectively) of the wall-induced velocity distribution along the tunnel center line are plotted for several airfoil angles of attack. The boundary values used in this analysis were simply the pressure distributions on both the airfoil and the upper and lower tunnel walls. The results, however, exhibit the characteristics expected from classical solid-wall interference theory. The upwash crosses zero near the airfoil quarter-chord with a gradient that increases with angle of attack. The blockage peaks over the airfoil and approaches a finite asymptote downstream that is indicative of wake blockage. Note in particular, the large blockage associated with the stalled flow at an angle of attack of 12°. This illustrates that even though the analysis is formulated by using potential flow relations, the effects of viscous phenomena are inherent in the experimental boundary values used.

The effect of streamlining the walls for an airfoil angle of attack of 6° is shown in figure 4. The analysis results confirm that the wall-induced velocities were nearly eliminated except for a small upwash gradient resulting from the finite length of the streamlined wall region. This work is described in more detail in reference 6 which also presents an outline of principles which may be used to extend this wall-interference assessment procedure to three-dimensional transonic conditions. These principles avoid the assumption of linear superposition of perturbations in extracting the wall-induced velocity field.

APPLICATIONS TO NTF

The Langley research program on transonic tunnel wall interference is expected to interface with the NTF project in several ways. At the preliminary tunnel design stage, recommendations were made to the NTF project to assure that the baseline test-section design exploited the best current understanding of the wall-interference problem and to assure that the basic structure and systems of the tunnel would not unduly inhibit future modification or replacement of the test section.

At present, the NTF is visualized as evolving toward the mode of operation described in figure 5 as the correctable-interference transonic tunnel. This mode would combine the capability for accurate assessment of wall interference with a limited capability for wall control. The assessment capability would be utilized to categorize the interference existing at each data point as negligible, correctable, or uncorrectable, and to apply corrections where they are valid. The wall-control capability would be used only for those cases assessed as uncorrectable, and then, only to the extent needed to reduce the gradients in wall-induced velocity at the model to an acceptable level.

Four areas in which research is needed to achieve the correctable-interference tunnel are indicated on figure 5. In view of the progress noted above in the two areas contributing to the wall-interference assessment capability, it is believed that this capability can be in hand by the time that NTF becomes operational and that it can be implemented in the baseline test section. The assessment capability alone will provide accurate wall-interference corrections where they are valid, and accurate knowledge of their limits of validity. Such an understanding of wall interference has not previously existed for transonic tunnels.

Full implementation of the correctable-interference mode in NTF will require significant effort to develop a suitable wall configuration and its control logic. It should be pointed out that the wall-control requirements are less restrictive than those for the fully adaptive tunnel aimed at zero interference; therefore, the correctable-interference wall might be simpler to develop and implement.

REFERENCES

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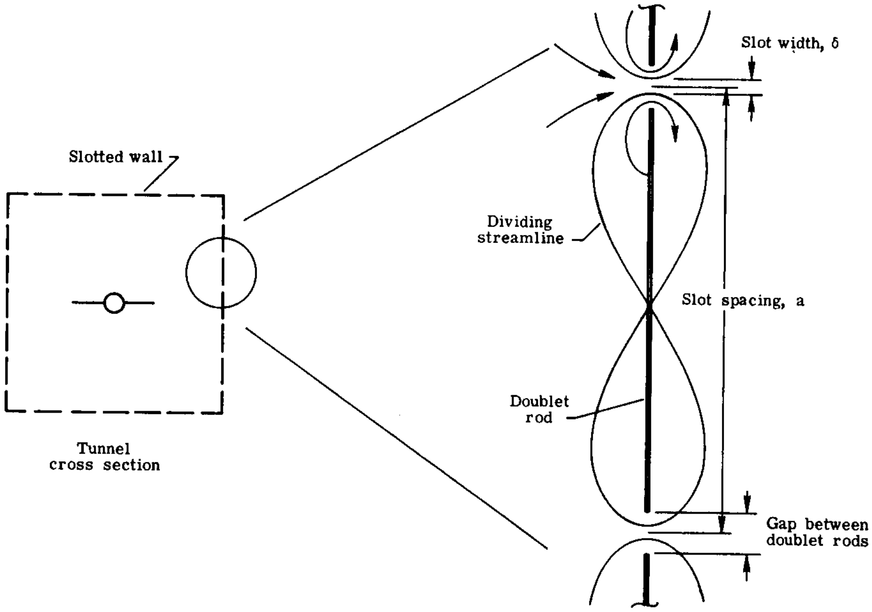

Figure 1.- Chen and Mears model of slotted wall.

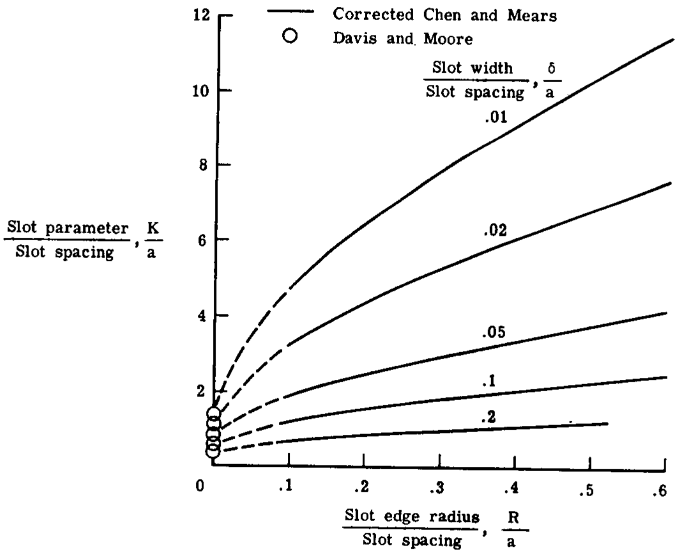

Figure 2.- Slot-parameter correlation.

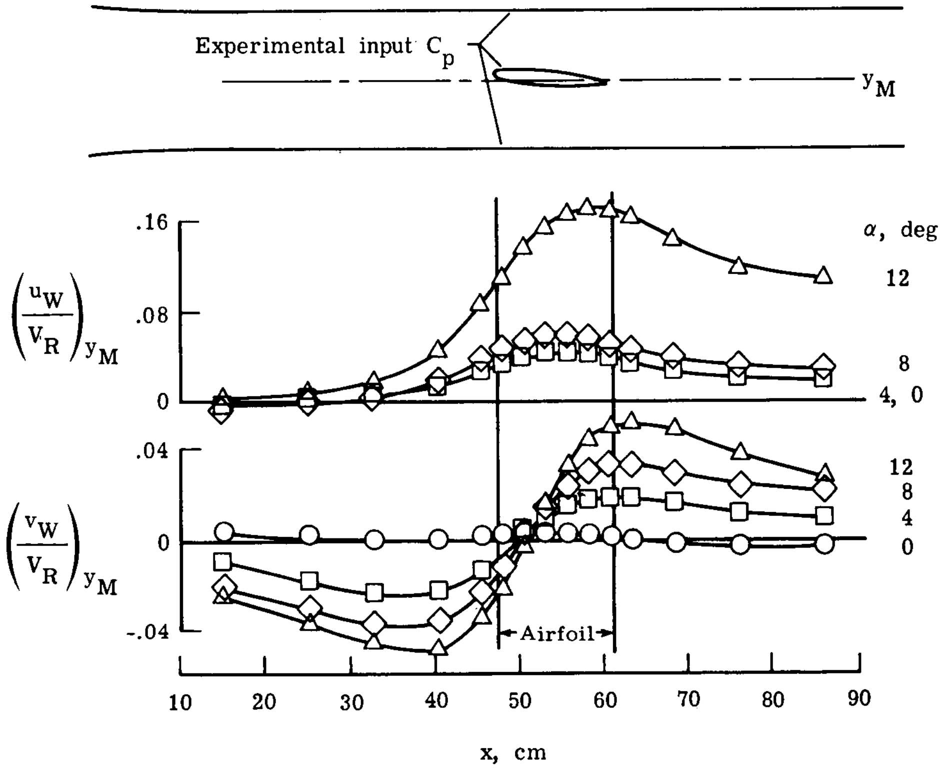

Figure 3.- Wall-induced velocities on tunnel axis. Straight tunnel walls.

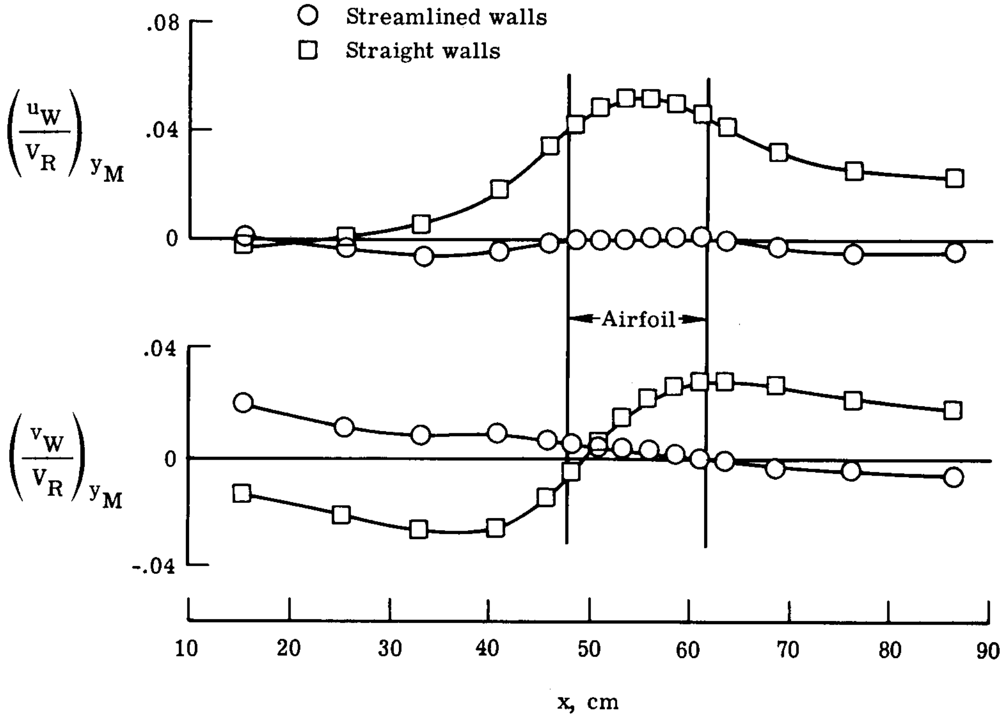

Figure 4.- Effect of streamlined walls. $\alpha = 6^o$.

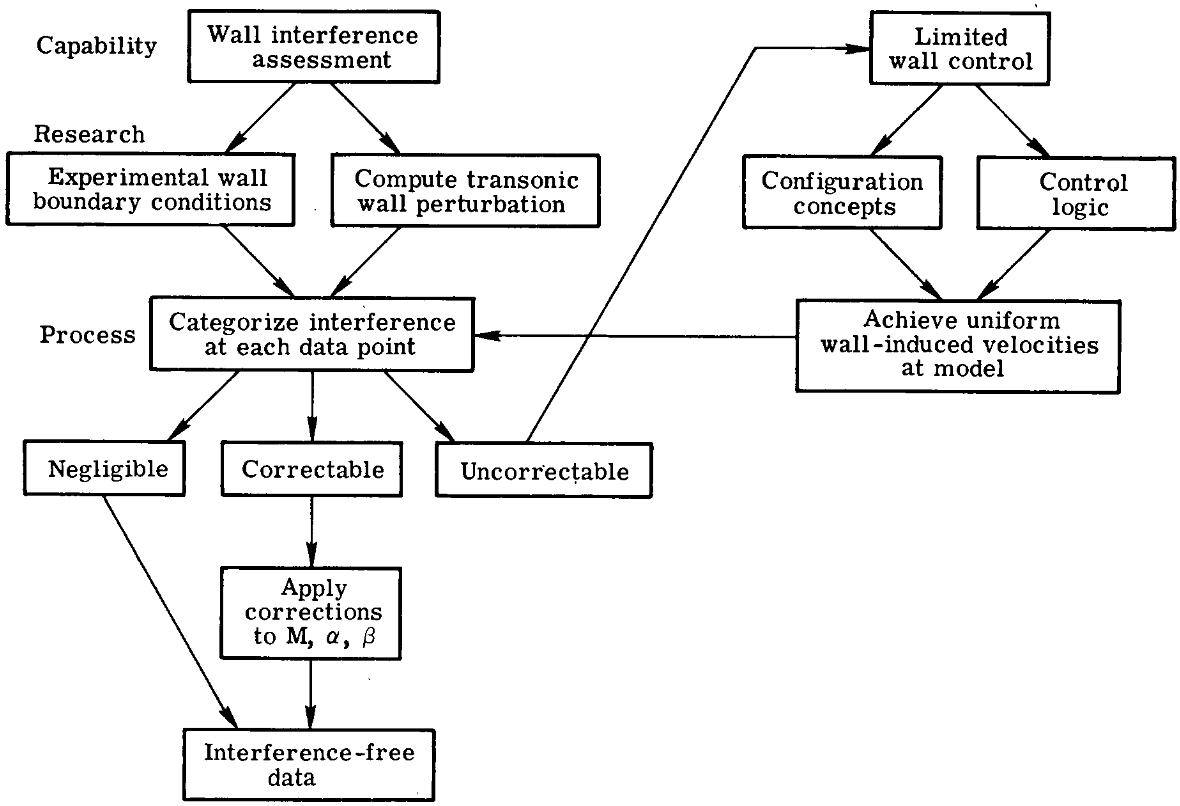

Figure 5.- The correctable-interference transonic wind-tunnel concept.