e=MSC engineering. education. enterprise. 2009VPD virtual product development conference

ME 451 – “Kinematics and Dynamics of Machine Systems” – A computational approach

Justin Madsen, Graduate student, University of Wisconsin - Madison
Makarand Datar, Graduate student, University of Wisconsin - Madison
Class taught by Professor Dan Negrut

MSC Software

Overview of Topics

- Description of the Course
  - Computational Approach to solving dynamics systems
  - Motivation for using MSC/ADAMS in the class
  - Topics covered
- ADAMS homework assignments
  - Examples
- Final projects
  - Examples of past projects
- Student feedback to using ADAMS in the course

Course description

- Taught by Prof. Dan Negrut
- Pre-requisites: Statics, Dynamics, Linear Algebra, Calculus
- Level: Graduate / Senior under-graduate
- Objectives:
  - Review understanding of kinematic and dynamic systems
  - Apply knowledge to more complex problems
    - Analytical component is presented in a general framework to promote computational solutions
    - ADAMS is used in homework & projects
      - Lets students see past equations and abstract constructs
      - Apply understanding to actual mechanical systems

Approaches to Kinematics and Dynamics

- When it comes to dynamics, there are several ways to approach the solution of the problem, i.e. find the time evolution of a mechanical system
  - As taught in Intro to Dynamics class, on a case-by-case fashion
    - In many circumstances, this requires following a recipe, not always clear where it came from
    - Typically works for small problems, not clear how to go beyond textbook cases
  - Use a graphical approach
    - Intuitive but doesn't scale particularly well
  - Use a computational approach
    - This is the methodology emphasized in this class

Computation approach to Kinematics and Dynamics

- Why use a computational approach?
  - Leverages the power of the computer
    - Relies on a unitary approach to finding the time evolution of any mechanical system
    - Sometimes the approach might seem to be overkill, but it's general, and remember, it's the computer that does the work and not you
    - In other words, we hit it with a heavy hammer that takes care of all jobs, although at times it seems like killing a mosquito with a cannon…
  - Works for most mechanical systems and scales well
    - Computational 3-step process
      1) Formulate Equations of Motion
      2) Solve EOMs as a set of ODE/DAEs
      3) Interpret results

Why use ADAMS in the class?

- Students taught to pose dynamics problems to be well suited to be solved using a computer…
- …so a computer can do the heavy lifting
  - Offers a pre-processor (ADAMS/View) to be able to generate models
  - Offers a solution engine (ADAMS/Solver) to be able to find the time evolution of models
  - Offers a post-processor (ADAMS/PPT) to be able to animate and plot results
- Students are able to apply analytical knowledge to simulate real mechanical systems
- Give students experience using commercial simulation software used in industry

Topics covered

Week	Topics	Details on Learning Objectives
1	Adams Tutorials	Getting familiar with the ADAMS simulation package
2	Scope of Kinematics and Dynamics analysis. Overview of existing methodologies	Understanding the scope and goals of the course. Review of matrix algebra and calculus concepts.
3	Vector Calculus, Basic concepts of planar kinematics	Vector and Matrix differentiation. Generalized and Cartesian coordinates. Kinematic constraints, DOFs, Reference frames.
4	Absolute kinematic constraints. Basic relative kinematic constraints	Single body position, angular constraints. Kinematic constraints involving pairs of bodies
5	Relative kinematic constraints. Composite joints, Cam-follower joints	Kinematic constraints involving pairs of bodies: Revolute and Translational joints.
6	Driving constraints	Cam/flat follower, point-curve constraint. Absolute and Relative driving constraints.
7	Position, velocity and acceleration analysis. Elements of the solution for kinematic analysis	Formulating and solving the kinematic problem. Implicit Function Theorem. Newton-Rhapson method. Gaussian Elimination
8	Singular Configurations of Mechanical systems	Mechanism lock-up, Bifurcations, Redundant constraints.
9	**Spring Break**	**Spring Break**

Topics covered, continued…

10	Dynamics of Planar Systems (D'Alembert's Principle). Inertia.	Variational approach to deriving EOM for a single body. Inertia properties for composite bodies.
11	Virtual Work and Generalized Forces	Computing generalized forces for translational and rotational force elements
12	Adams tutorials, Equations of Motion for constrained systems	Adams design of experiments, Adams Controls. Variational form of the EOM for a system of bodies. Contribution of constraints to the EOM
13	Lagrange Multipliers, Initial Conditions. Constraint Forces.	Lagrange multiplier form of the EOM. Differential Algebraic Equations, difference between ODEs and DAEs
14	**Exam, Engineering Expo**	**No Class**
15	Numerical integration methods. Elements of dynamic analysis in Adams	Coordinate partitioning method: ODE methods. Direct Index 3 approach: DAE methods. Debugging dynamic analysis models in Adams
16	Three dimensional rotation, Inverse Dynamics and Equilibrium conditions	Orientation matrix for 3D motion. Euler angles and Euler parameters

Homework assignments

- Three types of homework are assigned
  - Hand-written assignments
    - Textbook problems to reinforce concepts
  - Matlab assignments
    - Used to solve textbook problems in a computational and to solve simple kinematic/dynamic EOMs
  - Adams assignments
    - Used to analyze simple and complex mechanisms
      - Simple systems are usually based on textbook problems, to verify analytical solutions
      - Complex mechanisms give students insight into the power and applicability of simulation software
  - A majority of homework assignments are the first and third types

Approach to ADAMS instruction

- First Tutorial
  - Basics of ADAMS interface
  - Modeling philosophy
  - Creating parts, joints, motions, measures, contacts….
  - Post-processing
- Second Tutorial
  - Basics of parameterization
  - Design of experiments, design optimization
  - Advanced simulation settings
  - Custom measures (function builder)
- Third Tutorial
  - Controls
  - Students were exposed to use of Adams for research in Dr Negrut's lab

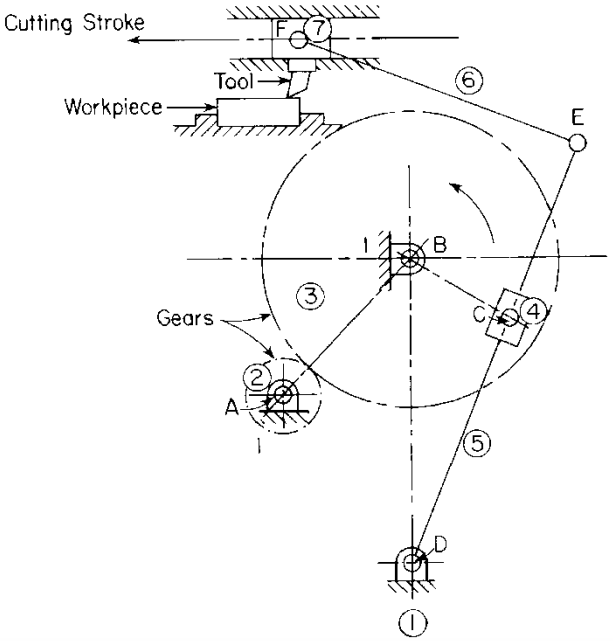
ADAMS homework example 1

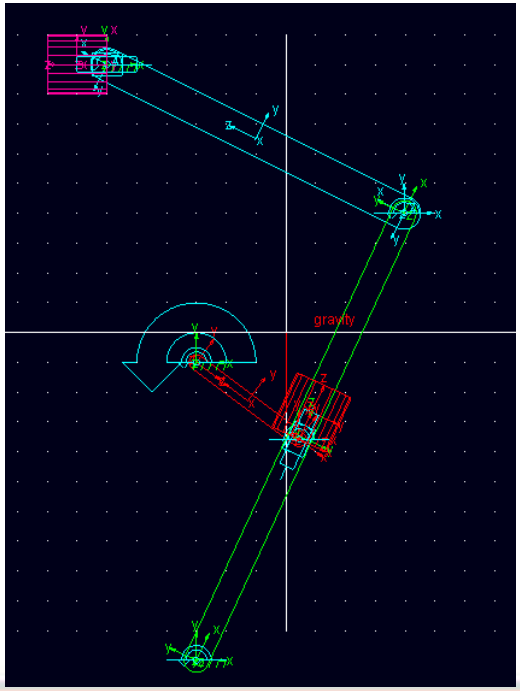
- Start with something very simple
  - Students get used to the software interface
  - Crawl walk run approach
  - Easy enough to analytically verify
    - Build confidence in the software

- Ball falling under gravity
  - Run a simulation
  - Build measures
  - Post-process results
  - Verify the answers analytically

ADAMS homework example 2

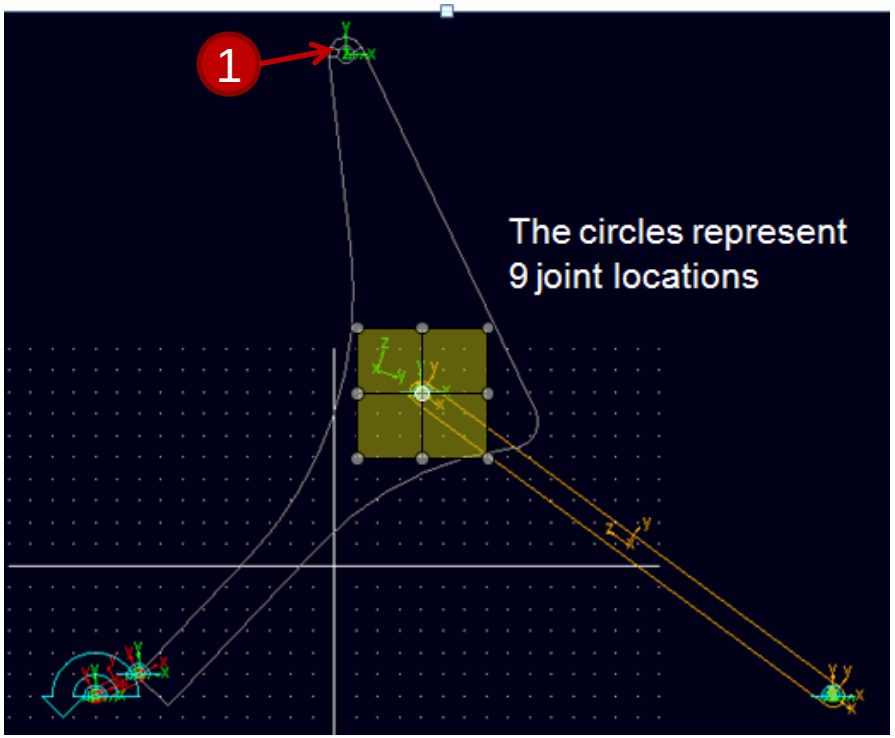
- Quick Return Mechanism
  - Model the mechanism
  - Post process and find the ratio of advance time to return time
  - Change the driving speed and link locations
  - Redo the calculations and study the effect of these changes





ADAMS homework example 3

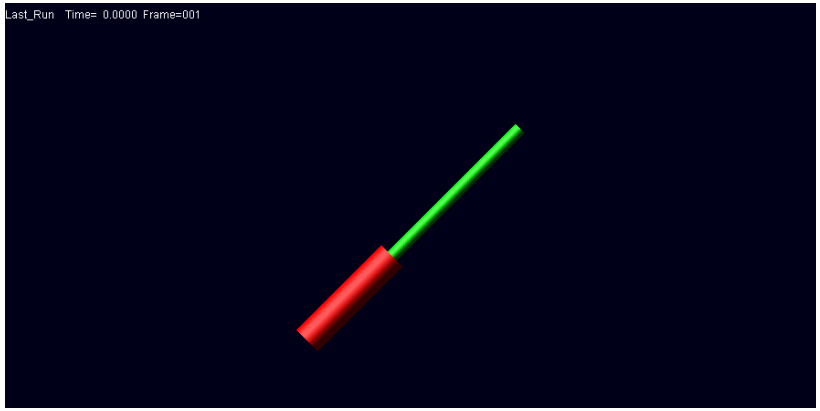
- Design of Experiments
  - Change a parameter and study its effect on the system
  - Automate the procedure by using design of experiments with design variables
  - Optimize for the design variables based on design requirement

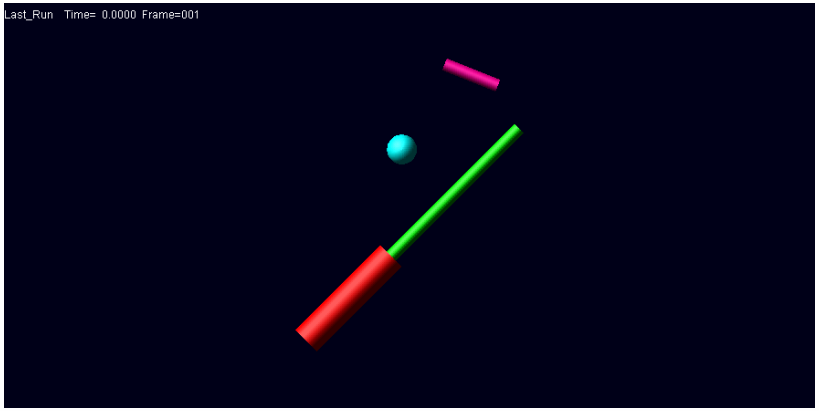


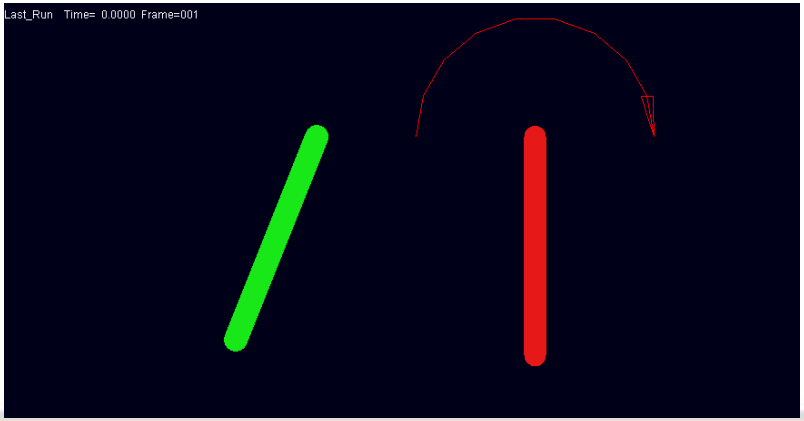
Optimize for:
1. Joint Forces
2. Area swept by point 1

ADAMS homework example 4

- Controls
  - Use of PID controls to dictate system response

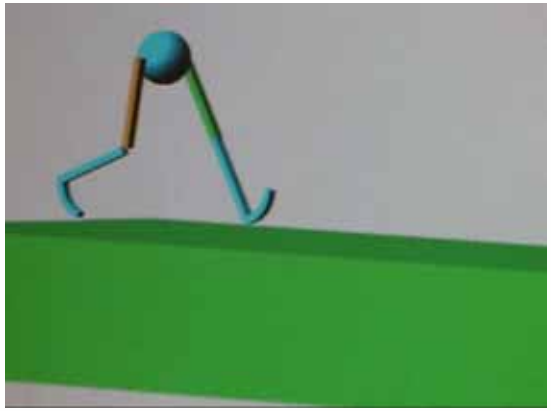


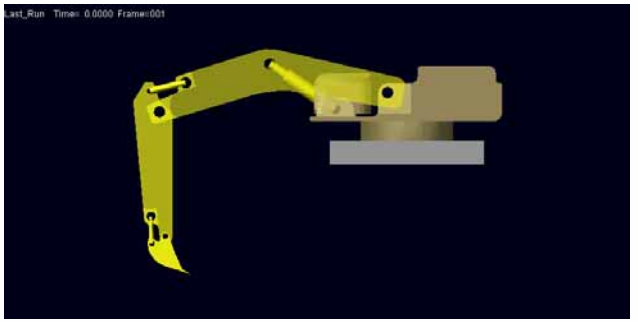


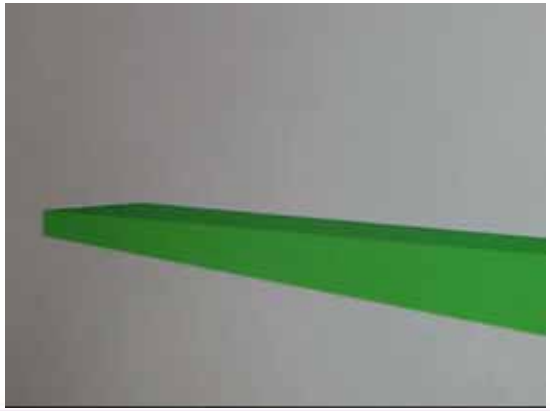


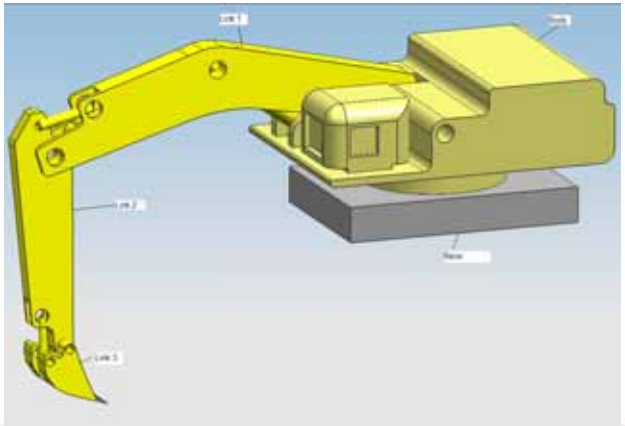
ADAMS project examples

- Students given option to do a final project for the class in ADAMS









Student feedback

- “ADAMS was very nice to work with”
- “I will forever have a greater understanding and appreciation of dynamics-related fields and appreciate the instruction I received in ADAMS”
- “Learning the use of MATLAB and ADAMS has really helped understand the practical and industrial relevance of the subject”

Other positives

- One student got hired for knowledge of ADAMS
- Continued use of ADAMS for research
- Benefits to UW Formula SAE team

Other positives

- All the ADAMS homework material and tutorials were generated by graduate student Makarand Datar

- Dan Negrut and Makarand Datar won the MSC Software's contest for use of Adams in ME 451 course
  - http://www.mscsoftware.com/university/view_success_story.cfm?storyId=14

Contact Details :

- For further information please contact

Justin Madsen email: jcmadsen@wisc.edu

Makarand Datar email: datar@wisc.edu

Professor Dan Negrut
2035 ME Building
1513 University Avenue
Madison, WI 53706-1572

608-890-0914

negrut@engr.wisc.edu

ME 451 Course Material can be found on our lab website:

Simulation Based Engineering Laboratory

http://sbel.wisc.edu