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NASA Johnson Space Center
EG3: Applied Aeroscience and CFD Branch
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NASA JSC

The Johnson Space Center (JSC) is NASA's operations center for human space flight programs. This includes the International Space Station (ISS), Commercial Crew Development (CCDev), and the Orion Multi-Purpose Crew Vehicle (MPCV).

NASA breaks down the centers into directorates. The two main directorates at JSC are the Mission Operations Directorate (MOD) and the Engineering Directorate. MOD deals with planning, training, and actually flying the missions while the engineering directorate develops and maintains the hardware and software necessary for space exploration.

My Branch

After directorates, the centers are broken down into divisions, then branches, and even sometimes into groups. EG is the Aeroscience and Flight Mechanics Division. EG3 is the Applied Aeroscience and Computational Fluid Dynamics (CFD) Branch.

EG3 focuses on providing aerodynamic, aerothermal, rarified gas dynamic, and parachute support for various vehicles and missions. Some of the current programs/projects include Orion, CCDev, ISS, and Morpheus (one of NASA's Advanced Exploration System (AES) projects).

Projects

Boeing Launch Abort Analysis

My first project for the summer was analyzing the Boeing CCDev Vehicle's abort aerodynamics using an inviscid solver (CART3D). The goal of the project was to develop the grid and CFD inputs necessary to use CART3D as a quick tool for investigating loading trends at various points along abort trajectories. As a supplementary task, I analyzed a few cases and compared them to the aerodatabase from the last generation geometry.

In order to run abort cases, I first needed to determine the best way to model the engines inside of CART3D. This is necessary because the solver only allows one specific heat ratio for the entire grid; therefore the engines must be run at a specific heat ratio of 1.4 to match the surrounding air. Changing the engines to this ratio reduces the mass flow through the nozzle thus possibly reducing the exit conditions that need to be matched in order to ensure that the final solution is accurately modeling the wake.

For this investigation, I considered three nozzle designs: the full geometry of the nozzle, a ‘virtual throat’ nozzle that uses the full geometry but cuts out the plenum and part of the expansion section, and ‘various plenum radii’ that maintain the expansion region and throat but vary the plenum radius. The full geometry design is intended to be used as a base case for comparison with the other two designs, the virtual throat design is intending to increase the throat area to match the mass flow that would be achieved with the actual engine specific heat ratio, and the various plenum radii are used to compare how the small inside shocks come off the throat with different throat contours.

After running a series of CART3D cases on each design, it became apparent that the exit plane contours of density and velocity were most closely matched by the full geometry and various plenum radii. The weak interior shocks were only apparent in the center of the exit plane and had little impact on the average exit conditions. Since the differences between the full geometry and the various plenum radii were so small, the full geometry was finally chosen to be implemented in the Boeing CCDev Vehicle’s grid.

The next part of this task included removing grids around the nozzle of the Service Module (SM) and replacing them to include the new nozzle grids (the original grid capped off the nozzles and was made to be used with a different solver). Once complete, a set of cases for the combined Crew Module (CM) and SM were setup. The main goals of the first set of runs were to compare the results of powered and unpowered cases, see if there were significant non-linearities in the loading with small steps in alpha, and determine if CART3D is matching the expected loading trends.

After running the cases and extracting the data it became clear, even with some difficulty converging unsteady solutions in a steady state solver, that the results were trending in the same way as higher fidelity data and further that the magnitude of the results themselves were close. Another result of this first set of runs was that the unpowered cases were much more difficult to resolve than the powered cases and exhibited more non-linearities. This is most likely due to the wake being more unsteady without active rear-facing nozzles. Overall, the results of this analysis point to CART3D being a great tool for analyzing a large sweep of cases, picking up non-linearities, and thus being able to narrow down the focus for the sweep of higher fidelity and experimental cases.

The second set of cases I investigated were the use of the CM & SM with the Launch Vehicle (LV) in proximity. There was very little existing data on these cases and the data that does exist does not include altitude as a varying parameter, despite the range of altitudes given for a single mach number in the abort trajectories. Therefore the main goal for this set of cases was to fill in some of the gaps in the data and determine how important altitude is in the loading on the vehicle.

The results of these cases indicated that the existing data did not quite cover the necessary range of separation distances and that altitude plays a large role in the deviation of the CM & SM only loads from the loading on the CM & SM in proximity to the LV. This is due to the effect of pressure on the size of the shock cells from the larger launch abort engines. The higher the altitude, the lower the pressure and thus an increase in the extension of the shock cell behind the SM.

Protuberance Heating Study

My second project for the summer dealt with investigating how heating changes as the height of a protuberance on top of a flat plate changes. The goal of this investigation is to better understand how to properly model heating on and around a protuberance. This is one of the biggest challenges when designing a re-entry vehicle because very small changes in the shape and conditions leading up to a protuberance, not to mention the protuberance geometry, will greatly impact the local heating.

This project was split into two parts: developing grid scripts to quickly prepare a large range of cases and running a set of various height protuberances inside of the full Navier-Stokes solver, OVERFLOW.

The development of the grid scripts involved writing from scratch how to create six overset grids that formed a flat plate and a protuberance. The only required inputs to the script are the type of protuberance (cylinder or rectangular prism), the size of the protuberance, and the length of the plate leading up to the protuberance. The rest of the grid spacing and cell number inputs are optional and set up as functions of the required inputs. This allows a large range of cases to be developed without the user having to iterate over the grid generation process.

After developing the scripts, I ran a set of eight protuberance heights with a single boundary layer thickness and both adiabatic and isothermal walls. After running the cases and combing through the results, a few interesting results became apparent. As the height of the protuberance increased, the heating on the plate leading up to the protuberance increased. This makes sense because aside from the freestream conditions, the heating on the plate is dominantly governed by how and when the flow separates ahead of the protuberance. This separation region is longer and thicker for larger protuberance, but the separation distance begins to converge as the height of the protuberance increases.

Another interesting result is that the heating on the face of the protuberance is maximized at some protuberance height that is approximately equal to the boundary layer thickness. This means that taller protuberances will actually see lower heating levels than some smaller protuberance. This is due to the location of the triple point, or shock-shock interaction point. On taller protuberances, the separation shock interacts with the bow shock at some point along its face. While on smaller or mid-sized protuberances, this triple point occurs above or right at the top leading edge of the protuberance. The heating on such a protuberance is fundamentally different and requires a different heating model.

Other Co-Op Activities

Being a co-op at JSC is about much more than just work. There is a large co-op community consisting of possibly over a hundred students at a time. With this large of a group in a city like Houston, it isn't hard to find something that interests you and a handful of people willing to tag along. In my time here, I have played coed volleyball and softball, gotten a SCUBA open water certification, gone skydiving, watched two NCAA sweet sixteen games, volunteered at the food bank, seen an air show, and much more.