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Reduction of pressure load and heat load by counter-flow jet on a blunt body in hypersonic flow

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Abstract

In hypersonic flow, pressure and heat loads and drag occur due to a shock wave generated in front of an aircraft, and the counter-flow jet was proposed as a technique for pressure load and heat reduction. When the counter-fow jet is injected, Long Penetration Mode(LPM) and Short Penetration Mode(SPM) was observed based on the total pressure ratio of the freestream and counter-flow jet (P_{0j}/P_{0f}, PR). As the PR increased, a recirculation region between the shock wave and the nose of the aircraft is wide, leading to decrease in the pressure, heat load and drag. In this study, reduction of pressure and heat loads and drag caused by the counter-flow jet on a blunt body in hypersonic flow was investigated. The experiment was conducted in the M 7.0 hypersonic shock tunnel. For measuring the heat flux on the surface of the blunt body, in-house K & E type fast response coaxial thermocouple was used. As a result of the experimental, as PR increases, the flow field was changed unstable LPM to a symmetrically stable SPM. In common with LPM and SPM, recirculate zone is generated caused pressure was decreased but there is some place where the pressure locally increases due to the oscillation region of reattachment shock. As a result of simultaneously measuring the temperature by mounting in-house coaxial thermocouple in the blunt body and converting it into a heat flux, no increase measured during test time regardless of LPM and SPM. And increase in a specific region due to the reattachment shock like pressure also did not measure. The drag reduction is more effective in SPM than in LPM, In the case of LPM, the drag reduction effect was up to 60% compared to when the counter-flow jet was not injected, and in SPM, it decreased by about 79%. As the PR increased, the time when drag affects has been delayed.

Keywords : Drag reduction, Counter flow jet, Hypersonic Flow, Penetration Mode, Total pressure ratio

Nomenclature

Latin
T – Temperature [K]
P – Pressure [bar]
t – Time [s]
q – Heat flux [W/cm^2]
N – Force [N]

Subscripts
$_\infty$ – Freestream
$_j$ – Counter-flow jet

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1. Introduction

Aircrafts operated in supersonic or hypersonic flow suffer from increased pressure load and heat load and drag due to shock waves generated at the forebody. The counter-flow jet has been proposed to address this problem. Research on counter-flow jets ejected from blunt bodies began in the 1950s[1] and is currently being explored. Experiments have been conducted to measure the pressure load and heat load based on the Mach number of the counter-flow jet,[2,3] and numerical simulations have been performed to calculate pressure and heat loads relative to the Mach number of the counter-flow jet.[4] However, cases measuring pressure and heat loads and drag simultaneously by a counter-flow jet are yet to be found. Hence, this study aimed to observe changes in pressure, heat flux and drag simultaneously. The counter-flow jet experiment was conducted in hypersonic shock tunnel, and in-house thermocouple was used to measure the temperature. And the measured temperature was converted into a heat flux.

2. Experimental Setup

2.1. Test facility and model

The experiments were performed in a hypersonic shock tunnel with Mach 7.0 flow. The flow passes through a nozzle with an exit diameter of 189mm and the test duration is approximately 2 ms.

The test model has a hemisphere with a diameter of 115.48 mm and nitrogen was used as the counter-flow jet gas. The shape of the test model is depicted in Figure 1. The Mach number at the nozzle exit of the hemisphere is 3.0.

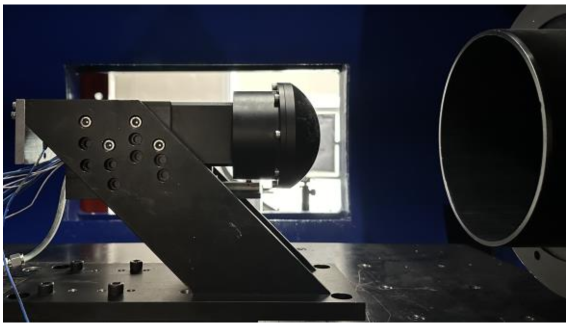

Fig 1. Installation of test model in test section

2.2. Sensor

A Kulite pressure transducer was used for pressure measurement, while in-house K & E type fast response coaxial thermocouple was used for temperature measurement. For the in-house K & E type fast response coaxial thermocouple, chromel and alumel or chromel and constantan were used for the exterior and interior material respectively. The response time of the thermocouple is the range of 100μs. The heat flux is derived as in Equation (1) using the one-dimensional semi-infinite assumption based on the temperature distribution measured over time.[5, 6]

$$q = 2\frac{\sqrt{\rho c k}}{\sqrt{\pi}}\sum_{i=1}^{n}\frac{T(t_i)-T(t_{i-1})}{\sqrt{t_n-t_i}+\sqrt{t_n-t_{i-1}}} \tag{1}$$

Eq 1. Equation of temperature to heat flux

Where q represents heat flux, T represents surface temperature, and t represents time. ρ, c, and k respectively denote the density, specific heat, and thermal conductivity of the thermoelectric material.

3. Result

To verify the heat reduction effects of the counter-flow jet, experiment without the counter-flow jet were initially conducted. As a result of the experiments, temperature changes on the hemisphere surface, and the calculated heat flux ranged from 127.7W/cm² to 999.5W/cm². Subsequently, experiments with the counter-flow jet were conducted by increasing the pressure ratio (PR) from 1.75 to 3.75. The experimental findings confirmed the formation of reattachment flow on the hemisphere's surface due to the counter-flow jet, causing significant pressure oscillations and increases at the reattachment point. With the increase in PR, a transition from Long Penetration Mode (LPM) to Short Penetration Mode (SPM) was observed, as depicted in Figures 2. Additionally, it was observed that as PR increased (from LPM to SPM), there was a decrease in pressure load. But in SPM, the pressure in some region increased instantaneously due to the oscillations from the reattachment shock. Heat load was not measured with counter-flow jet injection and increase some region due to reattachment shock was also not measured. The drag reduction was 60% effective in LPM and 79% effective in SPM. Taken together, it is effective to reduce pressure, heat load and drag in SPM.

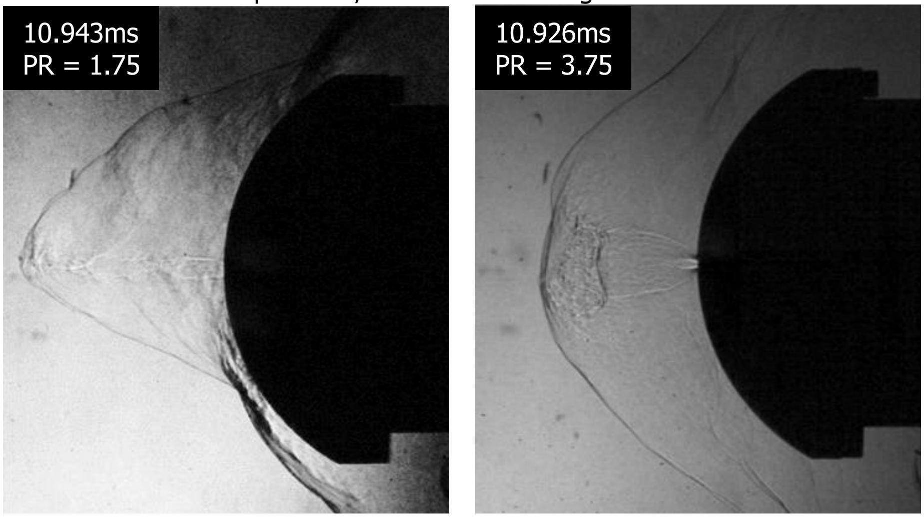

Fig 2. Schlieren images of LPM(left) and SPM(right)

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