Marshall Space
Flight Center

NASA MSFC Status Updat

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Control Systems Design & Analysis Bran

Aerospace Control and Guidance Systems Committee
Meeting #114, Cleveland, Ohio
October 15 - 17, 2014

Agenda

- **Space Launch System**
  - Program Status
  - LSQI
  - AAC
  - Slosh Testing
- **Small-Scale Projects**
  - Mighty Eagle Robotic Lander Testbed
  - Miniaturized Science Instruments on CubeSat
  - Lunar CATALYST Space Act Agreement
  - Propulsive CubeSat Demonstration Mission
  - iodine Satellite (iSAT)

Space Launch System Program Status

- **Core Stage passes Critical Design Review (CDR)**
  - CDR completed July 1, 2014
- **Completed Key Decision Point C (KDP-C)**
  - Review completed in August
  - Development cost baseline for 70-metric ton SLS of $7.021B through November 2018
- **Final delivery to Flight Software, January 2015**
- **First SLS Flight scheduled for December 2017**
- **Orion Flight Test December 2014**

Flight Testing of the SLS Autopilot with Adaptive Augmenting Control on an F/A-18

- **Adaptive Augmenting Controller**
  - New, advanced control algorithm baselined for SLS
  - Allows the controller to sense and react to the vehicle dynamics in real-time
  - Algorithm does not change control behavior in a nominal launch scenario

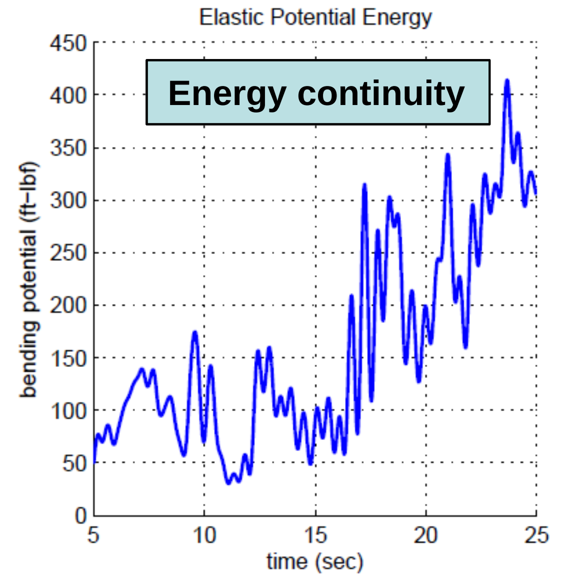
- **Integration**
  - Marshall-developed SLS model integrated with aircraft so that the controller "thinks" it is flying SLS
  - Actual prototype SLS autopilot flight software controlled the aircraft

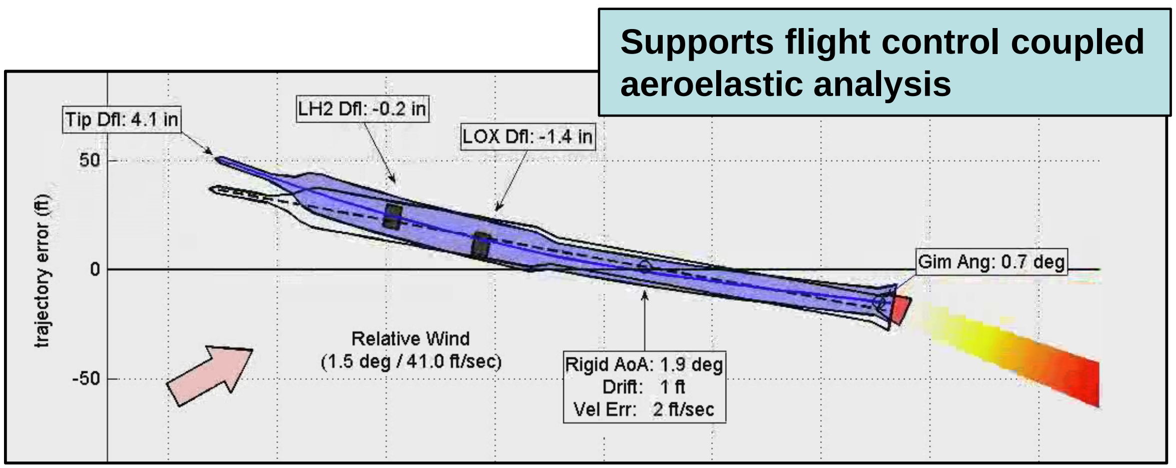
- **Flight Test Results**
  - 102 launch vehicle-like trajectories over six flight tests were completed in November and December 2013 at Armstrong Flight Research Center
  - All test objectives have been successfully met, each supported under varying test scenarios
  - In-flight demonstration of algorithm increases its maturity and adds confidence as CDR approaches

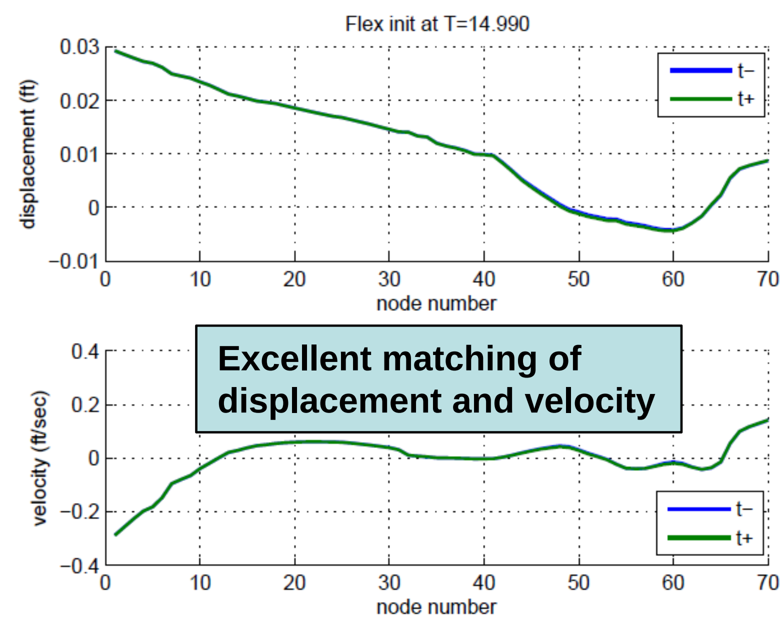
- **Multi-Center Partnership**
  - Marshall Space Flight Center, Armstrong Flight Research Center, NASA Engineering and Safety Center, Space Technology Mission Directorate

Quadratic Inequality Constrained Least Squares Flex Modeling

- **New technique developed for modeling time-varying structural dynamics using a sequence of finite element models**
  - Useful for modeling effects of changing mass and stiffness in a launch vehicle while capturing physical effects of bending on GN&C
  - Uses energy constraints and transforms the initialization problem into a well-posed constrained optimization problem that can be solved in one time step
  - Provides continuity of energy while maintaining physical displacements across transitions with truncated modal models



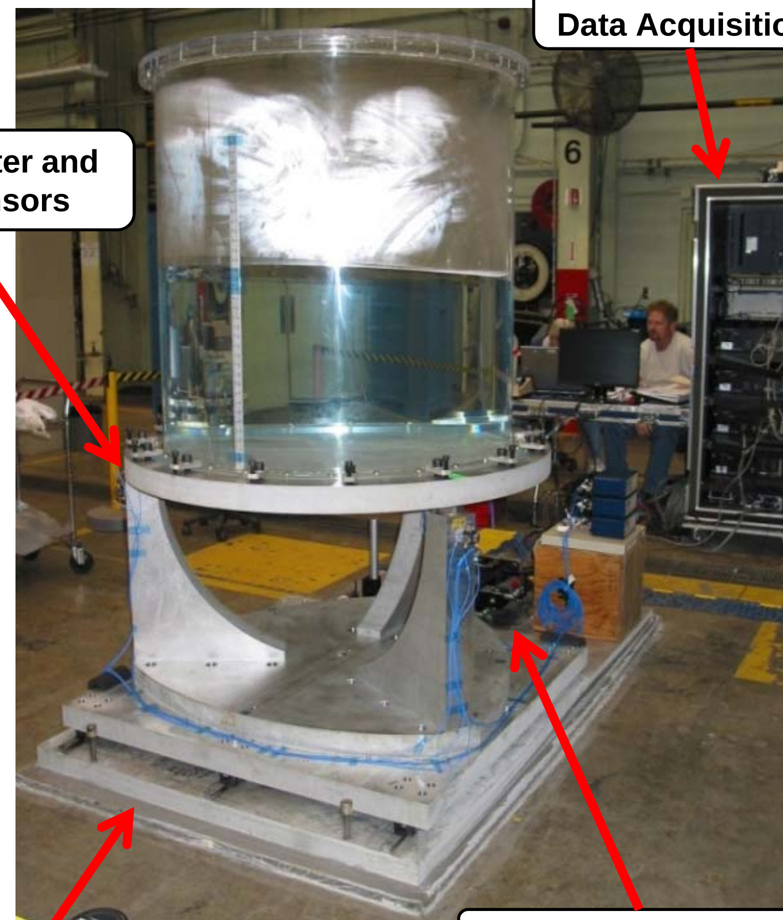




1. Jurenko, B., et al., "Elastic Model Transitions: A Hybrid Approach Utilizing Quadratic Inequality Constrained Least Squares (LSQI) and Direct Shape Mapping (DSM)", AAS 14-034, 2014.
2. Orr, J., "Elastic Model Transitions Using Quadratic Inequality Constrained Least Squares," AIAA 2012-4561, 2012.

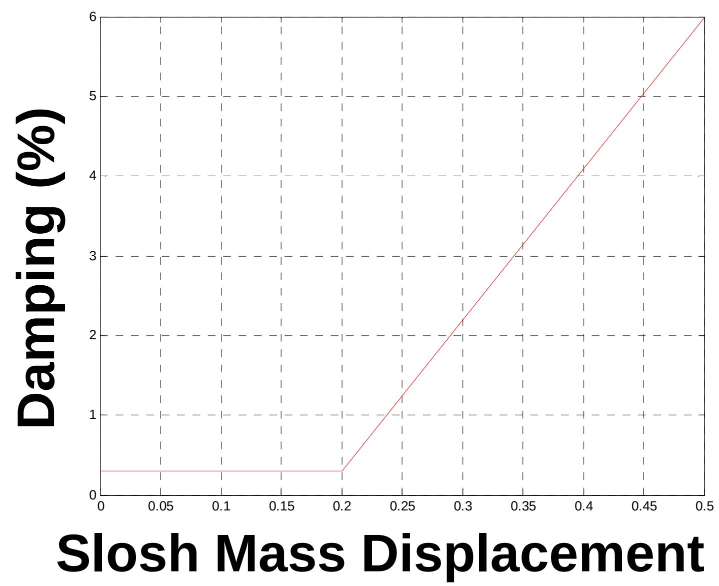
Subscale Propellant Tank Slosh Testing Supporting MSFC GN&C

- Subscale propellant tank slosh testing performed by Test Laboratory at MSFC in support of MSFC GN&C.
- Testing provides validation of slosh parameters for slosh models used by MSFC GN&C (slosh mass, slosh mass location, frequency and damping).
- Recently testing was performed to validate baffle damping model for SLS Core stage LOX tank.
- Test setup consists of test tank containing water on a linear slip table driven by a hydraulic actuator.



Subscale Propellant Tank Slosh Testing Supporting MSFC GN&C

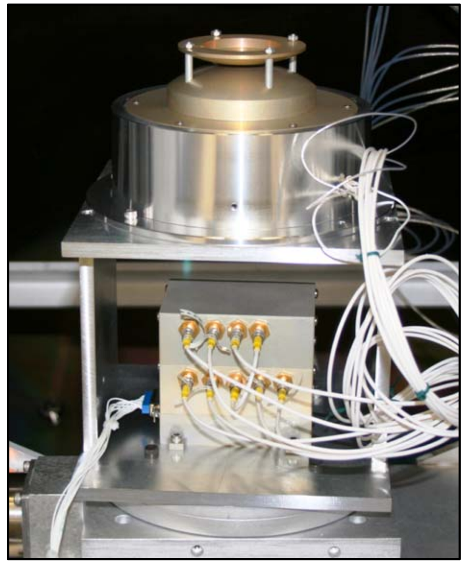
- MSFC GN&C has developed a process for flight control design using a nonlinear damping model.
- To support the GN&C approach, slosh testing has also been used in conjunction with CFD to generate nonlinear damping model.
- Traditional (overly-conservative) approach is use constant damping for small slosh wave amplitudes which can result in larger propellant tank damping requirements driving baffle design, unnecessary vehicle performance loss and unwarranted flight control certification issues.
- Approach is to take advantage of higher damping at larger slosh wave amplitudes and reduce conservatism.



Smaller-Scale Projects

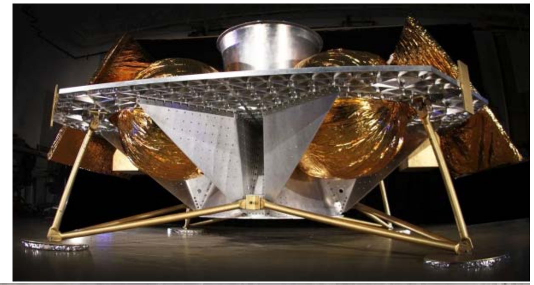
Mighty Eagle Warm Gas Test Article

Miniaturized ionospheric electron/ion instruments on a CubeSat



Lunar CATALYST

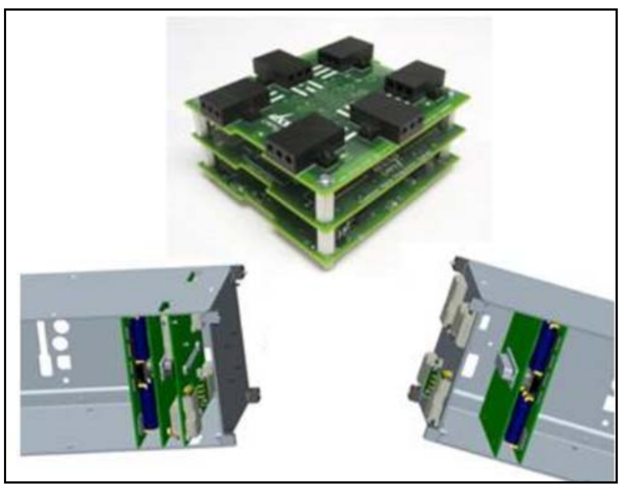
Astrobotic Griffin Lander



Masten XEUS lander

Moon Express MX-1 Lander

Propulsive CubeSat Demonstration Mission



iodine Satellite (iSAT)