Navigator

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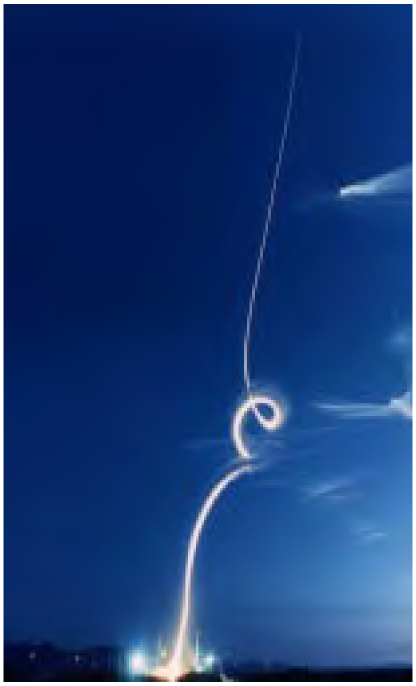
Design and Evaluation of the THAAD Missile

Donald McClure, PEO Missile Defense



Recent computational success for the U.S. Army's Theater High Altitude Area Defense (THAAD) missile project has been made possible through the extensive use of high performance computing (HPC) assets. These HPC resources provided rapid solutions of complex equations, which generated engineering and aerodynamic data that would otherwise not have been available for the development and checkout of the missile.

This data was utilized for improved design understanding, autopilot tuning and sensitivity studies, ground and flight test data analysis, and improved flight simulations. Analysis of each aspect of reaction jet control contributed to an improved understanding of the missile aerodynamics and performance objectives. A greater confidence in the present design and future requirements has also been achieved.

During the last two years, this Challenge project examined extensive details of jet interaction (JI) phenomena associated with aerodynamic control of the missile. The JI effects of interest to investigators are caused by the aerodynamic interactions between the control jet exhaust and the oncoming flow of air. These effects generally work against the desired action of the control jet and must therefore be included in the autopilot design to achieve robust and reliable flight performance.

The analysis of various aspects of JI control for THAAD helped to increase understanding of JI from CFD simulations, which led to improved predictions of missile performance. An understanding of each of these JI control aspects fed directly into autopilot designing and tuning, flight data reconstruction (e.g., thruster performance derivation), and flight test anomaly investigations.

Background

Performance requirements for rapid and robust responsiveness, both in and out of the sensible atmosphere, compelled the use of reaction control jets as a divert and attitude control system (DACS). This system consists of ten liquid bi-propellent jets, with four located at the center of gravity for divert capability and the remaining six placed at the aft end for pitch, yaw, and roll control. Figure 1 illustrates jet placement on the kill vehicle (KV) and the computational grid used in the studies. Research focused on scaling cold jet wind tunnel data to flight, JI afterburning effects, yaw control, and transient jet phenomena.

Different models were required for the jet exhaust, depending on the level of complexity required in the simulation. For example, comparisons with wind tunnel data required only a cold air jet, while the study of afterburning effects required a finite rate chemistry model for the bi-propellent mixture. Each of these modeling aspects and their implications for missile performance and computational resource requirements were analyzed in this research.

PROJECT:
Analysis of Jet Interaction for the THAAD Interceptor

PRINCIPAL INVESTIGATORS:
Donald McClure, PEO Missile Defense, Huntsville, AL

Rex Chamberlain, Tetra Research Corporation, Huntsville, AL

Anthony Dang, ADRC Inc., Huntsville, AL

ASSIGNED SITE/SYSTEM:
NAVO MSRC T90, SMDC Origin 2000

CTA:
Computational Fluid Dynamics

URL:
http://www.tecom.army.mil/hpcw/1998/chamber/chamber.html

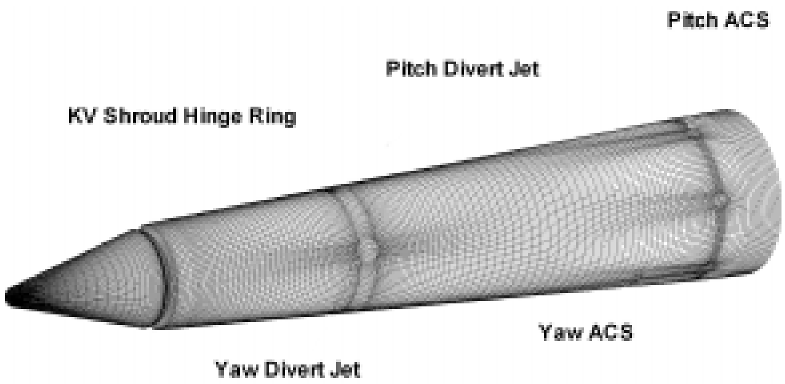


Figure 1. Jet Placement on THAAD

Technical Approach and Resource Requirements

For an acquisition program on a very aggressive schedule, it was not enough to solve the equations on an arbitrarily fine grid, perform some visualizations, and declare the problem solved, even in principle. The autopilot needed extensive force and moment input data to correct for JI control effects in appropriate parts of the battlespace. This in turn required a large number of computational solutions to define aerodynamic trends that could not be measured in ground or flight tests. The technical approach to understanding the fluid dynamics associated with JI was through the numerical solution of the compressible Navier-Stokes equations. It was clear from the beginning that Challenge resources were needed to understand each aspect of the JI control problem in a timely fashion.

The computational techniques required to successfully address JI phenomena must be robust since the numerical aspects of such demanding flow fields often created stability and convergence problems. An additional requirement for a fully coupled finite rate chemistry to study the effects of exhaust afterburning imposed significant computational resource requirements that must be addressed with multiple processors to achieve timely solutions.

The production software used for the most stressing aerodynamic problems was a parallelized version of General Aerodynamic Simulation Program (GASP). Hardware resources included the NAVO MSRC 22-processor T90 and the Space & Missile Defense Commands (SMDC) 128-processor Origin 2000.

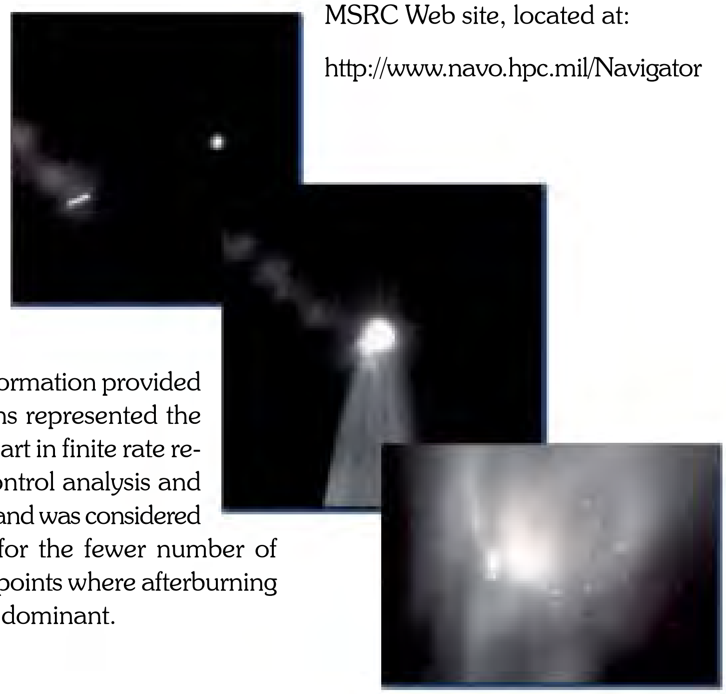
A typical run-time to achieve steady-state, non-reacting multiple (single) jet solution was 120 (60) Central Processing Unit (CPU) hours on a single T90 processor. The turnaround time at NAVO MSRC was 1 to 2 days, using eight processors in the given queue structure. Finite rate chemistry runs required an order of magnitude more computational effort, but those solutions, besides being more numerically sensitive, could still be obtained in 2 to 3 weeks. The new information provided by these runs represented the state-of-the-art in finite rate reaction jet control analysis and technology, and was considered acceptable for the fewer number of battlespace points where afterburning effects were dominant.

Results

Insight into JI control has been greatly enhanced by comparing different physical solutions (e.g., geometric scaling and altitude scaling), by examining trends across Mach number and altitude ranges, and by evaluating the resulting behavior of flight simulations using the predicted JI inputs. As of this writing, more than 150 single and multiple jet analyses have been accomplished using Challenge resources. An increased understanding of JI control behavior, ground and flight testing, and autopilot simulations extends beyond the present missile program to provide a starting point for future work. This includes the systematic development of a detailed, research-oriented experimental JI database, which is needed for CFD code and model validation, and for benchmarking solutions across HPC platforms. This complementary activity will leverage the computational efforts, which have already enhanced the understanding of critical design.

You can find this article, Jet Interaction Phenomena for the THAAD Missile, presented in full on the NAVO MSRC Web site, located at:

http://www.navo.hpc.mil/Navigator



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Stennis Space Center, MS 39522