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HEAT TRANSFER IN ROCKET COMBUSTION CHAMBERS

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Complexities of liquid rocket engine heat transfer which involve the injector faceplate and film cooled walls are being investigated by computational analysis. A conjugate heat transfer analysis was used to describe localized heating phenomena associated with particular injector configurations and film coolant flows. These components were analyzed, and the analyses verified when appropriate test data were available. The component analyses are being synthesized into an overall flowfield/heat transfer model. A Navier-Stokes flow solver, the FDNS code, was used to make the analyses. Particular attention was given to the representation of the thermodynamic properties of the fluid streams. Unit flow models of specific coaxial injector elements have been developed and are being used to describe the flame structure near the injector faceplate.

The FDNS code was modified to compute through the two orders of magnitude density variation encountered in the region where the hot exhaust gases and cold oxygen mix at the exit of a coaxial injector. A thermal equation of state based on a modified principle of corresponding states was used to represent the real fluid properties of the propellants.

The flowfield and heat transfer for a main injector element of the Space Shuttle Main Engine were simulated; the resulting temperature field is presented in Fig. 1. The oxygen, entering the LOX post as a liquid at 200 °R, reaches temperatures of 240 °R (still a liquid) along the element axis, and 304 °R (dense gas) at the wall in the exit plane of the LOX post, prior to mixing with the hot exhaust gases. The exhaust gases have been cooled from 1500 to around 1440 °R. A similar analysis for a baffle element has also been made. For this case, the oxygen remains a liquid as it emerges from the LOX post, reaching temperatures of 223 to 230 °R. The lower heating, compared to the main injector element, is due to the use of coolant hydrogen with a temperature range of 465 to 450 °R. Both analyses provide a good approximation to the flowfield where the propellants leave the injector elements and enter the combustion chamber.

To investigate the effects of film cooling, a Rocketdyne RP-1/ O_2 test motor which utilized slightly film cooled walls was simulated and compared to the same motor operated at uniform O/F ratio. The analysis for the constant O/F ratio case matched the test results very closely. Wall heat flux prediction for the film cooled case are shown in Fig. 2. The dotted line prediction indicates that even though the film is initially cold enough to provide the correct wall heating, the film mixes too fast to match the measured wall heat flux distribution. Apparently, the turbulent mixing, which is based on an incompressible K-ε turbulence model, is too fast. This phenomena has been observed repeatedly in variable density flowfield predictions. A thicker film specification on the startline would have a similar effect, but such a specification is not physically realistic. Delays associated with RP-1 droplet vaporization could also cause such effects. This is not thought to be the case, but vaporization effects are still under investigation. The problem was further analyzed by using the temperature correction to the incompressible K-ε turbulence model which was successfully used by these investigators to predict a dump combustor flowfield. The improvement in the predicted wall heat flux distribution, shown by the solid line in Fig. 2, is dramatic. Although the experiment did to provide enough detailed data to verify this analysis, the qualitative features of the film cooling were well predicted.

The results of the main injector element flow and heat transfer analysis are now being used as upstream boundary conditions to continue the analysis into the combustion chamber. The combustion chamber analysis is still in progress.

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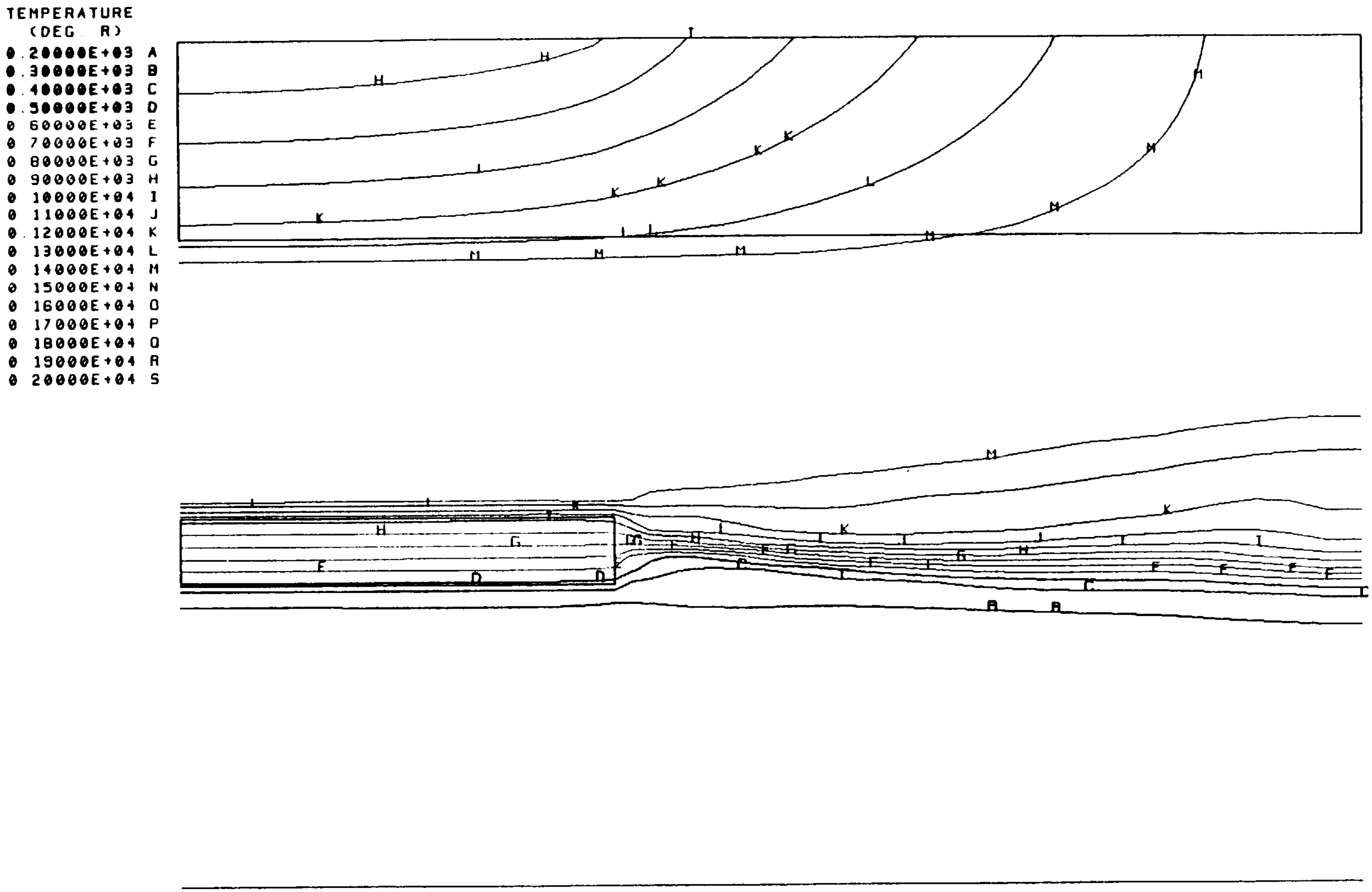
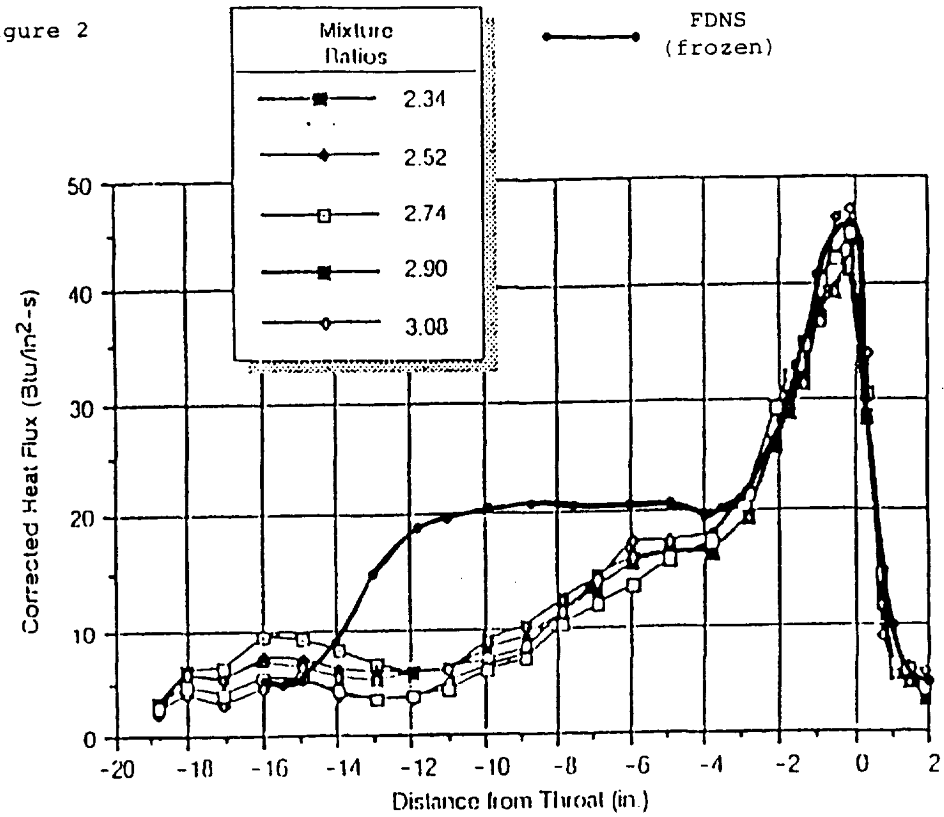
Figure 1

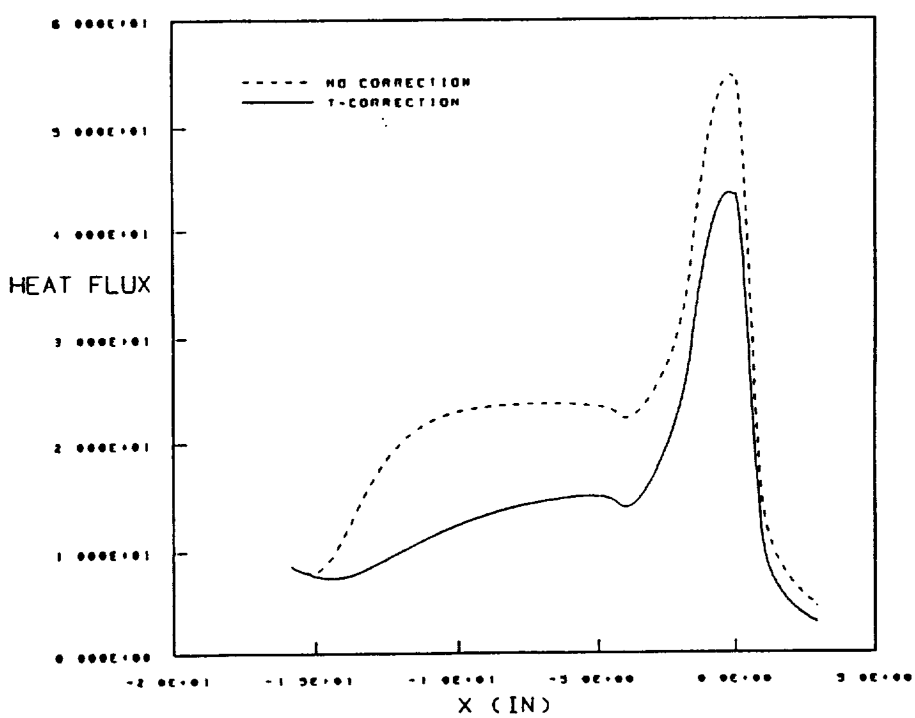


TEMPERATURE IN MAIN INJECTOR ELEMENT EXIT

Figure 2



EXPERIMENTAL HEAT TRANSFER DATA



HEAT FLUX DISTRIBUTION FOR THE MODIFIED CONFIGURATION OF CIRCUMFERENTIAL FAN INJECTOR (FINITE RATE, EXTENDED K-E)