Random Vibrations in COMSOL Multiphysics

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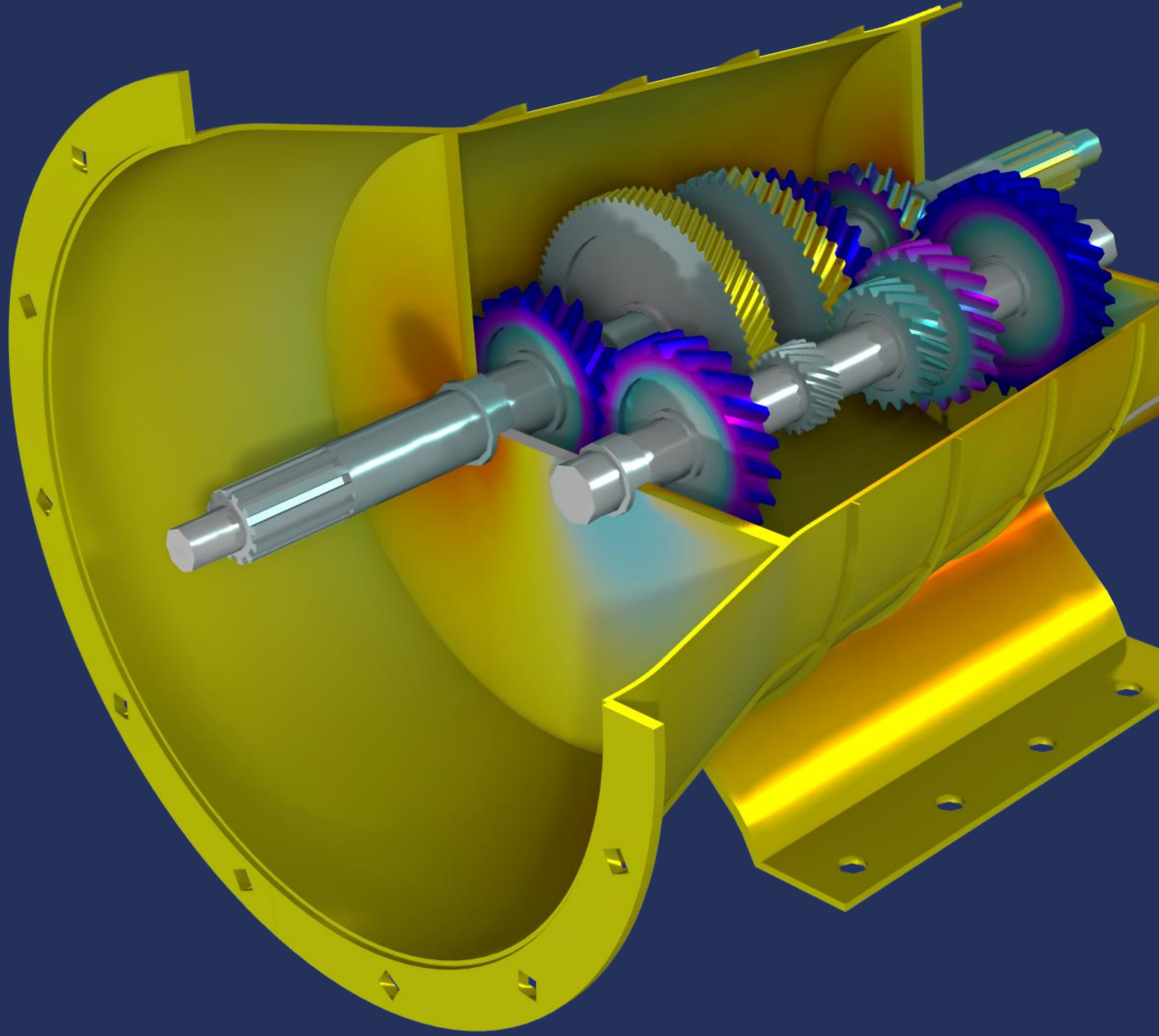
Schedule

1. Reduced-Order Modeling
2. Random Vibrations
3. Random Vibrations - Showcase
4. Discussion



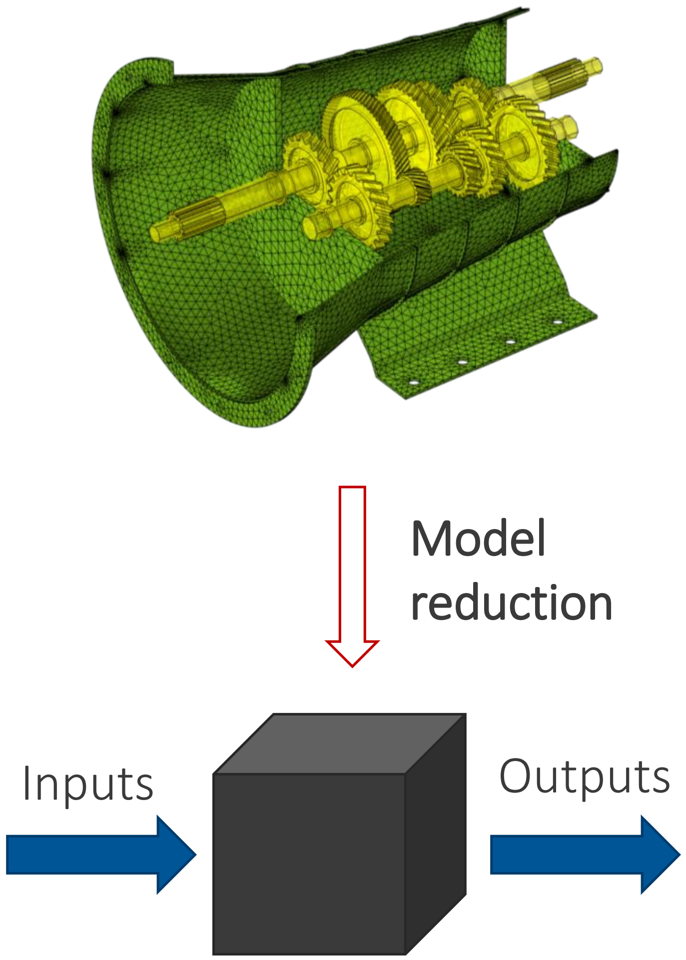
Reduced-Order Modeling

Tomáš Vrbata

Reduced-Order Models

- A larger FE model is reduced to a black box with a small number of degrees of freedom
- A ROM can have any number of scalar inputs and outputs
- A ROM is created by a special *Model Reduction* study step
- The ROM must be linear
  - The material model must be *Linear Elastic Material*
  - No other non-linear contributions
  - Geometric nonlinearity is disabled when building the ROM

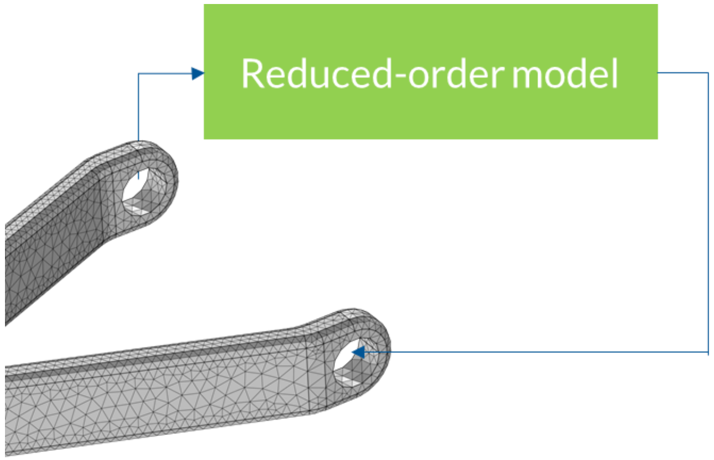
- (The Random Vibration analysis is based on ROMs)



Reduced-Order Models

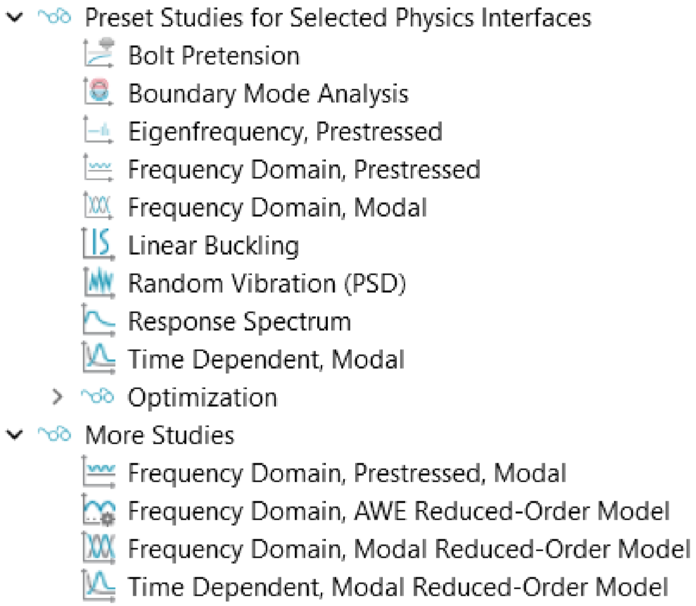
1. A ROM can be used standalone (in 0D component)
   – Efficient way to compute scalar outputs from scalar inputs
2. A ROM can have reconstruction capability
   – The full solution in the original (FE) model can be obtained
   – Evaluation of nonlinear expression

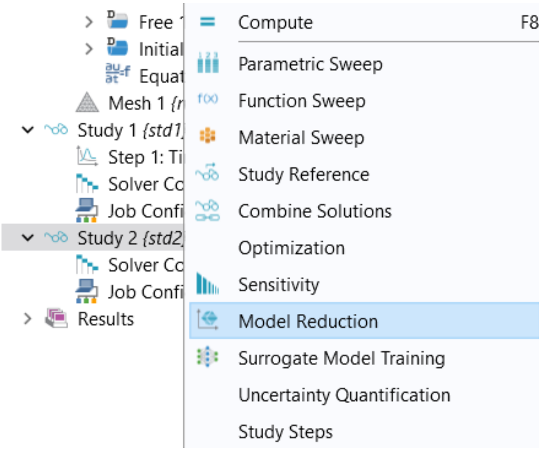
   ☑ Ensure reconstruction capability
3. A ROM can be a component in another FE model

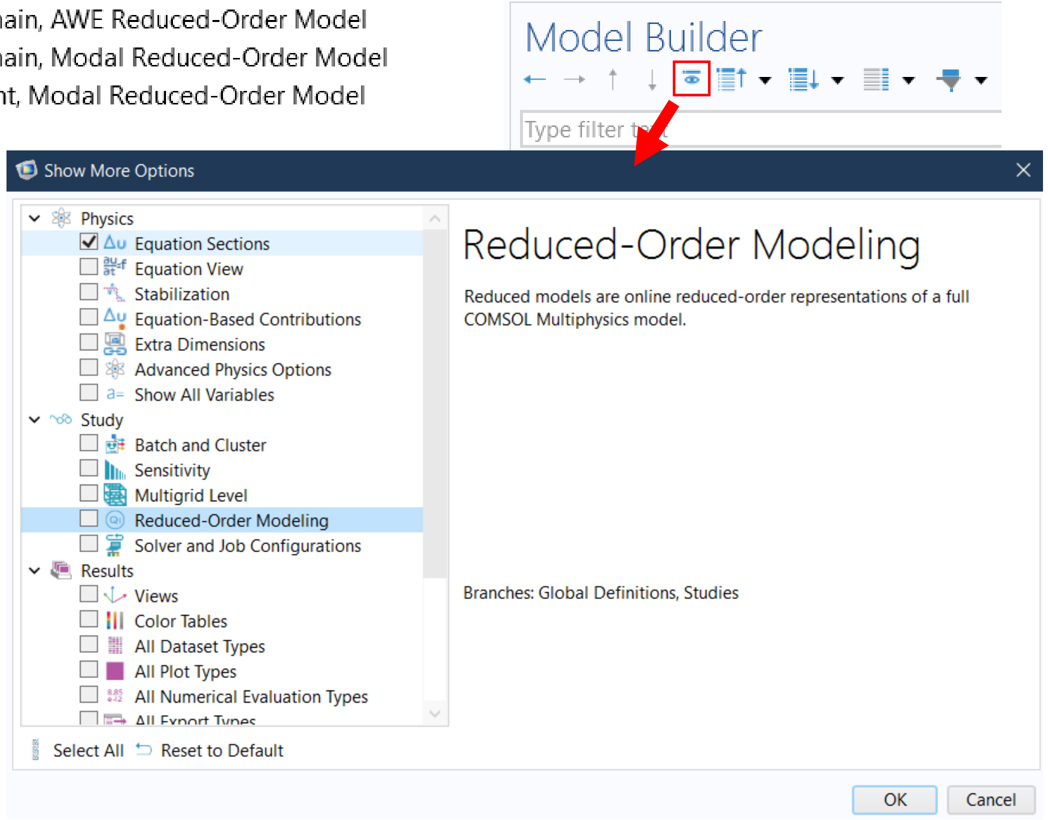


ROM Studies

- Predefined studies for some physics interfaces
  - *Frequency Domain, Modal Reduced-Order Model*
  - *Frequency Domain, AWE Reduced-Order Model*
  - *Time Dependent, Modal Reduced-Order Model*
  - *Random Vibration (PSD)*
- Can be added to any study
  - Requires the *Reduced-Order Modeling* preference to be set

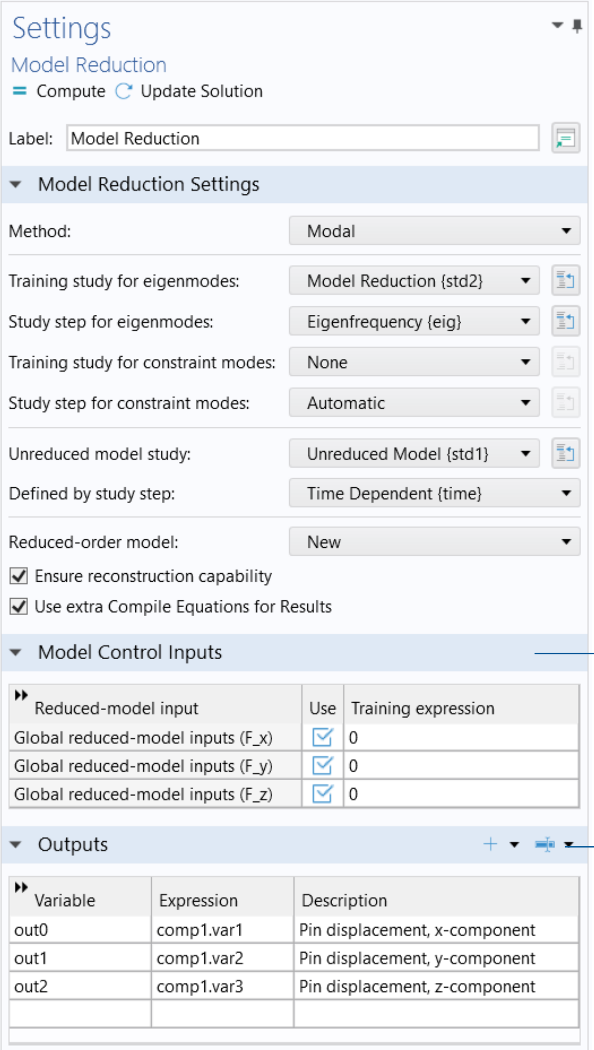




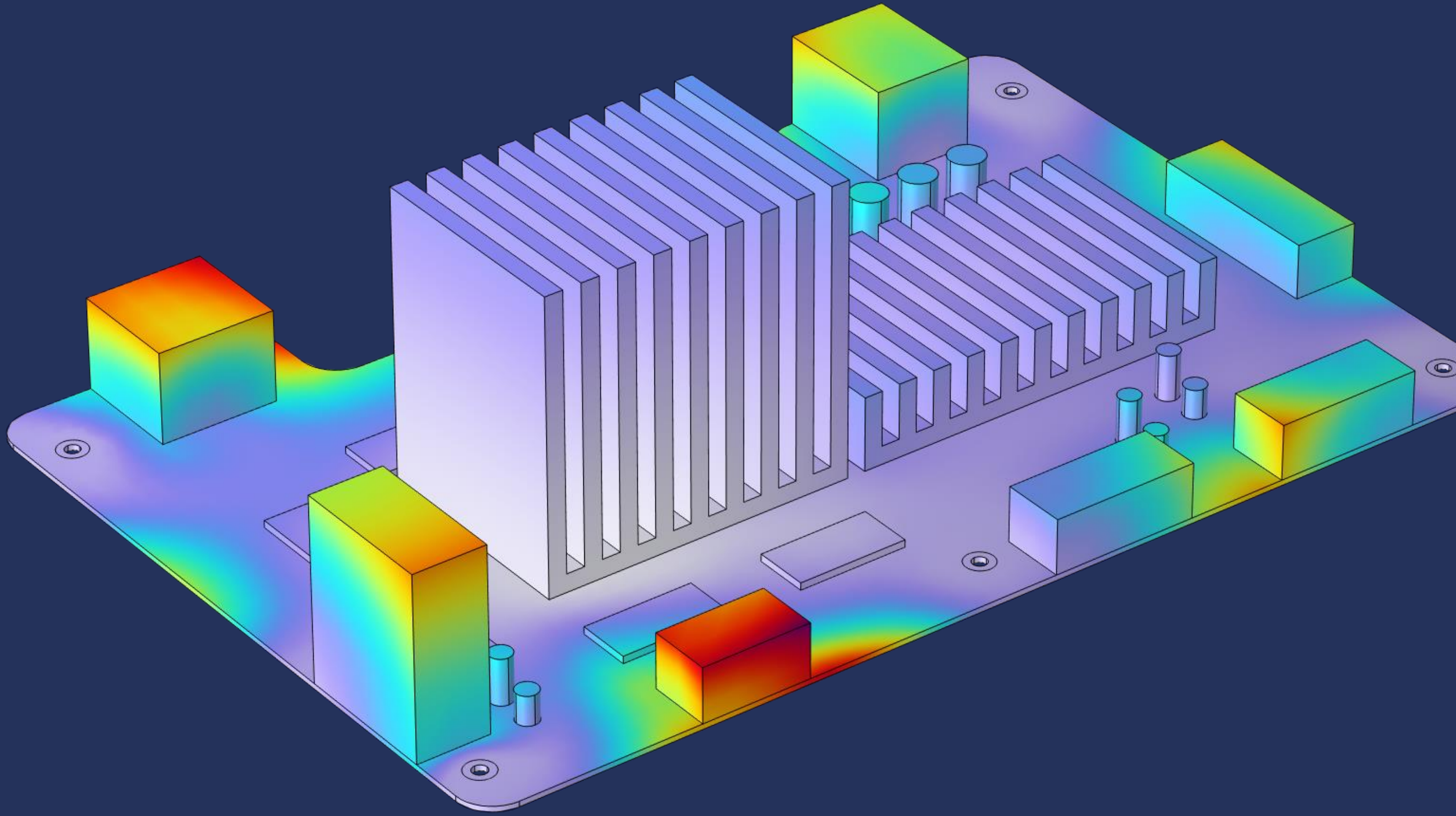


Model Reduction Study Step

- Method: Usually Modal
- Training study for eigenmodes: An eigenvalue or eigenfrequncy solution.
- Training study for constraint modes: Used for non-zero Dirichlet conditions.
- Unreduced model study: Points to a study used as to determine ROM type (frequency domain or time dependent).
- Reduced order model: Points to the ROM after computation.
- Ensure reconstruction capability: Full solution can be retrieved. Necessary for evaluation of non-linear quantities.



- Model Control Inputs
  - Defined in a *Global Reduced Model Inputs* node
  - Use the check box if some are not needed
- Outputs
  - Add any global expression
  - Use probes, integration, operators, etc.
  - Become global variables in calling model



Random Vibrations

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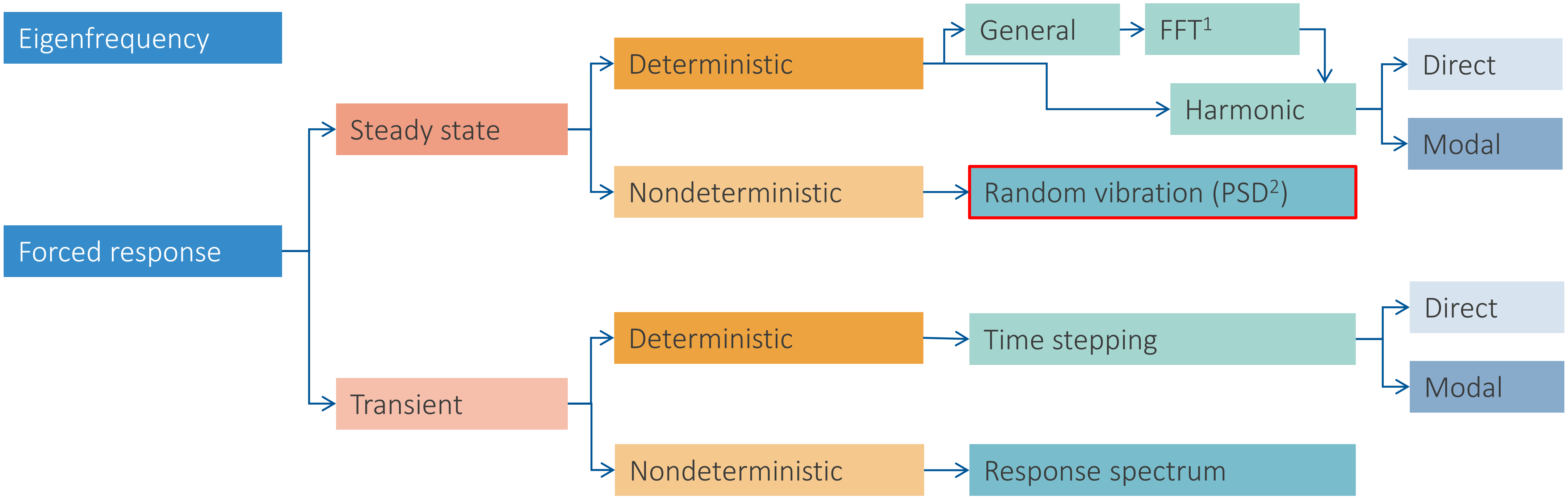
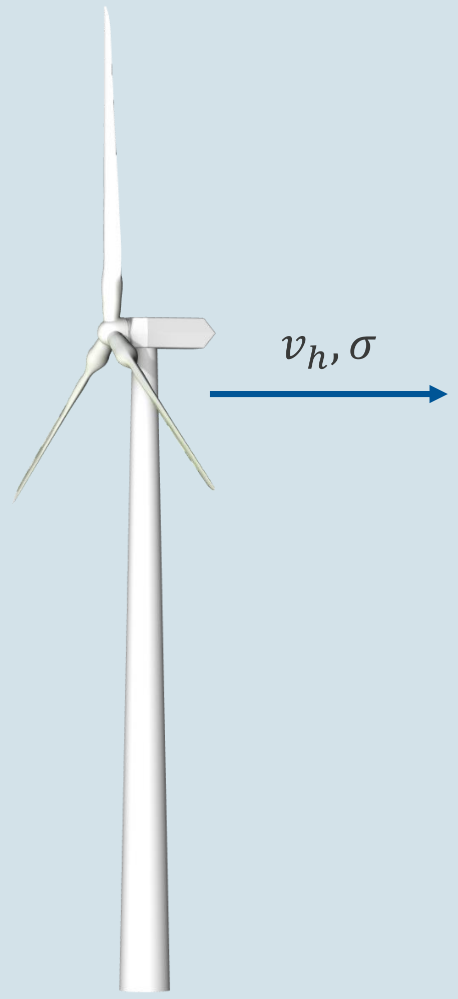
CLASSIFICATION OF DYNAMIC STUDIES IN COMSOL MULTIPHYSICS®



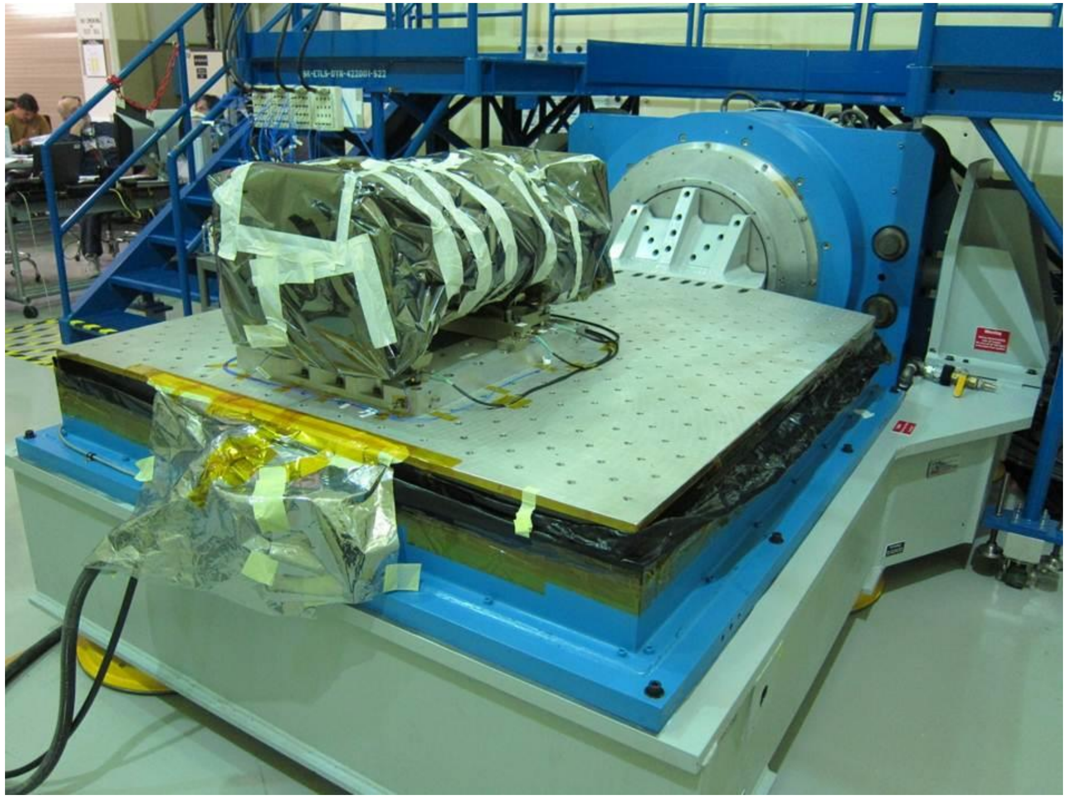
Random vibrations

- Steady-state non-deterministic dynamic motion
- Examples of random vibrations:
  - Uneven road or track exciting a vehicle
  - Wind load
  - Rocket motor ignition
  - Vibration testing
    - Probably the most common case
  - Random excitation from a supporting structure
    - Provided as spectra in a number of attachment points
    - Piping system in a building



Vibration Testing

- Pseudo-random vibration:
  - Time history with required spectral properties
- Usually three directions tested independently
- Prediction by analysis reduces the probability of failure



GOES-R SUVI Undergoes Vibration Testing

PHOTO CREDIT: Lockheed Martin

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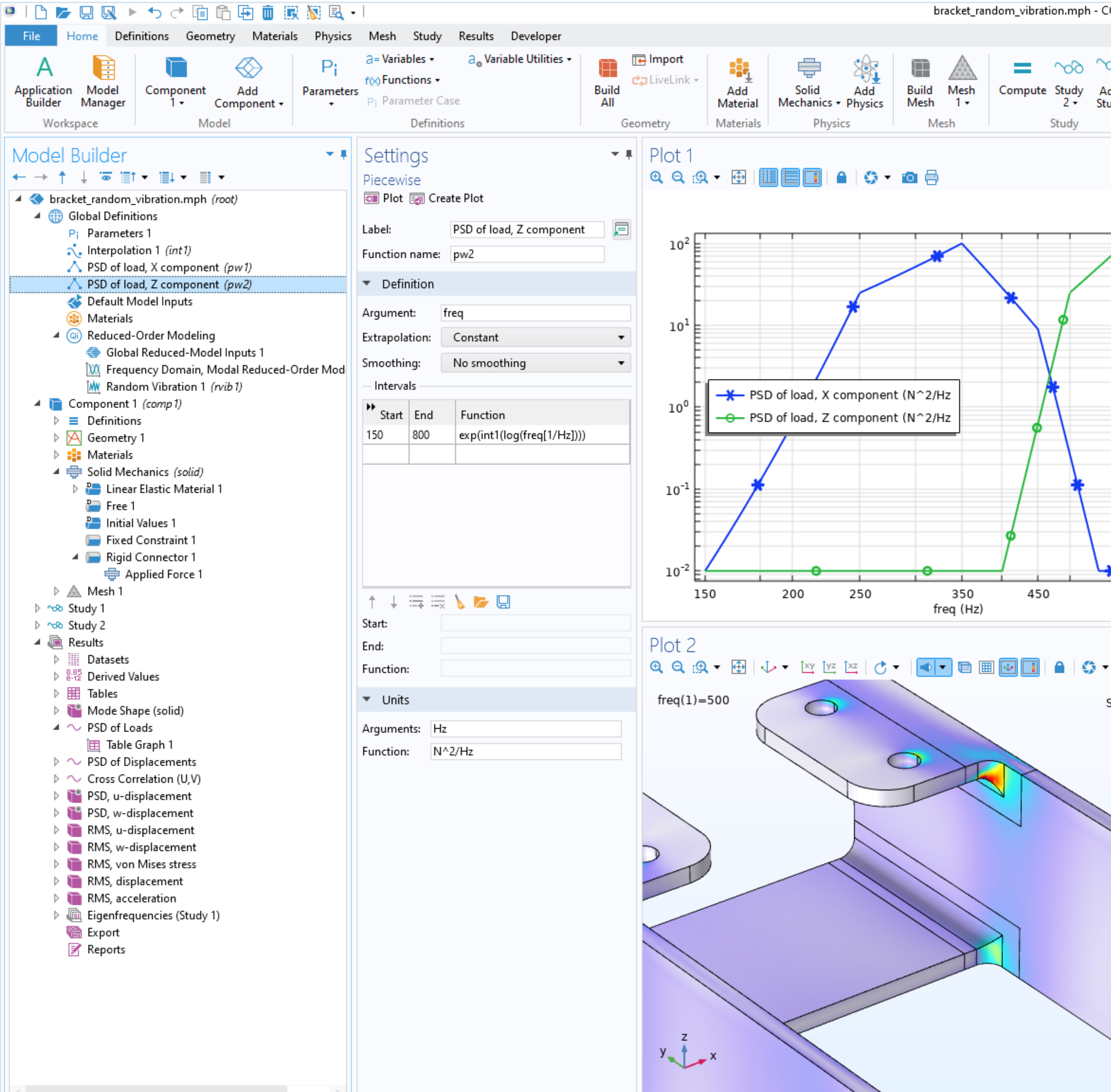
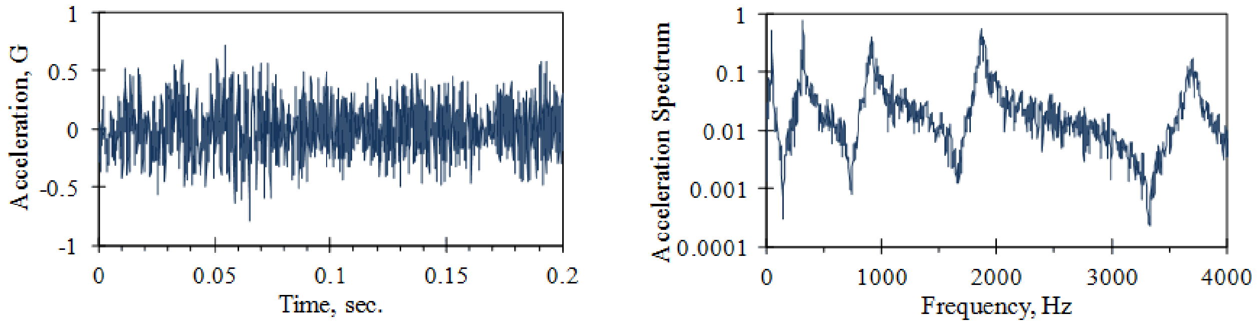
Random Vibration in COMSOL Multiphysics

- Based on the reduced-order model (ROM) framework
  - Mode superposition
  - Uses transfer functions to compute output PSD from input PSD
- Input is PSD as functions:
  - Depends on frequency
  - No spatial dependency
  - Different PSD can be applied for different loads
  - Any type of loading (forces, pressure, acceleration)
- Results
  - RMS value
  - PSD and Cross-correlation



Power Spectral Density (PSD)

- Describes how signal energy (e.g. acceleration) is distributed across frequencies
- How to obtain PSD?
  - Measure acceleration and window the data
  - Compute FFT and square magnitude
  - Normalize to get PSD



Source: https://vru.vibrationresearch.com/wp-content/uploads/2018/08/why-spectral-figure1.png

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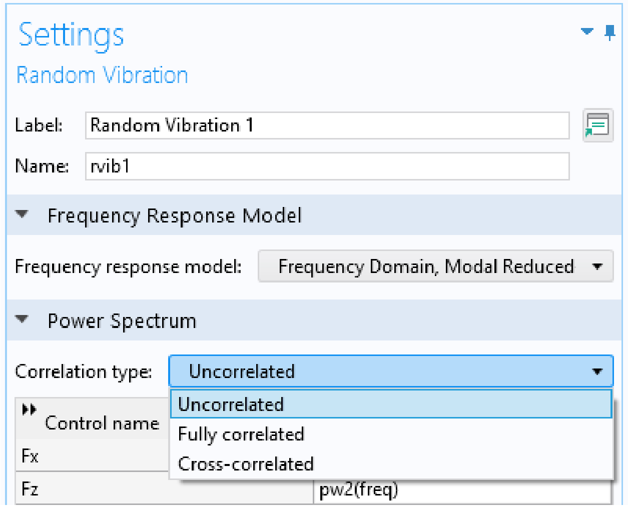
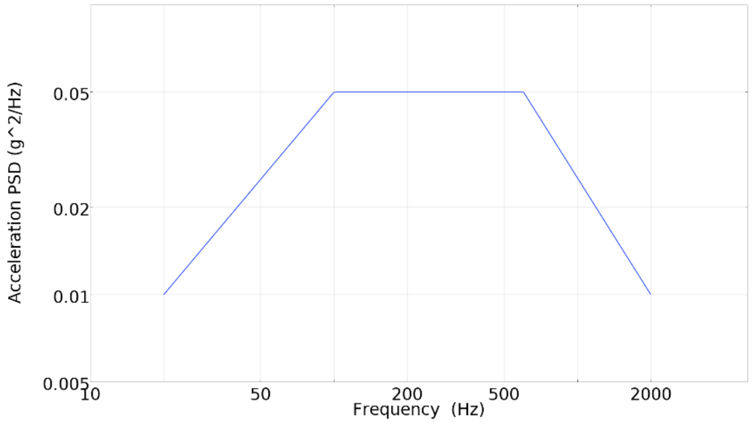
Input Data for Random Vibrations

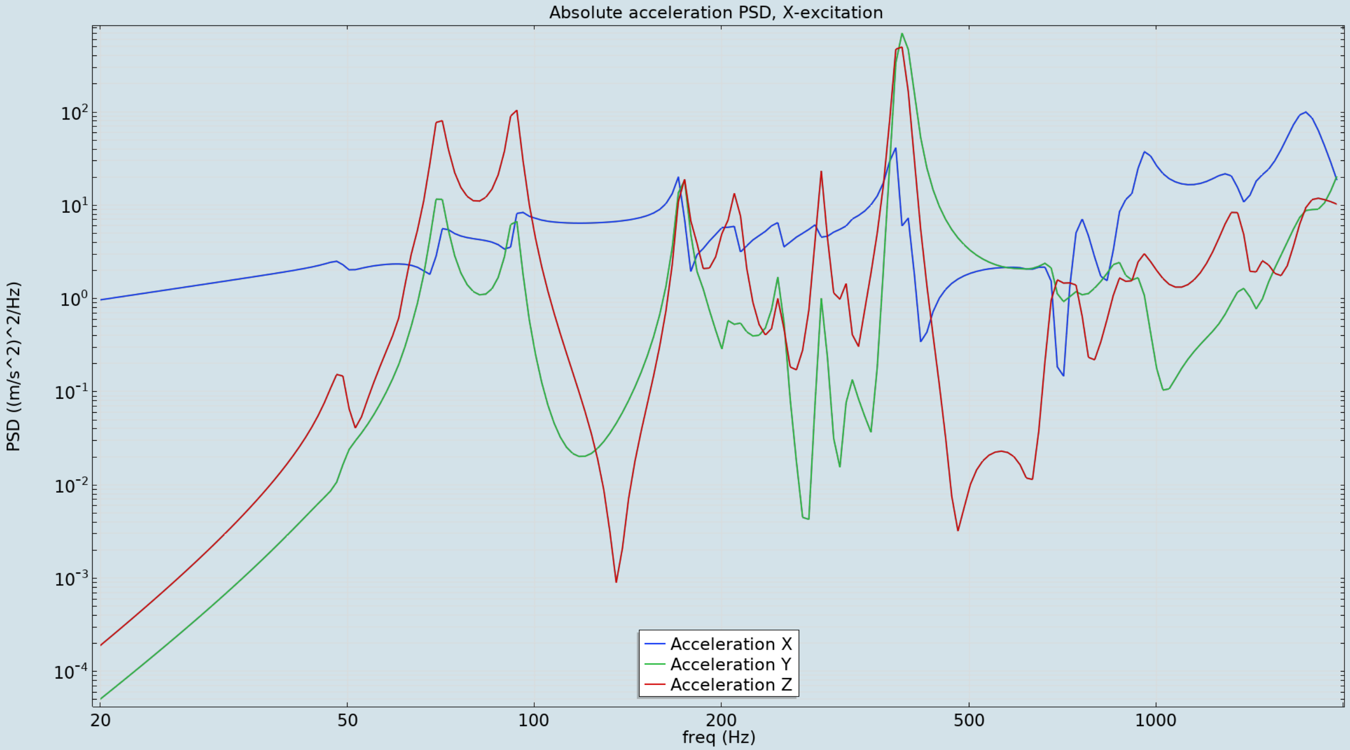
- Power spectral density (PSD) describes excitation:
  - Force: N^2/Hz
  - Pressure: $(N/m^2)^2$/Hz
  - Acceleration: g^2/Hz or $(m/s^2)^2$/Hz
- With several excitations, correlation is also needed:
  - Uncorrelated
    - Two drilling machines in a building
  - Fully correlated
    - Two vector components of the same random load
  - Cross correlated; the correlation spectral densities must also be given





Results

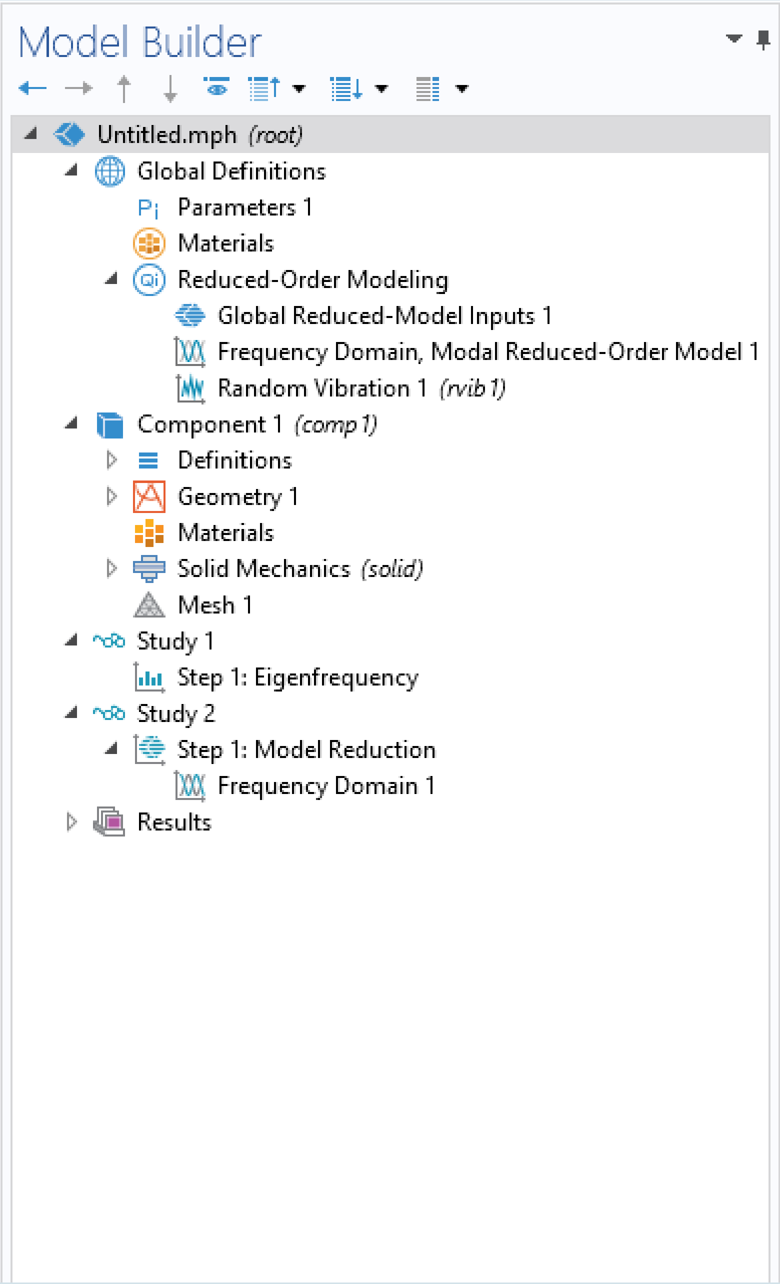
- RMS
  - Integration of the output PSD over frequency
  - Any linear quantity can be evaluated
- Peak Value
  - Not given by the theory
  - Often assumed to be 3 or 4 times RMS
- PSD
  - The PSD of any linear quantity can be evaluated
- Cross-correlation
  - Cross-correlation between any two linear quantities can be evaluated



Random Vibration Study

The *Random Vibration (PSD)* study adds five nodes:

- Two studies:
  - *Eigenfrequency*
  - *Model Reduction*
- Under *Global Definitions > Reduced-Order Modeling*:
  - *Global Reduced-Model Inputs*
  - *Frequency Domain, Modal Reduced-Order Model*
  - *Random Vibration*

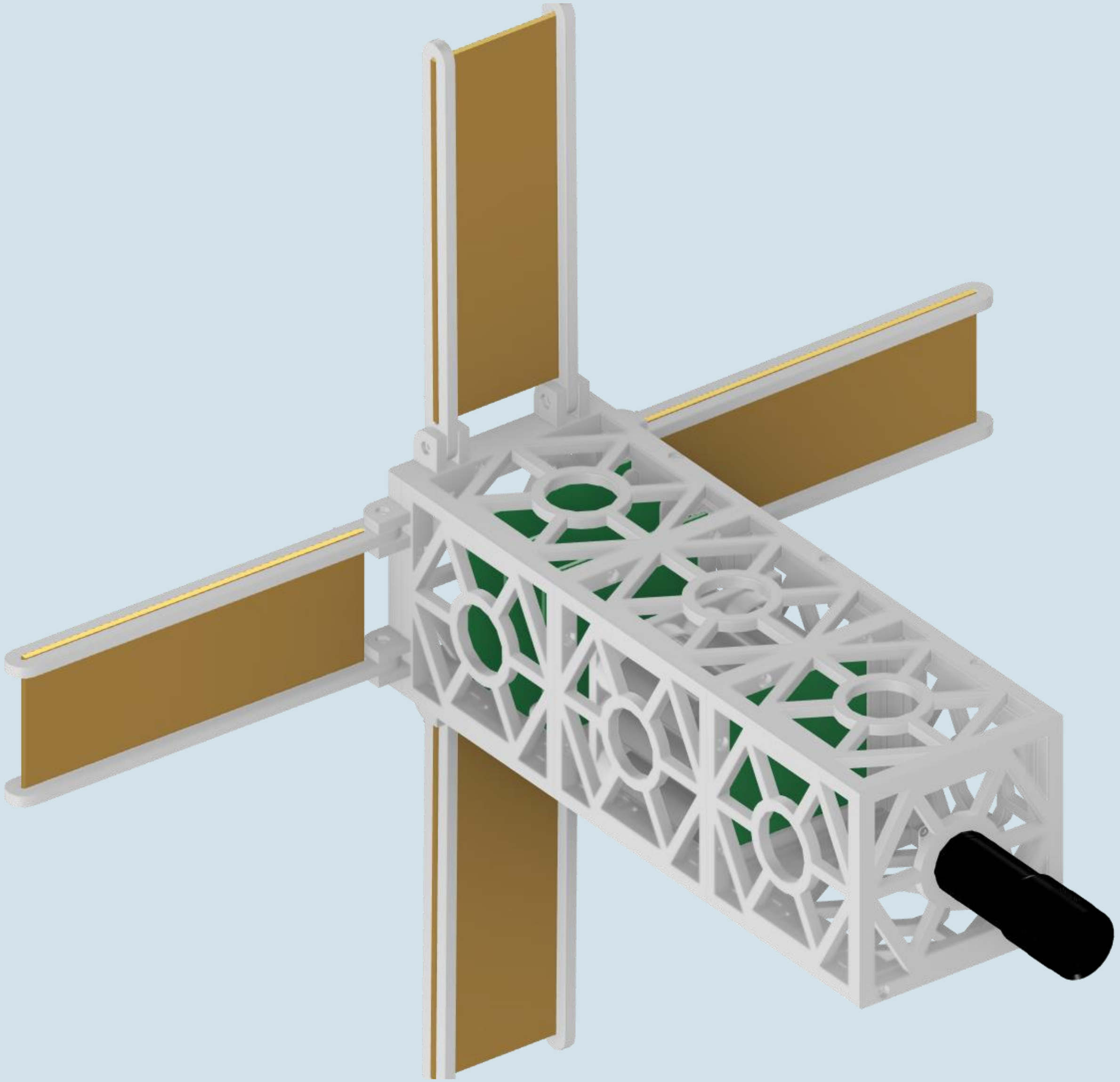


Random Vibration – Modeling Summary

1. Linear model is required
2. Contact pairs are not allowed
   - Replace with *Rigid Connectors* or *Identity Pairs*
3. Eigenfrequency study
   - Disable damping
   - Ensure sufficient number of modes to cover the frequency range of interest.
4. Results
   - RMS
     - Integration of the output PSD over frequency
   - Peak value is often assumed to be 3 or 4 times RMS

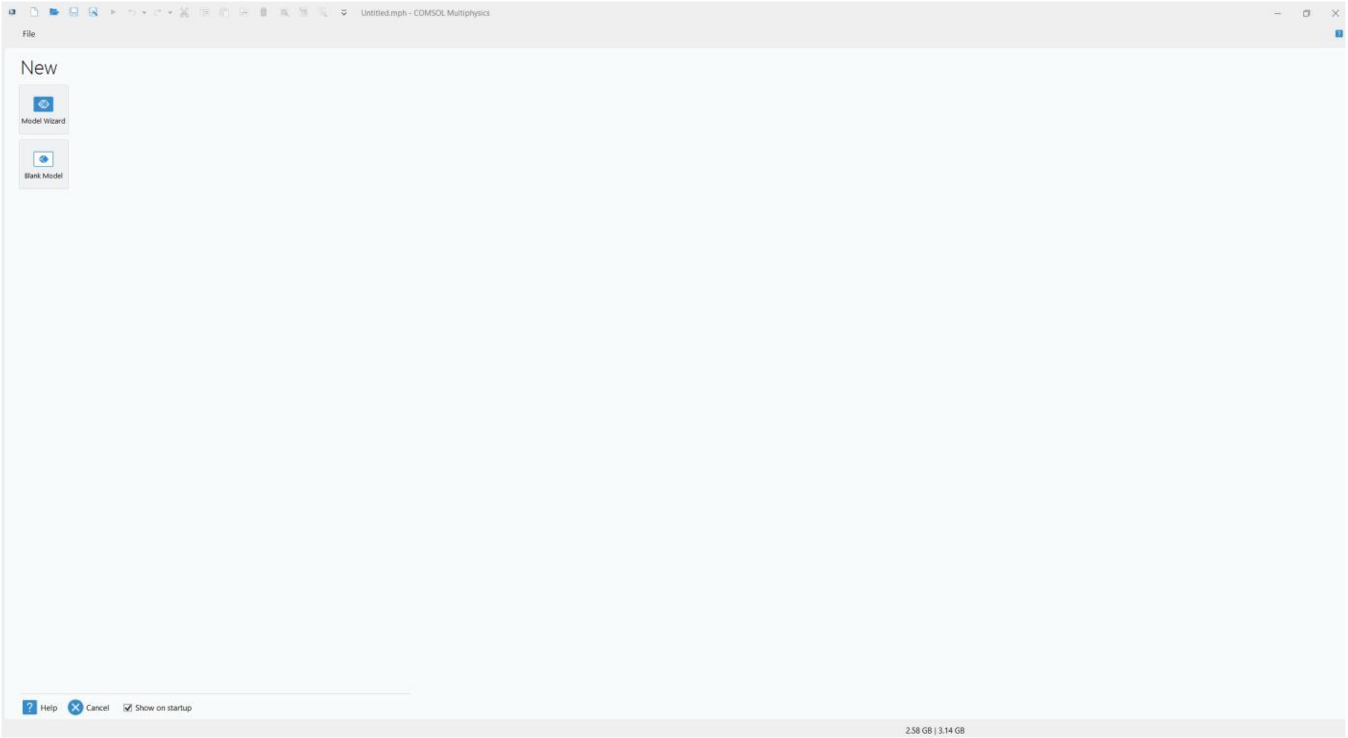
Random Vibrations Showcase Setup

- Random vibrations testing
- Vibrations in all three directions
- Input: Power spectral density of acceleration
- Outputs: RMS of acceleration



Showcase: Geometry Preprocessing

- Removal of small details
  - Small surfaces
  - Holes
  - Radii
- Domain removal
  - Camera PCB
  - Replacement by mass at the centre of gravity



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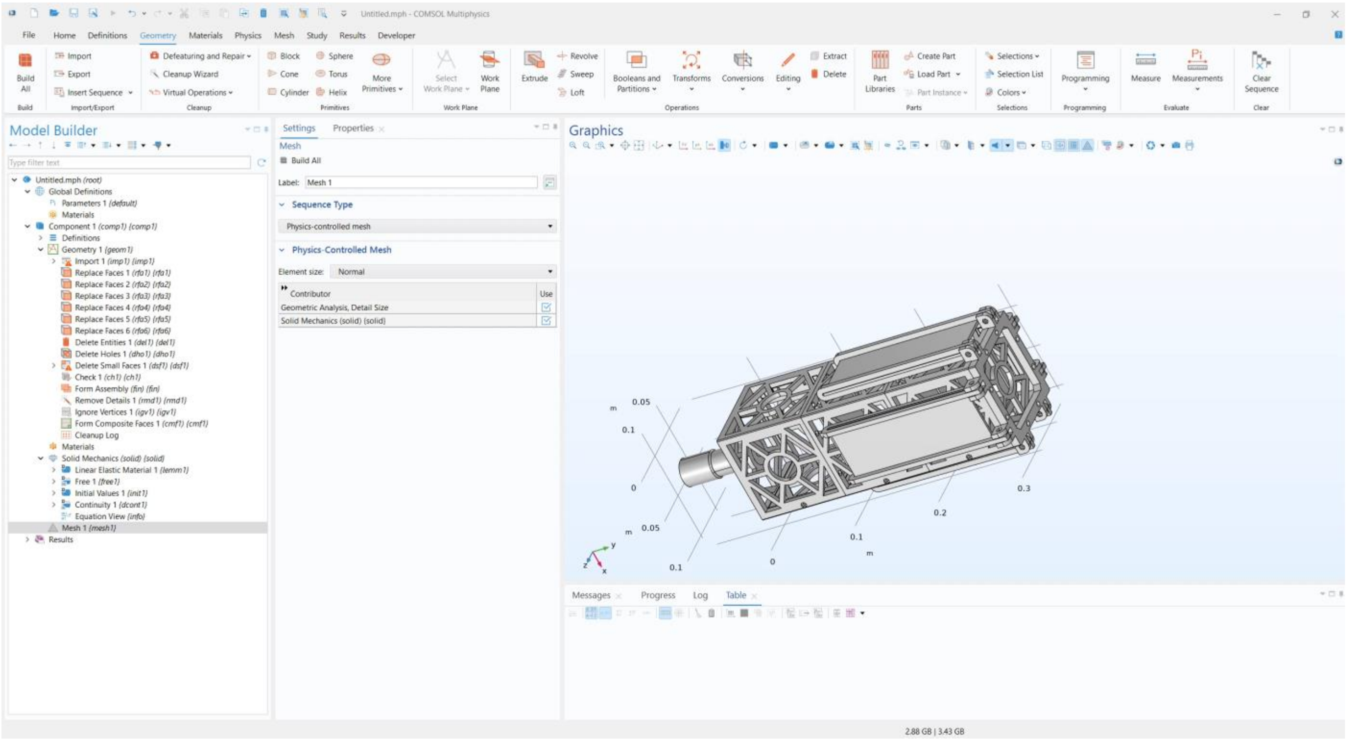
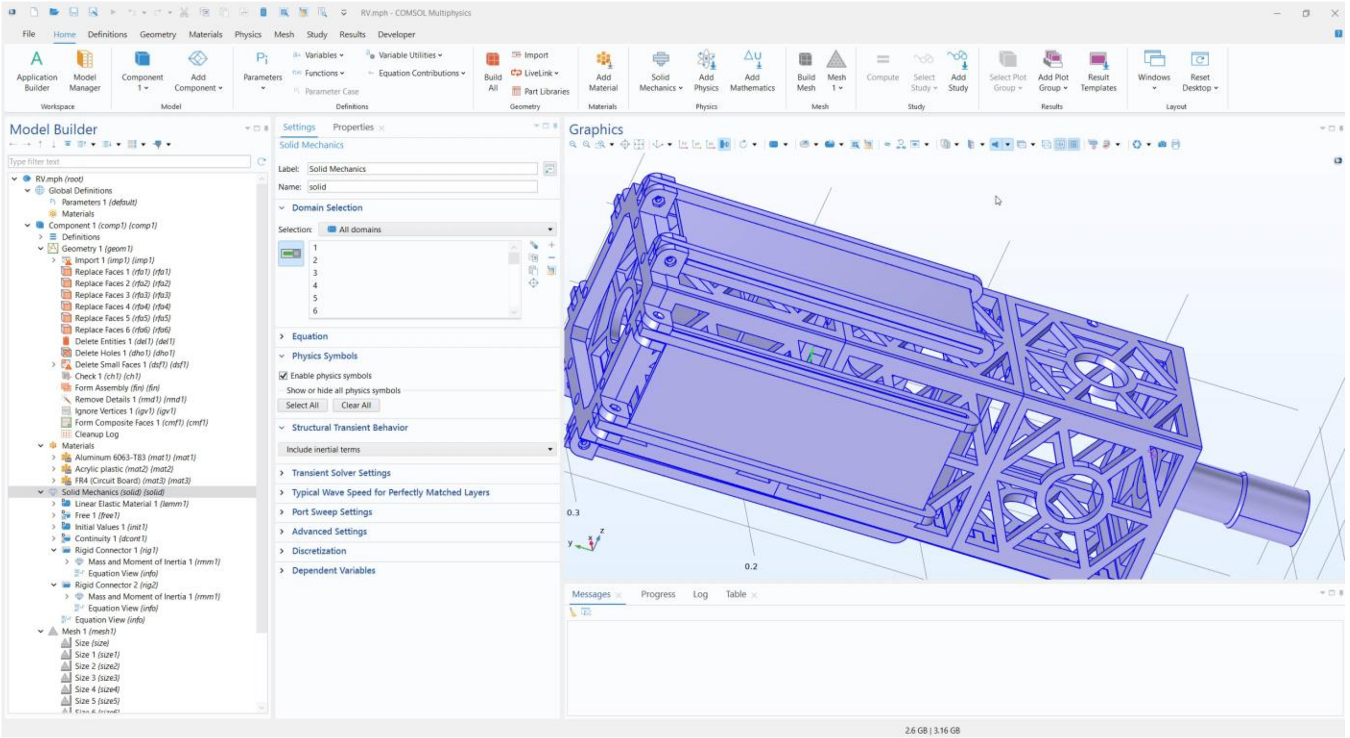
Showcase:
Mesh, Material and Physics

- Hybrid Mesh
  - Swept mesh on solar panels
- Materials
  - Aluminum, FR4, plastic
- Solid Mechanics
  - Rigid Connector – Mass
    - Camera PCB
    - Batteries + holder



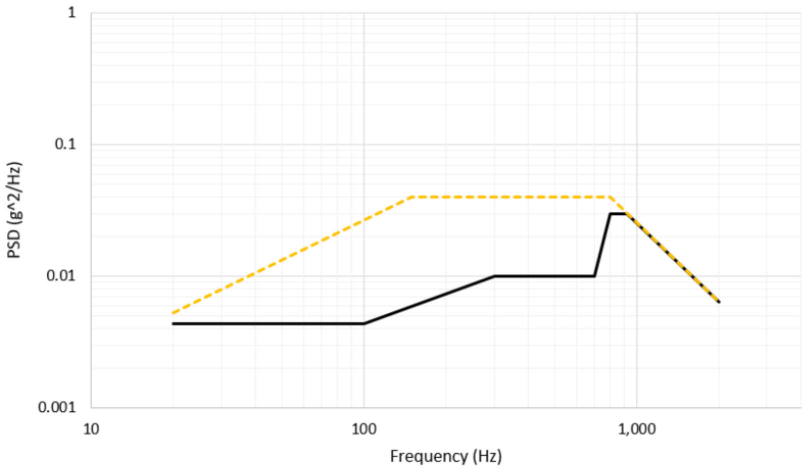
Showcase: Physics

- Solid Mechanics
  - Rigid Connector – Mass
    - Camera PCB
    - Batteries + holder
  - Rigid Connector – External Connection
    - Prescribed displacement and rotation
  - Base Excitation – for RV
  - Material Damping

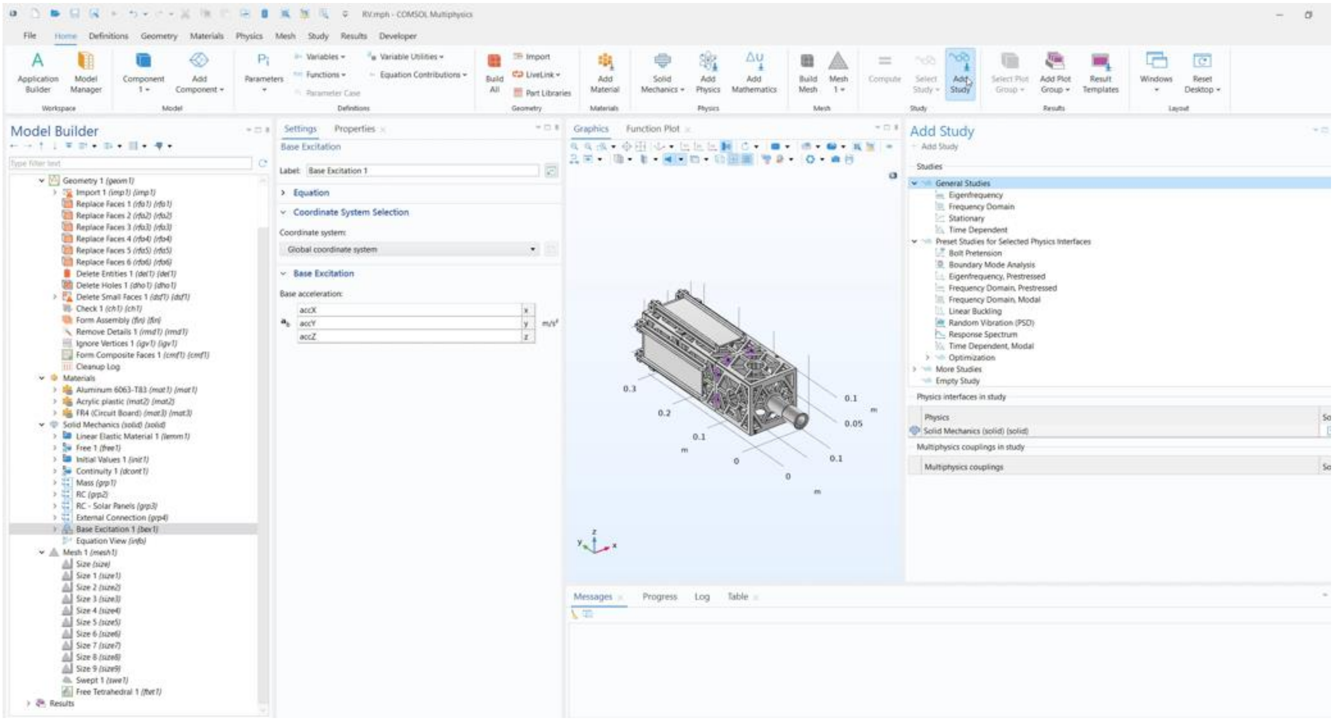


Showcase: Random Vibration and Postprocessing

- Random vibration
  - PSD curve - input
  - ROM – model reduction
  - ROM – random vibration in x, y, z



Source: https://www.spacex.com/media/falcon-users-guide-2021-09.pdf



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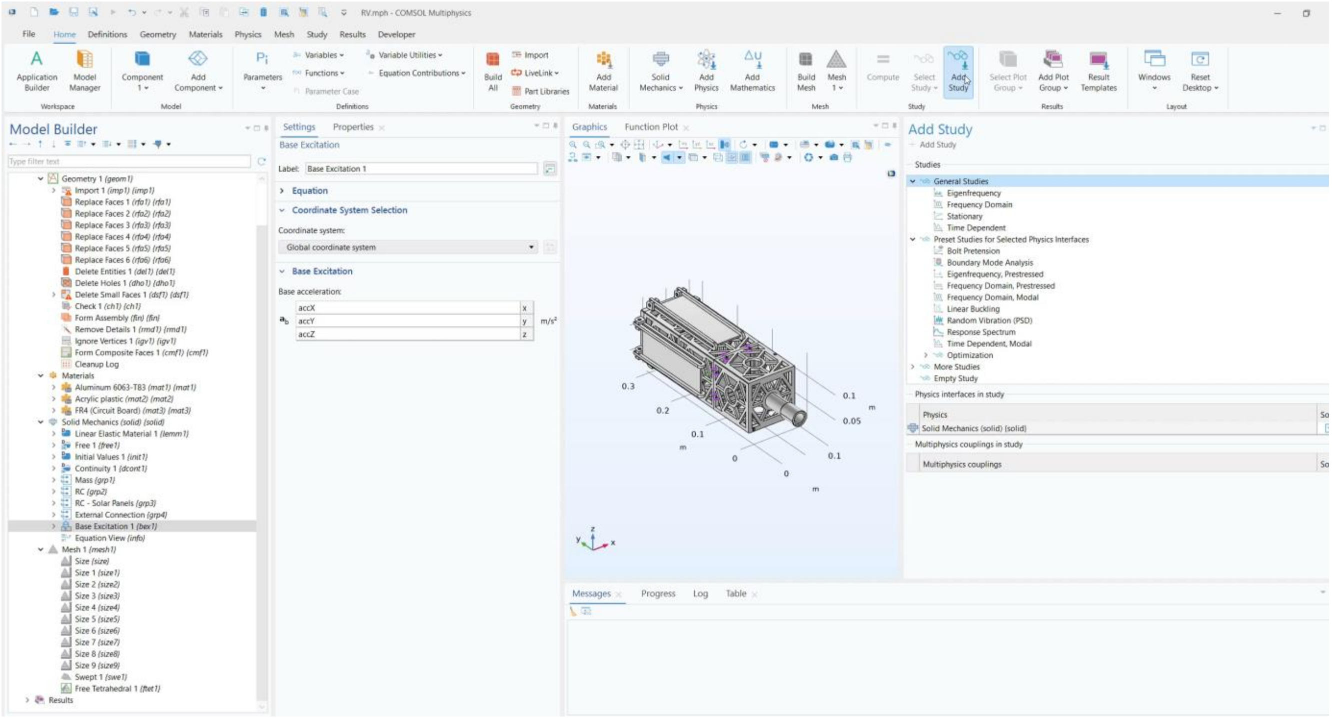
Showcase: Random Vibration and Postprocessing

- Random vibration
  - RV input – Power Spectral Density
  - ROM – model reduction
  - ROM – random vibration in x, y, z
- Postprocessing
  - RMS absolute acceleration
  - Acceleration PSD at critical point



Questions?

Thank you for your attention
30 min break, we continue at 17:00!