Cable Design Project

Assignments

1. Team Steel assigned 1045 Steel
2. Cable Design
3. Buckle Design
4. Analyze Cable Design within given Temperature Range
5. Mars Modification
6. Cost to get Project into to Orbit
7. Temperature Issue on Mars

Team Members

- David Rogers (Dave)
- Michael Roeback (Mike)
- William Wyant (Bill)

Assignment #1- Design a cable that can support a 5 ton load using the "Modulus of Elasticity" numbers for the materials shown in the Lecture 3 slides.

Modulus of Elasticity (Hook's Law)

E = Stress / Strain

- Only for loading below the Proportional Limit
- Is a measure of **STIFFNESS**
- Is different (but, constant) for each material

Aluminum:	$E \approx$ 10,000,000 psi
Titanium:	$E \approx$ 12,000,000 psi
Copper:	$E \approx$ 15,000,000 psi
Steel:	$E \approx$ 30,000,000 psi

Cable Selection

Based on 10% Elongation

	Capability	Load	Stress	in^2	Min. Diameter (in) CSA					
Al	10,000,000	10000	1,000,000	10.0E-3	0.11284					
Ti	12,000,000	10000	1,200,000	8.3E-3	0.10301					
Copper	15,000,000	10000	1,500,000	6.7E-3	0.09213		Cable size			
Steel	30,000,000	10000	3,000,000	3.3E-3	0.06515		Best Diameter to use		1/8	in
e=l-lo/lo	σ=P/Ao			Fractional/Decimal Conversion			Steel			
Capability	5	tons		2	2		FALSE	2	To Big	Check
Weight	10000	lbs		1 3/4	1.75		FALSE	1 3/4	To Big	Check
Length=	25	ft		1 1/2	1.50		FALSE	1 1/2	To Big	Check
Cable Length	25	ft		1 1/4	1.25		FALSE	1 1/4	To Big	Check
Allowable Stretch	10.00%			1	1.00		FALSE	1	To Big	Check
Max. Length	27.5	ft		3/4	0.75		FALSE	3/4	To Big	Check
Strain	0.1			1/2	0.500000		FALSE	1/2	To Big	Check
				7/16	0.437500		FALSE	7/16	To Big	Check
				3/8	0.375000		FALSE	3/8	To Big	Check
				5/16	0.312500		FALSE	5/16	To Big	Check
				1/4	0.250000		FALSE	1/4	To Big	Check
				3/16	0.187500		FALSE	3/16	To Big	Check
				1/8	0.125000		TRUE	1/8	To Big	Check
				1/16	0.062500		FALSE	1/16	Check	To Small
				1/32	0.031250		FALSE	1/32	Check	To Small
				1/64	0.015625		FALSE	1/64	Check	To Small

Assignment #2 - Determine the lateral stress in the cable design

Modulus of Elasticity (Hook's Law)

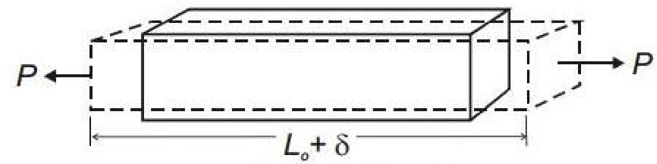
E = Stress / Strain

- Only for loading below the Proportional Limit
- Is a measure of **STIFFNESS**
- Is different (but, constant) for each material

Aluminum:	$E \approx 10{,}000{,}000$ psi
Titanium:	$E \approx 12{,}000{,}000$ psi
Copper:	$E \approx 15{,}000{,}000$ psi
Steel:	$E \approx 30{,}000{,}000$ psi

Poisson's ratio

When a prismatic bar is stretched, it not only gets longer, it gets thinner.



So there is a tensile strain in the axial direction and a compressive strain in the other two (lateral) directions.

Define **Poisson's ratio** as: $\nu = \dfrac{-\text{lateral strain}}{\text{axial strain}} = \dfrac{-\varepsilon_{lateral}}{\varepsilon_{axial}}$

Greek letter ν (nu)

If axial strain is tensile (+), lateral strain is compressive (-).
If axial strain is compressive (-), lateral strain is tensile (+).
So Poisson's ratio is a positive number.

Courtesy of:
http://www.eng.ox.ac.uk/~kneabz/teaching/seh/Stress1_mt07.pdf

How Poisson's Ratio Transfers from Strain to Stress

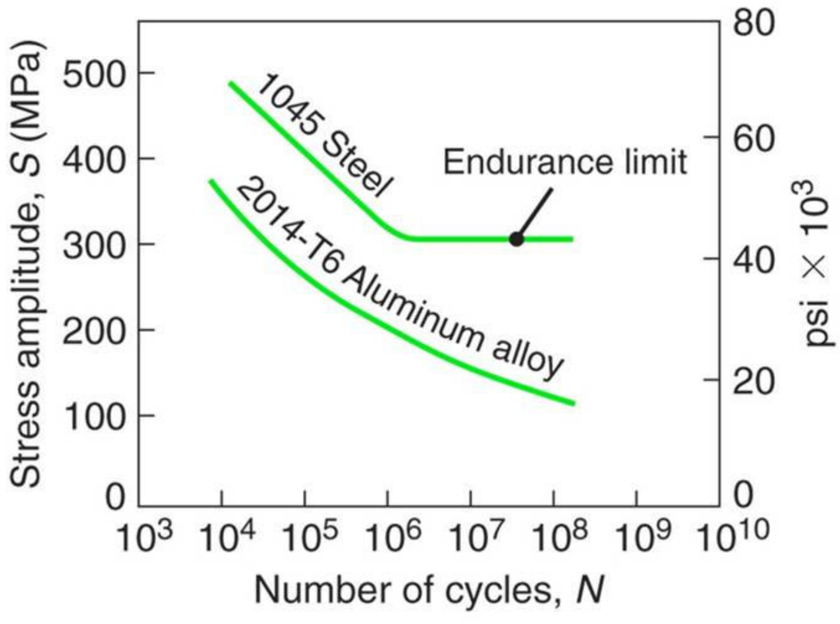
Capability=	5	tons
Weight=	10000	lbs
Length=	25	ft
Cable Length=	25	ft
Allowable Stretch=	10.00%	
Max. Length=	27.5	ft
Strain=	0.1	
Cable Diameter=	1/8	in
Cable CSA=	12.272E-3	in^2
Cable Stress=	814.873E+3	psi
Poisson's Ratio=	0.30	
Laterial Strain=	-0.03	
Stress/Strain=	8.149E+6	psi
Lateral Stress=	-244.462E+3	psi
Stress Ratio=	-300.0E-3	

- Poisson's Ratio for Steel is .30

- A direct relation between Axial force and Lateral force.

•Strain went from 0.01 to -0.03 so Force went from 10000 flb to -3000 flb.

Assignment #3 – Design a buckle with a Cyclic Life of 100k to be used with the Cable



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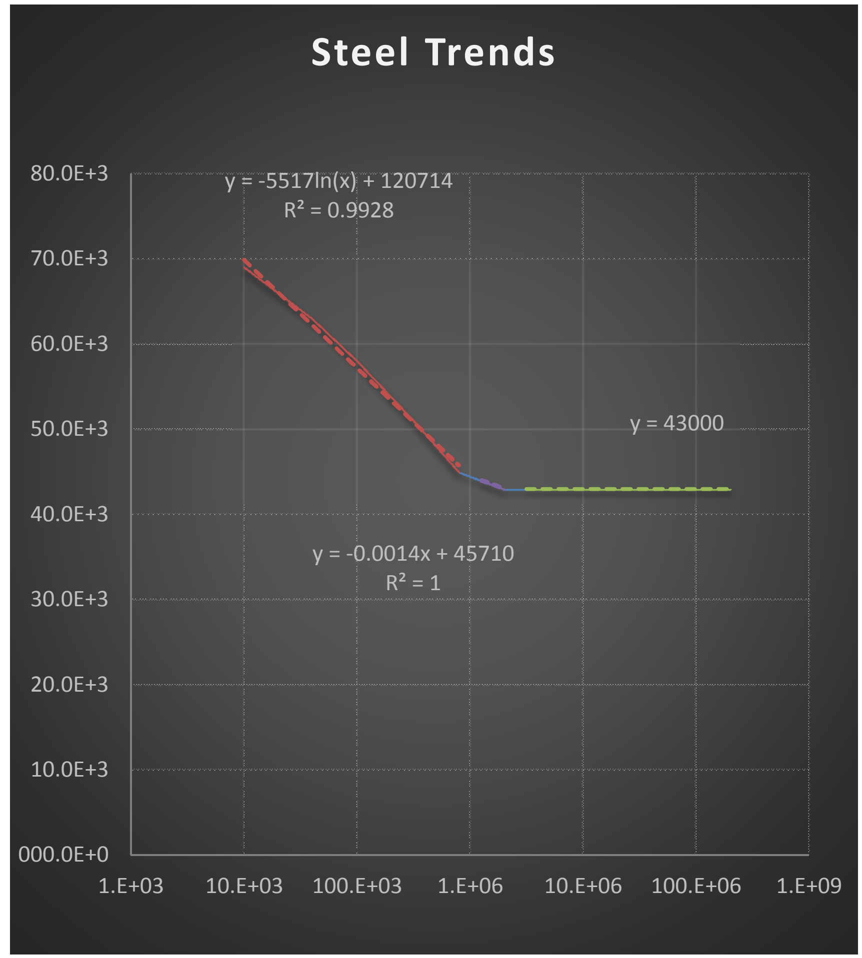


1045 Steel 100k Cycle Threshold

Cycles	psi	Mpa	at 10^5 Cycles	Coeffic.	Constant
10.0E+3	69.0E+3	475.738253	57.2E+3	-5517	120714
39.8E+3	63.0E+3	434.3697093	57.2E+3	-5517	120714
100.0E+3	58.0E+3	399.8959228	57.2E+3	-5517	120714
316.2E+3	51.0E+3	351.6326218	57.2E+3	-5517	120714
794.3E+3	45.0E+3	310.2640781	57.2E+3	-5517	120714
1.3E+6	44.0E+3	303.3693208	45.7E+3	-0.0014	45710
2.0E+6	43.0E+3	296.4745635	45.7E+3	-0.0014	45710
3.2E+6	43.0E+3	296.4745635	43.0E+3		43000
10.0E+6	43.0E+3	296.4745635	43.0E+3		43000
100.0E+6	43.0E+3	296.4745635	43.0E+3		43000
199.5E+6	43.0E+3	296.4745635	43.0E+3		43000

Diameter (d)	1/2*d	π*r^2	10000/CSA	10000/CSA
Buckle Size (in)	Radius (r)	CSA (in^2)	Stress (PSI)	Stress (Mpa)
1/16	0.031	3.068E-3	3.259E+6	22.473E+3
1/8	0.063	12.272E-3	814.873E+3	5.618E+3
3/16	0.094	27.612E-3	362.166E+3	2.497E+3
1/4	0.125	49.087E-3	203.718E+3	1.405E+3
5/16	0.156	76.699E-3	130.380E+3	898.937E+0
3/8	0.188	110.447E-3	90.541E+3	624.262E+0
7/16	0.219	150.330E-3	66.520E+3	458.641E+0
1/2	0.250	196.350E-3	50.930E+3	351.147E+0
9/16	0.281	248.505E-3	40.241E+3	277.450E+0
5/8	0.313	306.796E-3	32.595E+3	224.734E+0
11/16	0.344	371.223E-3	26.938E+3	185.731E+0
3/4	0.375	441.786E-3	22.635E+3	156.065E+0

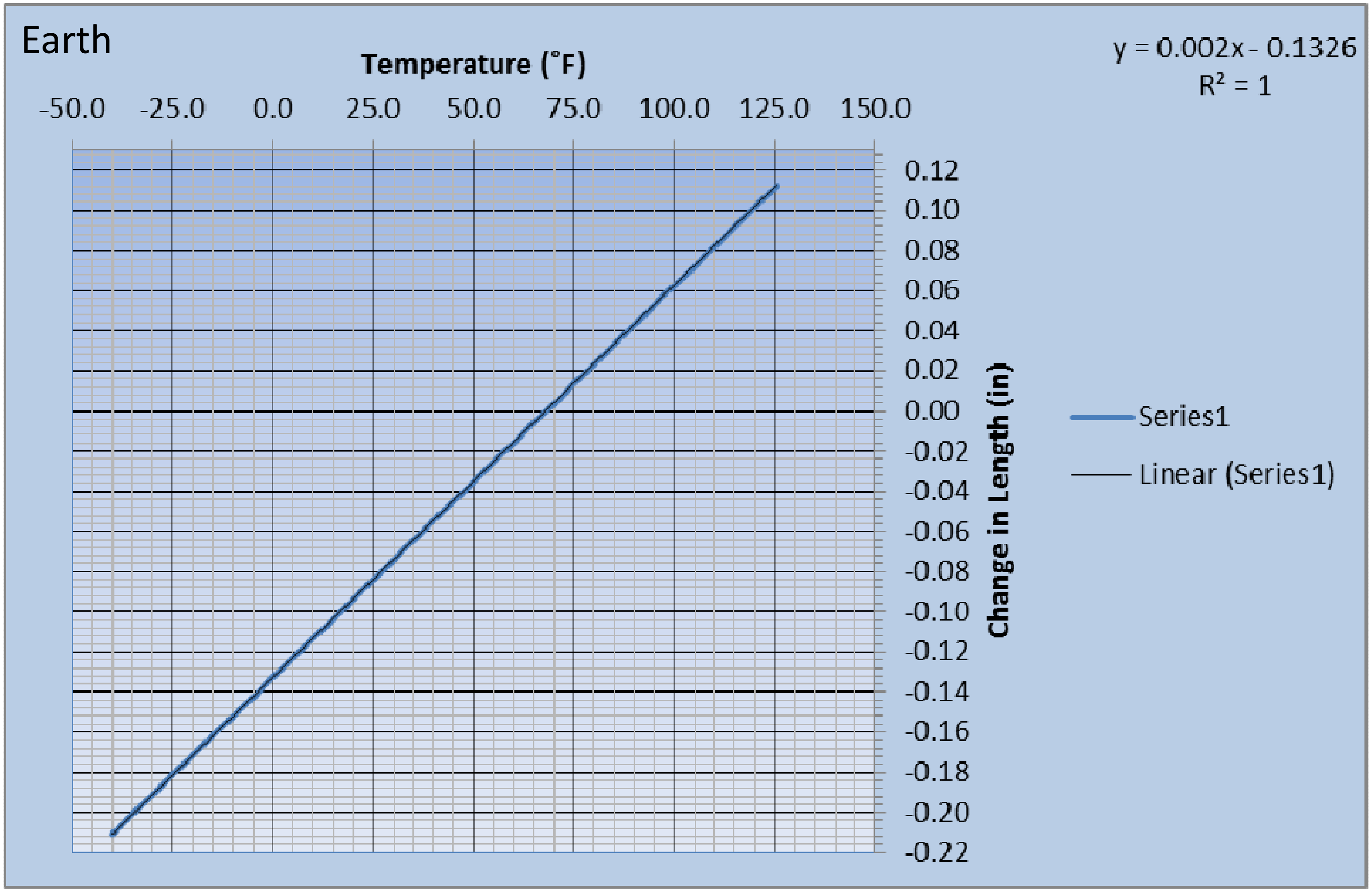
Assignment #4 - Temperature Range
-40ºC to 125ºF

Original Temperature =	68˚F	20˚C	
α (steel) =	0.0000065		
Original Length =	300	in	25ft

$$\Delta L=\alpha * L_o * \Delta T$$

ΔL		**ΔT**			**$Temp_f$**	**˚C**	**$Temp_f$**	**˚F**
-0.21060	in	-108.0	˚F		-40	˚C	-40.0	˚F
-0.20358	in	-104.4	˚F		-38	˚C	-36.4	˚F
-0.19656	in	-100.8	˚F		-36	˚C	-32.8	˚F
-0.18954	in	-97.2	˚F		-34	˚C	-29.2	˚F
-0.18252	in	-93.6	˚F		-32	˚C	-25.6	˚F
-0.17550	in	-90.0	˚F		-30	˚C	-22.0	˚F
-0.16848	in	-86.4	˚F		-28	˚C	-18.4	˚F
-0.16146	in	-82.8	˚F		-26	˚C	-14.8	˚F
-0.15444	in	-79.2	˚F		-24	˚C	-11.2	˚F
-0.14742	in	-75.6	˚F		-22	˚C	-7.6	˚F
-0.14040	in	-72.0	˚F		-20	˚C	-4.0	˚F
-0.13338	in	-68.4	˚F		-18	˚C	-0.4	˚F
-0.12636	in	-64.8	˚F		-16	˚C	3.2	˚F
-0.11934	in	-61.2	˚F		-14	˚C	6.8	˚F
-0.11232	in	-57.6	˚F		-12	˚C	10.4	˚F
-0.10530	in	-54.0	˚F		-10	˚C	14.0	˚F
-0.09828	in	-50.4	˚F		-8	˚C	17.6	˚F
-0.09126	in	-46.8	˚F		-6	˚C	21.2	˚F
-0.08424	in	-43.2	˚F		-4	˚C	24.8	˚F
-0.07722	in	-39.6	˚F		-2	˚C	28.4	˚F
-0.07020	in	-36.0	˚F		0	˚C	32.0	˚F
-0.06318	in	-32.4	˚F		2	˚C	35.6	˚F
-0.05616	in	-28.8	˚F		4	˚C	39.2	˚F
-0.04914	in	-25.2	˚F		6	˚C	42.8	˚F
-0.04212	in	-21.6	˚F		8	˚C	46.4	˚F
-0.03510	in	-18.0	˚F		10	˚C	50.0	˚F
-0.02808	in	-14.4	˚F		12	˚C	53.6	˚F
-0.02106	in	-10.8	˚F		14	˚C	57.2	˚F
-0.01404	in	-7.2	˚F		16	˚C	60.8	˚F
-0.00702	in	-3.6	˚F		18	˚C	64.4	˚F
0.00000	in	0.0	˚F		20	˚C	68.0	˚F
0.00702	in	3.6	˚F		22	˚C	71.6	˚F
0.01404	in	7.2	˚F		24	˚C	75.2	˚F
0.02106	in	10.8	˚F		26	˚C	78.8	˚F
0.02808	in	14.4	˚F		28	˚C	82.4	˚F
0.03510	in	18.0	˚F		30	˚C	86.0	˚F
0.04212	in	21.6	˚F		32	˚C	89.6	˚F
0.04914	in	25.2	˚F		34	˚C	93.2	˚F
0.05616	in	28.8	˚F		36	˚C	96.8	˚F
0.06318	in	32.4	˚F		38	˚C	100.4	˚F
0.07020	in	36.0	˚F		40	˚C	104.0	˚F
0.07722	in	39.6	˚F		42	˚C	107.6	˚F
0.08424	in	43.2	˚F		44	˚C	111.2	˚F
0.09126	in	46.8	˚F		46	˚C	114.8	˚F
0.09828	in	50.4	˚F		48	˚C	118.4	˚F
0.10530	in	54.0	˚F		50	˚C	122.0	˚F
0.11232	in	57.6	˚F		52	˚C	125.6	˚F

Assignment #4 cont.



Assignment #5 – Adjust Cable & Buckle Design to work on Mars

Modified Cable design for Mars Weight

Cable Design	EARTH		MARS	
Mass (truck)=	310.85	lbs(m)	310.85	lbs(m)
Grav. Acc.=	32.17	ft/s^2	12.06375	ft/s^2
Weight	10,000	lbs	3750	lbs
Cable Length	25	ft	25	ft
Allowable Stretch	10.00%		10.00%	
Max. Length	27.5	ft	27.5	ft
Strain	0.1		0.1	
CSA	3.333E-03	in^2	1.250E-03	in^2
Min. Diameter (in) CSA	65.147E-3		39.894E-3	
Best Diameter to use	1/8	in	1/16	in

Weight=Mass*Gravity Acceleration

Modified Buckle design for Mars Weight

Diameter (d)	1/2*d	π*r^2	10000/CSA	10000/CSA	3750/CSA	3750/CSA
Buckle Size (in)	Radius (r)	CSA (in^2)	Stress (PSI)	Stress (Mpa)	Stress (PSI)	Stress (Mpa)
1/16	0.031	3.068E-3	3.259E+6	22.473E+3	1.222E+6	8.428E+3
1/8	0.063	12.272E-3	814.873E+3	5.618E+3	305.577E+3	2.107E+3
3/16	0.094	27.612E-3	362.166E+3	2.497E+3	135.812E+3	936.392E+0
1/4	0.125	49.087E-3	203.718E+3	1.405E+3	76.394E+3	526.721E+0
5/16	0.156	76.699E-3	130.380E+3	898.937E+0	48.892E+3	337.101E+0
3/8	0.188	110.447E-3	90.541E+3	624.262E+0	33.953E+3	234.098E+0
7/16	0.219	150.330E-3	66.520E+3	458.641E+0	24.945E+3	171.990E+0
1/2	0.250	196.350E-3	50.930E+3	351.147E+0	19.099E+3	131.680E+0
9/16	0.281	248.505E-3	40.241E+3	277.450E+0	15.090E+3	104.044E+0

Assignment #6 - Figure Cost to get Cable/Buckle Assembly into Orbit

- Figure weight of Cable and Buckle Assembly
- Figure possible shipping methods and cost to ship weight
- Comb through Design and Process for Errors

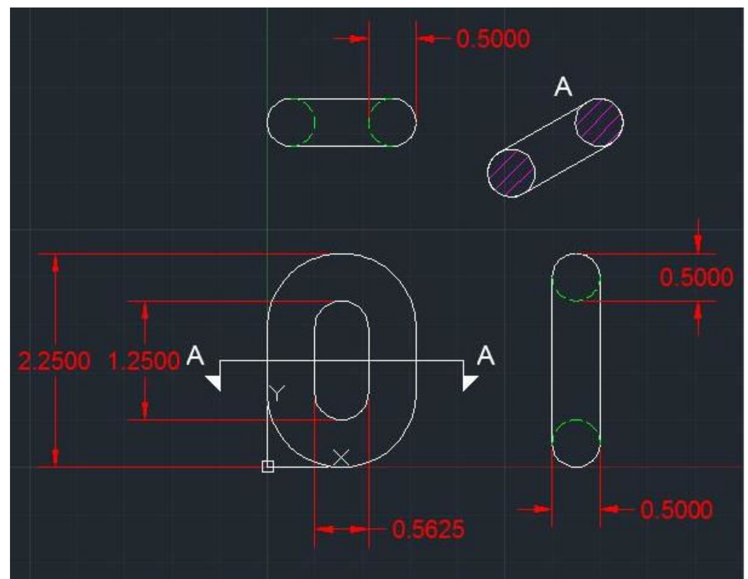
Weight for Shipping Cost to Mars

Weight = Volume*Density

Physical Properties

Physical Properties	Metric	Imperial
Density	7.87 g/cc	0.284 lb/in^3

Cable & Buckle Design	Earth	Units	Mars	Units
Mass (truck)=	310.85	lbs(mass)	310.85	lbs(mass)
Grav. Acc.(@45°)=	32.17	ft/s^2	12.06375	ft/s^2
Weight	10000	lbs	3750.00	lbs
1 psi =	0.006894757	megapascals		
Cyclic Operations=	100.0E+3			
1045 Density=	0.284	lbs/in^3	0.1065	lbs/in^3
Buckle Inner Dia.=	0.6352	in^2	0.2481	in^2
Buckle Outer Dia.=	2.9917	in^2	1.1686	in^2
Buckle Area (Front)=	2.3565	in^2	0.9205	in^2
Buckle Volume=	462.698E-3	in^3	70.601E-3	in^3
Buckle Weight (on earth)=	131.406E-3	lbs.	20.051E-3	lbs.
Cable CSA=	12.272E-3	in	3.068E-3	in
Cable Weight (on earth)=	1.046E+0	lbs.	261.390E-3	lbs.
Combo Weight (on earth)=	1.177E+0	lbs.	281.441E-3	lbs.
Combo Weight (on Mars)=	441.363E-3	lbs.	105.540E-3	lbs.

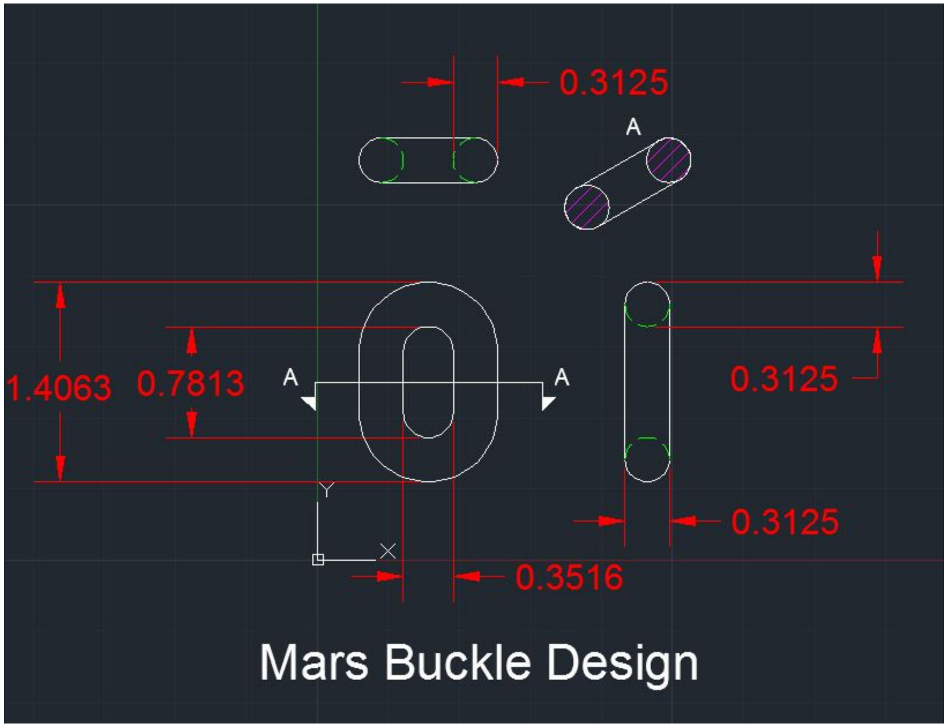


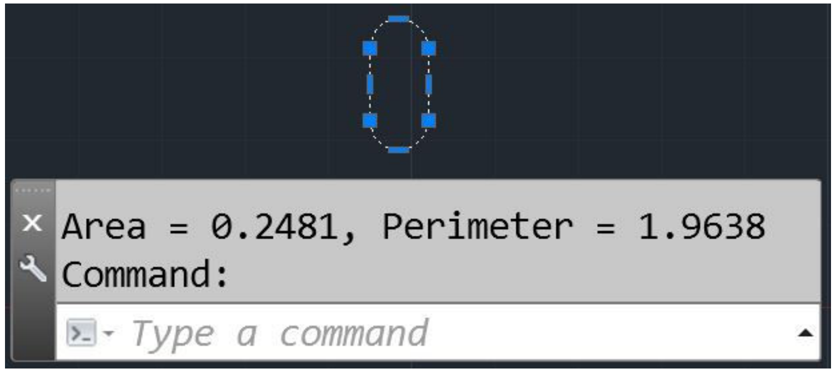
Earth Buckle Design

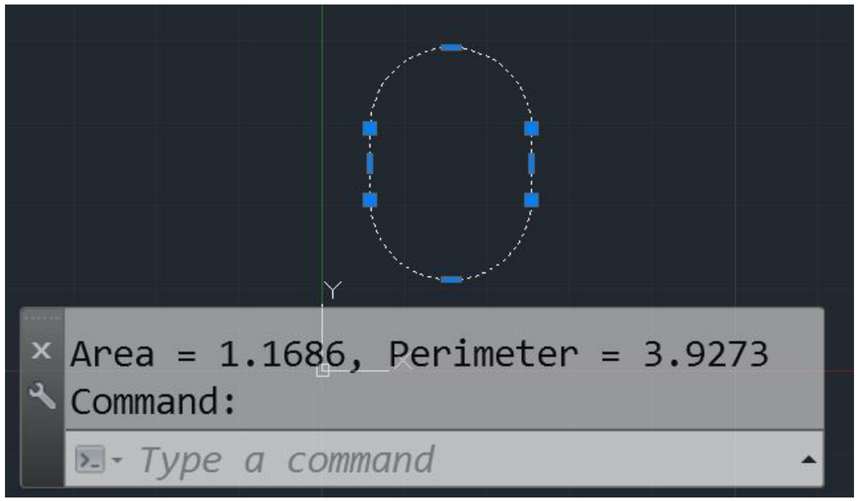
http://www.azom.com/article.aspx?ArticleID=6130 For 1045 Steel Density
Auto Cad for Volume of buckle

BuckleVolume = Front Area*CSA

Subtract Inner Area from Outer Area to get Total Front Area.







Shipping Cost

- 1/16in Cable
- Found weight using Volume and Density
- Found Price per pound for 5 different rockets

Shipping Cost

- Weight of Cable and Buckle combined
  - Cost for Low Earth Orbit (LEO)

Weight	1.177E+00
Rocket types	Cost per lbs
Falcon 9 v 1.1	$ 4,109.00
DNEPR	$ 3,784.00
Ariane 5	$ 10,476.00
Delta IV	$ 13,072.00
Atlas V	$ 13,182.00
Cost	
Falcon 9 v 1.1	$ 4,836.29
DNEPR	$ 4,453.77
Ariane 5	$ 12,330.25
Delta IV	$ 15,385.74
Atlas V	$ 15,515.21

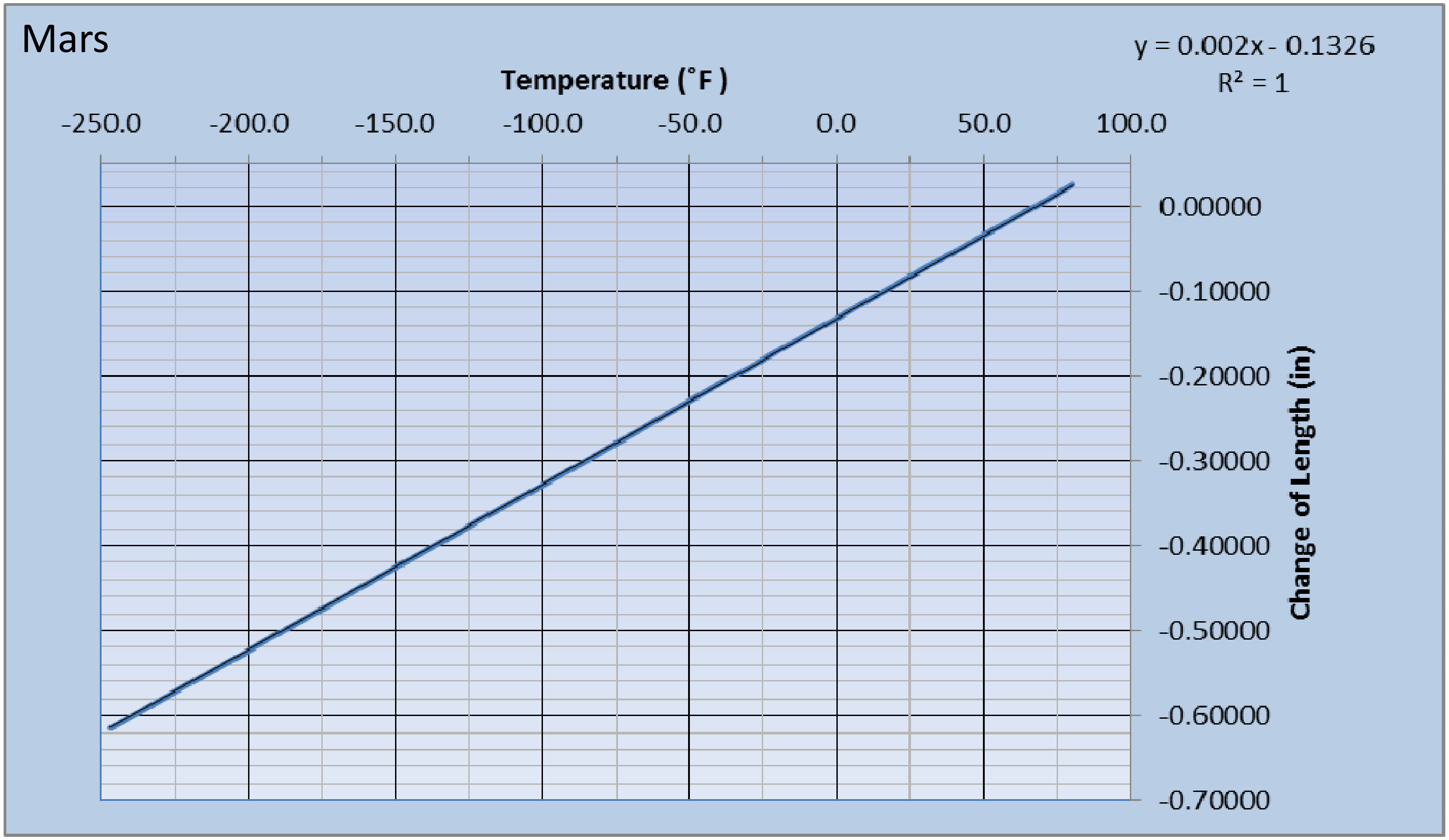
Assignment #7 – Mars Temperature

Reference Temperature (T_o)=	68˚F	20˚C	
Temperature Range =	-225˚F - 70˚F	(Temp can be as low as -225˚F at poles and high as 70˚F at equator in summer.)	
α (Steel) =	6.5E-06		
Original Length =	300	in	25 ft

ΔL		**ΔT**			**$Temp_f$**	**˚C**	**$Temp_f$**	**˚F**
-0.61425	in	-315.0	˚F		-155	˚C	-247.0	˚F
-0.59670	in	-306.0	˚F		-150	˚C	-238.0	˚F
-0.57915	in	-297.0	˚F		-145	˚C	-229.0	˚F
-0.56160	in	-288.0	˚F		-140	˚C	-220.0	˚F
-0.54405	in	-279.0	˚F		-135	˚C	-211.0	˚F
-0.52650	in	-270.0	˚F		-130	˚C	-202.0	˚F
-0.50895	in	-261.0	˚F		-125	˚C	-193.0	˚F
-0.49140	in	-252.0	˚F		-120	˚C	-184.0	˚F
-0.47385	in	-243.0	˚F		-115	˚C	-175.0	˚F
-0.45630	in	-234.0	˚F		-110	˚C	-166.0	˚F
-0.43875	in	-225.0	˚F		-105	˚C	-157.0	˚F
-0.42120	in	-216.0	˚F		-100	˚C	-148.0	˚F
-0.40365	in	-207.0	˚F		-95	˚C	-139.0	˚F
-0.38610	in	-198.0	˚F		-90	˚C	-130.0	˚F
-0.36855	in	-189.0	˚F		-85	˚C	-121.0	˚F
-0.35100	in	-180.0	˚F		-80	˚C	-112.0	˚F
-0.33345	in	-171.0	˚F		-75	˚C	-103.0	˚F
-0.31590	in	-162.0	˚F		-70	˚C	-94.0	˚F
-0.29835	in	-153.0	˚F		-65	˚C	-85.0	˚F
-0.28080	in	-144.0	˚F		-60	˚C	-76.0	˚F
-0.26325	in	-135.0	˚F		-55	˚C	-67.0	˚F
-0.24570	in	-126.0	˚F		-50	˚C	-58.0	˚F
-0.22815	in	-117.0	˚F		-45	˚C	-49.0	˚F
-0.21060	in	-108.0	˚F		-40	˚C	-40.0	˚F

-0.05265	in	-27.0	˚F		5	˚C	41.0	˚F
-0.04914	in	-25.2	˚F		6	˚C	42.8	˚F
-0.04563	in	-23.4	˚F		7	˚C	44.6	˚F
-0.04212	in	-21.6	˚F		8	˚C	46.4	˚F
-0.03861	in	-19.8	˚F		9	˚C	48.2	˚F
-0.03510	in	-18.0	˚F		10	˚C	50.0	˚F
-0.03159	in	-16.2	˚F		11	˚C	51.8	˚F
-0.02808	in	-14.4	˚F		12	˚C	53.6	˚F
-0.02457	in	-12.6	˚F		13	˚C	55.4	˚F
-0.02106	in	-10.8	˚F		14	˚C	57.2	˚F
-0.01755	in	-9.0	˚F		15	˚C	59.0	˚F
-0.01404	in	-7.2	˚F		16	˚C	60.8	˚F
-0.01053	in	-5.4	˚F		17	˚C	62.6	˚F
-0.00702	in	-3.6	˚F		18	˚C	64.4	˚F
-0.00351	in	-1.8	˚F		19	˚C	66.2	˚F
0.00000	in	0.0	˚F		20	˚C	68.0	˚F
0.00351	in	1.8	˚F		21	˚C	69.8	˚F
0.00386	in	2.0	˚F		21.1	˚C	70.0	˚F
0.00702	in	3.6	˚F		22	˚C	71.6	˚F
0.01053	in	5.4	˚F		23	˚C	73.4	˚F
0.01404	in	7.2	˚F		24	˚C	75.2	˚F
0.01755	in	9.0	˚F		25	˚C	77.0	˚F
0.02106	in	10.8	˚F		26	˚C	78.8	˚F
0.02457	in	12.6	˚F		27	˚C	80.6	˚F

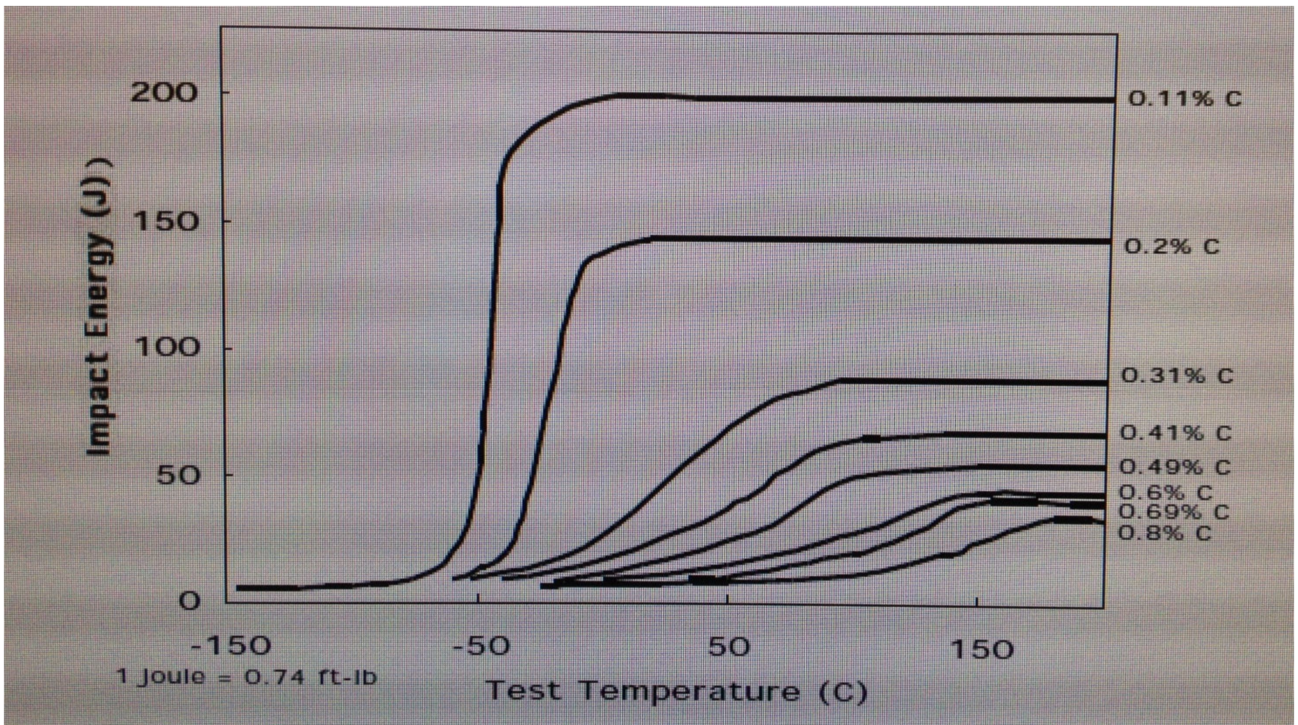
Assignment #7 cont.



Mars Temperature Issue

Ductile to Brittle Transition (DBTT)

This problem deals with the fact as the temperature gets colder, the material (1045 Steel) gets more brittle to the point where it can't hold a load without breaking.



*Pulled graph from Steel_Metallurgy_Ohio-State.pdf

- 1045 Steel is ~.45% Carbon

(1 Joule (J) is .74 ft*lbs of Force or 100 (J) is 74 ft*lbs)

Mars Temperature Solution

We decided to use a slightly different steel material called A353 Type 1. This type of steel is used in cryogenics and can handle temperatures down to -196 ˚C. As you can see it contains Nickel and Silicon along with less Carbon:

Components of Steel		
	1045 Steel	**A353 Type 1**
Carbon -	.43 - .50 %	0.13%
Manganese -	.60 - .90 %	0.90%
Phosphorous -	0.04%	0.35%
Sulfur -	0.05%	0.35%
Silicon -	-	.15 - .40 %
Nickel -	-	8.5 - 9.5 %

From what we have found, A 353 Type 1 Steel should work both on Mars and Earth.

	Modulus of Elasticity		
A353 Type 1	at 70˚F (21˚C) =	27×10^6	psi
	at -320˚F (-196˚C) =	30×10^6	psi
1045 Steel		30×10^6	psi

Info on A353 Type 1 Steel was used from ArcelorMittal 9 percent nickel.pdf