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Simulation of the Coupled Multi-Spacecraft Control Testbed at the Marshall Space Flight Center

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1994 NASA Langley Workshop on Software Systems
June 15-16, 1994
Hampton, VA

The capture and berthing of a controlled spacecraft using a robotic manipulator is an important technology for future space missions and is presently being considered as a backup option for direct docking of the Space Shuttle to the Space Station during assembly missions. The dynamics and control of spacecraft configurations that are manipulator-coupled with each spacecraft having independent attitude control systems is not well understood and NASA is actively involved in both analytic research on this three-dimensional control problem for manipulator-coupled active spacecraft and experimental research using a two-dimensional ground based facility at the Marshall Space Flight Center (MSFC). This paper first describes the MSFC testbed and then describes a two-link arm simulator that has been developed to facilitate control theory development and test planning. The motion of the arms and the payload is controlled by motors located at the shoulder, elbow and wrist.

A symbolic manipulator, MAPLE, is used to derive the equations of motion based on a Lagrangian formulation. The equations are programmed using the autocode feature of MAPLE in FORTRAN and are then embedded in a usercode block of MatrixX which is the primary simulation software engine. The simulator implements a digital joint motor controller. The joint motor control scheme generates commands for the motor based on the difference between the joint angles derived from telerobotic translational command inputs using inverse kinematics and joint angle measurements.

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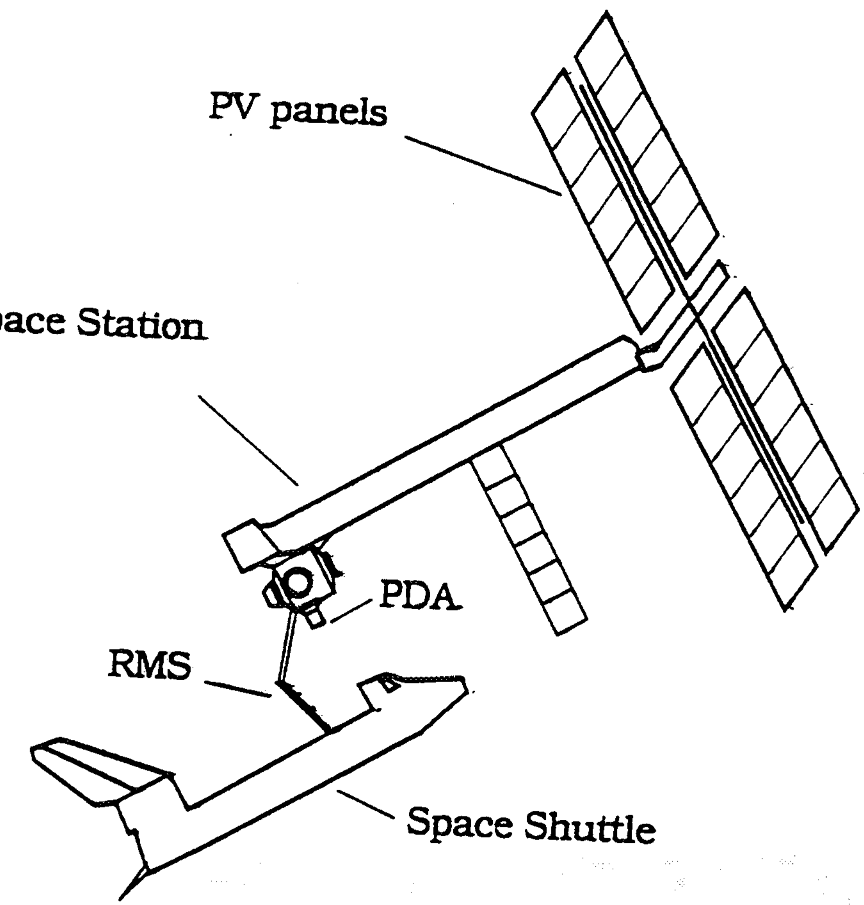
PRESENTATION OUTLINE

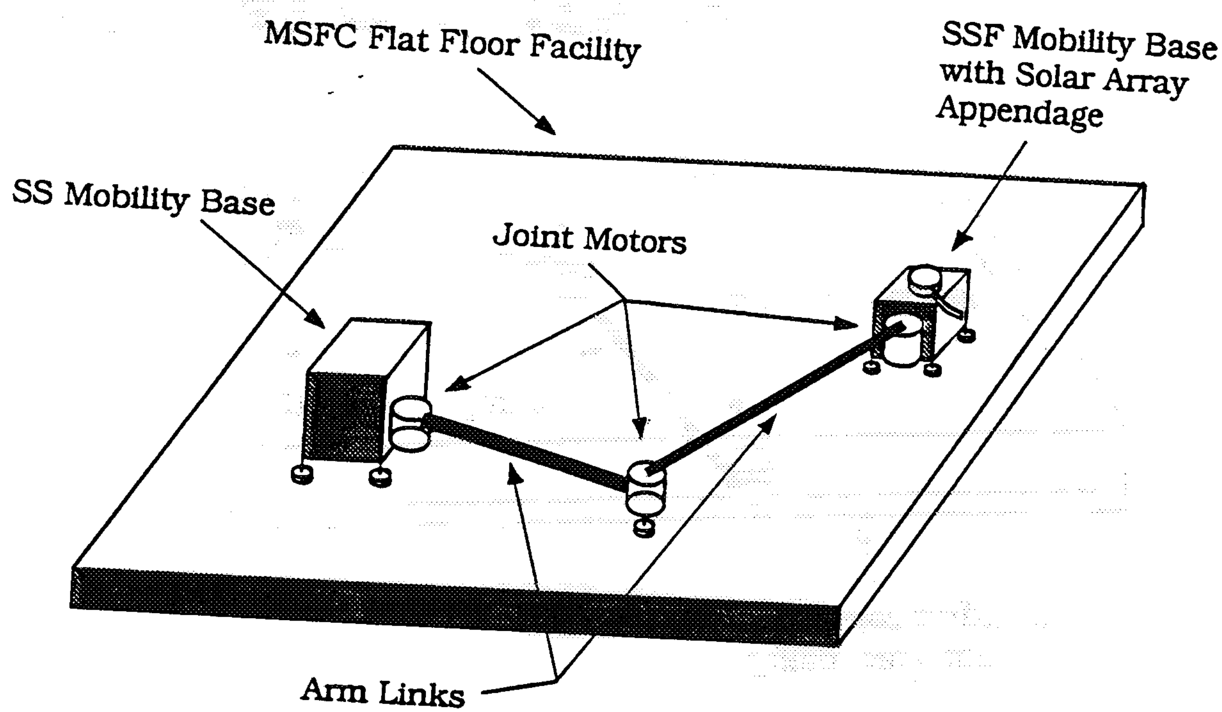
- Problem
- Research Facility
- Simulator
    - Overview
    - Modelling
    - System
- Results
- Concluding Remarks

Multi-Body Spacecraft Control Problem

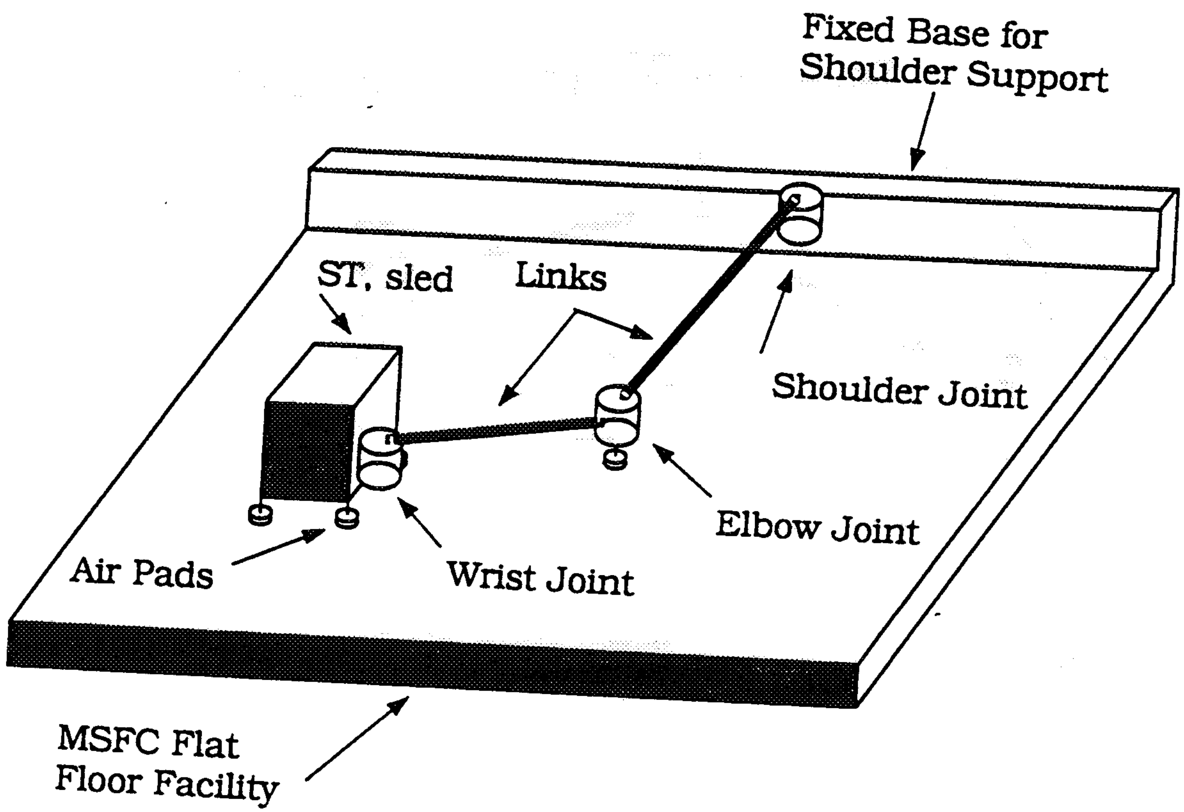
Space Station Berthing to the Space Shuttle



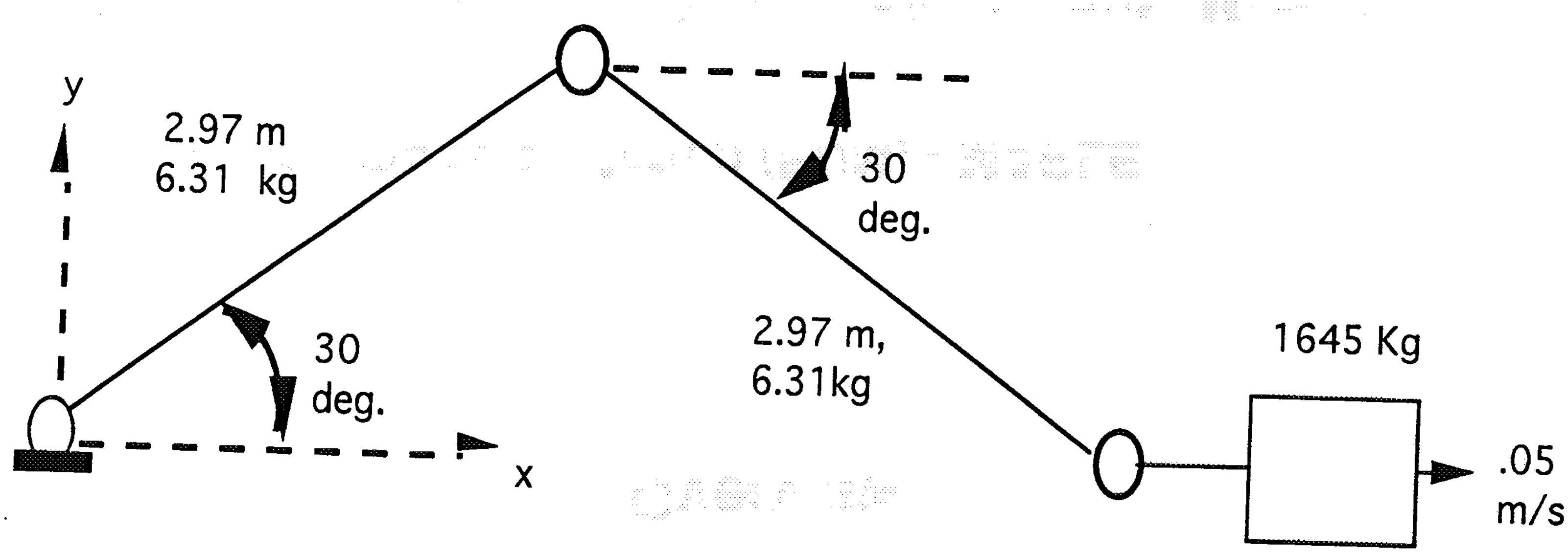
PLANNED RESEARCH TESTBED



CURRENT RESEARCH TESTBED



Physical Parameters



SIMULATOR

Overview

- Derive Equations of Motion (EOM) - MAPLE
- Numerically integrate EOM for a given input - MatrixX

SIMULATOR

Derivation of Equations of Motion

- Based on Lagrangian Formulation
- Employs Symbolic Manipualtion (MAPLE)
- Code for the Equations of Motion are generated in FORTRAN
- Equations are embedded in a usercode block of MatrixX

MODELLING

Equations of Motion

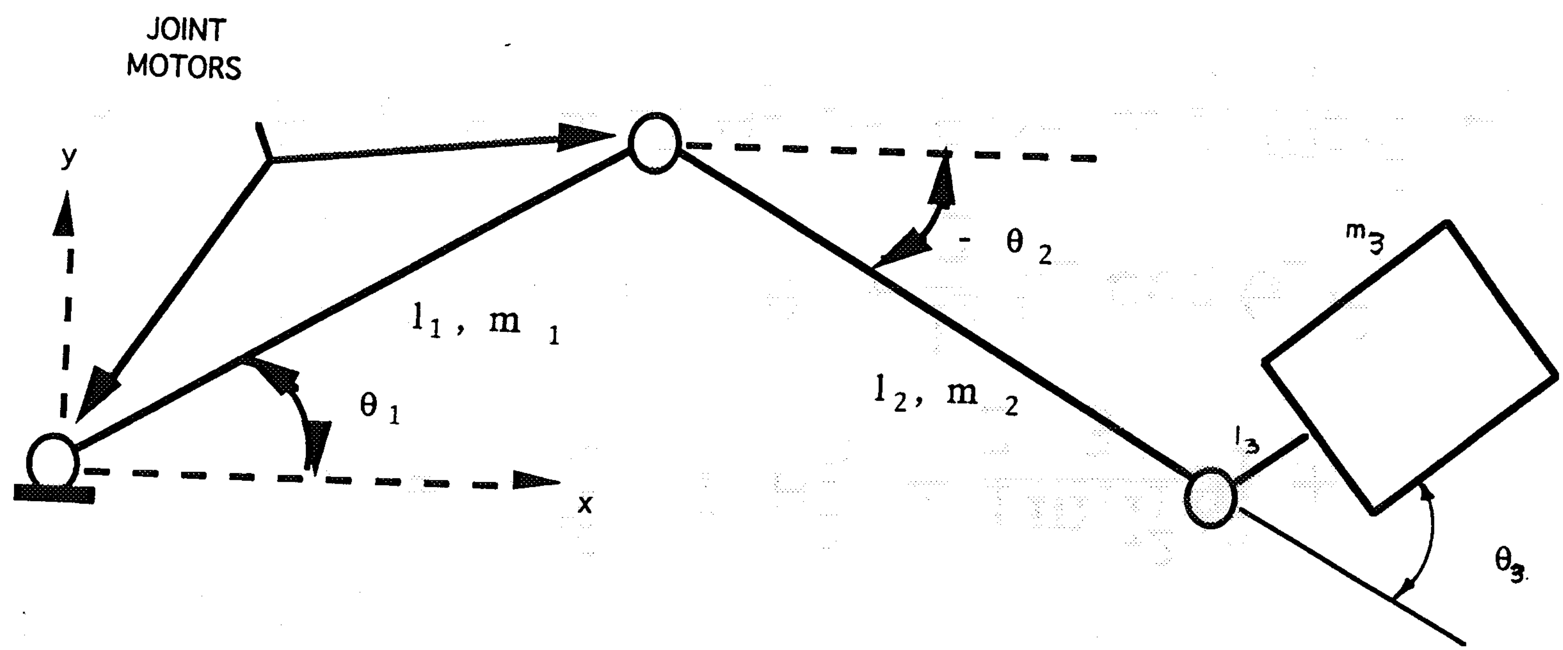
$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_i}\right) - \frac{\partial L}{\partial q_i} = \frac{\partial W}{\partial q_i} - \frac{\partial F}{\partial \dot{q}_i}$$

Lagrangian : $L = T - V$

Raleigh Dissipation : F

Virtual Work : W

System Model Used



MODELLING
(continued)

- **Kinetic Energy**

$$T = \frac{1}{2}\sum_{i=1}^{3} I_{S_i}\dot{\theta}_{S_i}^2 + \frac{1}{2}\frac{m_1 l_1^2}{3}\dot{\theta}_1^2 +$$

$$\frac{m_2}{2}[(l_1\,\dot{\theta}_1 \cos\theta_1 + \frac{l_2}{2}\,\dot{\theta}_2 \cos\theta_2)^2$$

$$+ (l_1\,\dot{\theta}_1 \sin\theta_1 + \frac{l_2}{2}\,\dot{\theta}_2 \sin\theta_2)^2] + \frac{1}{2}\,\frac{m_2 l_2^2}{12}\;\dot{\theta}_2^2$$

$$+ \frac{m_3}{2}\;[(l_1\,\dot{\theta}_1 \cos\theta_1 + l_2\,\dot{\theta}_2 \cos\theta_2 + l_3\,\dot{\theta}_3 \cos\theta_3{}^2$$

$$+ (l_1\,\dot{\theta}_1 \sin\theta_1 + l_2\,\dot{\theta}_2 \sin\theta_2 + l_3\,\dot{\theta}_3 \sin\theta_3{}^2\,]$$

MODELLING
(Continued)

Potential Energy

$$V = \frac{1}{2} k_{x_1} (\theta_1 - \theta_{s_1})^2 + \frac{1}{2} k_{x_2} (\theta_2 - \theta_{s_2})^2$$

$$+ \frac{1}{2} k_{x_3} (\theta_3 - \theta_{s_3})^2$$

Virtual Work $W = T_{E_1} \theta_{S_1} + T_{E_2}(\theta_{S_2} - \theta_1) + T_{E_3}(\theta_{S_3} - \theta_2)$

Raleigh dissipation

$$F = \frac{1}{2} k_{v_1} (\dot{q}_1 - \dot{q}_{s_1})^2 + \frac{1}{2} k_{v_2} (\dot{q}_2 - \dot{q}_{s_2})^2 + \frac{1}{2} k_{v_3} (\dot{q}_3 - \dot{q}_{s_3})^2$$

EQUATIONS OF MOTION

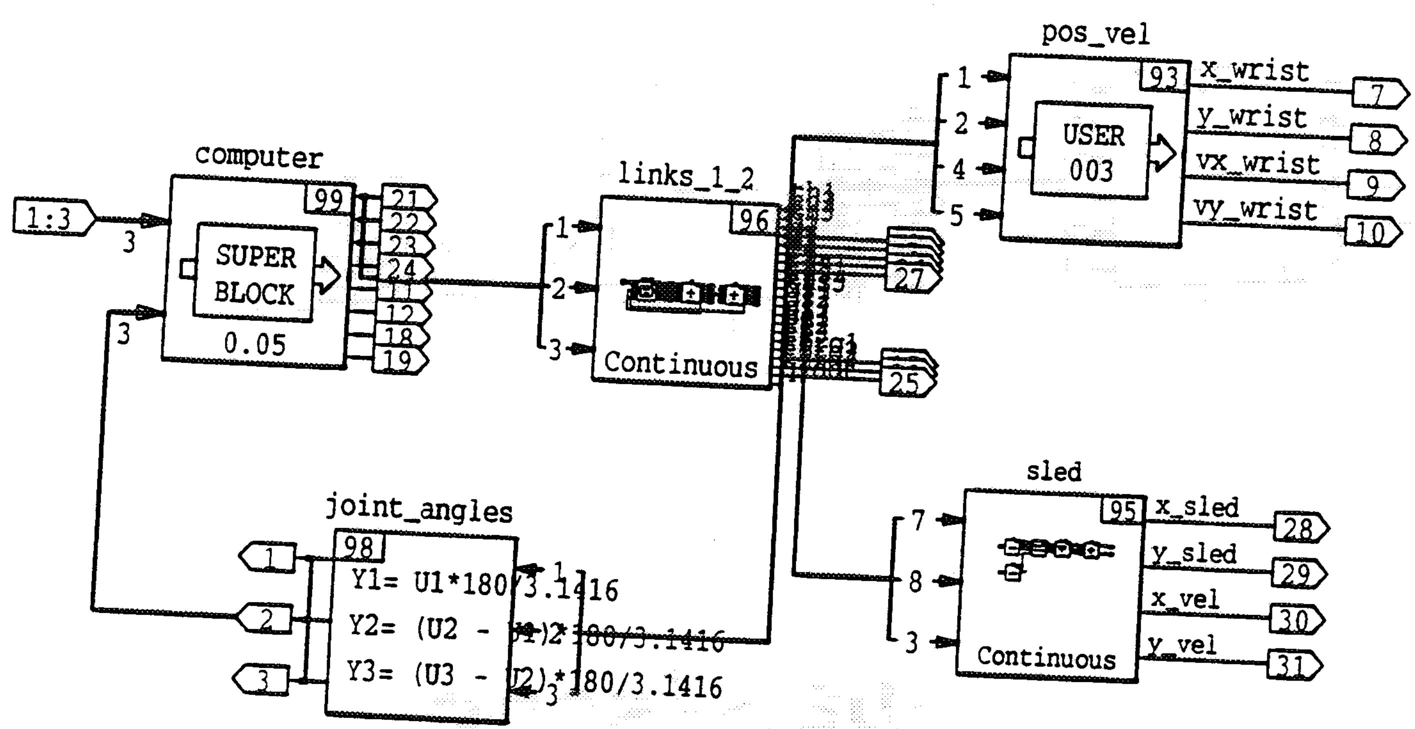
- **Coupled non-linear ODE s**

$$\mathbf{M}(\theta)\ddot{\theta} + \mathbf{C}(\theta,\dot{\theta})\dot{\theta} + \mathbf{K}\theta = \mathbf{Q}$$

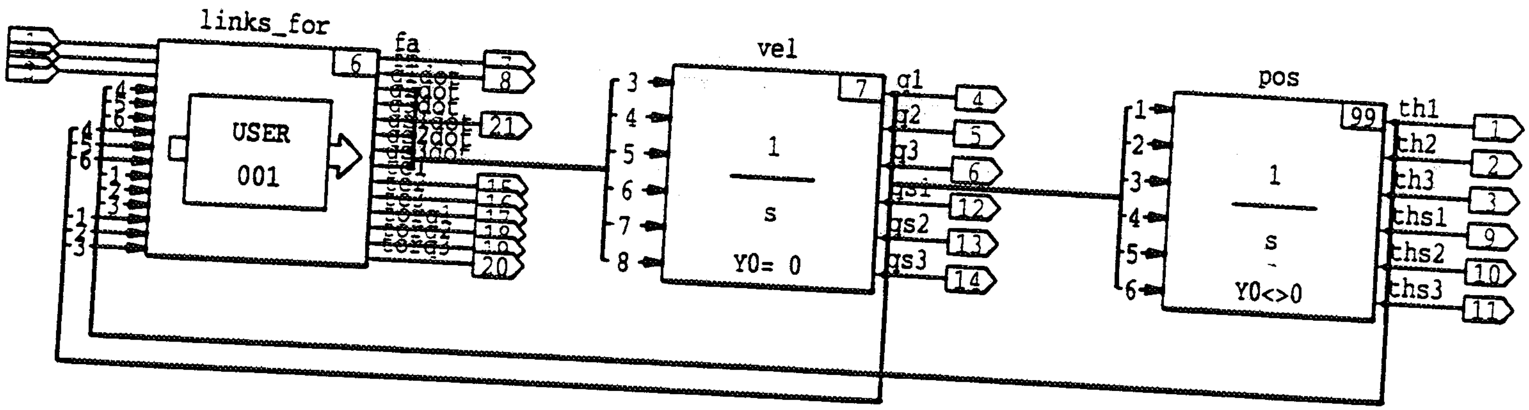
$$\ddot{\theta} = \mathbf{M}^{-1}(\theta)\,(\mathbf{Q} - \mathbf{C}(\theta,\dot{\theta})\dot{\theta} - \mathbf{K}\theta)$$

Matrix inversion done symbolically by MAPLE

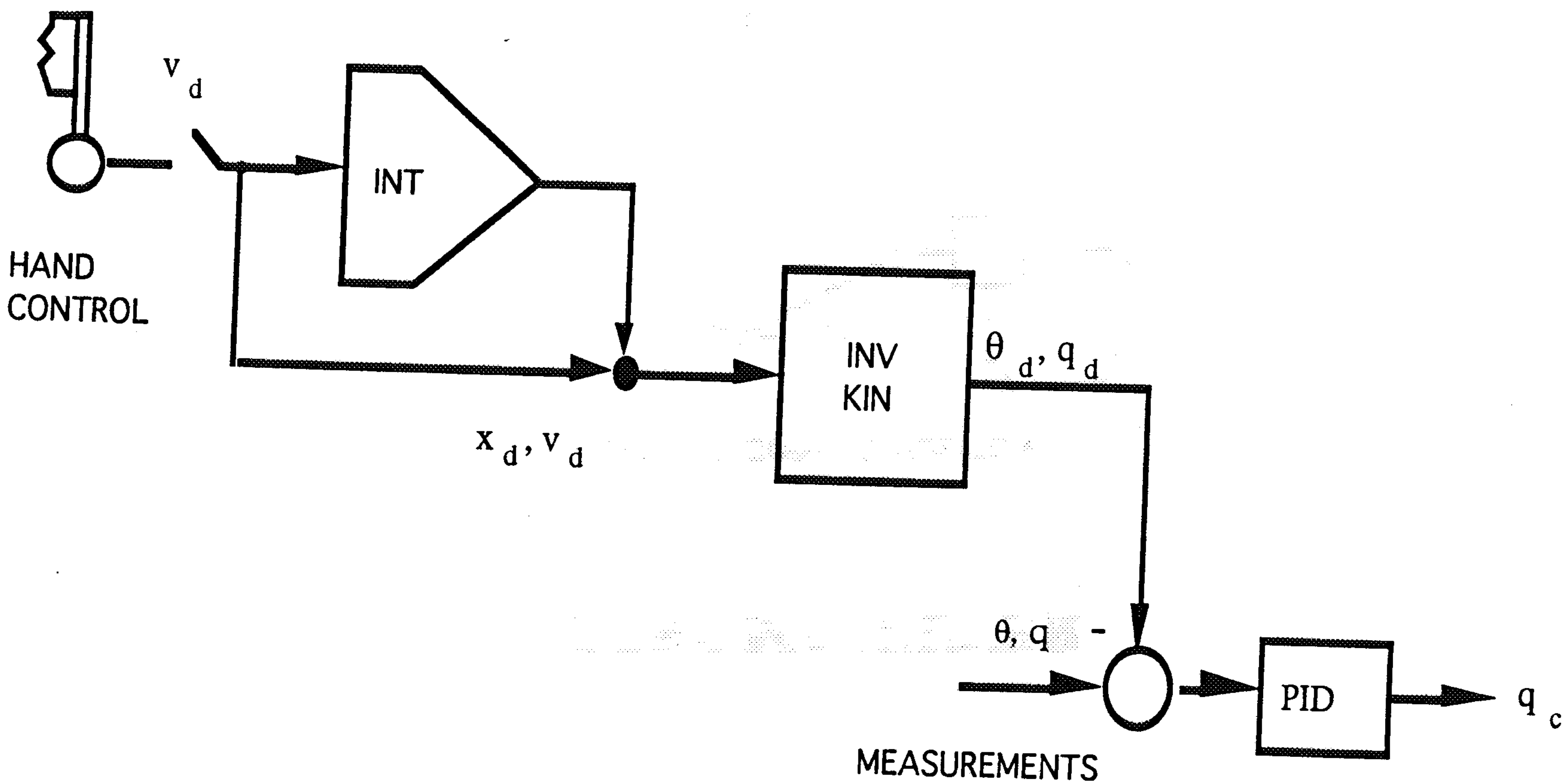
System Simulator



Subsystem

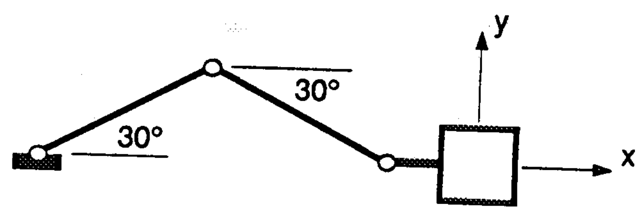

links_for
USER
001
fa
vel
1
s
Y0= 0
q1
q2
q3
qs1
qs2
qs3
pos
Y0<>0
th1
th2
th3
ths1
ths2
ths3

Control System

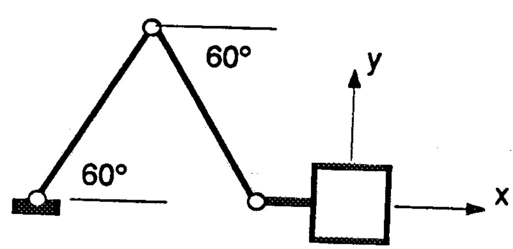


TEST MANEUVER

INITIAL CONFIGURATION



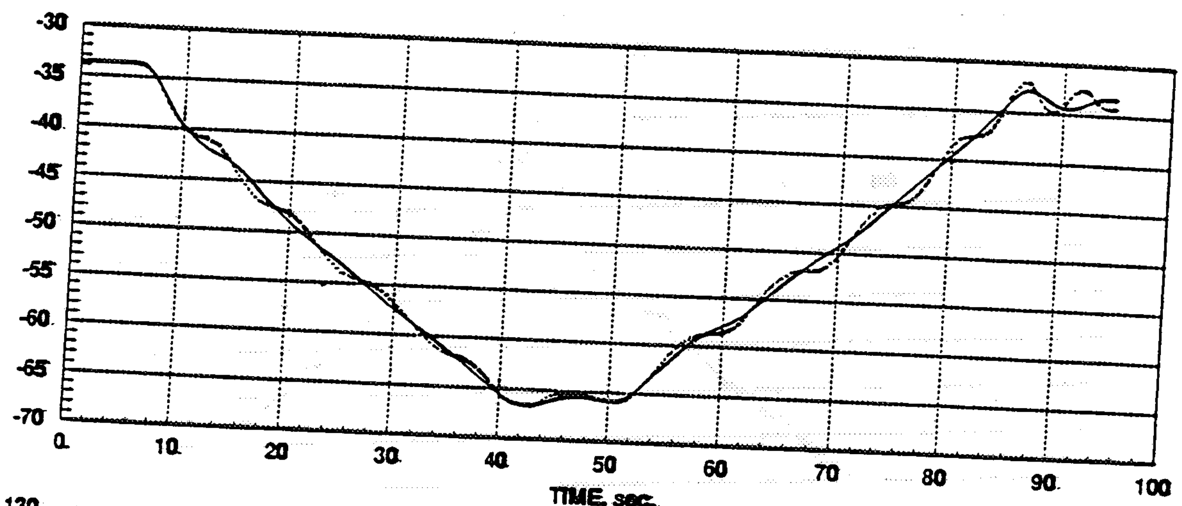
RETRACTED CONFIGURATION



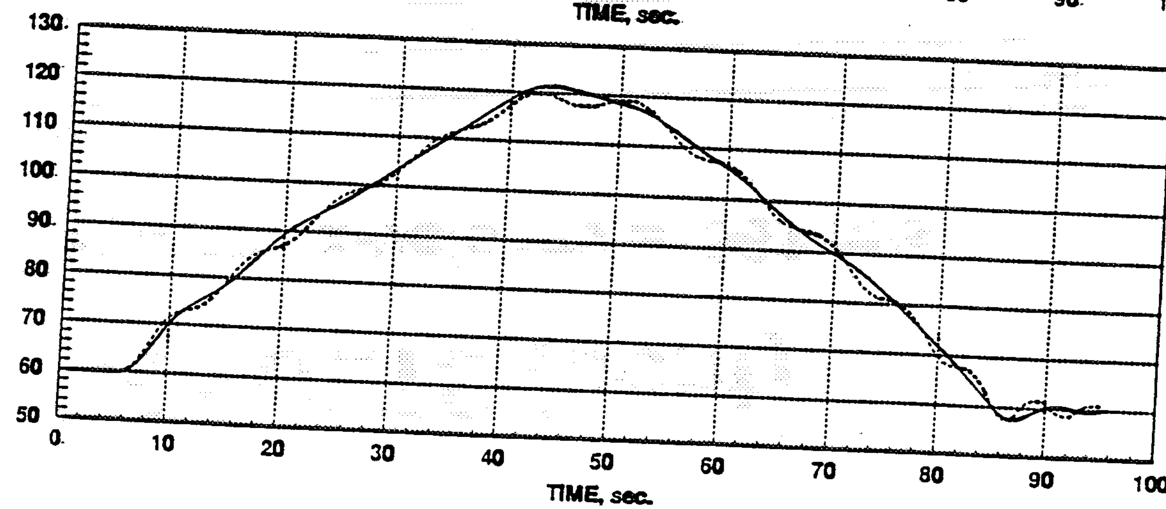
RESULTS

Payload x-velocity = .061 m/s

Shoulder joint angle, deg.



Elbow joint angle, deg.

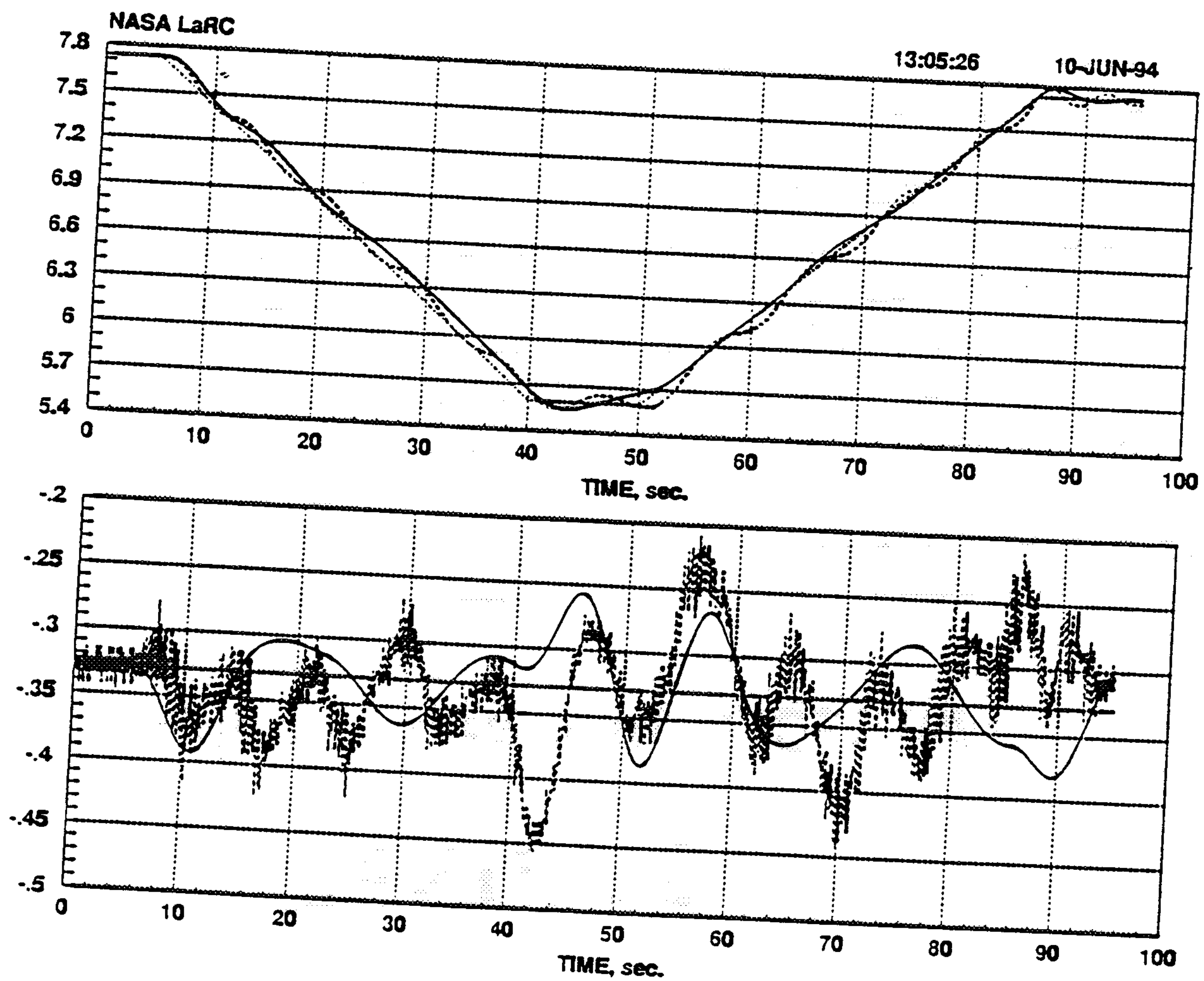


RESULTS (cont)

Payload x-velocity = .061 m/s

X disp, m

Y disp, m



Concluding Remarks

- Results are encouraging
- Simulation tools used effectively
- Improvements needed in modelling

SESSION 10 Languages

Chaired by

Robert F. Estes

10.1 Object Oriented Numerical Computing in C++ - John Van Rosendale

10.2 Hardware Description Languages - Jerry H. Tucker

10.3 High Performance FORTRAN - Piyush Mehrotra