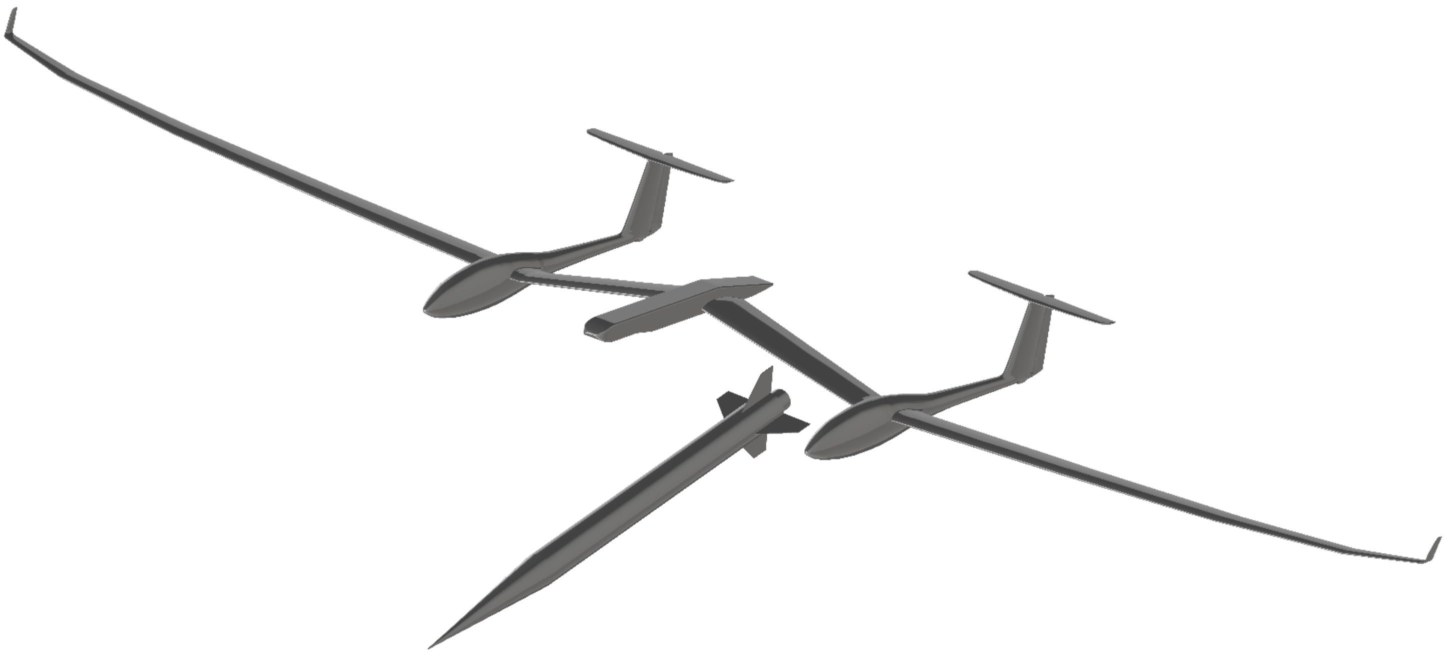
NASA Armstrong's Approach to Store Separation Analysis



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Outline

Store Separation Background

- What is Store Separation?
- Why is NASA Armstrong Pursuing This Capability?

Toolset & Methodology Introduction

- Major Approaches in Store Separation Analysis
- NAVSEP – US Navy Store Separation Code
- Cart3D – Euler CFD Code
- Star-CCM+ - Full Navier-Stokes CFD Code
- Python Scripting Work
- Workflow Overview

Store Separation Analysis Example

- Initialization of Store Separation Capability for Towed Glider Air Launch System

Store Separation Background

What is Store Separation?

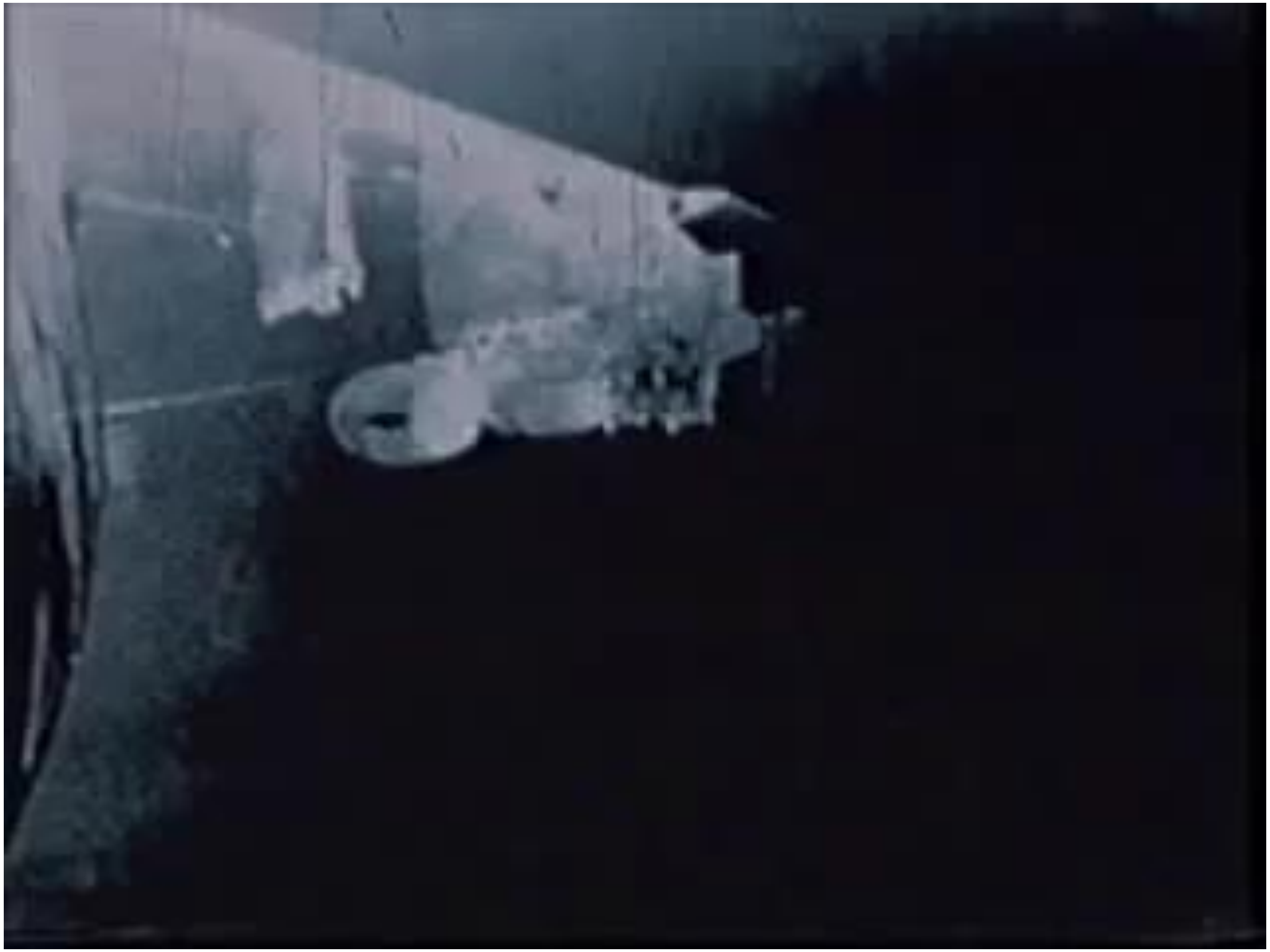
- Store – any device meant for external or internal carriage and mounted on aircraft suspension or release equipment
- Store separation – detachment of store from vehicle
- Safe and Acceptable Separation
  - Safe
    - Store does not hit aircraft or other stores
    - Store does not disintegrate or explode
  - Acceptable
    - Store does not tumble
    - Rates are captured if equipped with sensors
    - Photogrammetric data is captured (if technique is used)

Why is NASA Armstrong Pursuing This Capability?

- Support the airworthiness and flight safety review process at Armstrong
- Help ensure safety of vehicle and crew
- Help ensure success of mission
- Support advocacy for new projects
- Support research efforts in-house and by potential customers
- Complement our flight research/test capabilities, as well as our self-certifying status

Store Separation Gone Wrong!

From https://www.youtube.com/watch?v=fPTnmZ_HPAs



Toolset & Methodology Introduction

Major Approaches in Store Separation Analysis

NAVSEP

Essentially a 6-DoF trajectory analysis for the store, given the initial launch/drop conditions. All aerodynamics properties for the store, as well as the carrying aircraft's influence are interpolated from look-up tables derived from CFD, wind tunnel tests, or flight testing

- Advantages:
  - Very fast computer run-time per simulation
  - Required for sensitivity studies/Monte-Carlo analyses where thousands of simulations are required
- Disadvantages:
  - Difficult to account for complex, time-accurate interactions between the store and carrying aircraft
  - Trajectory might be off due to interpolation from sparse look-up table

DIRECT TIME-ACCURATE CFD

The flow around both the store and the carrying aircraft is fully modeled in a time-accurate and transient manner in the CFD solver

- Advantages:
  - No interpolation involved
  - Highest fidelity store separation analysis possible with current analysis techniques
  - Provides verification of the NAVSEP results
- Disadvantages:
  - Time-, compute-, and labor-intensive
  - Only tens of simulations are realistically possible in an analysis campaign

NAVSEP Introduction

Summary of NAVSEP

- Generalized store separation code used by the US NAVY
- Developed by the Store Separation Branch at NAVAIR
- Tracks the 6 DoF trajectory of the store using aerodynamic look-up tables
- Can be loosely-coupled to a CFD code
- Capabilities:
  - Can input thrust profile (time vs. thrust)
  - Can input ejector forces (time or displacement vs. force)

Inputs:

- Aerodynamic databases (freestream and grid)
- Mass properties
- Flight condition
- Reference lengths / CG locations
- Initial position and orientation in defined coordinate system

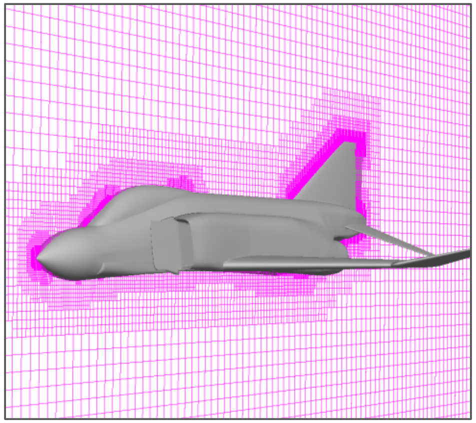
Outputs:

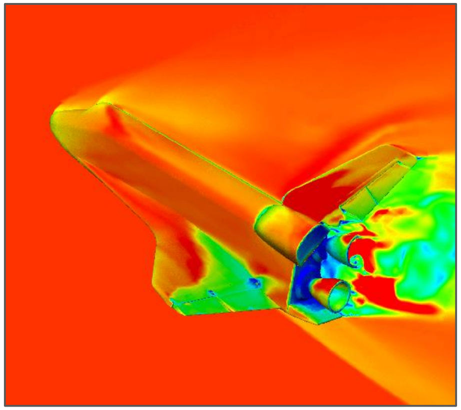
- Velocity
- Position
- Orientation
- Forces
- Moments
- Time
- Orientation rate of change
- Alpha
- Beta

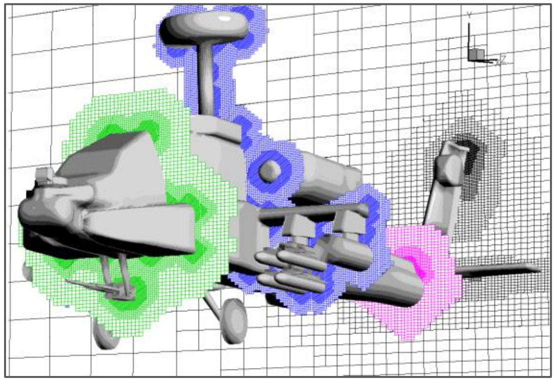
Cart3D Introduction

Summary of Cart3D

- High-fidelity Euler code
  - No boundary layer, no viscous effects, no turbulence models
- Unstructured, adaptively refined Cartesian grids
- Efficient for complex geometries
- Turn around time is fast for a single case compared to a full Navier-Stokes run
  - Simply need a surface grid and input files
- Can use multiple processors to decrease run time
- Developed at the NASA Ames Research Center
- Capable of wide range of Mach numbers

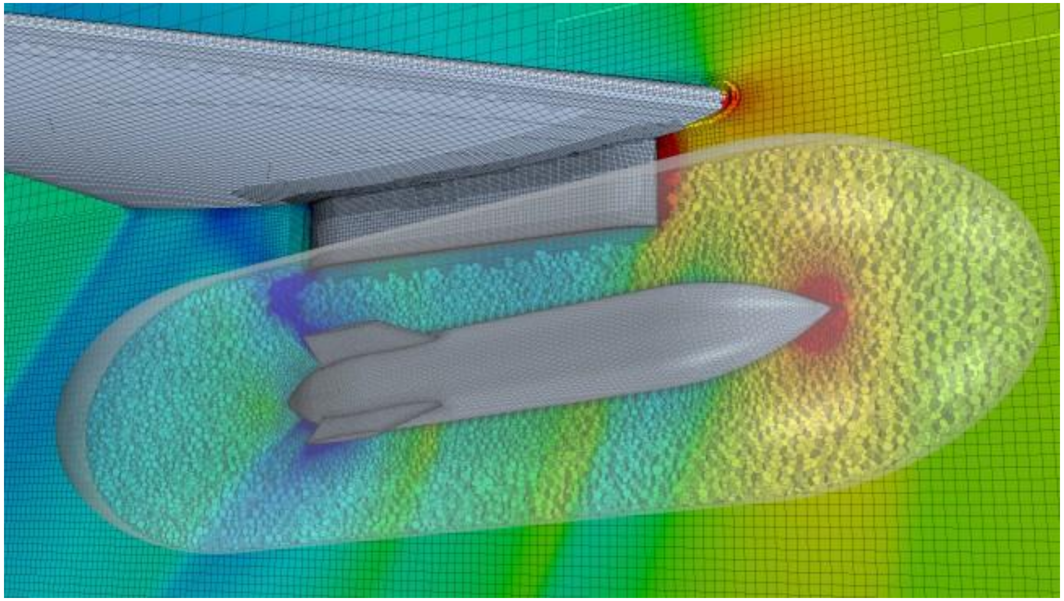






Star-CCM+ CFD Code

- Unstructured polyhedral full Navier-Stokes CFD code with Euler, RANS, DES, and LES approximations
- Unsteady/time-accurate and overset mesh capabilities allow arbitrarily complex geometries to be analyzed in a store separation analysis
- In continuous use at NASA Armstrong since 2008 with good results in support of a wide variety of flight projects including our GIII and F-15 flight research testbeds
- Used together with Cart3D to construct aerodynamic look-up tables for the NAVSEP approach
- Also could be used to conduct direct time-accurate CFD store separation analysis



Python Scripting

Summary of Python Use

- Python is used to set up Cart3D runs for creation of aerodynamic databases
  - Creates folder structure, translates geometry, and creates all input files for Cart3D

- Python is also used to parse NAVSEP output and create plots of store position and orientation over the course of the simulation

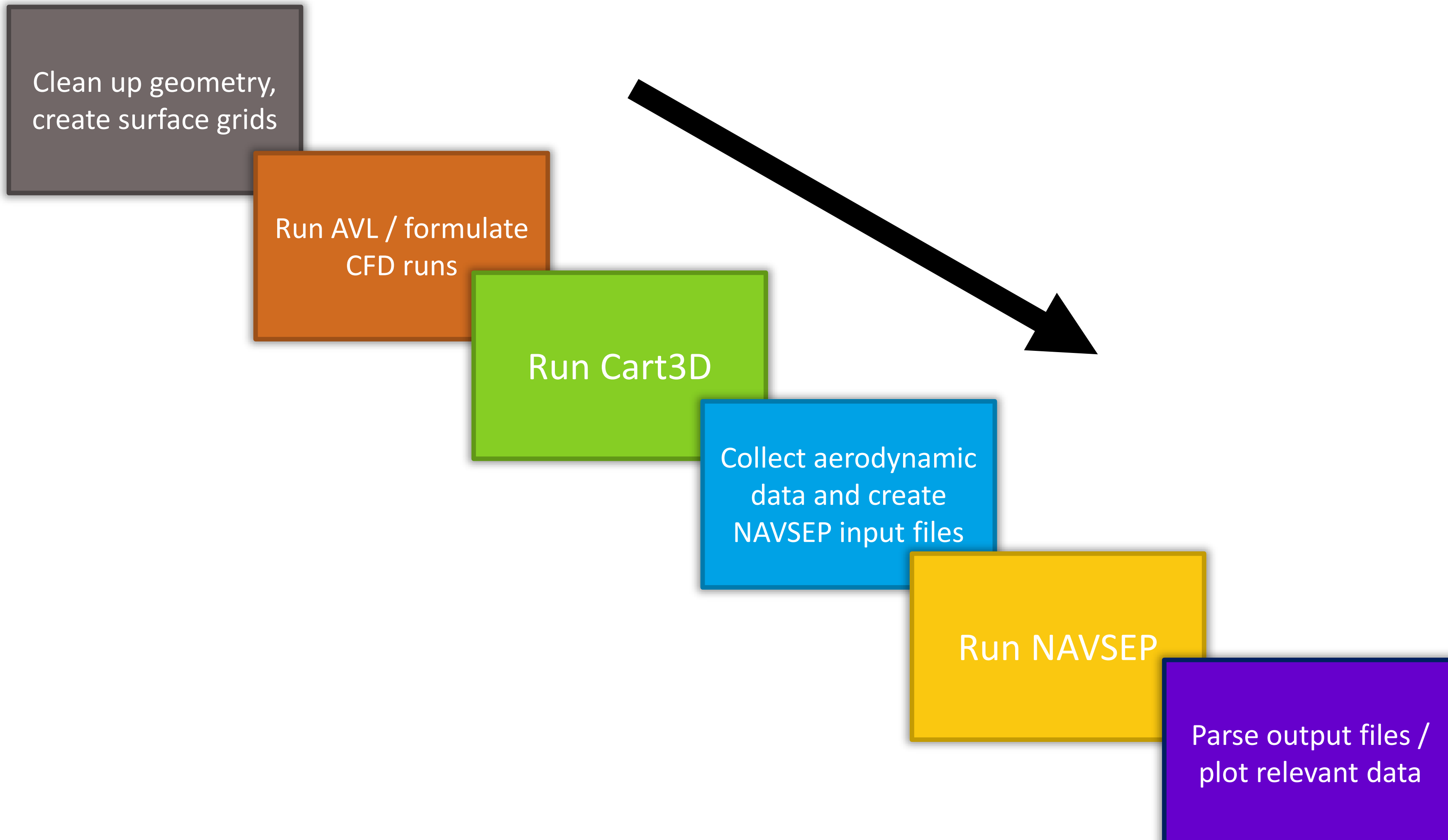
- Currently using Anaconda Python Distribution
  - Python distribution that includes many packages that are useful for scientific / engineering work
  - Includes Python
    - Key packages utilized
      - Matplotlib – used for creating plots
      - Spyder (integrated development environment) – useful for writing / debugging code

Overall Workflow for Store Separation Analysis

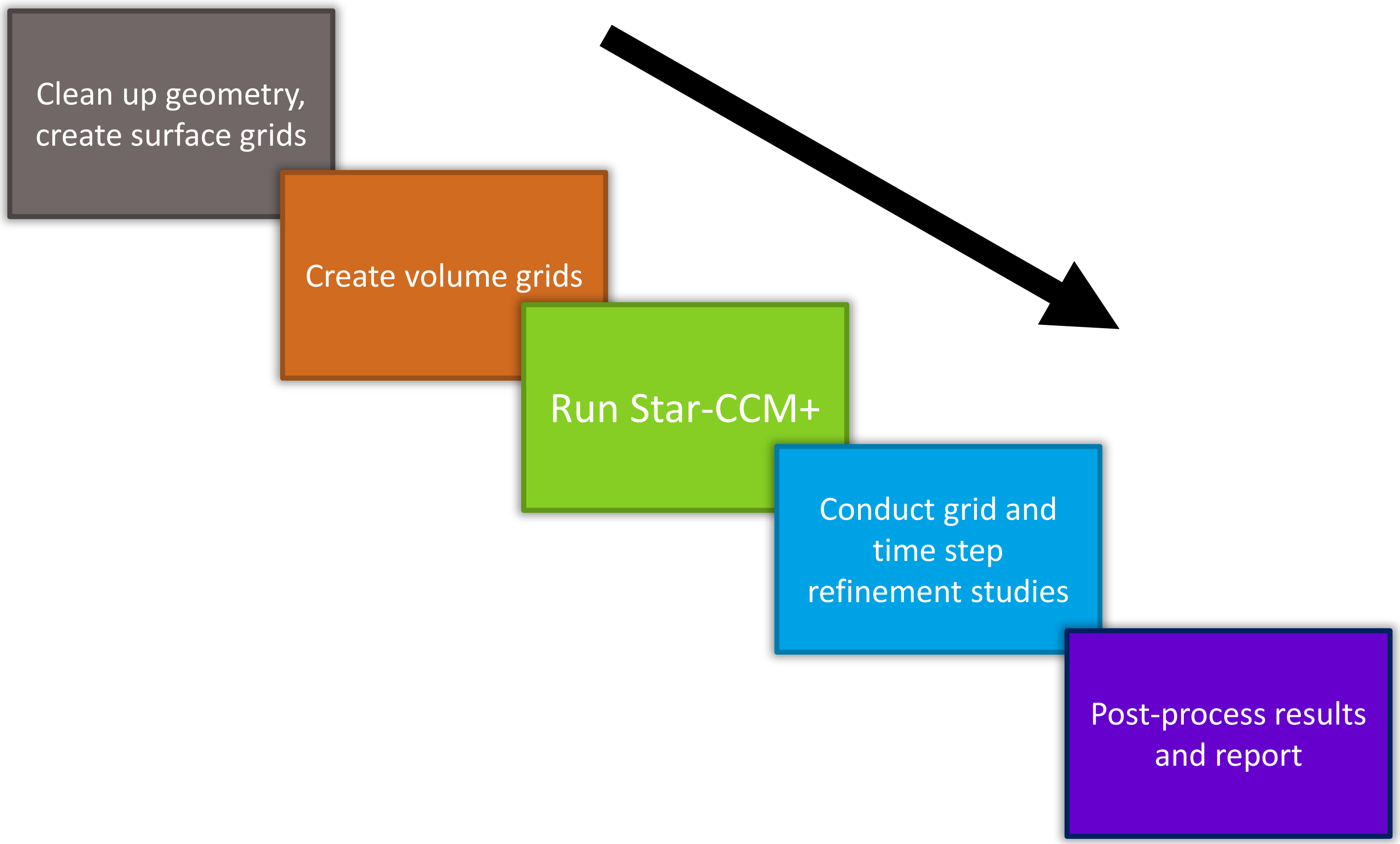
1. Assume initial store release conditions
2. Conduct sensitivity studies using NAVSEP
3. Finalize the design release condition from NAVSEP sensitivity studies
4. Verify clearance for the final design release conditions using Star-CCM+
5. Provide results to support project advocacies or flight readiness reviews

All simulation files and scripts are saved to support future analysis requirements for similar projects/airplanes and/or mishap investigations

NAVSEP Workflow for Store Separation Analysis



Star-CCM+ Workflow for Store Separation Analysis



Validation of Computational Toolset and Models

How Would We Validate Our Computational Toolset and Models?

- Perform mesh and time step refinements
- Compare to available store separation validation datasets
- Compare to available wind tunnel test data
- Compare to flight data:
  - Photogrammetry data
  - Differential GPS data between store and carrying aircraft
  - Inertial 6-DoF data packs in both store and carrying aircraft
  - A combination of all these approaches to provide a more comprehensive understanding as well as redundancies in data collection

Store Separation Analysis Example Towed Glider Air Launch System (TGALS)

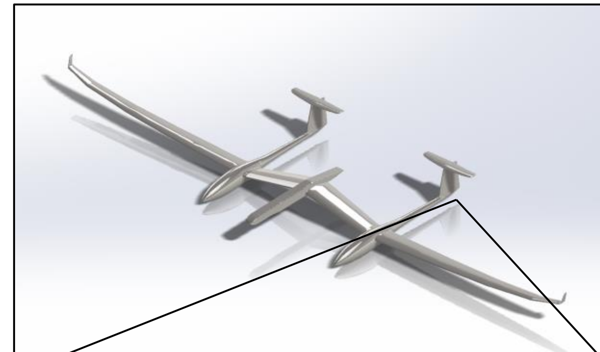
Aircraft CAD / Clean-Up

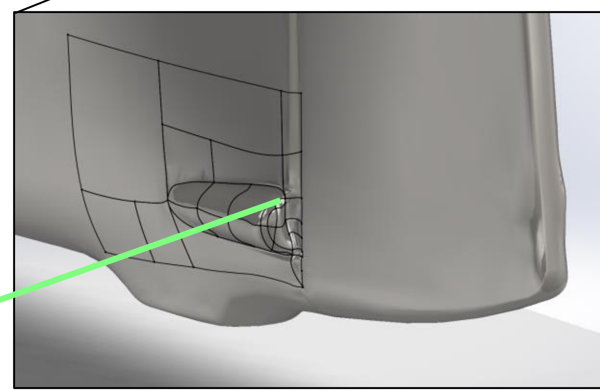
Twin fuselage glider used as the aircraft

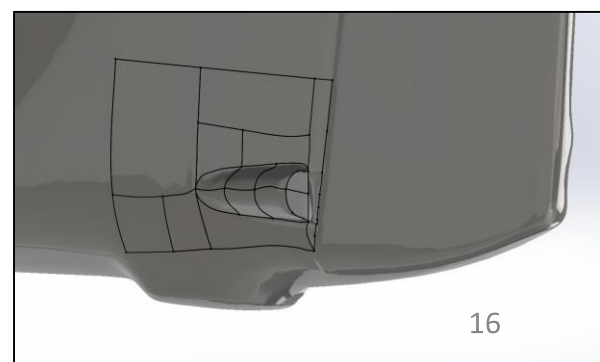
- High-quality laser scan is available for configuration
- Laser scan was performed by Operations Engineering branch

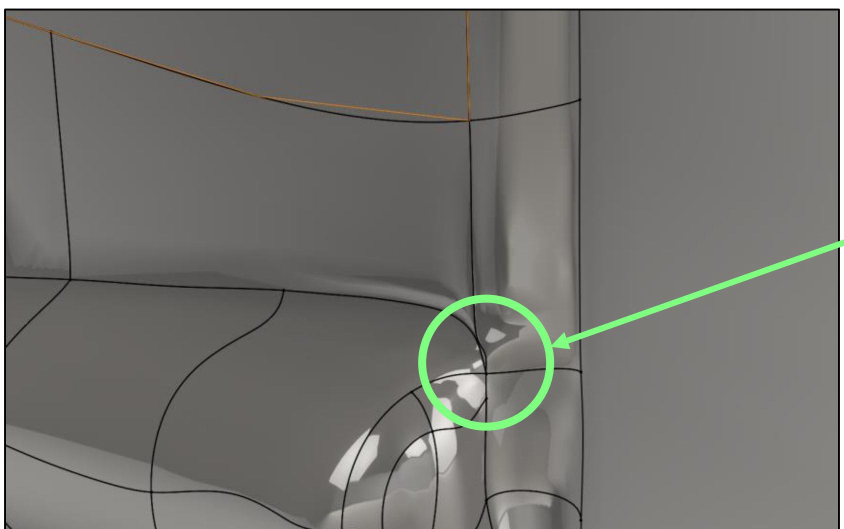
CAD clean-up was relatively simple

- Several areas had self-intersecting geometry problems (green circle)
- These areas were approximated with 3D splines and adjusted to fix the issues









Store CAD Creation

Aerospike rocket from the Dryden Aerospike Rocket Test Project served as the initial store for analysis purposes

- Used only for store separation demonstration purposes. Final store geometry and mass properties will be used as available
- Aerospike rocket is a great choice for this initial look, since we already have geometry and mass properties data

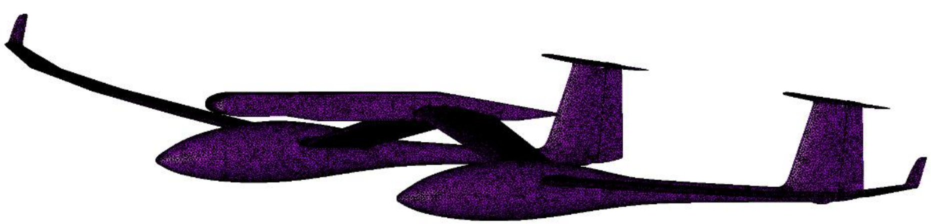
Store CAD creation

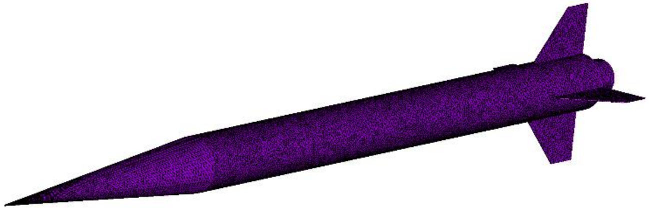
- Rocket dimensions and mass properties taken from publicly-available publications

Surface Grid Generation

Glider and Rocket Surface Grid Generation

- Created triangulation in Pointwise
- Uniform spacing of ds = 0.5 on both glider and rocket
- Since grid is created for Euler simulation, not much refinement as been performed for leading edges, trailing edges, areas of high curvature, etc…
- Geometry preservation was not great on nosecone, so triangulation was made from a structured grid of the nose cone
- CAD was cleaned-up before grid generation commences

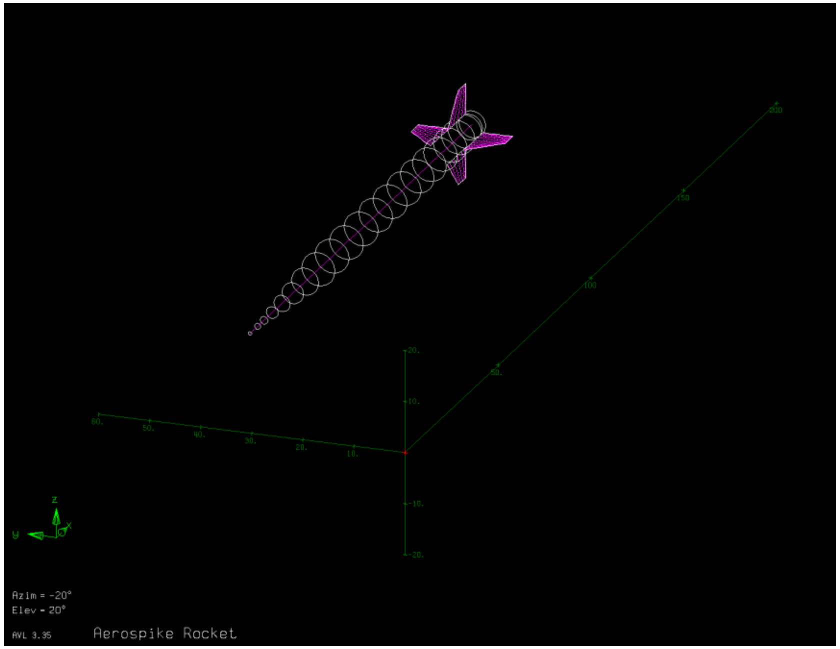




Athena Vortex Lattice Model

An AVL Model was created to obtain damping coefficients required by NAVSEP

- Store roll-damping coefficient, C_{l_p}
- Store pitch-damping coefficient, C_{m_q}
- Store yaw-damping coefficient, C_{n_r}
- Model consists of fins with general outline of body of rocket
- User's guide suggests excluding body, but it seemed to make a difference in the damping coefficients



CFD Run Formulation

What NAVSEP Needs

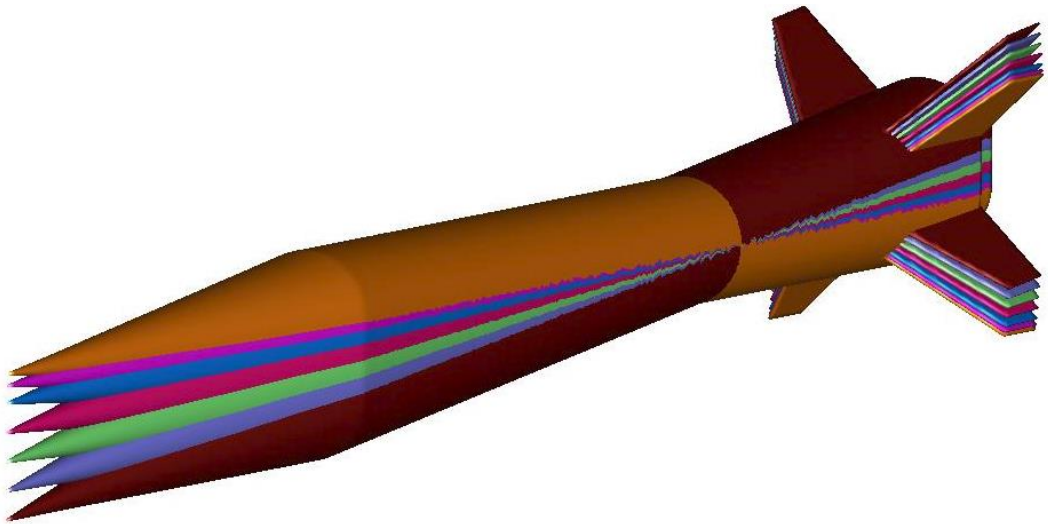
In order to calculate a store trajectory, NAVSEP needs an aerodynamic database for 2 scenarios:

- Aerodynamic data about just the rocket in the freestream (freestream case)
- Aerodynamic data about the rocket in the influence of the mothership (grid case)

CFD Run Formulation, continued

Freestream CFD Runs

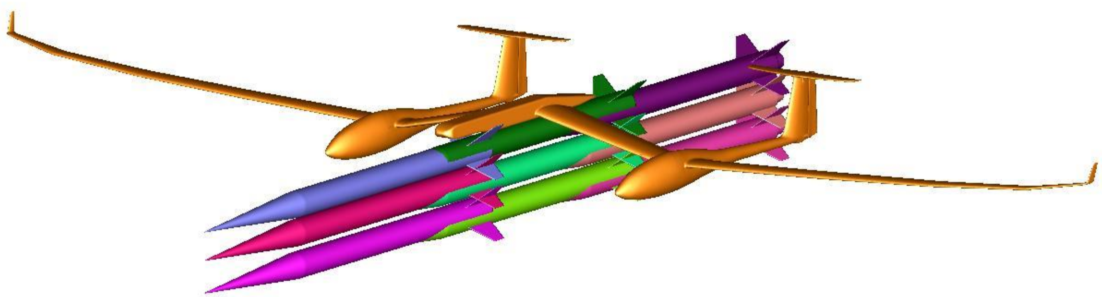
- 7 points were chosen to create the aero databased NAVSEP needs
  - 7 different angles of attack, all at $\beta = 0^{\circ}$



CFD Run Formulation, continued

Grid CFD Runs

- 9 points were chosen to create the aero database NAVSEP needs
  - 9 different X, Y, Z positions, $\beta = 0^{\circ}$

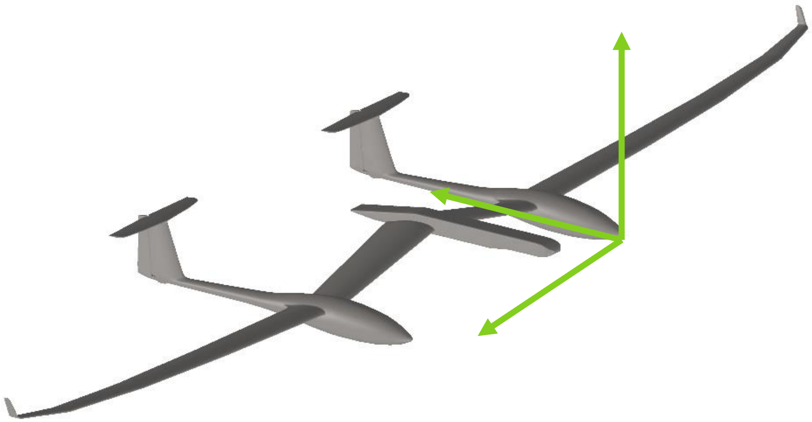


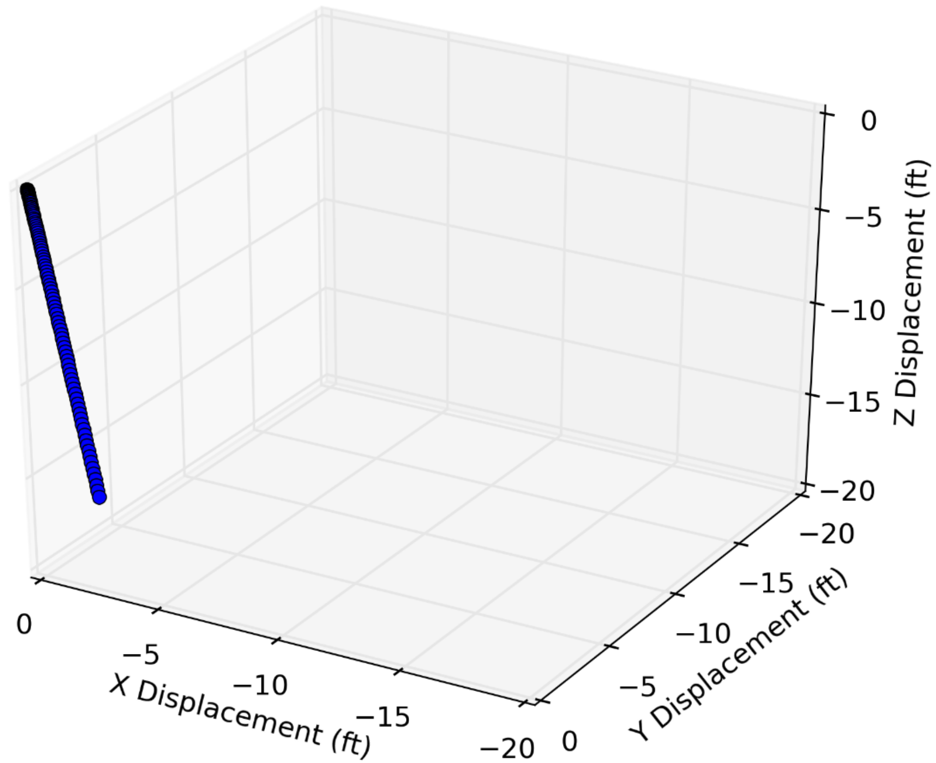
NAVSEP Set Up

Scripts were reused from earlier efforts

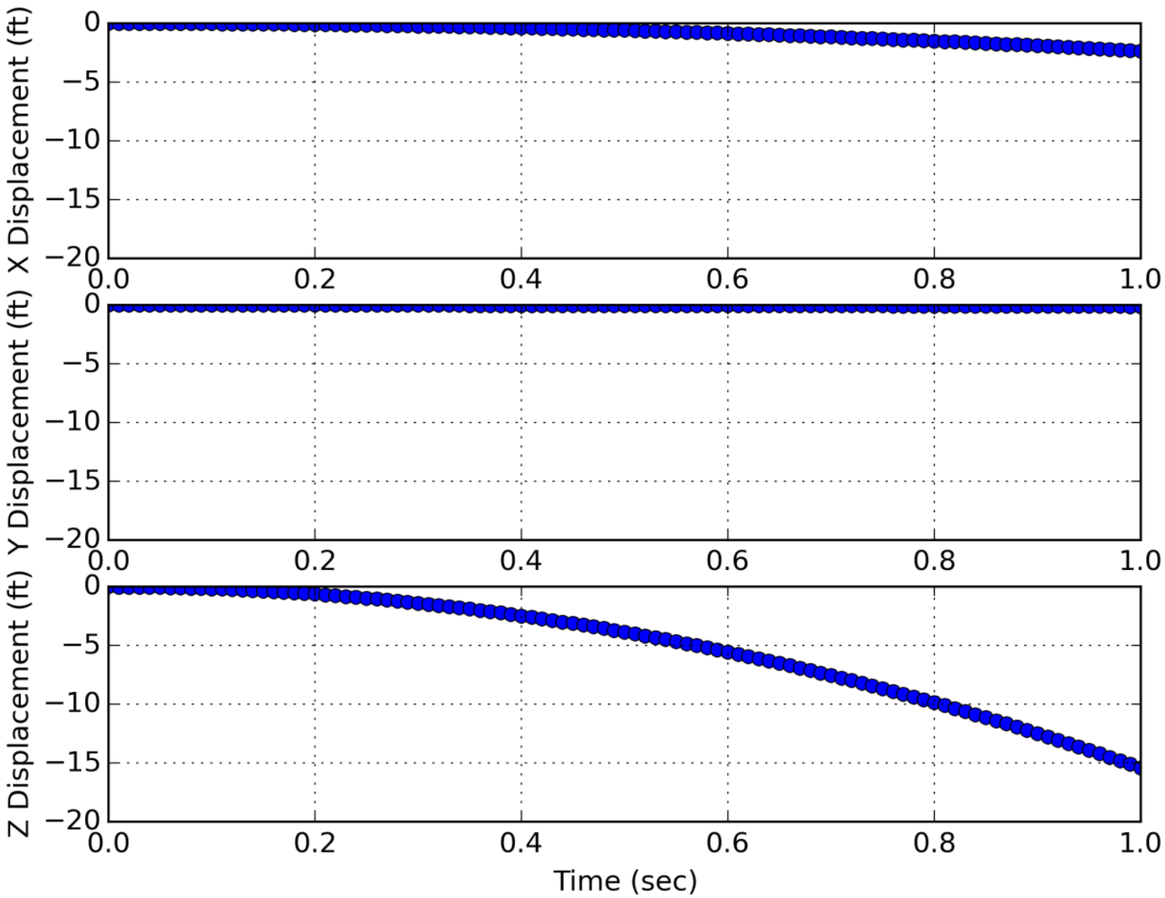
- No need to really do much work setting up NAVSEP
- Python scripts work well for running and plotting NAVSEP
- Run time <1 second
  - Takes Python longer to plot the results than it does to run NAVSEP
- All that was needed were the new grid and freestream files created from the Cart3D runs
  - These were created by hand using the results from the Cart3D runs
- Once everything was in place, NAVSEP ran great!

NAVSEP Results: Trajectory

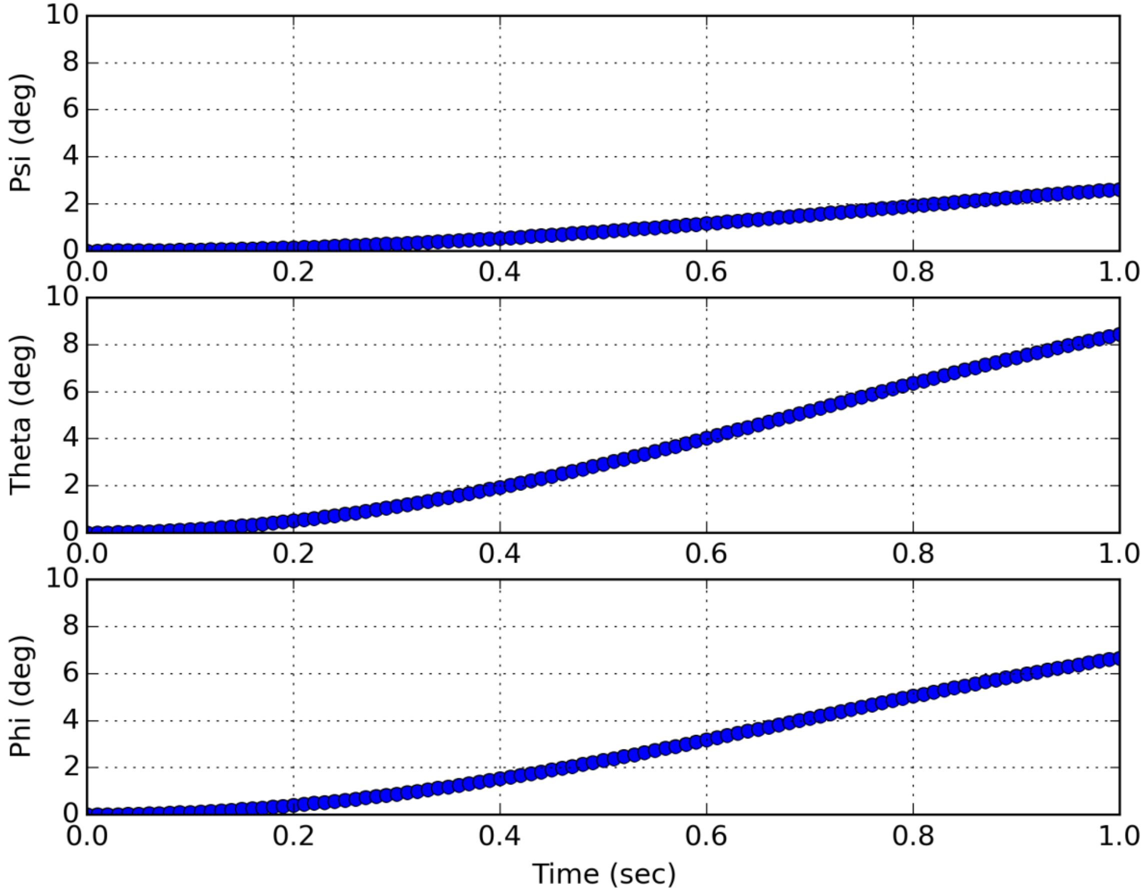




NAVSEP Results: Displacement

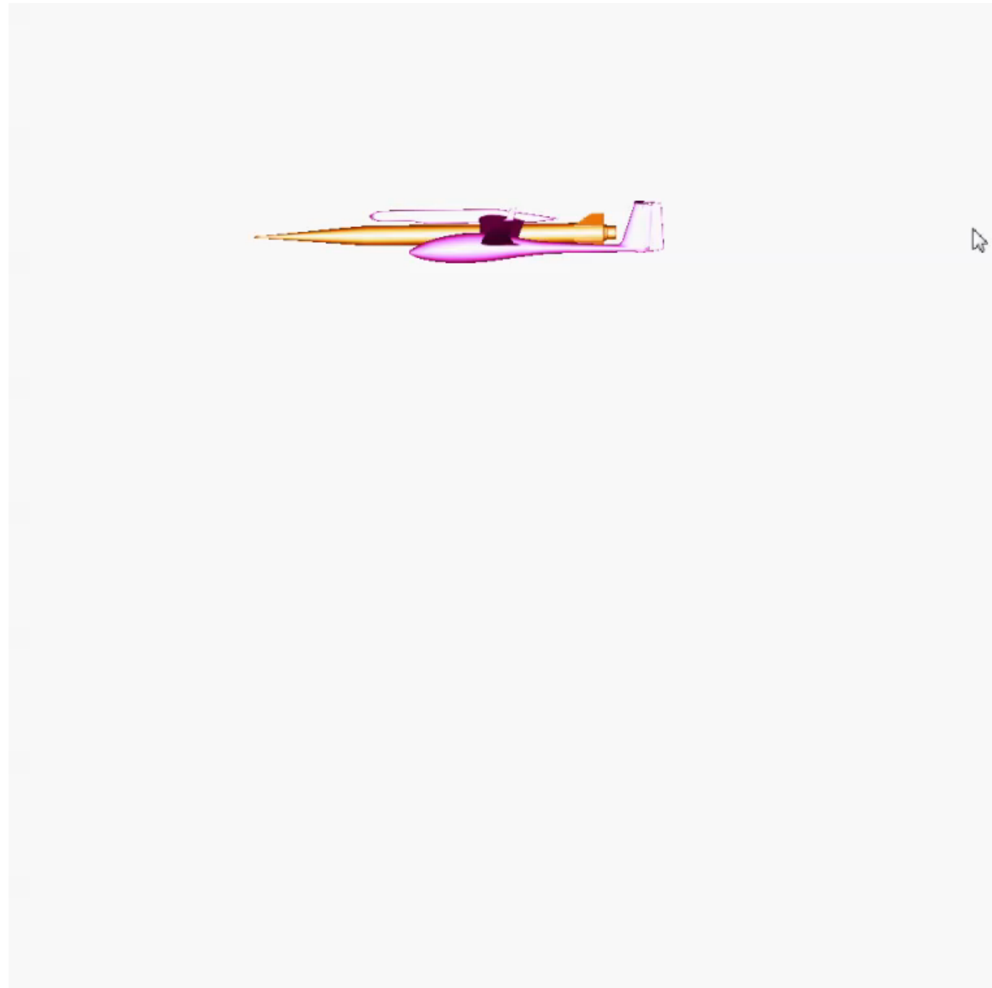


NAVSEP Results: Orientation



Store Separation Animation

- Preliminary NAVSEP result only
- Clean separation for the present aircraft and store as well as release conditions
- Final design release condition will be verified using Star-CCM+ Navier-Stokes code before flight



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