Random Vibrations in COMSOL Multiphysics



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Schedule

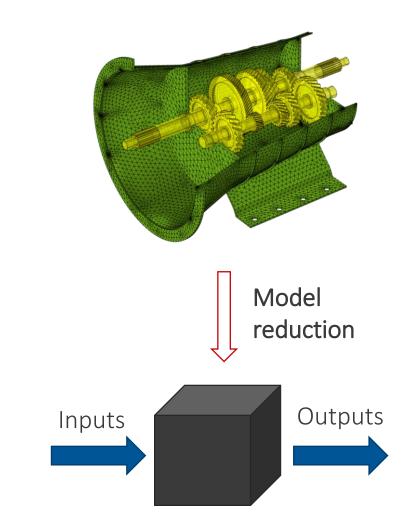
- 1. Reduced-Order Modeling
- 2. Random Vibrations
- 3. Random Vibrations Showcase
- 4. Discussion

Reduced-Order Modeling

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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)

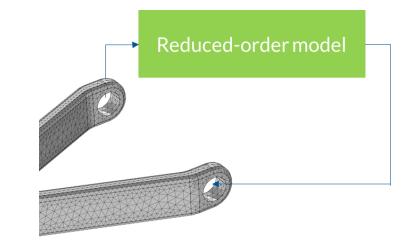


Reduced-Order Models

- 1. A ROM can be used standalone (in OD 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

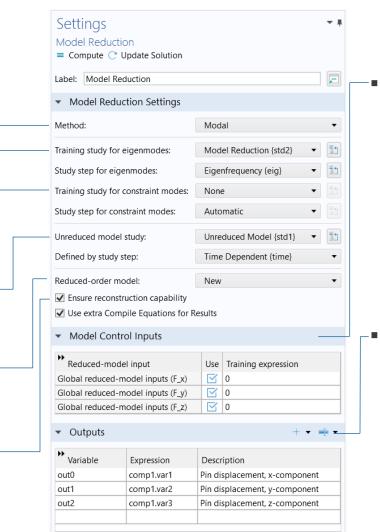
- Predefined studies for some physics interfaces
 - Frequency Domain, Modal Reduced-Order Model
 - Frequency Domain, AWE Reduced-Order Model
 - Time Dependent, Modal Reduced-Order Model
 - Random Vibration (PSD)
- Can be added to any study
 - Requires the *Reduced-Order Modeling* preference to be set

> 🔚 Free = Compute F8 ✓ № Preset Studies for Selected Physics Interfaces > 🔚 Initia Parametric Sweep 🛃 Bolt Pretension ∰f Equat Mesh 1 {r Function Sweep Boundary Mode Analysis ✓ ™ Study 1 {std1 Material Sweep Eigenfrequency, Prestressed 🖳 Step 1: Ti Study Reference Solver Co Frequency Domain, Prestressed 🚽 Job Confi Combine Solutions 🔍 Frequency Domain, Modal ✓ ™ Study 2 {std2 Optimization Linear Buckling Solver Co Sensitivity 🛃 Job Confi 🗮 Random Vibration (PSD) > 🖲 Results Model Reduction 📐 Response Spectrum Surrogate Model Training 🔼 Time Dependent, Modal Uncertainty Quantification > 🔊 Optimization Study Steps ✓ ∞ More Studies 🞬 Frequency Domain, Prestressed, Modal S Frequency Domain, AWE Reduced-Order Model Model Builder 💹 Frequency Domain, Modal Reduced-Order Model ← → ↑ Le Time Dependent, Modal Reduced-Order Model Type filter Show More Options Physics Reduced-Order Modeling ✓ △ U Equation Sections Equation View Stabilization Reduced models are online reduced-order representations of a full Equation-Based Contributions COMSOL Multiphysics model. Extra Dimensions Advanced Physics Options a= Show All Variables Study Batch and Cluster Sensitivity Multigrid Level Reduced-Order Modeling Solver and Job Configurations Results Views Branches: Global Definitions, Studies Color Tables All Dataset Types All Plot Types All Numerical Evaluation Types All Export Types Select All 📁 Reset to Default

OK

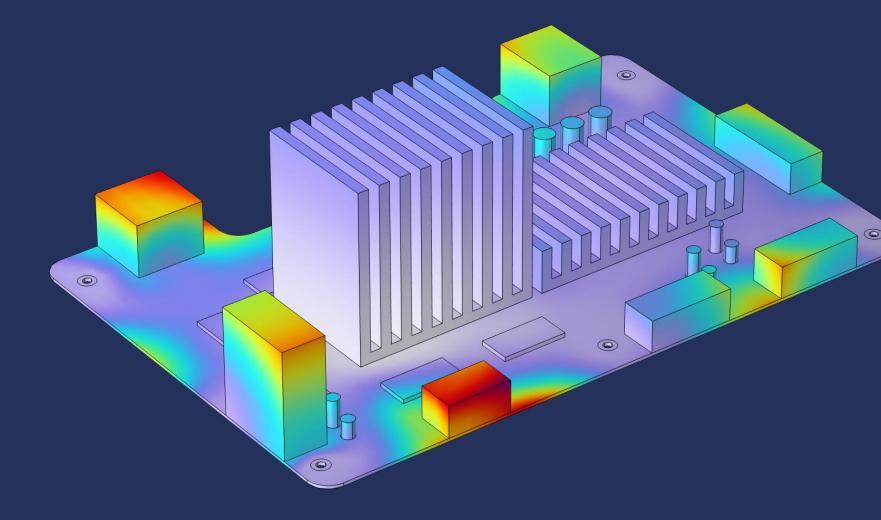
Model Reduction Study Step

- 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.



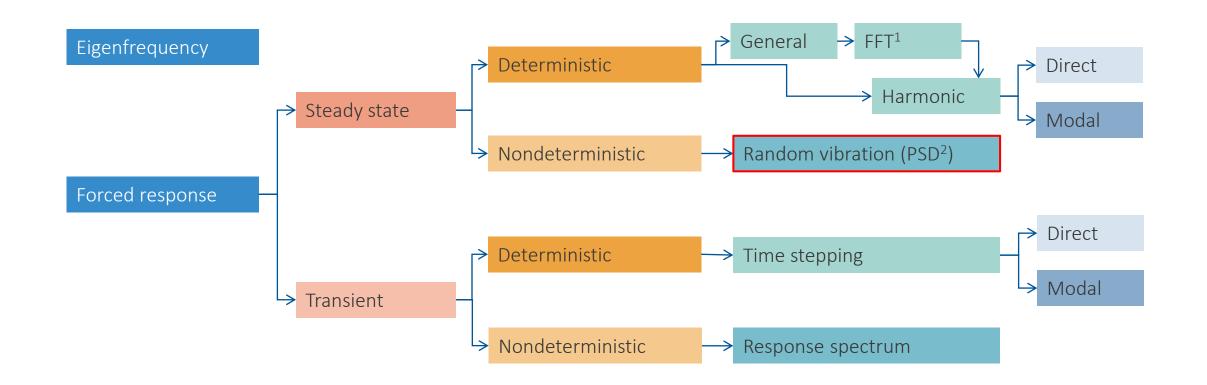
- Model Control Inputs
 - Defined in a Global Reduced Model Inputs node
 - Use the check box if some are not needed

- Outputs
 - Add any global expression
 - Use probes, integration, operators, etc.
 - Become global variables in calling model



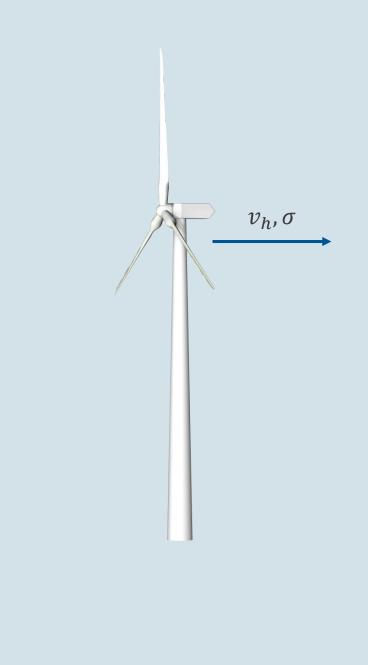
Random Vibrations

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

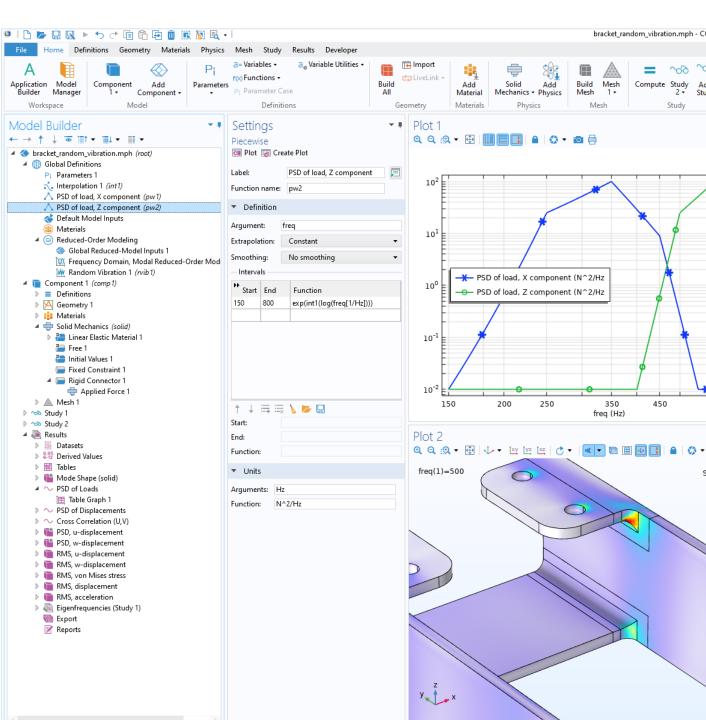


GOES-R SUVI Undergoes Vibration Testing

PHOTO CREDIT: Lockheed Martin

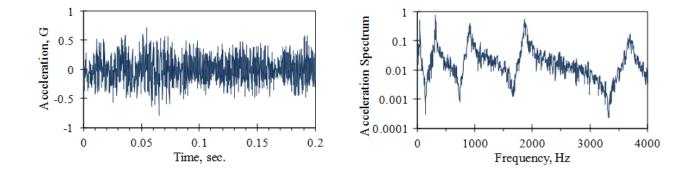
Random Vibration in COMSOL Multiphysics

- 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



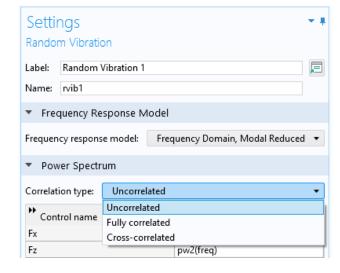
Power Spectral Density (PSD)

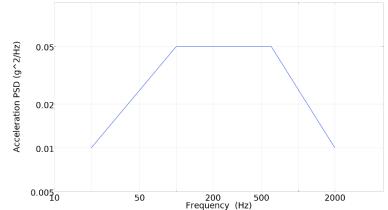
- Describes how signal energy (e.g. acceleration) is distributed across frequencies
- How to obtain PSD?
 - Measure acceleration and window the data
 - Compute FFT and square magnitude
 - Normalize to get PSD



Input Data for Random Vibrations

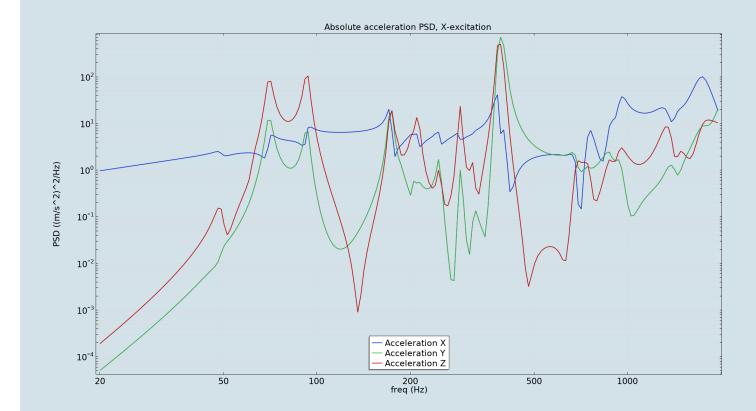
- Power spectral density (PSD) describes excitation:
 - Force: N²/Hz
 - Pressure: $(N/m^2)^2/Hz$
 - Acceleration: g²/Hz or (m/s²) ²/Hz
- With several excitations, correlation is also needed:
 - Uncorrelated
 - Two drilling machines in a building
 - Fully correlated
 - Two vector components of the same 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

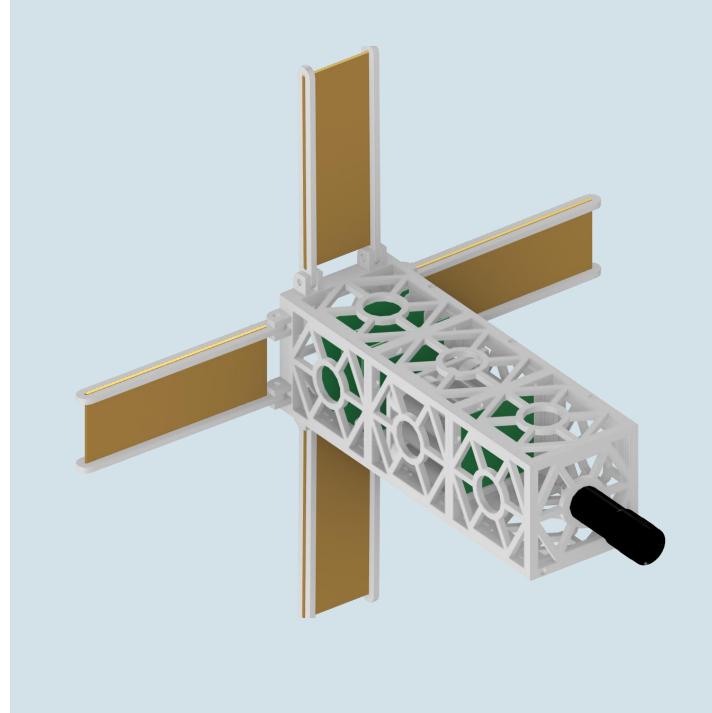
Model Builder
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🔺 🌐 Global Definitions
Pi Parameters 1
(iii) Materials
🔺 回 Reduced-Order Modeling
Global Reduced-Model Inputs 1
🕅 Frequency Domain, Modal Reduced-Order Model 1
🗽 Random Vibration 1 (rvib1)
A T Component 1 (comp 1)
Definitions
Geometry 1
Materials
Solid Mechanics (solid)
\land Mesh 1
▲ 🗠 Study 1
step 1: Eigenfrequency
▲ ¹
Step 1: Model Reduction
Frequency Domain 1
Results

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



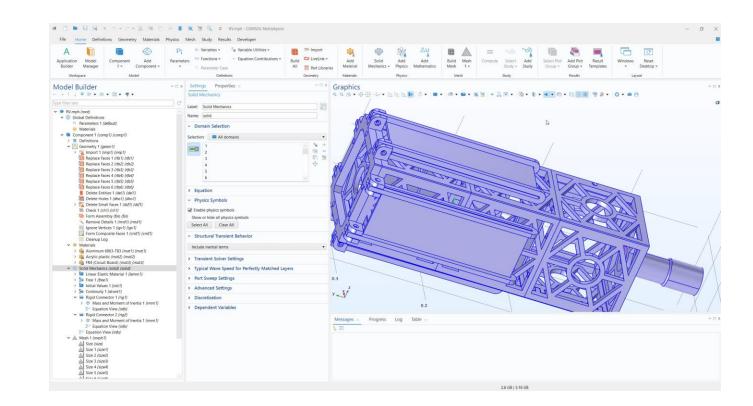
Showcase: Mesh, Material and Physics

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

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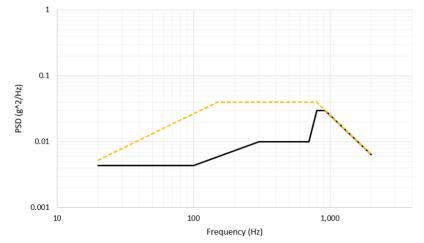
Showcase: Physics

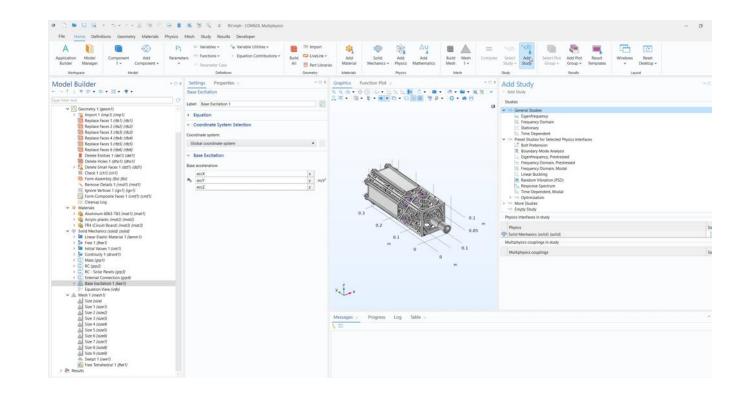
- Solid Mechanics
 - Rigid Connector Mass
 - Camera PCB
 - Batteries + holder
 - Rigid Connector External Connection
 - Prescribed displacement and rotation
 - Base Excitation for RV
 - Material Damping



Showcase: Random Vibration and Postprocessing

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

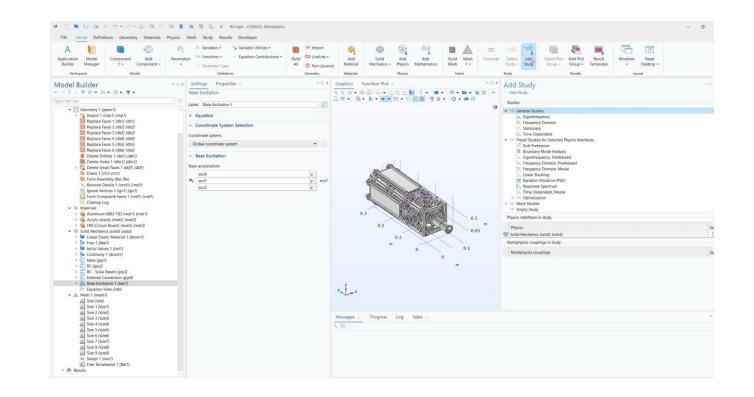




Source: https://www.spacex.com/media/falcon-users-guide-2021-09.pdf

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!