Shuttle Arm

By Aaron Klapheck

Contributors: Jose Granda and Roman Montu

Brain Storm Session:

I knew that I was going to be working with Granda on a NASA project. I took his advice and researched the various projects available that I had to work on. As a result of my research on ESMD's student internship webpage I found six projects which I fancied the most. Two of the projects are offered by the Ames Research Center the other four are offered at the Langley Research Center. See below for the details of all of the projects.

Ames Research Center (ARC)

ARC1-01-09-AN	Spring, Summer, Fall	Electrical, Electronic, Computer Engineering, Mechanical Engineering, Mechanics, Computer Science	LUNAR UTILITY ROBOTICS: The focus of this project is to develop utility robots and procedures to automate lunar operations. Utility robots will perform: (1) tedious, highly repetitive, long-duration tasks that can be off-loaded from astronauts and (2) rapid response for addressing time-critical situations. Example tasks include: systematic site surveys, mobile camera platform, inspection, emergency response, site preparation, instrument deployment. This project involves software development in C++ under Linux and Java / Eclipse.

ARC5-24-09-AN	Spring, Summer, Fall	Aerospace, Aeronautical, Astronautical Engineering, Electrical, Electronic, Computer Engineering, Mechanical Engineering, Mechanics	SMALL SPACECRAFT - MISSION DESIGN: Small spacecraft show great promise for future NASA missions. Because of their nature, these spacecraft typically have very low margins in mass, power, and propulsion. In order to make these systems viable, NASA needs evaluate what is possible with innovative concepts for micro spacecraft Landers, rovers, and communications relays that could be used for very low cost robotic lunar precursor missions. This project focuses on innovative mission concepts for specific targets.

Langley Research center

LRC1-01-08-AN	Spring, Summer, Fall	Civil Environmental, Health Engineering, Electrical, Electronic, Computer Engineering, Engineering Physics, Mechanical Engineering, Mechanics, Physics, Mathematics, Applied Mathematics, Computer Science, Other Other: Any major with strong programming background	Algorithm Development for Robotics Applications Using LABVIEW: This project involves the development of algorithms relating to autonomous mobility and navigation based on stereo, omni-directional, and thermal imagers. The intern should be interested in robotic systems and well-versed in computer programming.

LRC1-04-08-AN	Spring, Summer, Fall	Civil Environmental, Health Engineering, Electrical, Electronic, Computer Engineering, Engineering Physics, Mechanical Engineering, Mechanics, Physics, Computer Science, Other Other: Any major with strong programming background	DESIGN AND INTEGRATION OF A ROBOTIC PLATFORM FOR SCIENCE INSTRUMENT TESTING: This project involves the development of software to support the operation of a robotic platform with application to the testing and deployment of science instruments. The tasks to be implemented include: image registration, behavioral robotic intelligence, and user interfaces for robot guidance and supervision. Ideal candidates for participation will be familiar with kinematics, machine pattern recognition, computer programming, and guidance and control.

LRC2-10-08-SU	Summer	Aerospace, Aeronautical, Astronautical Engineering, Materials, Metallurgical Engineering, Mechanical Engineering, Mechanics, Other Other: Structural Analysis	INTEGRATED DIAGNOSTIC AND PROGNOSTIC AEROSERVOELASTIC METHODS FOR ADAPTIVE CONTROL SYSTEM: The purpose of this project is to develop integrated diagnostic and prognostic aeroservoelastic methods to generate static and dynamic load constraints due to structural damage and upset conditions for adaptive control system. The focus will be on the following: damage characterization and residual strength; rapid modeling and analysis methods; dynamic impact simulation; and probabilistic methods.

LRC4-20-09-AN	Spring, Summer, Fall	Aerospace, Aeronautical, Astronautical Engineering, Engineering Physics, Mechanical Engineering, Mechanics, Mathematics, Applied Mathematics	SYSTEMS ANALYSIS: Development of an ARES I Aerodynamic Database: The ARES I database will be derived from separate wind tunnel, CFD, and engineering code datasets. The work involves the integration of these separate items into a single database with routines being developed in MATLAB.

As a result of my research I found I had the most interest in NASA's robotics and control programs. Because of this when Granda announced that the Shuttle arm could be modeled in more detail I took this assignment first thing.

Objectives

- Sketch preliminary drawings of arm components and their associated motions for both Nastran4D and Working Model.
- Create a scenario in which the arm will be used and analyzed.
- Recreate the scenario in Working Model. Display velocities, accelerations, and forces.
- Model parts in SolidWorks. Animate basic motions of each arm's component connections in SoldWorks.
- Recreate the scenario in Nastran4D and perform an analysis on the arm and other effected components. The analysis should include a motion study of velocities, accelerations, and forces.
- Verify the numerical answers in Working Model and Nastran4D by comparing them.
- Perform finite element analysis (FEA) in both Nastran4D and SolidWorks.
- Integrate a control system build in Simulink that will simulate the NASA's response to control the motion of the arm after the accident.

Preliminary Sketches

Figure #1 Shuttle Arm Preliminary Sketches

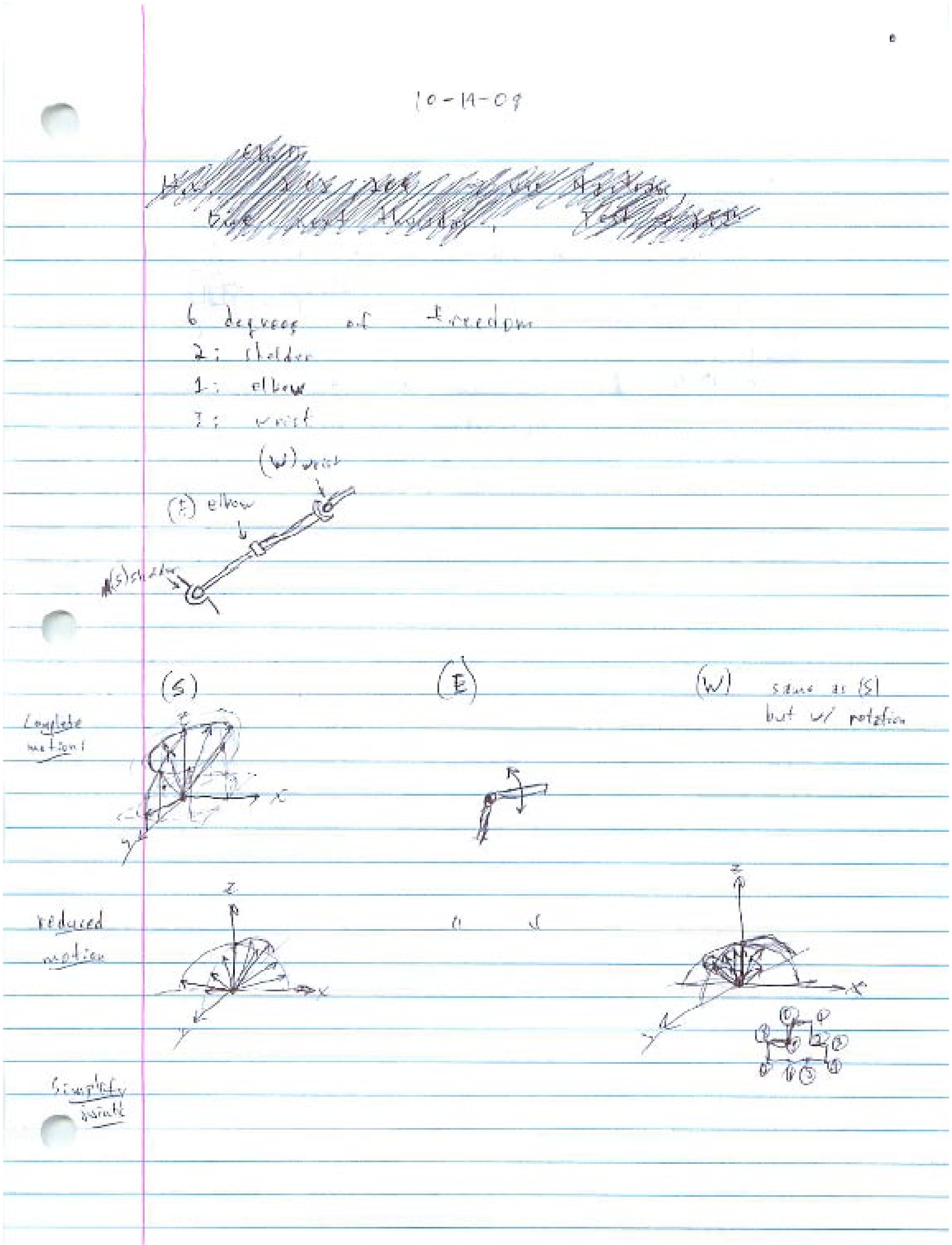


Figure #2 Shuttle Arm Basic Sketch for use in Working Model

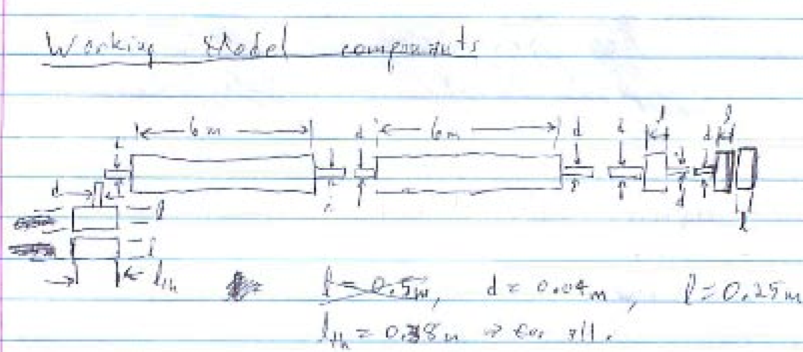


Figure #3 Shuttle Arm Sketches for use in Solid Works

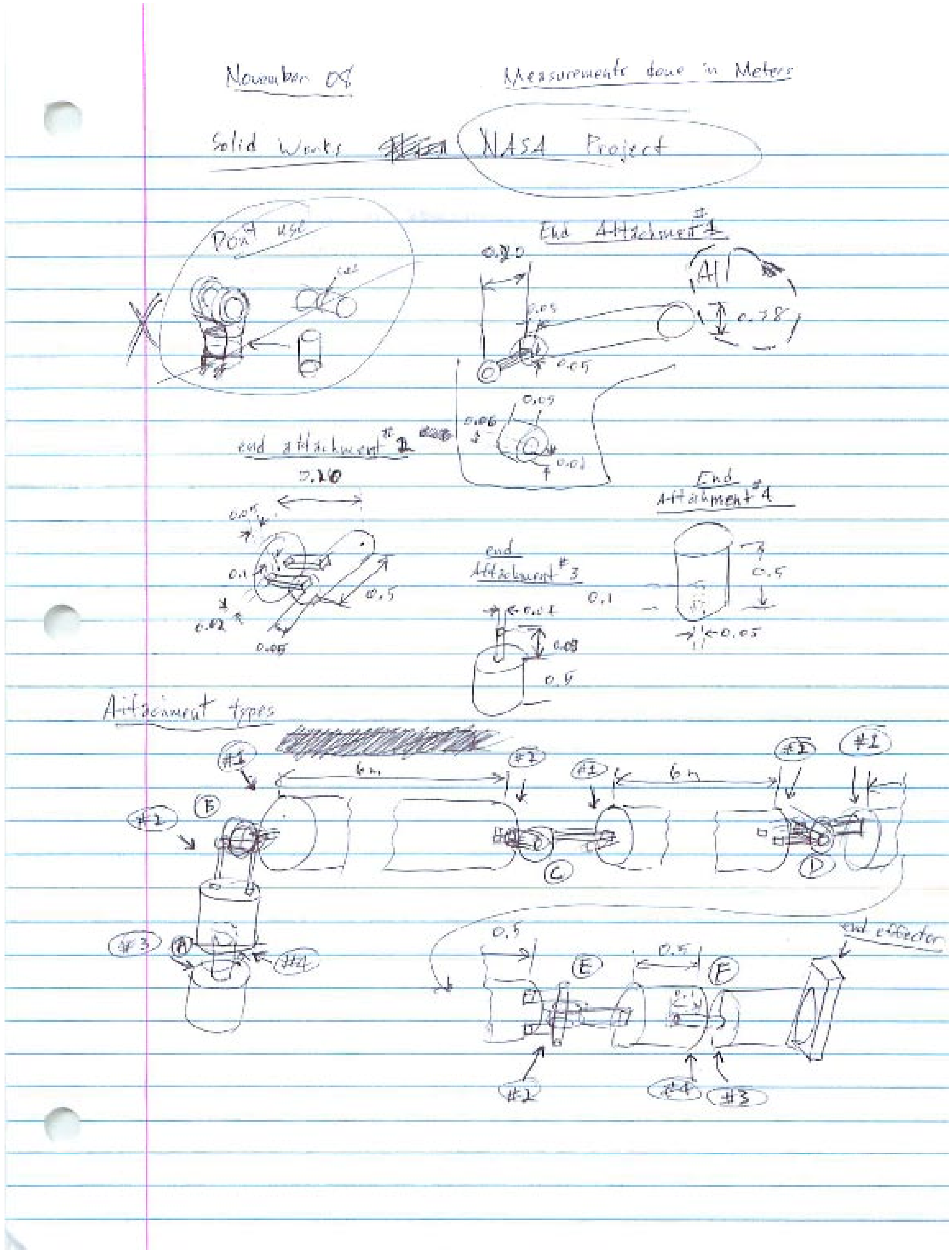
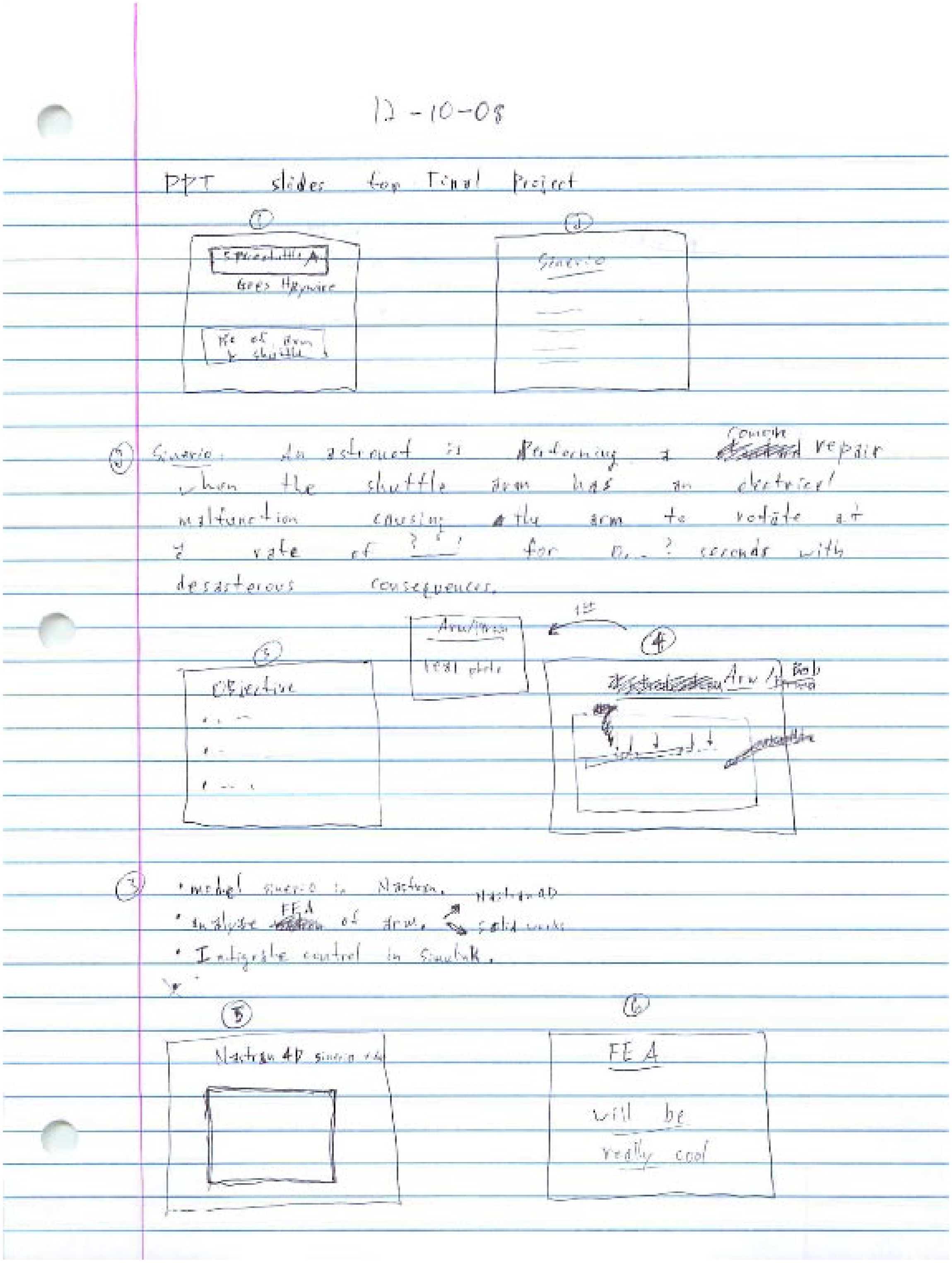


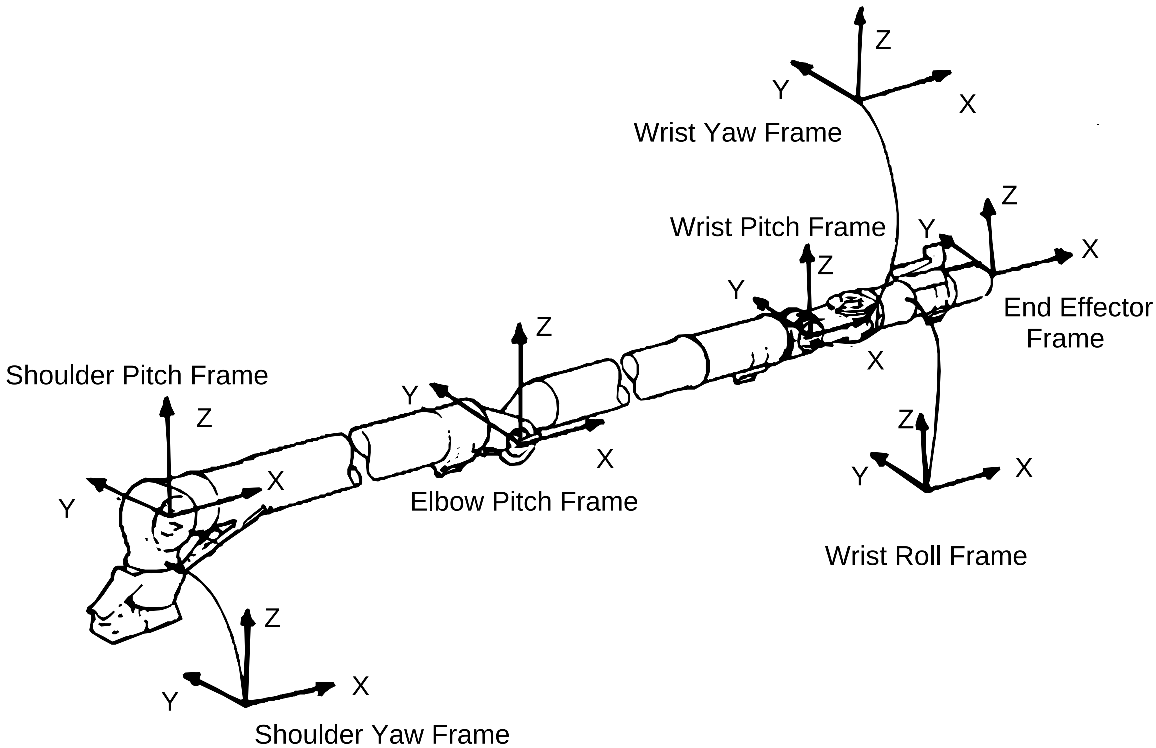
Figure #4 Shuttle Arm Presentation Preliminary Sketches



The Scenario

An astronaut is performing a common repair when the shuttle arm has a severe electrical/mechanical malfunction. This malfunction causes a 6E4 N*m torque at the arm for less than 2 Seconds. This has disastrous consequences for the astronaut involved and the shuttle arm. The part that malfunctions is the controller for the Shoulder Pitch Frame (see figure #1 below).

Figure #5 Shuttle Arm design obtained from Roman Montu



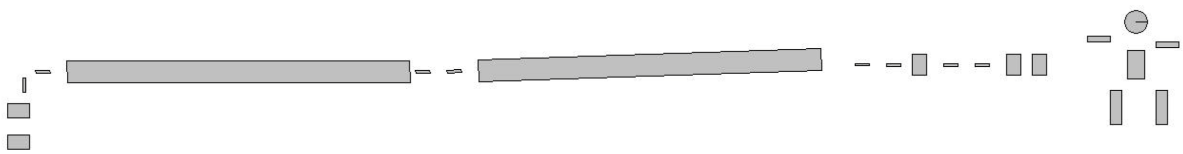
Inspiration: found on line.

Working Model

I took my sketches of the arm (see figure #2) and created them in Working Model. The steps I took to build the model are listed below.

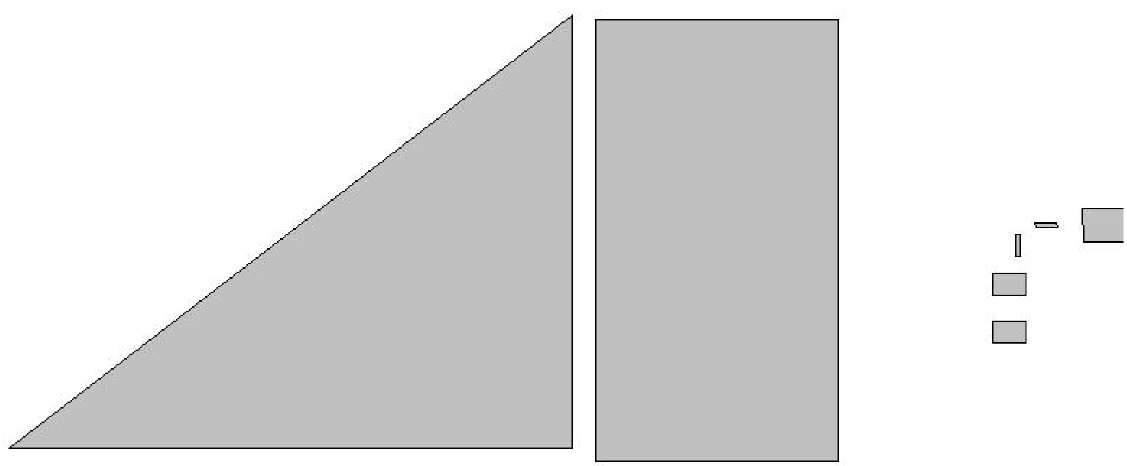
Step 1

Create the basic components that make up the person and the shuttle arm.



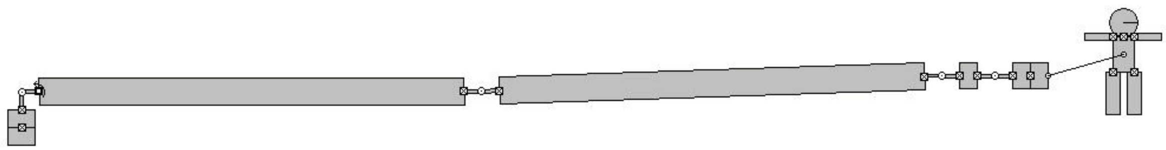
Step 2

Create a part of the space shuttle that the arm will run into.



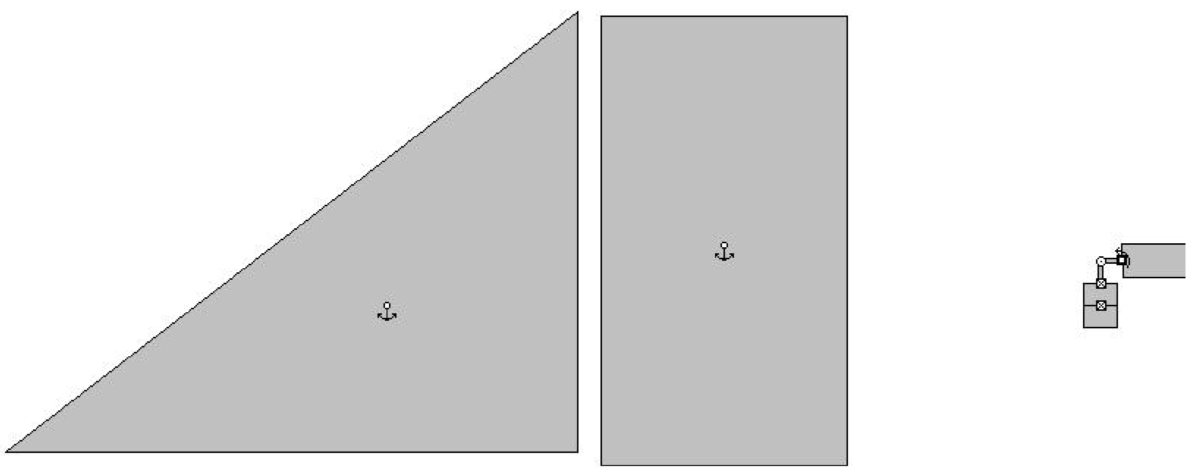
Step 3

Assemble the shuttle arm. Had to make sure to assemble arm from left to right in order for constraints to function properly. Fixed the leftmost part to the ground. Attached a torque to the "shoulder to elbow" component of 6E4N*m.



Step 4

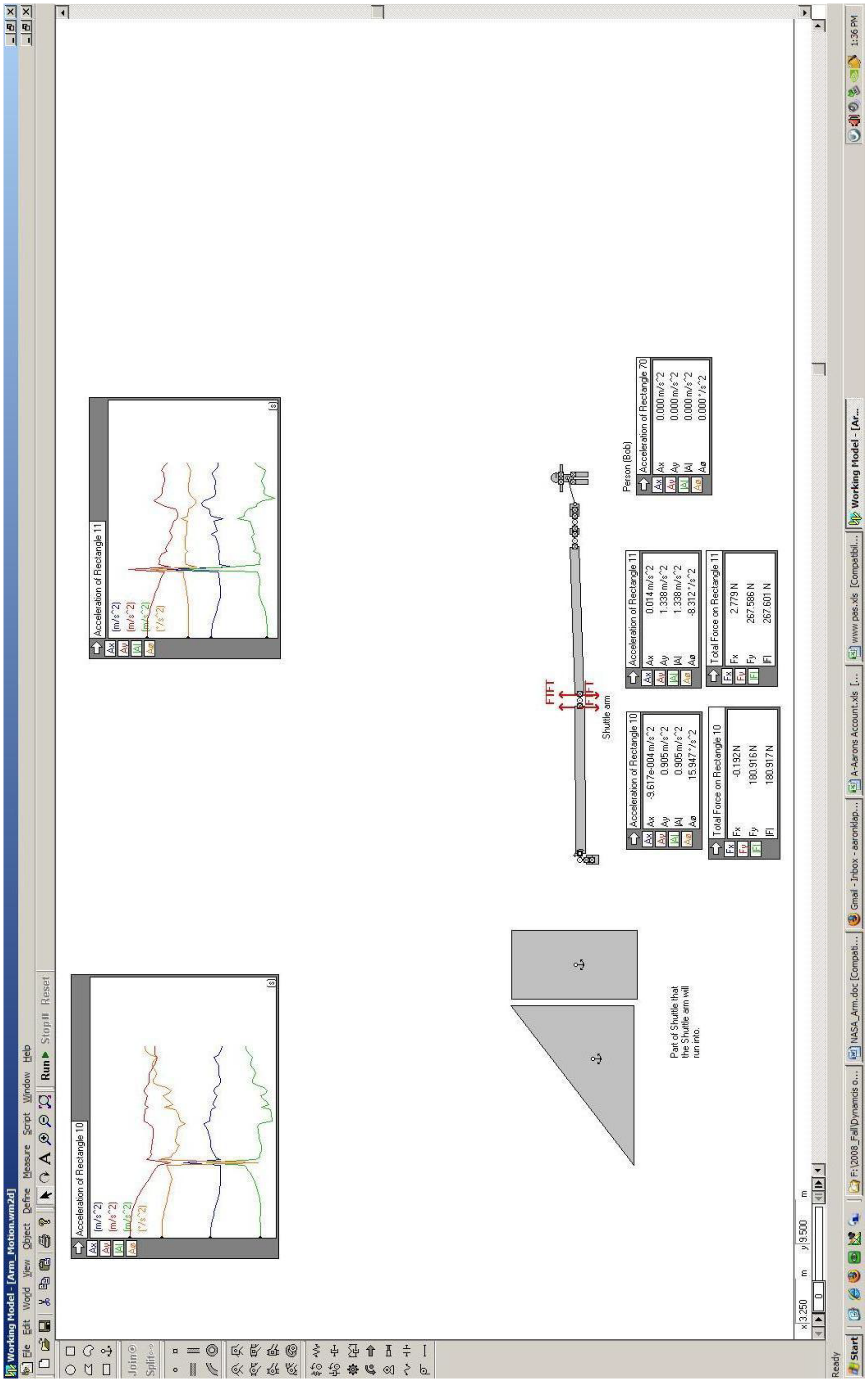
Fixed the position of the two shuttle parts.



Step 5

Inserted acceleration and force measurement graphs and displays.

Figure #6 Working Model Design of Shuttle Arm and Person in Scenario.



****To see the model in motion please see the presentation. File: Arm_Motion.wm2d**

**See the working model documentation in appendix A.

The mail results learned from the Working Model was that as the lower arm impacted part of the shuttle its acceleration goes from 0.242 m/s in toward the shuttle to 0.245 m/s away from the shuttle in just under 2 seconds resulting in an impulse of 200N*s

acceleration*mass*(change in time) = 200N*s

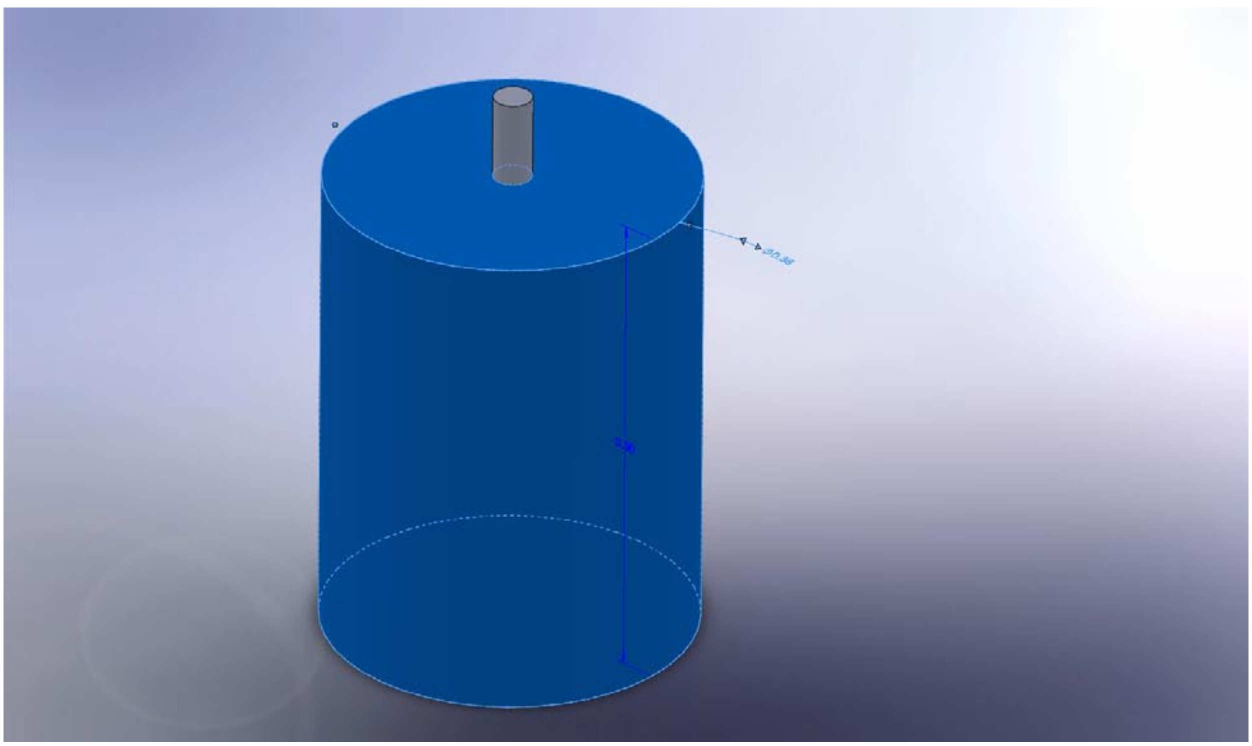
Accelerations: 0.242m/s^2 for the "Shoulder to elbow" part, 3.052 m/s^2 for the "elbow to wrist" part.
Forces: 48.48N for the "Shoulder to elbow" part, 610 N for the "elbow to wrist" part.

SolidWorks Modeling

I took my shuttle arm sketches (see figure #3) and created them in SolidWorks. The concept sketches were inspired by a report written by Roman Montu. The steps I took to build the shuttle arm are included below:

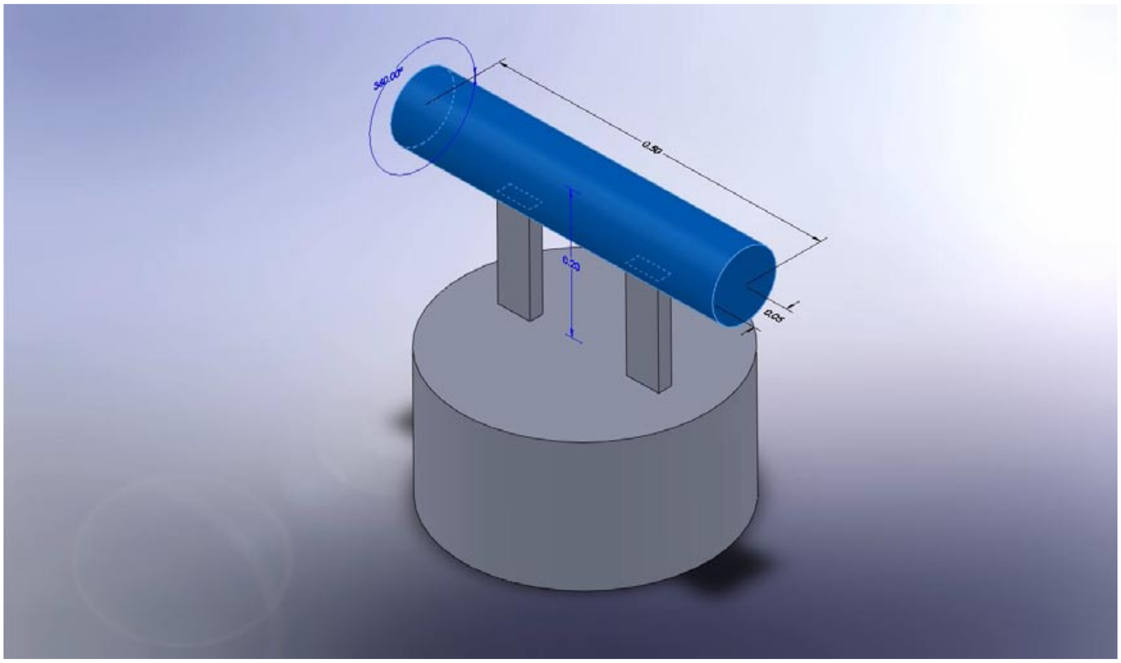
Step 1

Create the base which the arm will be mounted on.



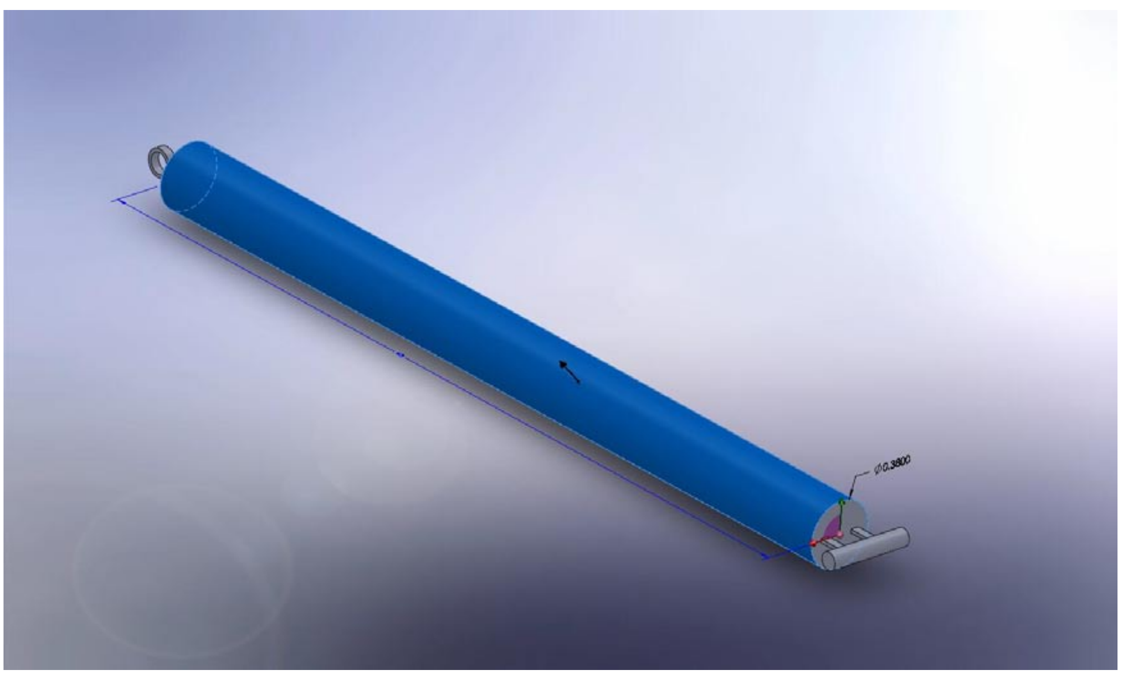
Step 2

Create the part that connects “shoulder” of the arm to the base.



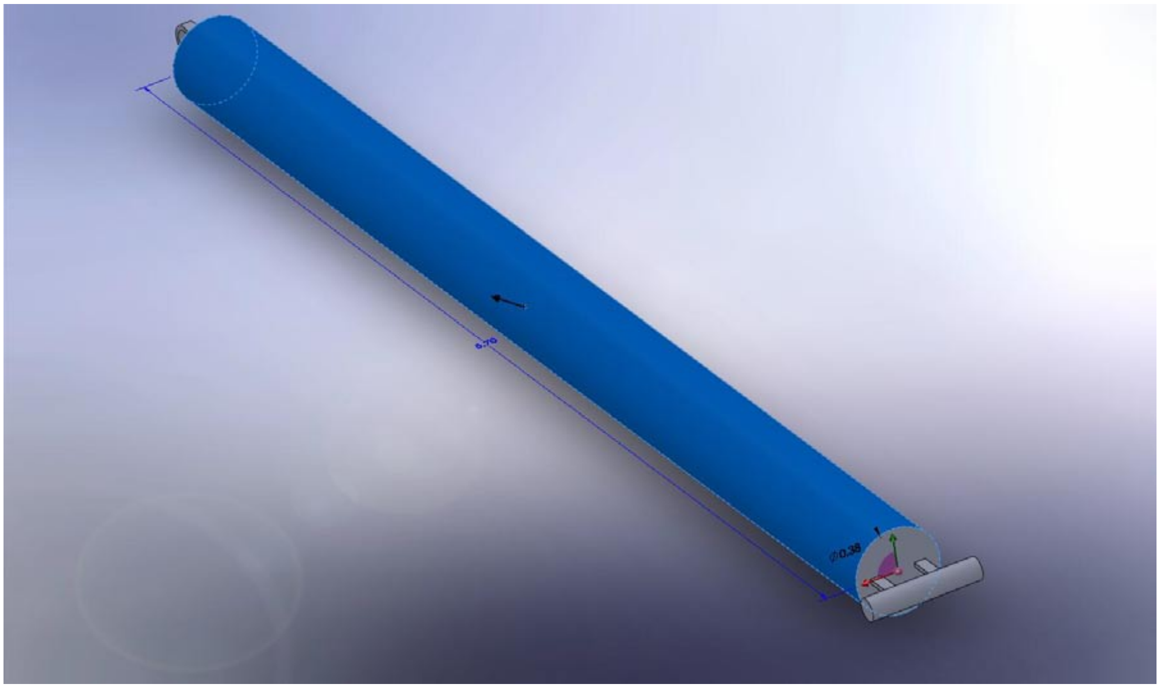
Step 3

Created the “Shoulder to Elbow” component.



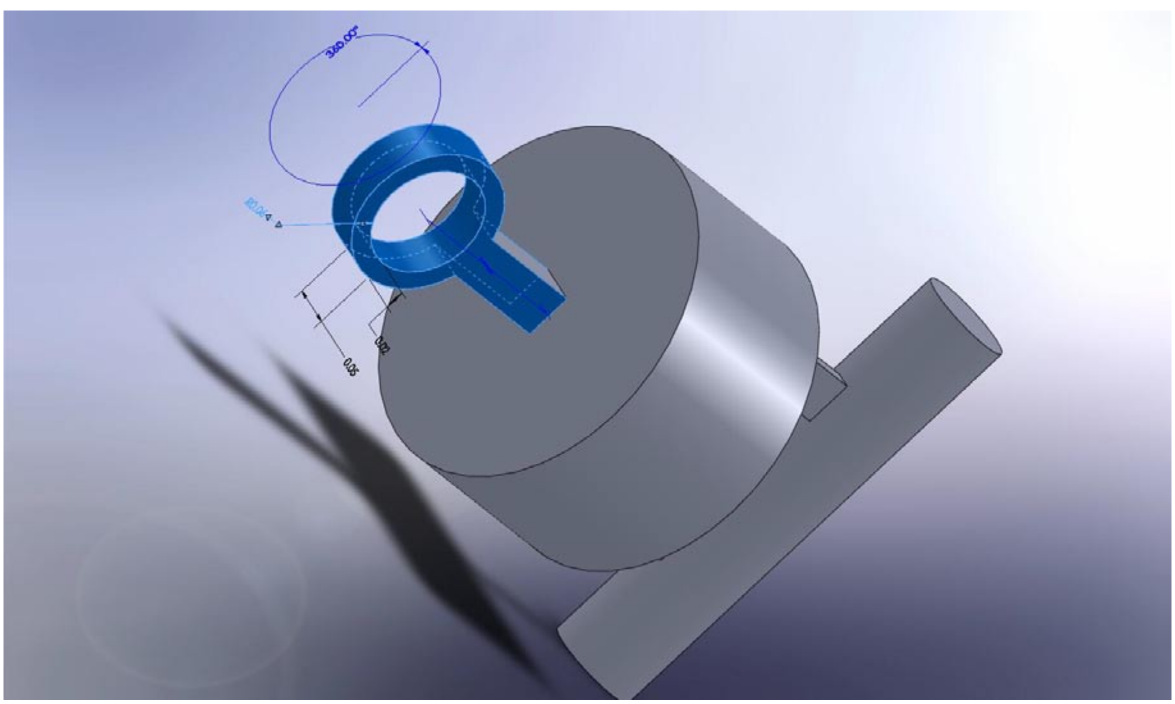
Step 4

Created the “Elbow to Wrist” component.



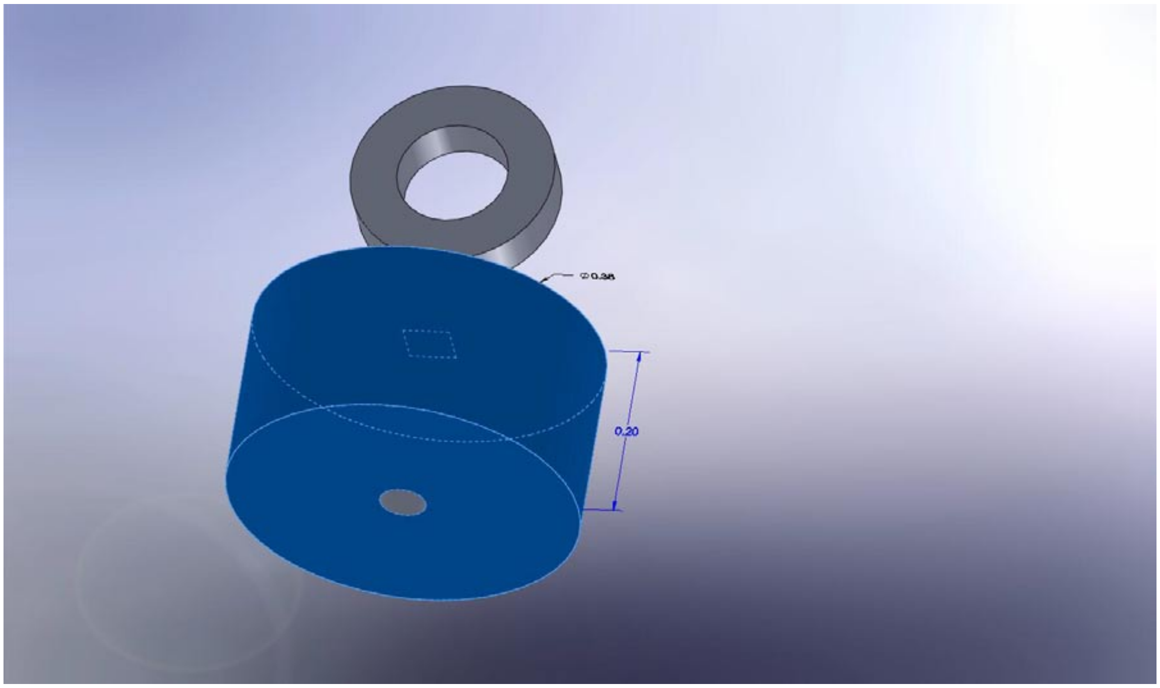
Step 5

Created the part that allows the wrist to pitch up and down.



Step 6

Created the part that allows the wrist to yaw back and forth.



Step 6

Created the part that allows the wrist to roll.

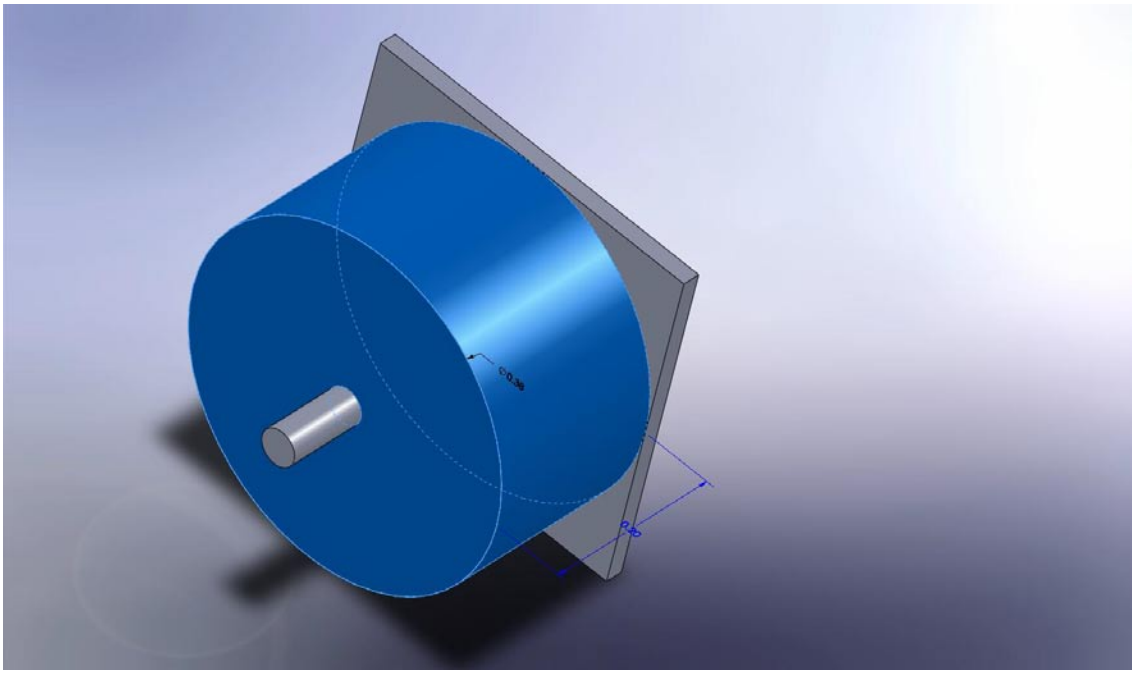
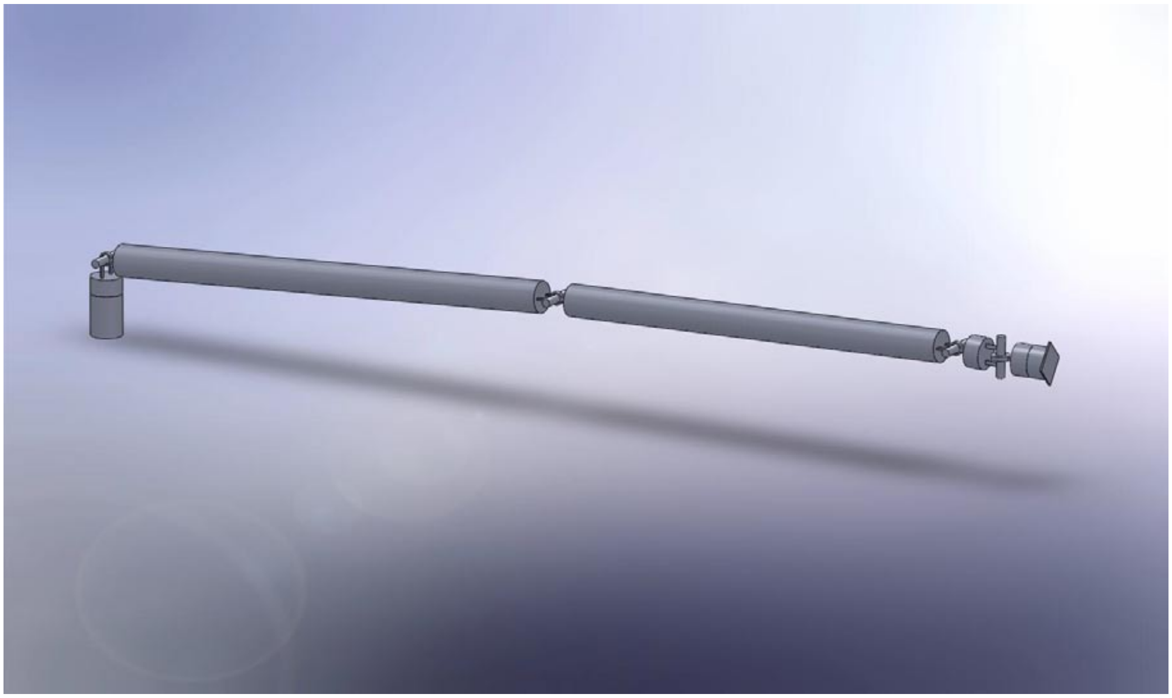
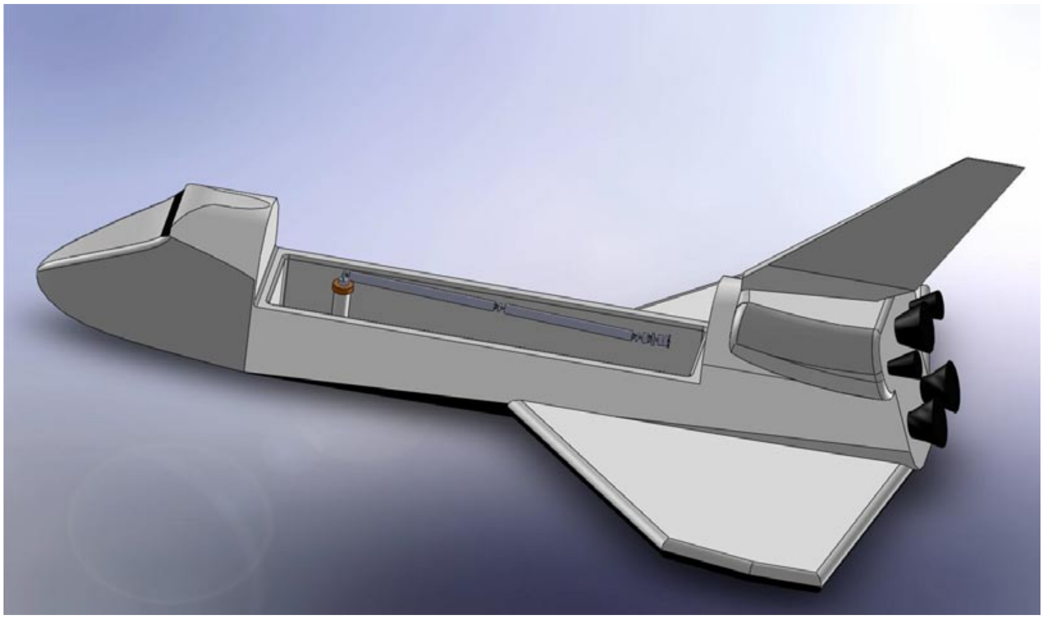


Figure #7 SolidWorks Design of Completed Shuttle Arm.



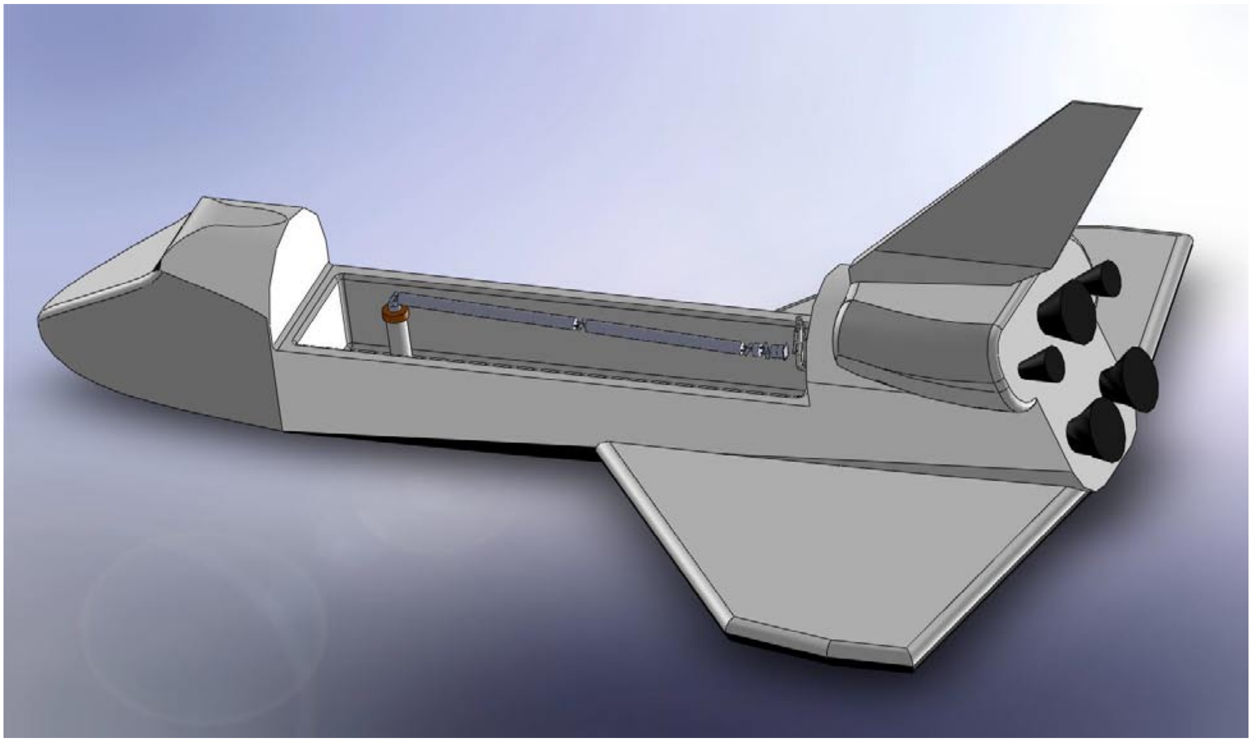
****To see the model in motion please see the presentation. File: Canada_Arm.SLDASM**

Figure #8 SolidWorks Design of Completed Shuttle Arm Inside Shuttle.



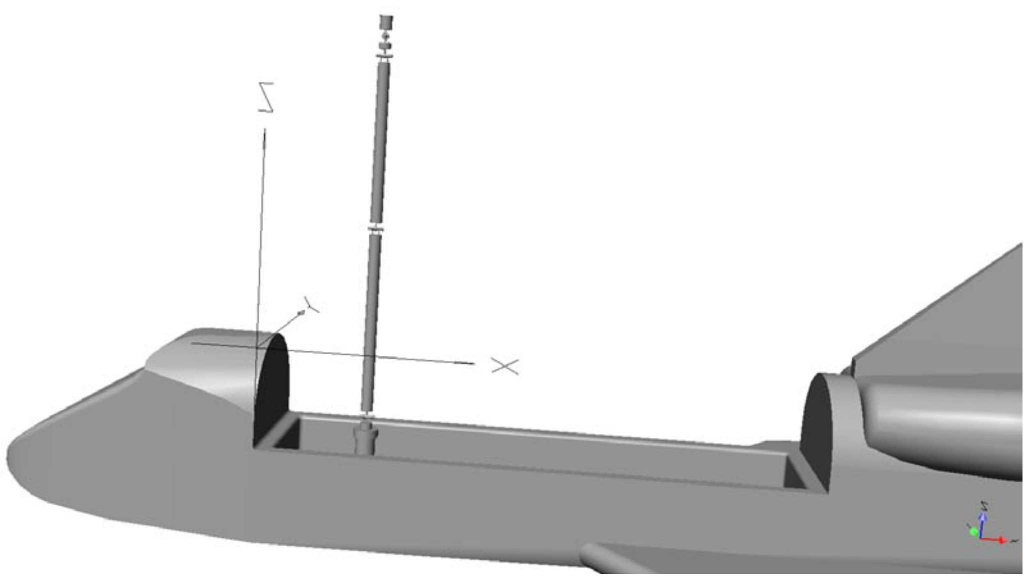
(Shuttle provided by professor Granda)

Figure #9 SolidWorks Design of Completed Shuttle Arm Inside Shuttle with Person.

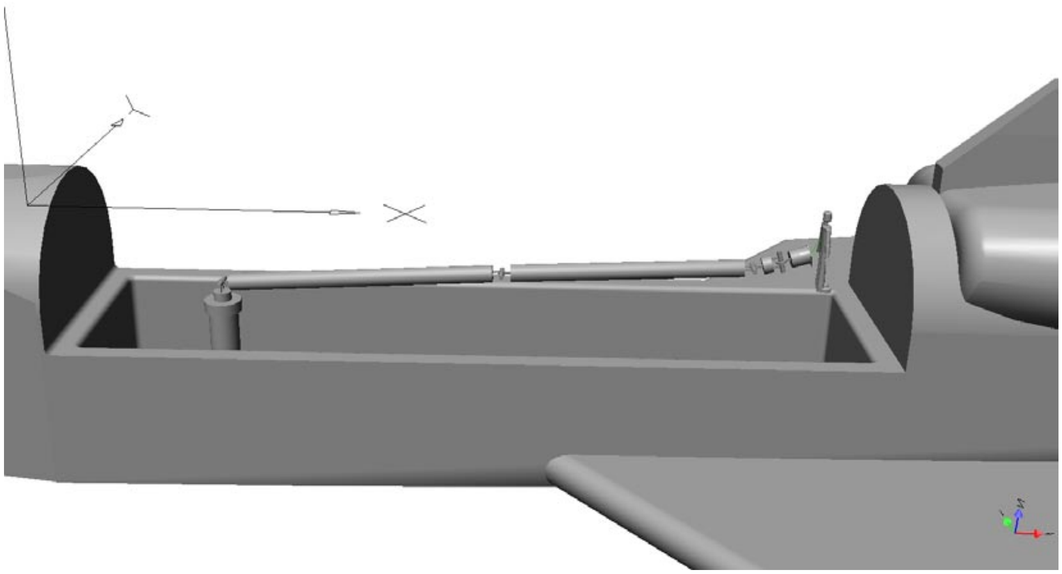


Nastran4D Model

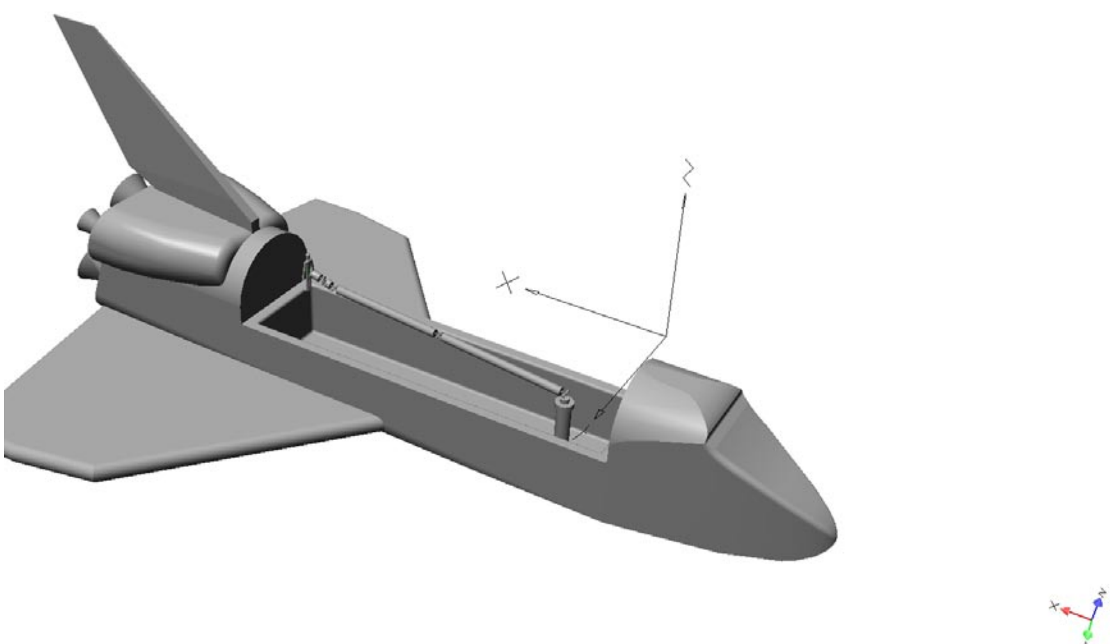
1st Imported SolidWorks parts into Nastran4D. Recreated constraints as needed.



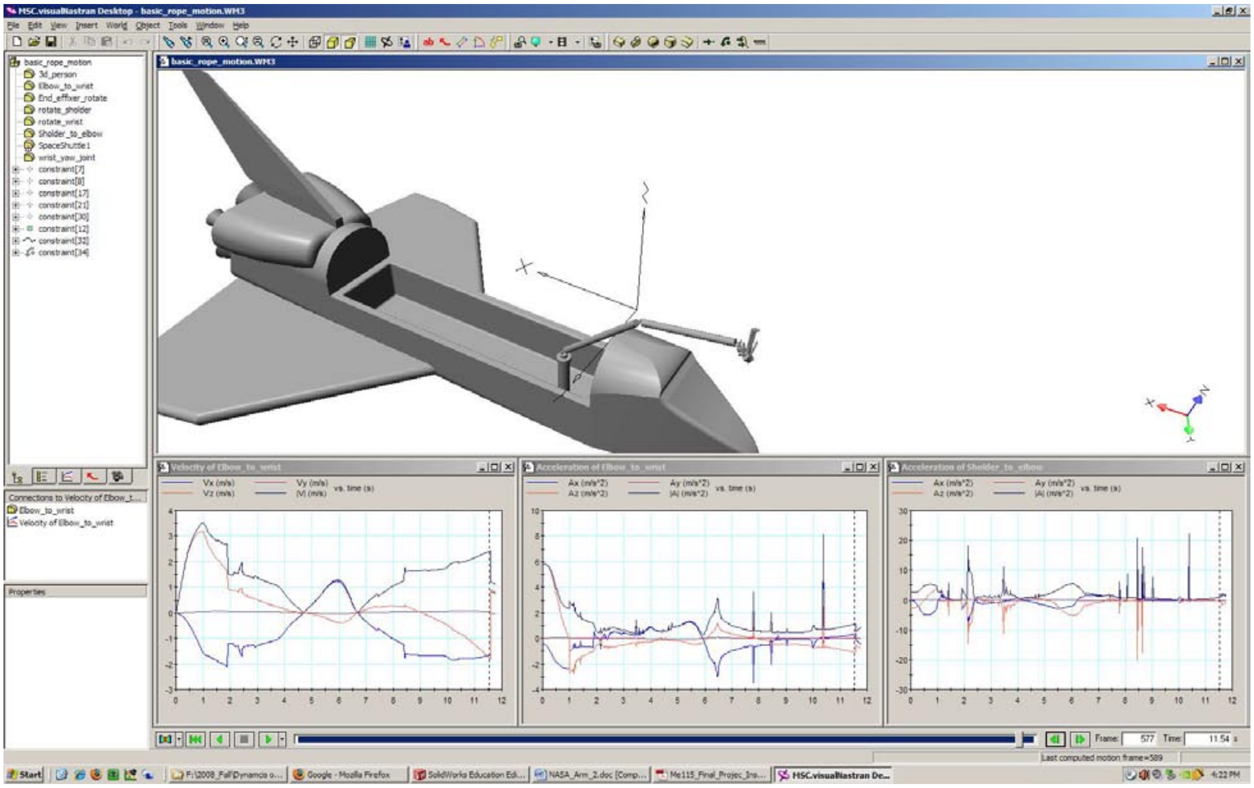
2nd Import person and reposition arm. Add rope constraint between arm and person.



3rd Add a torque to the “shoulder to elbow” component of 6E4 N*m



****To see the model in motion please see the presentation. File: basic_rope_motion.WM3**



Note: The labels “Shoulder to elbow” and “elbow to wrist” should be exchanged.

All the values below are at the point of collision.

Accelerations for the “Shoulder to elbow”: go from 0.4m/s^2 to 0.15m/s^2 which average out to 0.275m/s^2.

Accelerations for the “elbow to wrist”: 1.2 m/s^2.
Velocities: 1.8m/s for the “Shoulder to elbow” part

Verification of models

The two models were compared against each other to ascertain their validity.

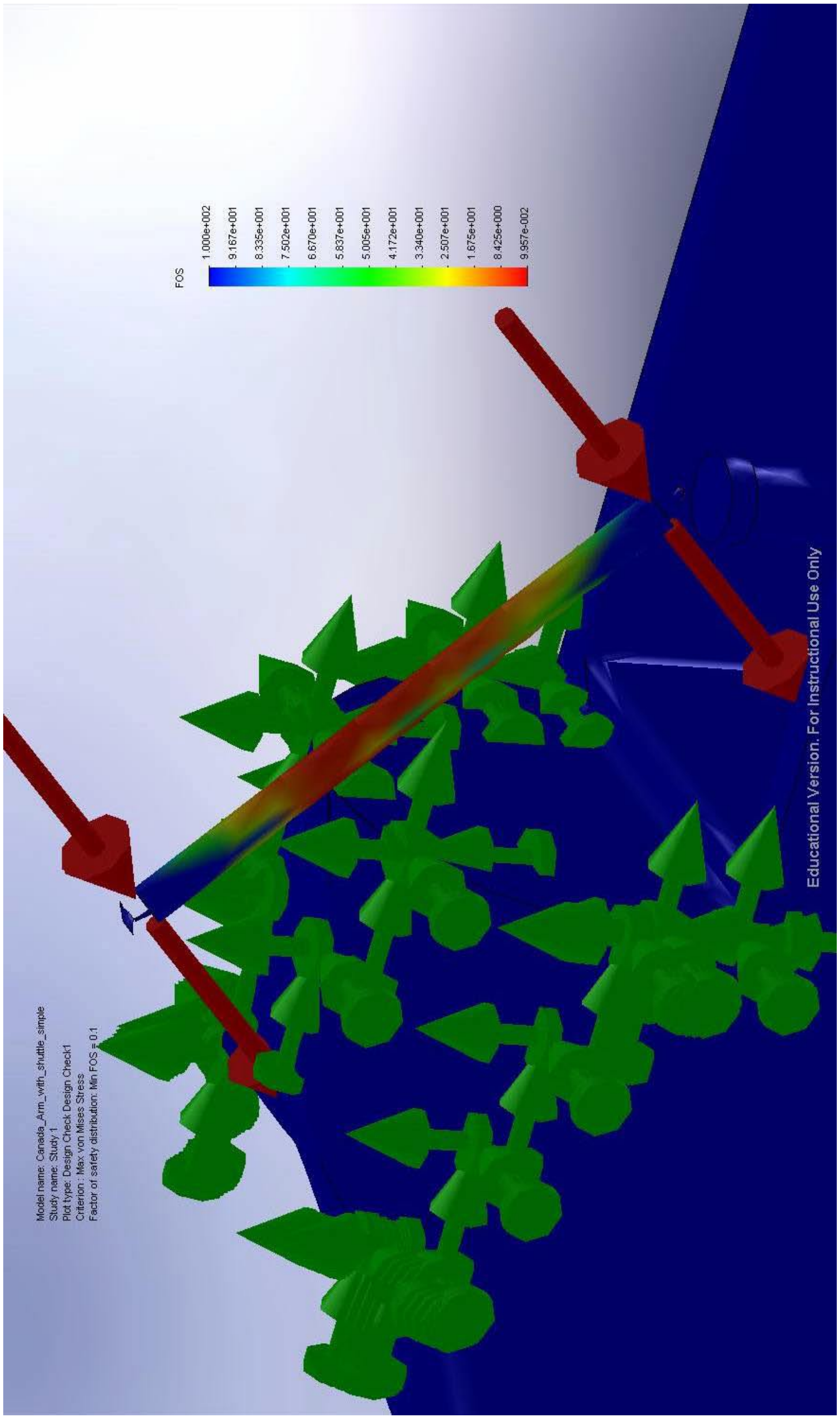
Comparison of “Shoulder to elbow” values: there is only a 14% difference between the answers of the two models.

Comparison of “elbow to wrist” values: These value are very close 1.2 m/s^2 compared to 3.052 m/s^2.

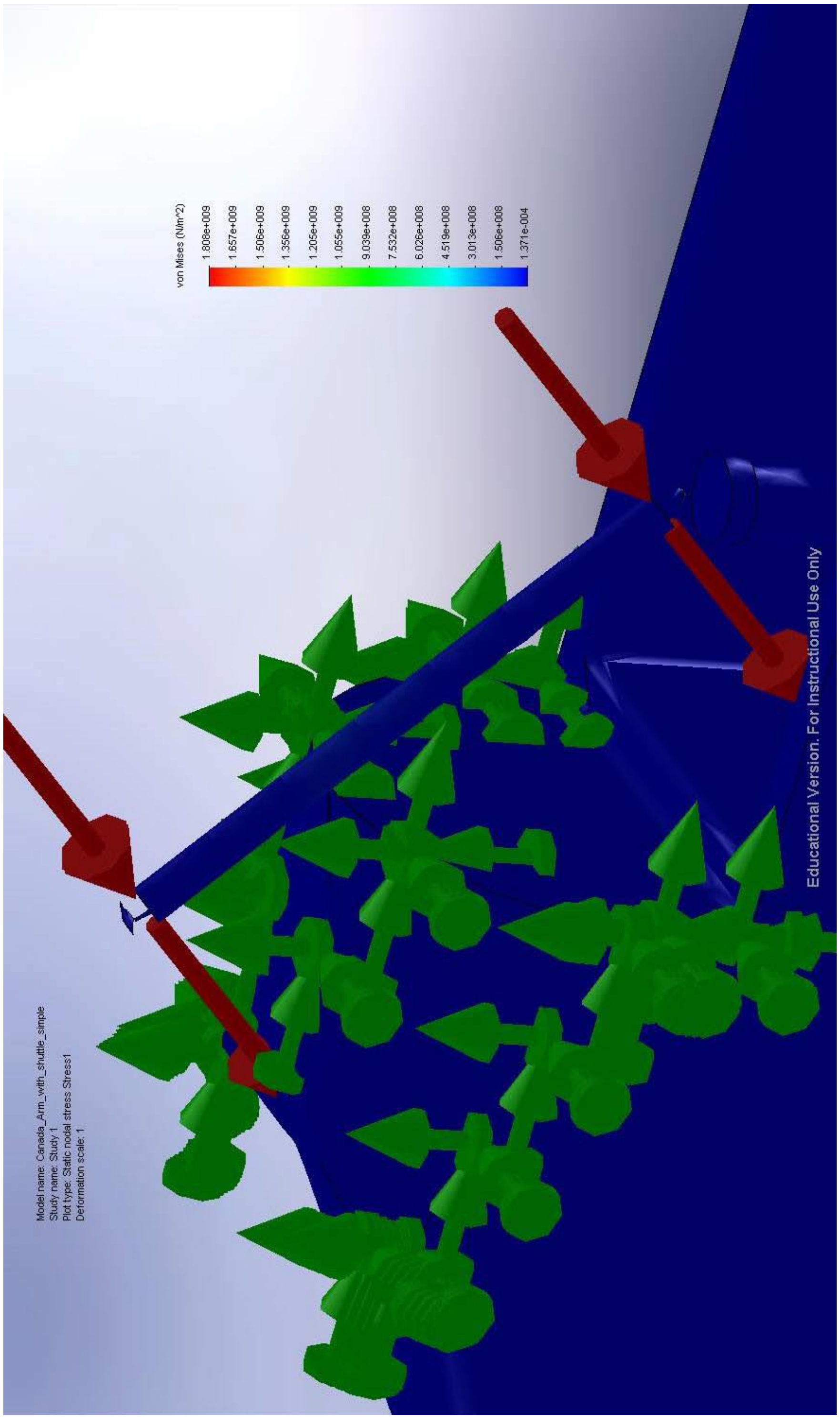
Finite Element Analysis FEA

SolidWorks:

***See Appendix B for the complete simulation report



Canada_Arm_with_shuttle_simple-Study 1-Design Check-Design Check1

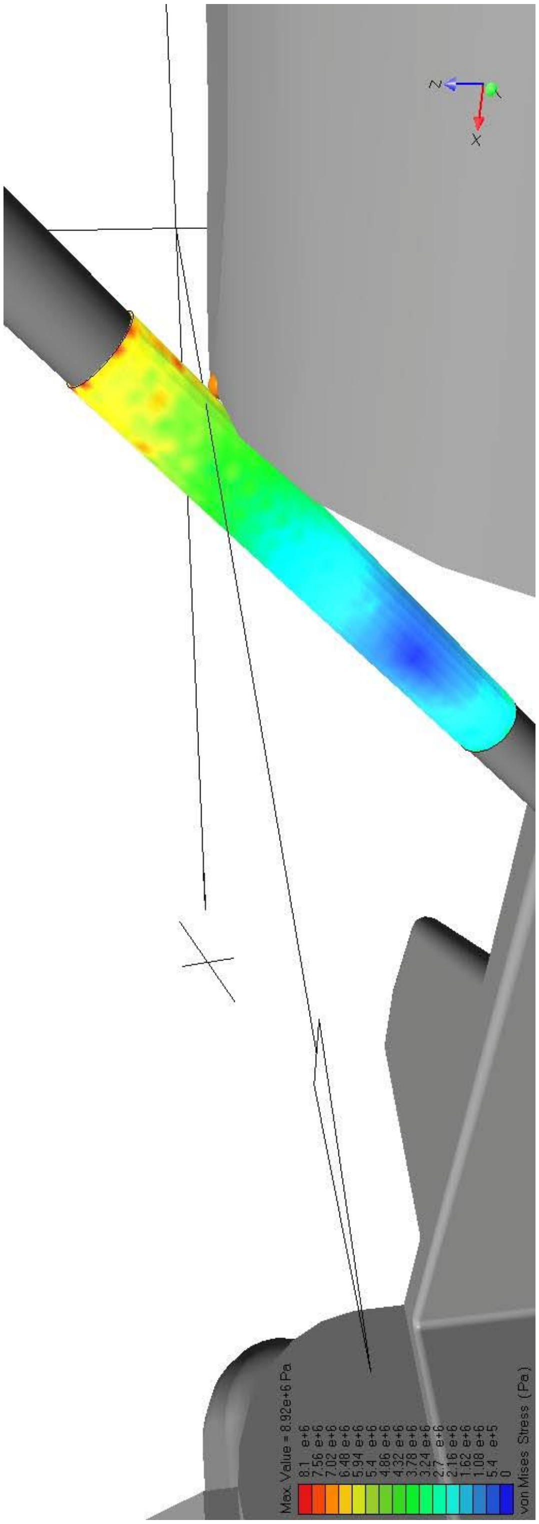


Canada_Arm_with_shuttle_simple-Study 1-Stress-Stress1

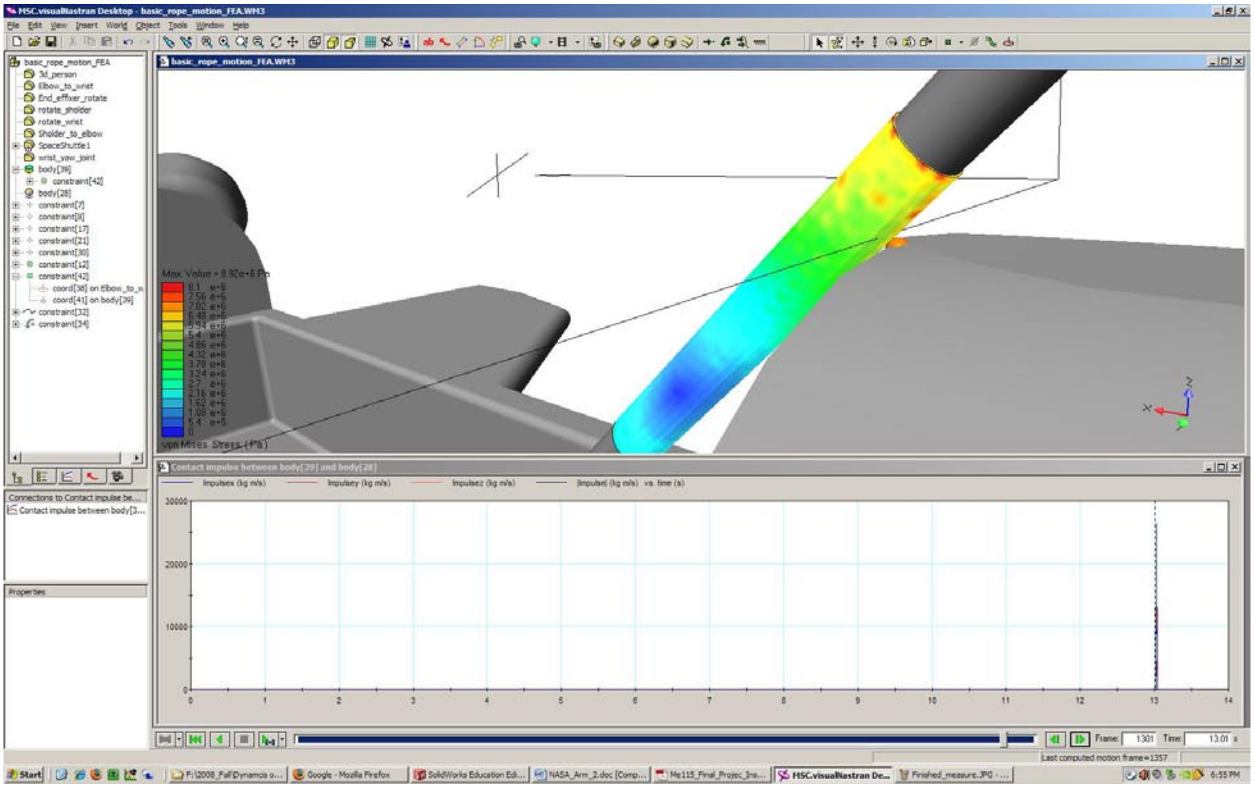
**** File: Canada_Arm_with_shuttle.SLDASM**

Nastran4D:

**See Appendix C for the complete simulation report.



The Stresses in the Shuttle Arm at impact – ** File: basic_rope_motion_FEA.WM3



The impulse at Shuttle Arm impact

As a result of the FEA analysis performed in Nastran4D the maximum stress in the Shuttle Arm was found to be 8.1*10^6 Pa. As a result of the FEA in SolidWorks the majority of the stress present in the model is concentrated at the point of contact between the shuttle arm and the shuttle as well as along the outer surface of the shuttle arm. This is expected because the bending stresses setup by the collision are most prevalent in the outer surface of the part. SolidWorks gave the factor of safety of 100 near the ends of the rod and a factor of safety of about zero near the point of impact. Again this makes sense because the safest points are the furthest away from the impact point. The stresses shown in the SolidWorks model are not shown accurately. Unfortunately due to a lack of time, an analysis of the model for the 14^{th} time could not be accomplished. The impulse as the Arm hits the shuttle was found to be 2.6*10^4 N*s.

Simulink Controls

To increase the accuracy of the simulation having a controlled environment is absolutely necessary. This is because although there is a torque applied to the arm for a brief period of time when the arm has a electrical malfunction, the control center at NASA would quickly take corrective actions as soon as the malfunction was over. This correction would be mainly to stop/stabilize the motion of the Shuttle Arm. This action can be simulated in Simulink.

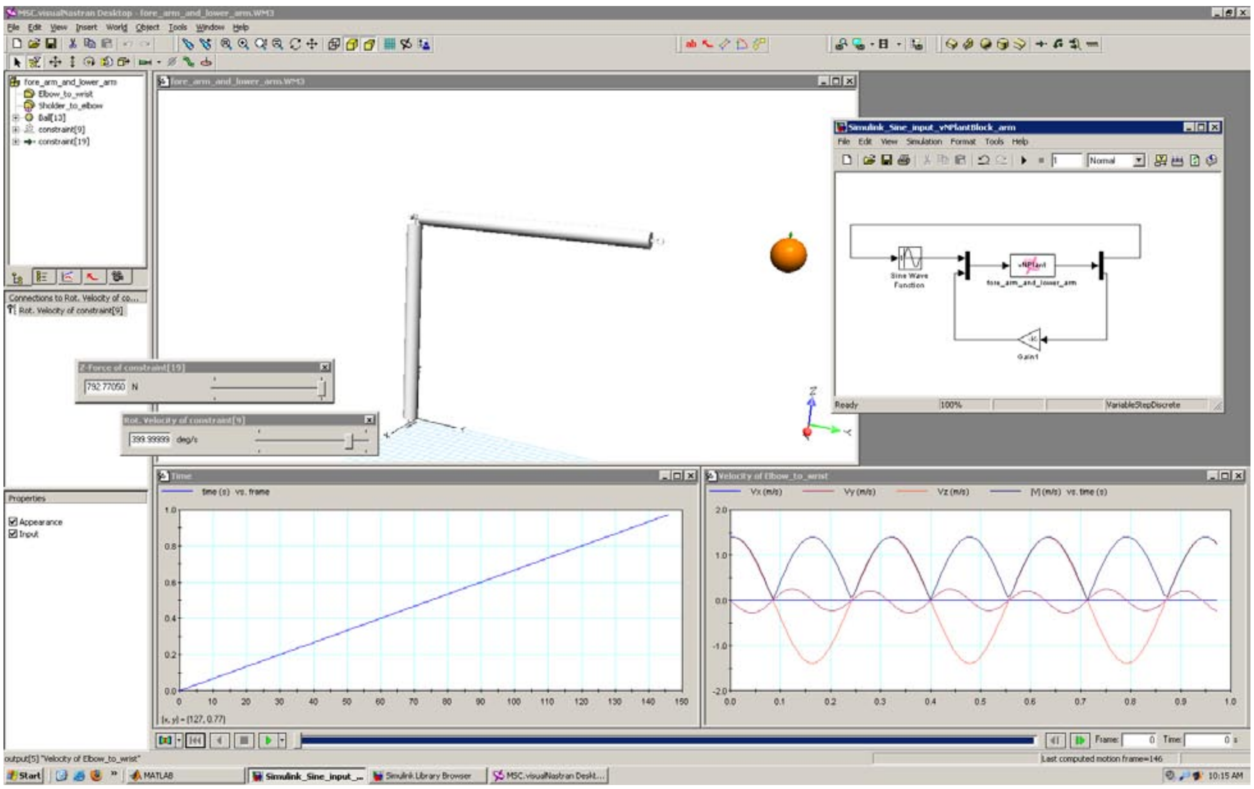


Figure of the Simulink Controlled Shuttle Arm

A preliminary model is shown above. Unfortunately, due to a lack of time the model of the actual Shuttle Arm controlled via Simulink was not accomplished. However, over part of the winter break a robust control system will be created.

Recommendations and Conclusion

For this project I would recommend that some changes be made. There are a number of error that have caught my attention but which I have ran out of time to solve. First, the names for two of the components of the Shuttle arm or reversed. Secondly, the control system should be developed further to increase the accuracy of the model. Third, the FEA analysis performed in SolidWorks could be altered to get an accurate reading for Von Misses stresses. Lastly, I would remake some of physical part connection so as to make the structure of the Shuttle Arm more stable.

With the data collected a recommended course of action would be to insure electrical components are secured safely inside the Shuttle Arm to avoid a problem of this kind in the future. If a problem such as this does occur then the immediate control of the arm to stabilize its motion is absolutely necessary. If control of the Arm cannot be established then I would recommend using a cold forged steel for the surface of the Shuttle Arm as this would be strong enough to take the impact of the Arm which would have an impulse of 2.6*10^4 N*s! As a result of the motion studies the acceleration of the lower portion of the Shuttle Arm will change from 0.275m/s^2 to -1 or -3m/s^2 (negative means in the opposite direction). This change in acceleration may seem small but for an object as large as the Shuttle Arm a change in acceleration of 1 to 3 m/s^2 would result in huge impact forces and stress. This is why annealed steel would also be a good chose as it can withstand high stresses. These stresses measured in the Shuttle Arm were found to be as high as 8.1*10^6 Pa.

As a result of this project I have learned a lot about the software needed to create an accurate representation of the mechanical world. Working Model is one of my favorite programs and I now own a copy to use at my home. I am trying to connect it with other software applications such as Simulink and hope to be able to do so over the winter break. Nastran4D is a great program that increased the dimensions of Working Model by one and can be interfaced with Simulink a number of ways. I hope to be getting the Nastran4D software soon. I have also learned a great deal about how to analytically solve problem of the kind shown in this project. Having knowledge of the theory behind why these programs work makes using them all the more interesting. I am planning on using the Working Model software to verify the statics work I did by hand and hope Moy (the statics teacher) can use my work to increase the understanding of his students. I would like to work with professor Granda to set up a tutorial for other students to go through who are taking statics classes that will get them oriented to Working Model ahead of time.

Appendix A: Working Model Documentation

Information Export Utility

version 1.0.2

Date: 12-19-2008

Time: 01:07:12

Simulation File: Arm_Motion_use

Section: Unit System

Distance:	meters	Energy:	joules	Force:	newtons	Frequency:	
Mass:	kilograms	Power:	watts	Time:	seconds	Velocity:	

Section: Integration Settings

Integrator	Variable/ Fixed	Animation Step	Overlap Error	Assembly Error	Gravity	Gravity Constant
kutta_merson	Variable	0.125	0.057	0.006	None	

Section: Bodies

Body Name Kind Px/ Vx/ Mass/ Sfric/ Geometry

Py/ Vy/ Area/ Kfric

Pr Vr Density COR

-

Body[1] Rectangle rect 2.450 0.000 0.095 0.300 Height: 0.250

-4.200 0.000 area 0.300 Width: 0.380

0.000 0.000 density 0.500

Body[2] Rectangle rect 2.450 0.000 0.095 0.300 Height: 0.250

-3.950 0.000 area 0.300 Width: 0.380

0.000 0.000 density 0.500

Body[3] Rectangle rect 2.450 0.000 0.012 0.300 Height: 0.250

-3.700 0.000 area 0.300 Width: 0.050

0.000 0.000 density 0.500

Body[4] Rectangle rect 2.575 0.000 0.012 0.300 Height: 0.050

-3.576 0.000 area 0.300 Width: 0.250

-0.560 0.000 density 0.500

Body[5] Rectangle rect 9.075 0.000 0.012 0.300 Height: 0.050

-3.636 0.000 area 0.300 Width: 0.250

1.302 0.000 density 0.500

Body[6] Rectangle rect 15.573 0.000 0.012 0.300 Height: 0.050

-3.492 0.000 area 0.300 Width: 0.250

-0.621 0.000 density 0.500

Body[7]	Rectangle	rect	16.073	0.000	0.012	0.300	Height:	0.050
			-3.498	0.000	area	0.300	Width:	0.250
			-0.621	0.000	density	0.500		
Body[8]	Rectangle	rect	8.825	0.000	0.012	0.300	Height:	0.050
			-3.637	0.000	area	0.300	Width:	0.250
			-0.560	0.000	density	0.500		
Body[9]	Rectangle	rect	16.323	0.000	0.012	0.300	Height:	0.050
			-3.500	0.000	area	0.300	Width:	0.250
			-0.621	0.000	density	0.500		
Body[10]	Rectangle	rect	5.700	0.000	2.280	0.300	Height:	0.380
			-3.607	0.000	area	0.300	Width:	6.000
			-0.560	0.000	density	0.500		
Body[11]	Rectangle	rect	12.199	0.000	2.280	0.300	Height:	0.380
			-3.565	0.000	area	0.300	Width:	6.000
			1.302	0.000	density	0.500		
Body[12]	Rectangle	rect	15.823	0.000	0.095	0.300	Height:	0.380
			-3.495	0.000	area	0.300	Width:	0.250
			-0.621	0.000	density	0.500		
Body[13]	Rectangle	rect	15.323	0.000	0.012	0.300	Height:	0.050
			-3.494	0.000	area	0.300	Width:	0.250

			1.302	0.000	density	0.500		
Body[14]	Rectangle	rect	16.573	0.000	0.095	0.300	Height:	0.380
			-3.503	0.000	area	0.300	Width:	0.250
			-0.621	0.000	density	0.500		
Body[15]	Rectangle	rect	16.823	0.000	0.095	0.300	Height:	0.380
			-3.506	0.000	area	0.300	Width:	0.250
			-0.621	0.000	density	0.500		
Body[64]	Rectangle	rect	-1.833	0.000	14.280	0.300	Height:	5.100
			-3.350	0.000	area	0.300	Width:	2.800
			0.000	0.000	density	0.500		
Body[70]	Rectangle	rect	18.005	0.000	0.150	0.300	Height:	0.500
			-3.218	0.000	area	0.300	Width:	0.300
			-0.621	0.000	density	0.500		
Body[71]	Circle	circ	18.010	0.000	0.126	0.300	Radius:	0.200
			-2.769	0.000	area	0.300		
			-0.621	0.000	density	0.500		
Body[72]	Rectangle	rect	18.357	0.000	0.040	0.300	Height:	0.100
			-2.972	0.000	area	0.300	Width:	0.400
			-0.621	0.000	density	0.500		
Body[73]	Rectangle	rect	17.658	0.000	0.040	0.300	Height:	0.100

-2.965 0.000 area 0.300 Width: 0.400

-0.621 0.000 density 0.500

Body[74] Rectangle rect 17.849 0.000 0.120 0.300 Height: 0.600

-3.767 0.000 area 0.300 Width: 0.200

-0.621 0.000 density 0.500

Body[75] Rectangle rect 18.149 0.000 0.120 0.300 Height: 0.600

-3.770 0.000 area 0.300 Width: 0.200

-0.621 0.000 density 0.500

Body[99] Polygon poly -5.667 0.000 16.250 0.300 V1x: 2.167 V1y: -1.667

-4.083 0.000 area 0.300 V2x: 2.167 V2y: 3.333

0.000 0.000 density 0.500 V3x: -4.333 V3y: -1.667

Section: Pins

Constraint Name Kind Body1/ Point1/ P1x/ P1y/ Active When

Body2 Point2 P2x P2y

Constraint[28] Pin Joint pin body[0] point[26] 2.450 -3.575 Always

body[3] point[27] (0.0) equation

Constraint[32] Pin pin body[0] point[26] 2.450 -3.575 Always body[4] point[29] equation (0.0)

Constraint[39] Pin pin body[8] point[37] equation (0.0) Always
body[5] point[38] equation (0.0)

Constraint[48] Pin pin body[13] point[46] equation (0.0) Always
body[6] point[47] equation (0.0)

Constraint[57] Pin pin body[7] point[55] equation (0.0) Always
body[9] point[56] equation (0.0)

Section: Rods, Ropes, and Separators

Constraint Name Kind Body1/ Point1/ P1x/ P1y/ Length/ Elasticity/
Body2 Point2 P2x P2y CLength Active When

-

Constraint[95] Rope rope body[15] point[93] equation (0.0) 1.096 0.000
body[70] point[94] (0.0) (0.0) 1.096 Always

Section: Torques

Constraint Name Body1 Point1 P1x P1y Torque Active When

-

Constraint[68] Torque   body[10]   point[67]   equation   (0.0)   4000.000

Section: Round and Square Points

Point	Name	Body	Px	Py	Constraint
Point[16]	Square Poin	body[0]	2.450	-4.075	constraint[18]
Point[17]	Square Poin	body[1]	(0.0)	equation	constraint[18]
Point[19]	Square Poin	body[2]	(0.0)	equation	constraint[20]
Point[21]	Square Poin	body[3]	(0.0)	equation	constraint[25]
Point[22]	Square Poin	body[0]	2.450	-3.825	constraint[24]
Point[23]	Square Poin	body[2]	(0.0)	equation	constraint[24]
Point[26]	Point	body[0]	2.450	-3.575	constraint[28]
Point[27]	Point	body[3]	(0.0)	equation	constraint[28]
Point[29]	Point	body[4]	equation	(0.0)	constraint[32]

Point[30] Square Poin body[8] equation (0.0) constraint[36]

Point[31] Square Poin body[10] equation (0.0) constraint[34]

Point[33] Square Poin body[4] equation (0.0) constraint[34]

Point[35] Square Poin body[10] equation (0.0) constraint[36]

Point[37] Point body[8] equation (0.0) constraint[39]

Point[38] Point body[5] equation (0.0) constraint[39]

Point[40] Square Poin body[5] equation (0.0) constraint[42]

Point[41] Square Poin body[11] equation (0.0) constraint[42]

Point[43] Square Poin body[11] equation (0.0) constraint[45]

Point[44] Square Poin body[13] equation (0.0) constraint[45]

Point[46] Point body[13] equation (0.0) constraint[48]

Point[47] Point body[6] equation (0.0) constraint[48]

Point[49] Square Poin body[6] equation (0.0) constraint[51]

Point[50] Square Poin body[12] equation (0.0) constraint[51]

Point[52]	Square Poin	body[12]	equation	(0.0)	constraint[54]
Point[53]	Square Poin	body[7]	equation	(0.0)	constraint[54]
Point[55]	Point	body[7]	equation	(0.0)	constraint[57]
Point[56]	Point	body[9]	equation	(0.0)	constraint[57]
Point[58]	Square Poin	body[9]	equation	(0.0)	constraint[60]
Point[59]	Square Poin	body[14]	equation	(0.0)	constraint[60]
Point[61]	Square Poin	body[14]	equation	(0.0)	constraint[63]
Point[62]	Square Poin	body[15]	equation	(0.0)	constraint[63]
Point[67]	Base Point	body[10]	equation	(0.0)	constraint[68]
Point[69]	Anchor	body[64]	0.000	-0.050	
Point[76]	Square Poin	body[71]	(0.0)	equation	constraint[90]
Point[77]	Square Poin	body[70]	(0.0)	equation	constraint[90]
Point[78]	Square Poin	body[70]	equation	equation	constraint[86]

Point[79]	Square Poin	body[70]	equation	equation	constraint[87]
Point[80]	Square Poin	body[70]	equation	equation	constraint[88]
Point[81]	Square Poin	body[70]	equation	equation	constraint[89]
Point[82]	Square Poin	body[73]	equation	(0.0)	constraint[86]
Point[83]	Square Poin	body[72]	equation	(0.0)	constraint[87]
Point[84]	Square Poin	body[74]	(0.0)	equation	constraint[88]
Point[85]	Square Poin	body[75]	(0.0)	equation	constraint[89]
Point[91]	Point	body[70]	(0.0)	(0.0)	
Point[92]	Point	body[15]	equation	(0.0)	
Point[93]	Point	body[15]	equation	(0.0)	constraint[95]
Point[94]	Point	body[70]	(0.0)	(0.0)	constraint[95]
Point[100]	Anchor	body[99]	(0.0)	(0.0)	

Appendix B: SolidWorks Simulation Report

Table of Contents

List of Figures

Description

Summarize the FEM analysis on Canada_Arm_with_shuttle_simple

Model Information

Document Name	Configuration	Document Path	Date Modified
Canada_Arm_with_shuttle_simple	Default	C:\Documents and Settings\klapheca\Desktop\SolidWorks\Model\FEA\Canada_Arm_with_shuttle_simple.SLDASM	Fri Dec 19 15:47:11 2008
Elbow_to_wrist-1	Default	C:\Documents and Settings\klapheca\Desktop\SolidWorks\Model\Elbow_to_wrist.SLDPRT	Fri Dec 19 14:46:46 2008
SpaceShuttle1-2	Default	C:\Documents and Settings\klapheca\Desktop\SolidWorks\Model\SpaceShuttle1.SLDPRT	Fri Nov 07 14:27:40 2008

Study Properties

Study name	Study 1
Analysis type	Static
Mesh Type:	Solid Mesh
Solver type	FFEPlus
Inplane Effect:	Off

Soft Spring:	Off
Inertial Relief:	Off
Thermal Effect:	Input Temperature
Zero strain temperature	298.000000
Units	Kelvin
Include fluid pressure effects from COSMOSFloWorks	Off
Friction:	Off
Ignore clearance for surface contact	Off
Use Adaptive Method:	Off

Units

Unit system:	SI
Length/Displacement	m
Temperature	Kelvin
Angular velocity	rad/s
Stress/Pressure	N/m^2

Material Properties

No.	Body Name	Material	Mass	Volume
1	Elbow_to_wrist-1	AISI 1010 Steel, hot rolled bar	5126.65 kg	0.651416 m^3
2	SpaceShuttle1-2	AISI 1010 Steel, hot rolled bar	5.27068e+006 kg	669.718 m^3

Material name:	AISI 1010 Steel, hot rolled bar
Description:	
Material Source:	Library files
Material Library Name:	cosmos materials
Material Model Type:	Linear Elastic Isotropic

Property Name	Value	Units	Value Type
Elastic modulus	2e+011	N/m^2	Constant
Poisson's ratio	0.29	NA	Constant
Shear modulus	8e+010	N/m^2	Constant
Mass density	7870	kg/m^3	Constant
Tensile strength	3.25e+008	N/m^2	Constant
Yield strength	1.8e+008	N/m^2	Constant
Thermal expansion coefficient	1.22e-005	/Kelvin	Constant
Thermal conductivity	51.9	W/(m.K)	Constant
Specific heat	448	J/(kg.K)	Constant

Loads and Restraints

Restraint

Restraint name	Selection set	Description
Restraint-1 <SpaceShuttle1-2>	on 2 Face(s) fixed.	

Load

Load name	Selection set	Loading type	Description
Pressure-1	on 1 Face(s) with	Sequential Loading	

<Elbow_to_wrist-1>	Pressure -60000 N/m^2 along plane Face< 1 > Dir 1		

Contact

Contact state: Touching faces - Bonded

Contact Set-1	Bonded contact pair: Between selected entities of SpaceShuttle1-2 and Elbow_to_wrist-1
Description:	
Contact Set-2	Bonded contact pair: Between selected entities of SpaceShuttle1-2 and Elbow_to_wrist-1
Description:	

Mesh Information

Mesh Type:	Solid Mesh
Mesher Used:	Standard
Automatic Transition:	Off
Smooth Surface:	On
Jacobian Check:	4 Points
Element Size:	0.87501 m
Tolerance:	0.04375 m
Quality:	High
Number of elements:	11206
Number of nodes:	19751
Time to complete mesh(hh;mm;ss):	00:00:07
Computer name:	URD

Reaction Forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Body	N	272338	-1635.59	304113	408235

Free-Body Forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Body	N	-2.15034	-0.111218	-0.729348	2.27339

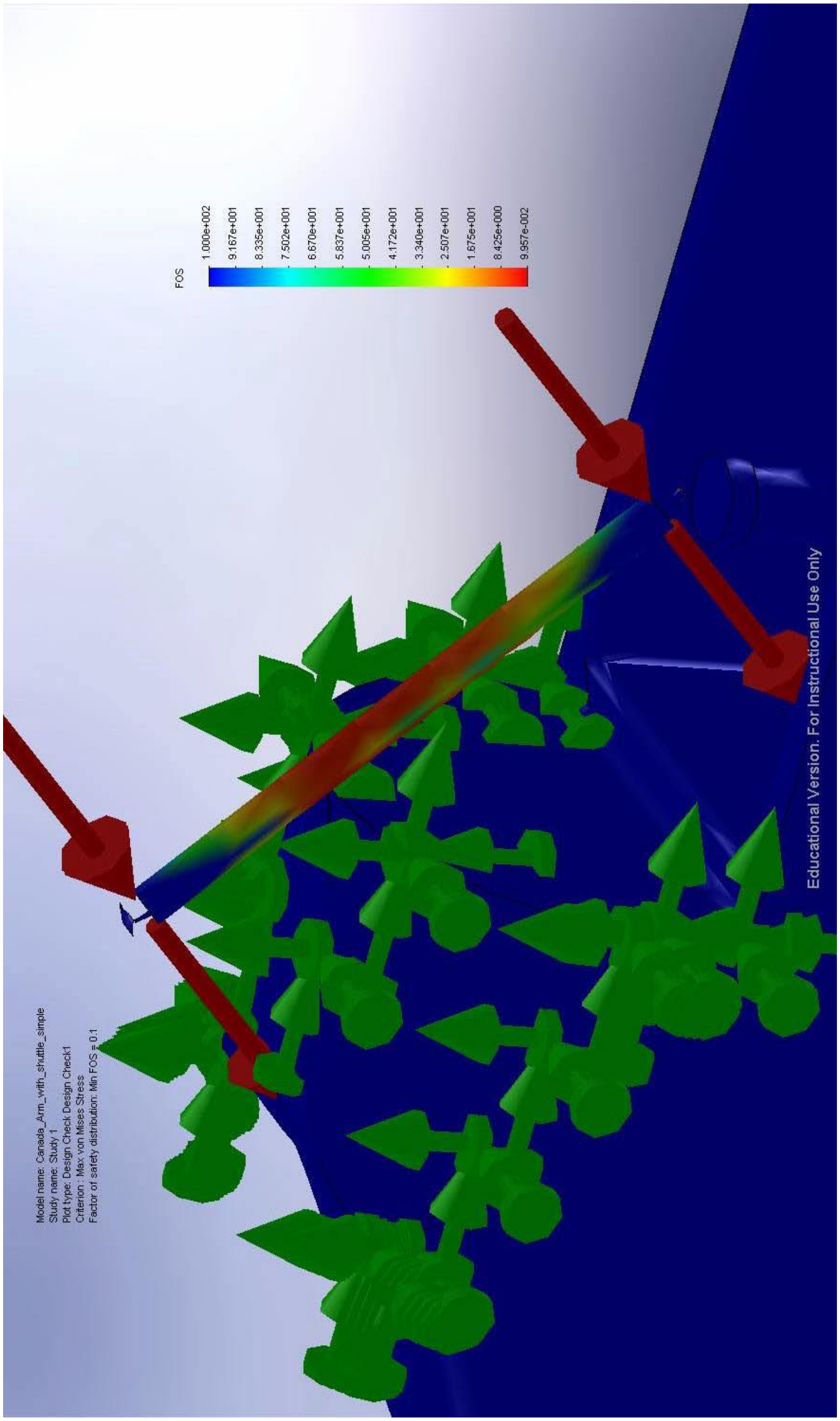
Free-body Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Body	N-m	0	0	0	1e-033

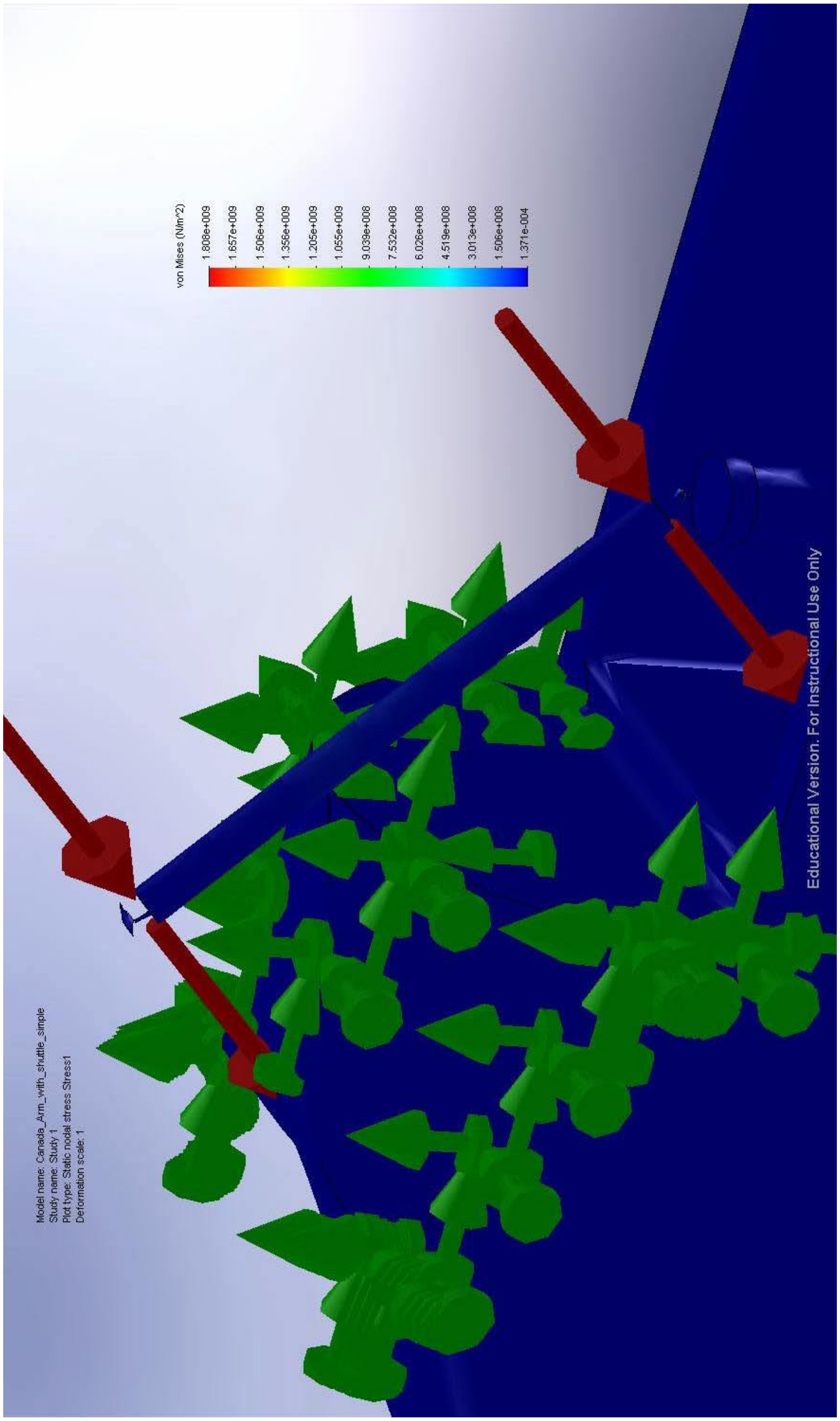
Study Results

Default Results

Name	Type	Min	Location	Max	Location
Stress1	VON: von Mises Stress	0.000137114 N/m^2 Node: 9921	(26.6405 m, 2.24632 m, 4.9227 m)	1.80772e+009 N/m^2 Node: 34	(3.11005 m, 2.37294 m, -2.57949 m)



Canada_Arm_with_shuttle_simple-Study 1-Design Check-Design Check1



Canada_Arm_with_shuttle_simple-Study 1-Stress-Stress1

Appendix C: Nastran4D Simulation Report

Cover Sheet

Document Properties Table

Organizational Data	
Title	
Subject	
Author	**ECS**
Manager	
Company Name	**CSUS**
Lexical Data	
Category	
Key Words	
Comments	
Document Data	
Tracking Number	
Source File Path and Name	**F:\2008_Fall\Dynamcis of Machinery\Final Project\Nasa Project\My_CanadaArm\Nastran\basic_rope_motion_FEA.WM3**
Source File Size	**197.72 MB**
Source Created	**Thursday, December 18, 2008 at 05:44:44 PM**
Source Last Modified	**Friday, December 19, 2008 at 07:00:08 PM**
Report Generated	**Friday, December 19, 2008 at 07:02:23 PM**

Input Settings

Analysis Type

Analysis Type Available	Selected
Stress	yes
Buckling	no
Vibration	no
Thermal	no
Motion	yes

Tolerance

Configuration Tolerance Position	0.010000 m

Integration

Animation Frame Rate Time	0.020000 s
Integration Step Type	Variable
Integration Steps per Frame	2
Integrator Type	Kutta-Merson

Gravity

Gravity Status	Off

Miscellaneous

Unit System	SI [degrees]
User Name	klapheca
Domain	ECS

Model Details

Assembly Table

Name	Material	Mass (kg)	Volume (m^3)	Bounding Box (m)
Elbow_to_wrist	Steel - ANSI C1020	5113.618034	0.651416	0.500000, 0.380000, 6.230000
SpaceShuttle1	Steel - ANSI C1020	5257149.555688	669.700580	37.306828, 23.792180, 13.447012
End_effixer_rotate	Steel - ANSI C1020	201.614661	0.025683	0.380000, 0.380000, 0.310000
rotate_sholder	Steel - ANSI C1020	209.701846	0.026714	0.500000, 0.450000, 0.380000
rotate_wrist	Steel - ANSI C1020	188.780822	0.024049	0.380000, 0.380000, 0.510000
Sholder_to_elbow	Steel - ANSI C1020	4490.421870	0.572028	0.500000, 0.380000, 5.530000
wrist_yaw_joint	Steel - ANSI C1020	217.076742	0.027653	0.380000, 0.500000, 0.730000

3d_person	Steel - ANSI C1020	588.340045	0.074948	0.815315, 1.800001, 0.326432
body[28]	Steel - ANSI C1020	6.875820	0.000876	0.118709, 0.118709, 0.118709
body[39]	Steel - ANSI C1020	2959.380280	0.376991	0.400000, 0.400000, 3.000000

Constraints Table

Name	Associated Parts
constraint[12]	SpaceShuttle1 and rotate_sholder
constraint[7]	rotate_sholder and Elbow_to_wrist
constraint[17]	Elbow_to_wrist and Sholder_to_elbow
constraint[21]	Sholder_to_elbow and wrist_yaw_joint
constraint[30]	rotate_wrist and wrist_yaw_joint
constraint[8]	rotate_wrist and End_effixer_rotate
constraint[32]	End_effixer_rotate and 3d_person
constraint[42]	Elbow_to_wrist and body[39]

Material Properties Table

Steel - ANSI C1020		
Property	**Temperature (K)**	**Value**
Density (kg/m^3)	constant	7.85e+3
Elastic Modulus (Pa)	constant	2e+11
Poisson's Ratio	constant	0.290000
Yield Stress (Pa)	constant	3.31e+8
Ultimate Tensile Stress (Pa)	constant	4.48e+8
Specific Heat (N m / kg K)	constant	418
Thermal Conductivity (W / m K)	constant	46.7
Thermal Coefficient of Expansion (W / m K)	constant	1.13e-5
Steel - ANSI C1020		
Property	**Temperature (K)**	**Value**
Density (kg/m^3)	constant	7.85e+3
Elastic Modulus (Pa)	constant	2e+11
Poisson's Ratio	constant	0.290000
Yield Stress (Pa)	constant	3.31e+8
Ultimate Tensile Stress (Pa)	constant	4.48e+8
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Yield Stress (Pa)	constant	3.31e+8
Ultimate Tensile Stress (Pa)	constant	4.48e+8
Specific Heat (N m / kg K)	constant	418
Thermal Conductivity (W / m K)	constant	46.7
Thermal Coefficient of Expansion (W / m K)	constant	1.13e-5

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Yield Stress (Pa)	constant	3.31e+8
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Density (kg/m^3)	constant	7.85e+3
Elastic Modulus (Pa)	constant	2e+11
Poisson's Ratio	constant	0.290000
Yield Stress (Pa)	constant	3.31e+8
Ultimate Tensile Stress (Pa)	constant	4.48e+8
Specific Heat (N m / kg K)	constant	418
Thermal Conductivity (W / m K)	constant	46.7

Property	Temperature (K)	Value
Thermal Coefficient of Expansion (W / m K)	constant	1.13e-5

Steel - ANSI C1020		
Property	**Temperature (K)**	**Value**
Density (kg/m^3)	constant	7.85e+3
Elastic Modulus (Pa)	constant	2e+11
Poisson's Ratio	constant	0.290000
Yield Stress (Pa)	constant	3.31e+8
Ultimate Tensile Stress (Pa)	constant	4.48e+8
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Thermal Coefficient of Expansion (W / m K)	constant	1.13e-5

Steel - ANSI C1020		
Property	**Temperature (K)**	**Value**
Density (kg/m^3)	constant	7.85e+3
Elastic Modulus (Pa)	constant	2e+11
Poisson's Ratio	constant	0.290000
Yield Stress (Pa)	constant	3.31e+8
Ultimate Tensile Stress (Pa)	constant	4.48e+8
Specific Heat (N m / kg K)	constant	418
Thermal Conductivity (W / m K)	constant	46.7
Thermal Coefficient of Expansion (W / m K)	constant	1.13e-5

Steel - ANSI C1020		
Property	**Temperature (K)**	**Value**
Density (kg/m^3)	constant	7.85e+3
Elastic Modulus (Pa)	constant	2e+11
Poisson's Ratio	constant	0.290000
Yield Stress (Pa)	constant	3.31e+8
Ultimate Tensile Stress (Pa)	constant	4.48e+8
Specific Heat (N m / kg K)	constant	418
Thermal Conductivity (W / m K)	constant	46.7
Thermal Coefficient of Expansion (W / m K)	constant	1.13e-5

Boundary Conditions

Structural Loading			
Name	**Associated Parts**	**Type**	**Load**
constraint[34]	Elbow_to_wrist	Torque	[-100000.000000 X N m, 0.000000 N m Y, 0.000000 N m Z]

Initial Conditions

Name	Initial Linear Velocity Vector (m/s)	Initial Angular Velocity Vector (deg/s)
Elbow_to_wrist	0.000000, 0.000000, 0.000000	0.000000, 0.000000, 0.000000
SpaceShuttle1	0.000000, 0.000000, 0.000000	0.000000, 0.000000, 0.000000

End_effixer_rotate	0.000000, 0.000000, 0.000000	0.000000, 0.000000, 0.000000
rotate_sholder	0.000000, 0.000000, 0.000000	0.000000, 0.000000, 0.000000
rotate_wrist	0.000000, 0.000000, 0.000000	0.000000, 0.000000, 0.000000
Sholder_to_elbow	0.000000, 0.000000, 0.000000	0.000000, 0.000000, 0.000000
wrist_yaw_joint	0.000000, 0.000000, 0.000000	0.000000, 0.000000, 0.000000
3d_person	0.000000, 0.000000, 0.000000	0.000000, 0.000000, 0.000000
body[28]	0.000000, 0.000000, 0.000000	0.000000, 0.000000, 0.000000
body[39]	0.000000, 0.000000, 0.000000	0.000000, 0.000000, 0.000000

FEA Summary

Name	Number of Nodes	Number of Elements
body[39]	2661	1484

FEA Results for 'body[39]'

	Minimum		Maximum	
	Value	Time (s)	Value	Time (s)
Stress: von Mises (Pa)	10.9	13.11	8.92e+6	13.01
Stress: Shear (Pa)	6.3	13.1	5.03e+6	13.01
Stress: Principal (Pa)	-5.74e+6	13.01	6.01e+6	13.01
Strain: von Mises (m/m)	4.69e-11	13.11	3.84e-5	13.01
Strain: Shear (m/m)	8.12e-11	13.1	6.48e-5	13.01
Strain: Principal (m/m)	-3.58e-5	13.01	3.73e-5	13.01
Displacement: Magnitude (m)	5.58e-12	13.15	1.37e-5	13.01