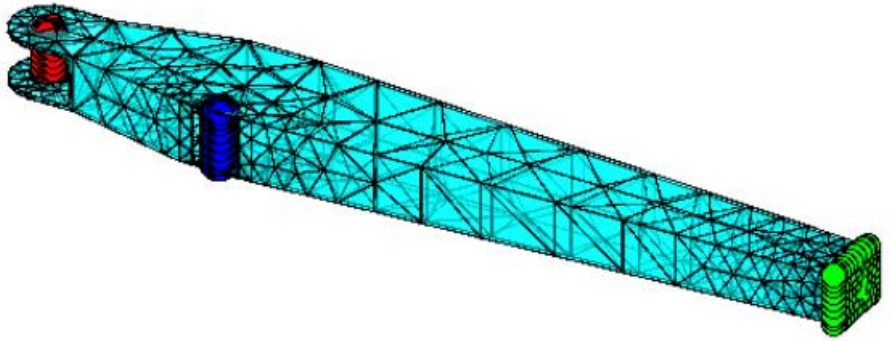
Accelerate System-Level Simulation with Reduced Order Models (ROMs) of Flexible Bodies



Chyannie Fahdzyana, Senior Application Engineer
Jens Lerche, Principal Application Engineer

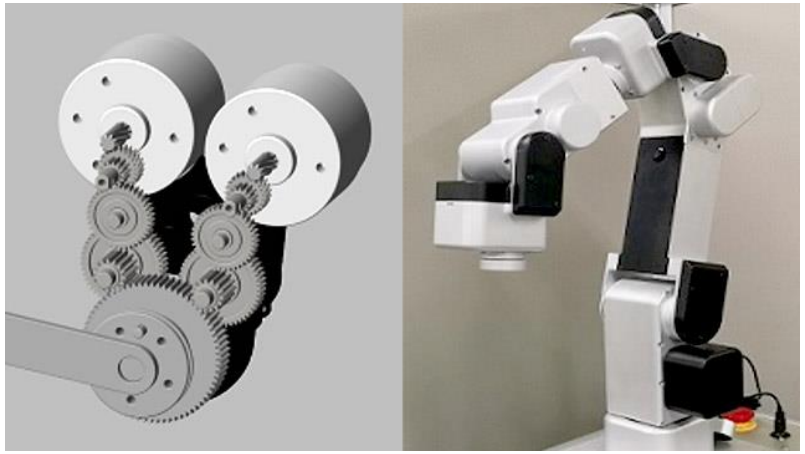
Agenda

1. Introduction to Reduced Order Model (ROM)
2. Creating ROMS in MATLAB
3. Demo – creating a ROM using MATLAB Script
4. Flexible Bodies in Simscape Multibody
5. Importing ROMs from external sources into Simscape
6. Demo – creating a ROM using Flexible Body Builder App
7. Demo – running a Simulink Simulation with a ROM

Agenda

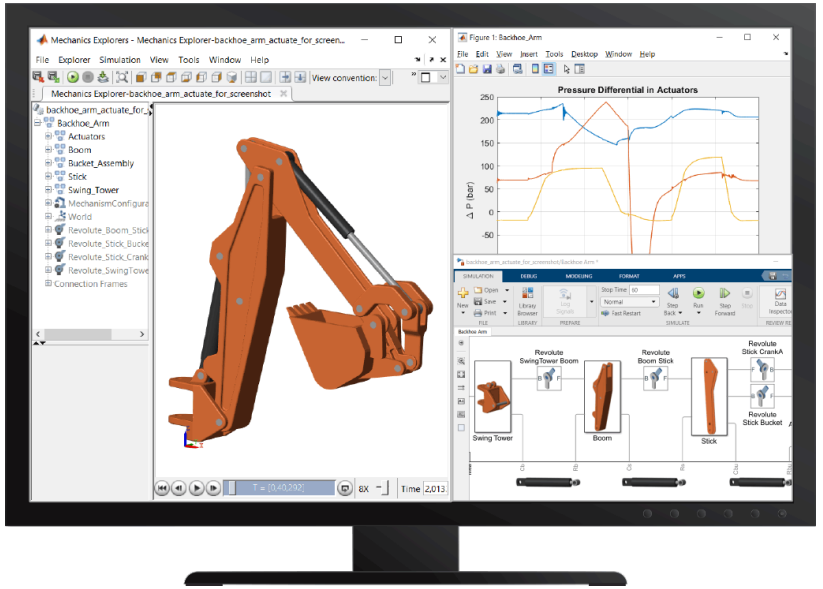
1. What is a Reduced Order Model (ROM)
2. Creating ROM's in MATLAB
3. How to reduce model order using a Craig Bempton Approach
4. Demo – creating a ROM using MATLAB Script
5. Flexible Bodies in Simscape Multibody
6. Importing ROM's from external sources into Simscape
7. Demo – creating a ROM using Flexible Body Builder App
8. Demo – running a Simulink Simulation with a ROM

Flexible Body Modeling



- Many engineering applications require flexible body modeling
- High fidelity, complex models

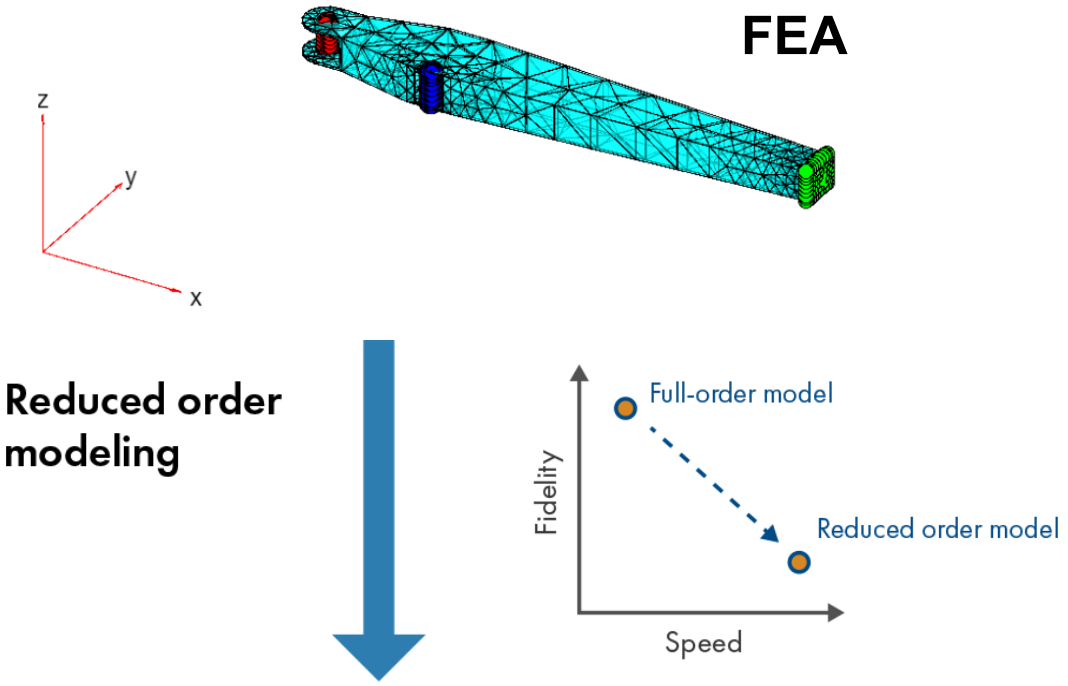
Reduced Order Model



Reduced Order Modeling

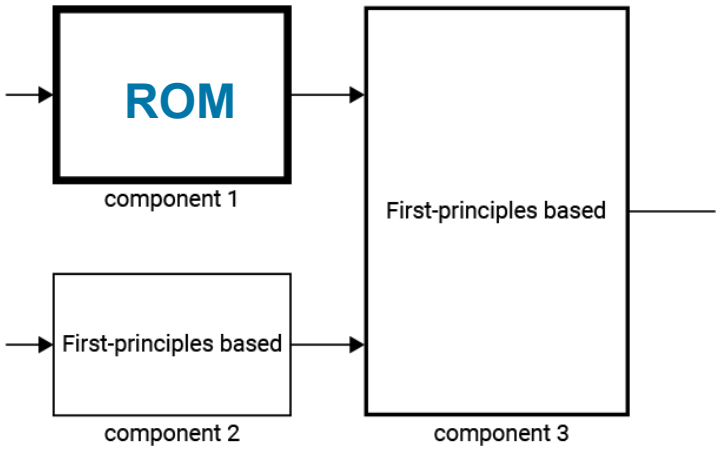
What

- Techniques to **reduce the computational complexity** of a computer model
- **Provide reduced, but acceptable fidelity**



Why

- Enable simulation of FEA models in Simulink
- Perform hardware-in-the-loop testing
- Perform control design
- Develop virtual sensors, Digital twins
- Enable desktop simulations for orders-of-magnitude longer timescales

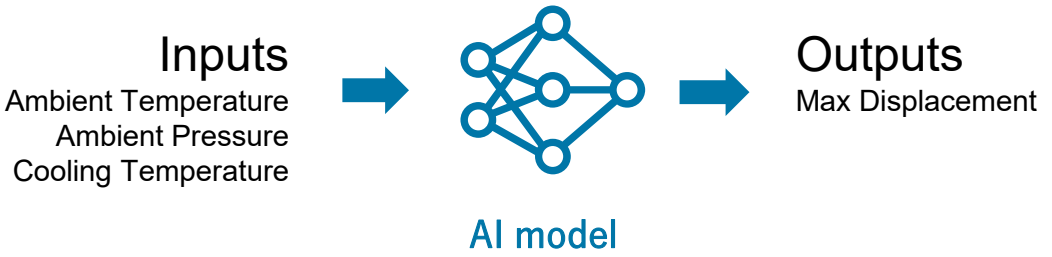


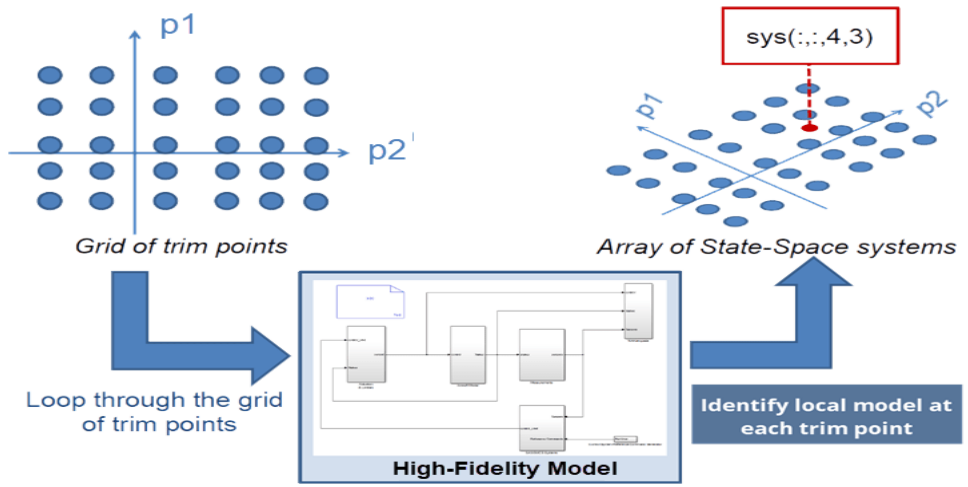
Reduced Order Modeling

How

Reduced order model

- **AI-Based Data-driven**
- **Linearization**
- **Model-based**





FEA Software → **Simulink**
Simscape Multibody
Control System Toolbox

focus today

Agenda

1. What is a Reduced Order Model (ROM)
2. Creating ROM's in MATLAB
3. How to reduce model order using a Craig Bempton Approach
4. Demo – creating a ROM using MATLAB Script
5. Flexible Bodies in Simscape Multibody
6. Importing ROM's from external sources into Simscape
7. Demo – creating a ROM using Flexible Body Builder App
8. Demo – running a Simulink Simulation with a ROM

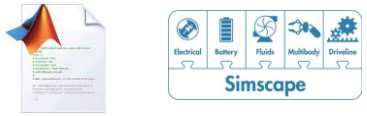
ROM Workflow in MATLAB/Simulink Environment

Import a CAD geometry into MATLAB/Simulink

.STL, from 3rd party FEM tool, etc.

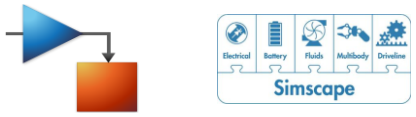
Create Reduced Order Model

MATLAB or Simscape



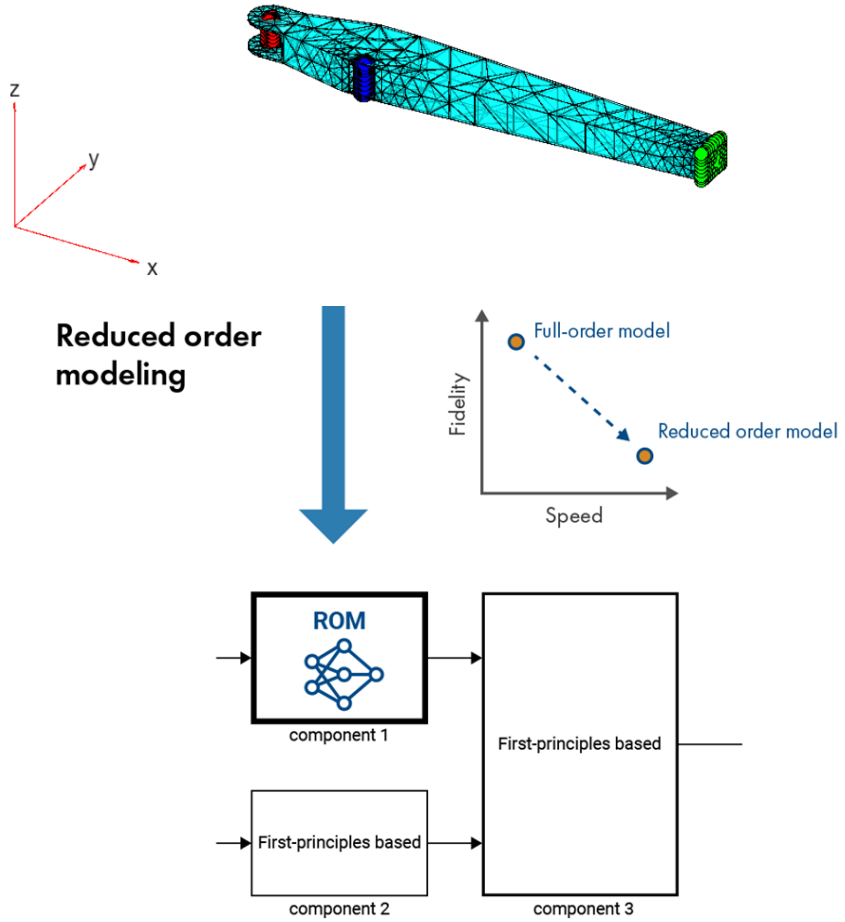
Integrate Reduced Order Model in System Simulation and Analysis

MATLAB, Simulink, or Simscape



Model Order Reduction with Craig-Bampton Method

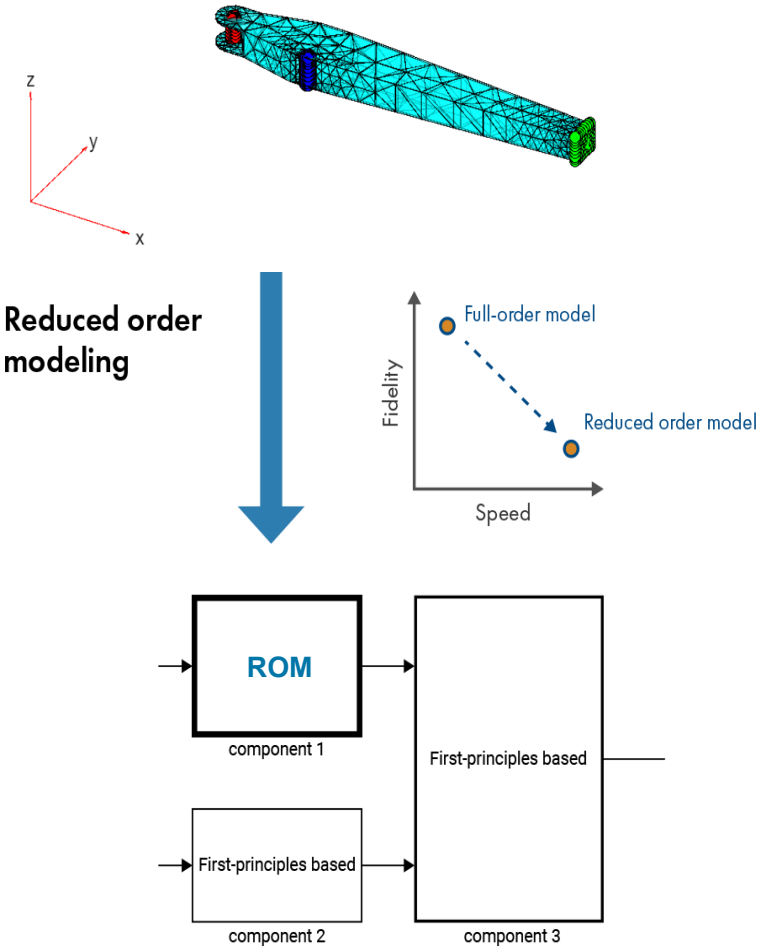
- A substructuring technique to reduce complexity of a structural model
- Returns the stiffness matrix, mass matrix, and position coordinates



Resources: https://www.mathworks.com/content/dam/mathworks/tag-team/Objects/s/Modeling-Flexible-Bodies-Simscape-Multibody-171122.pdf

ROM with MATLAB Workflow Example: Excavator Arm

- Load a 3D geometry model into MATLAB
- Create mesh of the geometry
- Apply the Craig-Bampton method, and generate a reduced-order model



Agenda

1. What is a Reduced Order Model (ROM)
2. Creating ROM's in MATLAB
3. How to reduce model order using a Craig Bempton Approach
4. Demo – creating a ROM using MATLAB Script
5. Flexible Bodies in Simscape Multibody
6. Importing ROM's from external sources into Simscape
7. Demo – creating a ROM using Flexible Body Builder App
8. Demo – running a Simulink Simulation with a ROM

Agenda

1. What is a Reduced Order Model (ROM)
2. Creating ROM's in MATLAB
3. How to reduce model order using a Craig Bempton Approach
4. Demo – creating a ROM using MATLAB Script
5. Flexible Bodies in Simscape Multibody
6. Importing ROM's from external sources into Simscape
7. Demo – creating a ROM using Flexible Body Builder App
8. Demo – running a Simulink Simulation with a ROM

Simscape Multibody

Flexible Body Modeling

Flexible Beam, Plates Library

Properties calculated from geometrical and material parameters

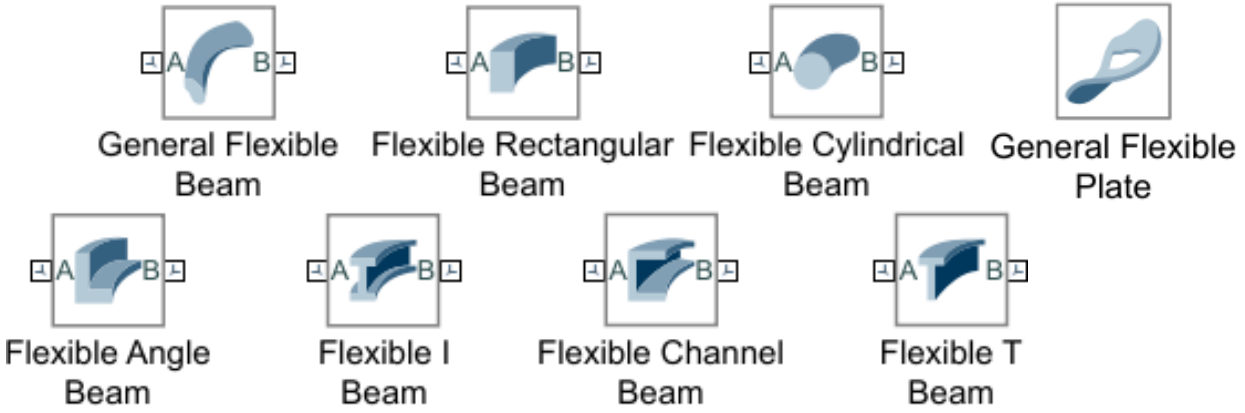
1. Constant cross sections (solid/hollow)
2. Length far exceeds height and width
3. Homogeneous, isotropic, elastic material
4. Connections at beam ends

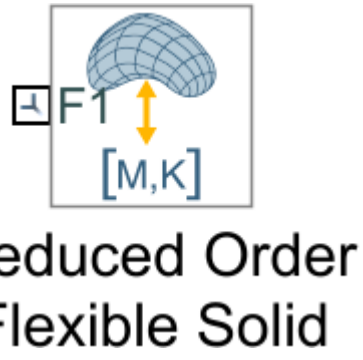
Reduced Order Flexible Solid

Properties obtained from finite element software via static and modal analysis data

1. Any shape
2. Any shape
3. Any elastic material
4. Any set of connection points

Both methods valid only for small, linearly elastic deformations



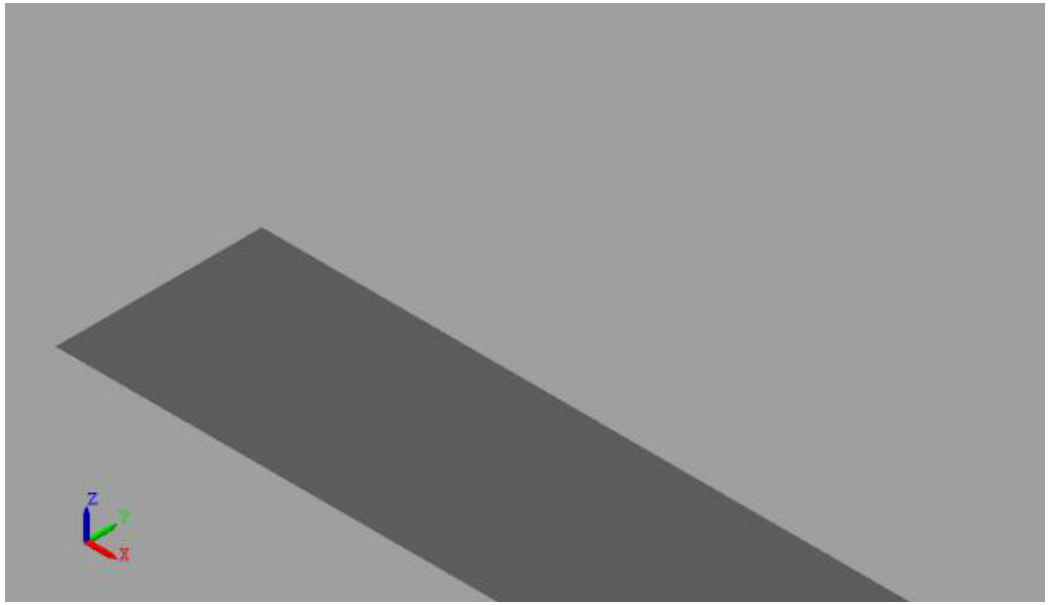


Reduced Order Flexible Solid

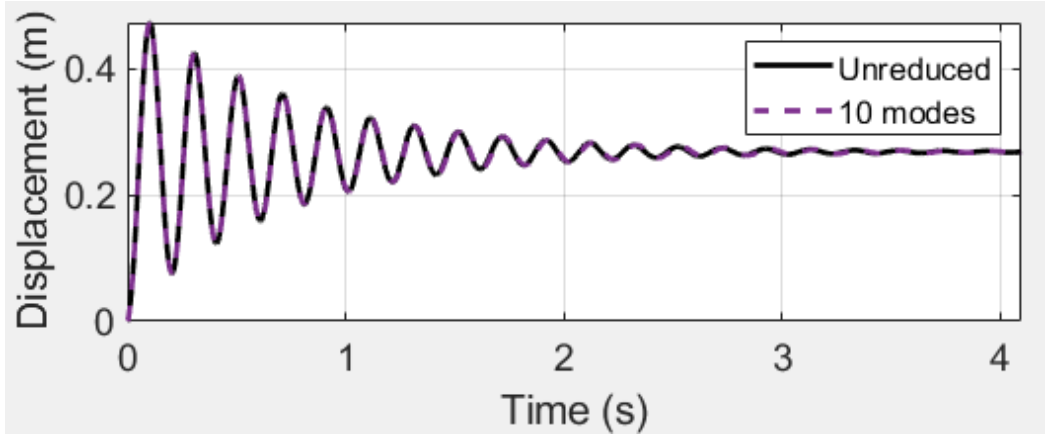
Simscape Multibody

Flexible Body Modal Reduction

- Simplify flexible bodies for faster simulation
  - Users specify the number of low frequency flexible modes to retain
  - Applies to all flexible bodies



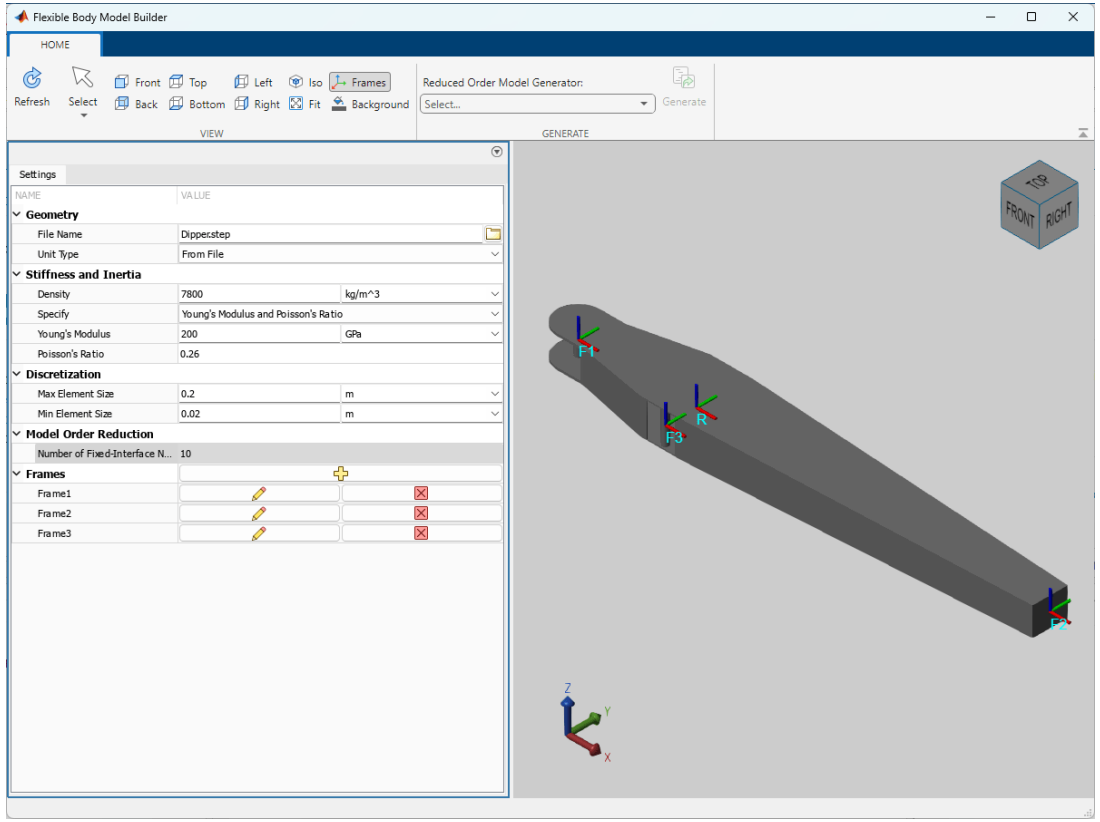
	10 modes	Unreduced
# Nodes	Sim Time (secs)	Sim Time (secs)
42	0.2	23
56	0.2	50
69	0.2	97
194	0.4	1871



Example: Using Modal Reduction in Flexible Bodies to Improve Simulation Performance

Simscape Multibody
Flexible Body Model Builder App

- Set up a flexible body by specifying its geometry, material properties and interface frames
- Create a reduced order model that efficiently captures its deformation characteristics
- Use the generated data in a Simscape Multibody model via the Reduced Order Flexible Solid block

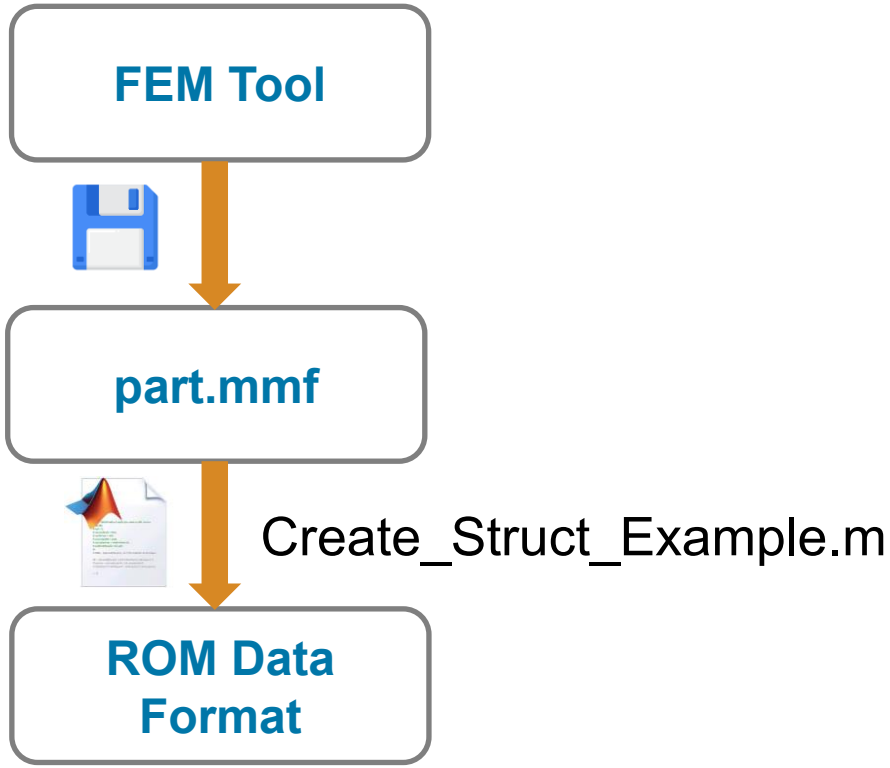


Agenda

1. What is a Reduced Order Model (ROM)
2. Creating ROM's in MATLAB
3. How to reduce model order using a Craig Bempton Approach
4. Demo – creating a ROM using MATLAB Script
5. Flexible Bodies in Simscape Multibody
6. Importing ROM's from external sources into Simscape
7. Demo – creating a ROM using Flexible Body Builder App
8. Demo – running a Simulink Simulation with a ROM

Importing ROM‘s from external Sources

Script to convert FEM Tool neutral files to ROFS Block ROM data format

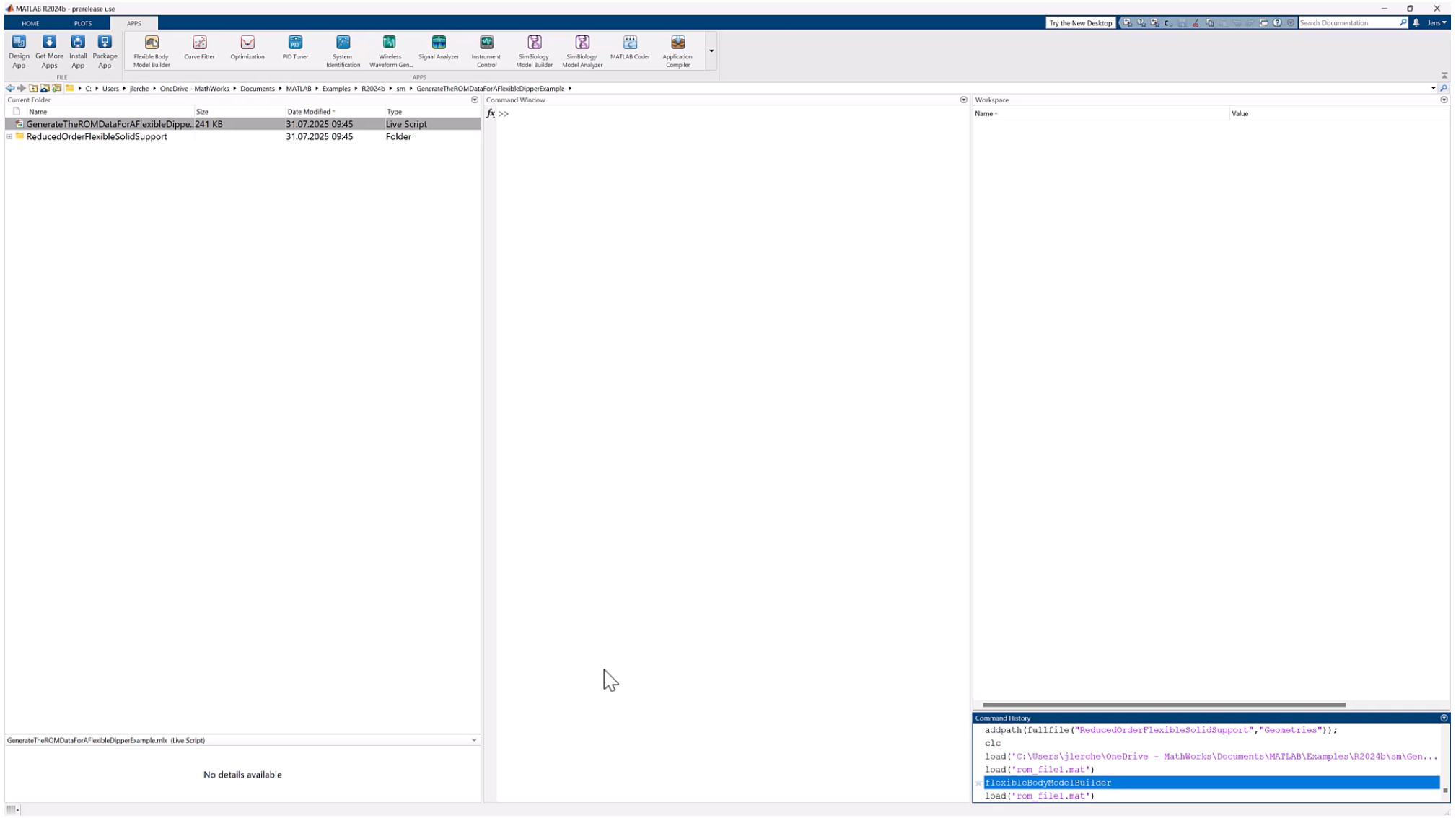


Dr. Jan Janse van Rensburg
Principal Product Specialist for Simscape Multibody at MathWorks

Agenda

1. What is a Reduced Order Model (ROM)
2. Creating ROM's in MATLAB
3. How to reduce model order using a Craig Bempton Approach
4. Demo – creating a ROM using MATLAB Script
5. Flexible Bodies in Simscape Multibody
6. Importing ROM's from external sources into Simscape
7. Demo – creating a ROM using Flexible Body Builder App
8. Demo – running a Simulink Simulation with a ROM

Demo – creating a ROM using Flexible Body Builder App

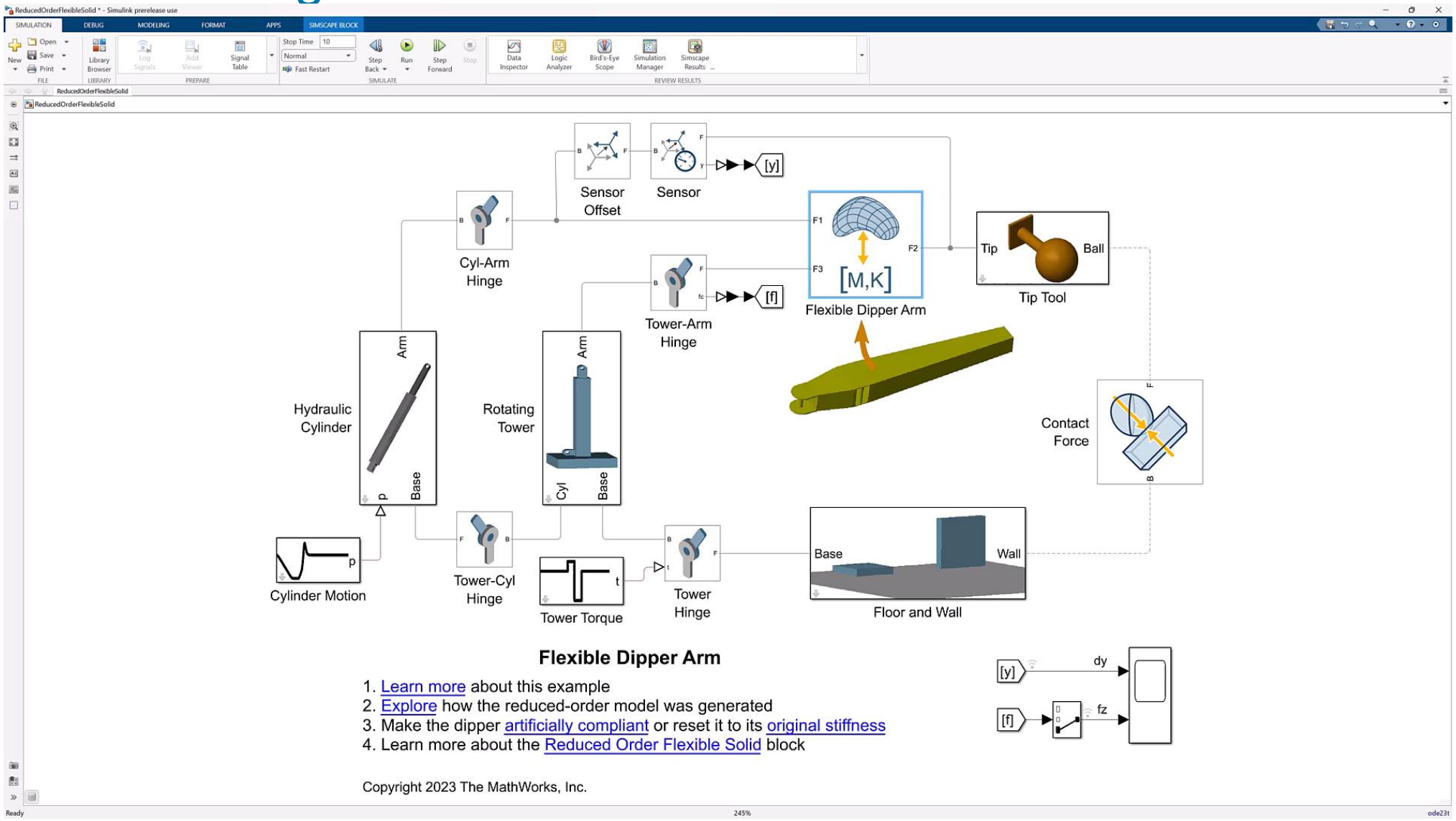


openExample('sm/GenerateTheROMDataForAFlexibleDipperExample')

Agenda

1. What is a Reduced Order Model (ROM)
2. Creating ROM's in MATLAB
3. How to reduce model order using a Craig Bempton Approach
4. Demo – creating a ROM using MATLAB Script
5. Flexible Bodies in Simscape Multibody
6. Importing ROM's from external sources into Simscape
7. Demo – creating a ROM using Flexible Body Builder App
8. Demo – running a Simulink Simulation with a ROM

Demo – running a Simulink Simulation with a ROM



openExample('sm/ReducedOrderFlexibleSolidExample')

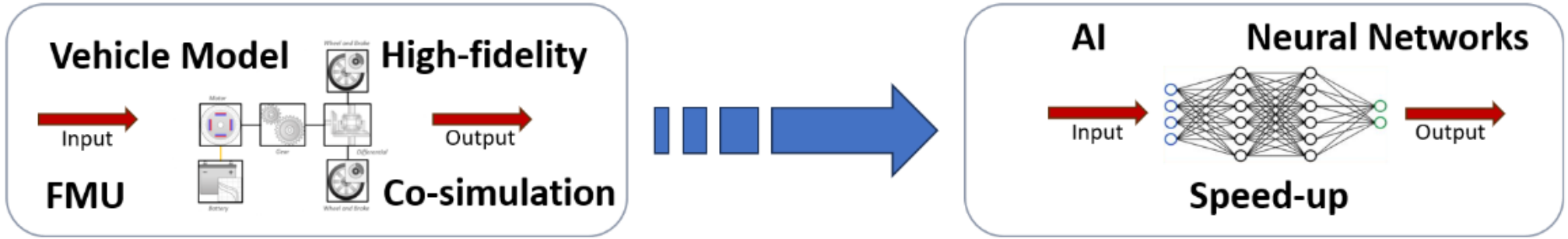
Summary

- What is a Reduced Order Model
- Benefits of Reduced Order Models
- Options for including Flexible Bodies into your Simulink Models
- Three different methods to generate a ROM
- How to integrate your ROM in system-level simulation

Additional Resources

- Import a CAD model into MATLAB
- Model Flexible Bodies with Simscape Multibody
- Flexible Body Builder App
- Reduced Order Flexible Solid Block
- Model Flexible Dipper Arm

Data Driven Reduced Order Modeling Training

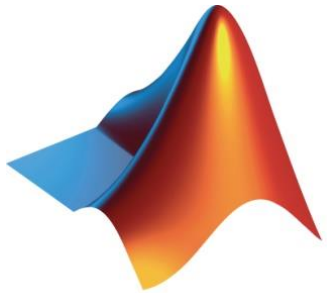


- Generating data for reduced order modeling
- Data-driven AI-ROM models as surrogates for high-fidelity components

- Validation and simulation with reduced order models
- Recurrent neural networks, neural state space models, and system identification techniques

Alex Dirmeier
adirmeie@mathworks.com
Andreas Krahnke
akrahnke@mathworks.com

Full Course Outline



MathWorks®

Accelerating the pace of engineering and science