National Aeronautics and Space Administration

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SPACE LAUNCH SYSTEM

AAS 18-132: 6DOF Testing of the SLS Inertial Navigation Unit

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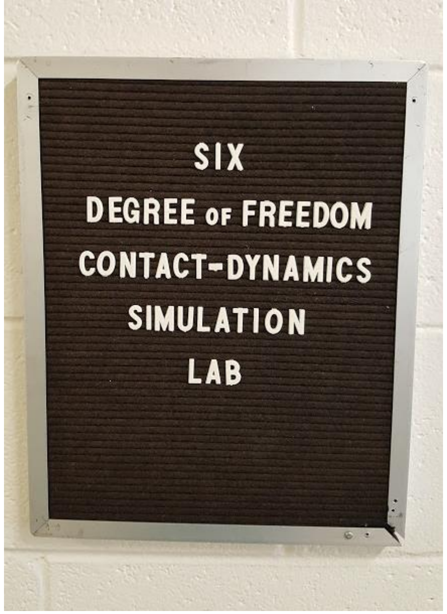
Test Background/Objectives

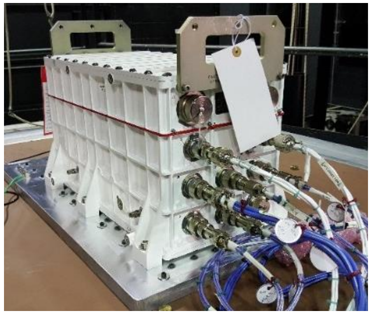
- **Test proposed & conducted to:**
  - Gain insight into gyrocompassing performance of a flight-like RINU under representative SLS on-pad dynamics
  - Provide gyrocompassing test data for validation of the RINU performance model
  - Test planned pre-launch RINU operational procedures
  - Assess the robustness of the RINU GCA algorithm to larger-than-predicted SLS on-pad dynamic environments

- **Performed in MSFC 6DOF Table Facility—formerly Contact Dynamics Simulation Lab (CDSL), site of:**
  - Hubble Space Telescope deployment, service, and Flight Support System (for deorbit), docking/berthing
  - Shuttle/ISS docking/berthing
  - HWIL Space Shuttle Arm training



Facility Test Equipment/Test Article

- **Equipment:**
  - **6DOF table with ~$4m^2$ top**
    - Stewart platform (hexapod) design
    - hydraulically actuated
  - ***ARTEMIS HWIL simulation framework**
    - commands table dynamics
    - emulates SLS flight software
  - ***MAESTRO user interface**
    - live data display
    - provides test operator interface
    - records1553 bus traffic
  - **GPS antenna for accurate time-tagging of data**
  - **Cameras, displays**
  - **Power supply, power quality monitoring/recording system**
  - **Theodolite, North-referenced mirrors**
    - measures RINU true azimuth
  - **Leica Laser Tracker System (LLTS)**
    - tracks position and attitude of table
  - **Leica inclinometer**
    - co-located with RINU to measure tilt



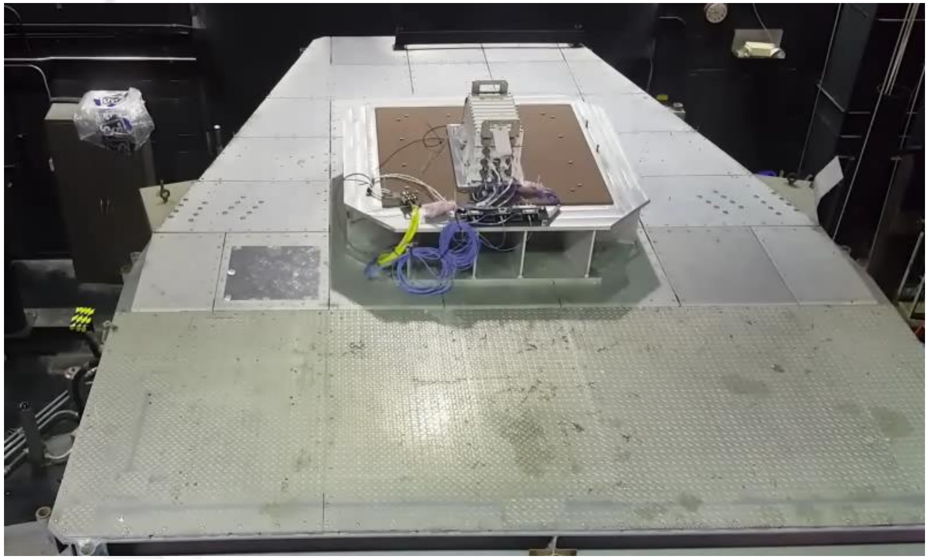
- **Test Article is RINU Flight-Equivalent Unit (FEU)**
  - identical hardware to RINU flight units
  - "equivalent" because acceptance testing is abbreviated
    - no shock/vibration/thermal testing

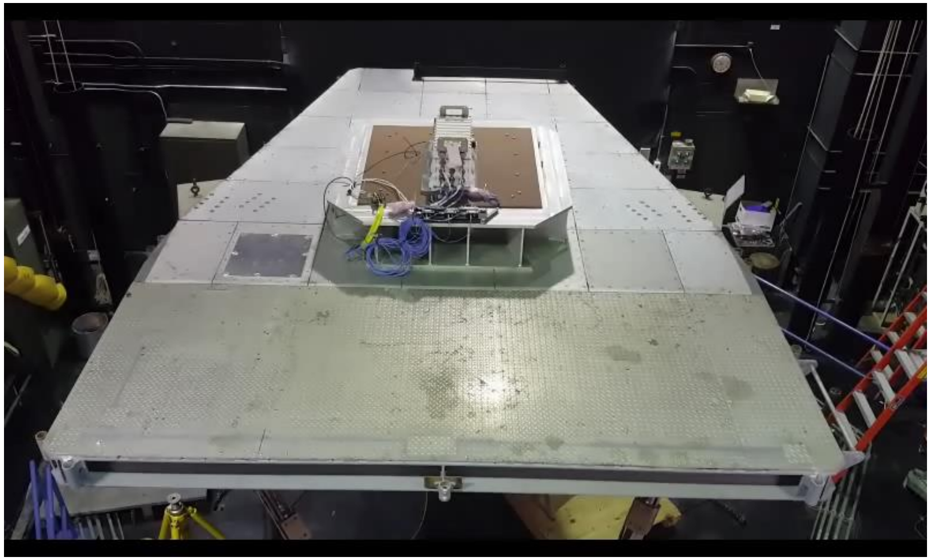
*** Used for SLS-Program-requirement-verification HWIL testing**

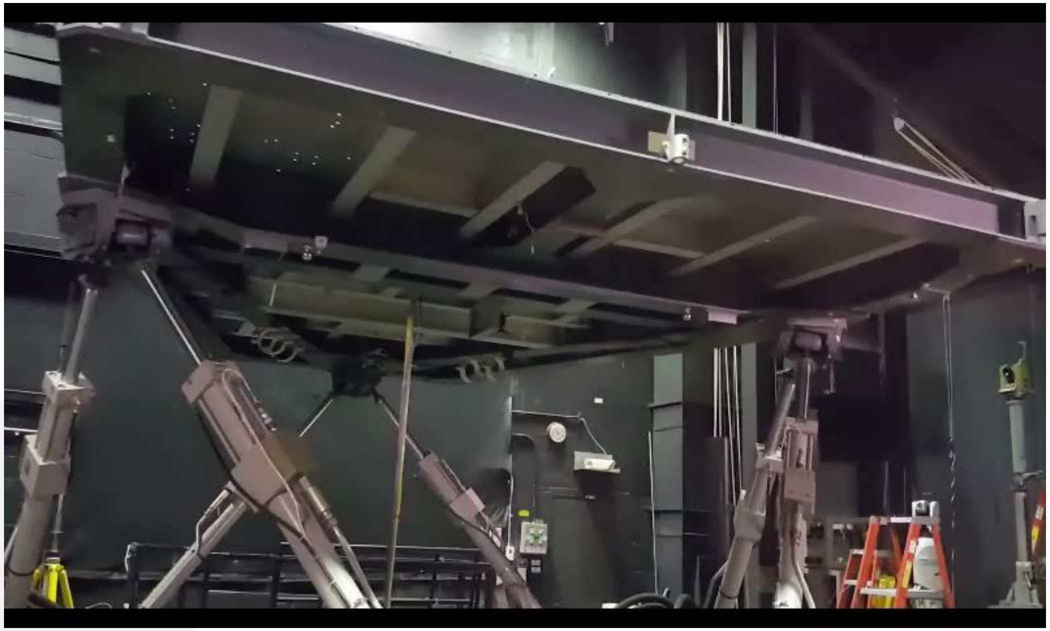
Test Operational Flow

- **Power on ARTEMIS/MAESTRO (HWIL software), table hydraulics & control, data recording/monitoring devices**
  - confirm nominal operation
- **Power on RINU, allow to thermally stabilize**
- **Initialize RINU**
- **Initiate 6DOF table dynamics**
- **Command RINU to GCA mode, gyrocompass for 60 minutes**
- **Command RINU to navigation mode**
- **Table dynamics end; lower table and power off**
- **Measure RINU azimuth via theodolite**
- **Power off RINU**

Table Motion





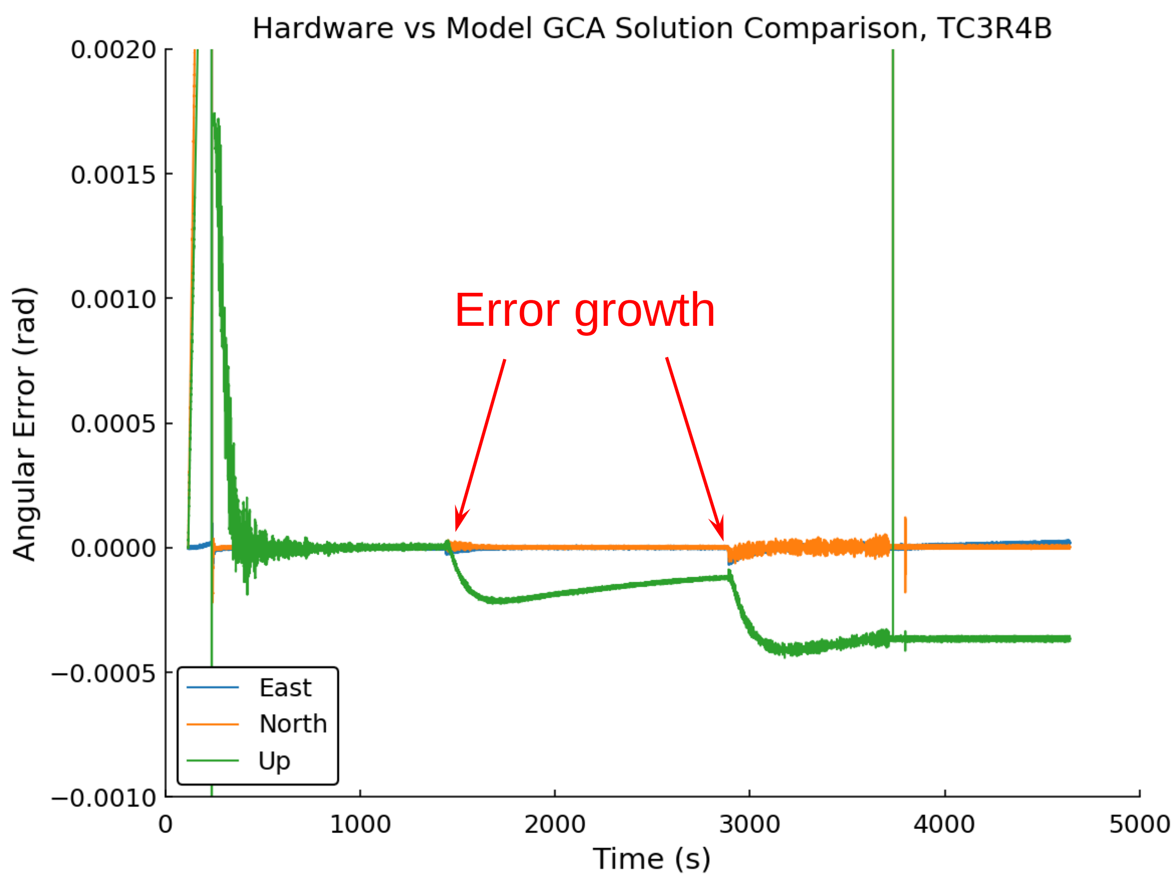


Test Case Summary

Purpose	Description
Preliminary Testing	Static GCA only; no nav
Baseline GCA	Static GCA with nav
Twist & Sway	3 dynamic twist & sway models: • Latest SLS • Early SLS • Vendor heritage
Robustness Testing	SLS twist & sway with scaled up dynamics
24-Hour Static	24-hour static GCA
7-Hour GCA	7-hour dynamic GCA

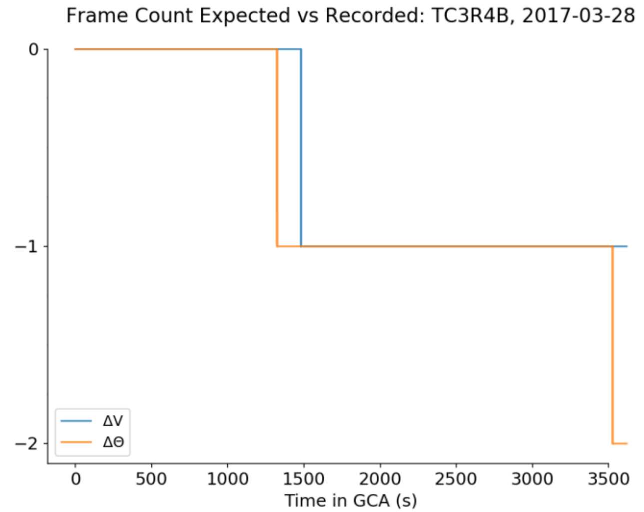
Post-Test Analysis: Sensor Bypass

- **Purpose:**
  - To provide validation evidence for RINU model by comparing hardware/model performance
- **Procedure:**
  - delta-V & delta-ϴ inputs to RINU GCA algorithm reported on 1553
  - input to the RINU performance model's GCA code (bypassing sensor model)
  - compare GCA solution to hardware

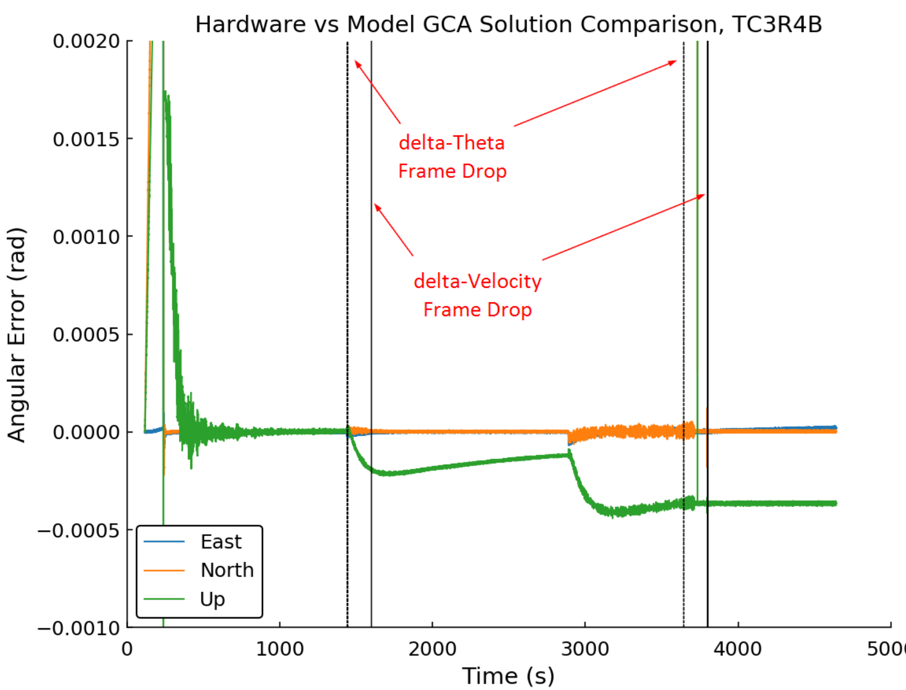


Post-Test Analysis: Sensor Bypass

- **Analysis of frame counter shows some missing data**
  - due to asynchronous polling effects



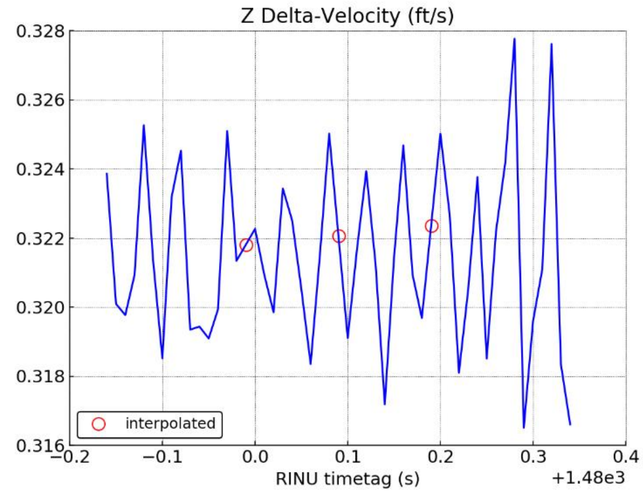
- **Missing data corresponds with some anomalous error growth times**

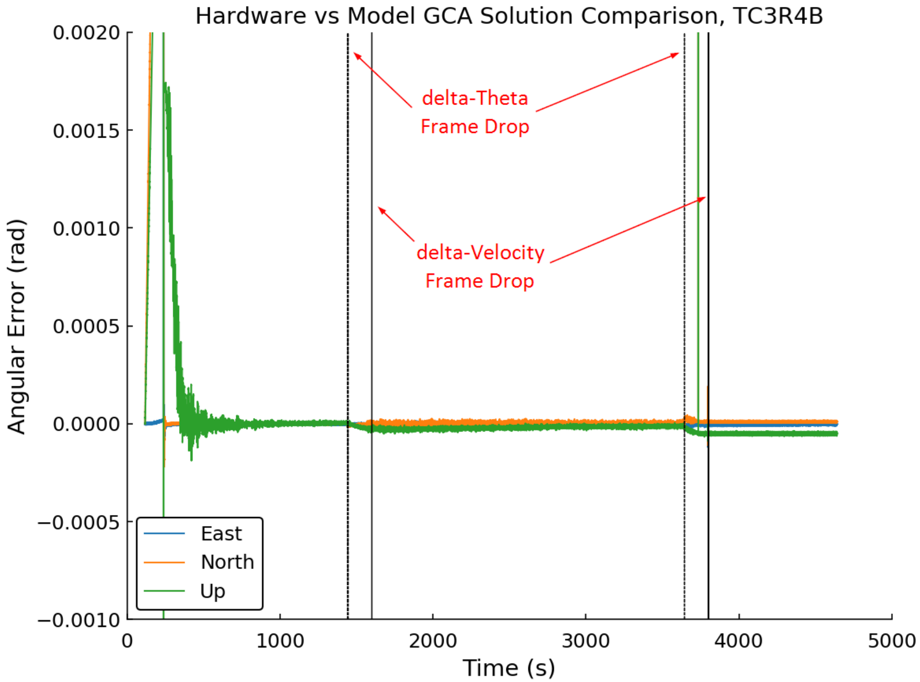


Post-Test Analysis: Sensor Bypass

- **Missing data was replaced with interpolated values**

- **Using interpolated data, comparison results were improved**





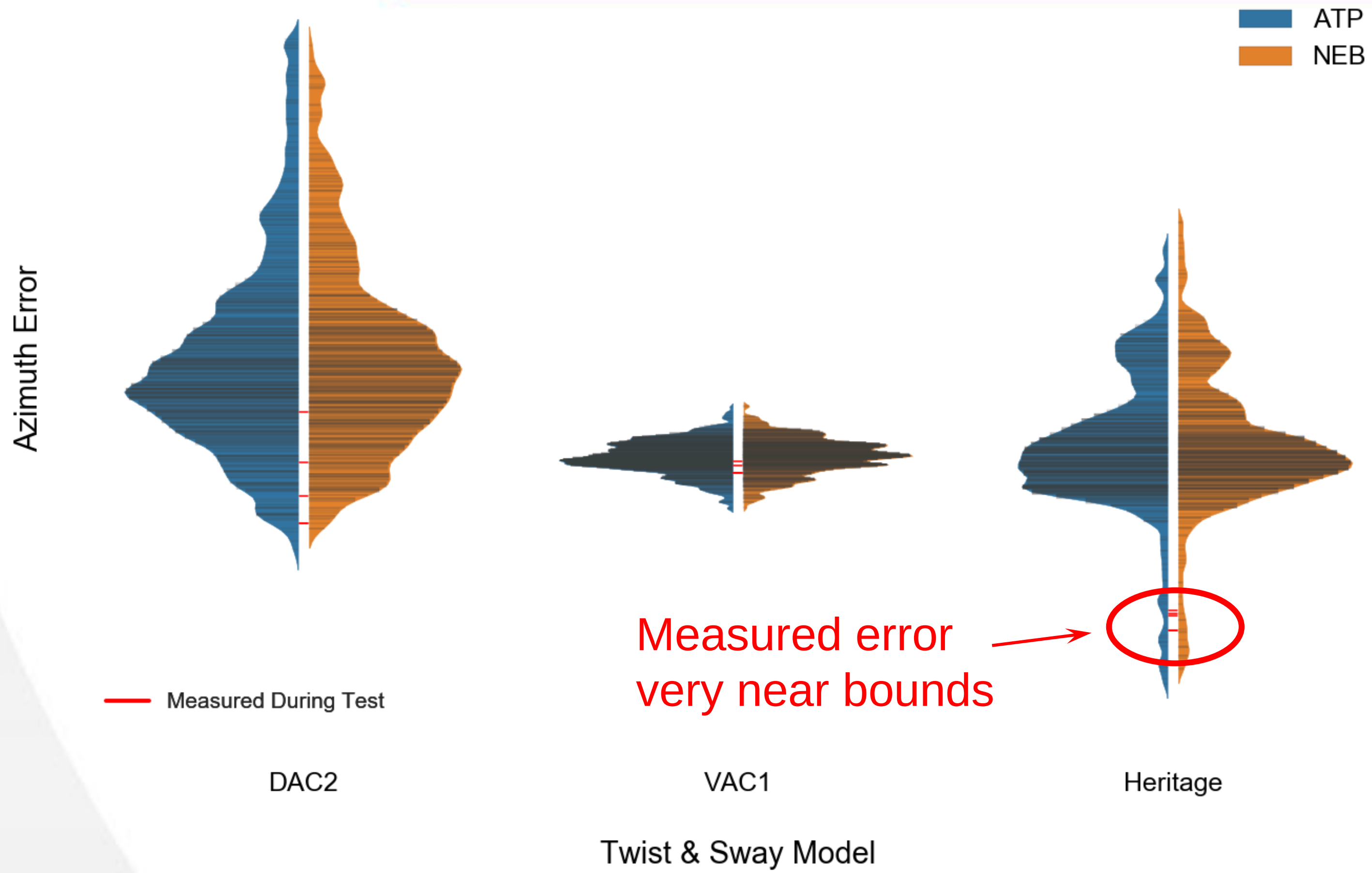
Post-Test Analysis: Sensor Bypass

Twist & Sway Dynamics	Difference in GCA Azimuth, radians
Early SLS	-0.000123 0.000162
Vendor Heritage	0.000128 0.000048
Latest SLS	-0.000054
SLS X4	0.000026
SLS X8	-0.000078
SLS X16	-0.000199
SLS X32	-0.000316
SLS X64	-0.000339

Post-Test Analysis: Monte Carlo Comparison

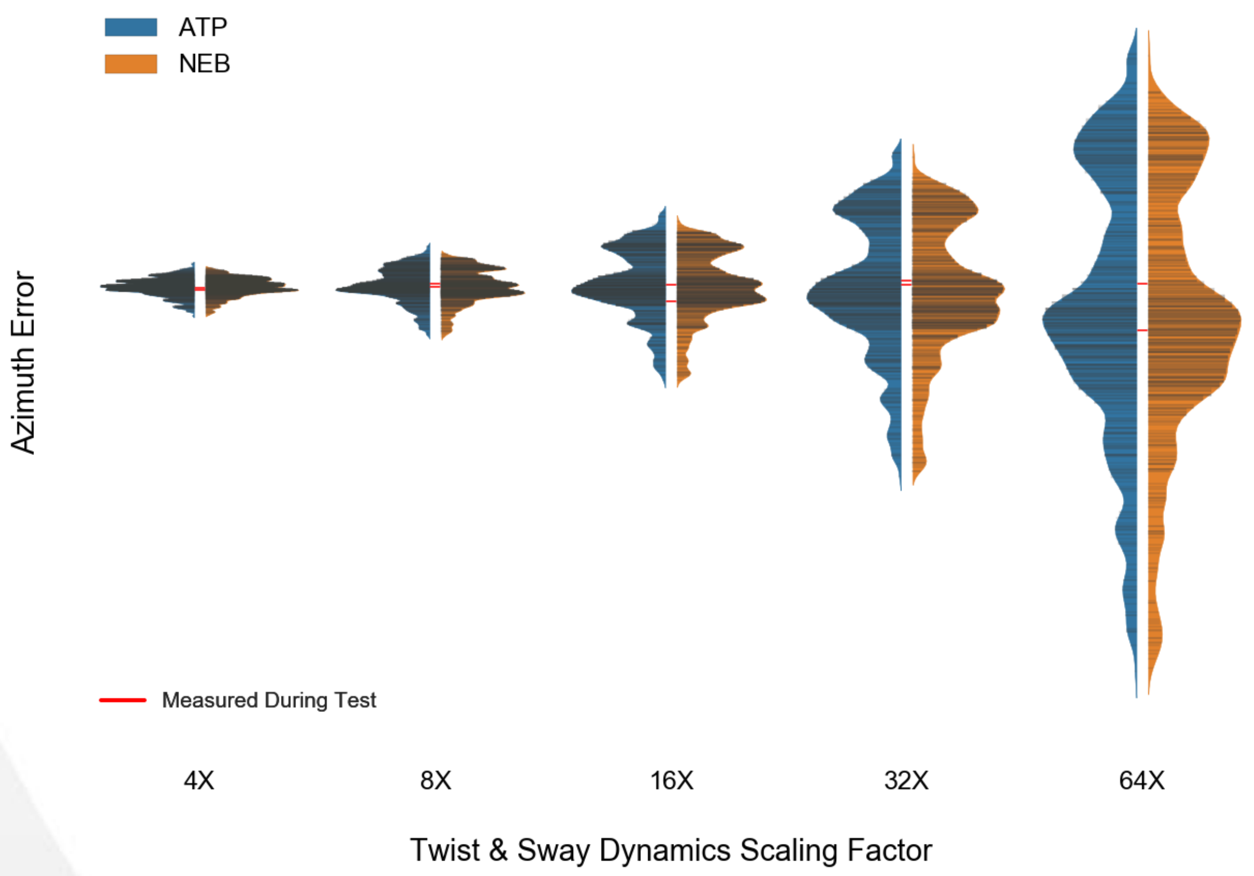
- **Purpose:**
  - Assess hardware test performance relative to expectation
- **Procedure:**
  - 500-case Monte Carlos
    - Same twist & sway dynamics used to produce table dynamics
    - 2 error budgets:
      - vendor capability estimate (labeled “NEB”)
      - derived from ATP test limits (labeled “ATP”)
  - Azimuth error for Monte Carlo solutions co-plotted against that measured in test

Post-Test Analysis: Monte Carlo Comparison



- **Vendor heritage case very near bounds of model prediction**
  - Possible explanations:
    - dynamics not structurally derived
    - large-amplitude dynamics—possibly stressing table control

Post-Test Analysis: Monte Carlo Comparison



- **All scaled-dynamics cases comfortably within modeled bounds**
- **Negligible sensitivity to error budget across all tested twist & sway environments**

Post-Test Analysis: Sensor Noise Characterization

- **Purpose:**
  - Examine RINU sensor noise and error characteristics
  - Provide validation evidence for RINU performance model
- **Procedure:**
  - Data from 24-hour runs used to perform Allan Deviation, spectral analysis
  - Recreated test condition using RINU model for comparison
- **Findings to feed back to change recommendations for RINU model developers**

Conclusions

- **Testing achieved all test objectives**
  - Gained insight into GCA performance
  - Produced test data for RINU model validation
  - Tested pre-launch RINU operational procedures
  - Assessed RINU GCA robustness

- **Post-test analysis providing RINU model validation insight**
  - Sensor bypass analysis provided direct GCA solution comparison
  - Modeled sensor noise/error characteristics were directly assessed via Allan Deviation and spectral analysis
    - Will likely drive future model updates

- **RINU hardware GCA performance was within expectation for all SLS and SLS-derived (scaled) environments**
  - Some potential lack of conservatism in modeled performance under vendor heritage environment
    - May merit further testing to confirm

Thank you!