# Numerical and Experimental Analysis of Transpiration Cooling in Carbon Dioxide Atmosphere at Hypersonic Mach Numbers

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## ABSTRACT

## 1. INTRODUCTION:

The aerodynamic heating is a major design concern for vehicles flying at hypersonic Mach numbers. The thermal load problem is handled by using an effective cooling system. In the transpiration cooling technique cold fluid is injected into the boundary layer through a porous media. Many experimental [1] as well as analytical and numerical [2-5] studies of transpiration cooling have been reported in the literature. The focus in recent times has been on the planet Mars and many probes have been sent to explore the life on Mars. The numerical solutions are obtained for skin friction, heat transfer to the wall and growth of boundary layer along the flat plate by employing two dimensional Navier–Stokes equations governing the hypersonic flow coupled with species continuity equation. Flow fields have been computed along the flat plate in $CO_2$ atmosphere in the presence of transpiration cooling using air and carbon dioxide as injecting gases.

## 2. GOVERNING EQUATIONS AND NUMERICAL ALGORITHM:

Assuming $CO_2$ as the test gas flowing at hypersonic Mach number while the transpiration cooling is achieved by injecting a coolant gas the basic Navier-Stokes (N-S) equations are modified with appropriate species continuity equations. The modified non-dimensional N-S equations in the conservative integral form are written as:

$$\frac{\partial \bar{U}}{\partial t}+\frac{1}{A}\oint_S \bar{F}\,\vec{n}\,dS=0 \qquad (1)$$

Where, $\bar{U}=\frac{1}{A}\iint U dA$ is the average value of the column vector of conserved variables $U=[\rho, \rho u, \rho v, \rho E, \rho m_1]^T$ in the control volume and $\bar{F}$ is the flux vector defined in Ref. [3]. The symbols have their usual meaning. The viscosity coefficient $\mu$ for the gas mixture is computed by using Wilkes mixture rule [3]. The CFD code developed is based on the finite volume method. In the present work, Roe's scheme is used to determine the inviscid fluxes. In the evaluation of viscous fluxes the derivatives like $\partial u/\partial x$ and $\partial u/\partial y$ at an interface are computed by using auxiliary cell approach. The resulting set of equations is treated with the Lind-Jacobi relaxation algorithm.

## 3. RESULTS AND DISCUSSIONS:

The code is used to compute flow fields at $M_\infty$=6 &7 and Re = $10^6$ and 2X $10^6$. The variation skin friction along the flat plate for $M_\infty$=6 and Re = $10^6$ for both the injecting gases for different blowing parameter is shown in Fig 1. The $CO_2$ is found to be more effective in reducing the skin friction [5]. The variation of temperature in the normal direction for the same Mach number and Reynolds number is shown in Fig 2. The results clearly show that the thermal boundary layer gets affected significantly due to blowing. It is also clear that the injecting gas reduces the wall temperature significantly. The experimental investigations have also been carried out to validate the CFD results and will be presented in the full length paper.

## REFERENCES

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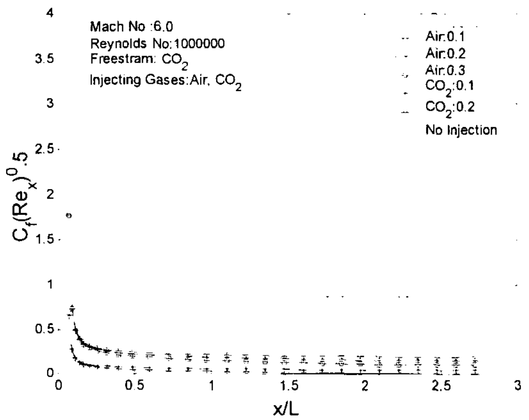


**Fig 1**. variation of skin friction for injection of different gases for $M_\infty = 6.0$ and $Re_\infty = 10^6$

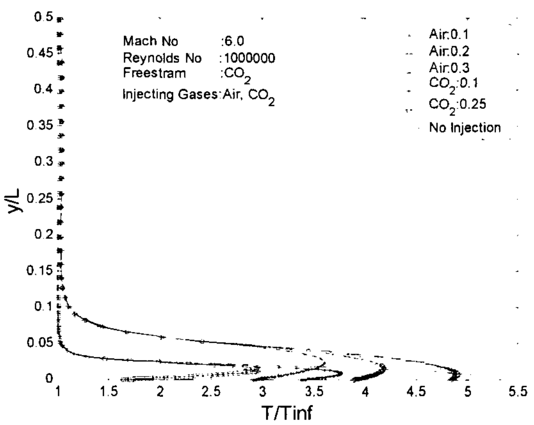


**Fig2**. variation of temperature profile in normal direction for $M_\infty = 6.0$ and $Re_\infty = 10^6$