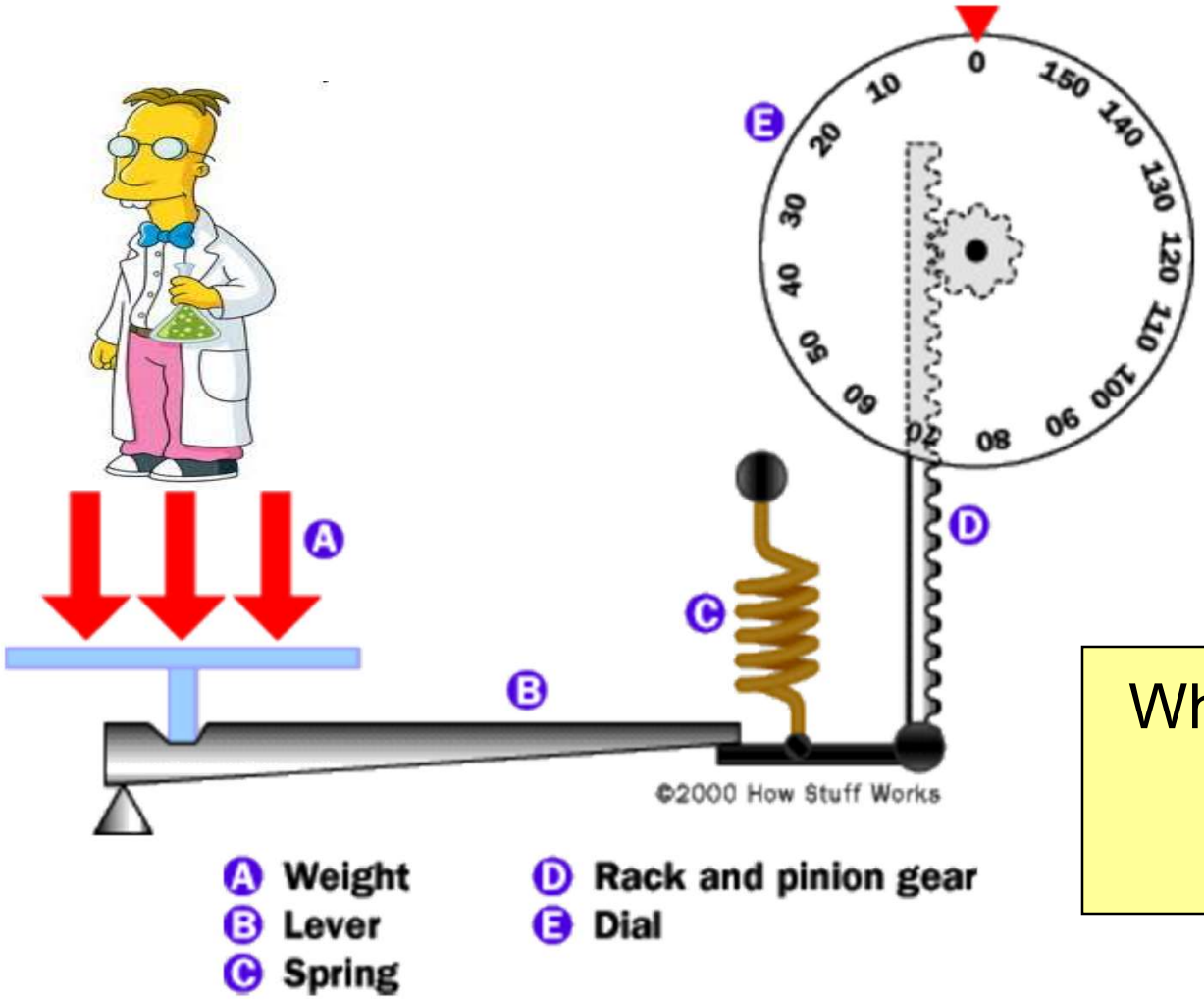
Reverse Engineering a Bathroom Scale

Note: Some of the numbers in here were just made up to illustrate the process. Others are valid.

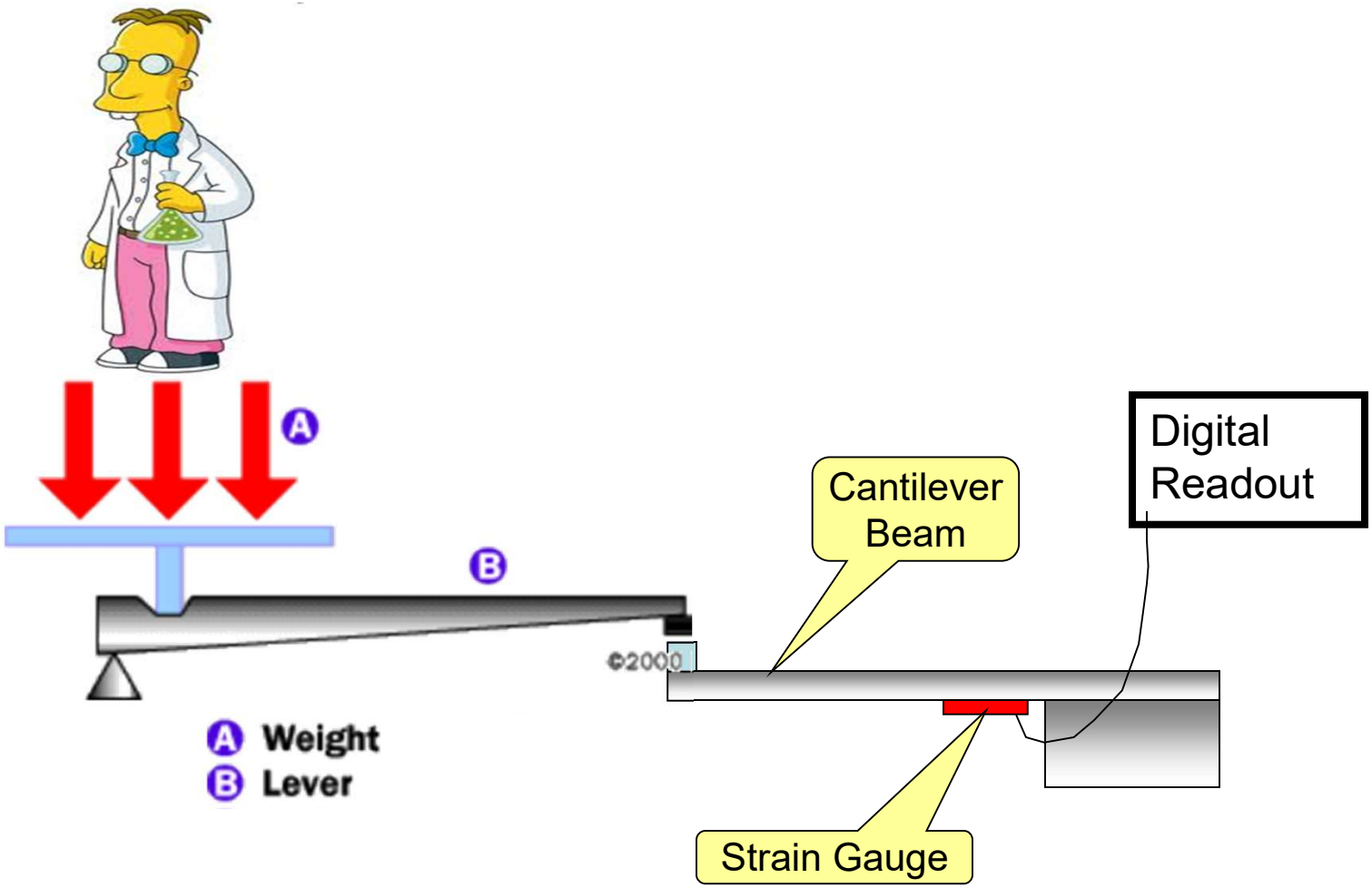
How the Analog Scale Works



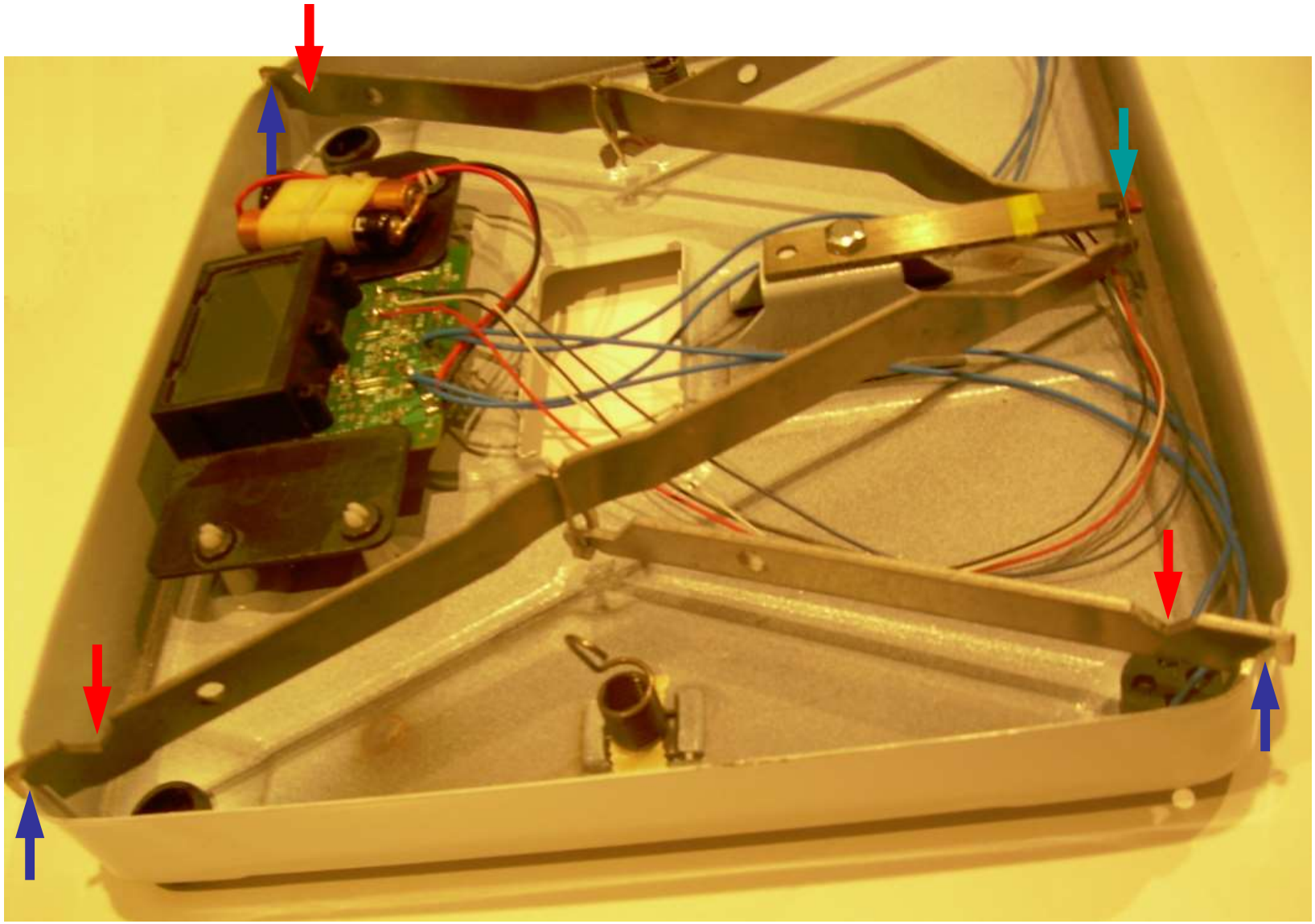
Analog Dial

What's wrong with this picture?

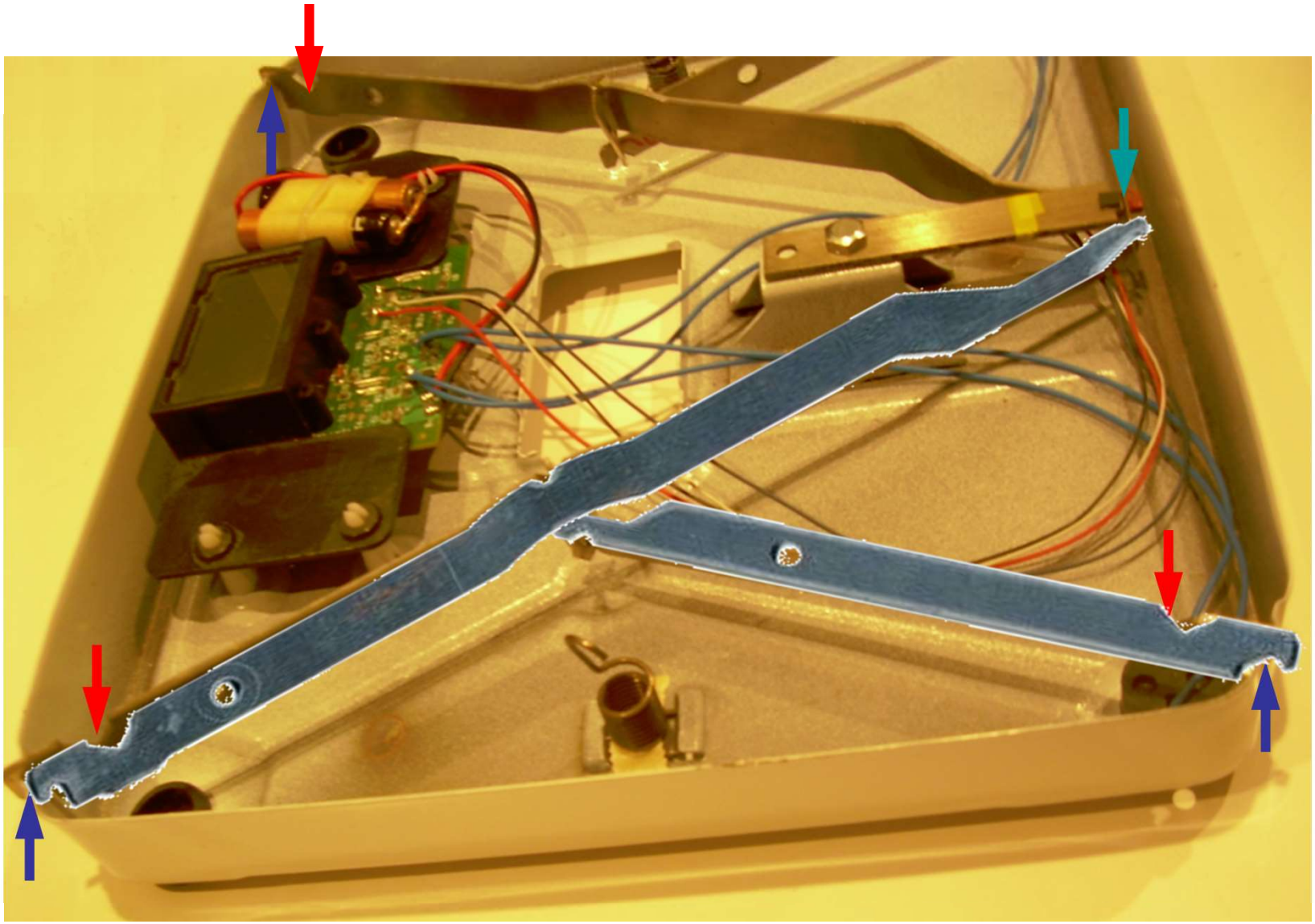
How the Digital Scale Works



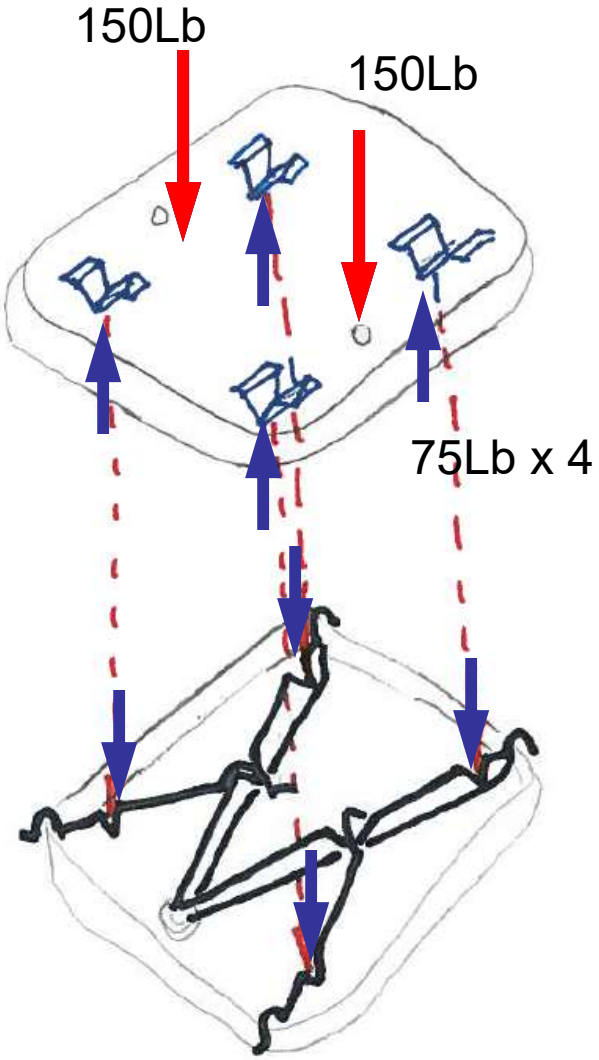
View of Digital Scale Mechanism



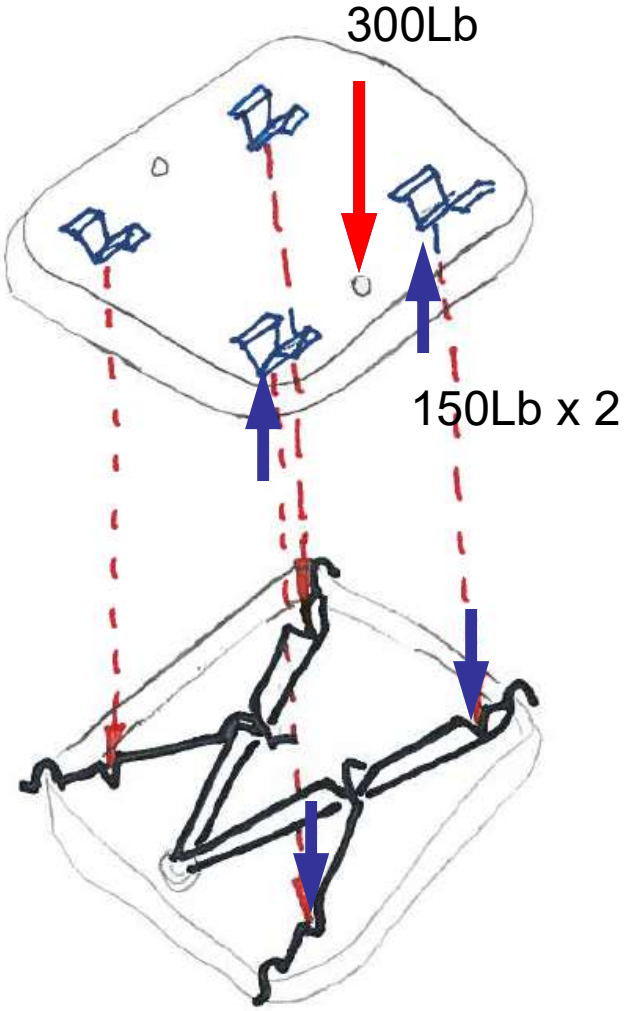
Two Levers per Side



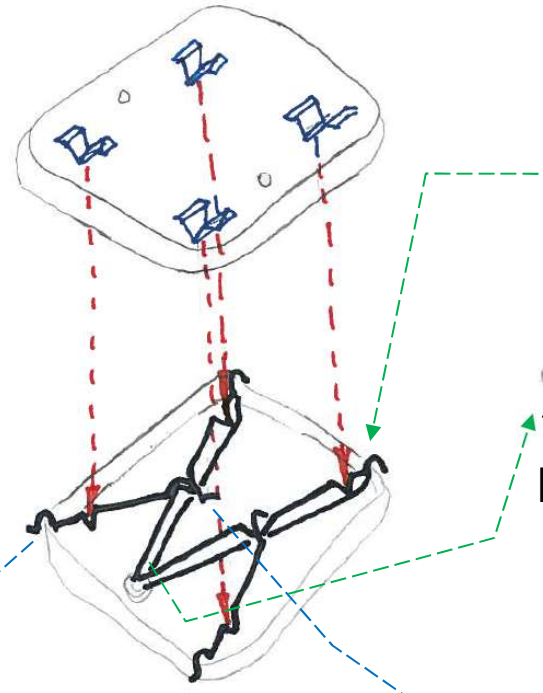
Free Body Diagrams for 300 Lb User



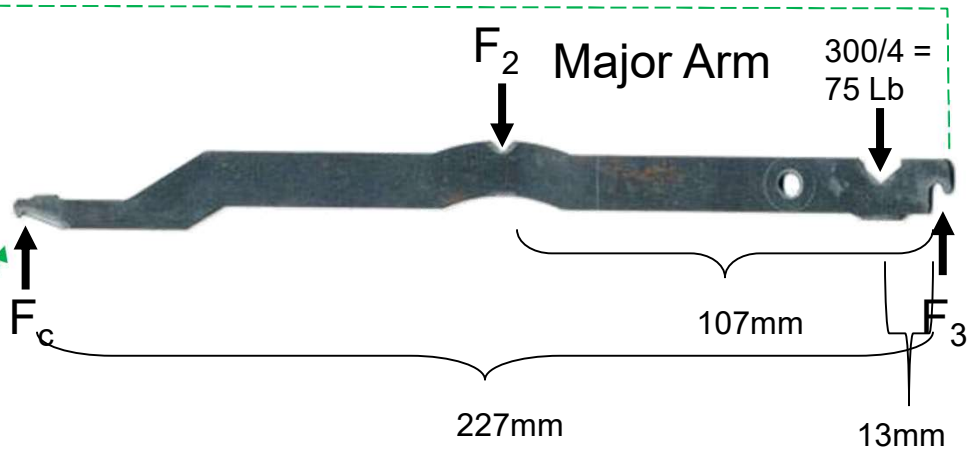
During Weighing –
Both Feet on Scale



Getting On & Off – Only
One Foot on Scale



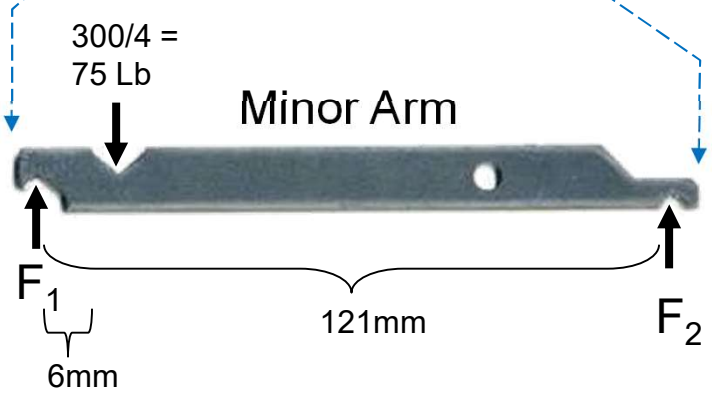
Free Body Diagrams for 300 Lb User



$$\sum M_{F_3} \quad F_C(227) = F_2(107) + (75)(13)$$

$$F_C = [(3.719)(107) + 975]/227$$

$$= 1372.9/227 = 6.048Lb$$



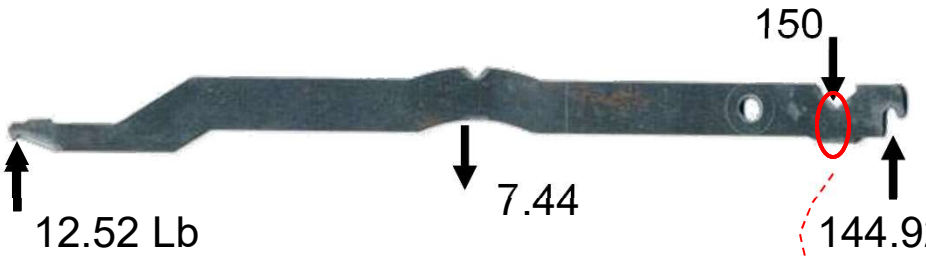
$$\sum M_{F_1} \quad (75)(6) = F_2(121)$$

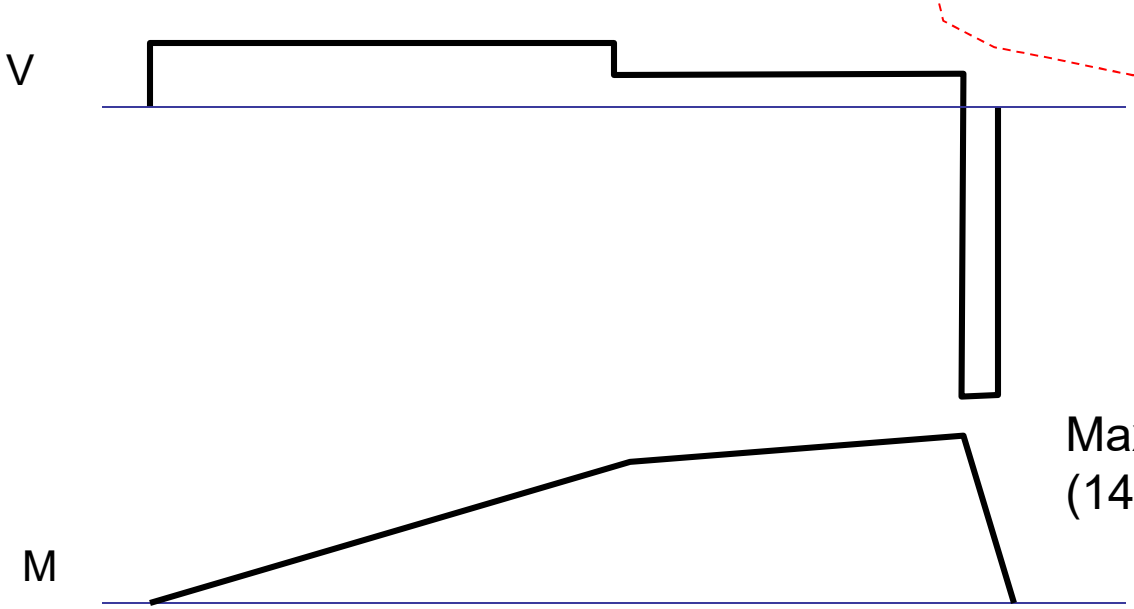
$$F_2 = 450/121 = 3.719Lb$$

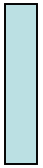
Weight Fraction on Cantilever

$$6.048/150 = 0.0403 = 1/24.8$$

Worst Case Stress Analysis of Major Arm







2.02 x 8 mm

Cross Section Area has an Area Moment of Inertia = $bh^3/12 = 0.000207in^4$

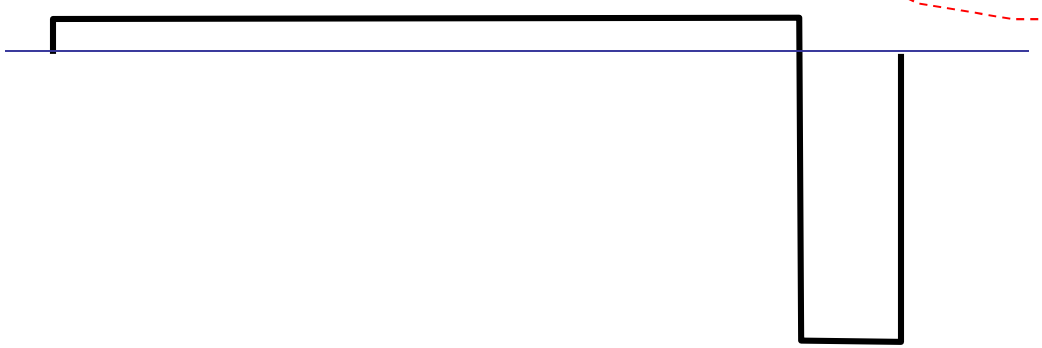
Max Moment = (145)(0.51) = 74.17Lb.in

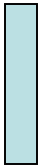
$$\sigma = \frac{Mc}{I} = \frac{(145)(0.51)(.157)}{0.000207} = 56.26ksi$$

Assuming this is 1040 steel with a yield strength of 51ksi, this gives a static FOS = 0.906.

Stress Analysis of Minor Arm

V



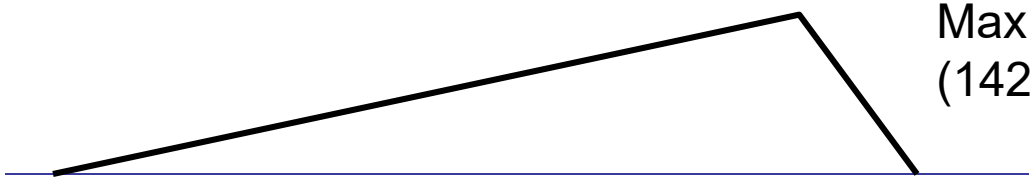


2.02 x 7 mm

Cross Section Area has an Area Moment of Inertia = $bh^3/12 = 0.000139in^4$

Max Moment = (142.56)(0.236) = 33.64Lb.in

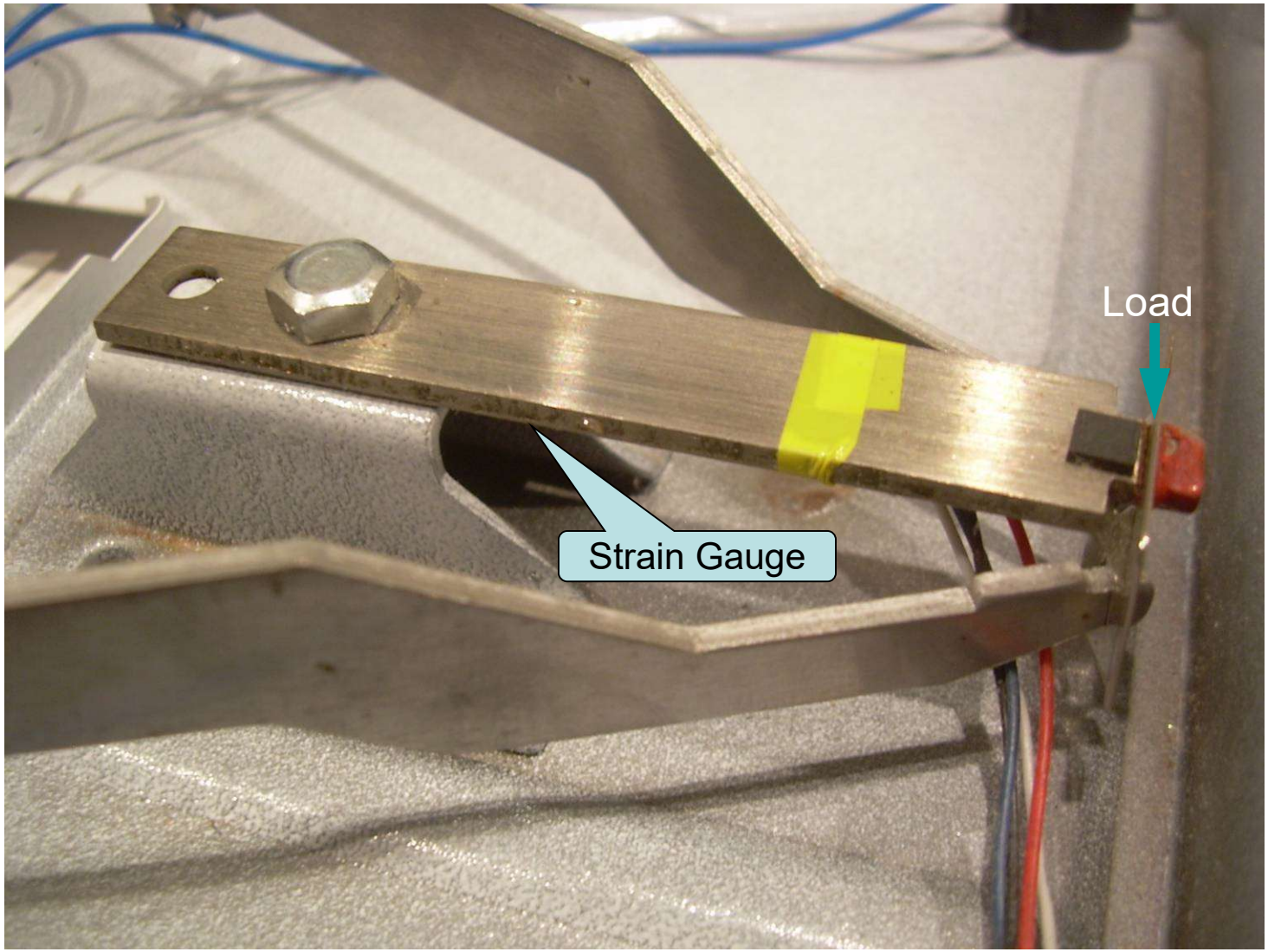
M



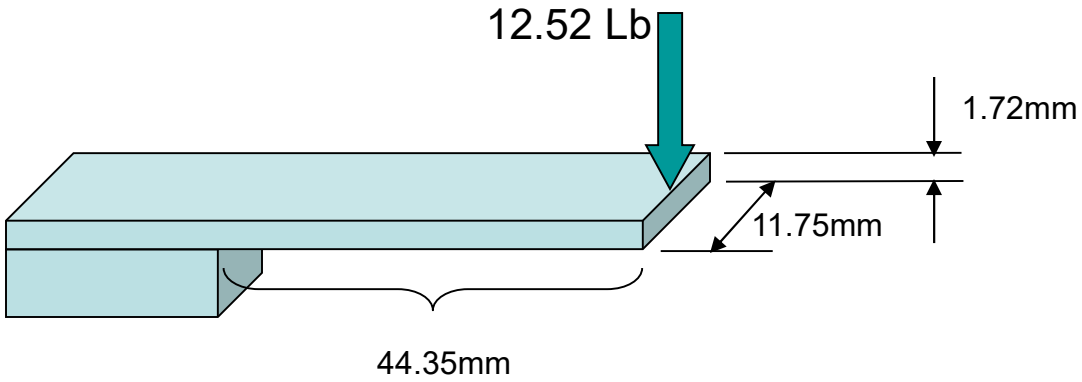
$$\sigma = \frac{Mc}{I} = \frac{(142.56)(0.236)(.138)}{0.000139} = 33.40ksi$$

Assuming this is 1020 steel with a yield strength of 43ksi, this gives a static FOS = 1.29.

Cantilever Beam with Strain Gauge On Underside



Load Sensing Arm

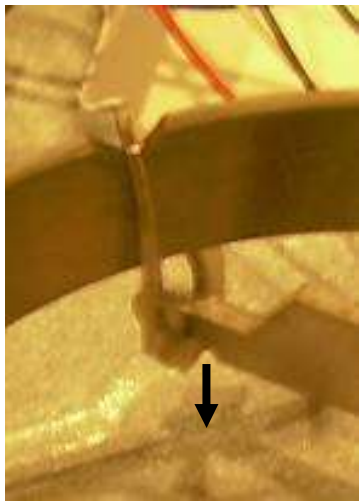


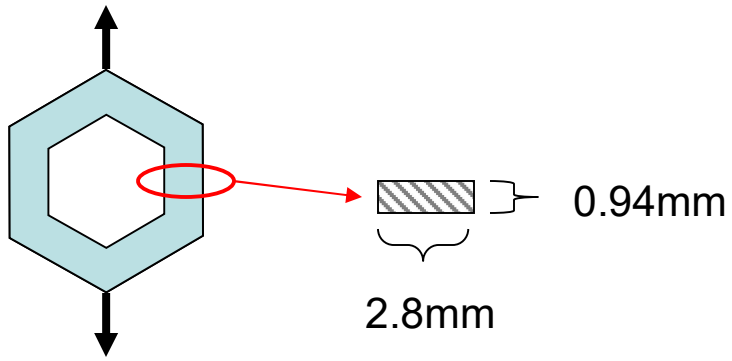
$$I = \frac{bh^3}{12} = \frac{(11.75)(1.72)^3}{12} = 4.98mm^4$$

$$\sigma_{bend} = \frac{Mc}{I} = \frac{(12.52)(4.448\text{N/Lb})(44.35)(1.72/2)}{4.98} = 426.3MPa$$ (61.8 ksi)

$$Deflection\ y = \frac{Fl^3}{3EI} = \frac{(12.52)(4.448)(44.35)^3}{(3)(207\times10^3\,MPa)(4.98)} = 1.57mm$$

Load Link



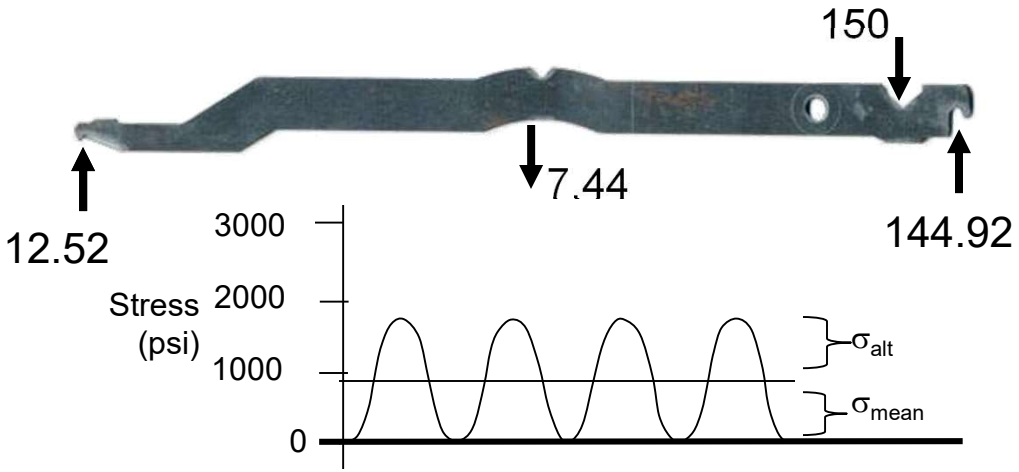


$$A = 2\ x\ w \times t = (2)(2.8)(0.94) = 5.26mm^2$$

$$\sigma_{axial} = \frac{F_2}{A} = \frac{(3.719Lb)(4.448N/Lb)}{5.26}$$

Assuming this is 1020 steel with a yield strength of 295MPa, this gives a static FOS = 93.9.

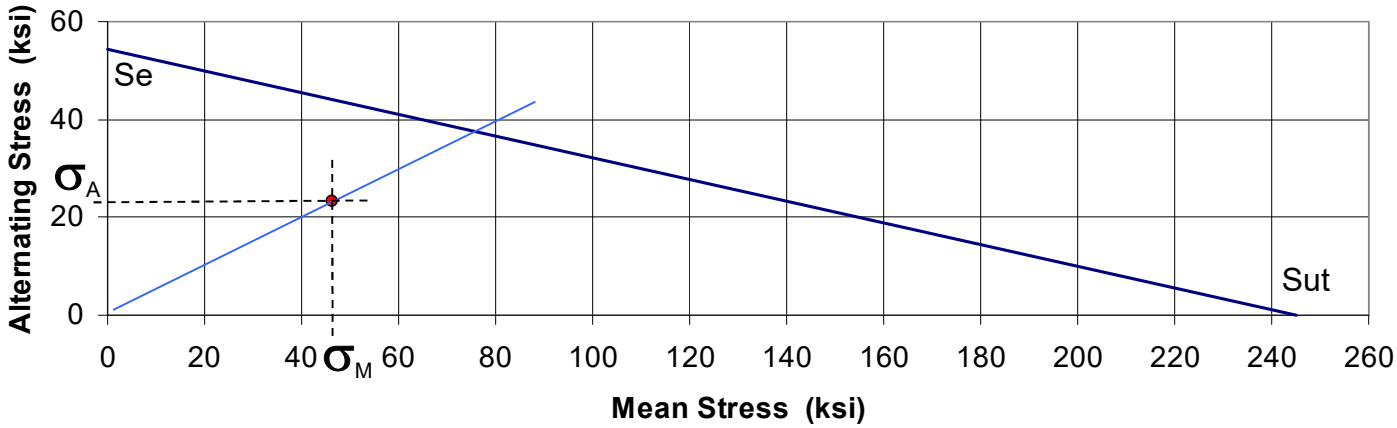
Fatigue Analysis of Major Arm



Surface Factor = X

Size Factor = Y

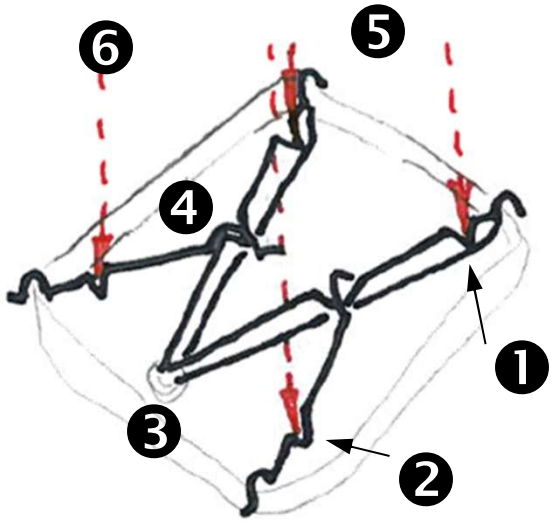
Reliability Factor = Z



Assuming this is 1020 steel, this component will have infinite life.

Summary

#	Component	Static FOS	Life
1	Major Arm	0.906	> 10^6
2	Minor Arm	1.29	
3	Cantilever	2.5	
4	Load Link	93.9	
5	Housing	100	
6	Cover V's	120	



Recommendations

- Do FEA on the Arms to get better stress analysis
- Make the arms out of thicker material
- Test the scale on a tensile tester to see what breaks first
- Include effect of jumping on scale
- Test the material to determine its properties
- Consider lateral buckling of the arms

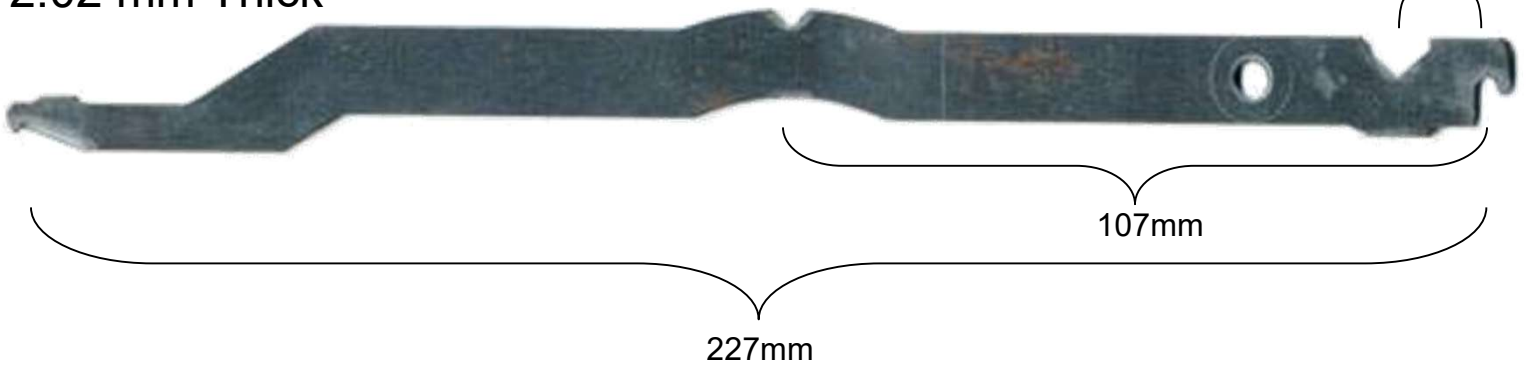
Reference:

Diagram of Scale: http://home.howstuffworks.com/inside-scale1.htm

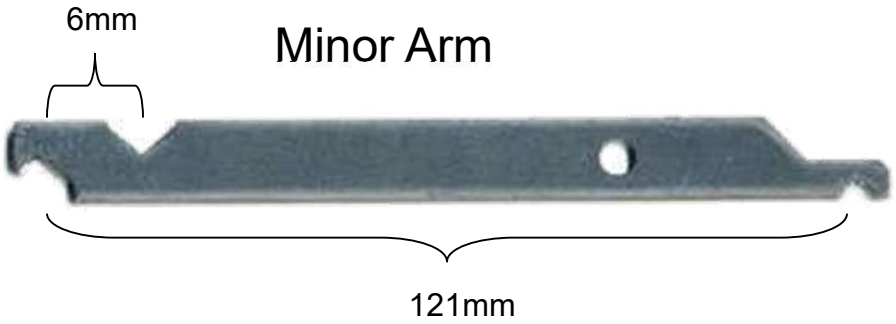
Critical Dimensions

Major Arm

2.02 mm Thick

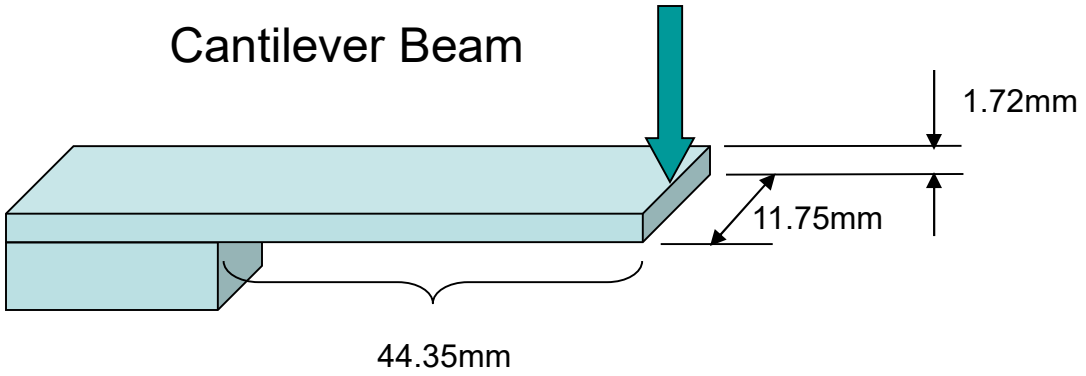


Minor Arm



2.02 mm Thick

Cantilever Beam



See-Through Scale