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SUPERSONIC LAMINAR FLOW CONTROL RESEARCH

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Technical Objectives

The objective of the research is to understand supersonic laminar flow stability, transition and active control. Some prediction techniques will be developed or modified to analyze laminar stability. The effects of supersonic laminar flow with distributed heating and cooling on active control will be studied. The primary tasks of the research applying to the NASA/Ames POC and LFSWT's nozzle design with laminar flow control are as follows:

1. Supersonic laminar boundary layer stability and transition prediction,

2. Effects of heating and cooling for supersonic laminar flow control, and

3. POC and LFSWT nozzle design with heating and cooling effects combining wall contour and length changes.

Status of Progress

A. Supersonic Laminar Boundary Layer and Stability Prediction

Two Computational Fluid Dynamics (CFD) codes have been used to carry out this study. The first one is a boundary layer code developed by Harris at NASA(Ref 1). It is a program that solves the laminar, transitional, or turbulent compressible boundary layer equations for two dimensional or axisymmetric flows. The output of the code is used as inputs for the second CFD code developed by a NASA's contractor Malik (Ref 2). This program utilizes the compressible linear stability theory to predict the stability characteristics and the transition location of the boundary layer.

Both codes for the present study were obtained from the Lyndell King, NASA/AMES with the original authors' permission.

B. Temperature effects on the Stability Analysis of the Laminar Boundary Layer of a Flat Plate

In order to study the temperature effects on the stability of the laminar boundary layer, heating has been applied to the leading edge ten percent of the flat plate and the rest of the plate was remained at the adiabatic wall temperature. It was found the step heating to 802 deg R on the 10 percent of the leading edge of the plate has enhanced the boundary layer stability comparing with the adiabatic wall temperature case(502 deg R) as shown in Fig 1 in term of the N factor. If the plate temperature increases uniformly over the complete plate (from the leading edge to the tailing edge) to 802 deg R, the stability of boundary layer is greatly reduced also shown in Fig 1. This confirms the local step heating effects will enhance the boundary layer stability. Three other cases of heating temperatures were input into the boundary layer codes ranging from 602 deg R, 702 deg R to 902 deg R. They all increase the stability of the boundary layer with the results of N factor getting smaller as the heating temperature increases. Details can be found in Section 5.2 of Lafrance's thesis(Ref. 3). These findings are consistent with theoretical results obtained for the subsonic flow in Ref. 4.

C. Application to the POC nozzle with Local Step Heating

Since the local step heating can enhance the stability on the flat plate(i.e. without pressure gradient), the idea is applied to a nozzle(i.e. with pressure gradient along the wall) to enhance the stability of the wall boundary layer.

Four different cases were studied for the M=1.6 PoC nozzle. First, two temperatures 800 R and 900 R were selected to heating a length being equal to the first 5 percent of the nozzle length. Second, this length was increased to the nozzle throat (approximately 9 percent of the nozzle length) for these two temperatures. For these four cases the total pressure and temperature were 10 psi and 530 deg R. These conditions produce an average adiabatic temperature of 510 deg R. The results indicate that the higher temperature provides more stability to the laminar boundary layer than the lower temperature. The longer length also has a more significant favorable effect for the same step heating temperature than the shorter one within the calculated cases. All the calculations are for the nozzle exit where the Reynolds number is 2.33 millions. As shown in Fig. 2, the N factor decreased significantly from the adiabatic case to the case with the longer heated length and hotter wall. However, it is important to note the large decrease in N factor when going from the adiabatic case to the case where the heated wall length and temperature were 800 deg R and 5% of the nozzle length. This shows that even only moderate temperature increase and heated length can produce interesting results. Details of these reults are given in Section 5.3 of Ref. 3.
These preliminary results are consistence with the experimental data obtained from MSU supersonic tunnel(Ref. 4)

Future Plan

Continue calculation of temperature effects on the POC nozzle to obtain the optimal selection of heating location.

Apply the calculation to the LFSWT nozzle wall.

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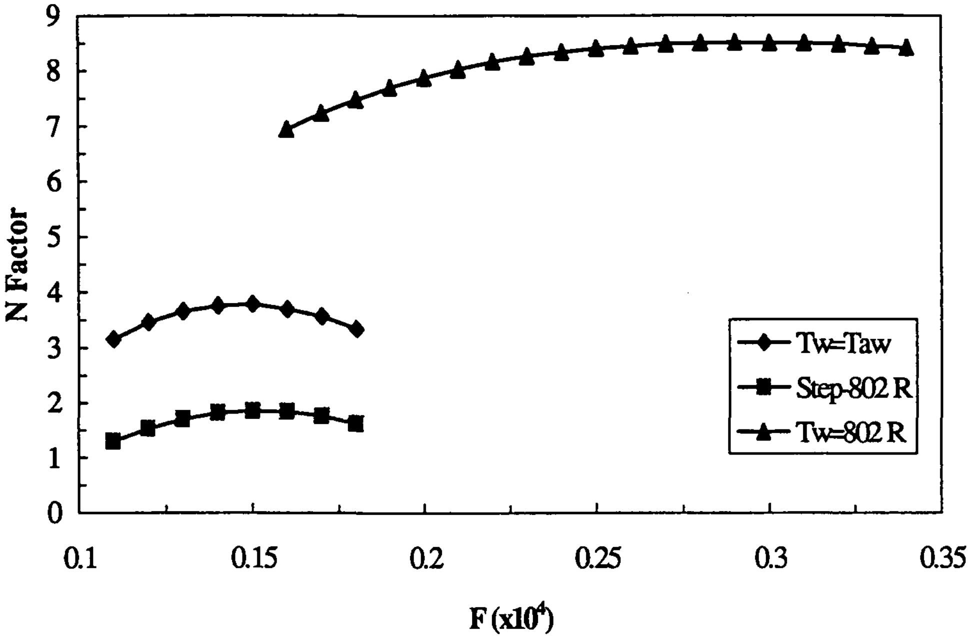

Figure 1. Flat Plate N Factor with Step Heating *(M=1.6, Po=10 psi, To=530 °R, T_{aw}=502 °R, Rex=3x10^6).*

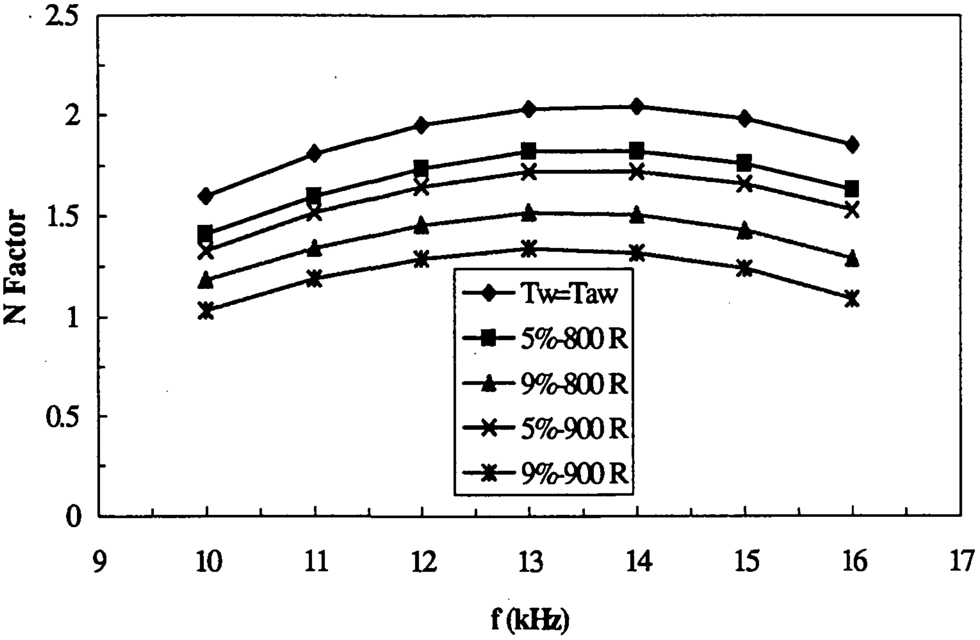

Figure 2. PoC Nozzle N Factors for Different Step Heating Lengths and Temperatures *(M=1.6, po=10 psi, To=530 °R, T_{aw}=510 °R, Rex=2.33x10^6).*