LUNAR REGOLITH EXCAVATOR

NASA : Corporation 2

Summer 2009

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Sponsor: Rob Mueller, NASA Lunar Surface Systems Lead Engineer

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Presenting: Harrison Davis, Dale Braxton

August 4, 2009

Mechanical Engineering
Senior Design
Systems Design Review
SAMUEL GINN
COLLEGE OF ENGINEERING
AUBURN UNIVERSITY

Outline

1. Introduction to Design Objective
2. Subsystems Concepts and Analysis
3. Resource Budgeting
4. Project Management
5. Conclusion and Future Goals

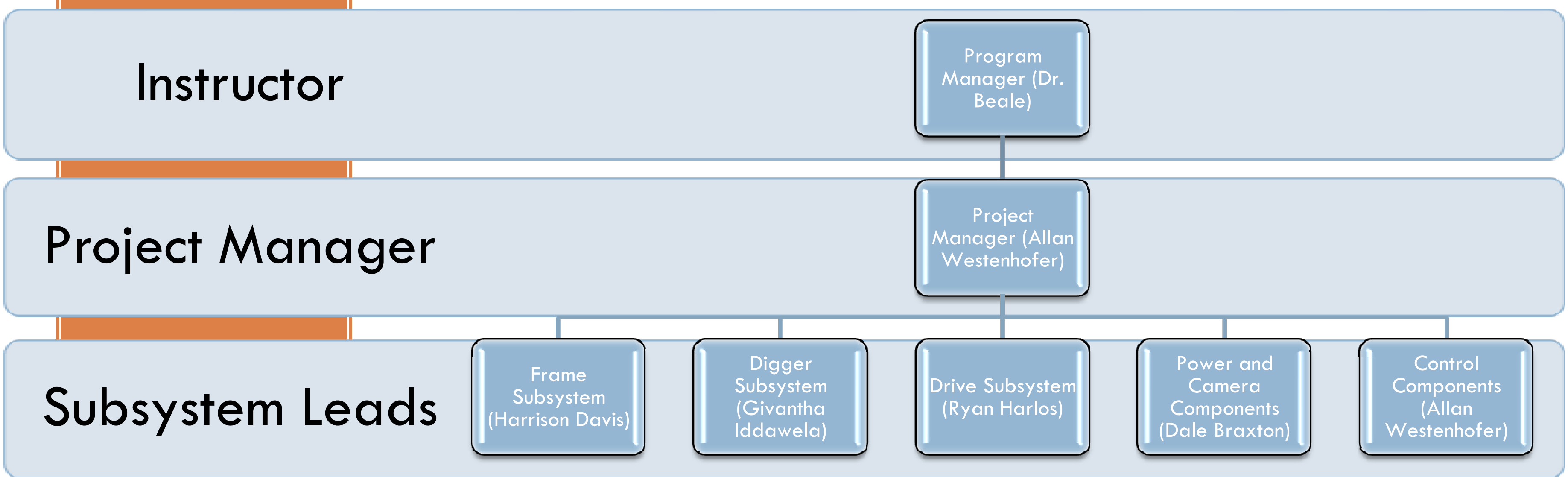
1.1 Mission Objective

- The mission objective is to create an un-manned lunar device that, while being self-propelled, excavates lunar regolith. The vehicle must be able to be driven and operated remotely. It must efficiently excavate 150 kg of regolith per 30 min in semi-lunar conditions.

1.2 Purpose of Design

- The design is to meet requirements for lunar conditions. The regolith excavated will be used by NASA in a process to extract oxygen and create water for a lunar colony. Certain requirements are set for power, size, and mass to ensure a feasible design. These requirements have been set by Rob Mueller, NASA Lunar Surface Systems Lead Engineer and the committee of the CSEWI competition.

2.1 System Hierarchy

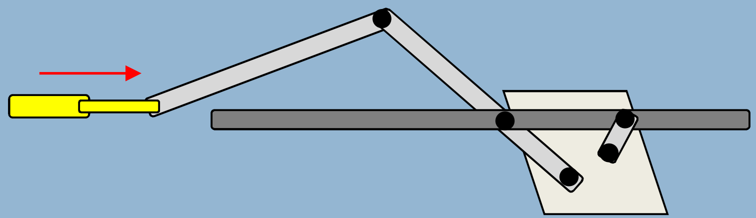
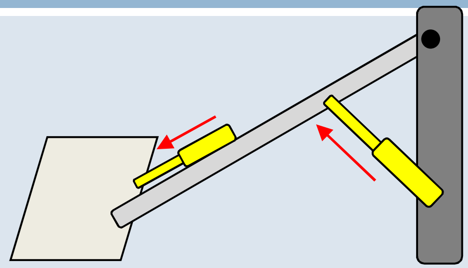
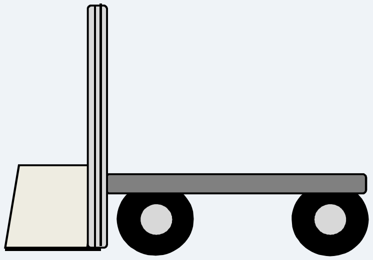


2.2.1 Digger Subsystem

- Design Objectives
  - Ability to raise the bucket above an elevation of 0.5 meters
  - The system length should be no longer than 1m
  - High bucket capacity
  - Light weight design
  - Minimal power usage
  - Simplicity

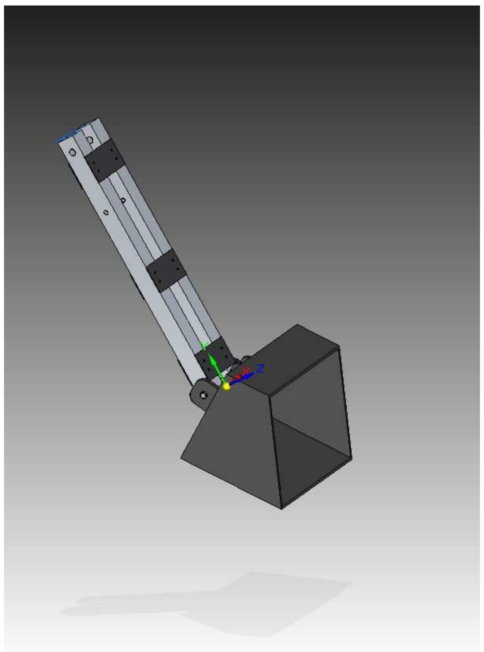
2.2.2 Digger Subsystem

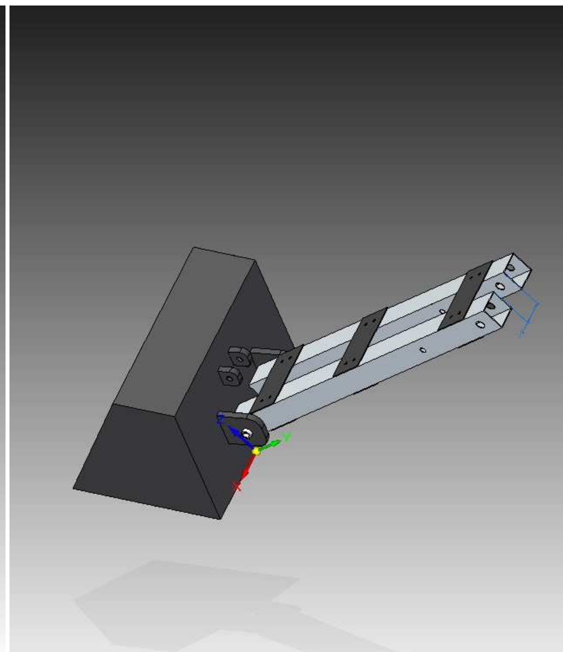
- Design Concepts

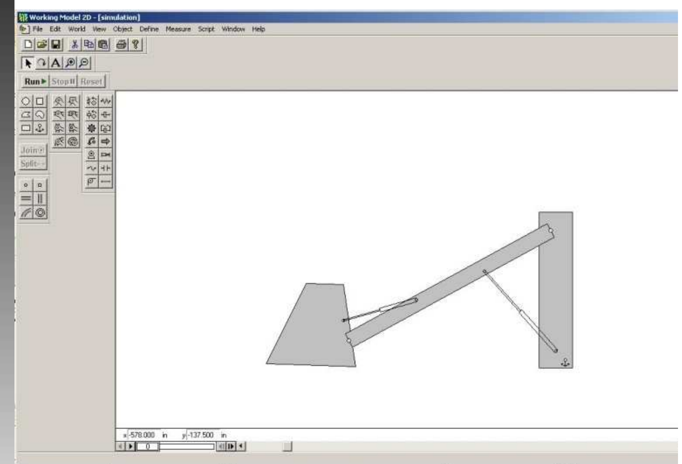
4-Bar Mechanism (previous design) One Actuator	
Dual Actuator system	
Forklift-type system	

2.2.3 Digger Subsystem

- The Design

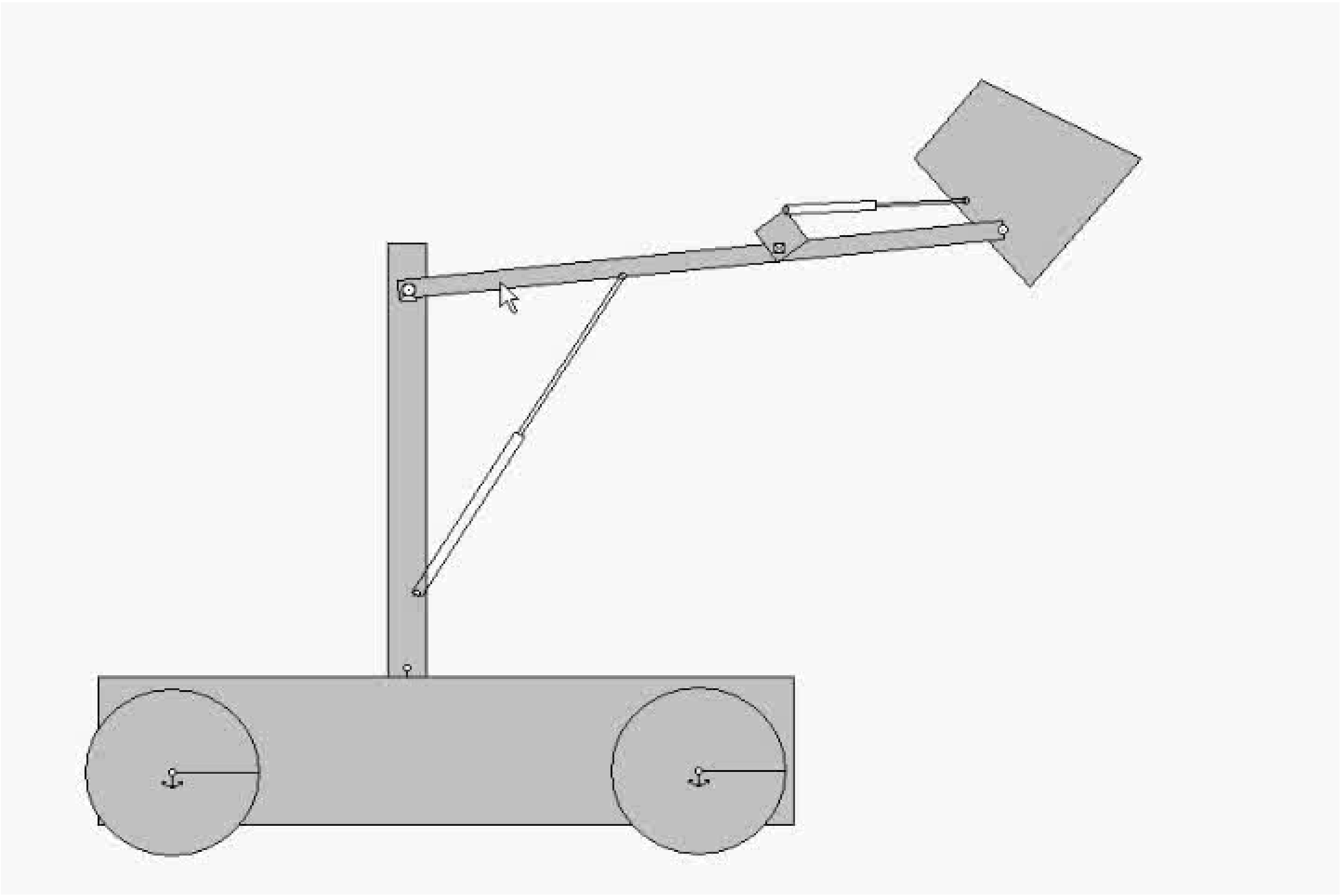






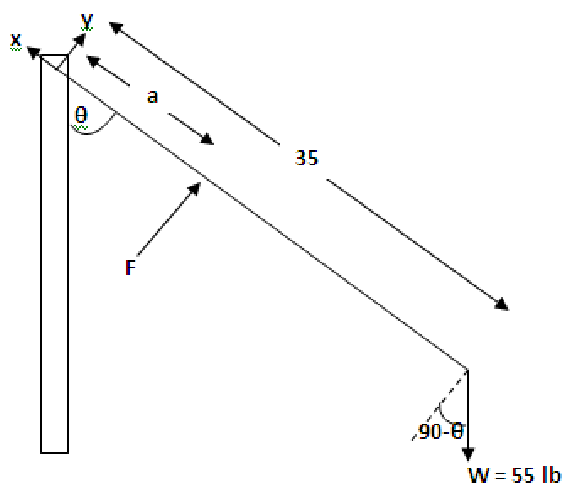
- Material: Carbon Fiber and Garolite

2.2.4 Digger System Animation



2.2.5 Digger/Joint Force Analysis

Digger Free Body Diagram



W= Weight of loaded bucket ≈ 55lb

F= Actuator Force

Θ= Arm angle

Starting position: θ=50 degrees

Carrying position: θ=70 degrees

Dumping position: θ=100 degrees

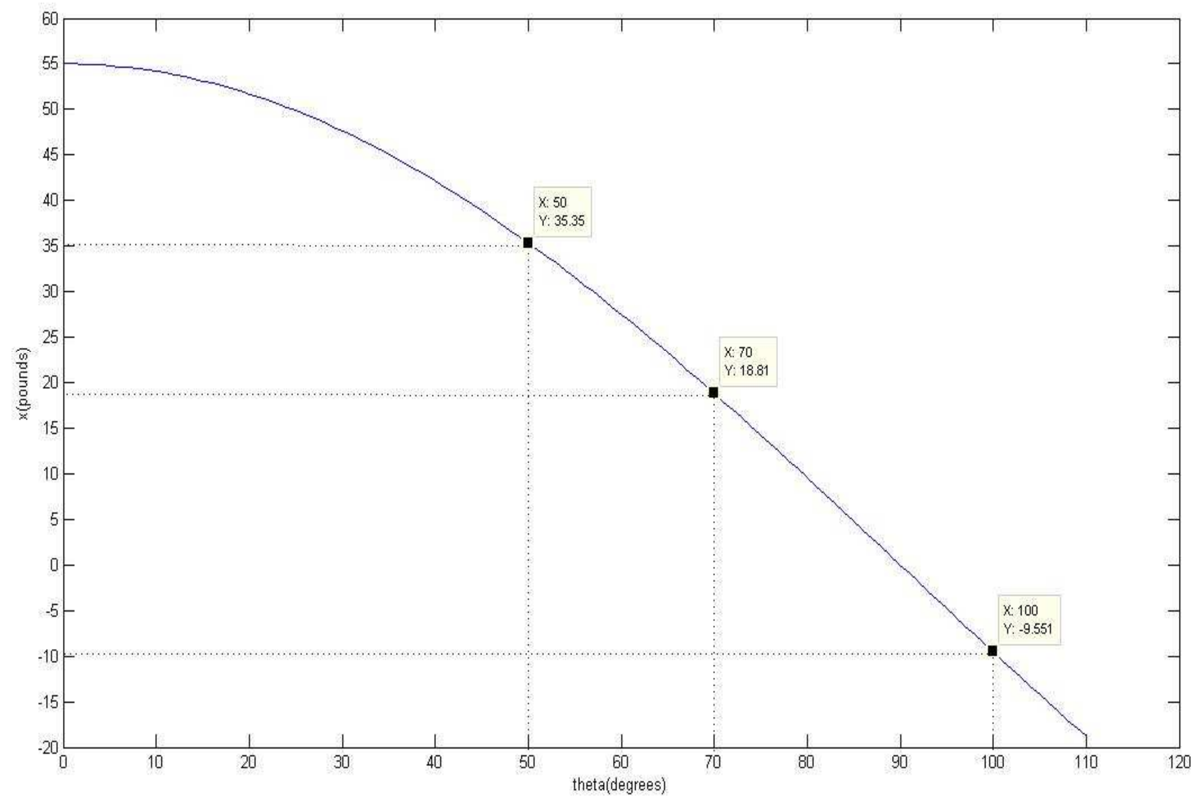
- The forces which were the main focus of this analysis are the actuator force and the forces at the main hinge.

2.2.6 Joint Force Analysis (cont.)

MatLab Analysis:

x vs theta (for a=7in)

As the angle of the arm increases, the force in the x direction decreases

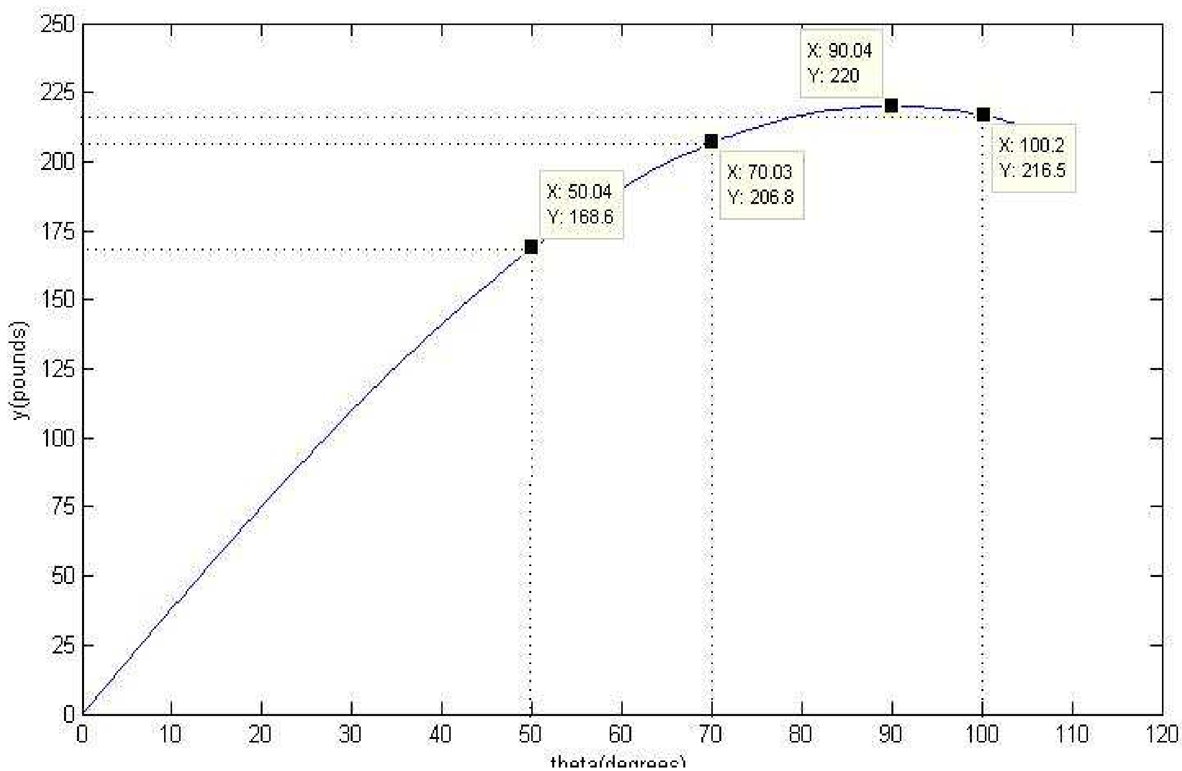


2.2.7 Joint Force Analysis (cont.)

MatLab Analysis:

y vs theta (for a=7in)

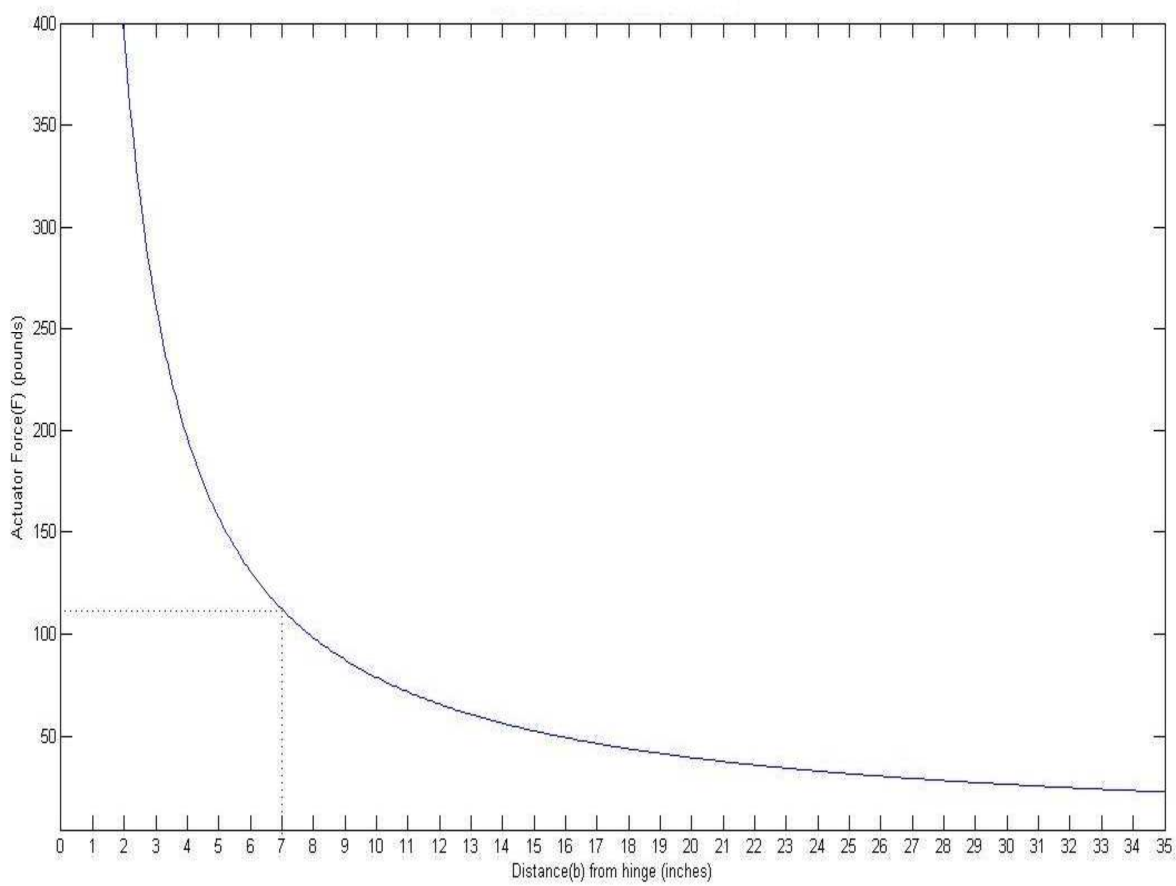
As the angle of the arm increases, the force in the y direction increases



2.2.8 Joint Force Analysis (cont.)

actuator force (F) vs a

As the distance of the arm actuator increases, the amount of force to raise the arm decreases



2.2.9 Arm Actuator

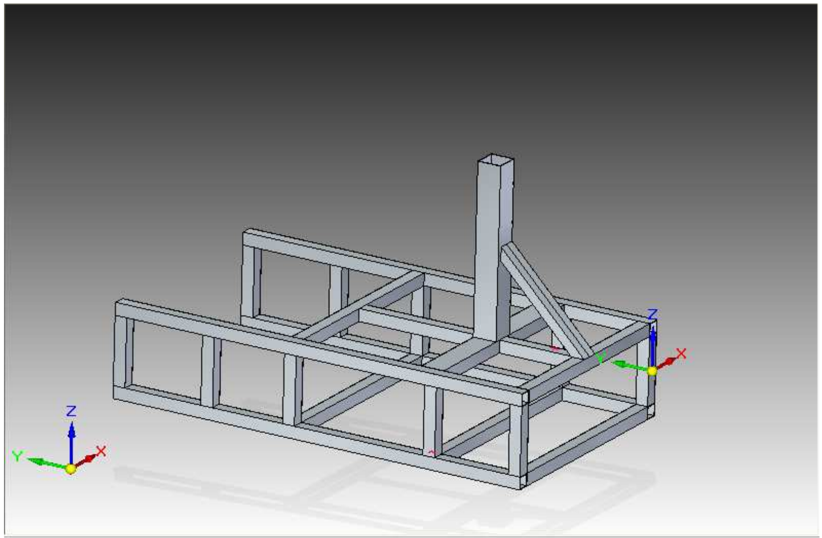
- Northern Industrial Linear Actuator
- Input voltage 12 Volt
- Stroke 11 13/16 in
- 8mm per second travel speed
- Center-to-center closed pin distance is 17 5/16in. (440mm)
- 1350-lb. maximum load capacity

2.2.10 Bucket Actuator

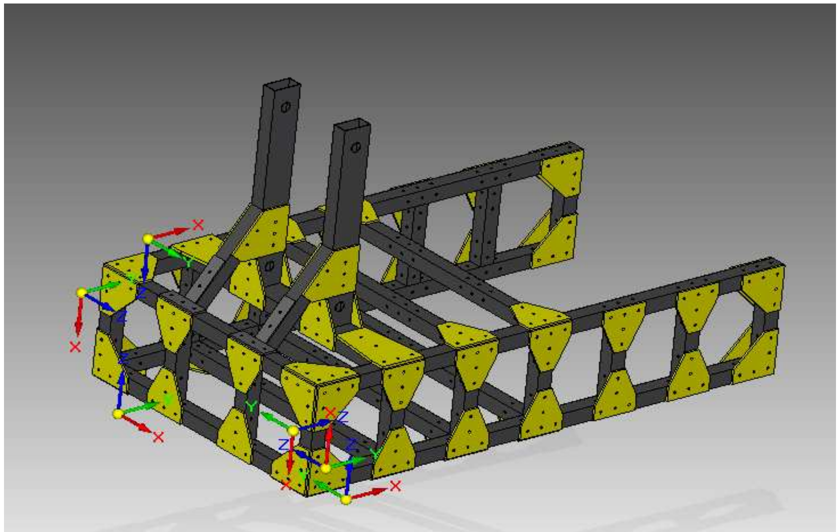
- Northern Industrial Linear Actuator
- Input voltage 12 Volt
- Stroke 3 15/16 in 8mm per second travel speed
- Center-to-center closed pin distance is 9 7/16in. (240mm)
- 1350-lb. maximum load capacity
- Measures 10 5/8in.L x 9in.H

2.3.1 Frame Subsystem

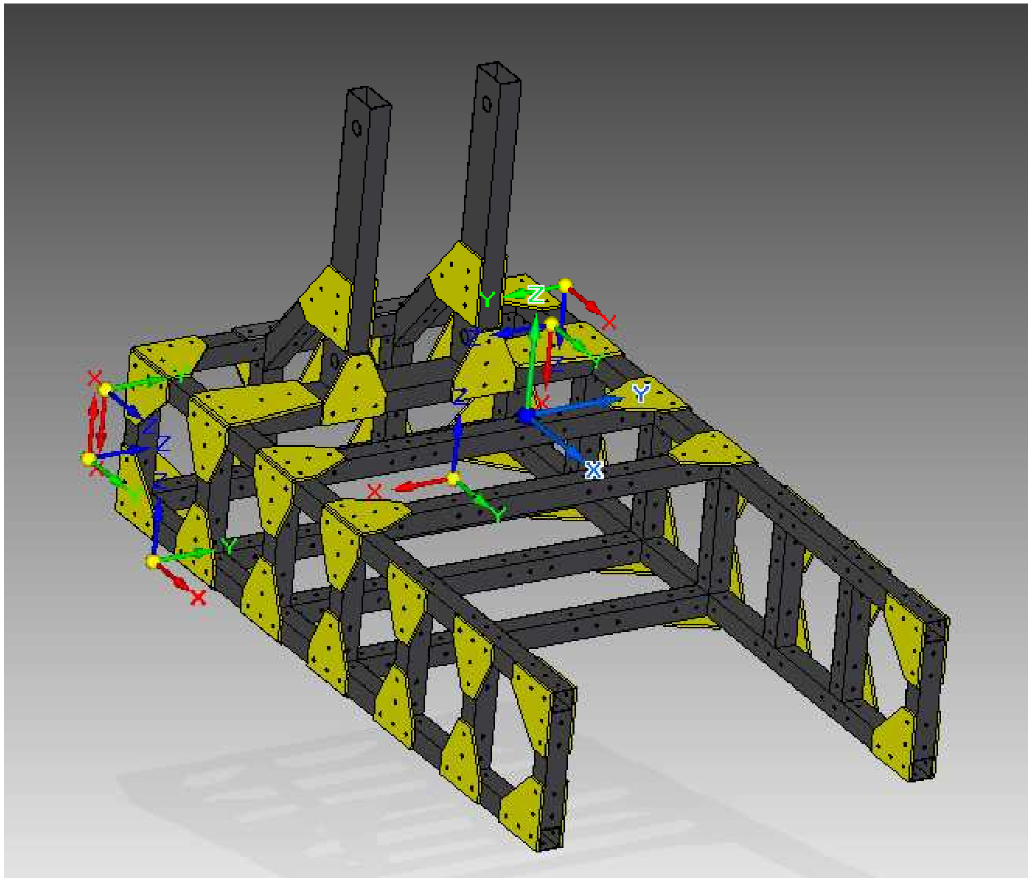
Original Concept



Final Design



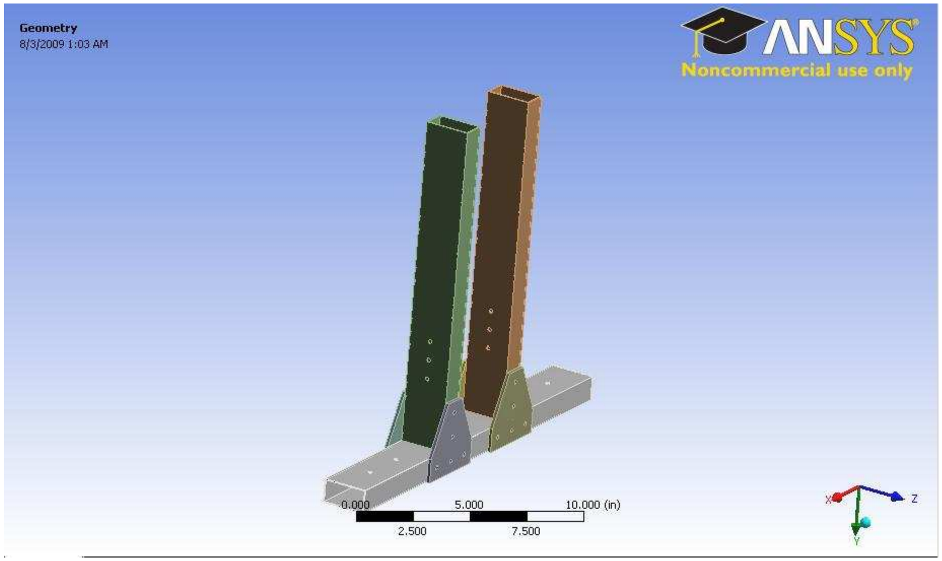
2.3.2 Frame Components



- Carbon Fiber Tubing
- Garolite Gussets
- Aluminum Blind Rivets
- Steel Screws
- Adhesive Epoxy

2.3.3 Frame Analysis with ANSYS

First Design for Digger Supports

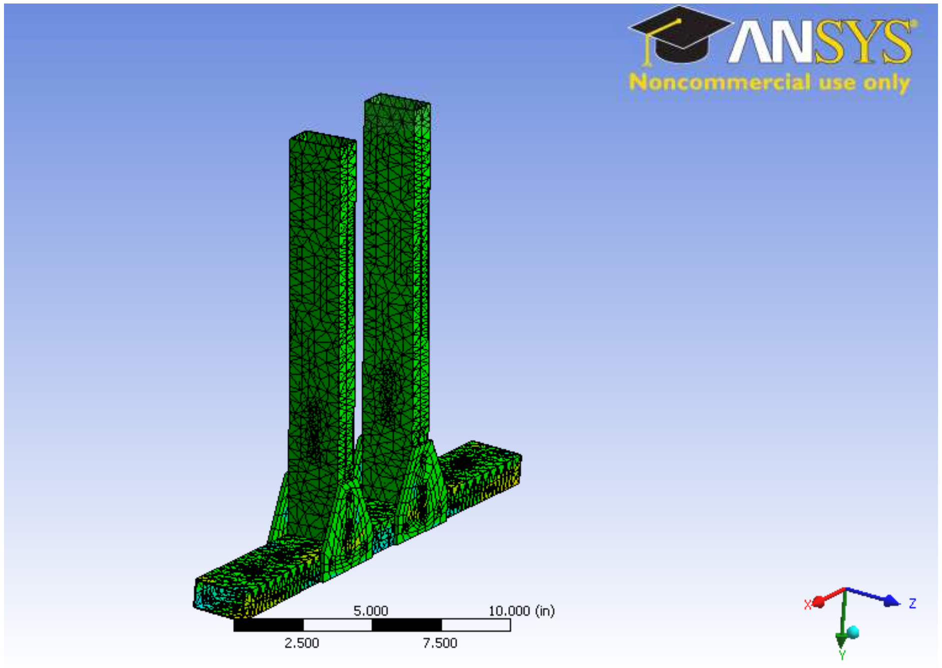


- Used to calculate maximum stress in model
- Ends of base beam are fixed
- Simulated with 100 lb force perpendicular to each support

2.3.3 Frame Analysis with ANSYS (cont.)

- Wire Meshing created to calculate results from acting loads on model
- Mesh: Patch Conforming Tetrahedrons and Sweeping
- Material properties of carbon fiber used in calculations

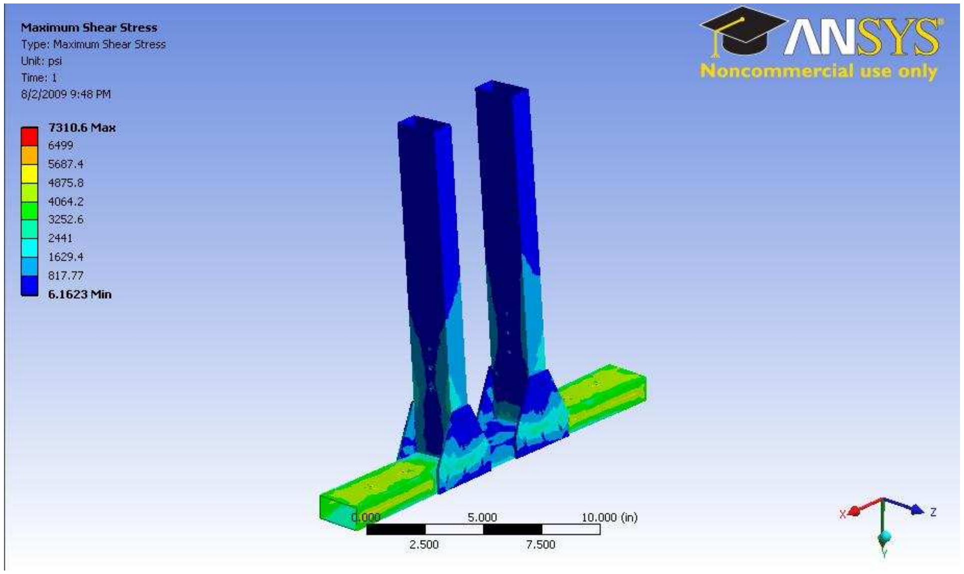
Wire Mesh Diagram



2.3.4 Frame Analysis with ANSYS (cont.)

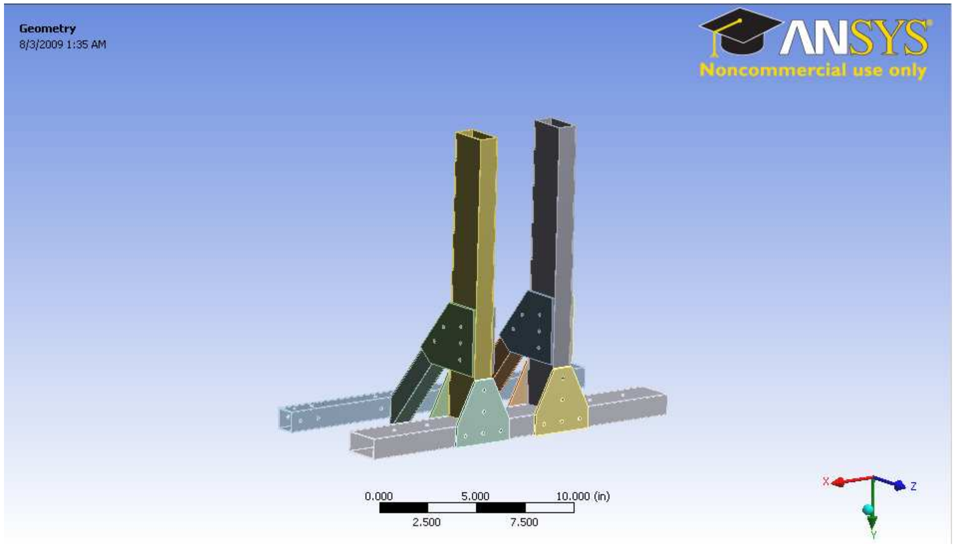
- Blue regions indicate low stress levels
- Green and yellow regions indicate higher stress levels
- Most stress concentrated in base beam
- Max stress is 7310 psi

Shear Stress Diagram



2.3.5 Frame Analysis with ANSYS (cont.)

Second Design on Digger Supports

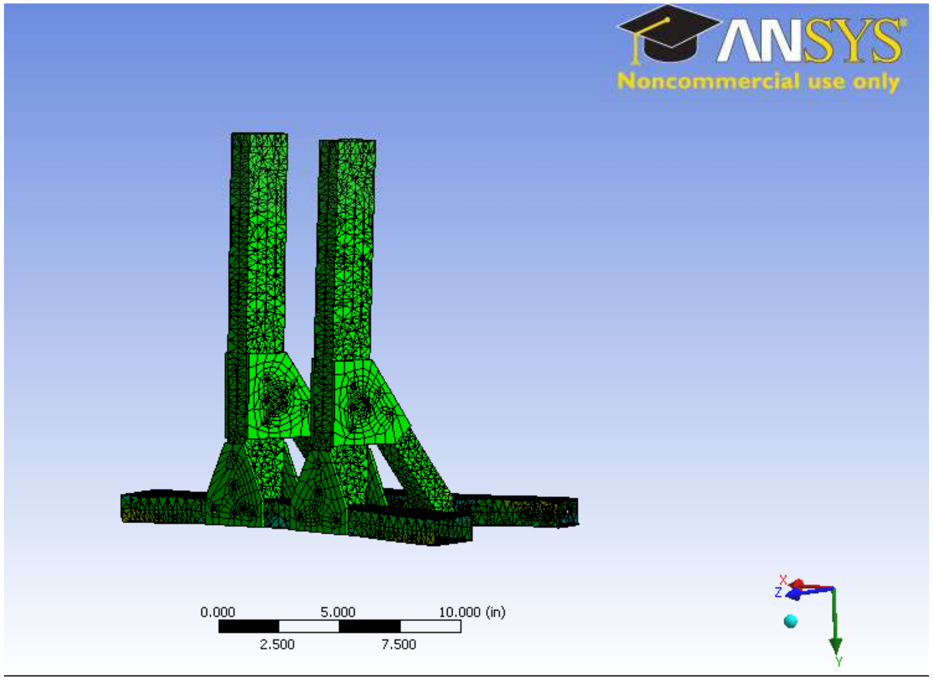


- Add angled support arms to reduce stress and efficiently distribute loads
- Want loads to be distributed to rear of frame to balance digging and transporting loads

2.3.6 Frame Analysis with ANSYS (cont.)

- Second Design simulated with 100 lb force on each support member
- Ends of base beam and support beam are fixed

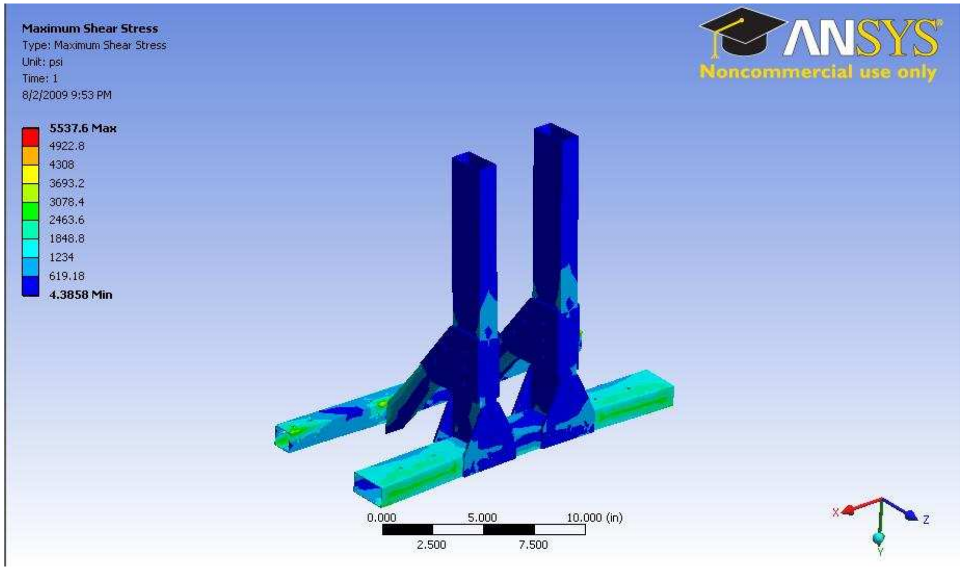
Wire Mesh Diagram



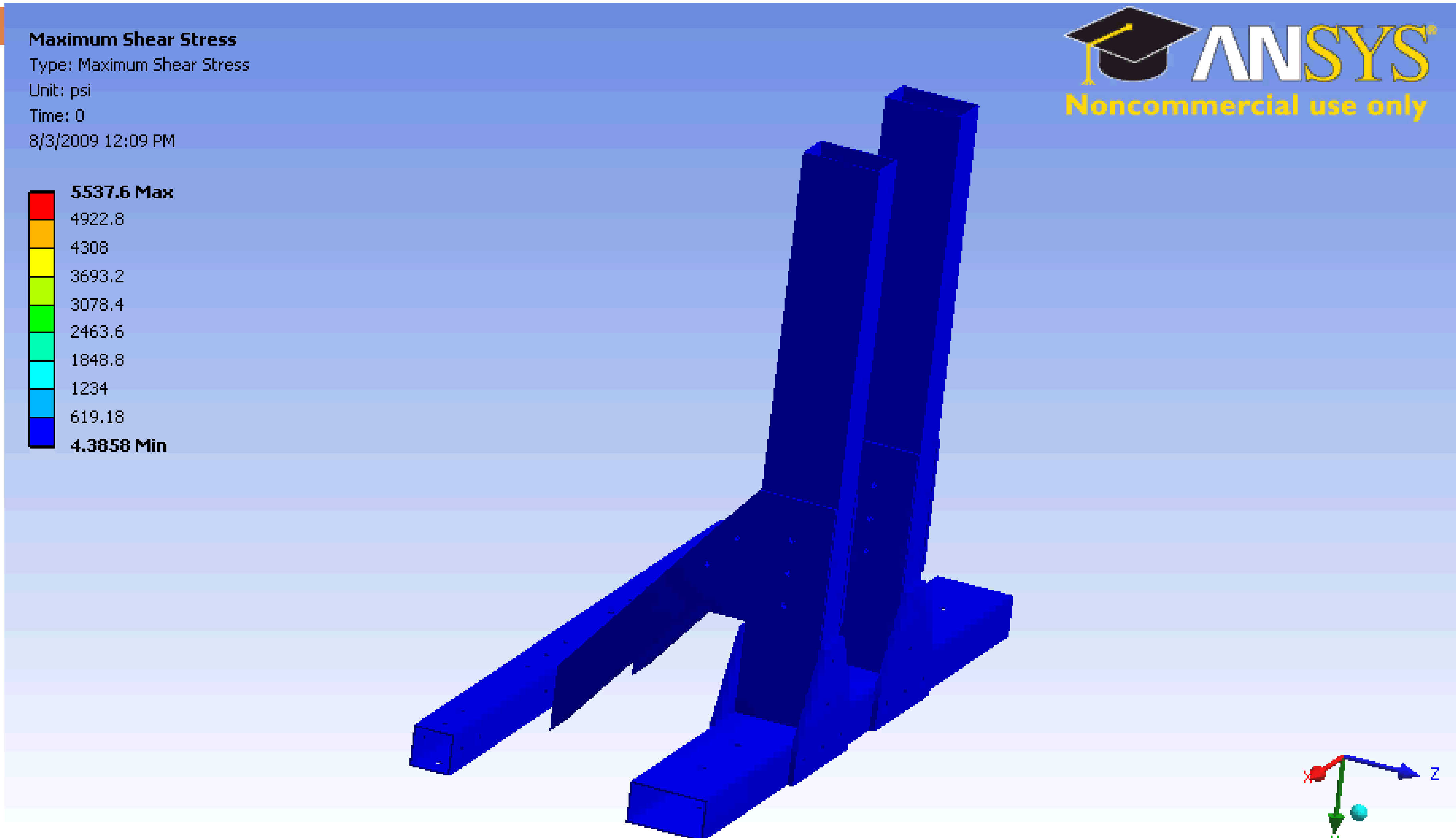
2.3.7 Frame Analysis with ANSYS (cont.)

- Max stress level reduced to 5537 psi
- Stress in base beam reduced
- Load distributed to back support beam and to rear of frame
- Factor of Safety: 115.5

Shear Stress Diagram



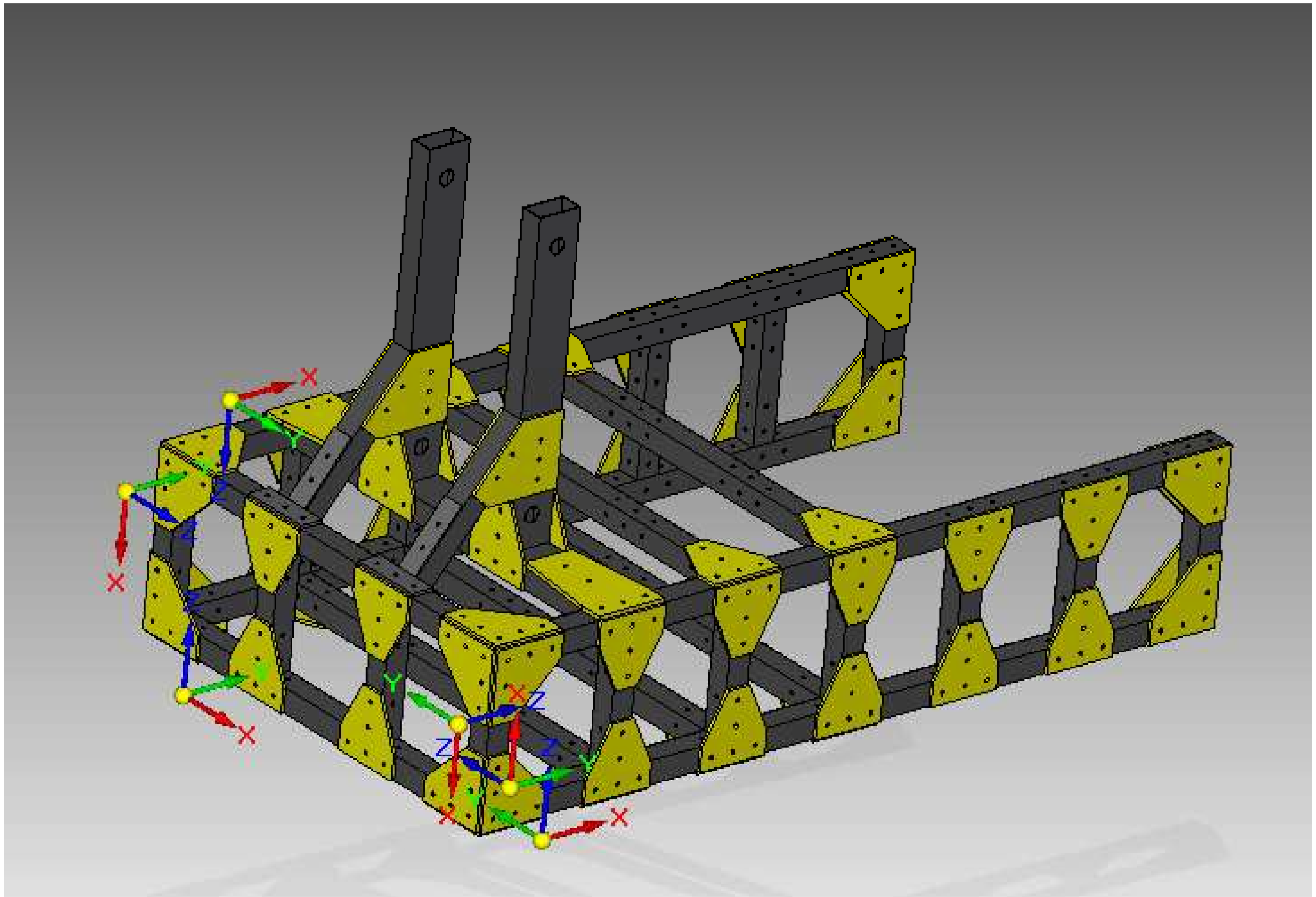
2.3.8 ANSYS Animation



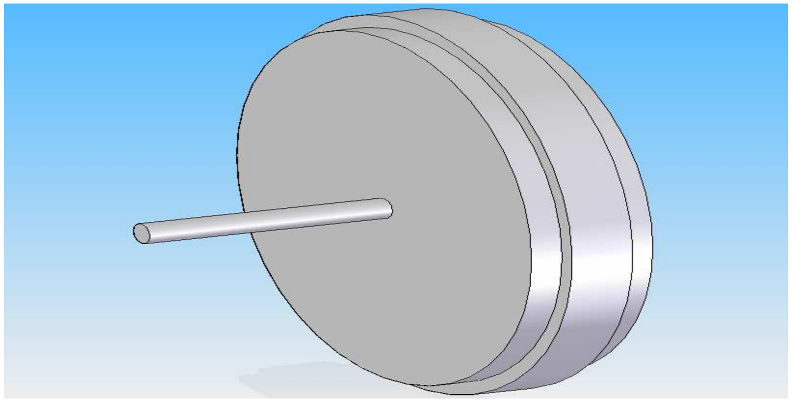
2.3.9 Final Frame Design

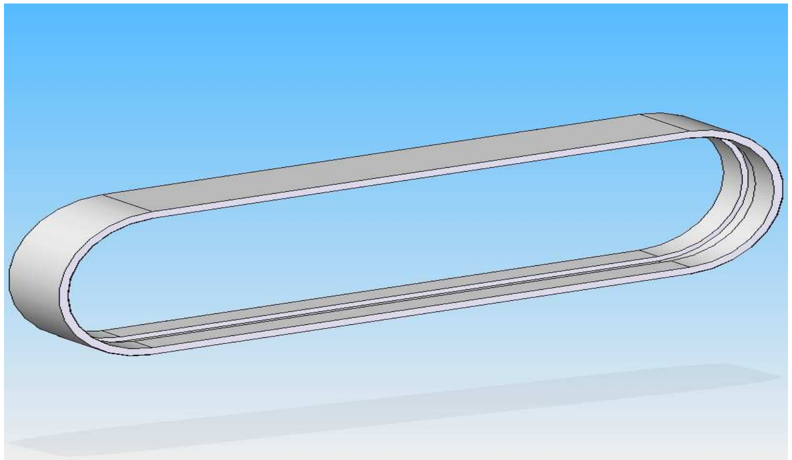
Cross members are spaced approximately 5 inches apart to maximize frame strength

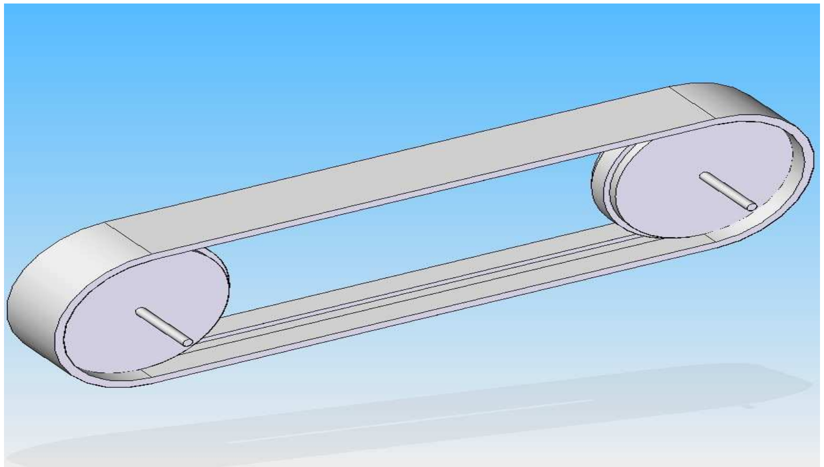
Rear cross bars and top cross bars will be placed with bolts to allow for easy removal



2.4.1 Drive Subsystem Design







2.4.2 Drive Subsystem Motor

- Proven Motor
- Gearbox To Increase Torque

直流馬達 (*DC Carbon-brush motors*)

IG-52
GEARED MOTOR
SERIES

IG-52GM

01&02 TYPE

REDUCTION RATIO	L	REDUCTION RATIO	L
1/3~1/4	53.0	1/150~1/676	99.5
1/12~1/19	68.5		
1/43~1/113	84.0		

GEARED MOTOR TORQUE/SPEED

	減速比 Reduction ratio	1/3	1/4	1/12	1/15	1/19	1/43	1/53	1/66	1/81	1/100	1/113	1/150	1/230	1/285	1/353	1/488	1/546	1/676		
12V	定格扭力(kg-cm) Rated torque	1.3	1.65	4.1	5.0	6.3	12	15	19	23	28	32	36	55	68	84	100	100	100		
	定格回轉數(rpm) Rated speed	1600	1290	457	369	305	130.5	122.5	98.5	68.5	55.5	49.5	37	24	19.5	15.5	11.5	10.3	8.3		
24V	定格扭力(kg-cm) Rated torque	1.8	2.2	5.5	6.8	8.5	16	20	25	31	39	44	48	74	92	100	100	100	100		
	定格回轉數(rpm) Rated speed	1555	1255	444	359	290	127	102.5	82.5	66.5	54	48	36	23.5	19	15.5	11.6	10.4	8.4		

馬達單體型式
MOTOR INSTALLATION

定格電壓(V) Rated volt	定格扭力(g-cm) Rated torque	定格回轉數(rpm) Rated speed	定格電流(mA) Rated current	無負荷回轉數(rpm) No load speed	無負荷電流(mA) No load current	定格出力(W) Rated output
12	480	5600	≦5600	6000	≦1750	58.6
24	650	5450	≦2750	6000	≦ 750	48.3

2.4.3 Torque Calculations

The purpose of the calculations is to verify if the motors provided enough torque to move from a stand still

Torque Calculations

- Average μ_s for tire vs. road - 0.9
- Average μ_s for tire vs. gravel/dirt - 0.3
- Estimated μ_s for treads vs. dirt - 0.5

F → Friction force needed to break coefficient of static friction
r → radius
m → mass
T → Torque needed to break coefficient of static friction

* Note: gravity is neglected in order to stay consistent with units from gear distributor

* From www.Superdroidrobots.com
- IG52-02 24V DC 103 rpm gear motor
  - Stall torque > 300 Kg-cm per motor
  - > 425 Kg-cm for 8 rpm motor

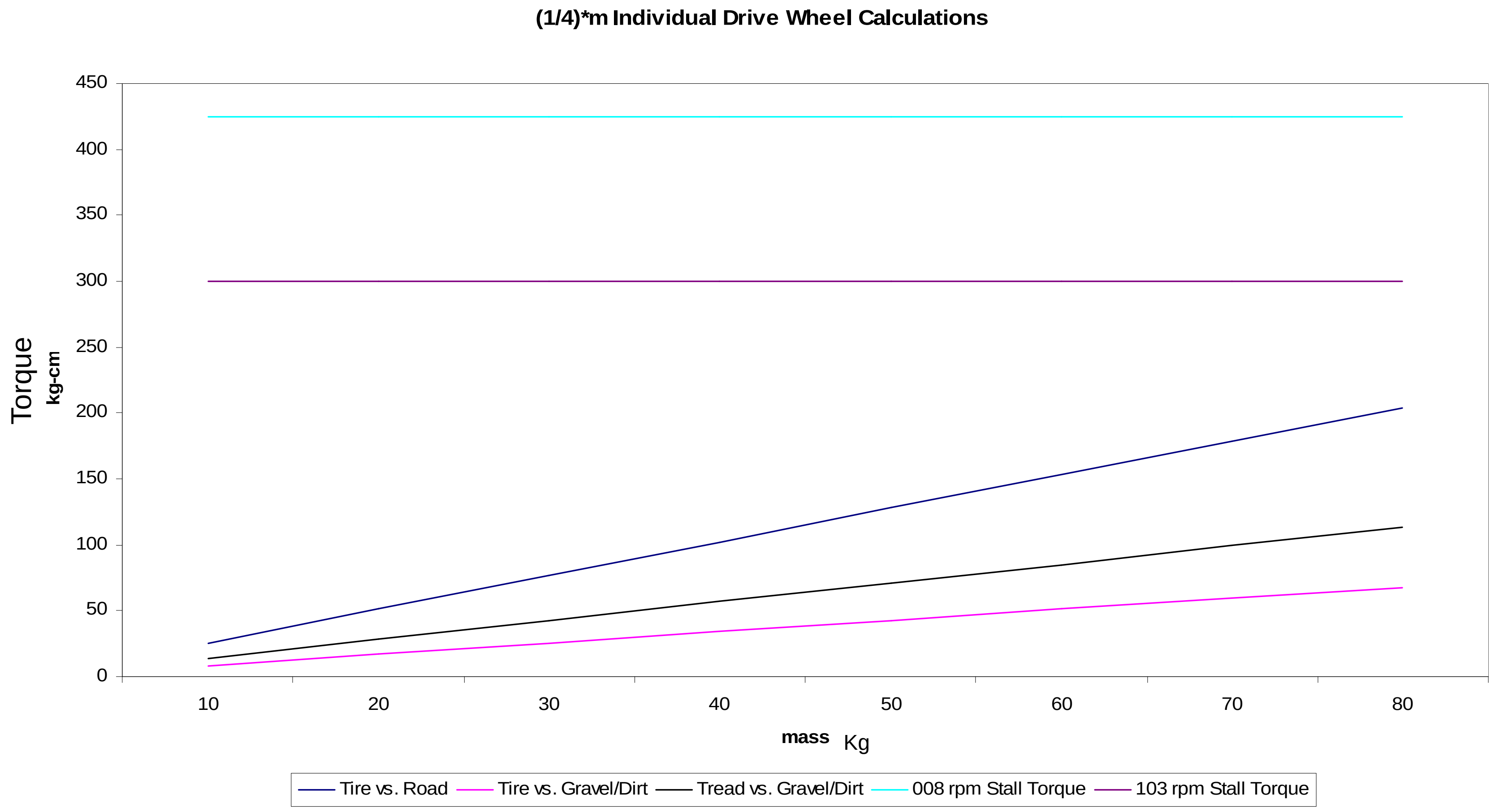
$r = 11.354$ cm
$m = 0 - 80$ Kg
$\mu_s = 0.3, 0.5, 0.9$

$F = \mu_s M$ (Assuming $M = (1/4) * m$)
- 1/4 of weight above each driven wheel

$T = F \cdot r$

* Calculations are being performed for one side (one motor) to verify that the motors can provide enough torque to move the excavator

2.4.4 Drive Wheel Calculations



2.4.5 Speed Calculations

Speed Calculations

V → velocity
ϕ → Diameter of wheel
T → time to traverse area (length of 400 cm)

$\phi = 22.708$ cm

$V = rpm * \frac{\phi \pi}{60}$

$T = \frac{400}{V}$

- For 8 rpm motor

  $V = 8 * \frac{(22.708)(\pi)}{60} = 9.512$ cm/s

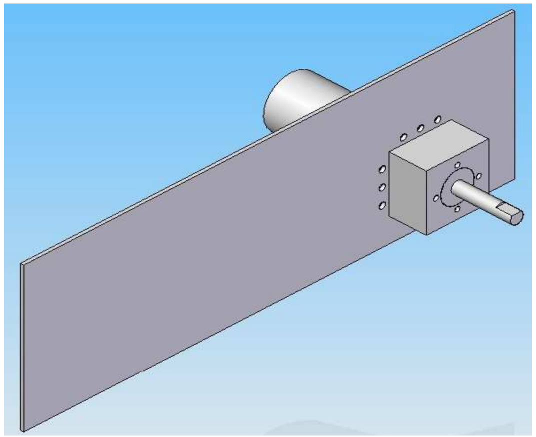
  $T = \frac{400}{9.512} = 42$ seconds

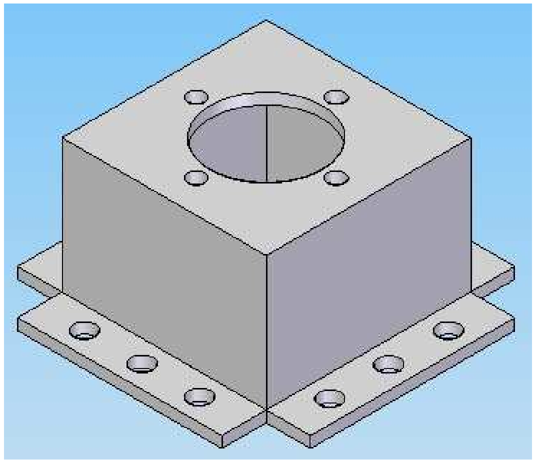
- For 103 rpm motor

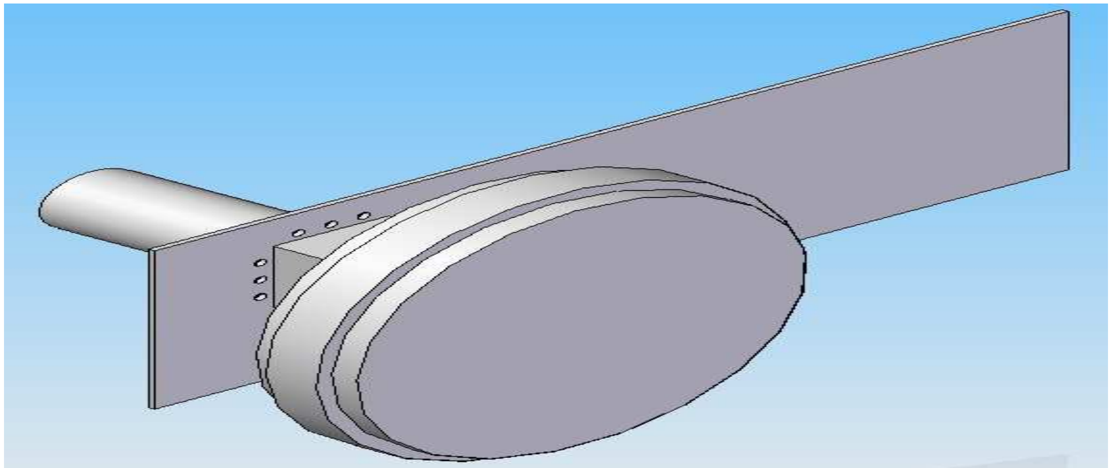
  $V = 103 * \frac{(22.708)(\pi)}{60} = 122.466$ cm/s

  $T = \frac{400}{V} = 3.26$ seconds

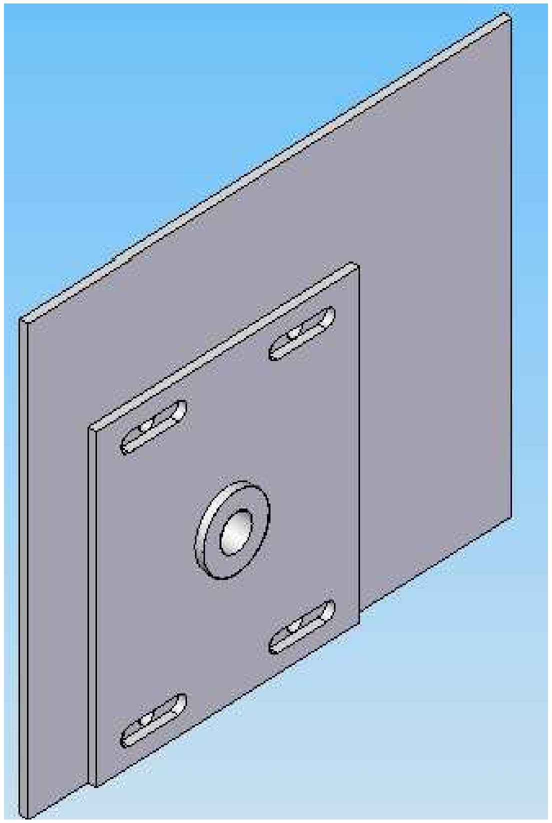
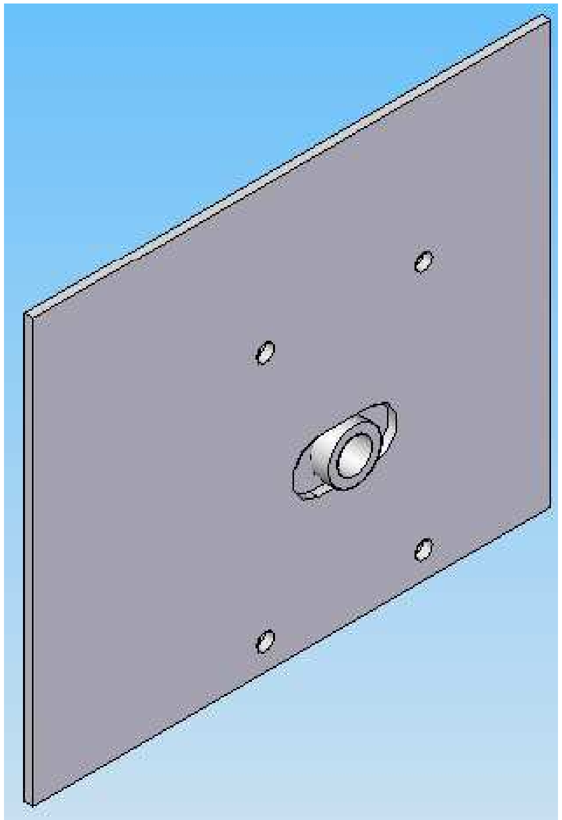
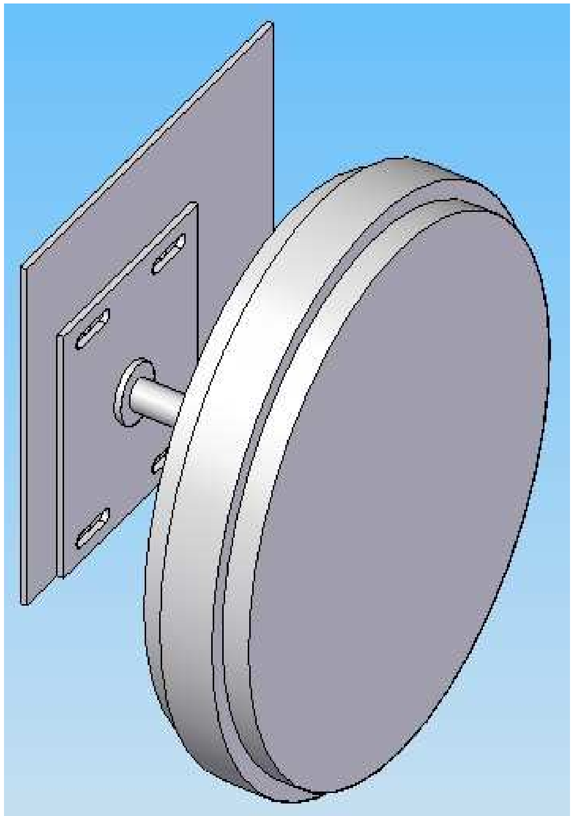
2.4.6 Drive Subsystem Design



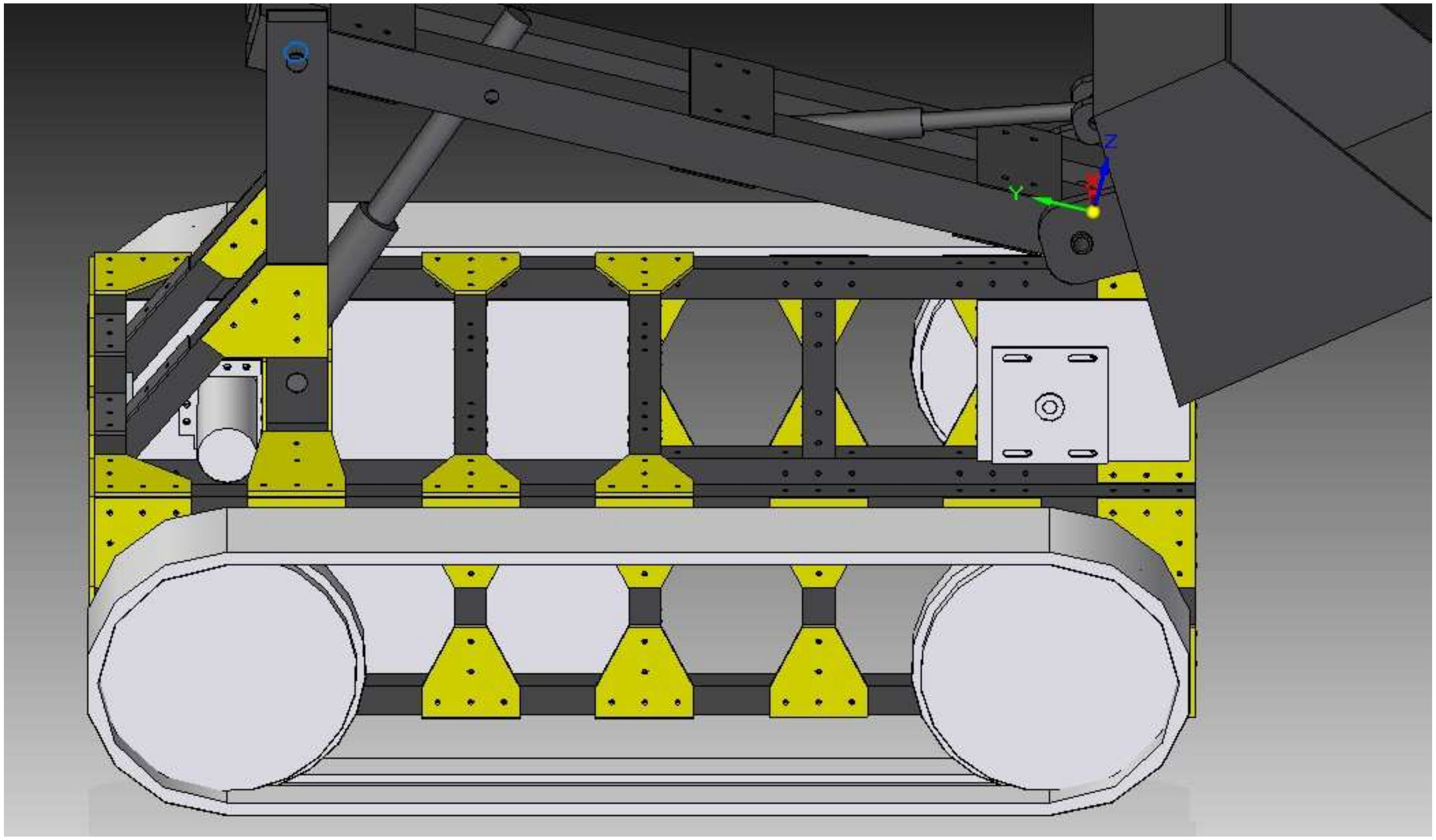




2.4.7 Drive Subsystem Design

2.4.8 Drive Subsystem Design



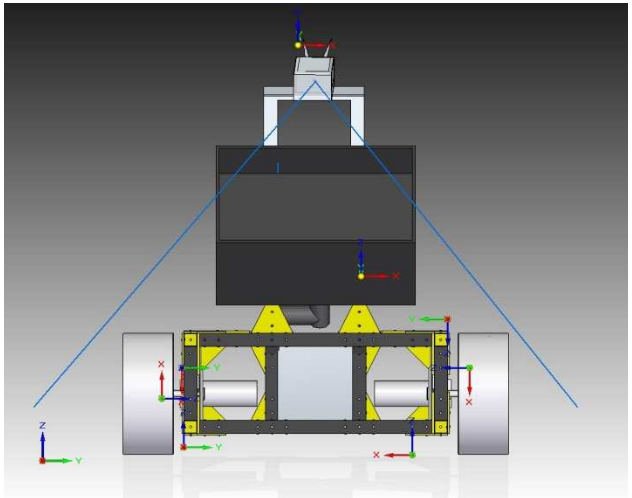
2.5 Power System

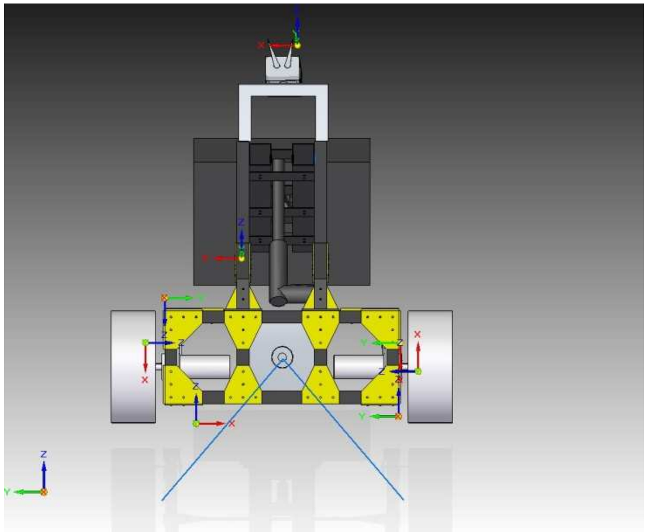
- Limits: 40V, 15A

12v Lead Acid Battery

Power Distribution			
Component	Voltage Required (V)	Current Consumed (mA)	Power Consumption (W)
Motors (2)	24	2750(2)	132
Cisco WVC2300 Wireless-G Business Internet Video Camera	12	1000	12
Actuators(2)	12	1750(2)	42
120mm Auxiliary Fan	12	.250	3
PIC Controller	5	100	0.5
Wireless bridge	5	1600	8
WiPort	3.3	400	1.3
Total Hardware (Idle, Connected to ground station)	12	750	9
Sonar Sensor	5V	2	0.01
Camera Board	5V	100	0.5
Siren Speed Controller	12V	100	1.2
Tank Mixer	?	?	?
Total Hardware (Max Load)	24	13052.25	312.254

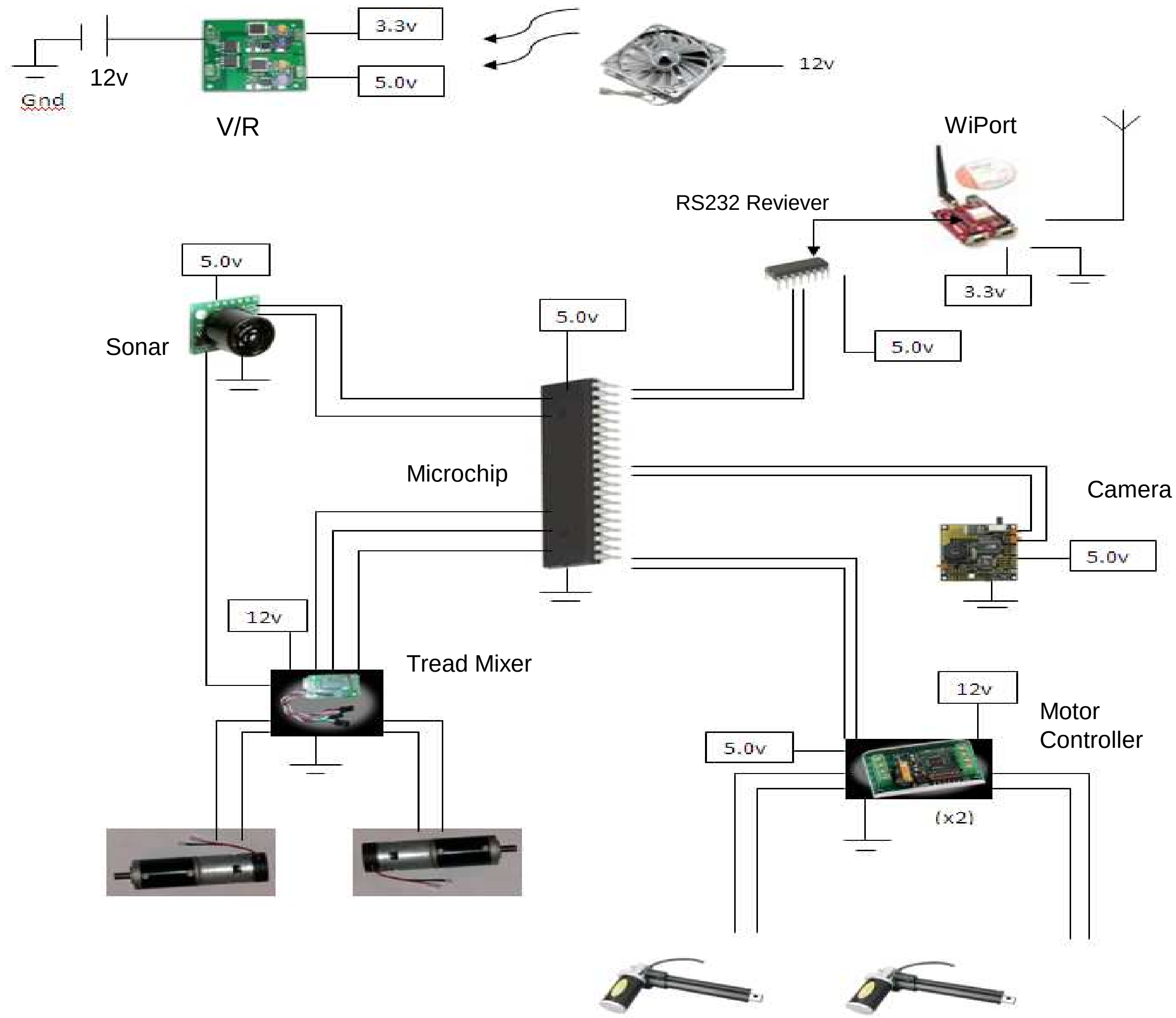
2.6 Camera System





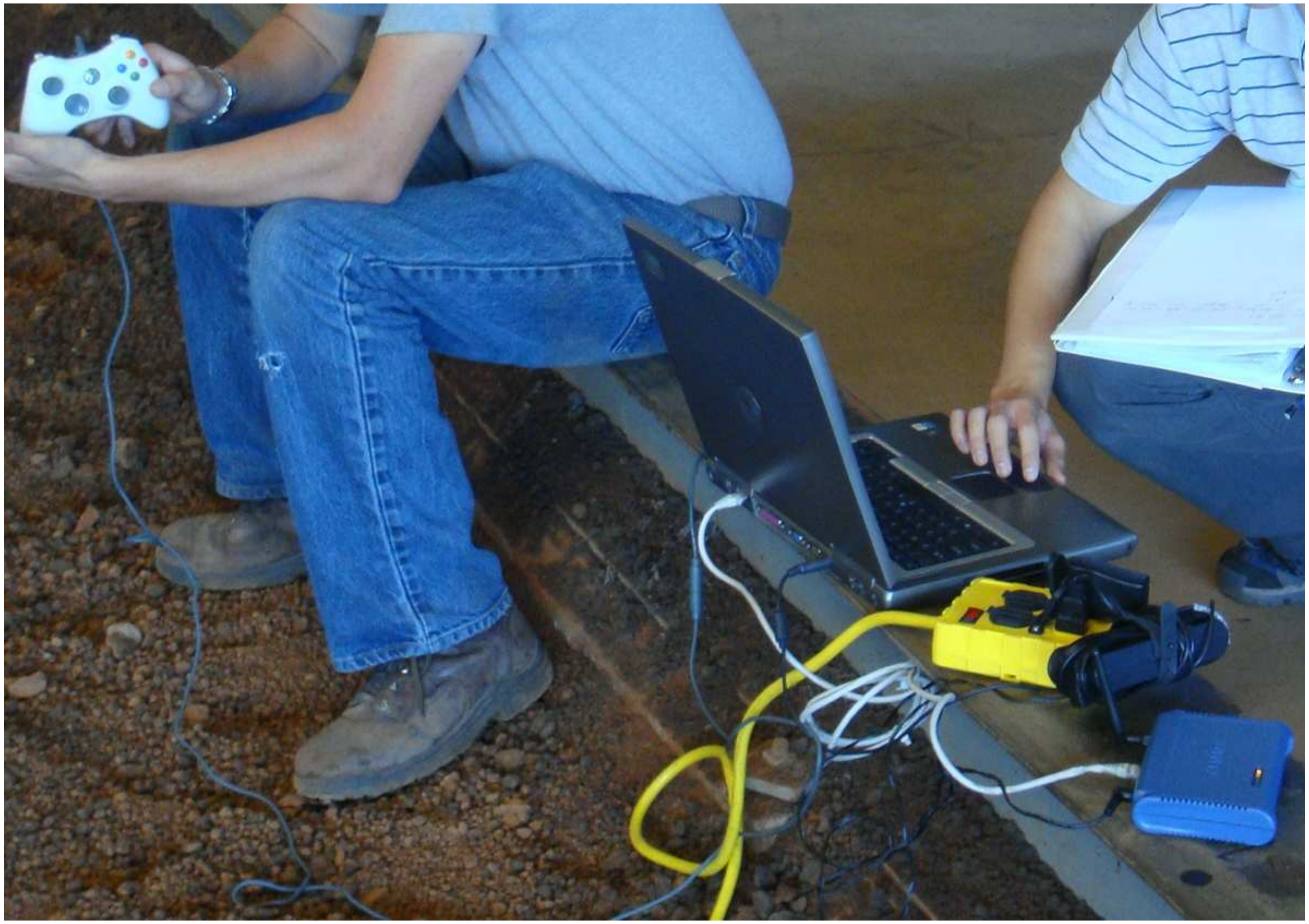
2.7 Control System

The processor in the microcontroller will send signals to the controllers to operate movement and operation of the digger arm. The WiPort will send and receive communication data with the ground station



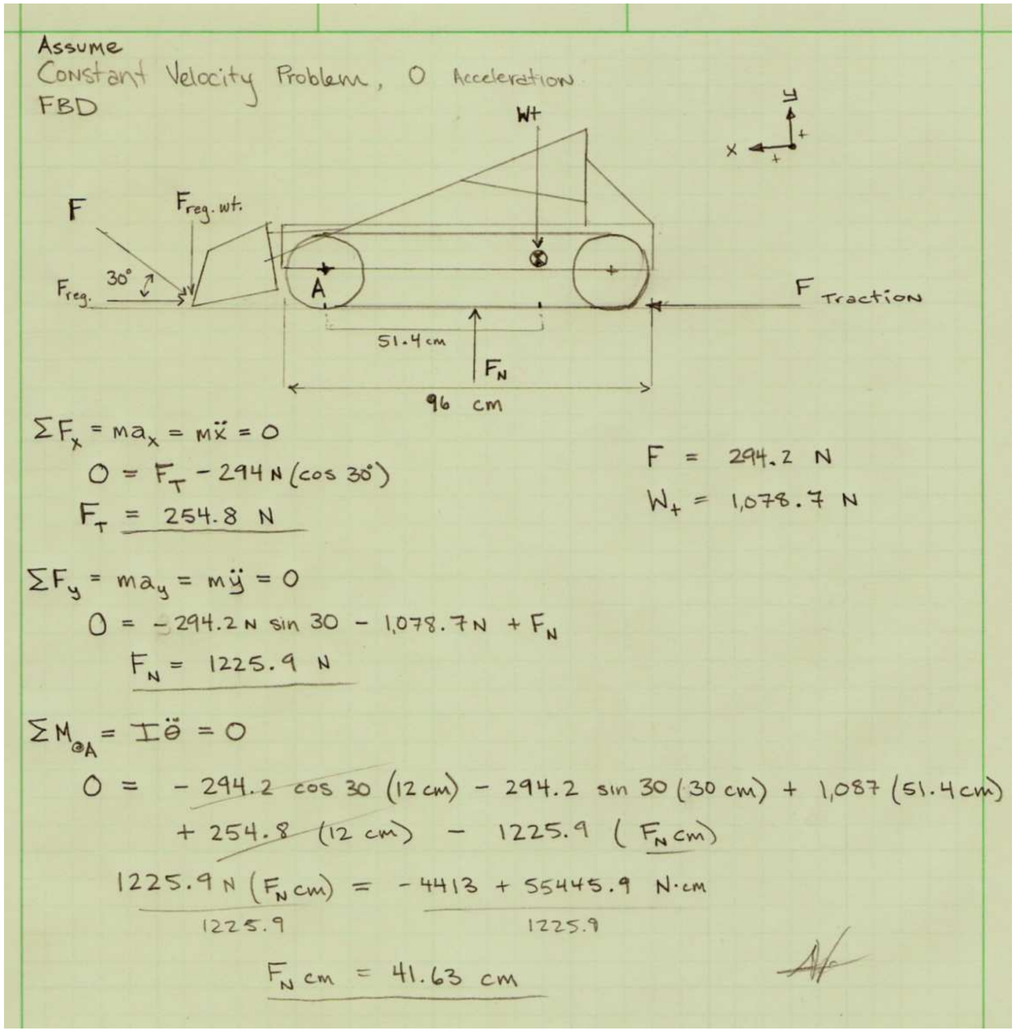
2.8 Control Ground Station

The ground station is where the operator can control the excavator with a handheld console control. The network adapter will receive the transmission from the WiPort located on board the excavator, and send input back to it.



2.9 System Calculations

This a Free Body Diagram done, with assumed parameters, to estimate forces on the excavator. We are using this approach to find the location where the bucket could dig and still provide the most traction force.



$\Sigma F_x = ma_x = m\ddot{x} = 0$

$0 = F_T - 294\ N(\cos 30°)$

$F_T = 254.8\ N$

$F = 294.2\ N$

$W_t = 1{,}078.7\ N$

$\Sigma F_y = ma_y = m\ddot{y} = 0$

$0 = -294.2\ N \sin 30 - 1{,}078.7\ N + F_N$

$F_N = 1225.9\ N$

$\Sigma M_{@A} = I\ddot{\theta} = 0$

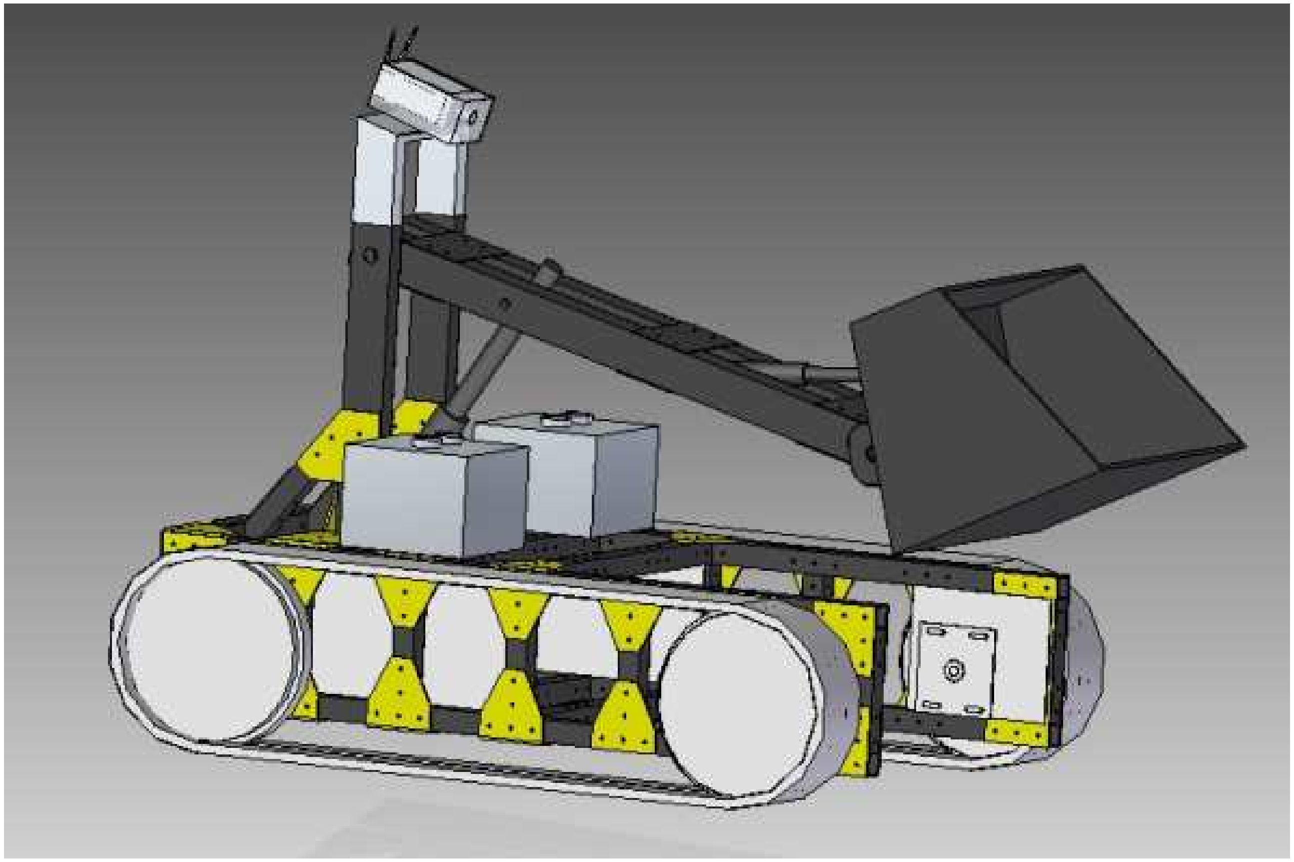
$0 = -294.2 \cos 30\ (12\ cm) - 294.2 \sin 30\ (30\ cm) + 1{,}087\ (51.4\ cm) + 254.8\ (12\ cm) - 1225.9\ (F_N\ cm)$

$\frac{1225.9\ N\ (F_N\ cm)}{1225.9} = \frac{-4413 + 55445.9\ N \cdot cm}{1225.9}$

$F_N\ cm = 41.63\ cm$

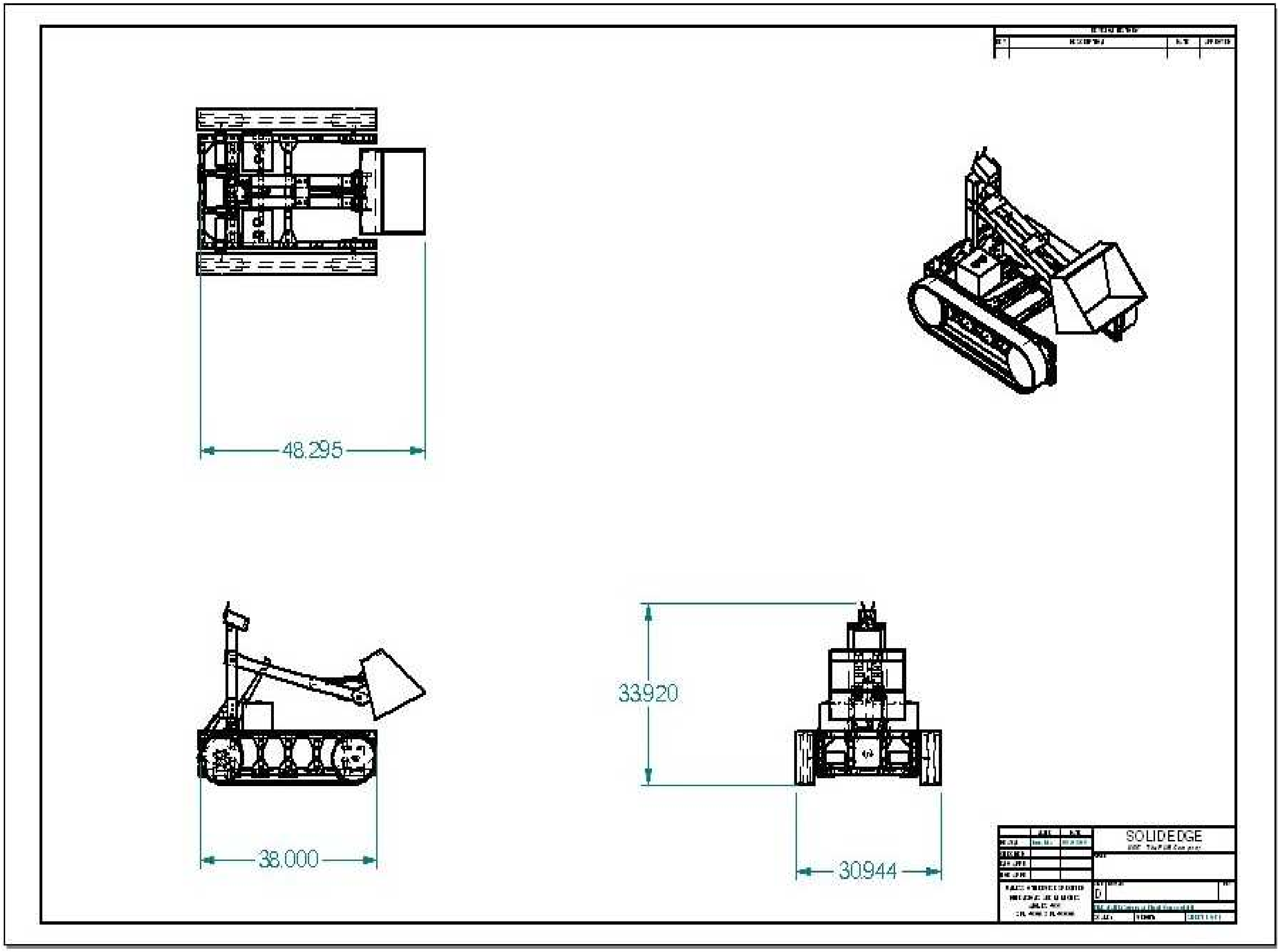
2.10 System CAD Drawing

Here is a 3D CAD drawing of the concept of the excavator.



2.11 System Dimensions

Here are the dimensions of the outside length, width, and height of the system.



3.1 Resource Budgeting

Bill of Materials –

This chart keeps track of prices and locations of purchased parts.

BILL OF MATERIALS						
Item	Part #	Qty	Description	Cost/per	Cost	Mfg. Source
1	WVC2300	1	Cisco Wireless-G Video Camera	$359.99	$359.99	Cisco.com
2	125012	1	12 V, 11 13/16 stroke linear Actuator	$159.99	$159.99	Northerntool.com
3	LA-12v26ah	2	12v Lead acid battery	$59.95	$119.90	batteryspace.com
4	125011	1	12 V, 7 7/8 stroke linear actuator	$149.99	$149.99	Northerntool.com
5	N/A	2	Sleeve Bearings	$0.80	$1.60	McMaster-carr
6	TD05200	1	4 in. Wide Tread set (2)	$580.63	$580.63	SuperDroidRobots.com
7	TD036290	2	IG52-02 24VDC 290 RPM Gear Motor w/ encoder	$127.80	$255.60	SuperDroidRobots.com
8	N/A	4	1 inch square carbon fiber tubing 96"	$325.00	$1,300.00	dragonplate.com
9	N/A	3	2 inch square carbon fiber tubing 24"	$150.00	$450.00	drgaonplate.com
10	N/A	1	1 inch by 2 inch C.F. rectangular tube 48"	$180.00	$180.00	dragonplate.com
11	9910T22	1	24"X24"Plate(1/8")G-10 Garolite	$55.86	$55.86	McMaster-carr
12	9910T21	1	12"X12"Plate(1/8")G-10 Garolite	$16.90	$16.90	McMaster-carr
13	97526A404	3	Blind Aluminum Rivets (100pk)	$7.14	$21.42	McMaster-carr
14	#2216	1	"Scotch-Weld" Epoxy Adhesive 26.7 fl. oz	$119.00	$119.00	drgaonplate.com

3.2 Resource Budgeting(Continued)

Bill of Materials –

This chart keeps track of prices and locations of purchased parts.

BILL OF MATERIALS						
15	6659A21	1	Blind Rivet Installation Tool	$25.18	$25.18	McMaster-carr
16	N/A	1	1/4" x 3/4" fasteners	$1.00	$1.00	N/A
17	N/A	1	1/2"x18" Shaft	$25.08	$25.08	McMaster-carr
18	N/A		Aluminum Sheet		$0.00	N/A
19	DVREG	1	Dual 5v +3.3v Switching Voltage Regulator	$74.95	$74.95	Roboticsconnection
20	SK 3720Q1	1	CMUCam2+ robot camera	$169.96	$169.96	Roboticsconnection
21	EZ3LV	1	Maxbotix Maxsonar-EZ3 Sensor	$24.95	$24.95	Roboticsconnection
22	130898	1	Aerocool Turbine 1000 silver 120mm Fan	$14.99	$14.99	xoxide.com
23	RL-IMX1	1	IMX-1 Invertable RC tank mixer	$39.95	$39.95	Robotcombat.com
24	0-SYREN10	2	SyRen 10A Regenerative Motor Driver	$49.99	$99.98	Robotcombat.com
25	17M0994	2	PIC18LF4682-I/P 8-bit Microcontroller	$8.35	$16.70	Microchip.com
26	N/A	1	Lantronix WiPort Eval kit	$299.99	$299.99	Lantronix.com
27	MAX232ECN	2	TXInst. RS-232 Line Driver/Reciever	$0.86	$1.72	Mouser electronics
					$0.00	
				Total Cost	$4,565.33	

3.3 Mass of Materials

It was necessary, as a design requirement to meet a weight requirement of 80 kilograms. We keep a budget of materials and made it to 20kg, neglecting some unselected parts.

BILL OF MATERIALS

Item	Part #	Qty	Description	Mass/per	Mass	Mfg. Source
1	WVC2300	1	Cisco Wireless-G Video Camera	520	520	Cisco.com
2	125012	1	12 V, 11 13/16 stroke linear Actuator	3175	3175	Northerntool.com
3	LA-12v26ah	2	12v Lead acid battery	8800	17600	batteryspace.com
4	125011	1	12 V, 7 7/8 stroke linear actuator	3175	3175	Northerntool.com
5	N/A	2	Sleeve Bearings	250	500	McMaster-carr
6	TD05200	1	4 in. Wide Tread set (2)	6000	6000	SuperDroidRobots.com
7	TD036290	2	IG52-02 24VDC 290 RPM Gear Motor w/ encoder	1140	2280	SuperDroidRobots.com
8	N/A	4	1 inch square carbon fiber tubing 96"	360	1440	dragonplate.com
9	N/A	3	2 inch square carbon fiber tubing 24"	236	708	drgaonplate.com
10	N/A	1	1 inch by 2 inch C.F. rectangular tube 48"	254	254	dragonplate.com
11	9910T22	1	24"X24"Plate(1/8")G-10 Garolite	2206	2206	McMaster-carr
12	9910T21	1	12"X12"Plate(1/8")G-10 Garolite	552	552	McMaster-carr
13	97526A404	3	Blind Aluminum Rivets (100pk)	0.25	0.75	McMaster-carr

3.4 Mass of Materials(Continued)

It was necessary, as a design requirement to meet a weight requirement of 80 kilograms. We keep a budget of materials and made it to 20kg, neglecting some

BILL OF MATERIALS						
15	6659A21	1	Blind Rivet Installation Tool	0	0	McMaster-carr
16	N/A	1	1/4" x 3/4" fasteners	200	200	N/A
17	N/A	1	1/2"x18" Shaft	750	750	McMaster-carr
18	N/A	1	Aluminum Sheet	1000	1000	N/A
19	DVREG	1	Dual 5v +3.3v Switching Voltage Regulator	20	20	Roboticsconnection
20	SK 3720Q1	1	CMUCam2+ robot camera	5	5	Roboticsconnection
21	EZ3LV	1	Maxbotix Maxsonar-EZ3 Sensor	4.3	4.3	Roboticsconnection
22	130898	1	Aerocool Turbine 1000 silver 120mm Fan	135	135	xoxide.com
23	RL-IMX1	1	IMX-1 Invertable RC tank mixer	25	25	Robotcombat.com
24	0-SYREN10	2	SyRen 10A Regenerative Motor Driver	26	52	Robotcombat.com
25	17M0994	2	PIC18LF4682-I/P 8-bit Microcontroller	5	10	Microchip.com
26	N/A	1	Lantronix WiPort Eval kit	500	500	Lantronix.com
27	MAX232ECN	2	TXInst. RS-232 Line Driver/Reciever	5	10	Mouser electronics
					0	
				Total Mass	41207.05	

4.1 Work Breakdown Structure

Item	Task	Resource Names	June 7 - 13	June 14 - 20	June 21 - 27	June 28 - July 4	July 5 - 11	July 12 - 18	July 19 - 25	July 26 - Aug. 1
1	Brainstorming	All								
2	Concept Generation	All								
3	Concept Design	All								
4	Verification analysis	All								
5	Excavator Subsystem	Givantha								
5.1	Concept Selection									
5.2	Materials/parts Selection									
5.3	CAD Drawings/ Verification									
6	Navigation Subsystem	Ryan								
6.1	Concept Selection									
6.2	Materials/parts Selection									
6.3	CAD Drawings/ Verification									
7	Frame Subsystem	Harrison								
7.1	Concept Selection									
7.2	Materials/parts Selection									
7.3	CAD Drawings/ Verification									
8	Camera Subsystem	Dale								
8.1	Concept Selection									
8.2	Materials/parts Selection									
8.3	CAD Drawings/ Verification									
9	Power Subsystem	Dale								
9.1	Concept Selection									
9.2	Materials/parts Selection									
9.3	CAD Drawings/ Verification									
10	Control Subsystem	Allan								
10.1	Concept Selection									
10.2	Materials/parts Selection									
10.3	Schematics/ Verification									
11	Systems Engineering	Allan								
12	Project Engineering	Allan								

5.0 Conclusion and Future Goals

Fabrication of Lunar Excavator

Analysis of System Performance

- In conclusion, the lunar excavator utilizes a simple design to accomplish the design objects. The lunar excavator was been theoretically proven to not only meet but exceed competition standards.

* Competition Standards	*Proven Results
-80kg Max	- 41kg
-Raise 0.5m	- Raise 0.7m

- Future Goals
  - Purchase Materials
  - Fabrication of Lunar Excavator
  - Analysis of Excavator Performance