Advanced LIGO Suspension Research

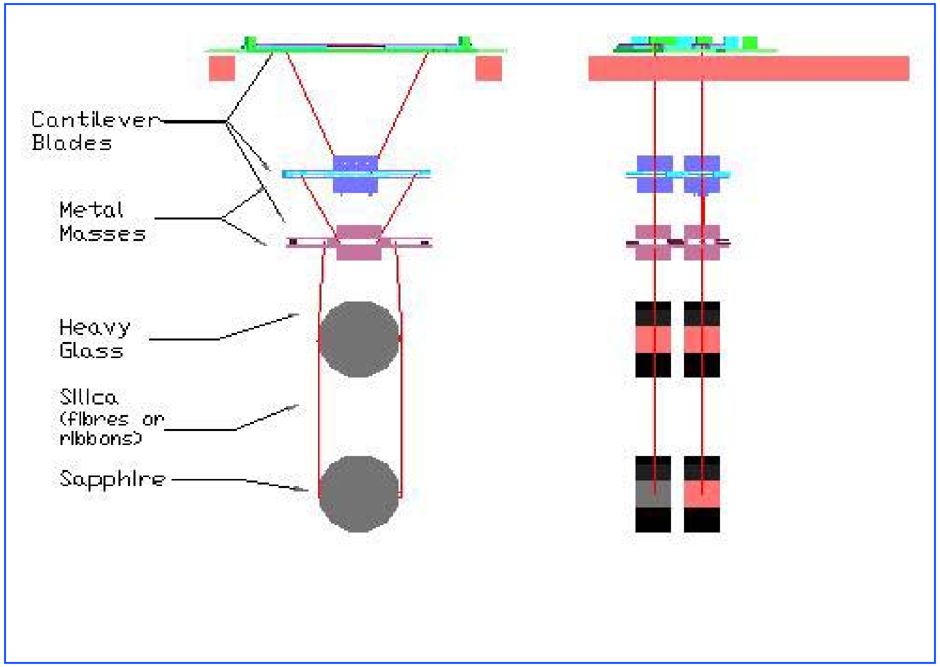
Dan Mason
John Veitch

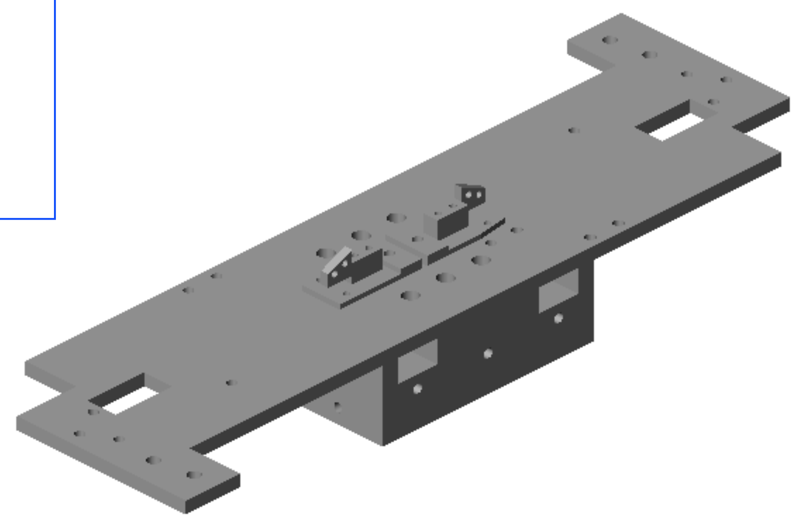
Mentors:
Dr. Calum Torrie
Janeen Romie

Upper Mass Bending Model

- Ends of upper mass bend up when blades are loaded
- Bending of upper masses changes spacing between stages and overall length of pendulum
- As a temporary solution, stiffening bars were added to stop bending
- Next generation prototype will be designed so that upper plate alone will not deflect >1 mm

The Quadruple Pendulum





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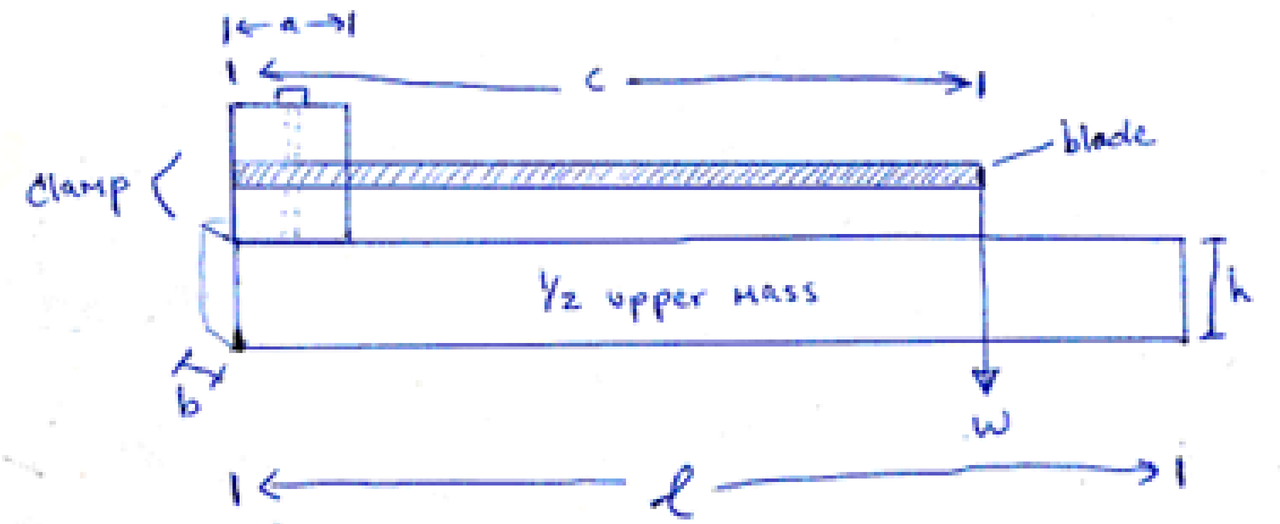
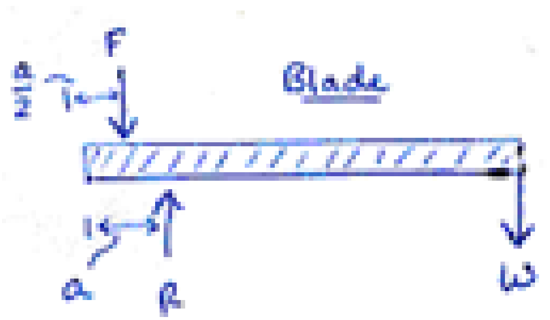
Bending Model Derivation #1



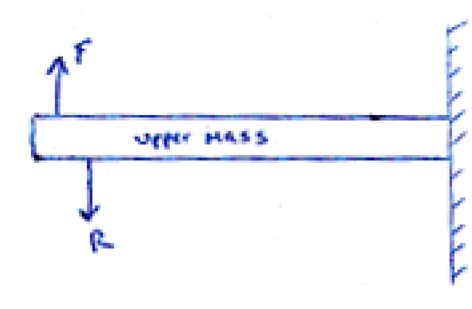
Two methods:

1. **Force Method**
2. **Force and Moment Method (Phil Willems)**

Force Method Model



- Force and moment balance gets values for forces F and R



- Transferring to upper mass results in a simple cantilever beam with two transverse forces

Force Method Model

- Superimposing deflections of Forces F and R obtains the formula below
- The first term (with F) refers to bending up, the second term refers to bending down

$$\delta = \frac{F\left(l - \frac{a}{2}\right)^2}{6EI}\left(2l - \frac{a}{2}\right) - \frac{R\,(l-a)^2}{6EI}\left(2l + a\right)$$

where

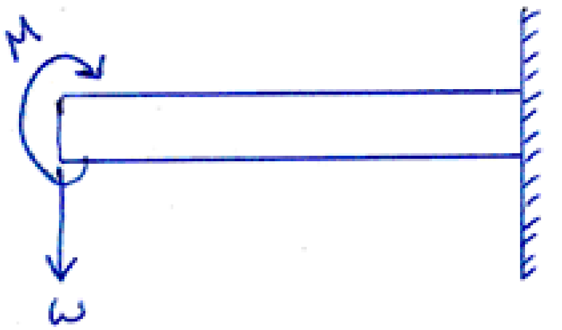
$$F = \frac{w(2c-a)}{a} - w$$

$$R = \frac{w(2c-a)}{a}$$

E = Modulus of Elasticity

$$I = \frac{1}{12} b h^3$$

Force / Moment Model



- Force/Moment model approximates the two forces as a couple and their resultant as a transverse force

•Once again, equation is a difference of two deflections

$$\delta = \frac{wc\ell^2}{2EI} - \frac{w\ell^3}{3EI}$$

Model Testing

Model was tested by fastening a thin piece of aluminum to the end of a table and loading the blade.

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Model Testing

Deflection Calculator		
Inputs		
a	width of clamps	0.02
b	width of upper mass	0.038
l	length of upper mass	0.597
h	thickness of upper mass	0.00634
c	length of blade	0.26
	width of blade	0.025
	thickness of blade	0.0023
d	mass overhang	0
m	mass applied	7.88
Calculations		
w	Force Applied	77.3028
R	Reaction Force (Down Push)	-1932.57
F	Reaction (Push Up)	1855.2672
I	Moment of Inertia	8.07E-10
E	Modulus of Elasticity	6.90E+10
Models		
	Force Model	
	Deflection Down	-2222.400
	Deflection Up	2188.962
	Overall deflection (Eq. 1)	-33.44
	Force/Moment Model	
	Force	-98.464
	Moment	64.323
	Overall Deflection (Eq. 2)	-34.14
	Average:	-33.79

- Experimental deflection numbers obtained by testing ten aluminum bars of different dimensions
- Calculated deflections obtained by entering parameters into Excel worksheet
- Both Force and Force/Moment methods are calculated and average of two used for comparison.

Results!

- Aluminum Bars
  - » Differences between experimental and calculated deflections < 10% for all bars
- MIT Quad
  - » Measured deflection: **~12 mm**
  - » Calculated deflection: **9.6 mm**
- Future Prototypes
  - » Designs for next-generation aluminum upper masses should be designed with a thickness between **18 mm** (lightest configuration) and **21 mm** (heaviest).
  - » For stainless steel upper mass, between **13 mm** and **16 mm**
  - » Numbers are for deflections of < 1 mm

Cold-Welding Experiment

- Cold-welding (galling) is the fusing of a moving part through excessive pressure, temperature, or friction
- Relevent to LIGO because it happens very frequently under very clean conditions (absence of lubricants)
- To be studied because of differing suggestions among machine shops as to size and threading of holes

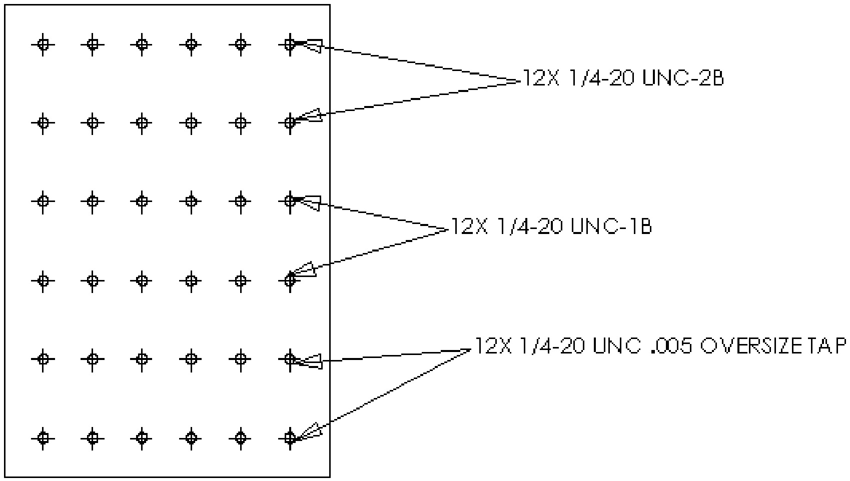
The Procedure

- Variables to be measured:
  - » 2 sizes of fasteners (4-40 and 1/4 –20 screws)
  - » 2 types of fasteners: silver plated and stainless steel
  - » 2 materials for base: stainless steel and aluminum
  - » 3 types of holes: UNC-2B, UNC-1B, Oversize taps

- All Parts cleaned and baked to LIGO specifications
  - » Ultrasonic clean in Liquinox
  - » Rinse in distilled water
  - » Ultrasonic clean in methanol
  - » Baked in vacuum

The Holes

- Plates manufactured with 12 each three sizes of holes

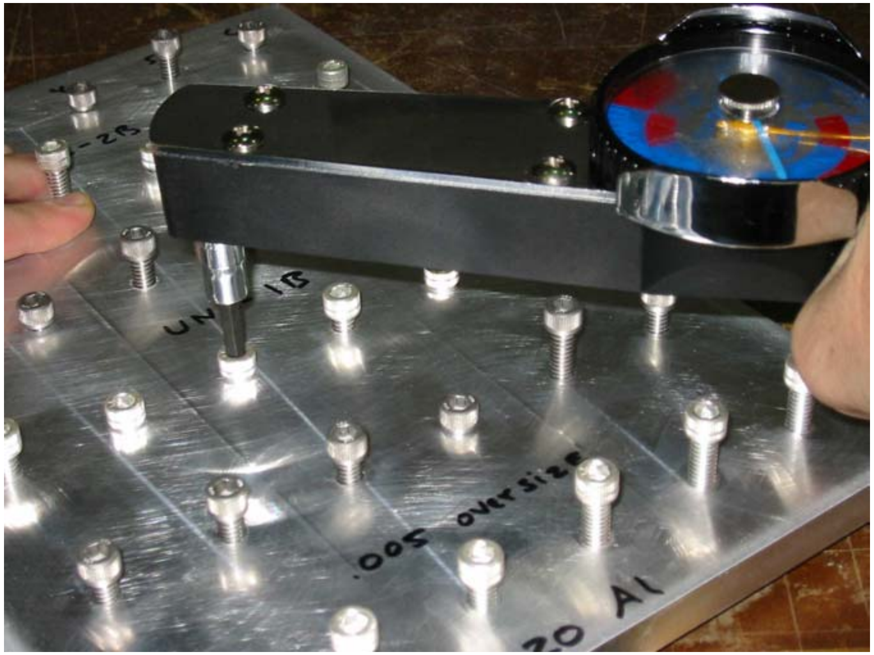


- Threaded Holes Primer:

  UNC-2B and UNC-1B are conventional sizes, oversize holes were custom-made

	Tap Drill Size	Range
4-40 UNC-2B	0.0938	.0958 - .0991
4-40 UNC-1B	0.0960	.0958 - .1012
4-40 .003 Oversize	0.0980	.0988 - .1042
1/4-20 UNC-2B	0.2055	.2175 - .2224
1/4-20 UNC-1B	0.2090	.2175 - .2248
1/4-20 .005 Oversize	0.2130	.2225 - .2298

The Science of Screwing



- Each bolt torqued to a given value, unscrewed by hand, and rated
- Rating system:
  - » 1: Very easy to unscrew
  - » 2: A little friction
  - » 3: Struggling
  - » 4: Frozen
- 4-40's torqued at 5, 8, 12, 16, 20 in lbs (recommended: 5)
- ¼-20's torqued at 12, 20, 40, 60, 80 in lbs (recommended: 65)

Results!

- High occurrence of freezing:
  - » Stainless screws in stainless plates (2B, 1B)
  - » Silver-plated screws in aluminum plates (2B, 1B)
- No galling:
  - » Stainless screws in aluminum plates
  - » Silver-plated screws in stainless plates
  - » All oversize holes
- Recommendation:
  - » Use stainless in aluminum
  - » Silver-plated in stainless
  - » Oversize holes (though 1B is an improvement over 2B)

Acknowledgements

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Calum Torrie

Janeen Romie

Phil Willems

. . . And Mr. John Veitch