



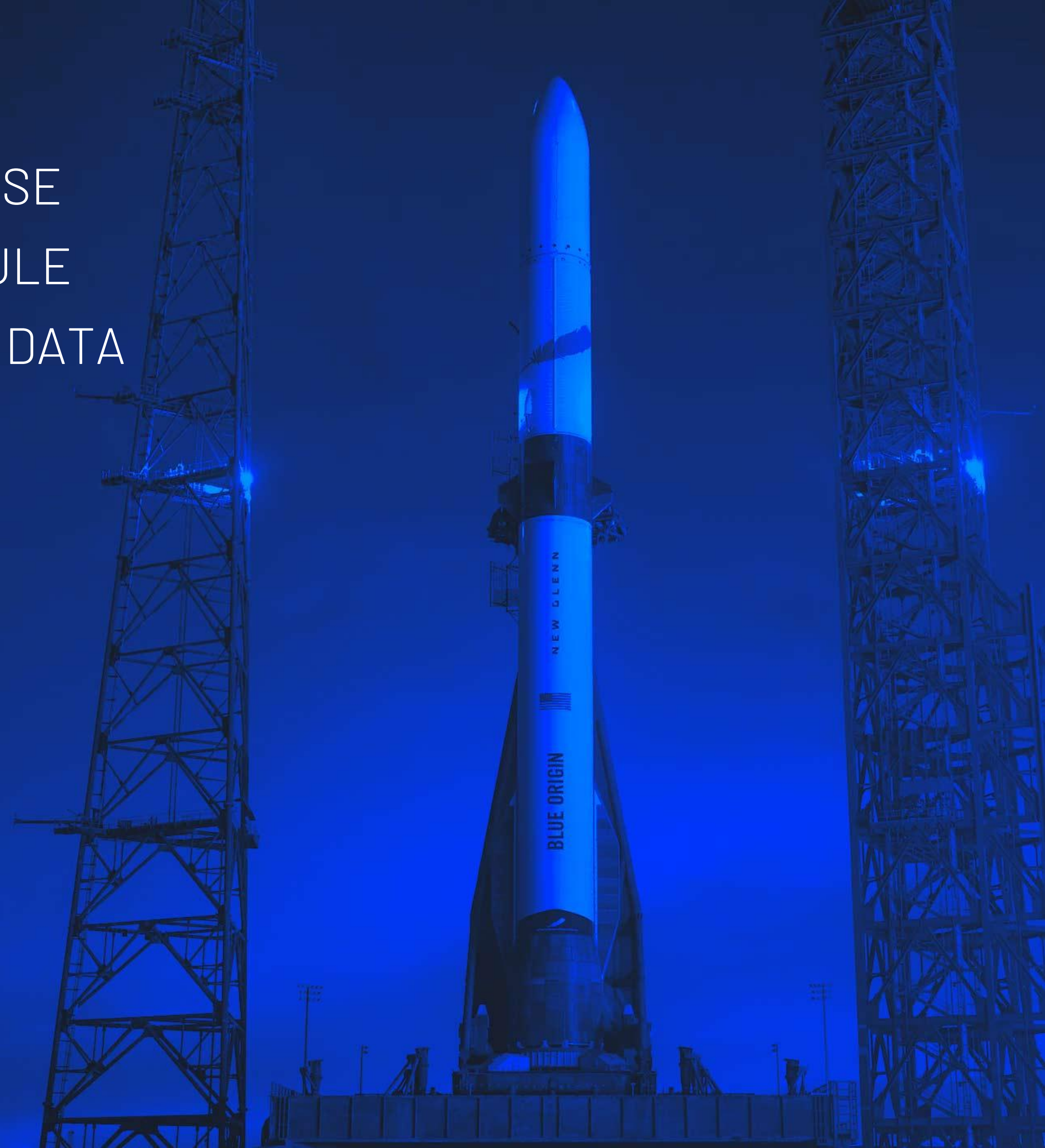
BLUE ORIGIN

FOR THE BENEFIT OF **EARTH**



CLOSED-LOOP TESTING WITH SLOSH AT MSFC

- 01 INTRODUCTION AND SCOPE
- 02 MSFC TEST FACILITIES AND EXPERTISE
- 03 BLUE ORIGIN CLOSED-LOOP TEST MULE
- 04 SIMULATION VERIFICATION VIA TEST DATA
- 05 CONCLUSIONS



Introduction and Scope

- The introduction of a unique flight control approach motivated a test campaign to demonstrate its capabilities to our NASA customer
- This presentation is NOT focused on Blue Origin IP related to closed-loop slosh control!
- It IS meant to inspire creative ways to use existing facilities and expertise to perform cost effective risk-reduction testing

MFSC Test Facilities and Expertise

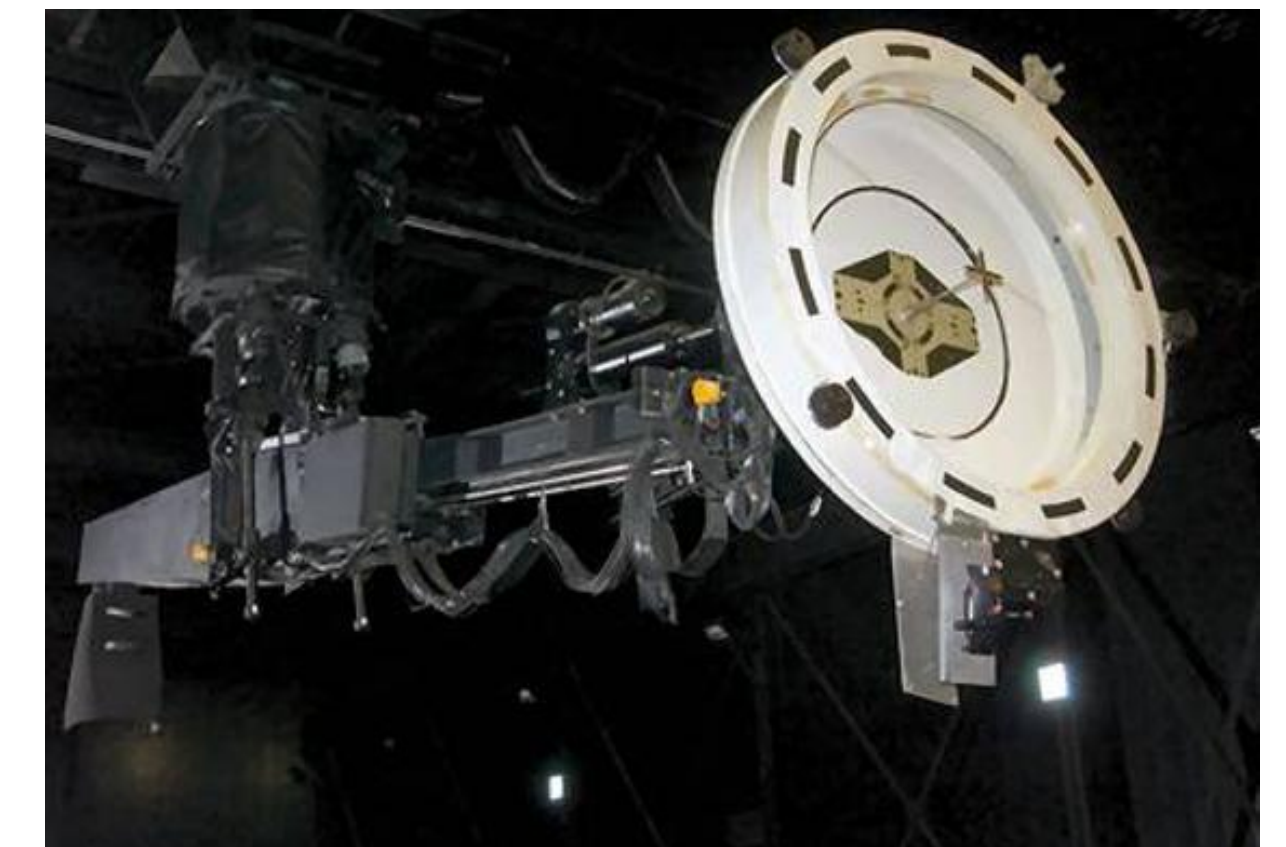
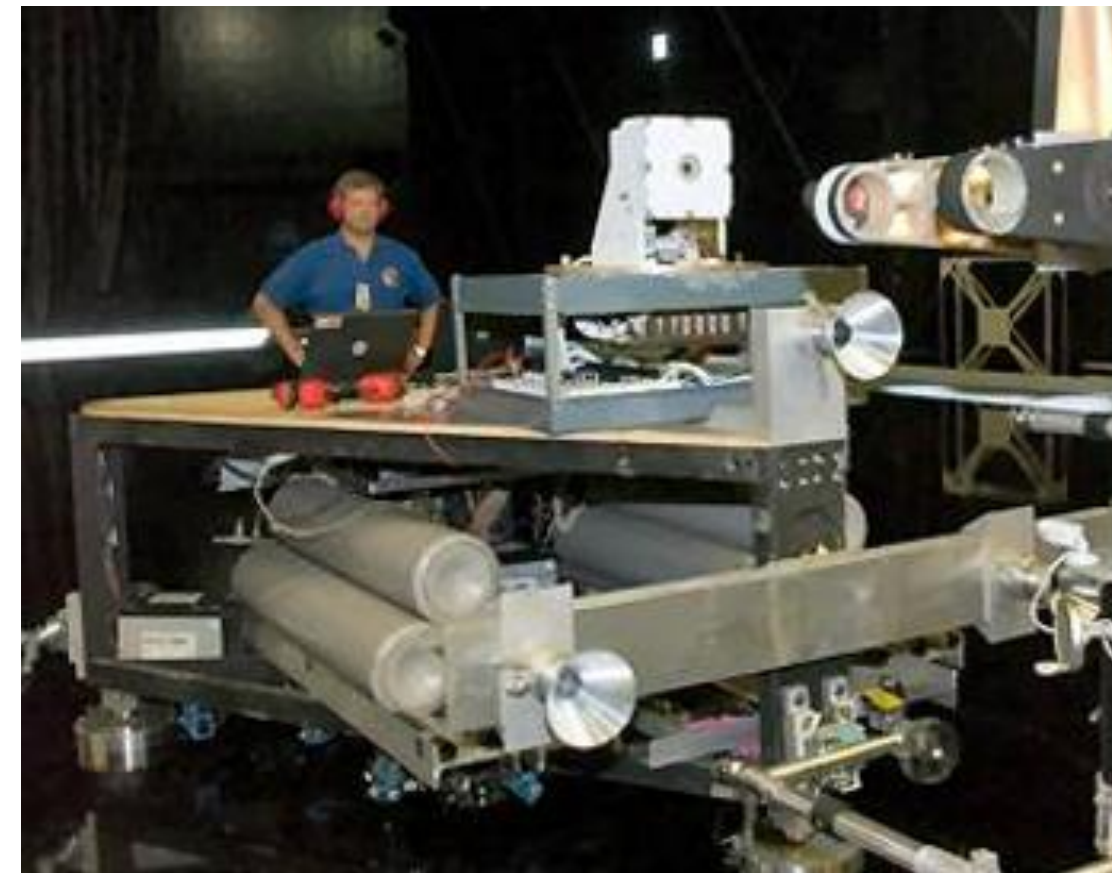
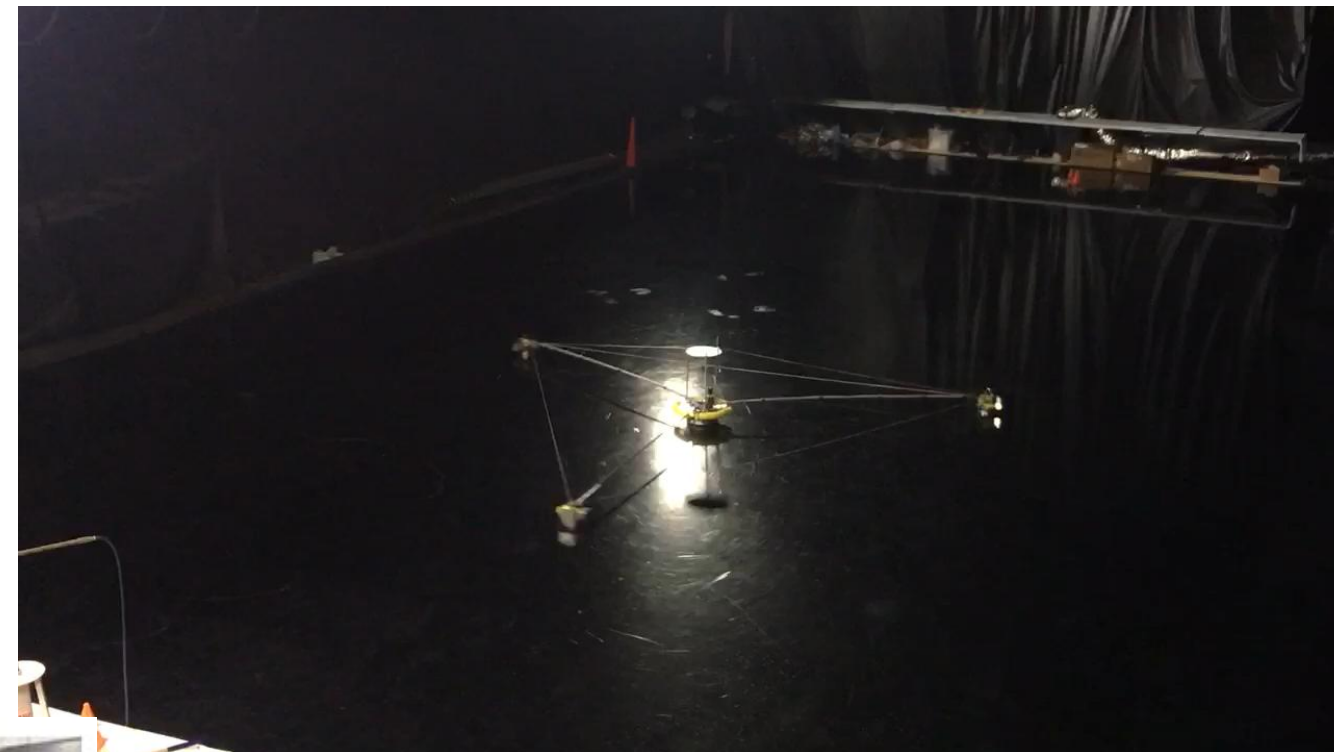
- There are government and commercial facilities across the country, but several Blue personnel have had recent test experience at MSFC¹ which inspired the current test campaign

Photos courtesy Jacob Brodnick, NASA MSFC-ER42 of slosh test facility used for recent SLS testing and recent lab upgrades

Video courtesy Tom Bryan, MSFC of dynamic testing simulating in-space deployment of tethered satellites

Photos from Tom Bryan, MSFC of their base platform with k-bottles and RCS thrusters. Overhead robotic arm with 800# capability for docking tests

Slosh Test Fixture
Cylindrical Tank Installed

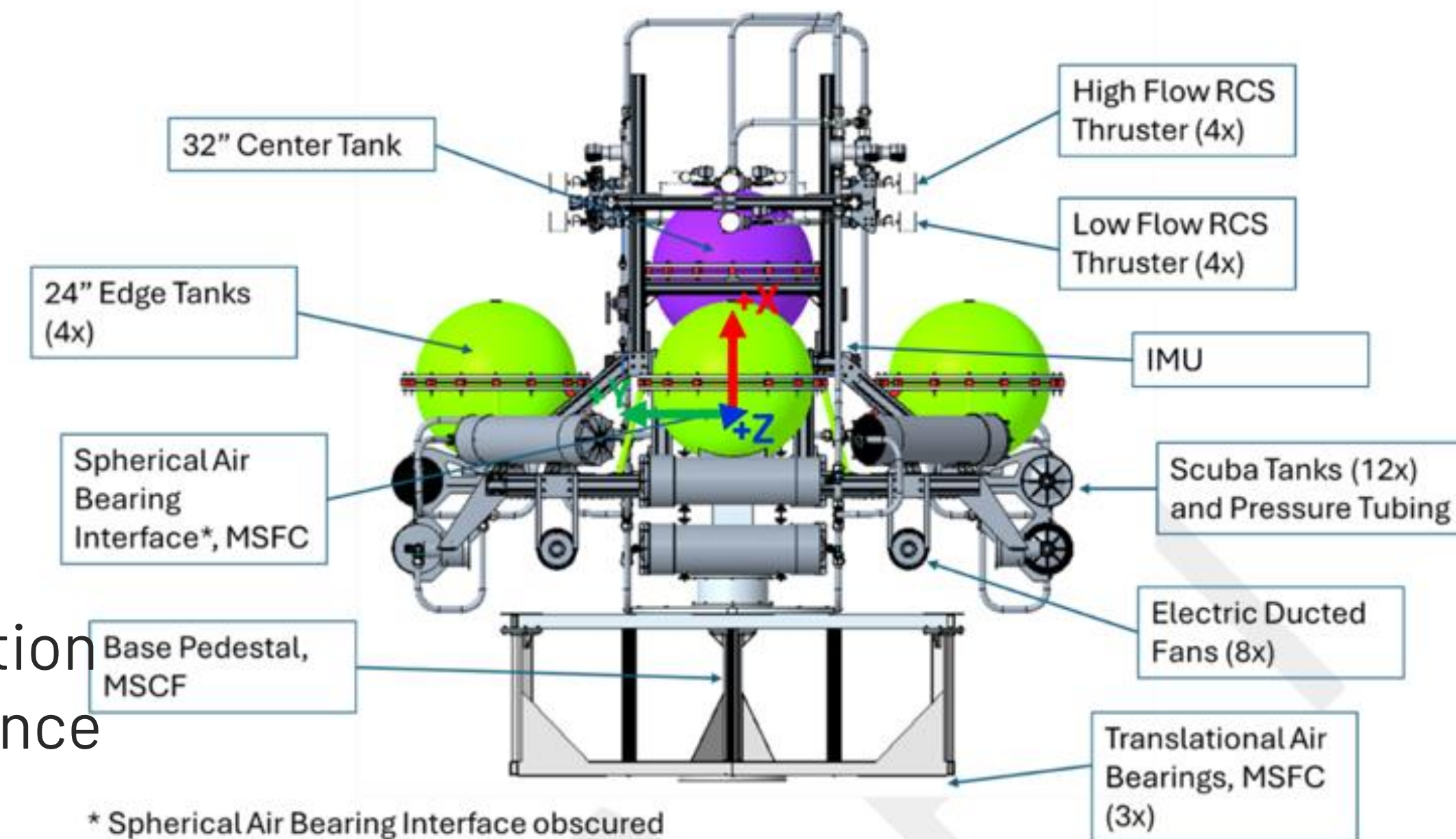


1) "Nonlinear Slosh Damping Analysis for Launch Vehicle Propellant Tanks", T. VanZwieten et.al, NASA/TM-2019-220278

Blue Origin Closed-Loop Test Mule

- Blue Origin makes a wide variety of vehicles of vastly different sizes and configurations that use liquid propellant, from the New Glenn rocket to in-space vehicles with an array of different tank geometries
- A generic test mule was desired that could demonstrate critical dynamic slosh and control system behaviors
 - Sized as large as practical to reduce similitude constraints
 - Single or multi-tank sloshing
 - Tanks that can be moved vertically to be in or outside the slosh "danger zone"
 - Capability to carry tanks of different dimensions
 - Linear effectors to simulate engine thrust control forces
 - Impulsive effectors to simulate RCS thrusters
 - Capable of either rotation-only or linear/rotational coupled motion
 - Completely wireless power and telemetry to avoid any disturbance forces or torques
 - Constructed of existing hardware or low-cost, OTS components wherever possible

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Generic Test Mule, not intended to be representative of any specific Blue Origin Vehicle

Blue Origin Closed-Loop Test Mule

- NASA air-bearing platform and spherical air bearing used for mounting
- All tanks can be raised or lowered, filled or left empty to simulate many vehicle geometries
 - Air bearing location near the vehicle cg limited simulation of some configurations
- Ducted fans simulate control forces to simulate gimballed engine torques
 - Reference 2 provides an excellent discussion on characterizing EDF responses
- RCS thrusters supplied by regulated high pressure air stored in 12 scuba tanks
- Spherical bearing disturbance torques were very low—the 2700# (max) test rig required sub-ounce increments of ballast to balance before each test
- Floor friction from the linear bearings was very low—measured in ounces
- Test article cg and inertias were measured with linear springs with spring constant of 0.7#/in
- Testing had to be performed with AC off to avoid blowing the test rig around!

2) "Experimental Characterization of an Electric Ducted Fan for the SUSAN 25% Scale Research Vehicle", R. Weinstein and B. Simmons, NASA Langley

Simulation Verification using Test Data

- Principles of Similitude were used to ensure the test article would exhibit the key behaviours expected to be seen in simulation
- Simulation models were updated to reflect as-tested mass properties, effector responses, test avionics latencies and processing, etc.
- Test results were documented in “MLRE-188101, Validation Test Report” available via appropriate program channels to our NASA customer

Conclusions

- This testing provided our customer with confidence in our modelling and control approach
- Test location at MSFC allowed easy access for our NASA customer to witness testing
- Availability of government test facilities and NASA expertise made this testing feasible, saving significant facility costs and schedule
- The Blue Test Mule is available for future closed-loop slosh testing





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JEFF BROUWER

SENIOR GNC CHIEF ENGINEER AND TECHNICAL FELLOW

Blue Origin Help Center / Trade Compliance Service ... / TC-12033

Non-IP Presentation on Testing using NASA Facilities, for NASA Slosh TIM at KSC



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LATEST

 **Jeff Brouwer** 02/Jun/26 9:14 AM

I don't believe there is anything in the list from Jira Admin in this presentation that would preclude release. There is a picture of hardware that the company fabricated, but it is a generic test article and does not disclose IP. All key parts are COTS or government-furnished except for generic tubing The photo is taken in a NASA facility. A test video of this article was posted on NASA's public website for several weeks after the test.

Request participants

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