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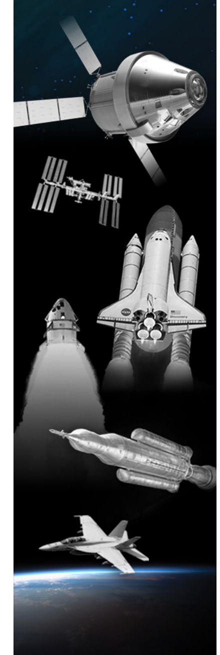


6DOF Check Cases

In 2015, the NESC released benchmark Earth-based check-cases for well specified, rigid-body, six-degree-of-freedom (6DOF) aero/spacecraft models to promote consistent and accurate flight simulations across multiple Agency tools and facilities. Recently, the NESC expanded upon that effort to add Lunar-based check-cases to support new lunar exploration initiatives. This study produced a smaller, focused set of cases that exercise new and unique features of missions in the lunar environment in comparison with 8 high-fidelity NASA simulation tools and provides a measure of validation for simulations supporting Human Landing Systems.

Checkcase Scenario Description

Case	Orbit	Body	3-body	Additional Notes
1	Low lunar orbit (LLO) ~120x120km	Cylinder	No	Keplerian gravity, permits analytical solution
2	LLO	Cylinder	No	Introduces 8x8 gravitational harmonics model
3	LLO	Cylinder	No	320x320 high-fidelity gravitational harmonics model
4	High lunar orbit (HLO) ~500x500km	Apollo	No	Introduces Apollo vehicle model
5	HLO	Apollo	Yes	Introduces third-body perturbations
5A	HLO	Apollo	Yes	Body tumbles about all three axes
6	Highly eliptical orbit (HEO) ~250x9385km	Cylinder	Yes	Re-visits cylinder model
6A	HEO	Cylinder	Yes	Zero inertial angular rotation
7	HEO	Apollo	Yes	Returns to Apollo model
8	NRHO	Apollo	Yes	Introduces NRHO orbit (radius from ~2000km to ~70,000km)
8A	NRHO	Apollo	Yes	Re-initializes at a true anomaly of 180 degrees, after approx. one half of orbital period
8B	NRHO	Apollo	Yes	Re-initializes at a true anomaly of 0 degrees, after approx. one complete orbital period
8C	NRHO	Apollo	Yes	Initial radius perturbed by +10m relative to case 8
8D	NRHO	Apollo	Yes	Initial velocity perturbed by +0.1 m/s relative to case 8
9	Low polar orbit (LPO) ~120x120km	Apollo	Yes	Polar orbit, includes a sensor station offset from the center of mass along one direction; tests Digital Elevation Model ingestion
9A	LPO	Apollo	Yes	Includes sensor station offset from center of mass in all three directions
9B	LPO	Apollo	Yes	Includes open-loop moment profile

The participating 6DOF simulation tools include:

Simulation Name	NASA Center	Description
Condor Flight Vehicle Toolkit	ARC	Translation of SimuPy's Flight Vehicle Toolkit
Dynamics Algorithms for Real Time Simulation (DARTS)	JPL	Multi-mission simulation tool for closed loop flight dynamics and EDL
GeneraLized Aerospace Simulation in Simulink	MSFC	Simulink environment for 6DOF aerospace vehicle simulation
JSC Engineering Orbital Dynamics (JEOD)	JSC	Open source trajectory simulation tool in NASA Trick Simulation Environment
Langley Standard Real-Time Simulation (LaSRS++)	LaRC	Object oriented framework for aerospace vehicle simulations
Marshall Aerospace Vehicle Representation in C (MAVERIC)	MSFC	3DOF/6DOF aerospace vehicle flight simulation program based on TFrames
Program to Optimize Simulated Trajectories II (POST2)	LaRC	Generalized 3DOF/6DOF event-based trajectory simulation software
Space Transportation and Aeronautics Research Simulation (STARS)	LaRC	MATLAB Simulink based air, launch and space vehicle dynamics simulation

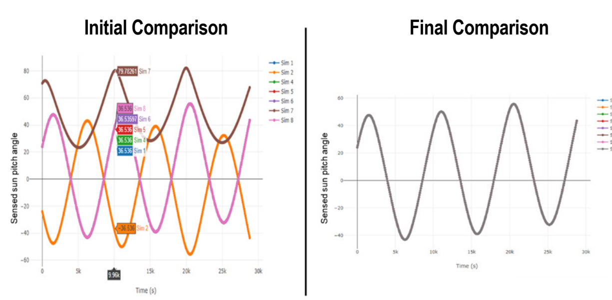
Results

The primary output of the check-cases is a time history of each output variable, which can then be plotted with any data plotting software. For simulation comparison, the results from multiple simulations are plotted together. A static website was developed as a tool for the simulation groups to perform quick data comparison using interactive plots, access scenario specifications, and catalogue the results.

Benefits for the FM Community

Utilizing benchmarking check-cases improves the simulations being assessed, reduces errors, builds confidence in solutions, and serves to build credibility of simulation results per NASA Standard 7009A Standard for Models and Simulations. Simulation comparisons can benefit from utilizing common standards for defining parameters and sharing models and elevates the validation for critical simulations used to support insight or requirement compliance through analysis.

Example Comparisons: Case 5 (HLO)
Sun Pointing Angle (pitch component) Regarding Vehicle Frame



The Initial Comparison plots show the simulations were not implementing Check Case 5 correctly, or had other issues. The Final Comparison plots show identical results once corrections were implemented to the simulations, indicating the importance of using check cases."

NESC tech bulletin