出國報告（出國類別：開會）

參加 **2012** 年國際航太工程研討會

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摘要

2012 年國際航太工程研討會 (2012 International Conference on Aeronautical and Astronautical Engineering, ICAAE 2012)，爲年度性之國際學術會議，本次會議由 WASET 協會主辦（World Academy of Science, Engineering and Technology），於 5 月 29~30 日於日本東京成田市的東武飯店舉行，進行一系列學術研究成果發表及新知討論。

本次研討會會共有來自五大洲等數十個國家及地區之多位學者專家及研究人員參與爲期二天之學術討論會，發表之論文包括航太、機械、控制、化學與環工、電機電子、地理、物理、通訊、製造、生醫、數學、資訊等領域之相關文獻，均深獲與會學者之興趣及討論。此外，藉由參與大會各國專家學者之交換研究心得及吸取他人寶貴之研究經驗，將可做爲個人日後教學及研究之參考。

筆者此次執行國科會計畫，其發表題目爲**”**氣動光學側窗具熱輻射的氣動熱效應研究 **Study of Aero-thermal Effects with Heat Radiation in Optical Side Window”**，達到與世界各國學者交流的目的，獲益良多。

目次

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壹、 會議目的

2012 年國際航太工程研討會 (2012 International Conference on Aeronautical and Astronautical Engineering, ICAAE 2012)，其會議宗旨在於結合世界各國有關機械、熱流、航空、太空等研究領域之學者專家，進行一系列學術研究成果發表及新知討論，本次會議由 WASET 協會主辦（World Academy of Science, Engineering and Technology），於 5 月 29~30 日於日本東京成田市的東武飯店舉行，有許多不同國家和地區的投稿。會議論文由 WASET 公開出版發行，包括 Excellence in Research for Australia (ERA)， Google Scholar, Scopus, Compendex, Thomson Reuters, WorldCat, EBSCO, GALE, Embase, Reaxys, Engineering Village / Engineering Index (EI), Library of Congress, British Library, Electronic Journals Library 均列入索引，筆者所投稿的文章有幸能接受。WASET 協會歷年來所主辦之學術研究年會、研討會及專題討論會，皆對該學術領域有深遠的影響及貢獻。因此，我們除了有機會參與大會之學術研討及發表研究論文外，更可藉由參與大會而與來自世界各地之專家學者交換研究心得及吸取他人寶貴之研究經驗，以做爲個人日後教學及研究之參考。

貳、會議過程

(一)本屆會議共有來自歐洲、美洲、澳洲及亞洲等數十個國家及地區之多位學者專家及研究人員參與爲期三天之學術論文發表及討論會。會議地點在大都會日本東京成田市舉行。此次會議計有十個國際期刊一同聯合，除了筆者投稿所收錄的International Journal of Mechanical and Aerospace Engineering期刊外，尚有化學與環工、電機電子、地理、物理、通訊、製造、生醫、數學、資訊等等幾乎涵蓋所有工程與科學爲一大型的研討會，共計278篇論文發表，與會者多爲各國在該領域學有專精之教授與學者，於此與各國學者相互交流之下獲益良多。

(二)筆者此次發表的論文，題目爲氣動光學側窗具熱輻射的氣動熱效應研究 Study of Aero-thermal Effects with Heat Radiation in Optical Side Window”，爲執行 100

年度國科會計畫「氣動光學側窗外部薄膜冷卻與層流條件下光學傳輸影像實驗與計算」的成果發表，其內容主要說明，光學導引飛彈光學側窗在極音速環境下，熱氣動力效應將使光窗難以承受高熱而產生裂痕或破碎導致無法作用。本文以計算流體力學探討光學側窗在外部冷卻噴流情況，模擬不同紊流 k-ε，k-ω 模式，爲更能符合實際的熱氣動環境，另加入熱輻射模式探討適量的外部冷卻劑與光窗的熱氣動問題。模擬結果顯示，無外部冷卻噴流時，因氣流在光窗頭、尾凹槽產生渦流，此二處的溫度最高約大 1600K 左右，當外部冷卻噴流量爲 0.15kg/s 時，光窗表面溫度可降至 280 度左右，加入熱輻射條件時，因熱通量耗散較快，光窗表面溫度從 280 度降至 260 度左右，較符合真實情況，冷卻劑量可再降低。全文詳如附件。

參、 會議心得

本次研討會WASET協會主辦，結合10類期刊所共同舉行的大型研討會，值得一提的該會議論文由WASET公開出版發行，包括Excellence in Research for Australia (ERA)， Google Scholar, Scopus, Compendex, Thomson Reuters, WorldCat, EBSCO, GALE, Embase, Reaxys, Engineering Village / Engineering Index (EI), Library of Congress, British Library, Electronic Journals Library均列入索引，筆者投稿有幸能收錄，與會期間與各國學者交談討論獲益不少，另於研討會中，透過各國學者不同領域的思考模式，於問答之間各取所需，達到智識精進功效，每天利用休息時間，更積極與各國學者交換演講意見達到學術交流目的，希冀爾後研究交流於此建立關係鏈。本次參加會議期間，巧遇自己的博士班指導教授，屏科大學術副校長戴昌賢教授，在國外與老師相遇倍感親切，在交談時發現老師的行程相當緊湊，除了要訪問日本筑波大學外，還要到大阪工業大學舉行學術演講，舟車勞頓不以爲苦，足爲學生們效法，同時老師也勉勵我要能持續在系上推動整合老師們的研究能量，團隊合作的力量要遠勝於個人，雖然過程並不容易，但要不計較個人得失、毀譽，此點我頗有所感，本校的學生、教師人數與研究經費爭取，均尚不能與教育部所轄大學相比，惟有整合有限資源互相合作，方可有所成。另於會中結識中原大學機械系林柏廷教授，林教授輔甫於今年2月1日返國任教，畢業於美國羅格斯大學爲一青年才俊，

除彼此交換名片外，林教授邀請筆者日後至中原大學進行學術演講，並進行交流，此為參加本次活動的另一段插曲。

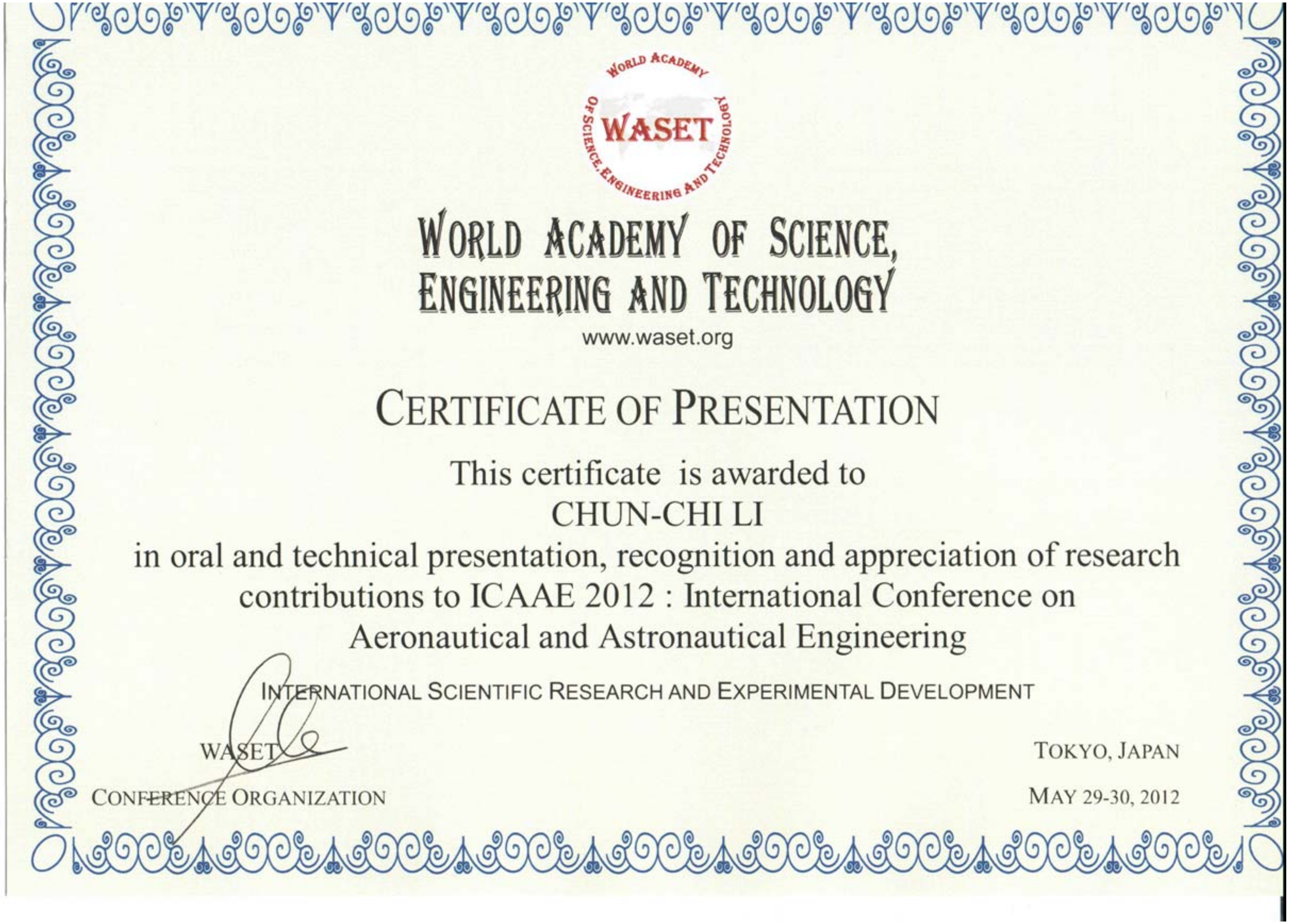
經過此次研討會歷練，使本人對未來之研究更具信心，將持續於此領域探討研析，並且對於後續之研究將會秉持精益求精的精神戮力完成，並盡已所能將學術研究之成果呈現於各大期刊。

肆、 建議事項

筆者此次出國參加學術研討會是執行國科會一般型研究計畫，已是筆者第四次的出國參加學術會議，本校出國的程序由於須經由國防部同意，因此作業的前置時間須50天前呈報，可能過於冗長，建議凡出國經費編列在國科會研究計畫項下，非國防部經費者是否能比照現行自費出國方式，由編階少將主官管核定即可，早期學術研討會出國即是如此方式，現行作業反較以往繁瑣。筆者去年曾建議，凡以國科會年度研究計畫項下之出國參加研討會，併年度結案報告於國科會呈報，毋須一案重覆二次呈報，以達節能減碳，效率精進的成果，惜未獲採納。本人仍再次建議本部考量，可否參卓行政院及教育部之作法，凡國科會年度研究計畫項下之出國參加研討會，併年度結案報告於國科會呈報，可達到簡化業務的效果。

此外，國科會出國補助的經費有逐年下降的趨勢，而國際會議的報名費則居高不下，而亞洲其它國家，如韓國、新加坡等國，對岸對於參與此類之學術活動相當熱烈，相信這些國家之科技發展進步神速，成就並非憑空而得，除該國學者藉由不斷參與國際研討會與它國學者學術交流外，更有系統規劃出國留學、短期進修等措施來補強提昇各項研究新知。更倘若國內能在補助的員額及經費再予以增加，相信對國內各方面研究工作的再提昇，必定會有所助益。

本人參與此次會議後，除檢討自己研究上之短處，並吸取別人的長處，加強縝密思考力，提升學術創造力。本校在研究獎勵教師、研究生出國參加研討會的措施尚有不足之處，應先迎頭趕上與國內一流院校相同，再放眼與國際一流學府相提並論，方有助於建構哲學、科學、兵學一體教育環境，並與國際接軌的一流軍事學府。



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INVITATION LETTER

January 31, 2012

Assoc. Prof. Dr. Chun-Chi Li
Chung Cheng Institute of Technology, National Defense University
Taiwan

To Whom It May Concern,

We are pleased to inform you that your peer-reviewed & refereed full paper entitled "Study of Aero-thermal effects with Heat Radiation in Optical Side Window" is accepted for oral and technical presentation at the ICAAE 2012 : International Conference on Aeronautical and Astronautical Engineering to be held in Tokyo, Japan during May 29-30, 2012.

This letter serves as confirmation of your participation in the conference.

We would greatly appreciate if you could facilitate granting the conference delegate the necessary visa.

Sincerely Yours,

C. Ardil,
Conference Secretariat
ICAAE 2012 Tokyo
Japan

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Study of Aero-thermal Effects with Heat Radiation in Optical Side Window

Chun-Chi Li, Da-Wei Huang, Yin-Chia Su and Liang-Chih Tasi

Abstract**—**In hypersonic environments, the aerothermal effect makes it difficult for the optical side windows of optical guided missiles to withstand high heat. This produces cracking or breaking, resulting in an inability to function. This study used computational fluid mechanics to investigate the external cooling jet conditions of optical side windows. The turbulent models k-ε and k-ω were simulated. To be in better accord with actual aerothermal environments, a thermal radiation model was added to examine suitable amounts of external coolants and the optical window problems of aero-thermodynamics. The simulation results indicate that when there are no external cooling jets, because airflow on the optical window and the tail groove produce vortices, the temperatures in these two locations reach a peak of approximately 1600 K. When the external cooling jets worked at 0.15 kg/s, the surface temperature of the optical windows dropped to approximately 280 K. When adding thermal radiation conditions, because heat flux dissipation was faster, the surface temperature of the optical windows fell from 280 K to approximately 260 K. The difference in influence of the different turbulence models k-ε and k-ω on optical window surface temperature was not significant.

Keywords**—**aero-optical side window, aerothermal effect, cooling, hypersonic flow

I. INTRODUCTION

RESERCH into aero-optics includes probes by high-speed flow on onboard imaging, the influence of atmospheric turbulence on optical images, and their corrections. This method is primarily applied to the new generation of interceptor missiles, the hood sides of which are called optical hoods. In general, these hoods are composed of three sections: casings, optical windows, and optical window cooling systems. The nearby optical windows receive infrared rays to guide tracking and intercepting high-speed aircraft. When interceptor missiles are flying at high speeds in the atmosphere, complex flow fields form between their optical windows and the airflow. This results in high heat, thermal radiation, and interference with image transmission in the seeker, leading to target image offsets, jitter, and fuzziness. This is called the aero-optical effect. The aero-optical effect includes the high-speed flow field optical transmission effect, shock waves, the window aerothermal radiation effect, and the optical window aerodynamic heating effect, as shown in Fig. 1. [1]

The high temperatures produced by the aerothermal effect result in heat loads, cracks, failure, and even rupture in the optical windows, influencing the normal operation of optical detection systems. In general, cooling technology must be used for protection and for lowering temperatures. Two methods are primarily adopted for optical window cooling, external jet cooling and internal convection cooling. This study investigates the aerothermal effect of external jet cooling. In external jet cooling, low-temperature airflow is sprayed from the front of the window (or all around it) on the outside of the window, forming a membrane and separating the optical window from the external hot airflow, thus providing insulation and cooling for the window. This demands that a uniform, stable gas membrane forms on the outside of the window during the entire work process. This method is also called external jet film cooling. The external cooling method is simple and easy to implement, but cooling gas and the gas boundary layer mix, forming a shear/mixed layer. Thus, complex turbulence flow fields and the aero-optical effect easily occur.

Currently, two forms for optical windows exist. The first is a mosaic window, which has a superior line of sight and tracking range, and does not require external aircraft roll control systems for alignment. However, the substantial optical diffraction effect, low aperture efficiency, and complex structure and processes are difficulties that must be overcome. The second type is the side-cooled optical window. In general, a planar optical window is installed on the surface of the side of the hood region. The position of the window is slightly lower than the missile surface maintaining the hood’s appearance. The beams are not restricted by the optical window aperture diffraction limit, and are easy to install. However, the most significant problem yet to be solved is that a large area of the optical window is exposed to the extremely hot boundary layer. When flying in the atmosphere, the optical window must be cooled.

Li et al. [2] simulated Terminal High Altitude Area Defense (TAAD) missiles at angles of attack from 0° to 30°. The turbulence method used was the Spalart-Allmar (SA) model. At a flying altitude of 30 km with a flight speed M = 6, by using active external cooling jet controls, when cooling air mass flow reached 0.15 kg/s, the entire optical window could be cooled to 500 K or less, protecting the function of the optical window. However, this study did not include thermal radiation conditions. Cooling jet may be over-forecast, leading to missile payload problems. In the study described above, the simpler SA turbulent model was adopted, and the problems of thermal radiation were not investigated. The actual optical transmission effect was caused by turbulence flow fields. The movement of turbulence flow fields was random and without rules, and there is yet no complete theoretical description of their laws of motion. This has been a hot topic in the field of fluid mechanics, and discussion of which turbulence model is most applicable to the aerothermal of aero-optical hoods remains inconclusive.

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Bertin et al. [3] indicated that during hypersonic flight at altitudes of 30 to 50 km, the aerothermal effect impacted the reliability of the material structure of optical windows, forcing the installation of a temperature protection system (TPS) on the flying body. Neale and Max [4] divided TPS conceptually into passive, semi-passive, and active models, as shown in Fig. 2. However, because the introduced cooling jets produce more complex mixed shearing phenomena with the mainstream, the chaotic features of the flow field are further intensified, influencing the interpretation of images by the infrared system within the optical window. Thus, calculating aero-optical influence quantitatively and adopting effective methods for calibration is a key issue in the development of high-speed interceptors. Hirschel [5] indicated that at altitudes of 50 km and less, the flow fields of flying bodies were governed by the viscous effect. The wall heat radiation effect must not be overlooked. Therefore, in actual conditions, the influence on temperature brought by the aerothermal radiation effect and the interfering noise of thermal radiation must be considered. In actual situations, the emissivity, absorption rate, index of refraction, and reflectivity of a material are functions of temperature and wavelength. Bartl et al. [6] indicated that the emissivity of opaque aluminum materials decreased following increases in radiation wavelength, whereas reflectivity increased. Similarly, semitransparent materials, such as sapphire crystals, showed different optical properties under changing environmental temperatures and radiation wavelengths. Dobrovinskaya et al. [7] indicated that the emissivity, reflectivity, absorption rate, and penetration of sapphire all change following changes in incident wavelength.

Following Li's research on external cooling jets for optical side windows, this study adds two different turbulence models, k-ε and k-ω. In addition, a thermal radiation model was included to better conform to actual aerothermal environments and to investigate suitable amounts of external coolant and the aerothermal problems of optical windows.

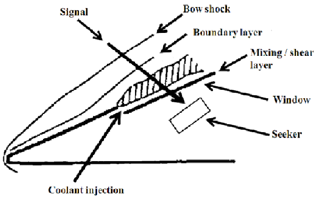

Fig. 1 Schematic diagram of aero-optical effects [1]

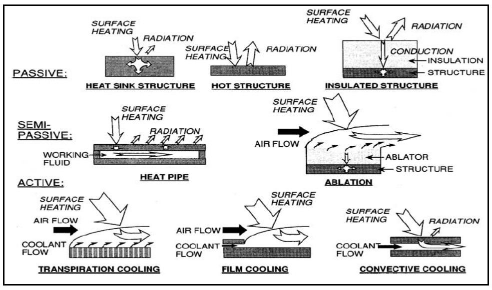

Fig. 2 Diagram of external cooling in different pattern [3]

II. PROBLEMS AND METHODS

A. Governing Equation and Numerical Methods

The governing equations are the Reynolds averaged Navier-Stokes equations, the conservation can be expressed as follows

$$\frac{\partial U}{\partial t}+\frac{\partial F}{\partial x}+\frac{\partial G}{\partial y}+\frac{\partial H}{\partial z}=\frac{\partial F_{\mathrm{v}}}{\partial x}+\frac{\partial G_{\mathrm{v}}}{\partial y}+\frac{\partial H_{\mathrm{v}}}{\partial z} \tag{1}$$

In solving equation (1), convection terms (F,G,H) are calculated by AUSM$^+$ scheme, while viscosity and diffusion flux terms (F_v, G_v, H_v) are calculated using the central difference method. Discrete space terms are to form a group of ordinary differential equations followed by time integration to obtain the numerical solution.

B. Turbulent and Radiation Models

In this paper, two different turbulence models adopted, including the realizable k-ε and standard k-ω model. The majority of wave bands considered for use in heat-seeking missiles were infrared bands, with radiation wavelengths between 3 and 5 μm. In addition, the research model in consideration investigated the optical transport phenomena of radiation absorption, penetration, refraction, reflection, and diffusion in opaque projectiles and semitransparent optical window materials. Thus, the non-gray discrete ordinate radiation model was used for simulation, with the radiative transfer equation provided below.

$$\nabla\cdot\left(I_\lambda(\vec{r},\vec{s})\vec{s}\right)+\left(a_\lambda+\sigma_s\right)I_\lambda(\vec{r},\vec{s})=a_\lambda n^2 I_{b\lambda}+\frac{\sigma_s}{4\pi}\int_0^{4\pi}I_\lambda\left(\vec{r},\vec{s}'\right)\Phi\left(\vec{s}\cdot\vec{s}'\right)d\Omega' \tag{2}$$

C. Boundary Conditions

This paper adopts computational fluid dynamics to study the external cooling characteristics of optical side window under different jet flow rates with flight speed of Mach 6, and 30 to 40 km altitude above sea level. The ambient pressure and ambient temperature are 50,000 Pa and 300K, respectively. The condition of inlet boundary and outlet boundary should be set at pressure-far-field condition and pressure-outlet condition, respectively. Besides, the cooling jet port is set to mass flow rates conditions. The projectile and optical window is set to no-slip and radiation conditions. Additionally, the real gas equation modified specific heat ratio is added.

D. 3-D Physical Model and Grid Configuration

This paper assumes the optical window to be rectangular for ease of modeling and prediction of flow field. According to the observation, it is known that the cooling jet hole is located at the bottom of leeward and its size is approximately half the height of leeward. Besides, the former configuration shows a groove tilt with a deep front and shallow end. Schematic model of missile is shown in Fig. 3. Adopted in this study three-dimensional computational grid of structural grid configuration shown in Fig. 4, for the confirmation of the computational grid is independent of the characteristics of the grid, for 300,000, 500,000 and 800,000 three kinds of fine mesh window in the same flow conditions (cooling jet = 0.15kg/s) test. The test results on the optical window position

(0.11~0.3m) of the surface temperature are shown in Fig. 5. 500,000 and 800,000 in the optical window grid has a more consistent temperature performance, and ultimately the results will be 500,000 of total grid as a follow-up study.

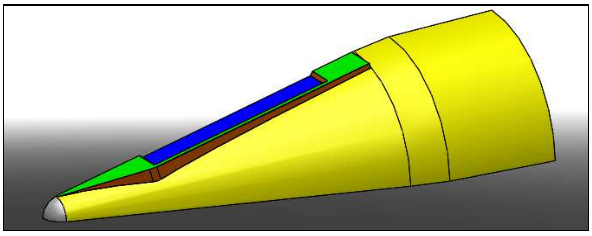

Fig. 3 THAAD guidance section model diagram

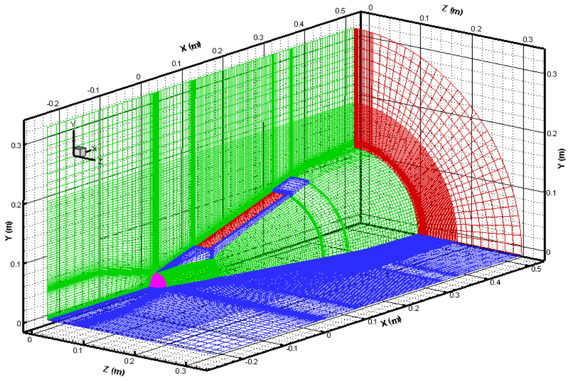

Fig. 4 3-D THAAD optical window grid diagram

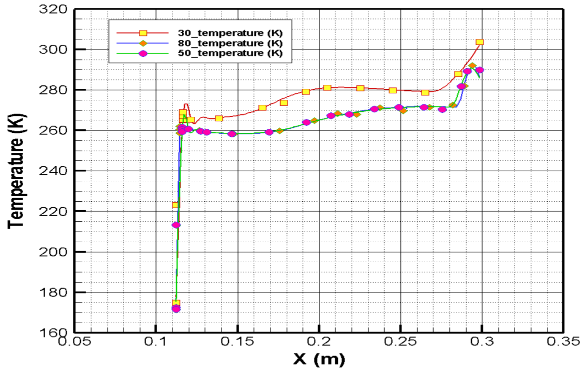

Fig. 5 Surface temperature of optical window in 3 type grid system

III. RESEARCH MATRIX

The different turbulent models are named Model A, B. The external cooling jet flow is divided into 2 categories according to their spray flow rates (J) including 0 (kg/s) and 0.15 (kg/s). Table 1 indicates the research matrix.

TABLE I
ÜRESEARCH MATRIX

Jet Flow(kg/s)	J=0	J=0.15	J=0.15& (radiation)
k-ε	A_0	A_1	A_2
k-ω	B_0	B_1	B_2

IV. RESULTS AND DISCUSSION

A. Numerical Code Validation

To verify the correctness of the formula in this software, the numerical simulation results of hypersonic flow passing through a ramp channel obtained by Algacyr Jr. [8] were referenced for comparison. The operating conditions included an inviscid flow, a Mach number of 3.5, an environmental temperature of 300 K, and a pressure of one atmosphere for two-dimensional flow field simulation. The isobaric charts for the simulation results are shown in Figs. 6 and 7. Comparison of the isobaric line distribution indicated that angles of the oblique shock waves, characteristics of the expansion waves, and the position and angle of the reflected wave on the wall were all extremely similar. The expected high-speed flow field characteristics were captured correctly, indicating that the simulation software used in this study can be feasibly applied to high-speed flow fields.

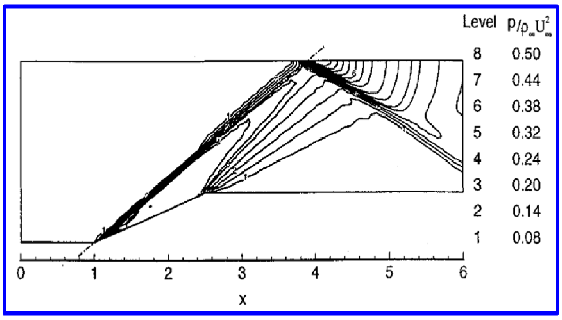

Fig. 6 Numerical simulation of Algacyr Jr. [8]

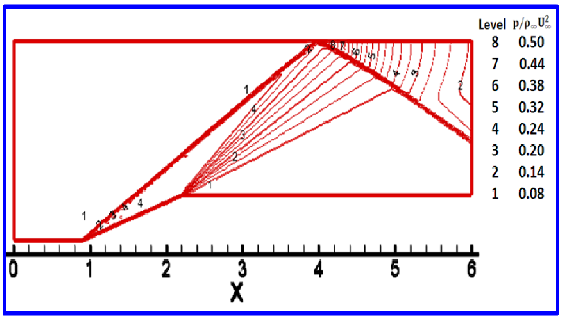

Fig. 7 Numerical simulation of present study

B. Optical Side Window Simulation Results

First, optical hoods flying at Mach 6 were simulated in conditions without cooling jets and without considering thermal radiation conditions. The results indicated that the surface temperature of the optical window was between approximately 1550 and 1620 K. Hot airflow on the optical window and the tail groove formed vortices, thus temperatures were higher. The optical window surface temperatures of the two turbulent models did not differ much, as shown in Figs. 8 and 9. The surface temperatures of the optical windows all exceeded the upper limit heat resistance temperature of 500 K in sapphire optical windows. Therefore, cooling jets had to be used.

When jet cooling was performed on optical side windows, the high-speed mainstreams that were initially close to the optical window surface were lifted upward due to injection of the cooling jets. In situations where the speeds of the jets and the mainstreams differed, the two produced a clear shear layer, as shown in Fig. 10~11. In conditions with cooling jets, when no thermal radiation was observed as shown in Fig. 10, the surface temperature of the optical windows dropped to approximately 280 K. Outside of the optical window, with no cooling jets, the hood nose and the surrounding area maintained a high temperature of approximately 1500 K. Fig. 11 reveals the situation with thermal radiation. The surface temperature of the optical windows dropped to approximately 260 K, whereas the hood nose and the surrounding area, which had no cooling jets, declined to approximately 1100 K. The simulation results when adding thermal radiation indicate that this model is better able to conform to the aerothermal conditions of actual flow fields because of the addition of heat flux dissipation.

Fig. 12 shows the optical side window surface temperature distribution at different turbulences and with no thermal radiation. Without radiation, the side window surface temperatures of different turbulence simulations were all approximately 280 K. With radiation, the side window surface temperatures were approximately 260 to 270 K. The temperatures at the ends of the side windows all rose, a result of weaker coverage from the cooling jets, as shown in Figs. 13 and 14. In addition, the surface temperatures of the optical windows were all less than 500 K. If thermal radiation is considered, the amount of cooling jets could be reduced to decrease the missile payload.

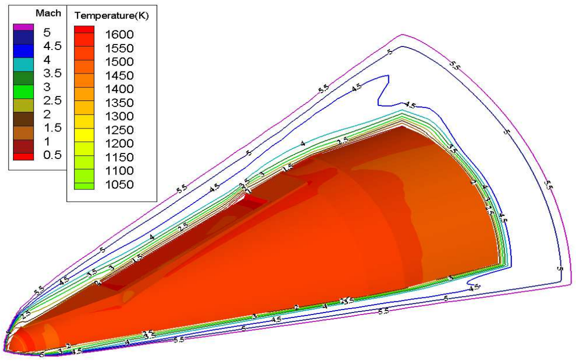

Fig. 8 Mach and temperature contour of model A_0

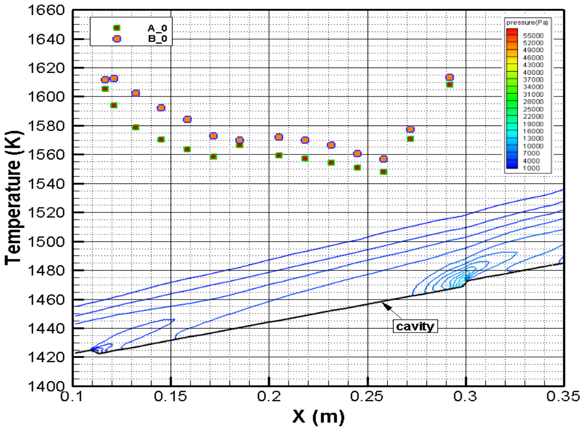

Fig. 9 Surface temperature of optical window in model A_0, B_0

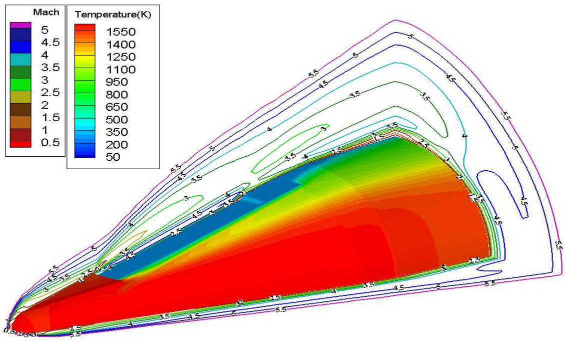

Fig. 10 Mach and temperature contour of model A_1

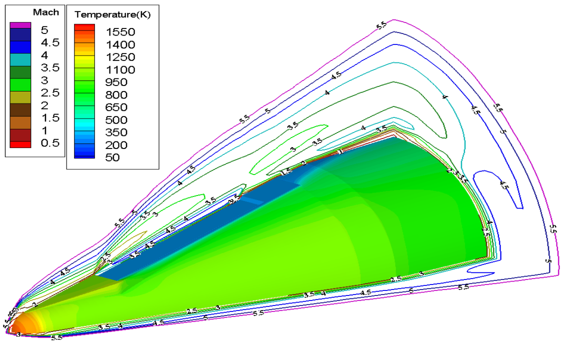

Fig. 11 Mach and temperature contour of model A_2

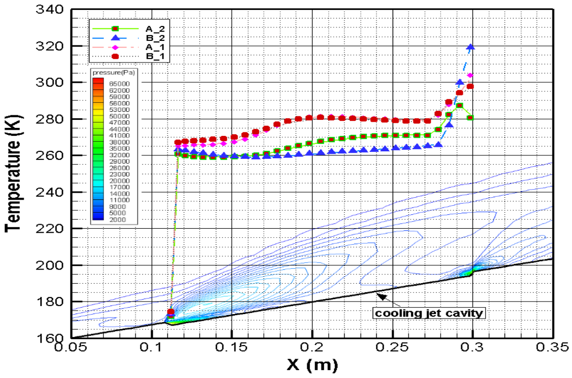

Fig. 12 Surface temperature of optical window in model A_12, B_12

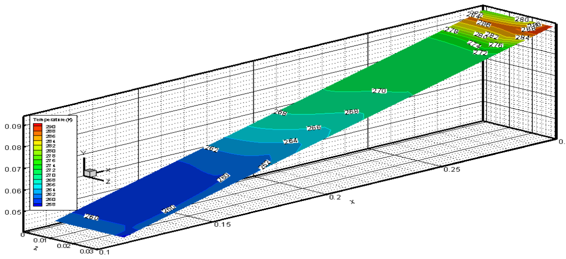

Fig. 13 Surface temperature of optical window in model A_2

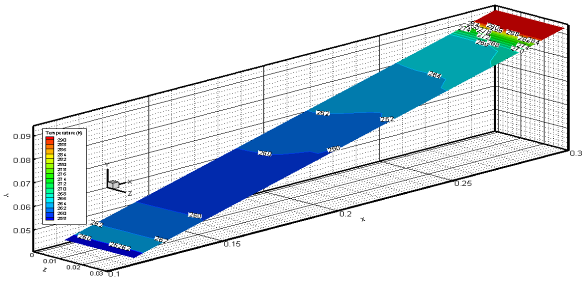

Fig. 14 Surface temperature of optical window in model B_2

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