*The 2016 World Congress on*
***The 2016 Structures Congress (Structures16)***
*Jeju Island, Korea, August 28-September 1, 2016*

# Numerical Analysis and Validation for Continuous Type Lateral Jet Controlled Missile

*Kyoung Tai Kang[1)], Eunseok Lee[2)], and Soogab Lee[3)]

[1), 2)] *Agency for Defense Development, Daejeon, Korea*
[1), 3)] *School of Mechanical and Aerospace Engineering, Seoul National University, Seoul, Korea*
[1)] *ktkang@gmail.com*

## ABSTRACT

Comparison of numerical simulations for continuous type lateral jet controlled missile with wind tunnel test results has been performed. Three dimensional flow fields were simulated by using unstructured based Reynolds averaged Navier-Stokes solver. Numerical results show good prediction capability of aerodynamic jet interference for continuous type lateral jet thruster. Jet interaction characteristics according to the change of flow and jet conditions was captured well. The comparison result also shows that the MPR is appropriate scaling parameter for subscale lateral jet wind tunnel tests. The validated numerical methods allow extensive utilization of CFD for aerodynamic jet interaction problems associated with the continuous type lateral jet thruster.

## 1. INTRODUCTION

The continuous type lateral jet thruster is adopted to the modern guided missile as additional control device, because it ensures omnidirectional control with short response time and large reaction forces. The continuous type lateral jet control is performed using four nozzles which are located in diametrically opposite directions in two orthogonal planes. Each nozzle has its own switching device to control nozzle thrust. The combinations of switching unit of nozzles enable thrust vectoring. Although it provides large control force with fast response characteristics, it causes complicate jet interaction with the free stream when it operates at the low altitudes. This jet interaction produces interference forces and moments on the airframe. So, these jet interaction effect should be taken into account utilizing the lateral jet on the missile.

The basic features of jet interaction phenomena created by a lateral jet firing into a supersonic free stream is well understood through the wind tunnel tests, flight tests, analytical and numerical studies over more than fifty years. A number of studies investigated the influence of lateral jets for missile systems. (Champigny 1994) reported

[1)] Senior Researcher, Graduate Student,
[2)] Senior Researcher
[3)] Professor

on the importance and difficulties of lateral jet control for tactical missile. (Roger 1999) reviewed the lateral jet control effectiveness for supersonic/hypersonic interceptors and scaling issues of wind tunnel tests. (Cassel 2003) described the evolution of analytical and computational modeling methods of jet interaction. However, most of studies were confined to impulse type small single lateral jet applications and the study for the continuous type lateral jet has not been proceeded. The principle of jet interaction mechanism of the continuous type lateral jet thruster is the same with the conventional lateral jet thruster as explained previously. But, the continuous type lateral jet controller has bigger size of jet nozzle than the conventional lateral and causes more complex aerodynamic jet interaction between lateral jet and supersonic free stream, due to multiple nozzle operation.

From the previous work (Kang 2015), numerical investigation of interaction effects of continuous type lateral jet thruster has been conducted. But, simulation results was only validated with single jet wind tunnel test results. In this paper, further validations of numerical analysis results for continuous type lateral jet controlled missile are presented.

## 2. NUMERICAL ANALYSIS FOR CONTINUOUS TYPE LATERAL JET

Numerical simulation was performed for the canard-tail configuration missile with continuous type lateral jet thruster. Steady-state Reynolds averaged Navier-Stokes (RANS) simulation was performed using STAR-CCM+, which employs finite volume method allowing the use of arbitrary polyhedral meshes. Fully-coupled density based solver formulation was applied with second-order upwind based AUSM+ scheme for the convective flux calculation and second-order central discretization for the diffusion terms. The k-$\omega$ SST model was used for turbulence closure. About 8 million polyhedral mesh cells were constructed for the body canard configuration missile with lateral jet and 20 prism layer were used for near wall boundary calculation. Rectangular shaped nozzle configuration of jet thruster was modeled from throat region and the stagnation inlet boundary condition was applied with the jet chamber conditions.

Aerodynamic jet interference is a function of many parameters which includes flight Mach number, altitude, size of jet forces, angle of attack, bank angle and jet direction(Eq. (1)). For the analysis of continuous type lateral jet with minimum simulation cases, we used defined jet directions. Considering full thrust conditions and null thrust state, the four jet directions (F0: zero reaction force null state, F1: jet direction $0°$, F2: jet direction $22.5°$, F3: jet direction $45°$) in Fig. 1 can represent all jet directions. Because all other jet direction conditions can be reproduced by the defined four jet direction cases with geometrical symmetry. So the simulation was conducted for these defined jet direction conditions at various free stream conditions. Jet interference effects was measured as the difference of aerodynamic coefficients between with and without the jet flow which is defined in Eq.(2).

$$\Delta C_w = f(M_\infty, H, |F|, \alpha, \phi, \theta_{jet}) \quad (1)$$

$$\Delta C_w = C_w(\text{with jet}) - C_w(\text{without jet}) \quad (2)$$

## 3. WIND TUNNEL TEST AND VALIDATION OF NUMERICAL METHOD

To evaluate uncertainty between CFD simulations and physical results, the wind tunnel test has been conducted on a subscale model representing a missile with continuous type lateral jet.

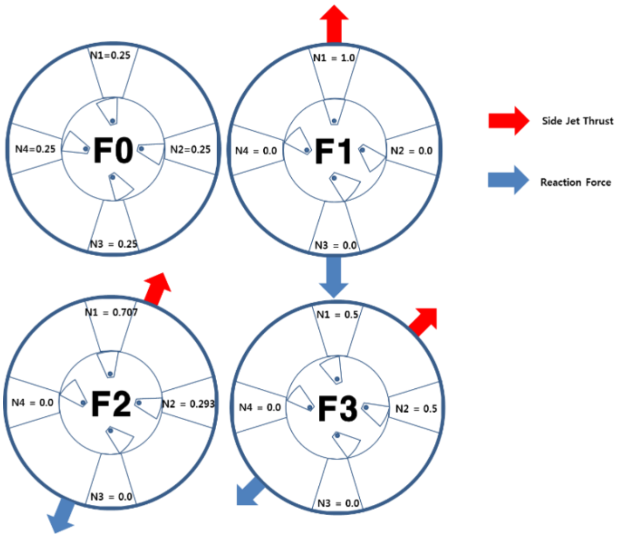


Fig. 1 Defined jet directions and corresponding nozzle combination for the simulation

Test model was designed to simulate jet flow for four defined jet directions: F0, F1, F2, F3. Compressed air gas was supplied to the jet nozzle from reservoir for generating various chamber pressure conditions. Test conditions were designed to simulate various flow conditions in the CFD simulation cases. But there are difficulties in simulating conditions in the wind tunnel with compressed air gas. So, MPR was selected as a similitude parameter to match actual flight conditions. Five components (Cy,Cz,Cl,Cm,Cn) balance was used to measure aerodynamic coefficients during the test. Jet interaction aerodynamic coefficients were obtained from differences between jet on and jet off tests.

$$MPR = \frac{\gamma_j P_j M_j^2}{\gamma_\infty P_\infty M_\infty^2}\left(\frac{A_j}{A_b}\right) \tag{3}$$

For the validation of numerical method, CFD simulations were performed at the wind tunnel test conditions. All computational data that were employed in actual flight test conditions were obtained using the lumped gas model($\gamma = 1.24$) for jet flow. The cold gas model($\gamma = 1.4$) was used to the simulations for the wind tunnel test conditions. The typical jet interaction force and moment coefficients are compared with numerical simulation results in Fig. 2, where jet interaction effects versus MPR at M = 3.0, $\alpha_t = 0^o$, $\phi = 0^o$ and jet direction index = F1 are displayed. The error bar of wind tunnel test data in the figure shows uncertainties of measurements. The jet interaction normal force and moment coefficients of the simulations are in agreement with the experimental data with less than 10% error range at MPR = 3.05. The jet interaction effects for hot gas and cold gas simulation results show the same behavior along the MPR change and the difference is small. This result shows that the MPR is good similitude parameter to describe jet interaction effects.

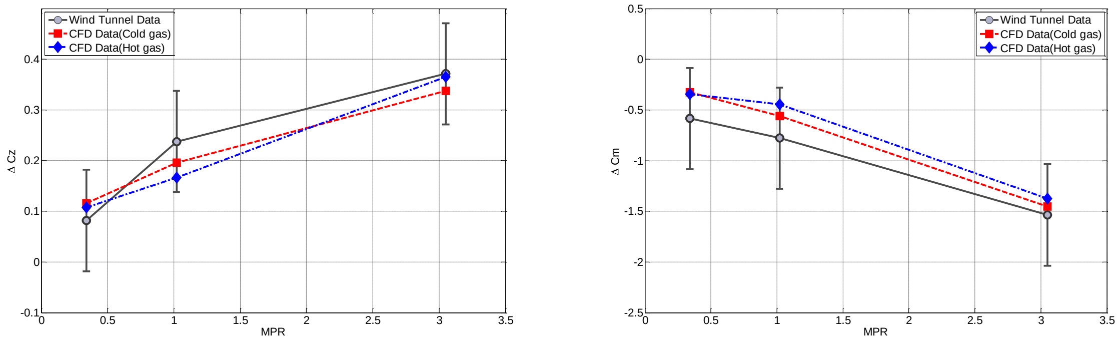


Fig. 2 Jet interaction normal force coefficients for defined jet directions at M=3.0 and MPR = 1.02

Fig. 3 and Fig. 4 show the comparison of jet interaction normal force and pitching moment response surfaces between cold gas CFD simulations results and wind tunnel test data at M = 3.0 and MPR = 1.02. Overall jet interaction trends in accordance with the change of angle of attack and roll angle are qualitatively the same. The differences are increased according to increase of the angle of attack. This seems the effect of strong interaction between jet flow and cross flow of missile at large angle of attack.

The differences of each aerodynamic coefficient were calculated and the maximum error of the change of the center of pressure( $\Delta Xcp$ ) due to jet interaction were measured as less than 1 caliber.

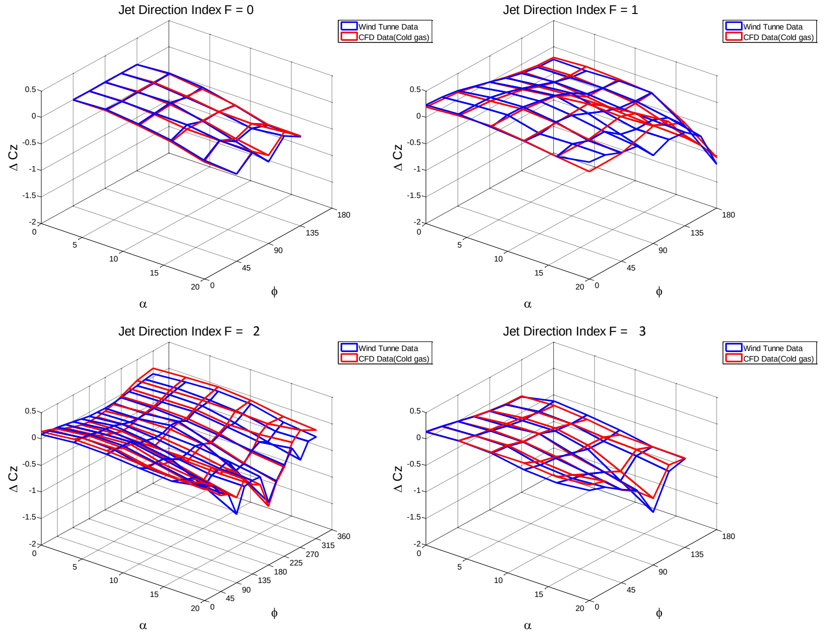


Fig. 3 Jet interaction normal force coefficients for defined jet directions at M=3.0 and MPR = 1.02

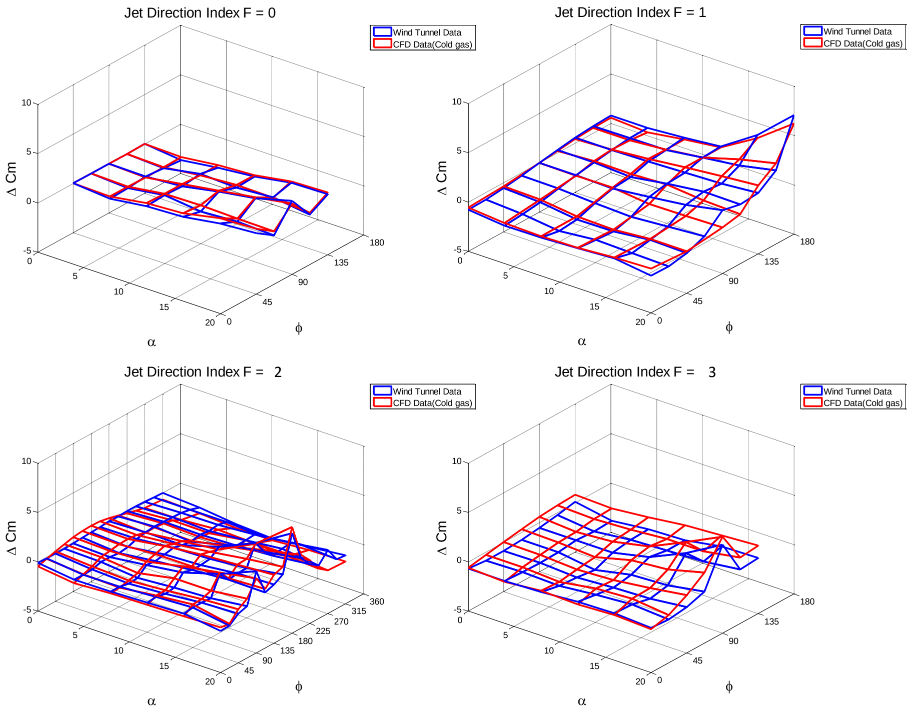


Fig. 4 Jet interaction pitching moment coefficients for defined jet directions at M=3.0 and MPR = 1.02

## 4. CONCLUSIONS

The aerodynamic analysis of jet interaction for the missile with continuous type lateral jet was developed by using CFD simulations. The three dimensional jet flow simulation was performed using the commercial unstructured based CFD solver, STAR-CCM+. All jet interaction effects between the free stream flow and the jet flow were accounted for as incremental terms.

The numerical method in this study was validated through comparison with the wind tunnel test data and the uncertainty level of CFD simulations of jet interaction was evaluated. The comparison result also shows that the MPR is appropriate scaling parameter for subscale lateral jet wind tunnel tests. The validated numerical methods allow extensive utilization of CFD for aerodynamic jet interaction problems associated with the continuous type lateral jet thruster.

## REFERENCES

Champigny, P., Lacau, R. G.(1994), “Lateral Jet Control for Tactical Missiles”, AGARD Report 804, pp. 301-3057

Roger, R. P. (1999), “The Aerodynamics of Jet Thruster Control for Supersonic/Hypersonic Endo-Interceptors: Lessons Learned”. AIAA 99-0804

Cassel, L. A. (2003), “Applying Jet Interaction Technology”, Journal of Spacecraft and Rockets, Vol.40, No. 4.

Kyoung Tai Kang, Eunseok Lee, Soogab Lee(2015), "Numerical investigation of jet interaction for missile with continuous type side jet thruster", International Journal of Aeronautical and Space Science, Vol.16, No 2, 2015, pp148-156