Development of a new integrated mechanism design and finite element analysis course

Raghu Echempati, Ph.D., P.E.

Professor of Mechanical Engineering

Kettering University, Flint, MI 48504

Integration of Simulation Technology into the Engineering Curriculum (*ISTEC 2008*): A University-Industry Workshop, July 25-26, 2008
Cornell University, Ithaca, New York

Outline of the presentation

- How is the Mechanisms/Multi-body analysis and FEA course taught using industrial-strength software?
- What are the challenges/benefits? How do our students respond? Is there any resistance or support from peer faculty?
- Plans for combining Mechanisms/Multi-body analysis and FEA
- Brief overview of PACE
- Relevant curriculum materials

How you teach Mechanisms/Multi-body analysis and FEA using industrial-strength software?

- Currently we (still) have 2 separate 500-level elective courses – Motion Simulation (Mechanism Design), and Introduction to FEA
- These two courses are required for those seniors with Machine Design as a specialty; it is an elective for others and for graduate students
- Each is a 4 credit hour course (total 8 credit hours)
- Typically, both these courses cover some theory augmented by CAE demonstrations and hands-on laboratory using Math and CAE tools
- The Mechanism Design course also requires that the students perform some stress and fatigue analysis of critical members

How you teach Mechanisms/Multi-body analysis and FEA using industrial-strength software?

- Basic concepts and theory is discussed and the students are free to choose any CAE tool for these courses
- Typically they used I-DEAS/ADAMS, SolidWorks or Pro/E for the Motion Simulation course
- For the FEA course, ANSYS, NX 3.0, Pro/E, I-DEAS 10, and SolidWorks were used by the students
- Modeling, Motion Simulation and/or FEA are performed as three different activities in these 2 courses by importing or exporting part model and data files between the different families of the same or different software
- Simple hand calculations are done to validate the results

Challenges/benefits? How do students respond? Is there any resistance/support from peer faculty?

- We have some issues with installing ANSYS 11, MSC/ADAMS 12, I-DEAS NX or UG NX 5.0 at Kettering due to hardware limitations
- UG NX 3.0 is the primary software that is used by many students
- Typically, the students do not have any preference as long as the learning curve is not too steep
- Faculty are open for the students to use any software tool that they are familiar with

The PACE program helped few faculty to integrate the entire toolbox throughout our curriculum, starting with the basic first-year engineering courses

PACE software is also used to by our KU Formula SAE Car as well in our Bio-Engineering and Fuel Cell projects

As mentioned by other PACE partners, these PACE tools are widely used in industries; but when they are integrated into our curriculum, they will greatly enhance our students' capability to work in teams and design projects in several engineering areas such that in their senior years, students will be familiar and comfortable with the engineering work environment and how business operates in our nation's leading global companies

Brief overview of PACE

The PACE Program enables college students to learn and train on the same cutting-edge as math-based modeling and design systems our co-op engineers use in the workplace to take a product from its concept through its entire lifecycle. Therefore, PLM is a core concept within PACE.

Brief overview of PACE

With Kettering's real world or co-op education and by using the cutting-edge tools right from the first-year engineering courses, our graduates are well prepared to join the applied research, development and technology efforts critical to Michigan's economic revitalization.

Brief overview of PACE

- **The application software in the areas of modeling and design simulation as well as rapid prototyping provided by PACE have been used extensively in many KU engineering courses.**
- **Example courses that utilize the design simulation methodologies at Kettering are:**

Brief overview of PACE

- **Graphics and Communication**
- **Introduction to CAE**
- **Machine Design**
- **Rapid Prototyping**
- **Finite Element Analysis**
- **Capstone Design**
- **Thermal Engineering Courses**
- **Automotive specialty courses**

Brief overview of PACE

I also received a GM-PACE or GM-Foundation grant to develop course modules in the area of Sheet Metal Forming Basics and Simulation. This work was completed some time back.

I give workshops and seminars on this subject area at many conference meetings, universities and industries

Plans for combining Motion Simulation and FEA Concepts

- **I-DEAS has Mechanism Design and FEA as separate Tasks under Simulation family**
- **UG NX 4.0 and NX 5.0 have Motion Simulation and Structures as separate modules**
- **HyperWorks has Motion Simulation and FEA**
- **Pro/E has separate Mechanisms and FEA modules**

Plans for combining Motion Simulation and FEA Concepts

- **ANSYS has flexible body kinematics and dynamics, but it is not free**
- **MSC Suite has ADAMS and NASTRAN**
- **Student chosen software – Pro/E, etc.**
- **Others**
- **I am open to any ideas but I am planning to try UG NX Motion + Structural Analysis until we can install MSC Products properly at KU**

Plans for combining Motion Simulation and FEA Concepts

PACE Forum 2008 Training Session Information

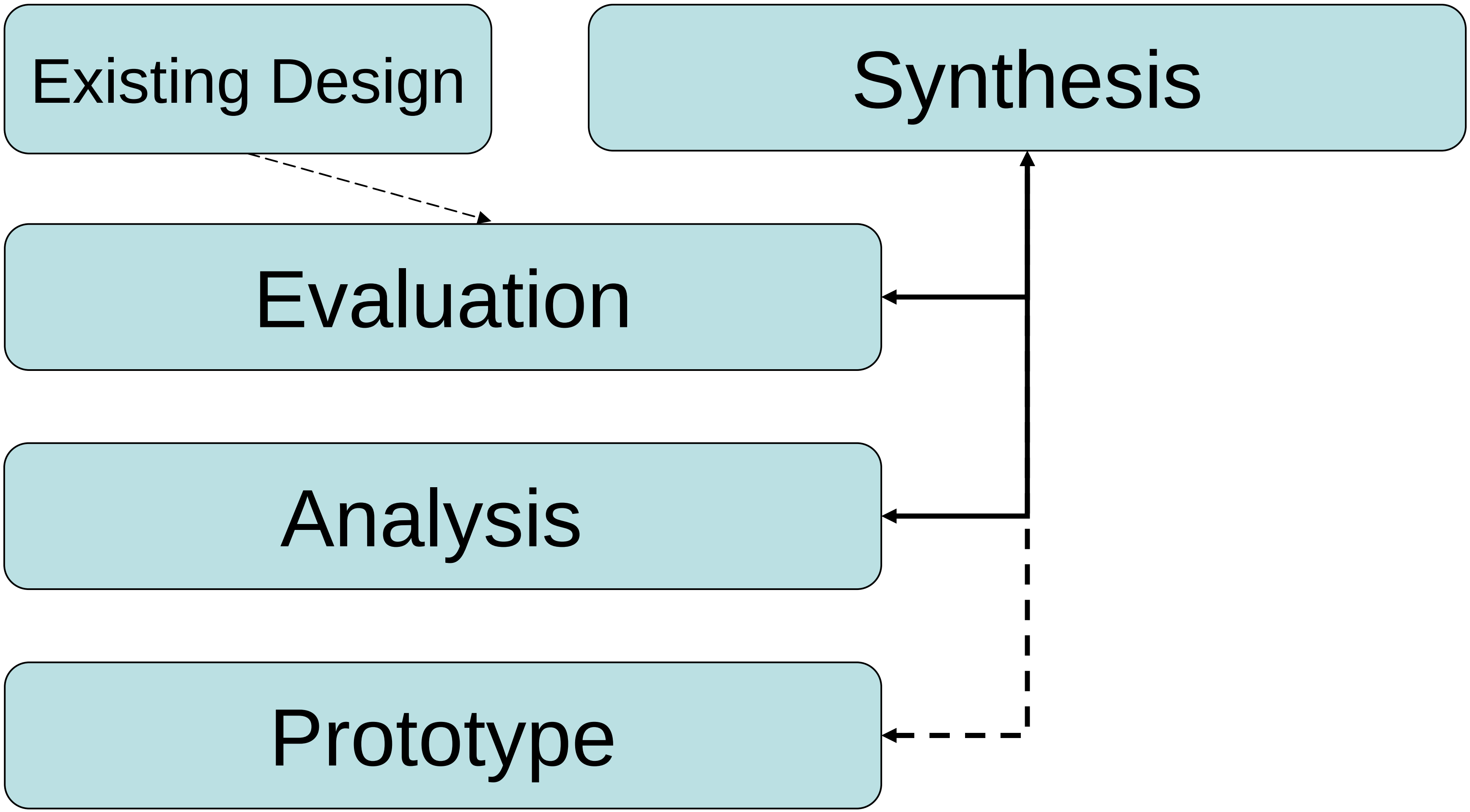
MECH-519: Motion Simulation and Finite Element Analysis (4-0-4)

Draft of New Course Proposal (Mezzanine Level)

- Credit Hours: 4 (4-0-4)
- Prerequisites: Design of Mechanical Components I; Introduction to CAE; Mechanics III (Rigid Body Dynamics)
- Corequisites: Dynamic Systems – I; Fluid Mechanics; Heat Transfer

MECH519_Syllabus_October2007

Student Project Examples

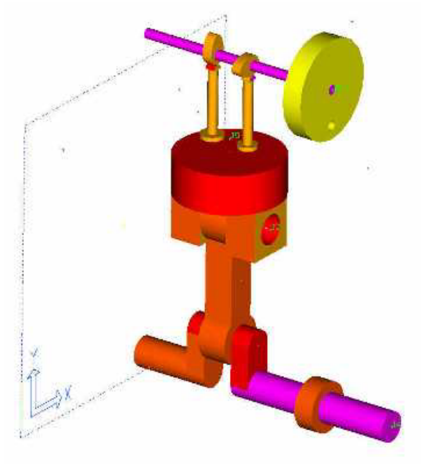


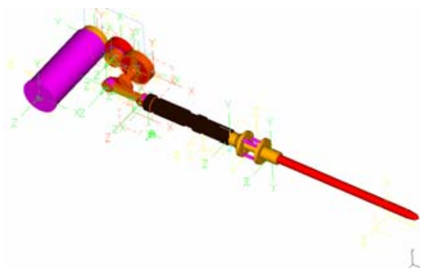
Student Project Examples

- Automotive applications
  - piston-cylinder linkage analysis
  - steering linkage analysis
  - overhead valve train analysis
  - gearbox and other transmission
  - suspension system
  - wind-shield wiper mechanism/door latch/window lifting
- Boat lifting platform
- Fishing reel analysis
- Bicycle transmission
- Paper shredder device
- Single action and triple-action press mechanism
- Other mechanism devices from textbooks

Student Project Examples

Projects involved design and analysis of a device that has a combination of lower pair and higher pair contacts or joints (Example: IC Engine)





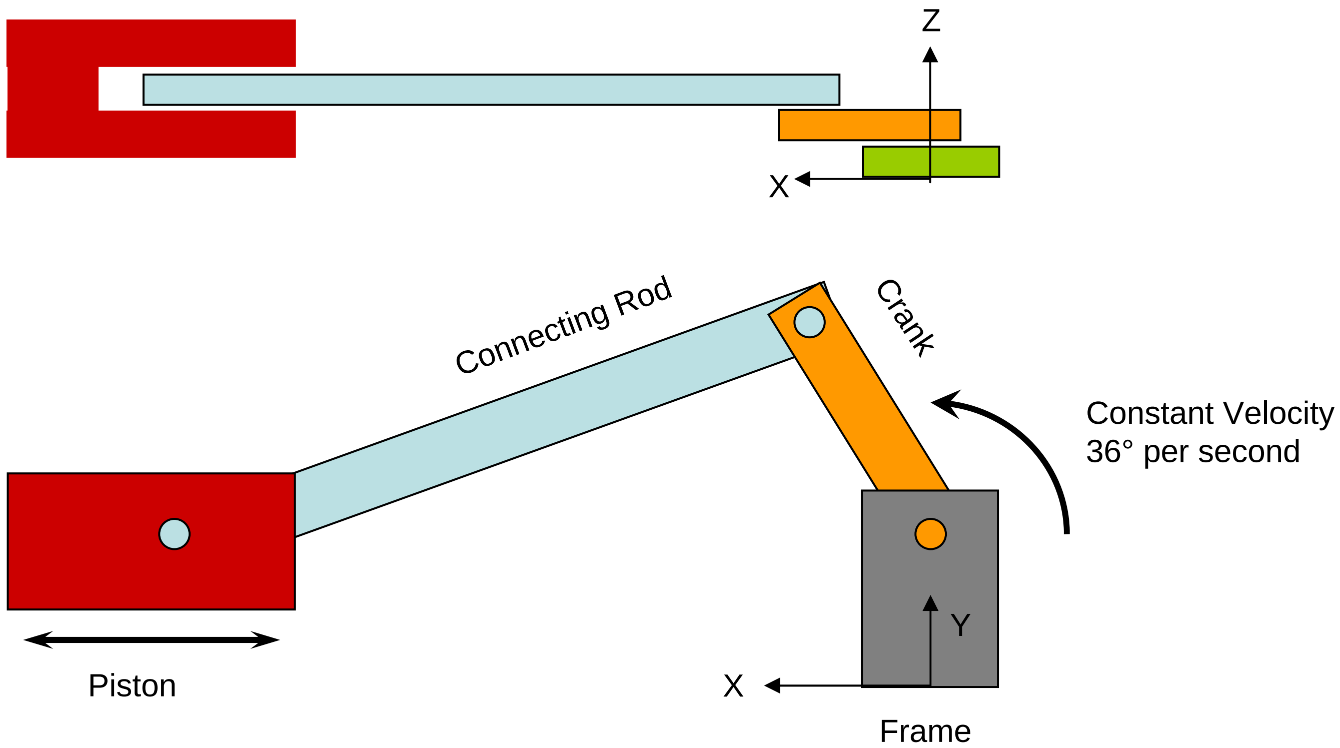
Acknowledgements

- ***Professor Rajesh Bhaskaran, CU***
- ***Jim Ryan, MSC***
- ***Kettering University***
- ***All the participants***

THANKS

Student Example

Description of Problem



Crank mechanism with constant velocity servo motor attached at frame end

Piston: Ø60mm x 50 long, split for link attachment; material: steel

Frame: 10mm thick; material: steel

Crank: 100mm center to center, Ø10 pin (part of link 1) to interface with block,Ø10 hole for pin for link 2, 10mm thick; material: steel

Connecting Rod: 300mm center to center, Ø10 pin (part of link 2) to interface with link 1,Ø10 pin double sided to interface with piston, 10mm thick; material: steel

Objective and Material Definition

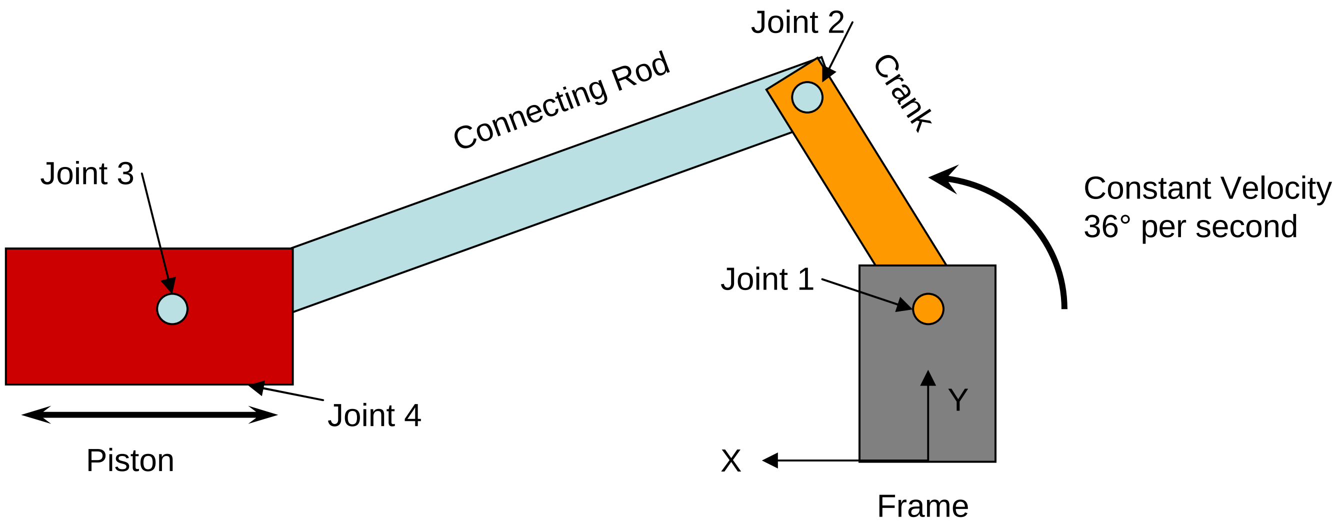
Objective:

- Perform Motion analysis on assembly to determine reaction forces on all pin joints
- Transfer reaction forces on pin joints from kinematic analysis to static analysis package (ProE)
- Use defined loads to perform a linear static FE analysis on the pin joints to understand stress in the pin joints versus rotation of the crank
    - Determine reaction forces and perform linear static FE analysis every 7.5° of crank rotation (48 load cases)
    - Build a graph representing stress versus rotation data for clear presentation

- Material Definition: AISI 1050 Carbon Steel, as rolled (UNS G10500) [(1)]
    - Density 7.85 g/cc (0.0785 g/mm^3)
    - Tensile Strength, Ultimate 725 MPa
    - Tensile Strength, Yield 415 MPa
    - Elongation at Break 20%
    - Reduction of Area 40%
    - Modulus of Elasticity 205 GPa (Young's Modulus)
    - Bulk Modulus 140 GPa
    - Poisson's Ration 0.29
    - Izod Impact 31 J
    - Shear Modulus 80 GPa

[(1)] MatWeb Material Property data, http://www.matweb.com/search/SpecificMaterial.asp?bassnum=M1050E

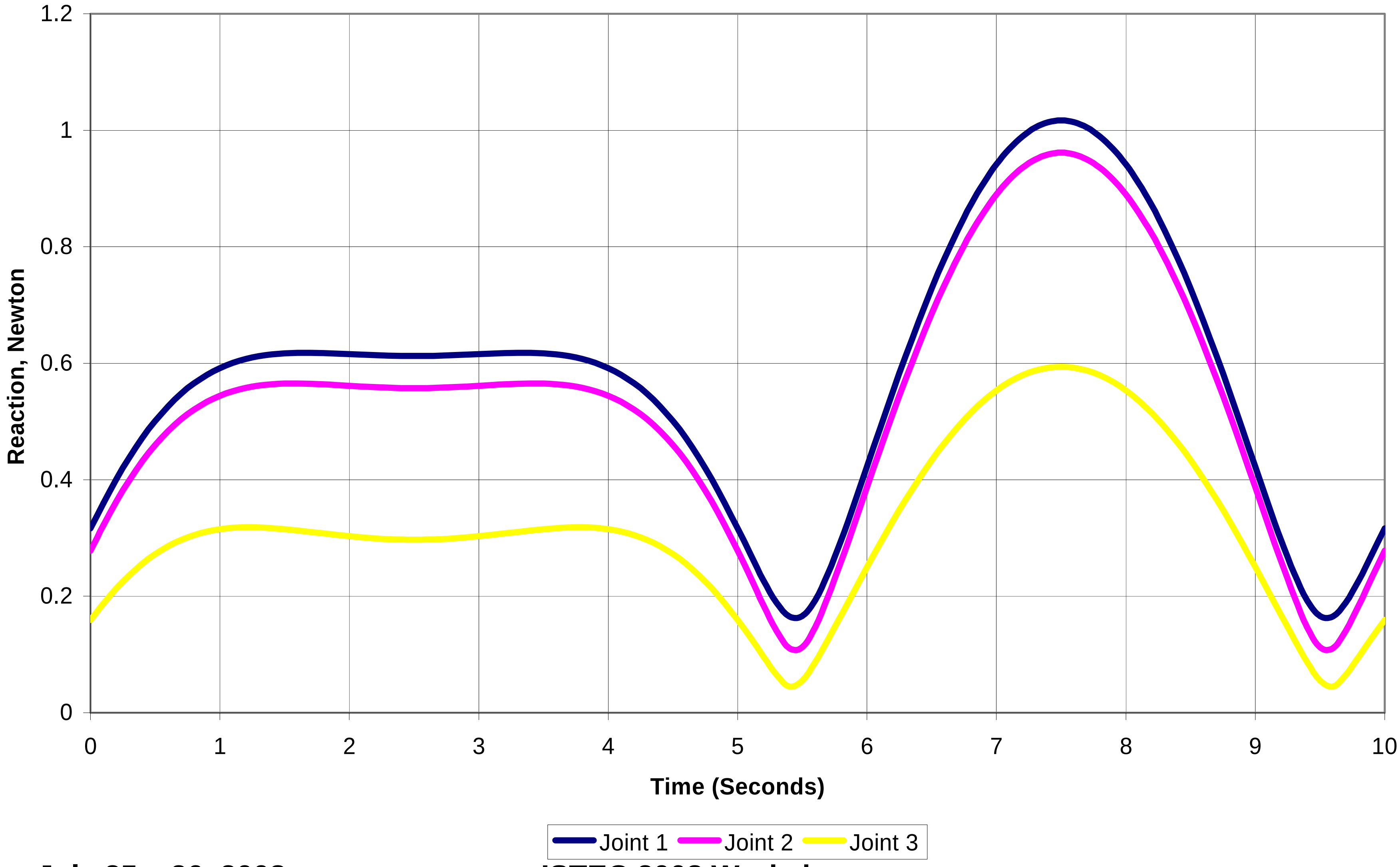
Mobility Tables

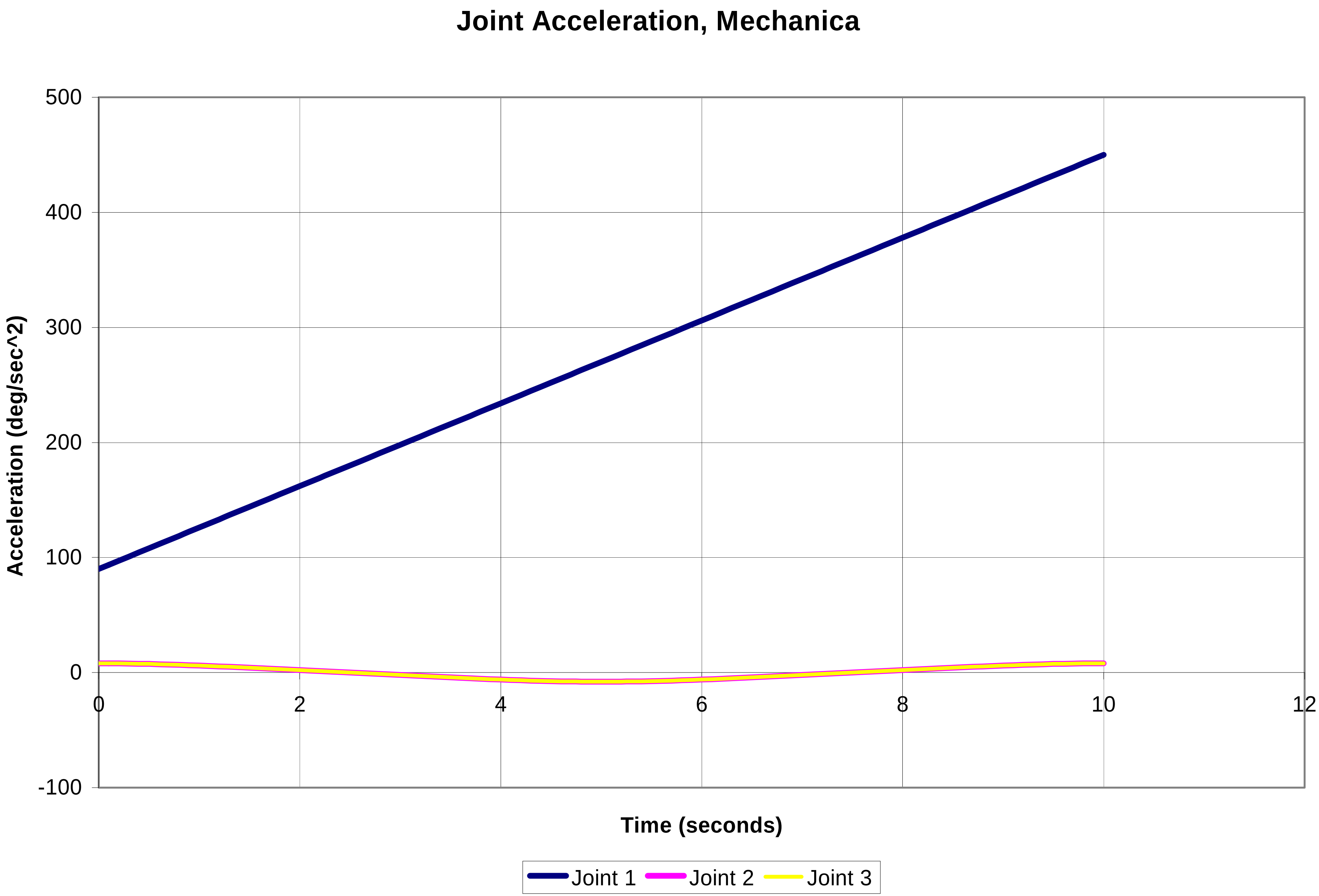


Link Mobility Table						
	Tx	Ty	Tz	Rx	Ry	Rz
Frame	No	No	No	No	No	No
Crank	No	No	No	No	No	Yes
Connecting Rod	Yes	Yes	No	No	No	Yes
Piston	Yes	No	No	No	No	No
Overall			No	No	No	

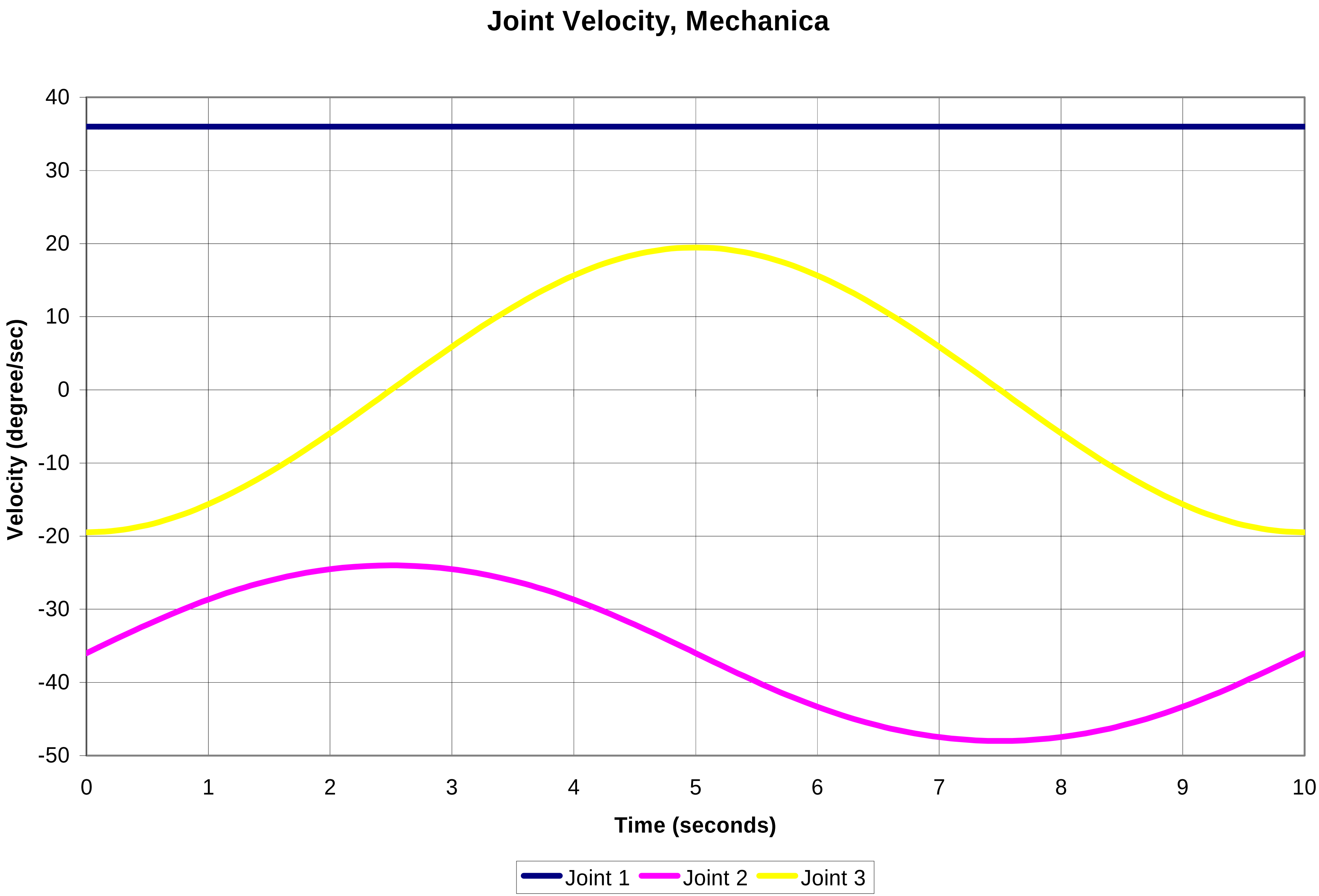
Joint Mobility Table						
	Tx	Ty	Tz	Rx	Ry	Rz
Joint 1	No	No	No	No	No	Yes
Joint 2	Yes	Yes	No	No	No	Yes
Joint 3	Yes	No	No	No	No	Yes
Joint 4	Yes	No	No	No	No	Yes
Overall			No	No	No	

Joint Reaction Force, Mechanica

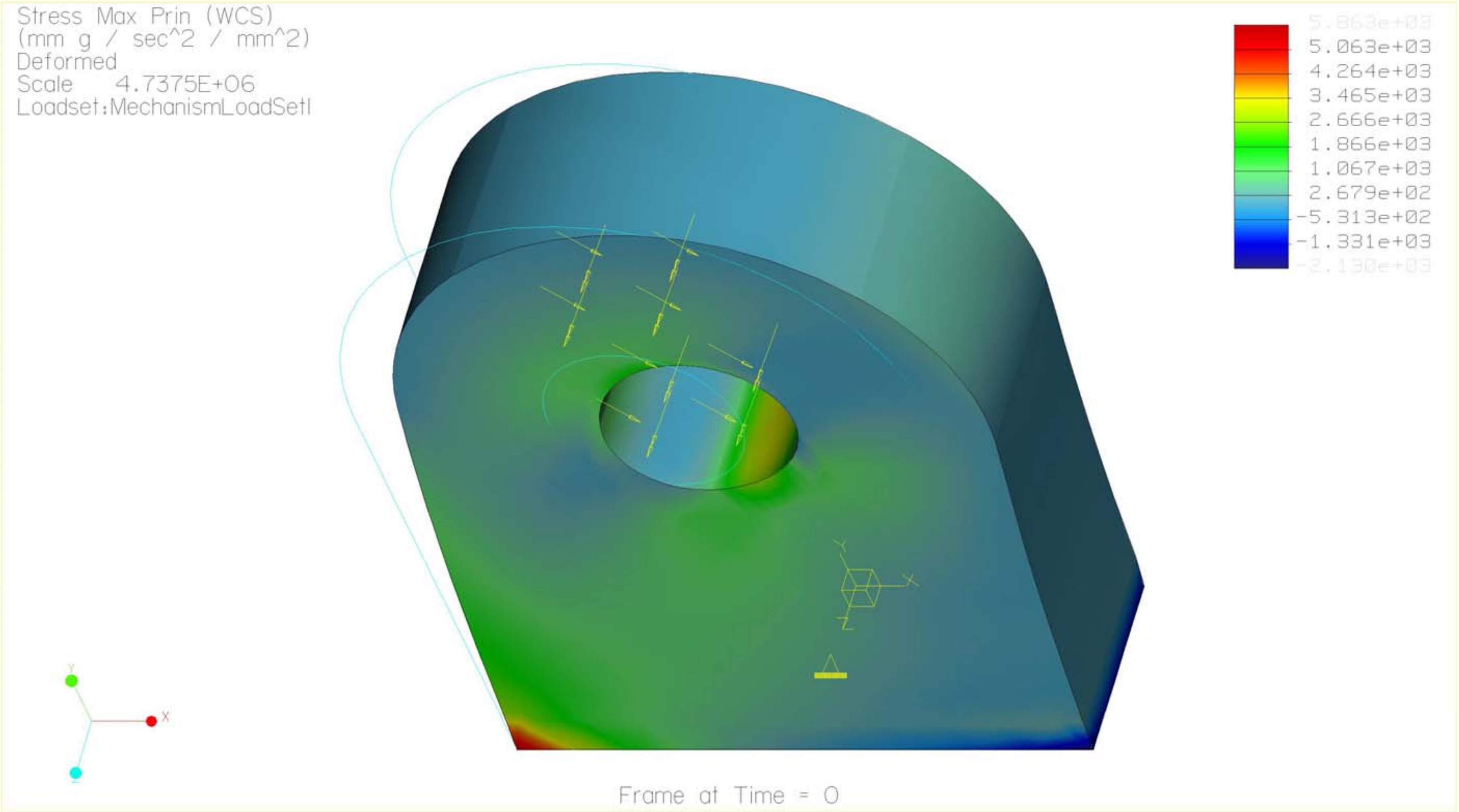




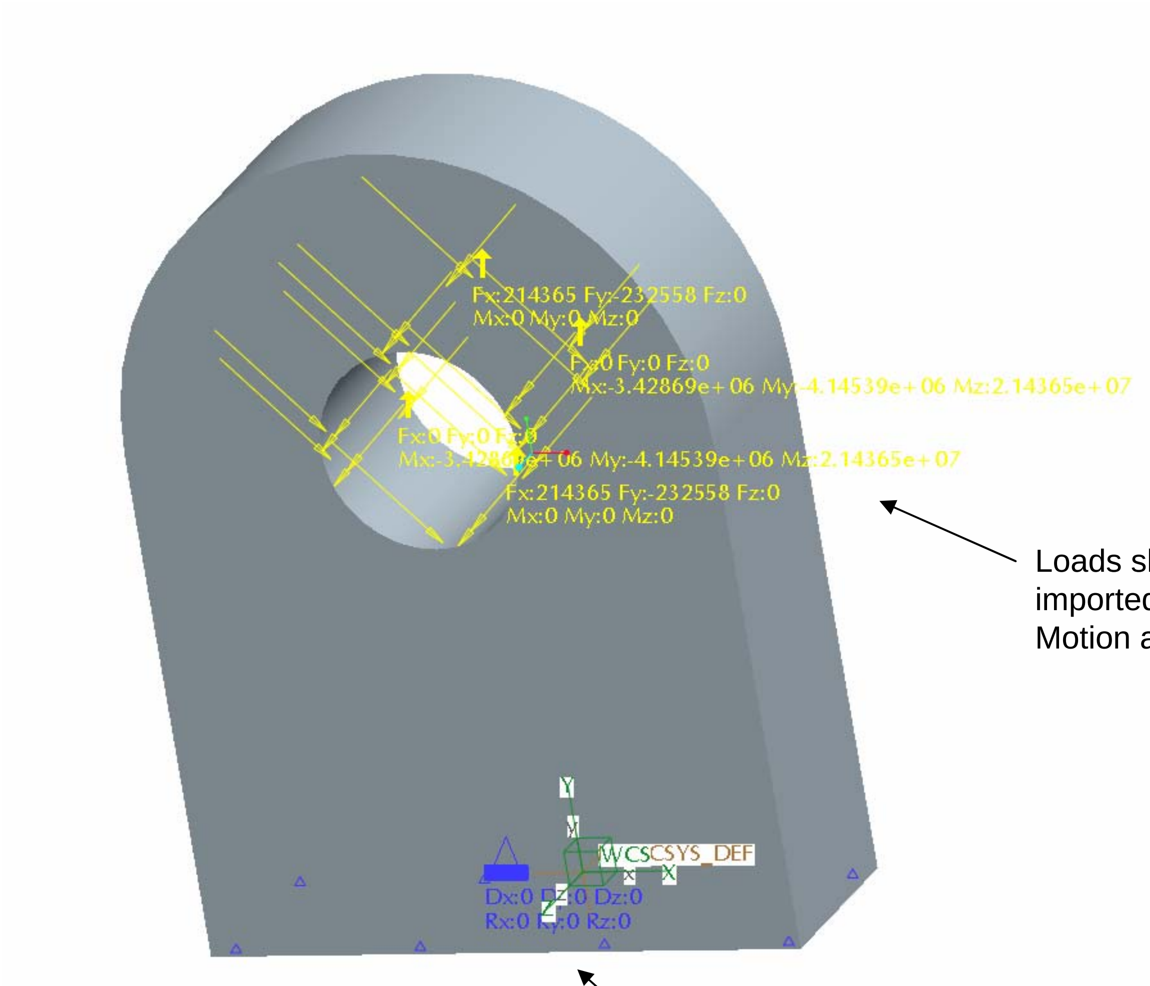
Joint Acceleration, Mechanica
Acceleration (deg/sec^2)
500
400
300
200
100
0
-100
0
2
4
6
8
10
12
Time (seconds)
Joint 1
Joint 2
Joint 3


Joint Velocity, Mechanica
Velocity (degree/sec)
40
30
20
10
0
-10
-20
-30
-40
-50
0
1
2
3
4
5
6
7
8
9
10
Time (seconds)
Joint 1
Joint 2
Joint 3

Max Principle Stress, Frame at Time 0



Frame Model Constraints in Mechanica

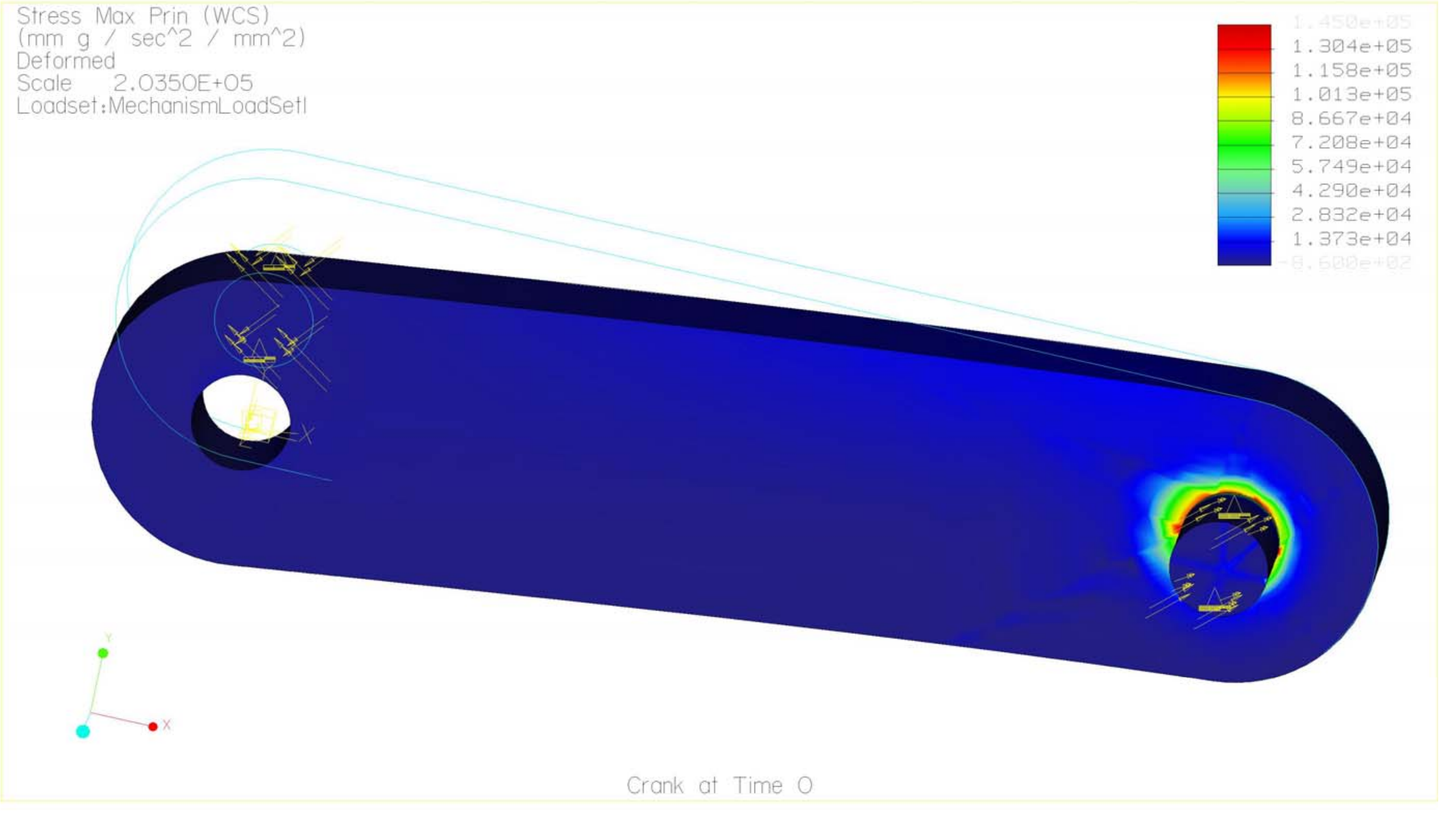


Loads shown in yellow are imported from Mechanica Motion at specific time interval

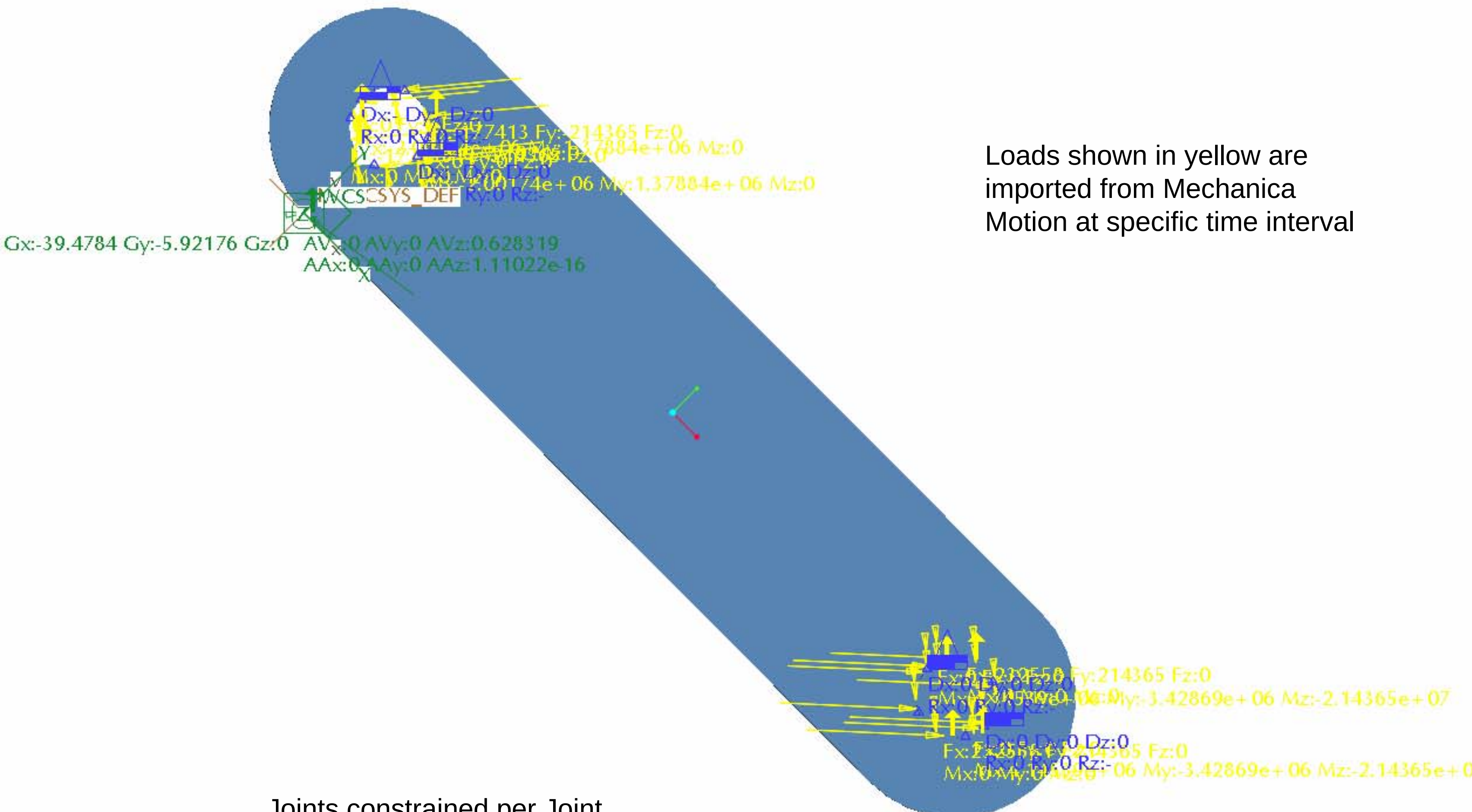
Fixed at base surface

(Tx, Ty, Tz, Rx, Ry, Rz = 0)

Max Principle Stress, Crank at Time 0



Crank Model Constraints in Mechanica



Loads shown in yellow are imported from Mechanica Motion at specific time interval

Joints constrained per Joint Mobility Table