# SMAP Observatory Antenna Pointing Errors Due to Dynamic Sources

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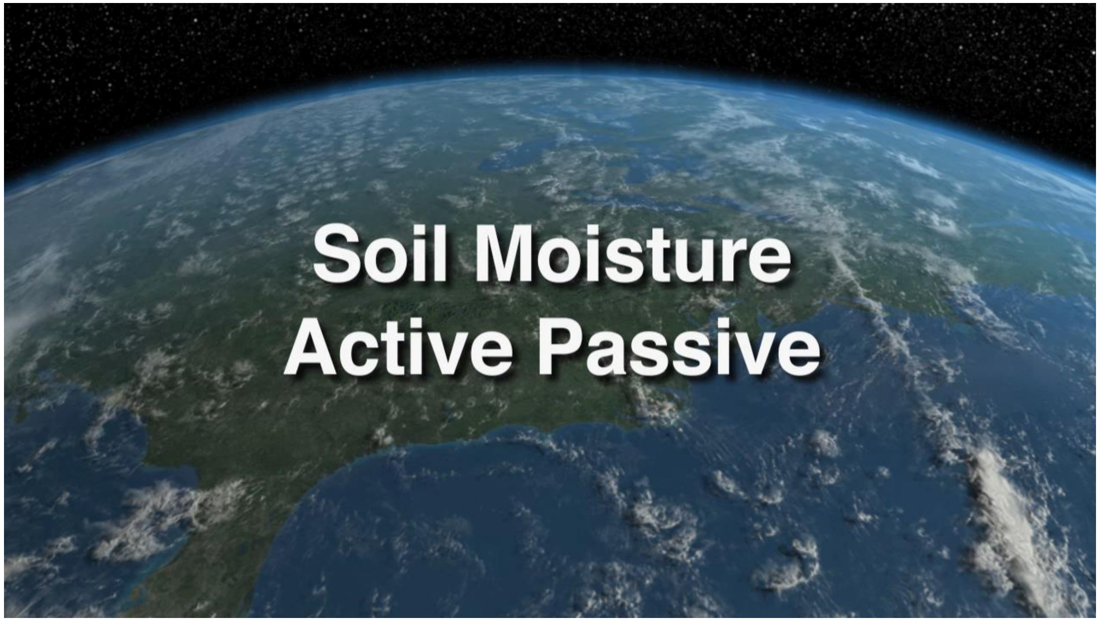
# Overview: SMAP Project

- The Soil-Moisture Active/Passive (SMAP) mission will provide global measurements of the soil moisture and its freeze/thaw state to enhance our understanding of processes that link the water, energy and carbon cycles
- Launch is planned for 2014

## Key Dynamic Characteristics

- **Balancing**
  - The goal is to null out any mass imbalance using passive balance masses
- **Momentum Compensation**
  - The Control system maintains a zero net angular momentum system, by nulling the spun momentum using Reaction Wheels
- **Frequency Separation**
  - Structural modes are way above the control bandwidth and spin rate freq to minimize the CSI and gyro-elastic coupling effects

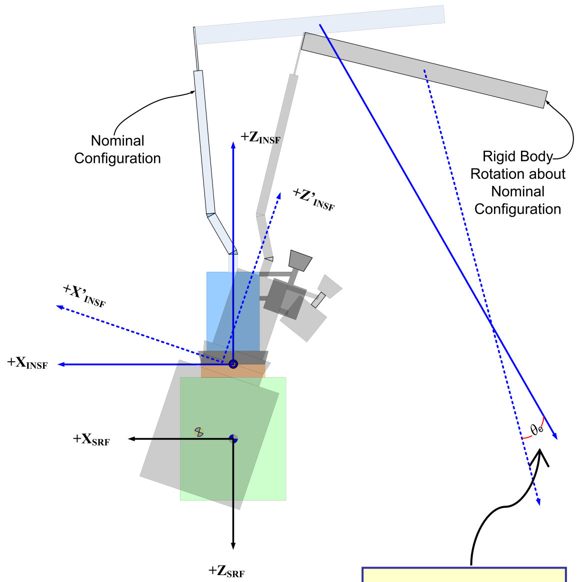


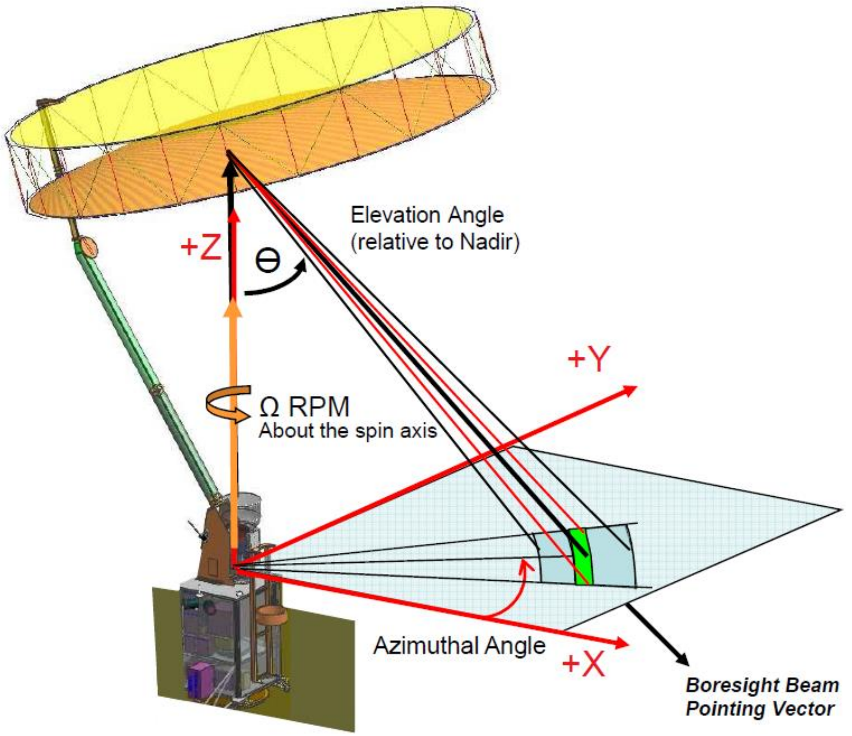

http://smap.jpl.nasa.gov/mission/

# Boresight Beam Pointing Errors

- Pointing Errors are generated by changes relative to the nominal system configuration defined as:
  - S/C is nominally nadir pointed
  - Instrument is nominally configured to be off-nadir pointed (ϴ degrees) & spun at Ω RPM

- On-Orbit perturbations of the above nominal system configuration lead to Azimuth and Elevation pointing errors



# Key Antenna Pointing Sensitivities

1. **Static Misalignment of spun to de-spun bodies:**
   – Leads to largest dynamic error at the spin rate frequency
   – *Due to large sensitivity to this error, and inability to measure this on the ground, we calibrate this out on orbit → <u>Drives design</u>*

2. **Mass Imbalance of the spun body**
   – Causes large SC wobble and large antenna pointing bias
   – Has to be limited to avoid SRU drops (0.5 deg/sec max rate)
   – *Leads to tight knowledge of mass properties → <u>Drives design</u>*

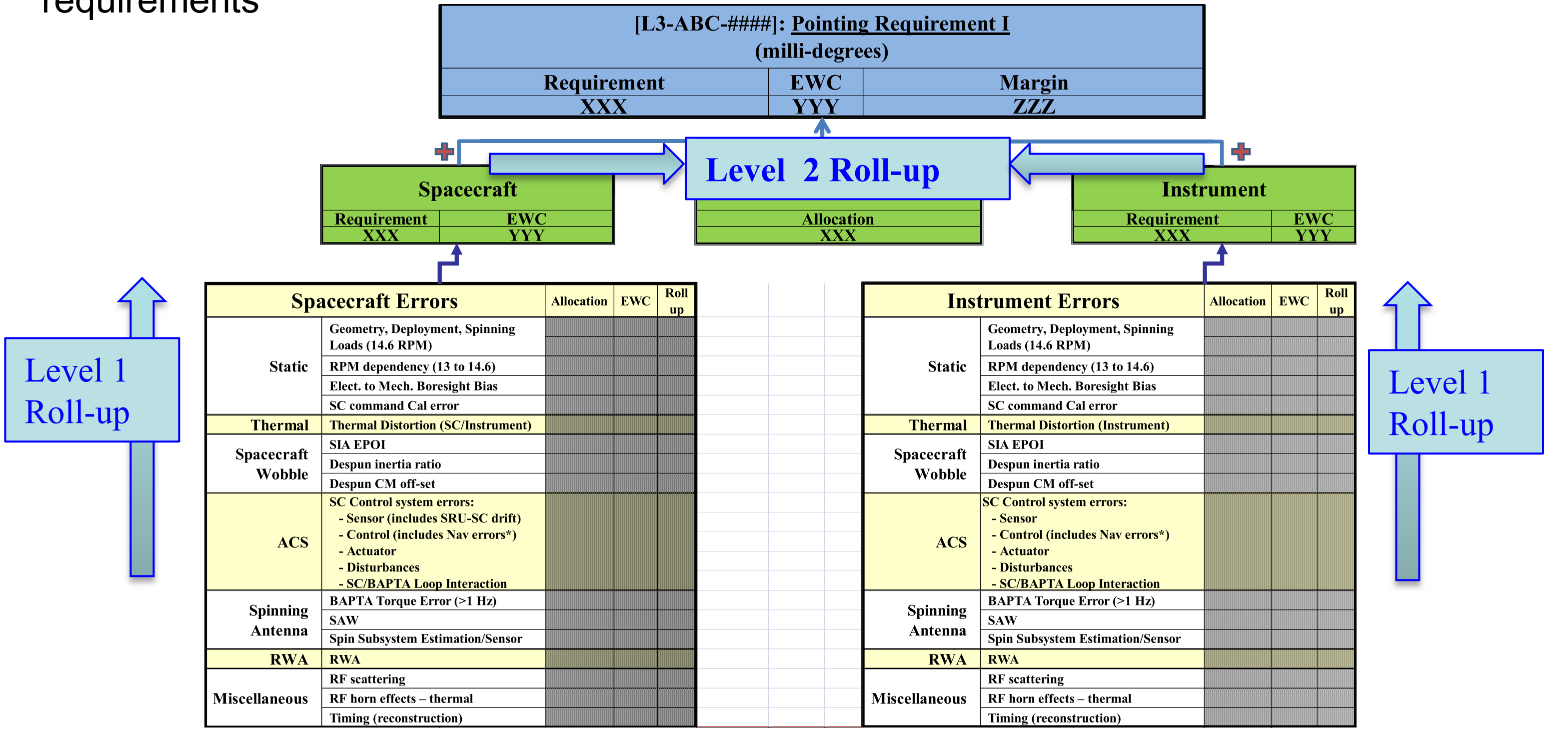
3. **Boom Bending due to centrifugal loading**
   – Causes large bias errors

4. **Attitude Control System (ACS) knowledge errors**
   – *Needed to reconstruct pointing → <u>Drives design</u>*

5. **CSI:**
   – *Boom/Reflector interacting with spin control system → <u>Drives design</u>*

# Pointing Errors Budget Structure

- An elaborate Error Budget system was designed to book-keep the contribution of various error sources to the observatory pointing errors
  - Each line items was given lower level requirements in order to meet the observatory science requirements




**List of pointing errors computed using ADAMS model**

I. Spacecraft (S/C) Wobble
   - induced by the spun mass imbalance (SIA EPOI)
   - induced by the despun CM offset
   - induced by the despun Inertia ratio

II. BAPTA Torque Error

III. Spin Axis Wobble (SAW)

# Overview: ADAMS Multi-Body Models

## Discrete model:

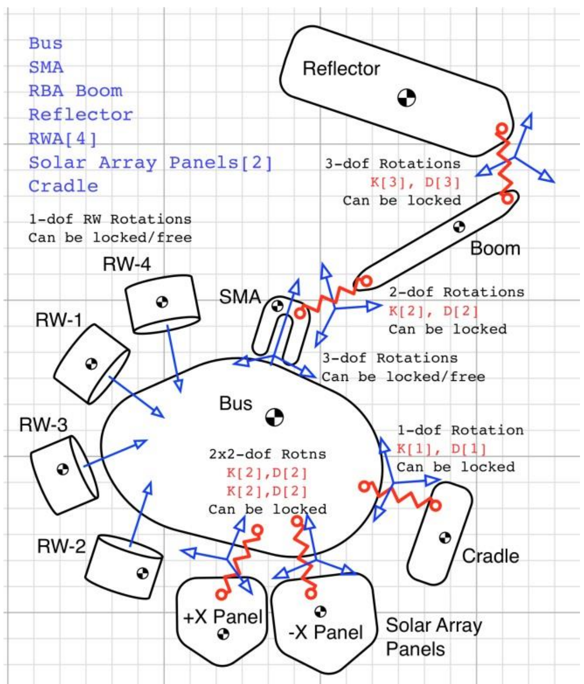
- Low Fidelity Lumped Mass/Stiffness model
- With few elastic DOFs
- Rigid Reflector (and no mesh)
- Much faster to simulate, hence suitable for the Monte-Carlo Analysis

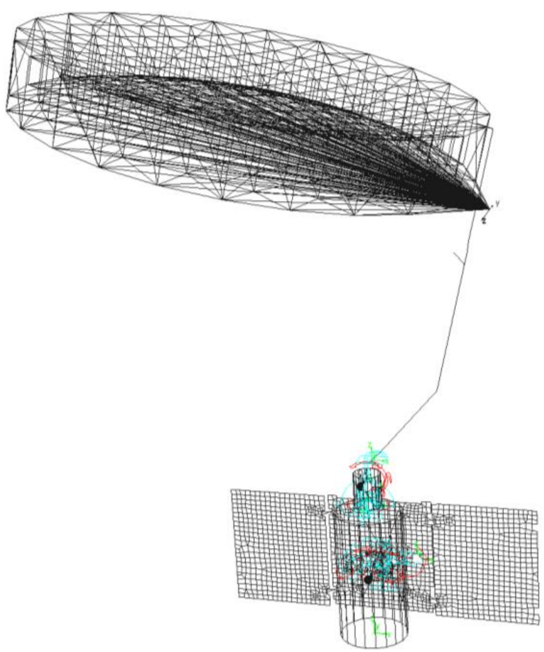
## CMS model:

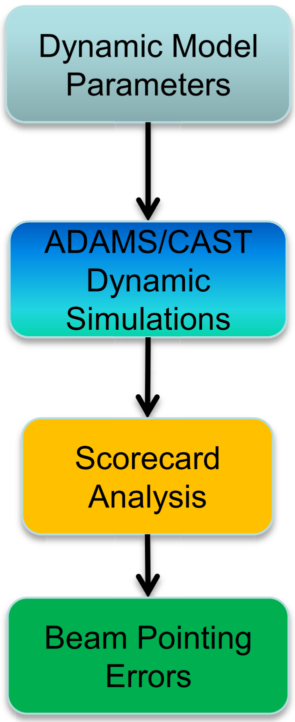
- Our highest fidelity model based on the Component Mode Synthesis (CMS) formulation
- Many elastic DOFs: depending on the number of component modes included
- Includes Reflector flexibility and its mesh preload

## Scorecard Program (postprocessor):

- Scorecard is a Matlab program that reads the dynamic states from time domain simulations and maps them to the electric beam boresight pointing errors





- The mass imbalance for the SMAP project is expressed in terms of the Effective Products of Inertia (EPOI):

$$I_{xz}^{effective} = I_{xz}^{s} + \frac{M_s M_d}{M_s + M_d}(z_s - z_d)x_s \qquad *s: \ spun, \ *d: despun$$

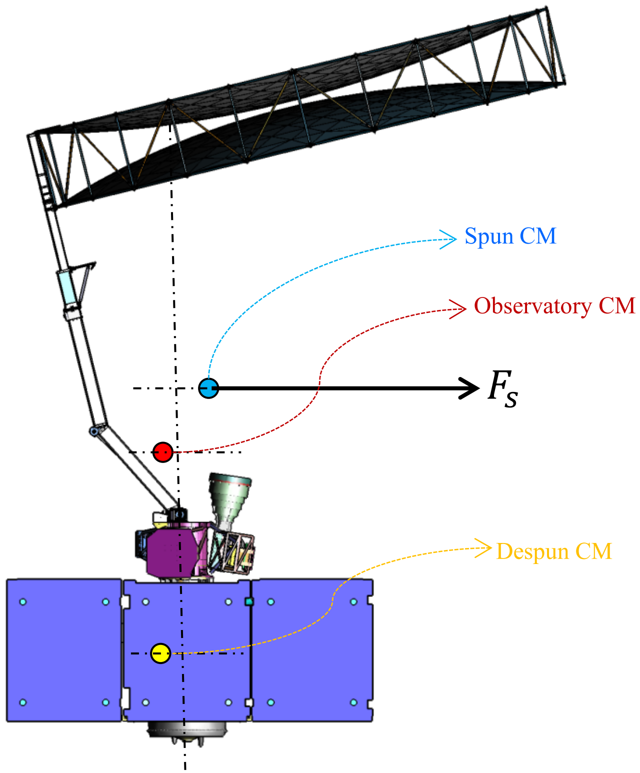
- EPOI derivation and its physical meaning:

$$F_s = M_s x_s \omega_s^2$$

$$T_{obs} = F_s \Delta z + I_{xz}^{s} \omega_s^2$$

$$T_{obs} = \left[M_s x_s \Delta z + I_{xz}^{s}\right]\omega_s^2 = I_{xz}^{effective}\ \omega_s^2$$

$$\Delta z = \left(\frac{M_d}{M_s + M_d}\right)(z_s - z_d)$$




- Consequently, if we can limit the ***Effective POIs***, we can limit the resulting observatory cross-axis torque, and hence limit the resulting cross-axis wobble (and resulting pointing errors)

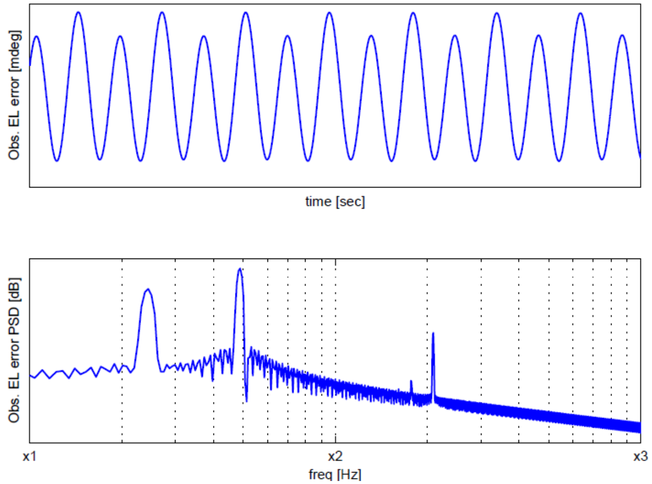
# Mass Imbalance

## Resulting Pointing Errors

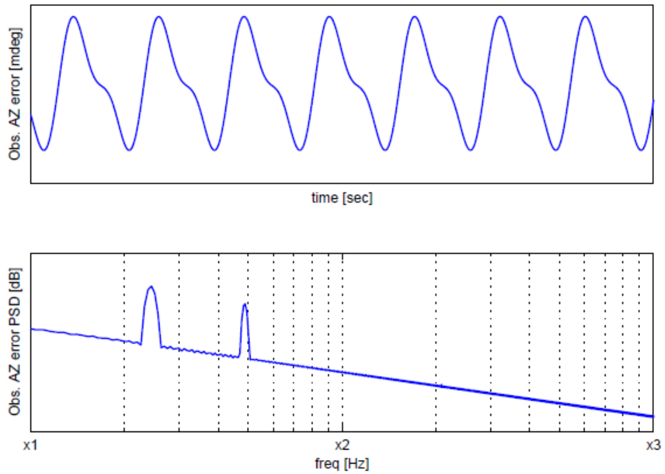
- The Goal is to zero out the EPOIs. The project has an extensive plan for mass props measurements for balancing the observatory by nulling the EPOI
- However we are limited by the knowledge errors from the component mass props measurements
- There are project requirements that limits the acceptable EPOI levels in the XZ and YZ planes
- Any excessive EPOI left-over after balancing (due to the knowledge errors), will cause a S/C wobble @ the spin rate frequency, which may challenge the star tracker capability and also induce unacceptable pointing errors as a result

## Representative PEs for a given Mass Imbalance (EPOI):

**Nadir Pointing Error**




**Azimuth Pointing Error**




**The PEs due to the EPOI mass imbalances are dominated by the f1 & f2 signals:**

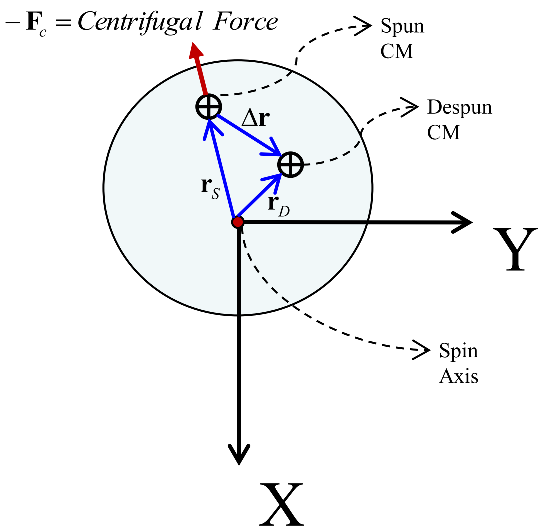
f1 Hz → Instrument spin rate @ Ω rpm

f2 Hz → twice the spin rate

# Spun/Despun CM Offset

## Definition and Effects

- In presence of the Spun CM offset, there exists a centrifugal shear force at the spun/despun interface.
- In addition, if the Despun CM is not aligned with the spin axis, the mentioned shear force creates a Torque about the Despun CM in the Z-direction as follows:




$$\left.\begin{aligned} &\mathbf{T} = \Delta\mathbf{r} \times \mathbf{F}_C \\ &\Delta\mathbf{r} = (\mathbf{r}_D - \mathbf{r}_S) \\ &\mathbf{F}_C = \frac{-\mathbf{r}_S}{|\mathbf{r}_S|} F_C \\ &F_C = m_S |\mathbf{r}_S| \omega^2 \end{aligned}\right\} \Rightarrow \mathbf{T} = -(\mathbf{r}_D \times \mathbf{r}_S) m_S \omega^2 = I_d^{zz} \ddot{\psi} \quad \Rightarrow \quad \psi \propto \frac{|\mathbf{r}_D \times \mathbf{r}_S|\ m_S\ \omega^2}{I_d^{zz}}$$

- The resulting torque causes a S/C yaw motion at the spin rate frequency, which is proportional to the spun & despun cm offsets, spin rate, and m(spun)/Izz(despun).
- It dominantly affects the Azimuth Pointing Errors.
- The Despun CM offset wrt the mean spin axis, has an effect on the Pointing Errors (PE), if and only if, there is a non-zero spun CM offset.

# Pointing Error Roll-up and Verification Approach

- **"*Worst Case*" roll-up for the individual Error Budget (EB) Line Items:**
  - The S/C and instrument Pointing Errors (PE) for each line item in the error budget are computed based on the expected worst case parameters for the error sources, assuming there is no significant coupling between them.
  - The observatory PEs are then computed by rolling-up (Sum or RSS) the individual line items.
- **"*Parametric Study*" simulations to verify the Observatory Pointing Errors:**
  - The parametric study simulations were conducted to verify the observatory PE roll-up from the EB line items. It serves the following purposes:

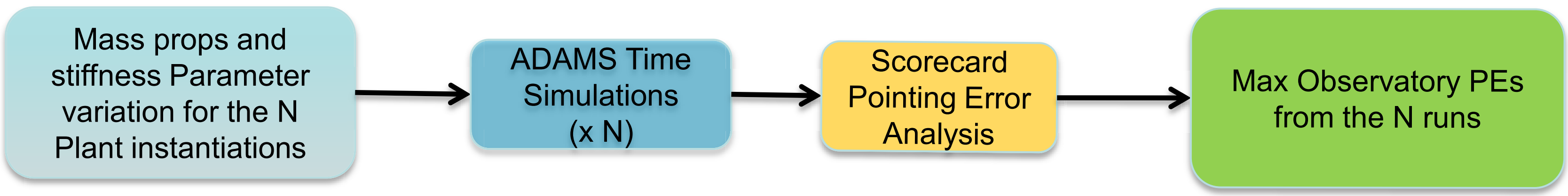
    - **To verify our worst case assumptions for the individual line items:**

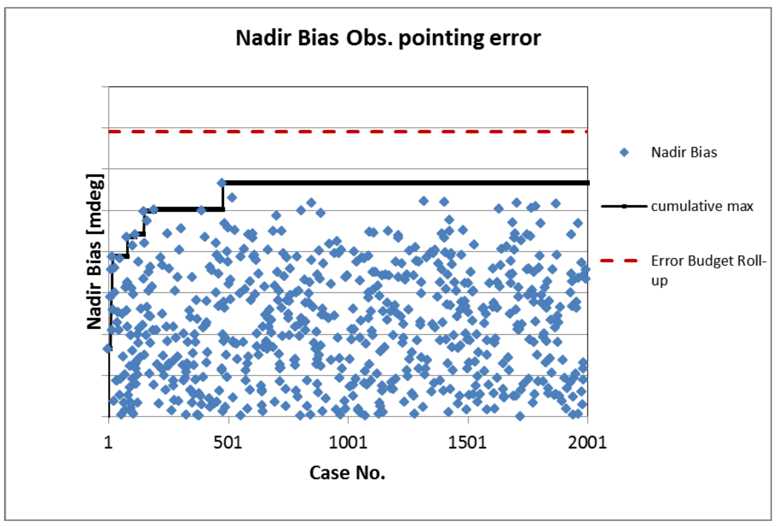
      i.e. to make sure our worst case are really *Worst Case*
    - **To verify the roll-up strategy to get the observatory pointing errors:**

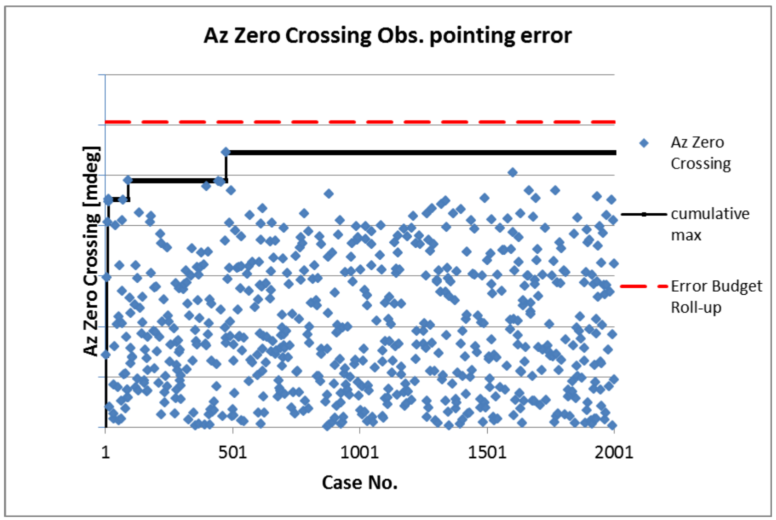
      In the EB there are two levels of PE roll-up (1) roll-up from line items to the top level S/C and Instrument, and (2) roll-up from the top-level S/C and Instrument to the observatory. There are RSS and Sum choices associated with each roll-up.

# The Parametric Study Simulations

- Varied the mass props, damping, stiffness, and spin rate parameters to create N *instantiations* of the SMAP dynamic model
- From that, generated N # of ADAMS models, simulated them and then computed the N set of observatory PEs




**Red line**: the worst case roll-up from the pointing error budget line items

**Blue dots**: observatory PEs from the N ADAMS simulations

**Black Line**: the Cumulative Max observatory PE from the N runs

## Observations:

- The Worst Case Pointing Error roll-up for the line items under discussion, bounds the observatory pointing errors calculated using a wide range of plant parameter variations (N instantiations).
- From the N runs, the cumulative maximum plots for the observatory PEs reach an asymptote below N/2, which is an indication of a practical convergence

# Summary

- The SMAP pointing error definition and error budget structure discussed
- The Antenna Pointing Sensitivities relative to major dynamic sources (the mass imbalance and CM offset) discussed using simple analytical formulations
- Dynamic model development in ADAMS for the SMAP project explained
  - The main objectives of the dynamic models are for pointing error assessment, and the control/stability margin requirement verifications
- Discussed the Pointing Error Roll-up and Verification Approach:
  - Used the "Worst Case" scenario for the individual Error Budget Line Items, and then roll-up using Sum/RSS to get the expected worst-case observatory PEs
  - The parametric study simulations were conducted to verify the observatory PE roll-up from the EB line items. It serves the following purposes:
    - To verify our worst case assumptions for the individual line items
    - To verify the roll-up strategy to get the observatory pointing errors

# Thank you



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