Coupling Free Flight CFD and Trajectory with US3D

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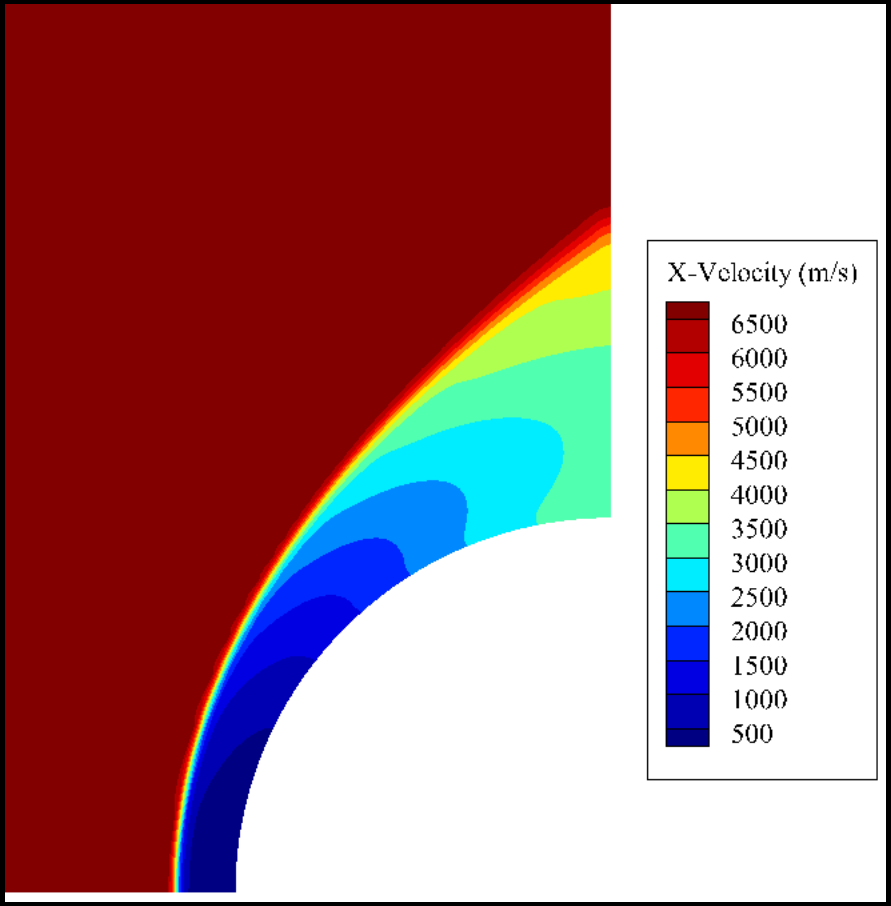
Importance of Free-Flight CFD

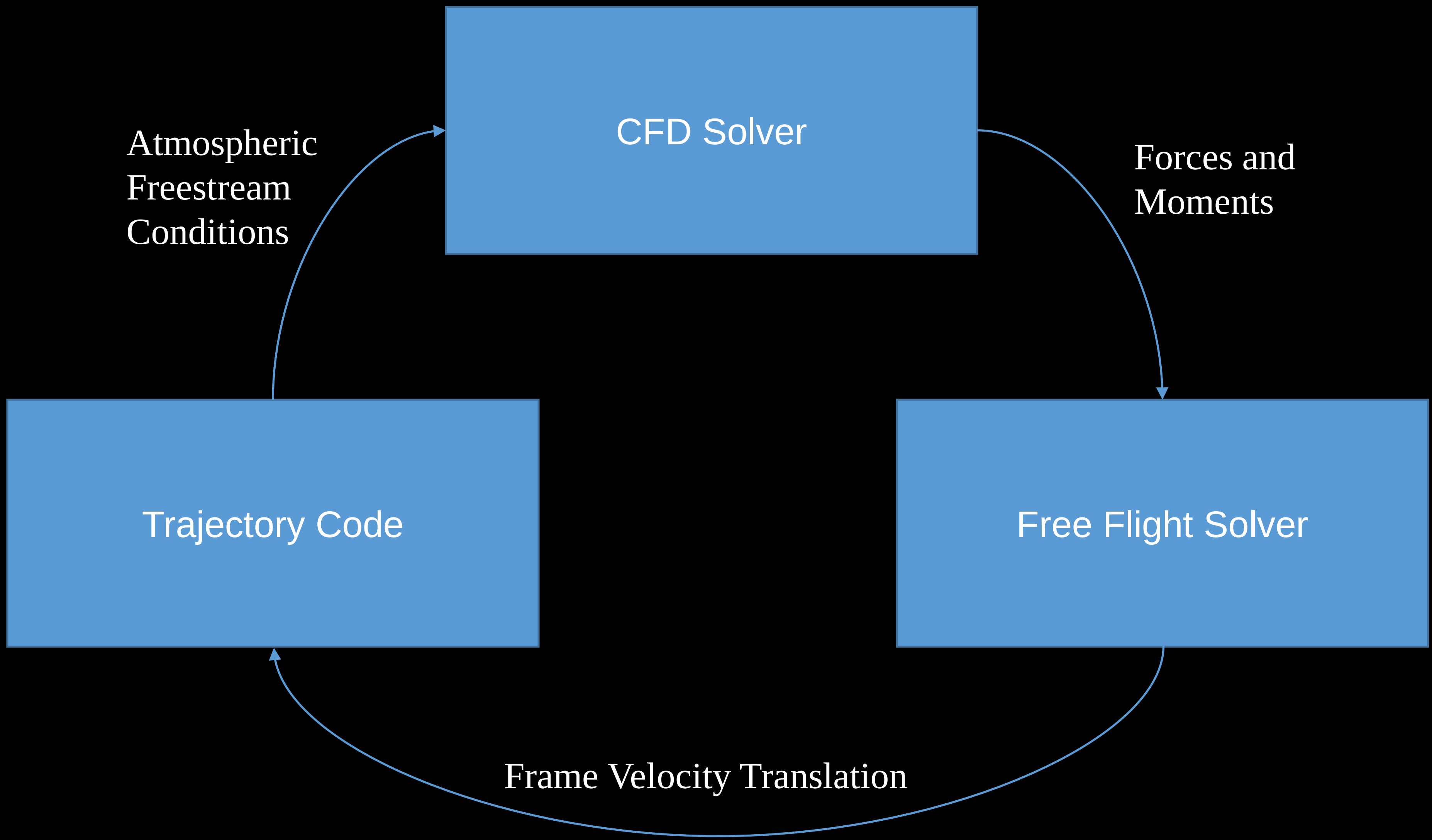
- CFD is a way of calculating and visualizing flow around a free flying object without relying on physical testing methods
- Free-Flight CFD extends these capabilities by enabling dynamic mesh deformation due to fluid forces



Coupling Trajectory Code

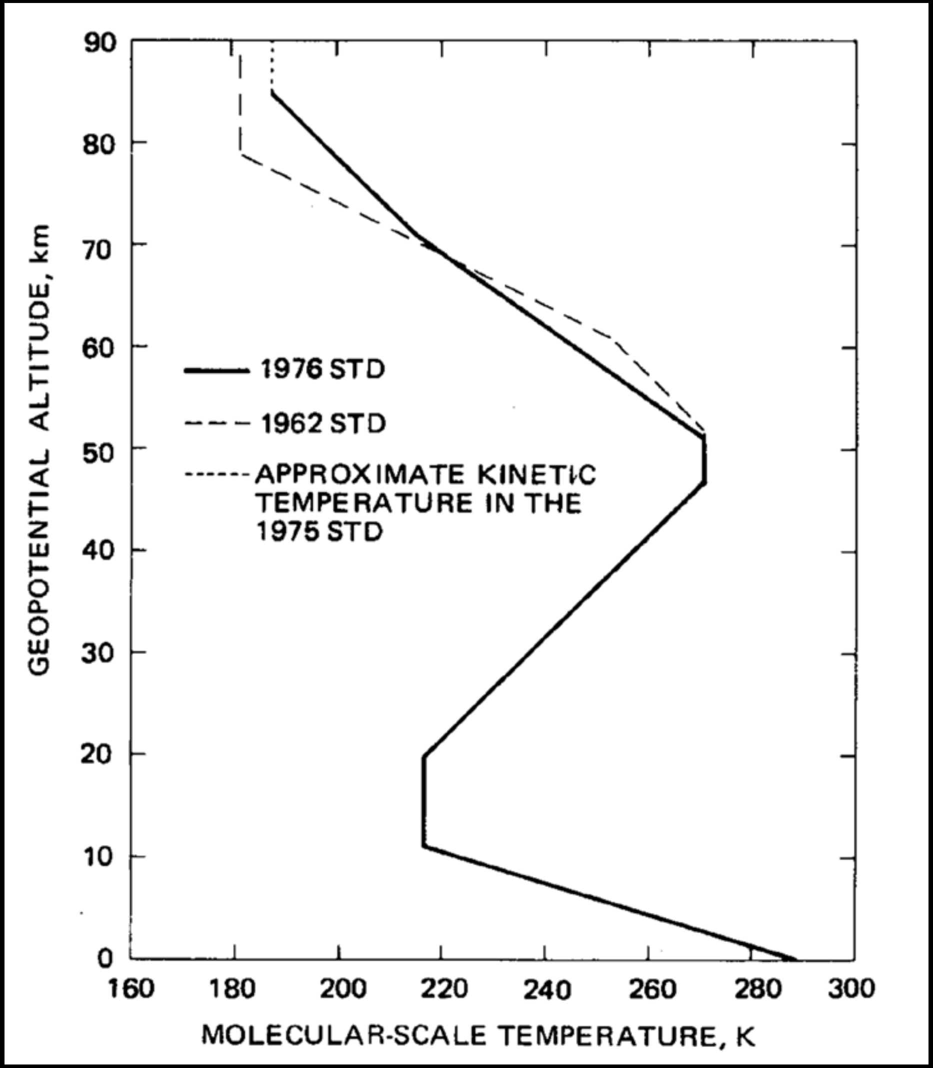
- The ability to model atmospheric changes in response to changes in altitude allows for the simulation of flight-relevant trajectories
- Enabling trajectory analysis within CFD improves fidelity of simulation dramatically
  - Altitude, latitude, and longitude determine freestream conditions
  - Having the code update trajectory and determine freestream conditions from new position takes the inherent unsteadiness of flight into account in the simulation
- Enabled by setting initial position and specifying velocity and acceleration vectors
  - Reference frame based on current flight path of body being analyzed
  - Can also manually load in a data file for trajectory

Environment



US Standard 76 Atmospheric model

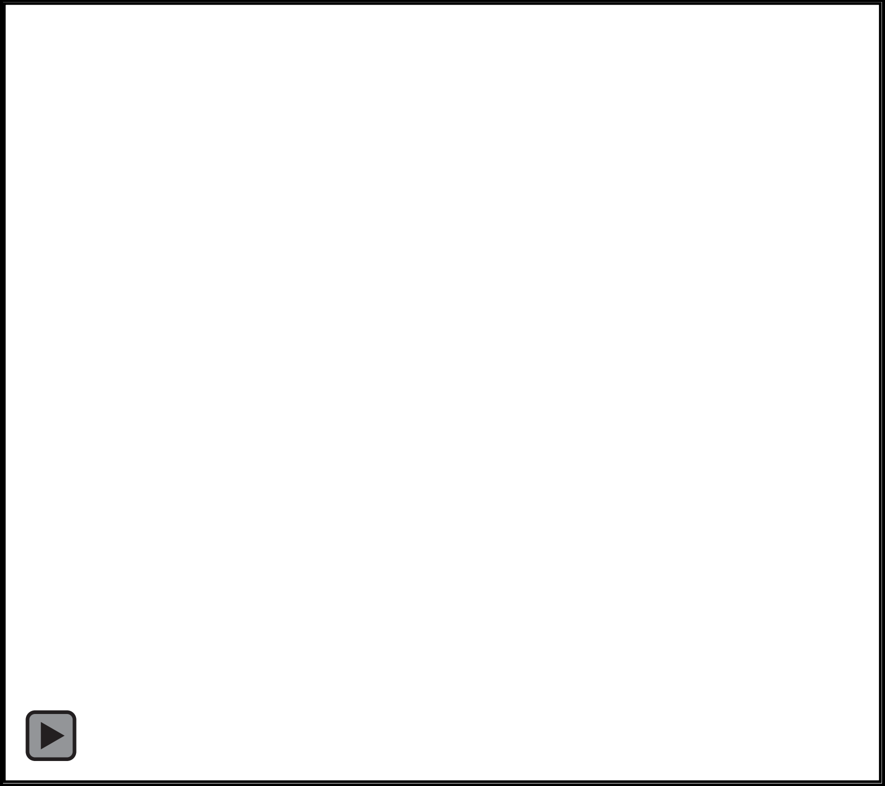
- Previous runs were performed using US Standard 76 model for atmosphere
  - This model calculates freestream conditions as a function of altitude
  - Calculations are based off of standard temperature and pressure at sea level (i.e. 1 atm, 298K)
  - Uses proportional relationships as well as thermal lapse rates to determine freestream conditions at altitude

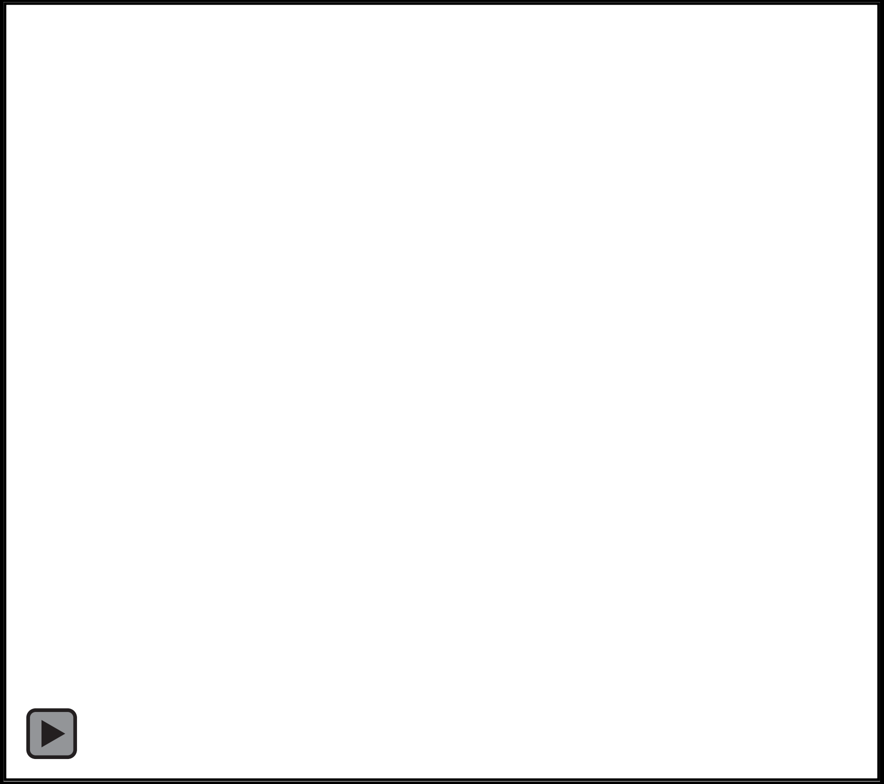


Credit: "US Standard Atmosphere, 1976", NASA Technical Reports Server, 10/01/1976

US Standard 76 Results

- This data was taken from simulating a free-falling cylinder starting at 80 kilometers above sea level falling at 5 km/s for 0.05 seconds



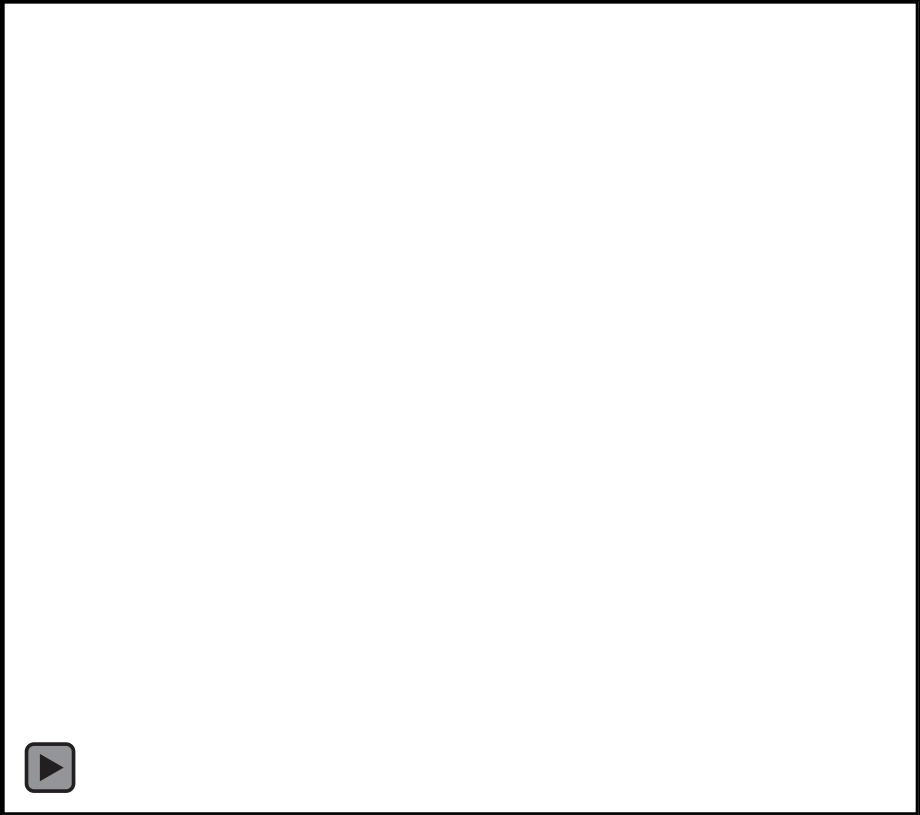


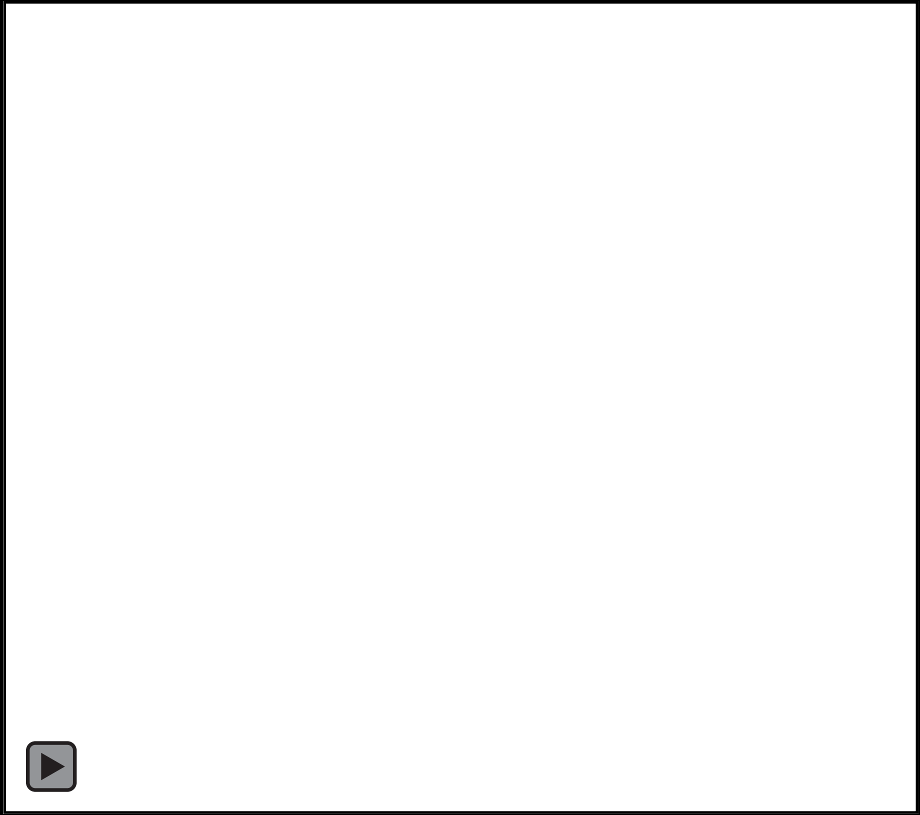
Updating the Atmospheric Model

- Standard 76 is a good model for initial validations, but has many limitations
  - Does not account for gusts or weather conditions like ambient temperature or humidity
  - Also does not account for effects of latitude or longitude on conditions
- Updating atmospheric model to Earth GRAM
  - Earth Global Reference Atmospheric Model
  - Takes into account variability caused by seasons, location, etc.
  - Gusts, drafts, and other wind conditions can be modeled

Earth GRAM Results

- Repeating the same conditions as with the US Standard 76 model gives the results below





Summary of Work

- Enabled Trajectory code within existing FFCFD environment
- Switched atmospheric model from US Standard 76 to Earth GRAM
- Verified that code and models were working effectively using quarter and half cylinder models
- Next Steps
  - Simulating a moving body simulation with trajectory code
  - Simulating flight trajectory and verifying against reconstructed data
  - Modify FFCFD/Traj. environment for use with EDL Vehicle
    - Start from restarted static run
    - Validate against experimental data (e.g. ballistic range tests, wind tunnel experiments, etc.)
  - Document methods and replicate FFCFD/Traj. environment with other software packages like FUN3D
  - Explore applications for non-EDL vehicles

Lessons Learned

- Importance of grid resolution level
  - Was given a quarter cylinder grid to test on, but had to generate a half grid in Pointwise and within US3D
  - If grid is too rough, it can worsen results or throw simulation off
  - Difficult to find a level of resolution that gives good results but also is easy to run
- Learning US3D and its plugins
  - Becoming familiar with the Linux environment
  - Understanding relationships between reference frames within US3D
  - Generating a grid within US3D

Questions?

Thank you for a great summer!

National Aeronautics and Space Administration

Ames Research Center
Entry Systems and Technology Division

Challenges

- Velocity frame issues
  - Two different variables were given the same name causing the velocity frame to be incorrect
  - Fixed by renaming variable in the trajectory code
- Enabling Earth GRAM
  - Software is based at NASA Marshall Space Flight Center and had to be ordered through NASA's Software Catalog
  - Earth GRAM has to be initialized before being able to be run, otherwise the simulation will error due to zero density and temperature
  - Fixed this issue by putting in an initial call to Earth GRAM

US Standard 76 Freesteam Conditions in Depth

Earth GRAM Freestream Conditions in Depth