Simscape Multibody for Mechanical System Simulation

1. Title

Simscape Multibody for Mechanical System Simulation

2. Target Audience

This course is designed for mechanical and automotive engineering students, researchers, and practicing engineers who need to analyze and simulate the kinematics and dynamics of mechanisms using both MATLAB scripting and Simscape Multibody 3D simulation. It suits learners with a working knowledge of MATLAB who want to progress from foundational kinematic theory through mechanism synthesis, force analysis, gear and cam design, and spatial mechanisms. No prior Simscape Multibody experience is required, though familiarity with statics, dynamics, and linear algebra is helpful for interpreting the analytical derivations.

3. Course Outcomes

- Understand foundational kinematic concepts and the mathematical tools used to describe mechanism motion.
- Apply vector and matrix methods to analyze planar mechanism kinematics.
- Create dimensionally synthesized mechanisms that satisfy defined motion requirements.
- Analyze static and dynamic forces acting on planar mechanisms.
- Design and evaluate gear trains and disk cam profiles for motion transmission.
- Analyze spatial (3D) mechanisms using both analytical and simulation-based methods.
- Build 3D multibody simulations in Simscape Multibody that validate analytical MATLAB results.
- Evaluate simulation output to verify mechanism performance and design assumptions.
- Troubleshoot common Simscape Multibody modeling issues (joint definitions, constraints, solver convergence).

4. Course Objectives

- Provide a structured, progressive learning path from kinematic fundamentals to full 3D multibody simulation.
- Build proficiency with both analytical (MATLAB) and simulation-based (Simscape Multibody) approaches to mechanism analysis.

- Prepare learners to design, analyze, and validate real mechanical systems including linkages, gears, and cams.
- Reinforce every concept through practical MATLAB and Simscape Multibody exercises paired directly with the analytical theory.
- Equip learners to cross-check hand and MATLAB-derived kinematic/dynamic results against Simscape Multibody simulation output.

5. Course Outline

The course comprises 40 hours of theory and labs and is divided into 10 different chapters. Each chapter will be followed by hands-on lab exercises to reinforce learning and gauge understanding of the topics covered.

6. Table of Contents (TOC)

Module 1: Introduction to Kinematics

- Overview of mechanism kinematics and its role in mechanical design
- Types of mechanisms and their classification
- Degrees of freedom and mobility analysis
- Introduction to MATLAB as a kinematic analysis tool (per Appendix A user instructions)
- Overview of the course's dual analytical/simulation approach (MATLAB + Simscape Multibody)

Module 2: Mathematical Concepts in Kinematics

- Vector algebra for mechanism position, velocity, and acceleration analysis
- Matrix methods for representing rigid-body transformations
- Coordinate transformations and reference frames
- Complex-number and graphical methods in planar kinematics
- Practical examples applying mathematical tools to simple linkages

Module 3: Fundamental Concepts in Kinematics

- Position, velocity, and acceleration analysis of mechanism links
- Instant centers of rotation
- Mechanism mobility criteria (Grubler's equation and variants)
- Relative motion analysis between mechanism links
- Practical examples of fundamental kinematic analysis

Module 4: Kinematic Analysis of Planar Mechanisms

- Position analysis of four-bar and slider-crank mechanisms
- Velocity and acceleration analysis of planar linkages
- Analytical (loop-closure) methods for planar mechanism analysis

- Implementing planar mechanism models in MATLAB
- Lab: building and validating a planar mechanism model in Simscape Multibody (per Appendix H)

Module 5: Dimensional Synthesis

- Motion, path, and function generation synthesis problems
- Graphical synthesis techniques for planar mechanisms
- Analytical (precision-point) synthesis methods
- Synthesizing mechanisms to satisfy defined design requirements
- Practical example: synthesizing a four-bar mechanism for a specified task

Module 6: Static Force Analysis of Planar Mechanisms

- Free-body diagrams for mechanism links
- Static equilibrium equations for planar mechanisms
- Analytical static force analysis using MATLAB
- Identifying reaction forces and required input torque
- Lab: validating static force analysis results in Simscape Multibody (per Appendix I)

Module 7: Dynamic Force Analysis of Planar Mechanisms

- Inertia forces and D'Alembert's principle in mechanism analysis
- Dynamic force analysis of planar linkages
- Analytical dynamic force analysis using MATLAB
- Comparing static vs. dynamic force analysis results
- Lab: simulating dynamic forces in Simscape Multibody (per Appendix J)

Module 8: Design and Kinematic Analysis of Gears

- Gear terminology, types, and standard tooth geometry
- Involute gear-tooth action and the law of gearing
- Gear train analysis (simple, compound, and epicyclic trains)
- Designing gears for specified velocity ratios
- Practical example analyzing a gear train's kinematic performance

Module 9: Design and Kinematic Analysis of Disk Cams

- Cam and follower types and terminology
- Displacement, velocity, and acceleration diagrams for cam profiles
- Cam profile design for specified follower motion
- Analytical cam analysis using MATLAB
- Lab: simulating a disk cam mechanism in Simscape Multibody (per Appendix K)

Module 10: Kinematic Analysis of Spatial Mechanisms

- Extending planar kinematic methods to 3D (spatial) mechanisms
- Homogeneous transformation matrices for spatial motion

- Position, velocity, and acceleration analysis of spatial linkages
- Analytical spatial mechanism analysis using MATLAB
- Capstone lab: building and validating a spatial mechanism model in Simscape Multibody (per Appendix K)