JOURNAL OF PROPULSION AND POWER
Vol. 25, No. 5, September–October 2009

Infrared Thermography and Pitot Pressure Measurements of a Scramjet Nozzle Flowfield

C. Hirschen[*] and A. Gülhan[†]
DLR, German Aerospace Center, 51147 Cologne, Germany

DOI: 10.2514/1.41787

An experimental study on single expansion ramp nozzle flows was carried out at a freestream Mach number of 7 in the hypersonic wind tunnel in Cologne, Germany. The Reynolds number in the tunnel flow was varied to study the performance of the scramjet nozzle at different flight altitudes. The effects of different nozzle pressure ratios were investigated and compared by pitot pressure measurements and schlieren photographs. The temperature distribution on the surface of the single expansion ramp was measured by using infrared thermography. The Stanton number and heat-flux distribution on the surface were determined from measured surface temperature history. Here, it can be seen that the external flow does not influence the temperature distribution. The temperature and Stanton number distribution, however, do depend on the nozzle pressure ratio. A pitot rake was used to measure the pitot pressure distribution in the nozzle wake and characterize the interaction between the nozzle and external flow, as well as the influence of the temperature on the nozzle flow. This showed that the nozzle core flow is independent from the external flow conditions, but the interactions between the two flows are highly dependent. The data obtained by the different measurement techniques gave insight into the properties of single expansion ramp nozzle flows.

Nomenclature

A = area, m^2
c = speed of light, 3×10^5 km $\cdot$ s^{-1}
c_p = specific heat capacity at constant pressure, J kg^{-1} K^{-1}
c_v = specific heat capacity at constant volume, J kg^{-1} K^{-1}
h = Planck constant, 1.381×10^{-23} J K^{-1}
I = momentum, kg m s^{-1}
k = Boltzmann constant, 1.381×10^{-23} J K^{-1}
L = radiant intensity, W $\cdot$ m^{-3}
M = Mach number
n = direction normal to the surface
p = pressure, N $\cdot$ m^{-2}
$\dot{q}$ = heat flux, W $\cdot$ m^{-2}
R = specific gas constant, m^2 s^{-2} K^{-1}
Re_U = unit Reynolds number
St = Stanton number
T = temperature, K
t = time, s
V = velocity, m $\cdot$ s^{-1}
x = streamwise distance from nozzle entry, mm
y = spanwise direction from nozzle centerline, mm
z = height above or below flap, mm
α = angle of attack, deg
γ = heat capacity ratio
ε = emissivity
λ = wavelength, m
λ = heat conductivity coefficient, W $\cdot$ m^{-1} $\cdot$ K^{-1}
ρ = density, kg $\cdot$ m^{-3}
σ = shock angle, deg
σ_B = Stefan–Boltzmann constant, W $\cdot$ m^{-2} $\cdot$ K^{-4}
Π = nozzle pressure ratio, $\Pi = p_{0,N}/p_\infty$

Subscripts

amb = ambient
cond = conductive
conv = convective
N = nozzle conditions
r = radiation
st = static
w = wall
0 = total conditions
∞ = wind-tunnel freestream conditions

I. Introduction

TO SAVE weight and increase the maximum payload of space transportation systems, airbreathing propulsion is an alternative to the existing rocket propulsion systems which carry their oxidant (e.g., liquid oxygen) onboard [1–3]. Aerodynamic stability and generation of sufficient thrust are major problems of a hypersonic vehicle with scramjet propulsion, whereby the nozzle and external base flow interactions play a large role [4]. Although the interaction of the hypersonic nozzle/afterbody flowfield with a cold plume flow has been extensively studied [5–7], there is still a lack of experimental data. It is therefore necessary to study the aerodynamic phenomena which arise from the interaction between the outer base flow and the hot nozzle flow, and to understand their effects on the nozzle performance. This interaction is mainly driven by temperature, viscosity, and heat capacity ratio effects. The infrared (IR) thermography, which provides the temperature and heat-flux distribution on the nozzle surface, contributes an additional data set to existing results [8,9] and improves the physical understanding.

The dynamic interactions between the aerodynamics of the vehicle and the thrust have also been studied numerically [10,11]. Ebrahimi [12] has introduced an efficient design code for scramjet nozzle design. In [13], Ishiguro et al. show the results of a three-dimensional analysis of scramjet nozzle flows which agree well in certain aspects with the experimental results. In [14], the effects on the flow interaction of employing simulant gasses instead of air for the scramjet nozzle flow are presented. Experimental studies investigating the interactions between the external flow and internal nozzle flow have been shown to be very complex and not fully understood as yet [15–17]. In [18], a broad experimental study on the boundary-layer effects in a scramjet nozzle has been carried out. These experimental and numerical studies, however, point to the necessity of further research in this field.

Received 24 October 2008; revision received 26 April 2009; accepted for publication 26 April 2009. Copyright © 2009 by Christian Hirschen. Published by the American Institute of Aeronautics and Astronautics, Inc., with permission. Copies of this paper may be made for personal or internal use, on condition that the copier pay the $10.00 per-copy fee to the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923; include the code 0748-4658/09 and $10.00 in correspondence with the CCC.

[*] Ph.D. Student, Wind Tunnel Department of the Institute of Aerodynamics and Flow Technology, Linder Höhe.

[†] Head of Department, Wind Tunnel Department of the Institute of Aerodynamics and Flow Technology, Linder Höhe. Member AIAA.