THERMAL ANALYSIS NEAR SECONDARY INJECTION HOLE IN SITVC SYSTEM

Jiwoon Song*, Jong Ju Yi*, Tae Hwan Kim*, Man Sun Yu*, Hyung Hee Cho*†, Ju Chan Bae**

***Department of Mechanical Engineering, Yonsei University, 50 Yonsei-ro, Seodaemun-gu,Seoul, Korea**
****Agency for Defense Development, Daejeon, Korea**

dolguard@yonsei.ac.kr;leeongreal@yonsei.ac.kr;kimth0610@yonsei.ac.kr;mech_mans@yonsei.ac.kr; hhcho@yonsei.ac.kr;77pongpong@hanamil.net

Keywords: *Secondary Injection Thrust Vector Control (SITVC), Infrared Thermography (IRT), Convective Heat Transfer Coefficient, Horseshoe vortex*

Abstract

The advantages of the Secondary Injection Thrust Vector Control (SITVC) system over conventional thrust vector systems include reduced weight and complexity due to the elimination of the mechanical actuators that are used in the vectoring and increased thrust by secondary injection. However, a strong bow shock at the ahead of the secondary jet is generated by the complex 3-dimensional flow field. The boundary layer/shock wave interaction results in boundary separation shock wave as well as strong recirculation flow including reattachment flow. As a result, local heat transfer is highly concentrated around the secondary injection hole. This could cause to thermal damage to the nozzle surface thus making difficult to maintain the system performance. Therefore, investigate the change of the flow field caused by the boundary layer-shock wave interference regarding secondary injection is requisite to thermal design. The momentum ratio and the injection angle of the secondary flow are as a parameter in this work. In this study we study the characteristics of the flow and heat transfer using numerical simulation, oil and lampblack method and Infra-red thermography (IRT).

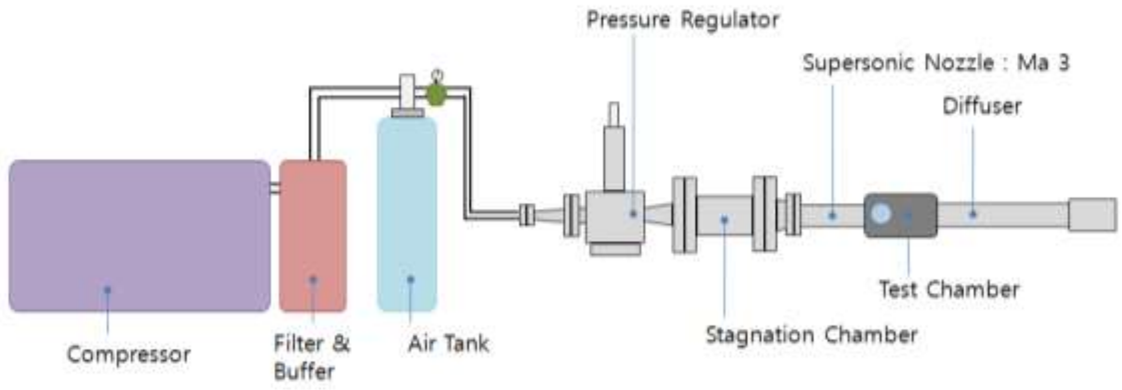
1 Introduction

SITVC(Secondary Injection Thrust Vector Control) is using for the rapid attitude control in the flight vehicle by using secondary injection to supersonic mainstream flow. Compare with mechanical deflector type TVC systems, SITVC has a light weight by elimination of complicated mechanical equipment. And it also has an additional thrust by secondary injection. But secondary injection in supersonic flow induces the complex thermal and fluid characteristics by shock/boundary layer interaction. The bow shock is occurred at the front of injection jet. And the interaction flows also cause the separation with separation shock to flow field. Moreover strong recirculation flow with reattachment is occurred. From these three dimensional complex flow, locally high heat and mass transfer is concentrated around the injection hole region. And locally high heat transfer makes the thermal stress. These thermal concentrations cause the thermal fracture. Actually, TITAN4 K11 has a thermal damage such as nozzle ablation by strong pressure and high heat transfer. Thus thermal fracture such as ablation by thermal concentration damages on the vehicle body is dangerous factor in flight. Therefore, many researchers [1-8] have interested in the thermal and flow characteristics on secondary injection to supersonic flow field.

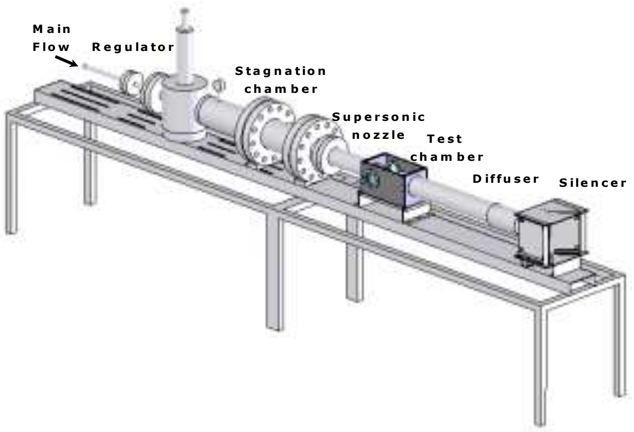
To understanding the thermal characteristic near the secondary injection hole, study about thermal and fluid characteristics by shock/boundary layer interaction near secondary injection hole should be preceded.
In this paper, thermal analysis near a secondary injection hole was studied. The pressure sensitive paint was employed for flow characteristic measurement around the hole. And infra-red thermography also performed to obtain the thermal characteristic around the injection hole

2 Experimental Apparatus

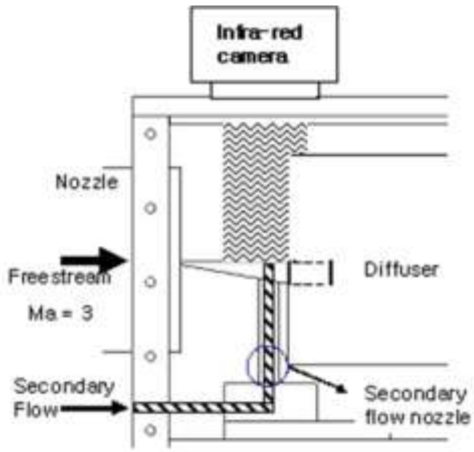
Figure 1(a) shows the overall configuration of the device also conducted experiments, and Fig, 1(b) is a schematic of a supersonic wind tunnel electric blowdown tunnel. It consists of four levels. The first step is a step in the air compression and storage. The compressor is made in the model MST-1000. Using a piston reciprocating compressors (Reciprocating compressor) to 475L per minute of air can be discharged, and the maximum compression pressure is 350kg/cm^2. Reciprocating compressor oil and moisture from the compressed air has. Thus, water filter and a step for step 7 to remove the oil filter, oil and moisture is removed by passing. Then compressed air down to an elevated temperature of the air in order to be stored in a buffer of size 70L. Lowered the temperature of the air storage tanks of compressed air is stored in a compressed 150atm. 1.8m^3 in total volume of air storage tank and is designed to withstand up



(a) System compositions



(b) Schematic of supersonic blowdown tunnel



(c) Schematic of test model in the test chamber

Fig. 1 Schematic of experimental apparatus to a maximum 450atm.

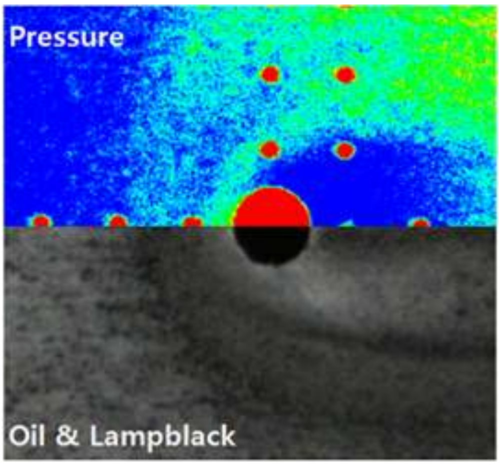
The second step is the formation flow. When the experiment begins, the pneumatic valve (SJ-65DA) opens the pressure regulator and compressed air is passed through a Main flow. Main flow 150atm pressure regulator compressed air is lowering about 7atm pressure. Then passes through expansion chamber is put into main flow congestion. Regulated uniform flow field flow and turbulence intensity in order to reduce the formation Cone-type separator and 5 stage screen will pass through. Main flow stagnation temperature and pressure in the chamber total pressure sensor (Pressure transducer) and Aspiration-type thermocouple is measured through designed. Main flow stagnation flow passing through a chamber designed for Mach 3, Mach 3 as it passes through a supersonic nozzle and enters the test chamber.

The third phase test chamber and diffuser is Hong [9] with reference to the writings of a supersonic nozzle design, MOC (Method of Characteristics) were used. Inside the test chamber, as shown in Fig. 1(c) is a test model is installed. Test chamber for Observing the two for the Visualization window, the test model to measure the surface temperature of the infrared camera (Infrared camera) is for the window. And in order to use an infrared camera inside the test chamber were coated in black. Additionally, the test chamber pressure sensor for measuring the static pressure holes, secondary holes for the supply of jet flow are drilled each. Supersonic flow through the test chamber after passing through the diffuser for pressure recovery is emitted into the atmosphere.

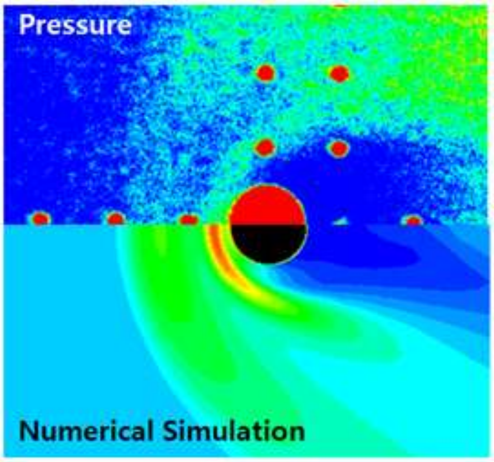
3 Results and Discussions

3.1 Pressure Distribution

Figure 2 shows the pressure distribution using the PSP. The jet to freestream momentum ratio is 1.5. As a general secondary injection fluid flow, such as the presence of the secondary injection nozzle flow separation and reattachment on the front due to the high-pressure distribution can be found to be formed. In addition, due to the secondary injection nozzle, low pressure area behind the formation of a wake that can be found. Near the injection hole to form a high pressure distribution, which is due to the horseshoe vortex. These phenomena result of oil and lampblack visualization and numerical results show good agreement with that.



(a) w/ oil & lampblack results

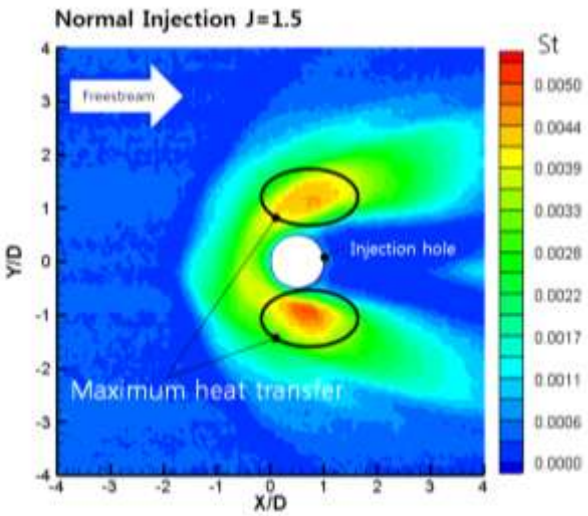


(b) w/ numerical simulation results

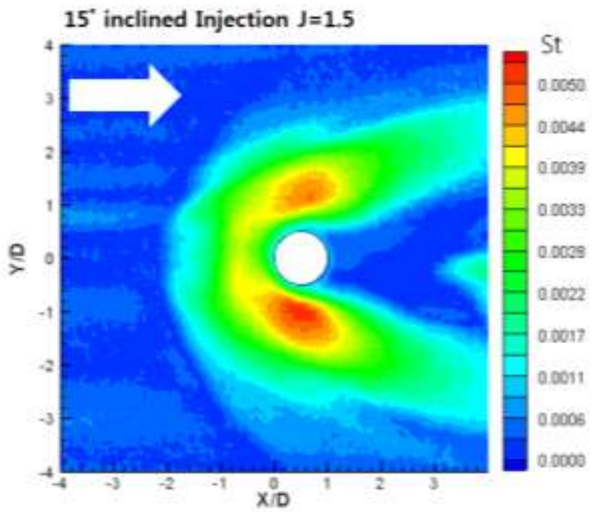
Fig. 2 Pressure distribution from PSP

3.2 Convective Heat Transfer Coefficient

Figure 3 shows the results [7] of the heat transfer around the hole when the secondary flow injected vertical and inclined. Momentum ratio is 1.5. Overall, promote convective heat transfer in the form of a symmetrical horseshoe region appeared. Secondary injection hole on both sides of the convective heat transfer



(a) Normal injection



(b) Inclined injection

Fig. 3 Stanton No. distributions from IRT

coefficient
distribution shows the highest. In addition, the convective heat transfer coefficient downstream of the secondary injection hole phenomenon could be seen sharply lower.

Test models developed at the tip under the influence of the boundary layer Stanton number is showing a decreasing trend. However, after the first separation line began to be intensified heat transfer phenomena. It appears after the first separation of a turbulent boundary layer has been enhanced convective heat transfer components that are believed to be strengthened. In particular, where the maximum heat transfers phenomena that appear after the second line is the separation. According to the results of numerical analysis, the secondary separation and strong secondary re-attachment between injection hole upstream phenomena that are captured. Thus, the second by the reattachment of the flow lines and the secondary injection hole separation high convective heat transfer between the upstream phenomenon that there can be. The highest angular momentum of the non-convective heat transfer phenomenon, but a little different point, Y / D = 2.0 is considered that appeared along. In particular, near the second injection hole, X / D = 0 ~ 1 between the high convective heat transfer phenomenon that has been identified. Through numerical analyzes, this part of the horseshoe vortex reattachment point where there are speculated. Thus, the horseshoe vortex reattached at both ends by a second injection holes be spattered with the high convective heat transfer can be inferred.

Horseshoe vortex flow when there is an obstacle to the flow inside the separation due to eddy current flowing through the sides of the obstacle is. In this study serves as an obstacle in a supersonic flow that is a secondary fluid injection. Even if a solid obstacle, unlike the fluid acts as an obstacle, but the horseshoe vortex that generates enough was verified through numerical simulations. When injected in a supersonic jet secondary flow field, secondary jet injection hole due to the supersonic flow around two in the secondary disturbances that can predict. In this case, the intensity of disturbances between the secondary injection and crossflow depends on the momentum ratio. With increasing momentum in the second injection the primary flow is injected with high pressure ratio. Thus, the secondary injection hole occurs in the neighborhood with more severe disturbances, and thereby re-attached to the surface when the horseshoe vortex, a strong heat transfer has occurred.

4 Summary

In this study, due to the secondary injection flow injection hole near the thermal/flow characteristics were studied. To study of flow and thermal characteristics, PSP, the oil & lampblack method and infrared thermography was adopted. There is a secondary injection flow reattachment point occurs when the hole in front of the pressure rise, and injection holes of each side of the horseshoe vortex passed and re-attached to form a high heat transfer distribution appears. These results in a near injection hole can be used as boundary conditions for predicting the thermal load

Acknowledgment

This work has been supported by Defense Acquisition Program Administration and Agency for Defense Development under the contract UD080018CD.

References

[1] Everett D.E., Morris M.J., Wall pressure measurements for a sonic jet injected transversely into a supersonic crossflow, Journal of Propulsion and Power, Vol. 14, No. 6, November-December, pp. 861-868, 1998
[2] Aso S., Hayashi M., and TAN A., Aerodynamic heating phenomena in three dimensional shock wave/turbulent boundary layer interactions induced by sweptback blunt fins" AIAA-1990-381
[3] Gruber M.R., and Goss L.P., "Surface pressure measurements in supersonic transverse injection flowfields, Journal of Propulsion and Power, Vol. 15, No. 5, September-October, pp633-640, 1999
[4] Stollery J.L., Glancing shock-boundary layer interactions, AGARD-R-764, 1990
[5] Huang W.M., Mistrek D.L., Murdock J.W. Nozzle erosion induced by thrust vector control Injection, AIAA 96-2638, 1996
[6] Yi J.J, Yu M.S., Song J., Cho H.H., Heat transfer in the perturbed boundary layer by cylinder and secondary injection in supersonic flow, Proceedings of the Korean Society of Propulsion Engineers Conference 2007 (in Korean), pp.276-280, 2007
[7] Song J.,Yi J.J, Yu M.S., Cho H.H., eat Transfer on Secondary Injection Surface in Supersonic Flow-field with Various Injection Angle, Proceedings of the Korean Society of Propulsion Engineers Conference 2008 (in Korean), pp.321-325, 2008
[8] Song J.,Kim T.H., Yu M.S., Cho H.H., Bae J.C., Heat transfer near secondary injection hole for SITVC, Proceedings of The Korea Institute of Military Science and Technology Conference 2010 (in Korean), pp.1592-1595, 2010
[9] Hong Y.S., Space Propulsion Technology, Cheongmungak, 1992

Copyright Statement