cSc

Dynamics of On-Orbit Construction Process

Good progress in only 5 months? effort.

K.C. Park

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Contents of Presentation

- Problem Definition and Motivation
- Survey of Current Technology
- Focus Problems
- Approach
- Progress/Discussion
- Future Direction and Anticipated Results

Problem Statement and Motivation

- In-space structural construction technology is yet to be demonstrated even for the planned space station.

- Construction procedures, logistics, the shuttle deployment duration for each flight are criticallydictated by how well we understand the interaction dynamics when two modules are assembled together.

- The interaction dynamics is, from the outset, an interdisciplinary problem, involving the multibody dynamics, the dynamics of the RMS, the control of maneuvering and contact/impact surge forces, and possibly also the shuttle attitude dynamics and control.

Existing Applicable Technology

- Truss Assembly Experiment in Buoyancy Tank
- In-Space Shuttle-Based Deployment of Solar Panel and Truss
- Den Hartog-Like Shock Isolation Elements
- Contact/Impact Predictability via Simulation ***Ren Su**
- High-Precision Flexible Multibody Simulation
- Adaptive Elements for Localized Shock Mitigation
- Fast Real-Time Control and Simulation

The Present Focus Problem

"Dynamics of On-Orbit Structural Construction"

- To identify the required forces for structure-structure rendezvous vs. construction/maneuvering speed
- To perform accident scenarios for safeguarding of unanticipated human/RMS operational mistakes
- To conduct trade-off studies between passive and active control of contact/impact mechanisms
- To perform integrated simulations involving the structural dynamics, RMS control maneuvering, and the shuttle orbital attitude dynamics/control
- And, finally, to assist the designers of "structural-structural rendezvous" mechanism devices in the evaluation of candidate devices.

Objectives

- Librational Motion of the Space Shuttle
- The Interaction of SRMS Motions and Attitude Dynamics
- Transient Vibrations of Shuttle/SRMS Combination
- The Starting and Stopping Strategies While Maneuvering SRMS
- Contact/Impact Behavior of SRMS with/without Payload
- Identify Possible Dynamic Instability and/or Control Requirements

Present Approach

1. Conduct the orbital perturbation effects of the shuttle due to rendezvous/disengagement of the shuttle from the space station and/or the structural payload to be assembled.

2. Construct RMS model (both rigid and flexible) and study the dynamics of RMS maneuvering scenarios.

3. Perform simple rigid-rigid, rigid-flexible, flexible-flexible contact/impact analysis vs. rendezvous speeds.

4. Establish dynamics/control operational requirements from the above three studies.

5. Develop "rendezvous" elements or concepts.

6. Develop simulation modules for others to use for the study of in-space construction procedures.

Progress (June – November, 1991)

- Modeling of shuttle perturbations due to possible construction disturbances
- SRMS modeling as an integral part of structural cargo maneuvering
- Study of a simple rendezvous dynamics model
- Development of 3-D special-purpose dynamics simulation
- Parameter study of assembly speeds vs. contact forces

Findings and Discussion

- For Trajectory/Motion Study only, one can employ rigid SRMS, rigid structural cargo models; however, for controlling multiple-contact assembly, dynamic flexible models of both SRMS and structural modules are necessary.

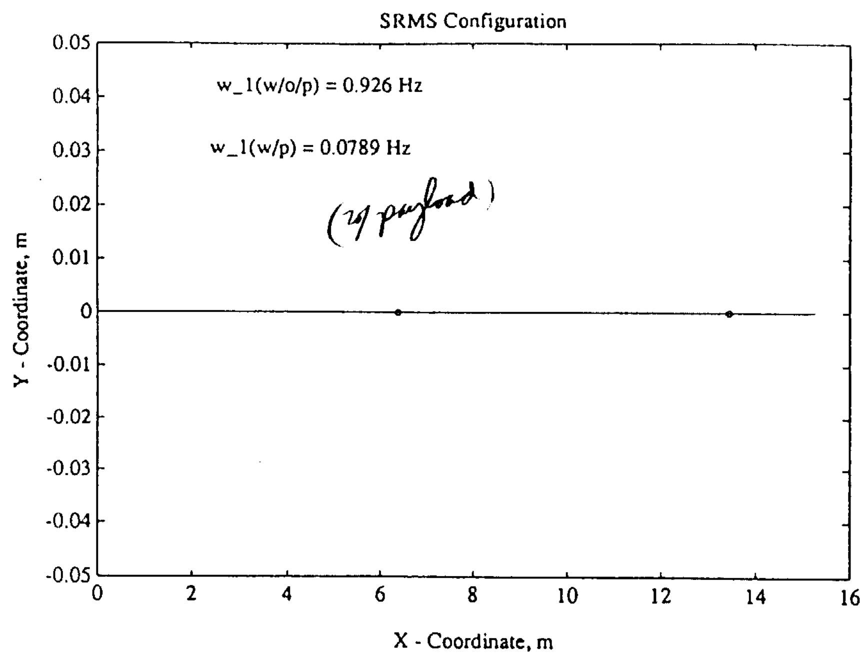
- If high-precision assembly is of primary concern, adaptive devices that absorb the contact surge stresses, and at the same time self-correct the dimensional errors can significantly improve the in-space structural assembly.

- No matter how slowly and carefully the assembly is to be carried out, an integrated dynamics model is important for assessing 'unwanted' abort maneuvering, accidents, safety margin (operational) evaluations.

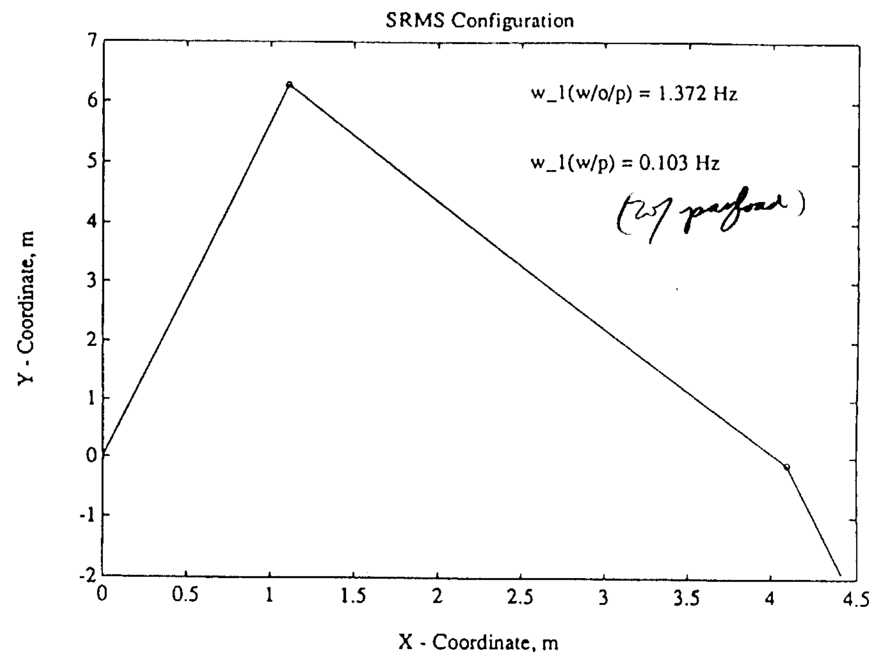
Future Activities and Anticipated Results

- Make our Multibody Simulator available to NASA/Langley team for shuttle-based structural assembly evaluations as an alternative tool.
- 3-Dimensional flexible multipoint assembly contact evaluations.
- Integrated simulation of structures, SRMS, shuttle orbital attitude motions.
- Development of Design Concepts for structure-structure Rendezvous Mechanism Devices.

Frequency Variations During Manuevering of SRMS

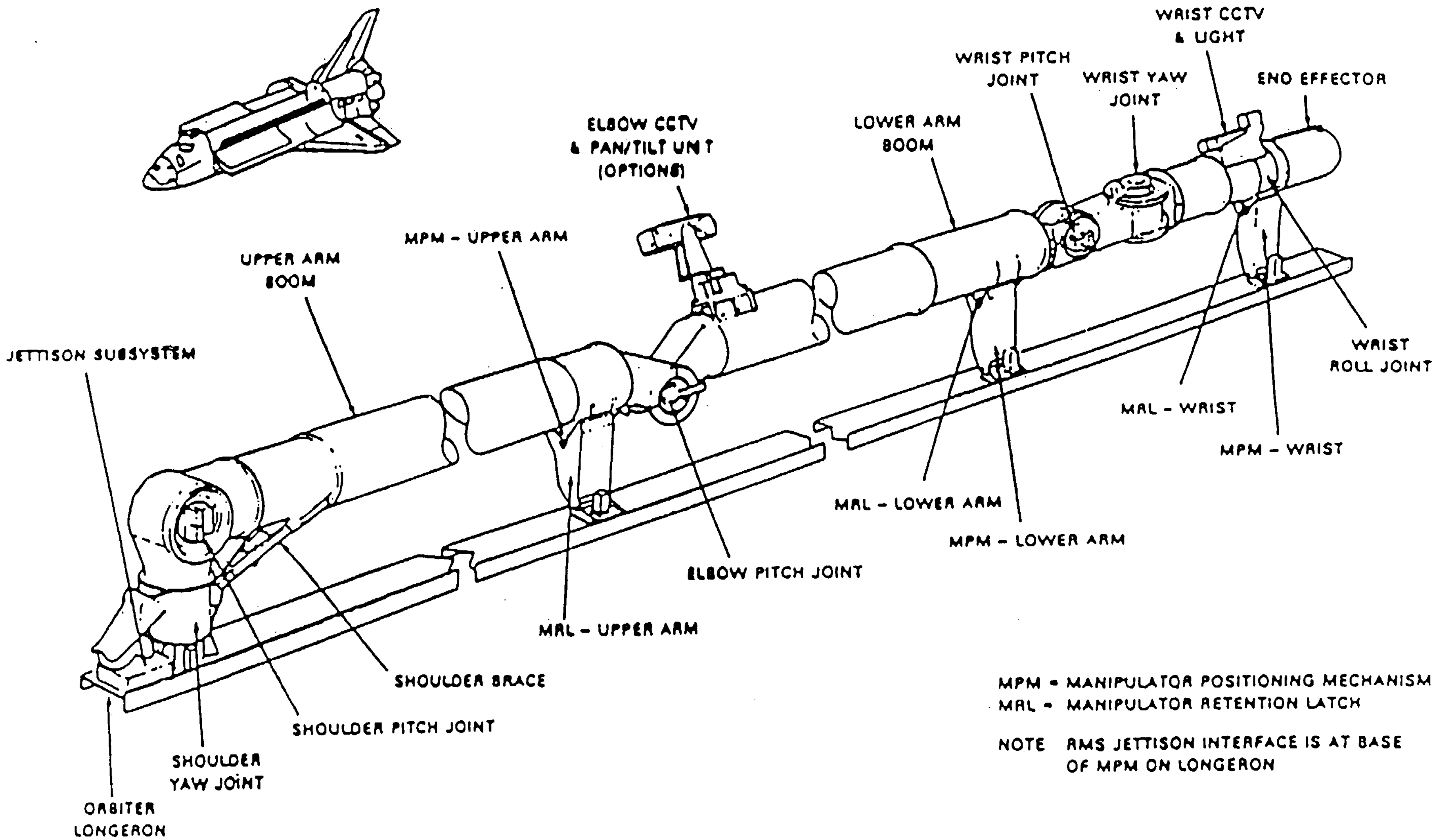


Straight Position



Intermediate Position

Question: How effective can linear control strategies be for changing frequencies and mode shapes?

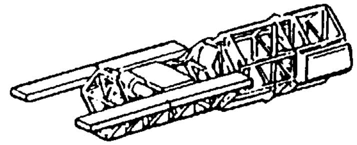


MPM = MANIPULATOR POSITIONING MECHANISM
MRL = MANIPULATOR RETENTION LATCH

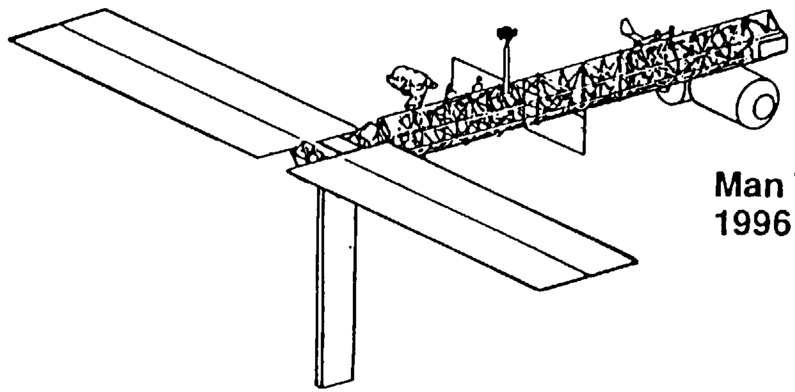
NOTE RMS JETTISON INTERFACE IS AT BASE OF MPM ON LONGERON

Figure 1 SRMS Mechanical Arm in Stowed Position

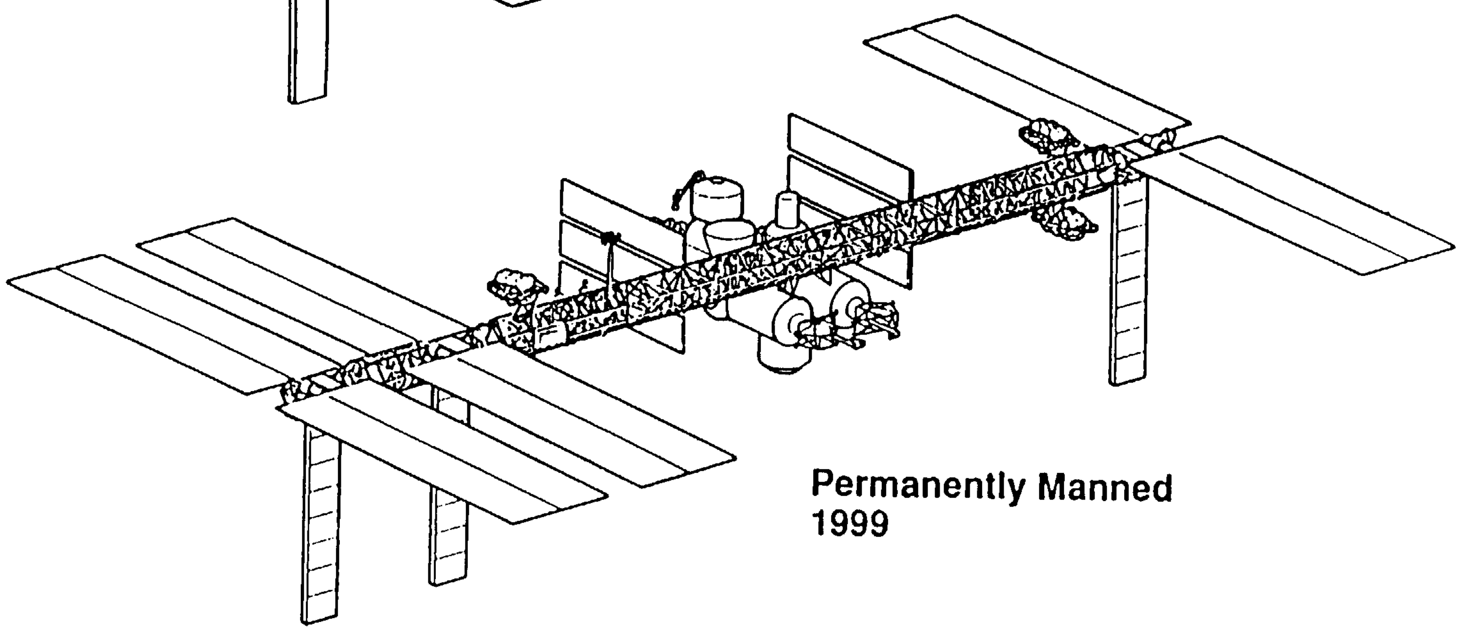
SPACE STATION FREEDOM ASSEMBLY SEQUENCE



First Element Launch
1995

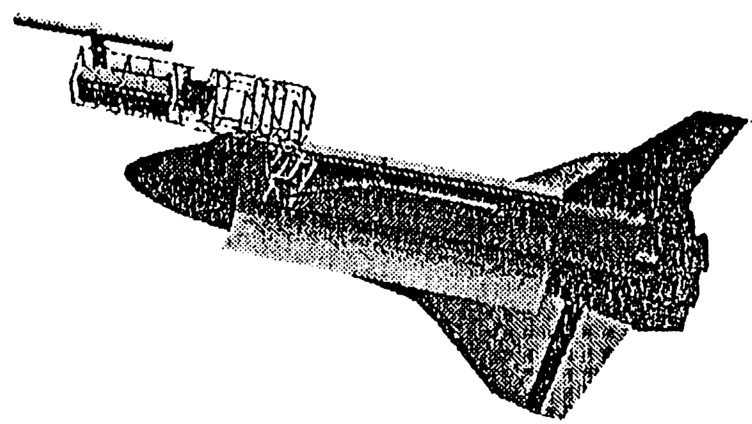


Man Tended Capability
1996

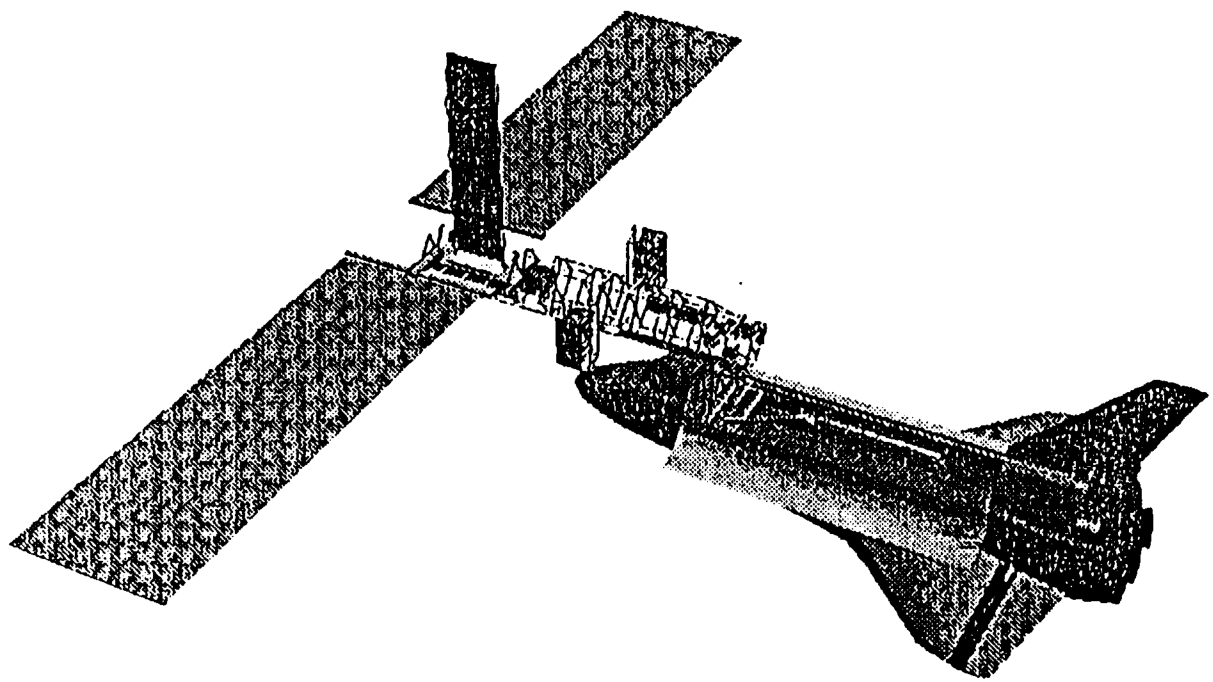


Permanently Manned
1999

MB-1

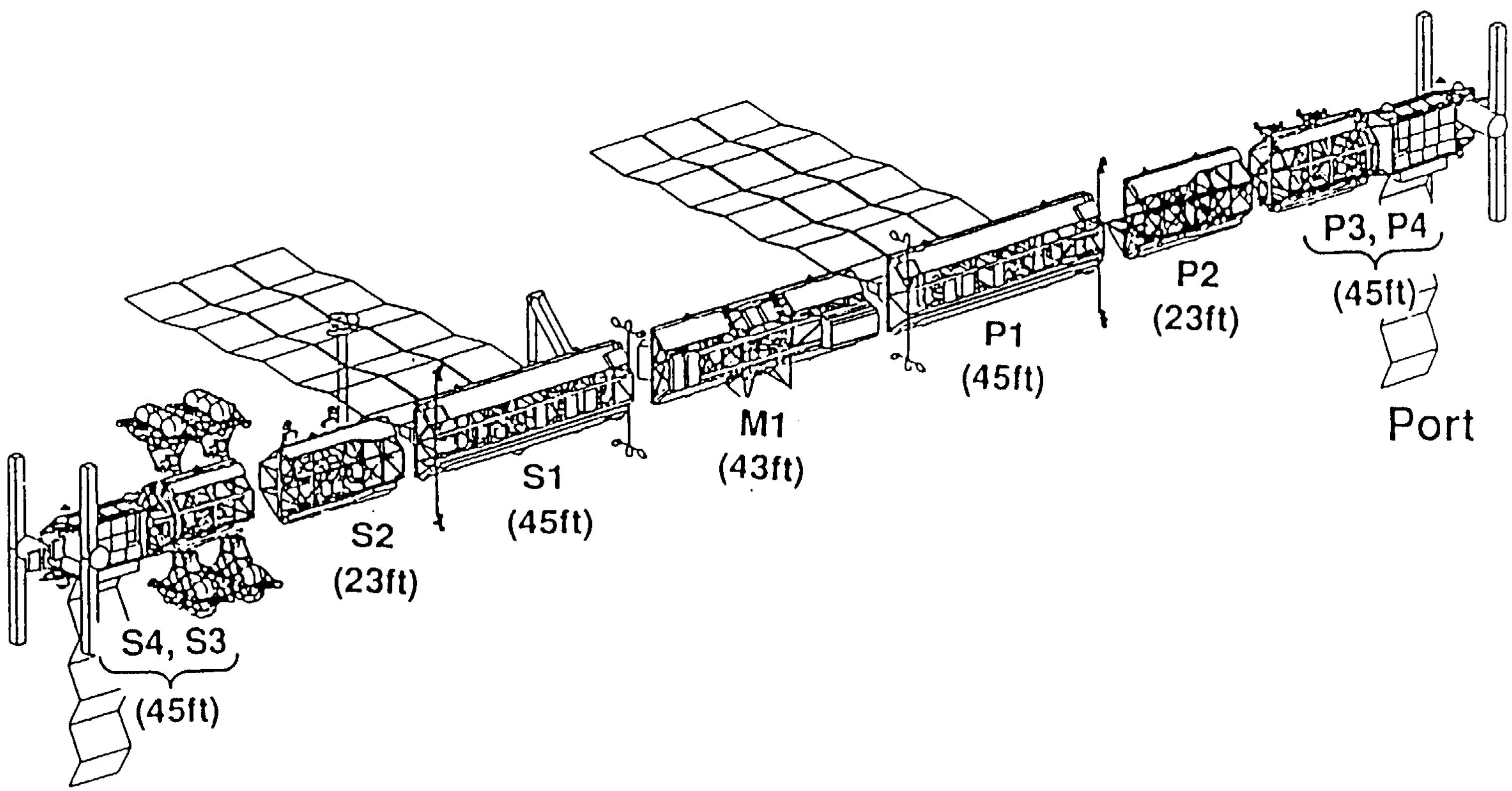


MB-2



THE SEGMENTS

VKB253 M3EL



Librational Motion of a Space Shuttle

- 100 minutes circular orbit
- $(I_{xx} - I_{zz})/I_{yy} = 1$
- Initial Disturbance: $\omega_1 = \omega_3 = 0, \omega_2 = -0.105$ deg/s

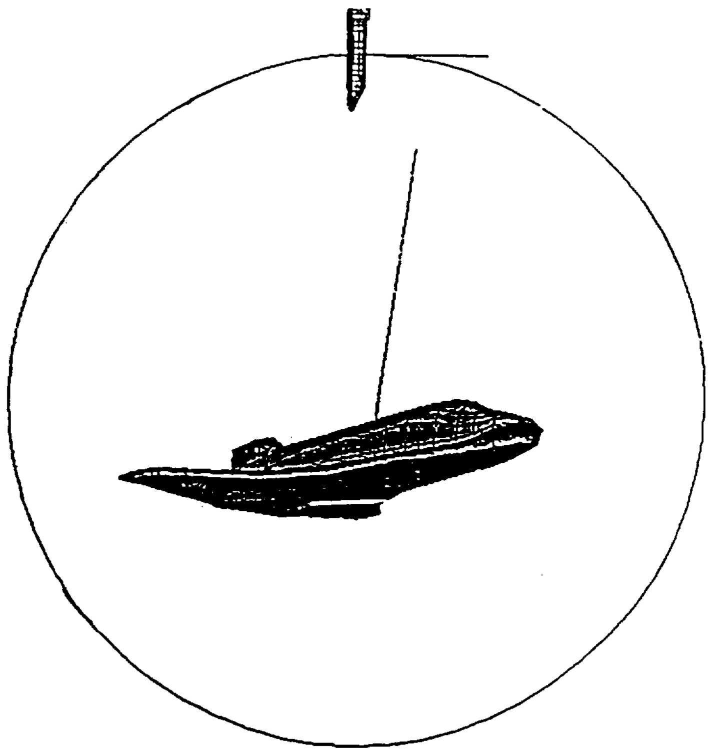


Fig. 1 Orbiting Space Shuttle with MRMS

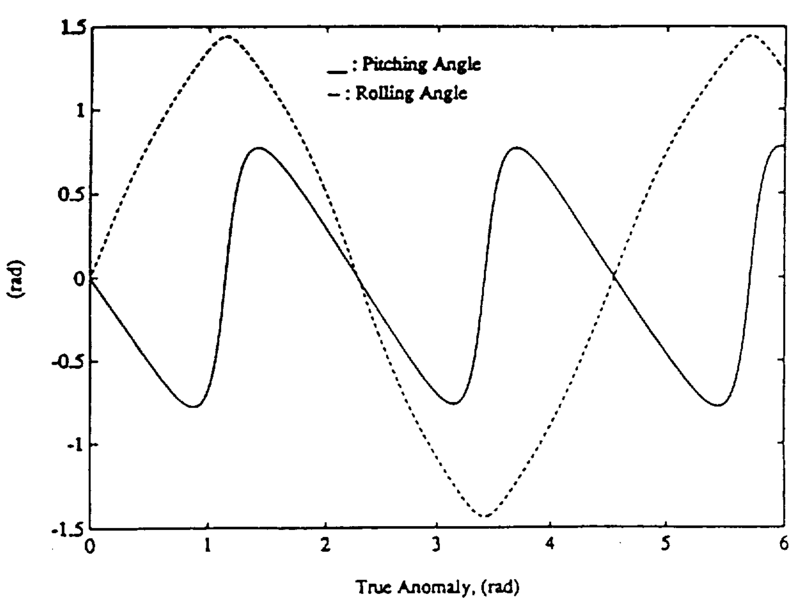


Fig. 2 Three Dimensional Librational Response

Librational Motion of a Space Shuttle

- $I_{xx}/I_{yy} = 0.958, \quad I_{zz}/I_{xx} = 0.126$
- (1) Initial pitching, rolling, yawing angles = 10 deg.
- (2) Initial pitching, rolling, yawing angles = 25 deg.

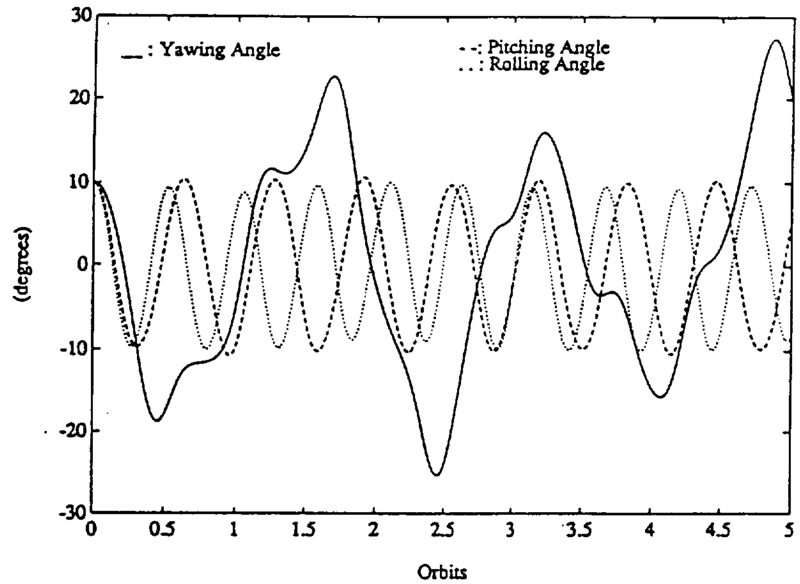


Fig. 3 Librational Response of a Space Shuttle Under Small Disturbances
Pitching Angle = Rolling Angle = Yawing Angle = 10 degrees

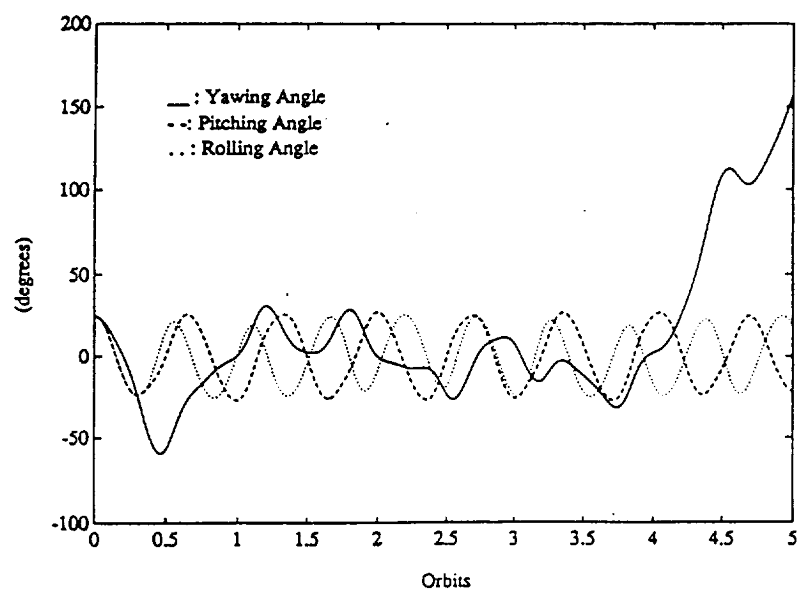
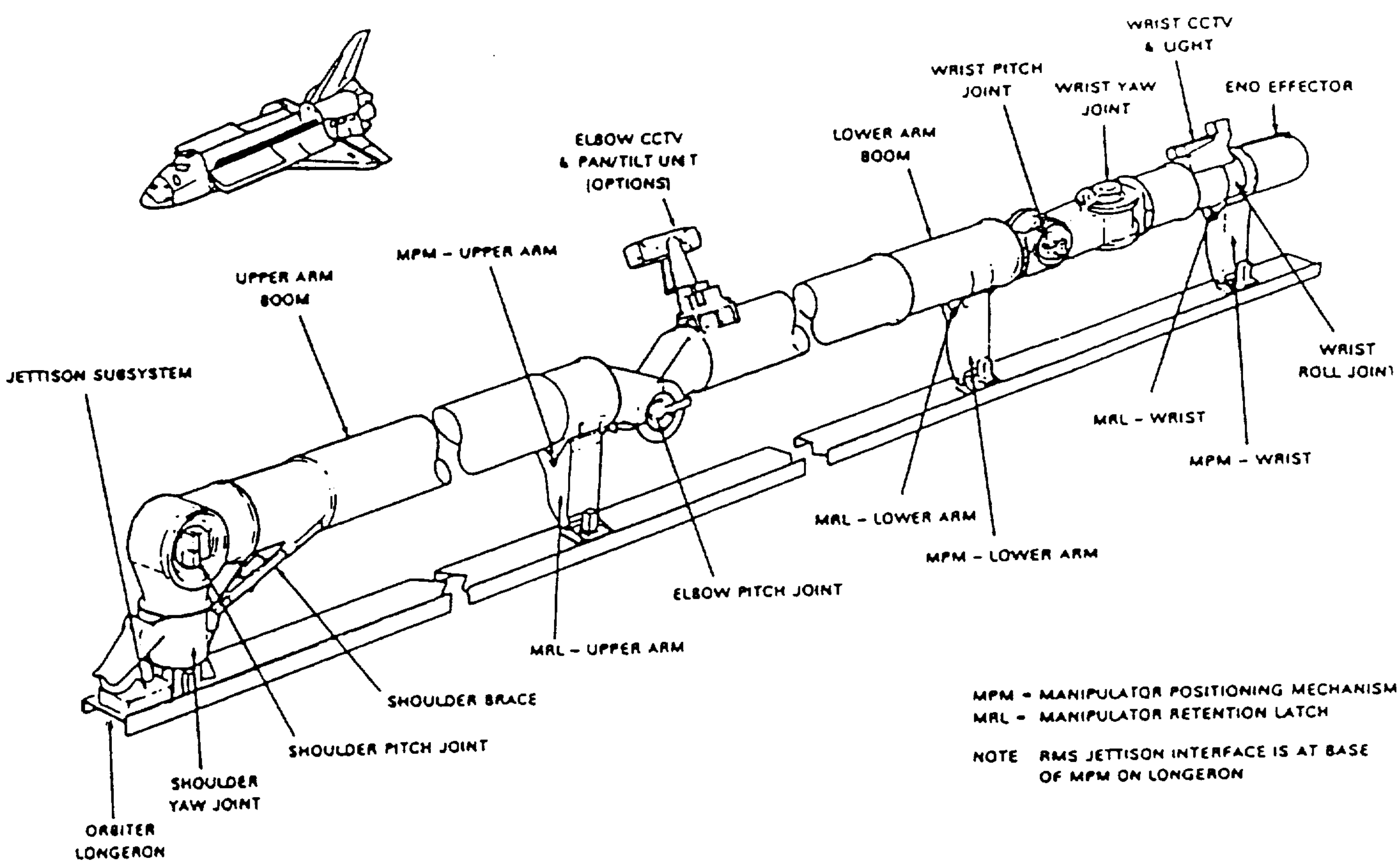


Fig. 4 Librational Response of a Space Shuttle Under Small Disturbances
Pitching Angle = Rolling Angle = Yawing Angle = 25 degrees

Maneuvering of Shuttle Remote Maneuverno Systems (SRMS)

Properties of SRMS:

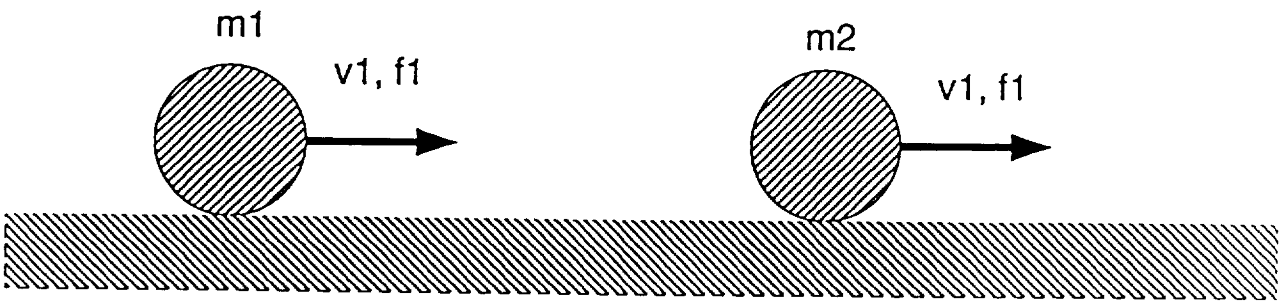
- Weight = 410 Kg
- Length = 15 m
- Cross Section Area = 0.0022 m^2
- Young's Module = 1.27 X 10^{11} Pa
- Shear Module = 3.18 X 10^{10} Pa
- Density = 1.2 X 10^4 Kg/m^3
- Tip Maneuvering Speed (without payload) = 0.6 m/s

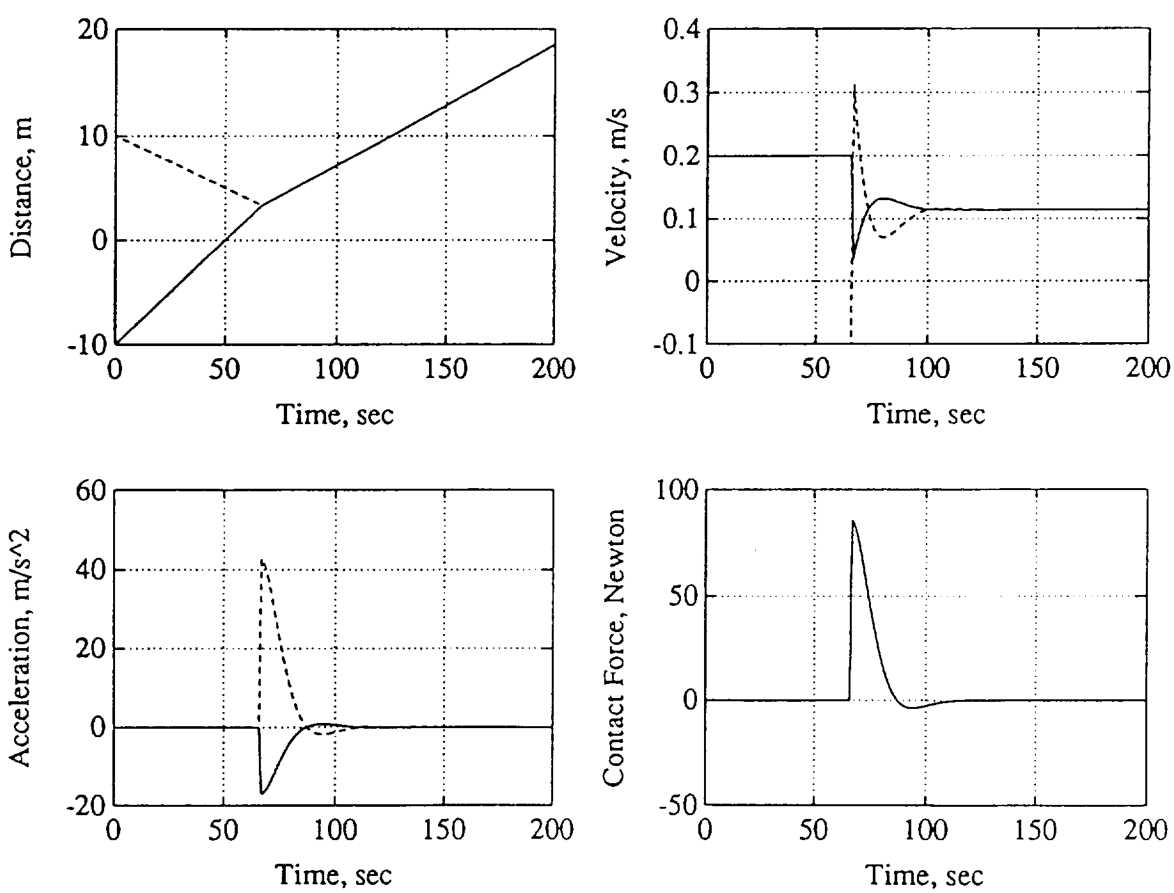


CONTACT/IMPACT OF 2 RIGID BALLS

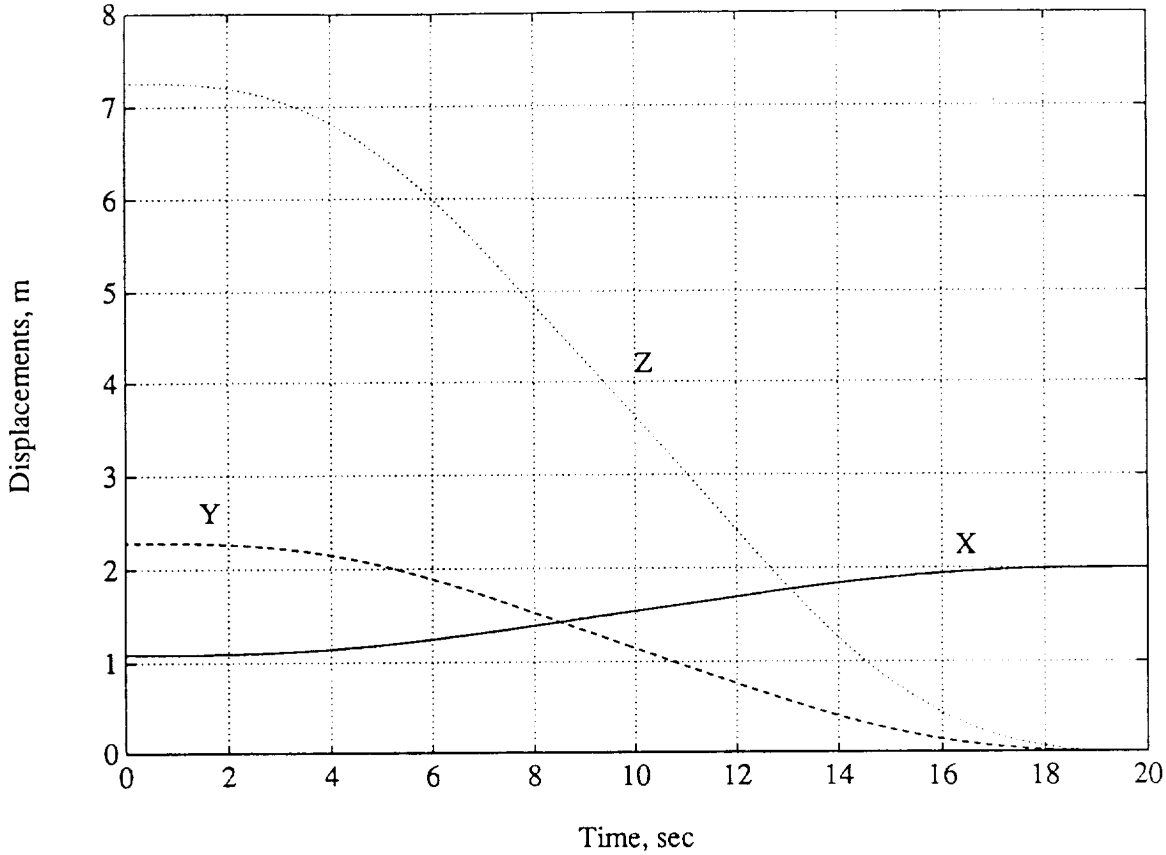
m1 = 5 kg,   m2 = 2 Kg

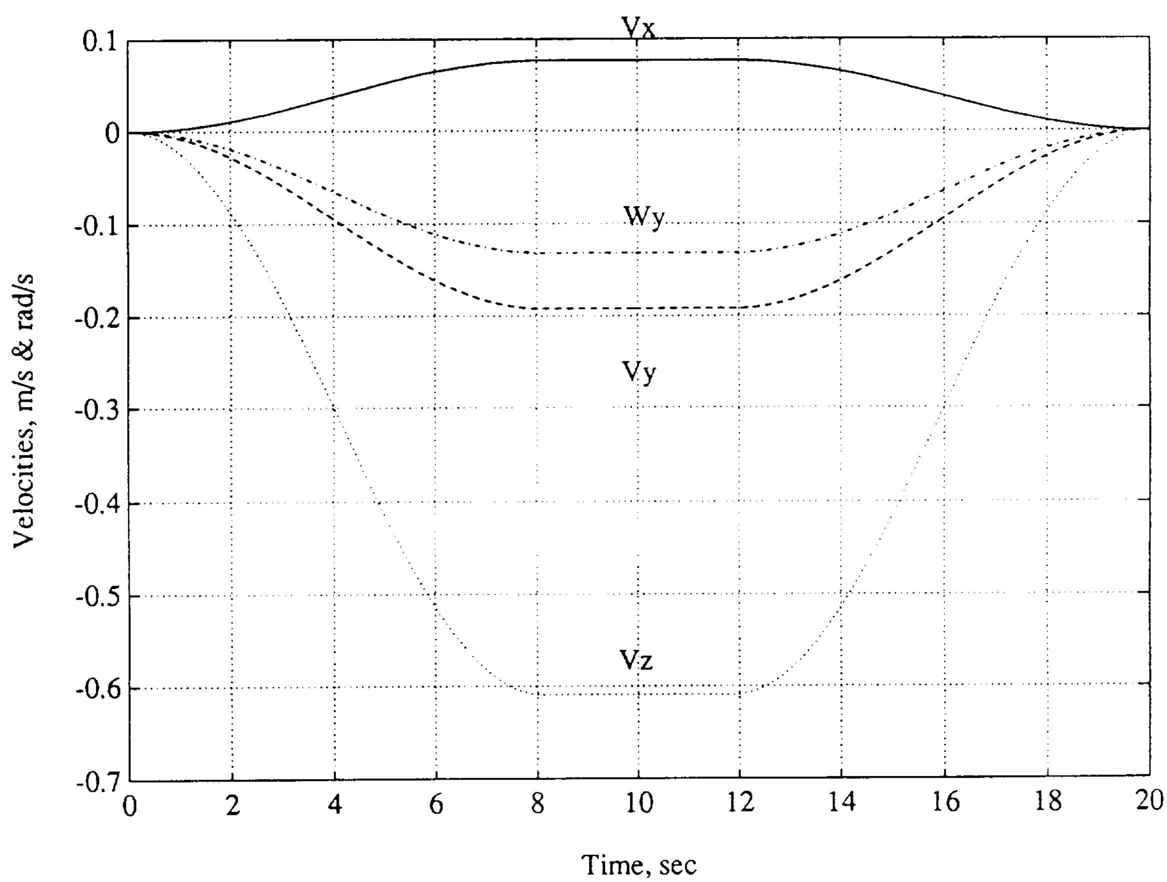
1) v1 = 0.2 m/s, v2 = - 0.1 m/s
2) f1 = 0.01 N,   f2 = - 0.008 N
3) v1 = 0.1 m/s, v2 = - 0.05 m/s, f1 = 0.01 N, f2 = -0.001 N

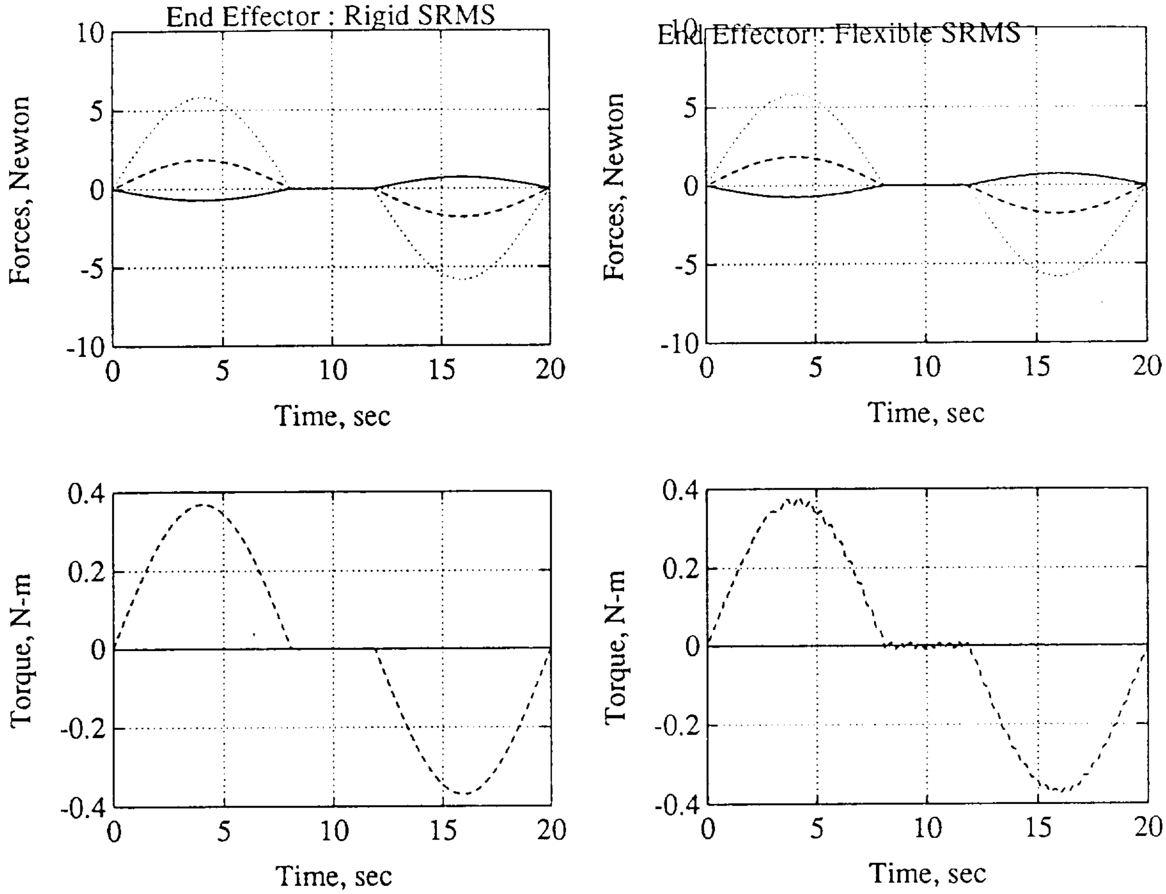


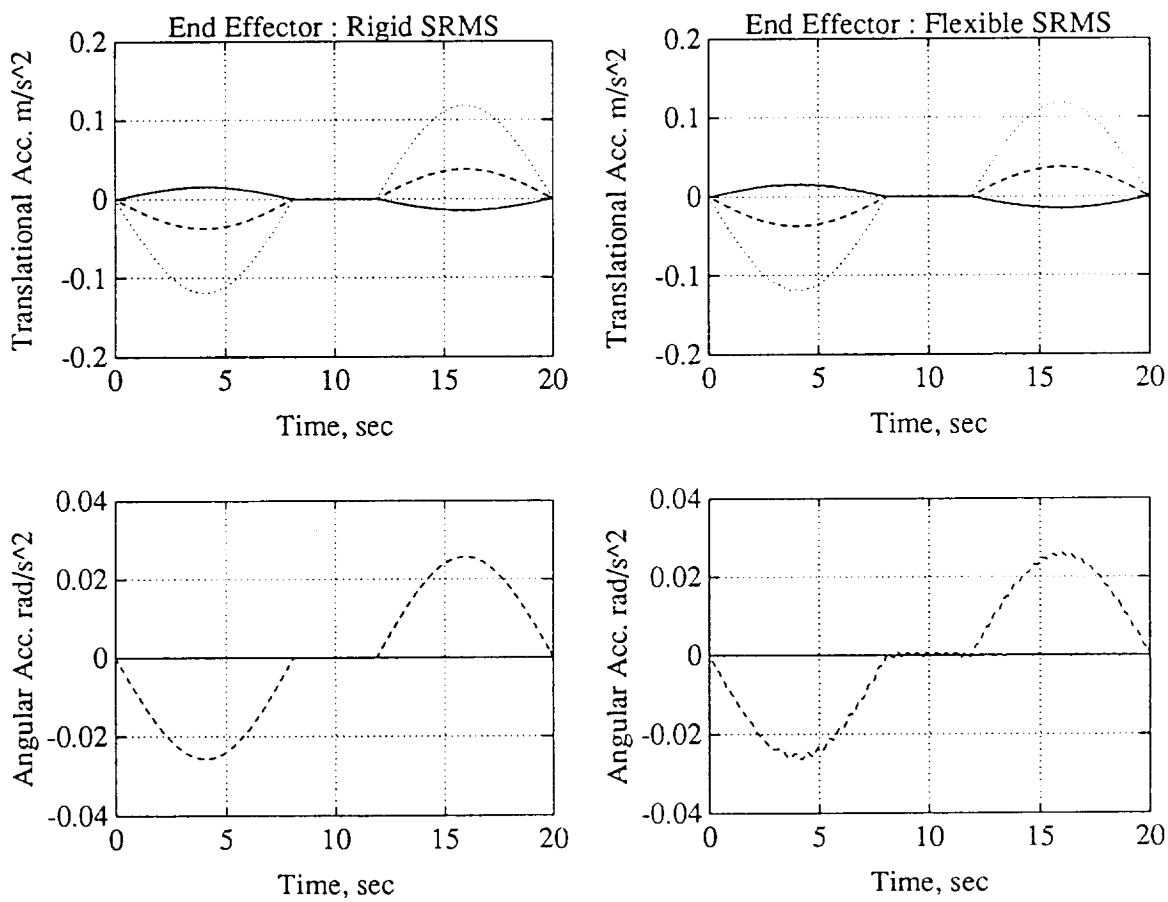


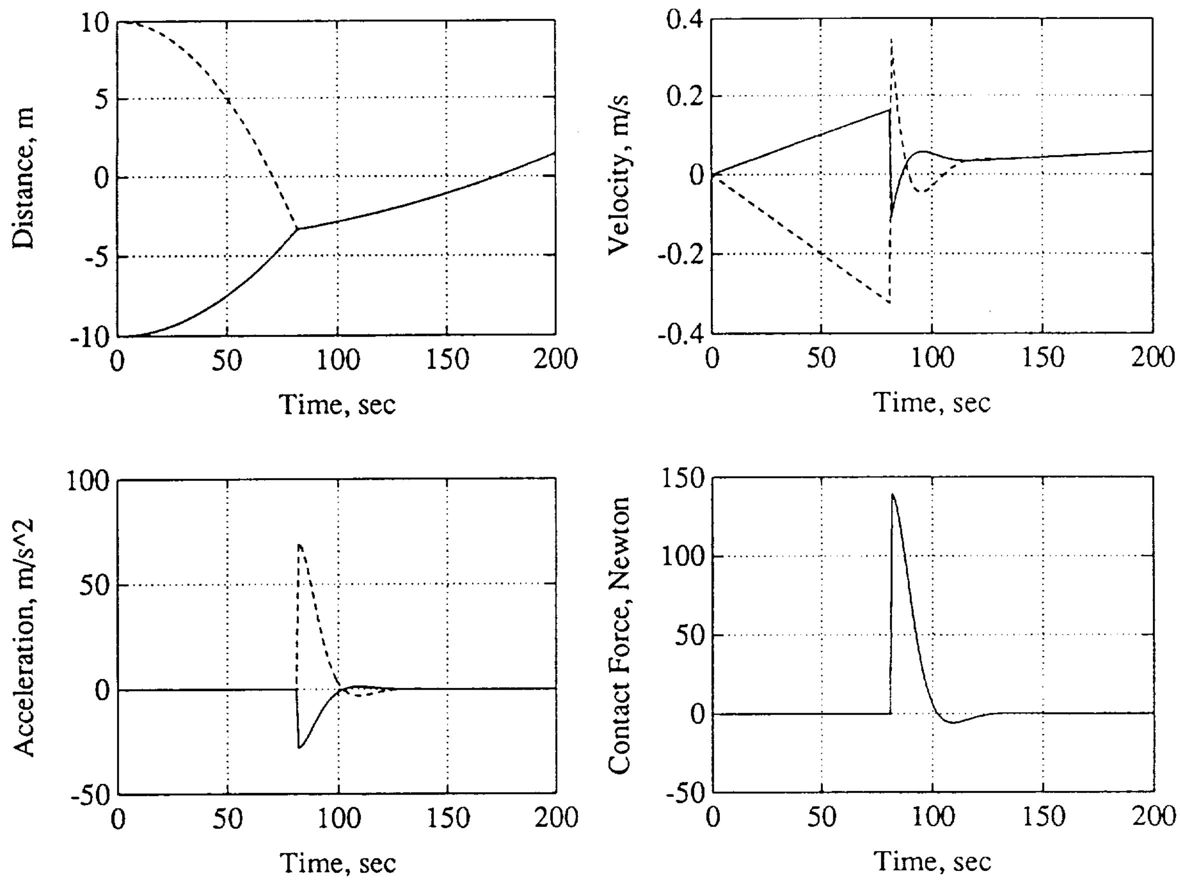
Tip Trajectory of Rigid & Flexible SRMS

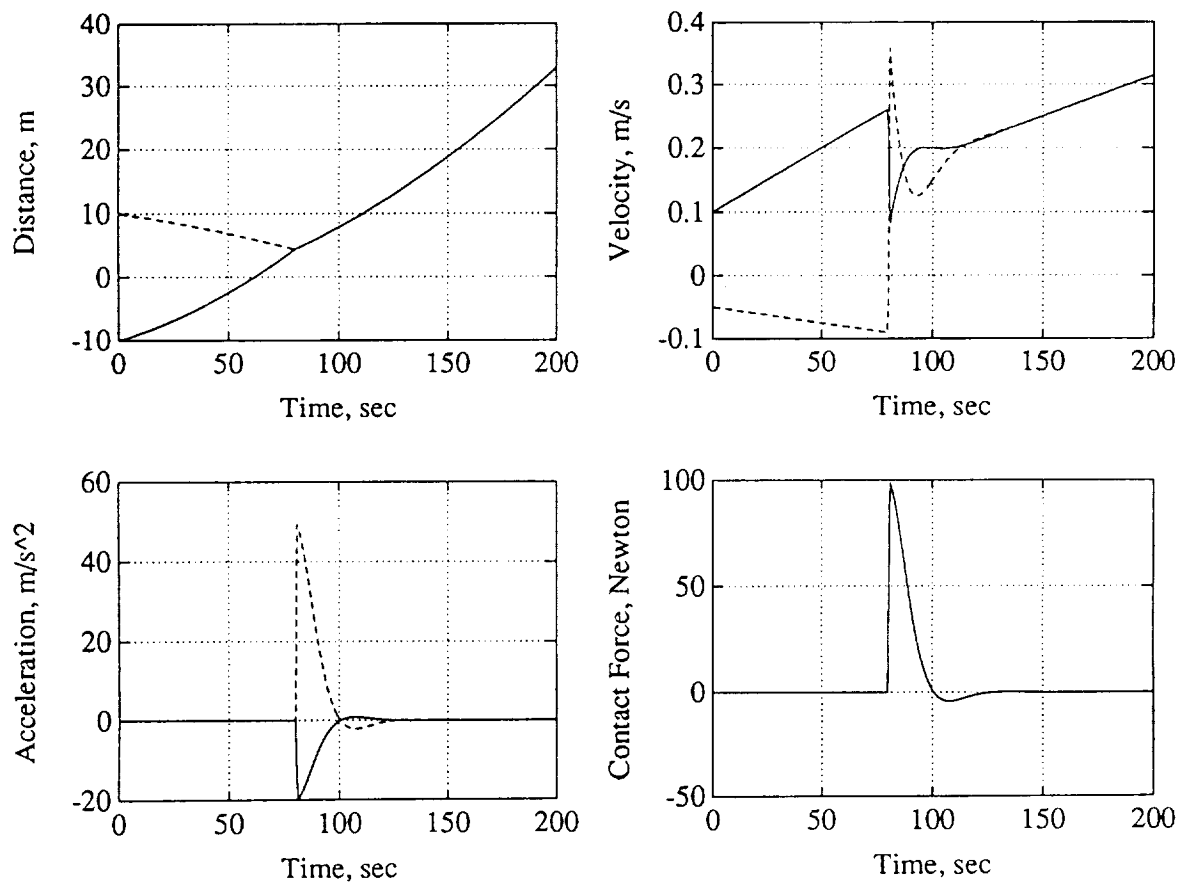


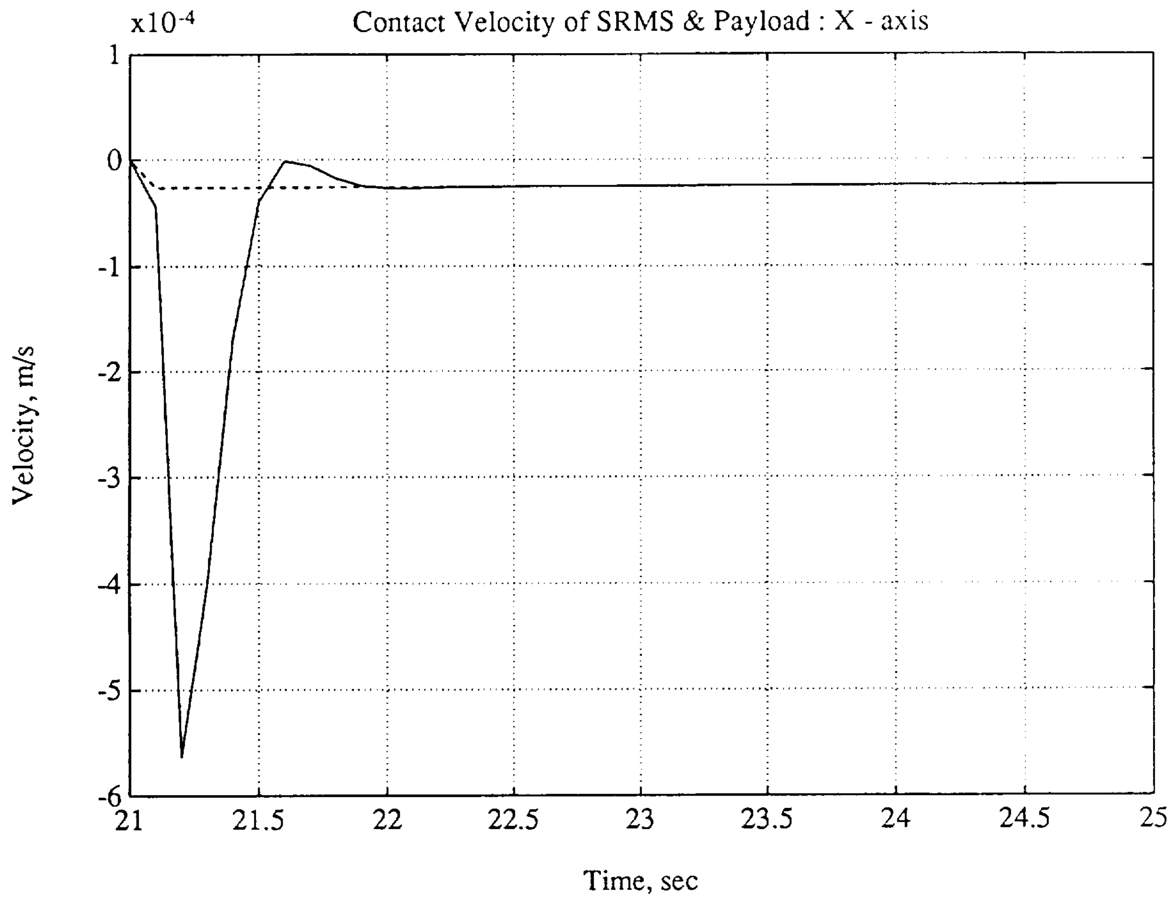


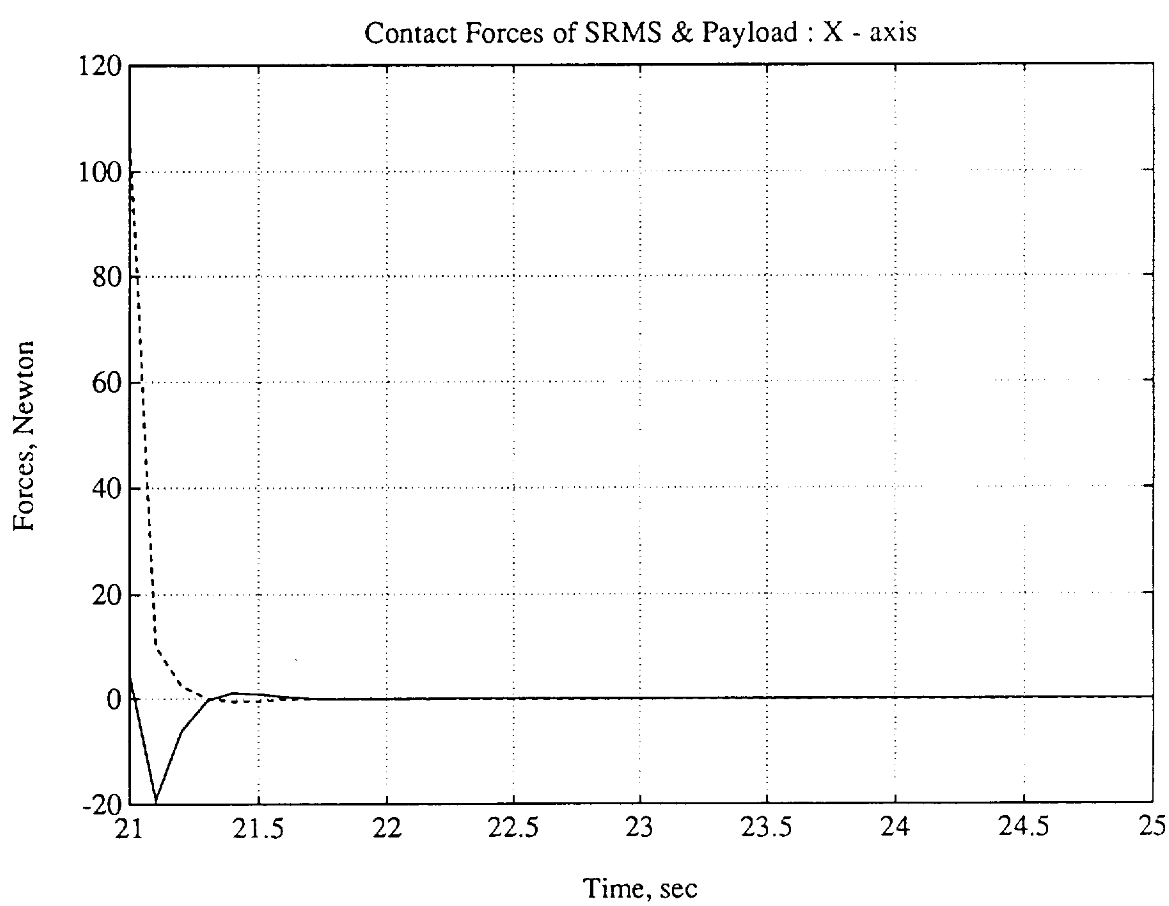

End Effector : Rigid SRMS
End Effector : Flexible SRMS
Forces, Newton
Torque, N-m
Time, sec
10
5
0
-5
-10
0.4
0.2
0
-0.2
-0.4
0
5
10
15
20

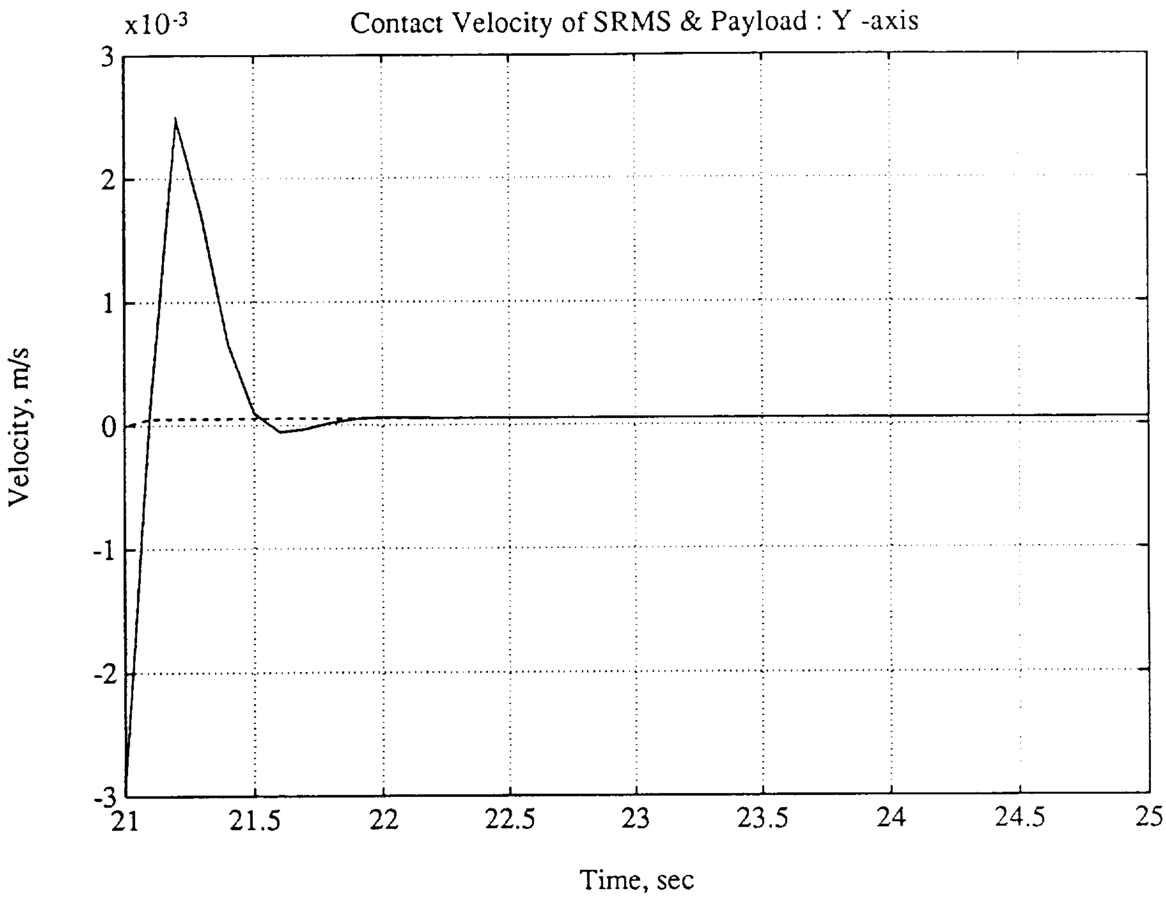

End Effector : Rigid SRMS
End Effector : Flexible SRMS
Translational Acc. m/s^2
Angular Acc. rad/s^2
Time, sec
0.2
0.1
0
-0.1
-0.2
0.04
0.02
0
-0.02
-0.04
0
5
10
15
20

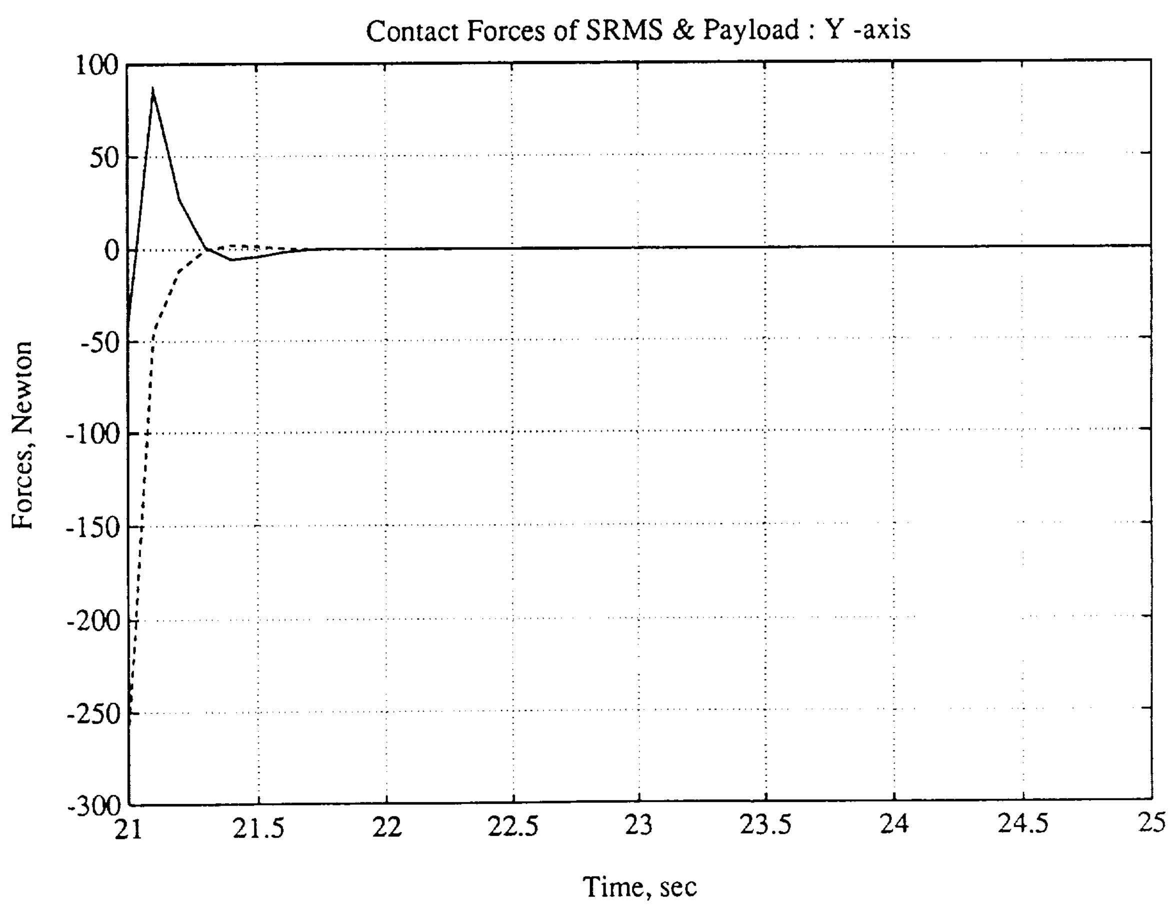

Distance, m
Time, sec
Velocity, m/s
Time, sec
Acceleration, m/s^2
Time, sec
Contact Force, Newton
Time, sec

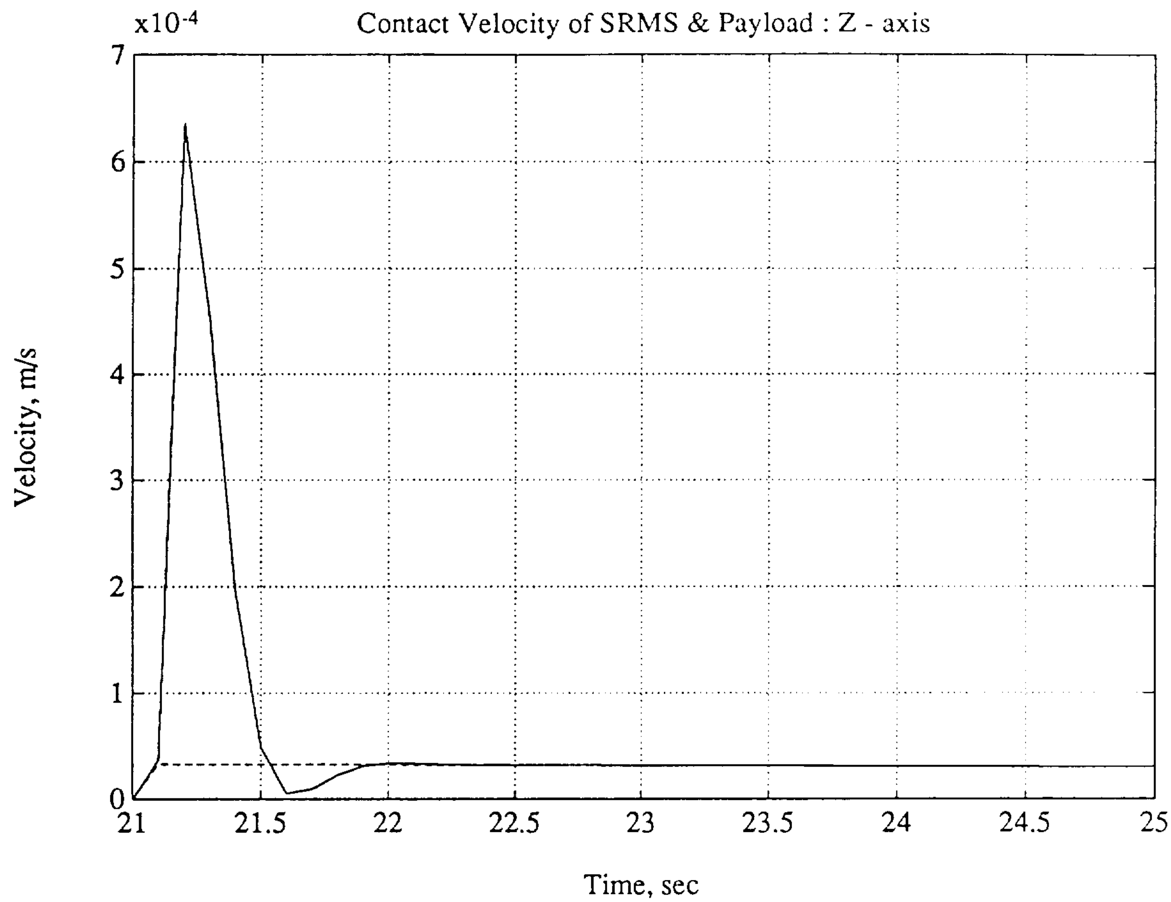

Distance, m
Time, sec
Velocity, m/s
Time, sec
Acceleration, m/s^2
Time, sec
Contact Force, Newton
Time, sec

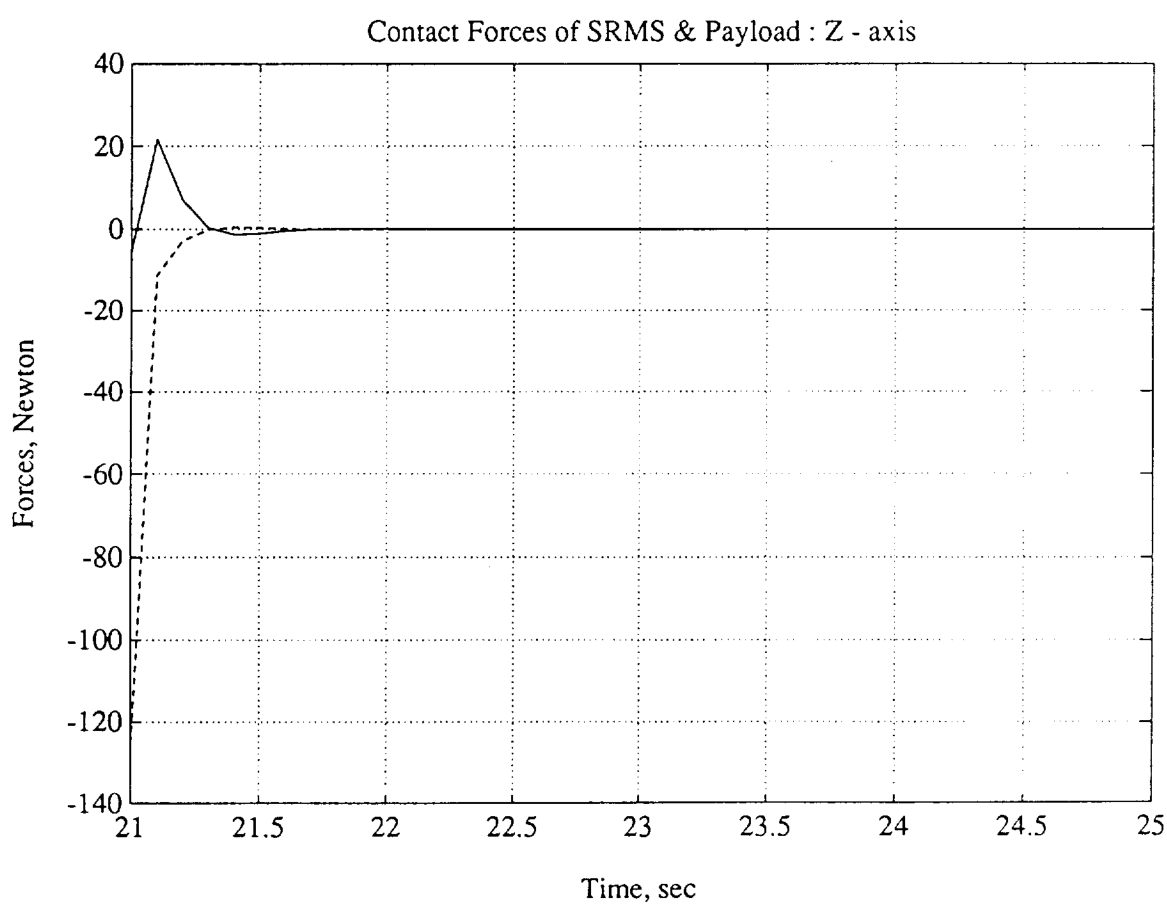

x10^-4
Contact Velocity of SRMS & Payload : X - axis
Velocity, m/s
1
0
-1
-2
-3
-4
-5
-6
21
21.5
22
22.5
23
23.5
24
24.5
25
Time, sec


Contact Forces of SRMS & Payload : X - axis
Forces, Newton
120
100
80
60
40
20
0
-20
21
21.5
22
22.5
23
23.5
24
24.5
25
Time, sec


Contact Velocity of SRMS & Payload : Y -axis
x10-3
Velocity, m/s
3
2
1
0
-1
-2
-3
21
21.5
22
22.5
23
23.5
24
24.5
25
Time, sec


Contact Forces of SRMS & Payload : Y -axis
Forces, Newton
100
50
0
-50
-100
-150
-200
-250
-300
21
21.5
22
22.5
23
23.5
24
24.5
25
Time, sec


x10-4
Contact Velocity of SRMS & Payload : Z - axis
Velocity, m/s
7
6
5
4
3
2
1
0
21
21.5
22
22.5
23
23.5
24
24.5
25
Time, sec


Contact Forces of SRMS & Payload : Z - axis
Forces, Newton
40
20
0
-20
-40
-60
-80
-100
-120
-140
21
21.5
22
22.5
23
23.5
24
24.5
25
Time, sec