

RET Summer Presentation “MEMS”

Research Teacher: Kim Doubleday

Santa Barbara Junior High

Mentor: Rajashree Baskaran

Advisor: Prof. Kimberly Turner

Funding: NSF

Background MEMS from Sandia National Labs



Summer Research

- I worked in Prof. Turner's MEMS Characterization Lab with Rajashree Baskaran.

Introduction

The purpose of the research I was involved in was to characterize a MEMS device “C2”, built by Rajashree Baskaran.

MEMS

- ✓ What are they?

- What are they?

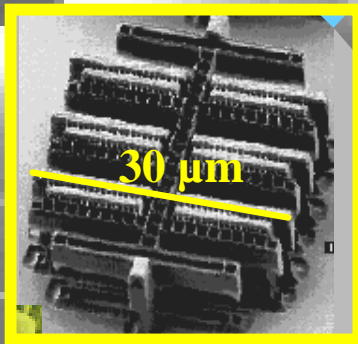
What are MEMS?

I said, "What are MEMS?"

- **Micro** - very *small* device (less than 1 mm)
- **ElectroMechanical** - turns mechanical energy into electrical energy or vice versa
- **Systems** - used with other electrical products, mostly as sensors

A MEMS device on a human hair

I said, "How small is a MEMS?"



A MEMS device 30 μm
across

Human hair 100 μm across



Think of the possibilities...

You could have multiple MEMS devices installed on your hair!!

Your hair



MEMS

- What are they?
- ✓ What are they good for?
- How are they made?

MEMS Saving Lives!

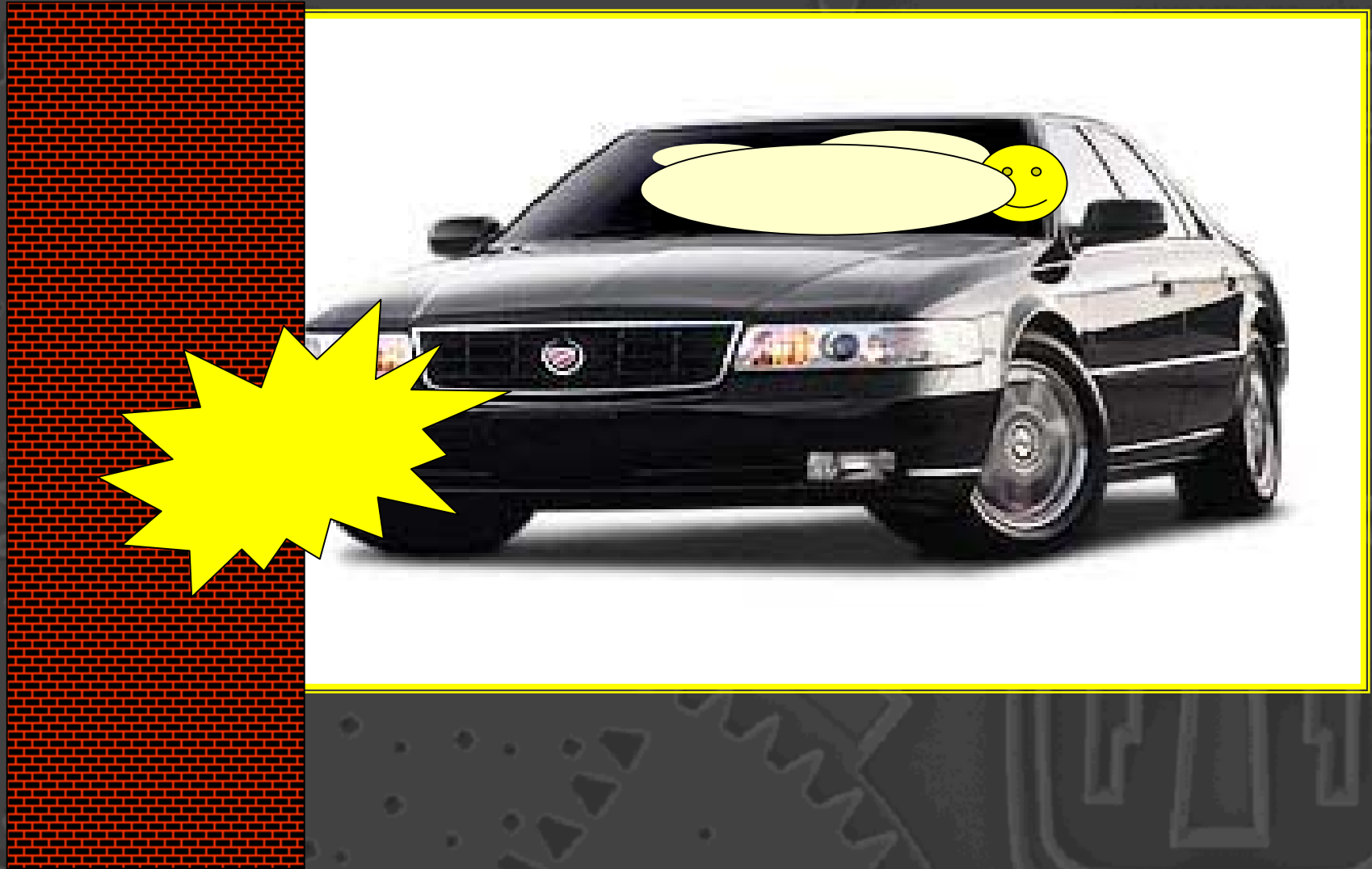


MEMS are used as sensors to deploy air bags!!

MEMS Saving Lives!



MEMS Saving Lives!

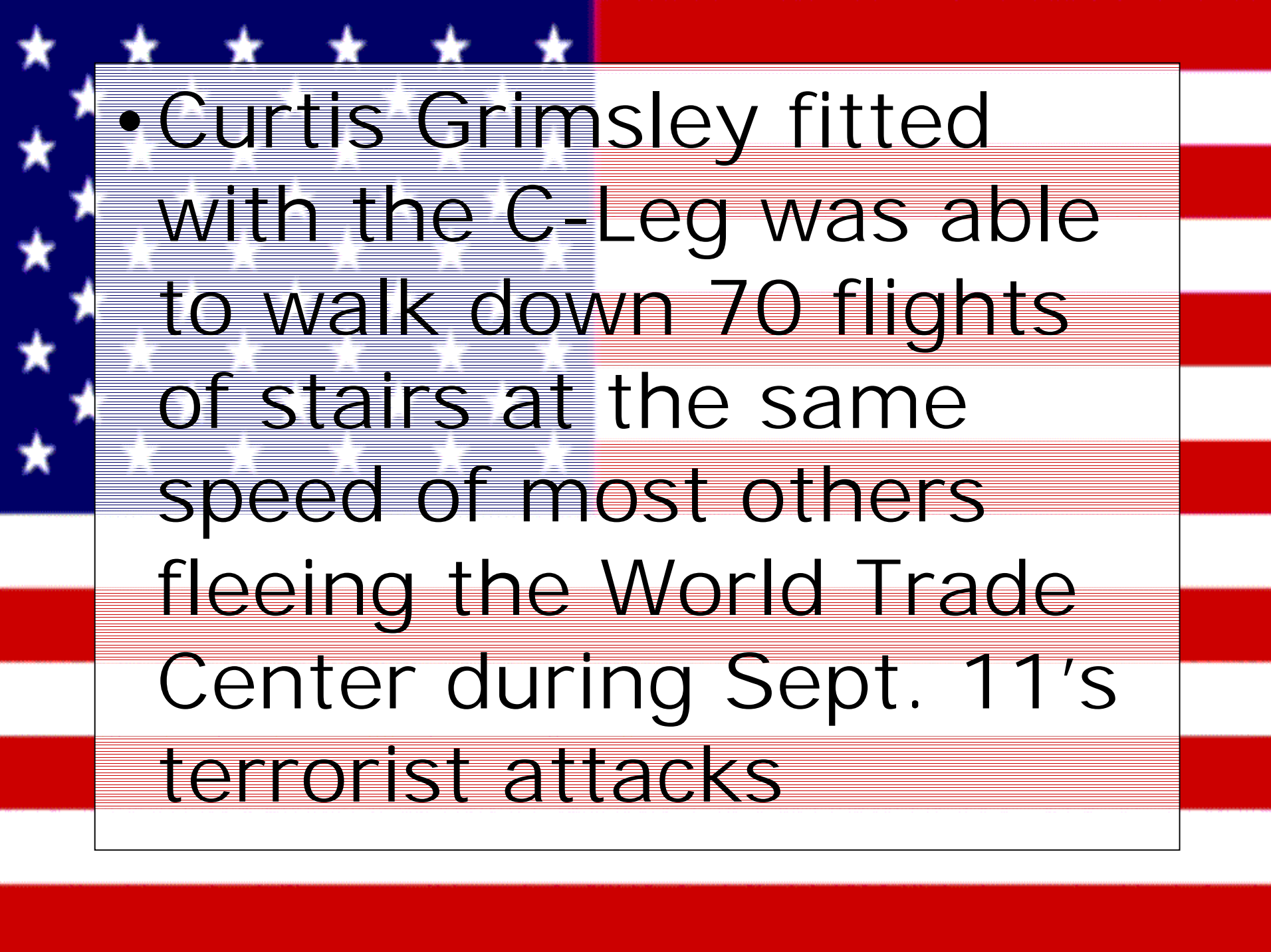


MEMS Saving Lives!

- The C-Leg is fitted with microprocessors and sensors that mimic the stability and step of a natural leg.

The C-Leg



- 
- The background of the slide is a stylized American flag, featuring a blue field with white stars on the left and red and white horizontal stripes on the right. The text is overlaid on a white rectangular area with a thin black border.
- Curtis Grimsley fitted with the C-Leg was able to walk down 70 flights of stairs at the same speed of most others fleeing the World Trade Center during Sept. 11's terrorist attacks

What else are MEMS good for?

GAMES!



Inside the Kirby Tilt n' Tumble Game

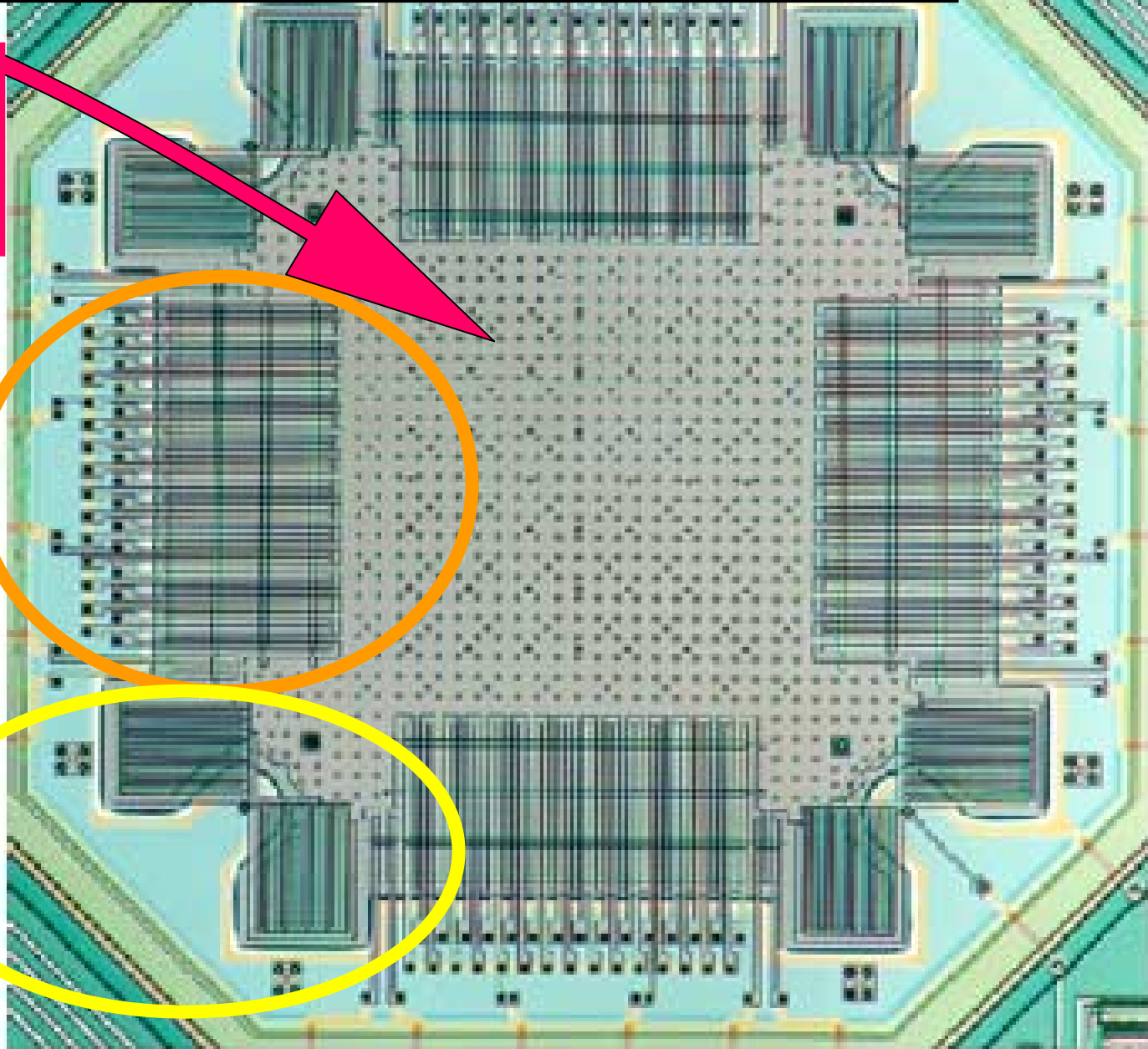
- A MEMS device and electrical circuits needed to operate the device.
- Let's examine the MEMS device inside the game.

The ADXL202 MEMS Device

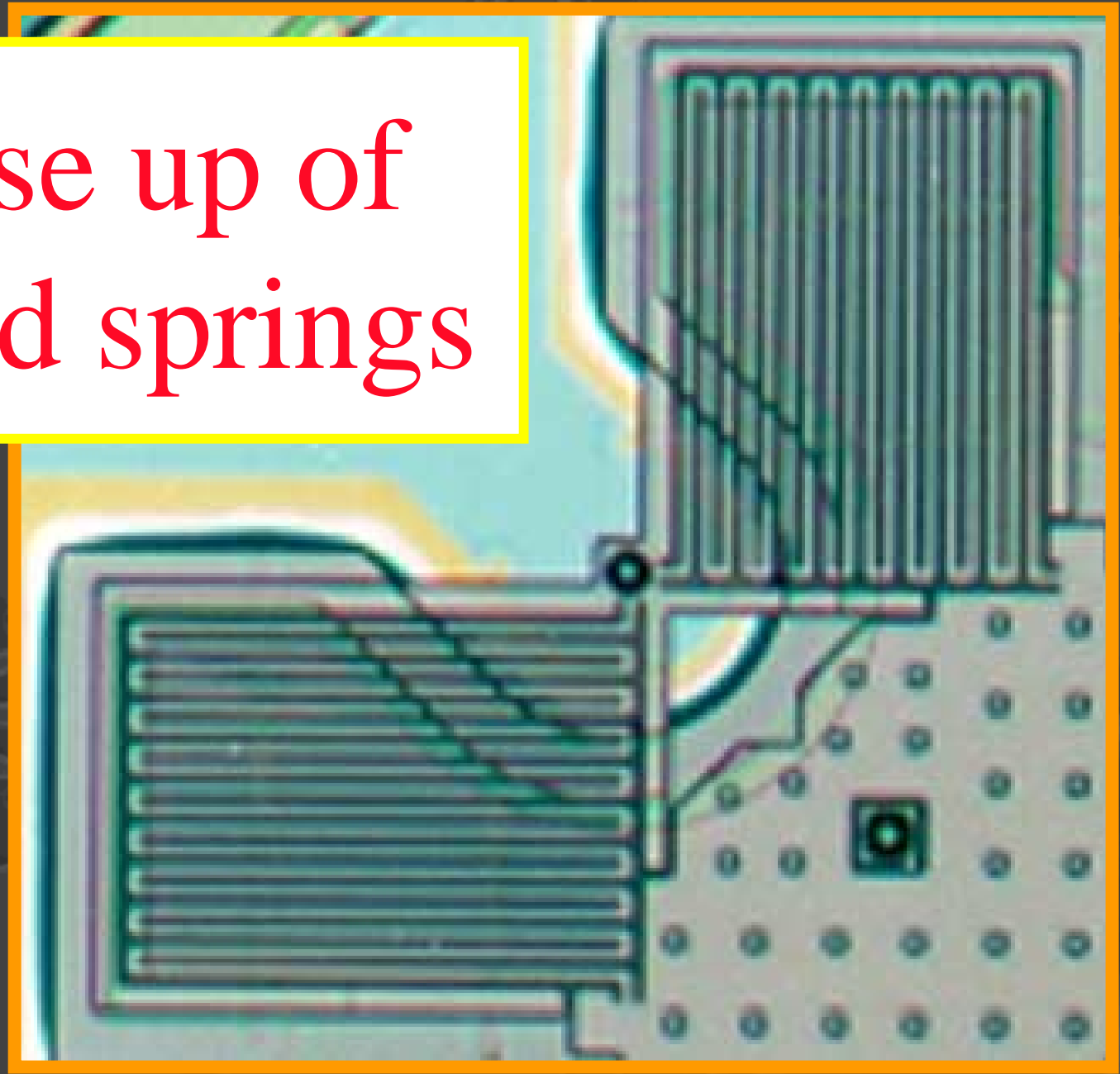
**Movable
Mass**

**Capacitors
“Combs”**

**Folded
Springs**



Close up of
folded springs



A close up of the capacitor “comb”

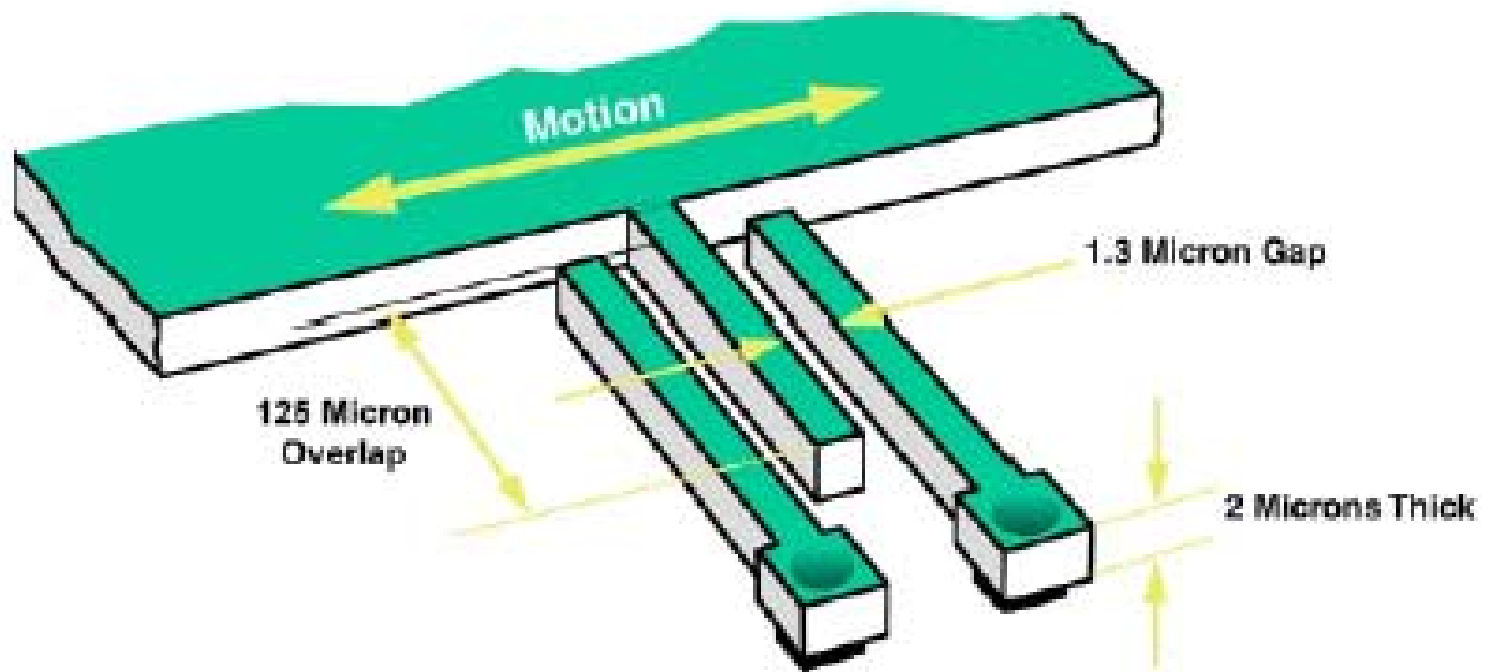


Figure 1. Beam Dimensions for a Single Finger.

Movement

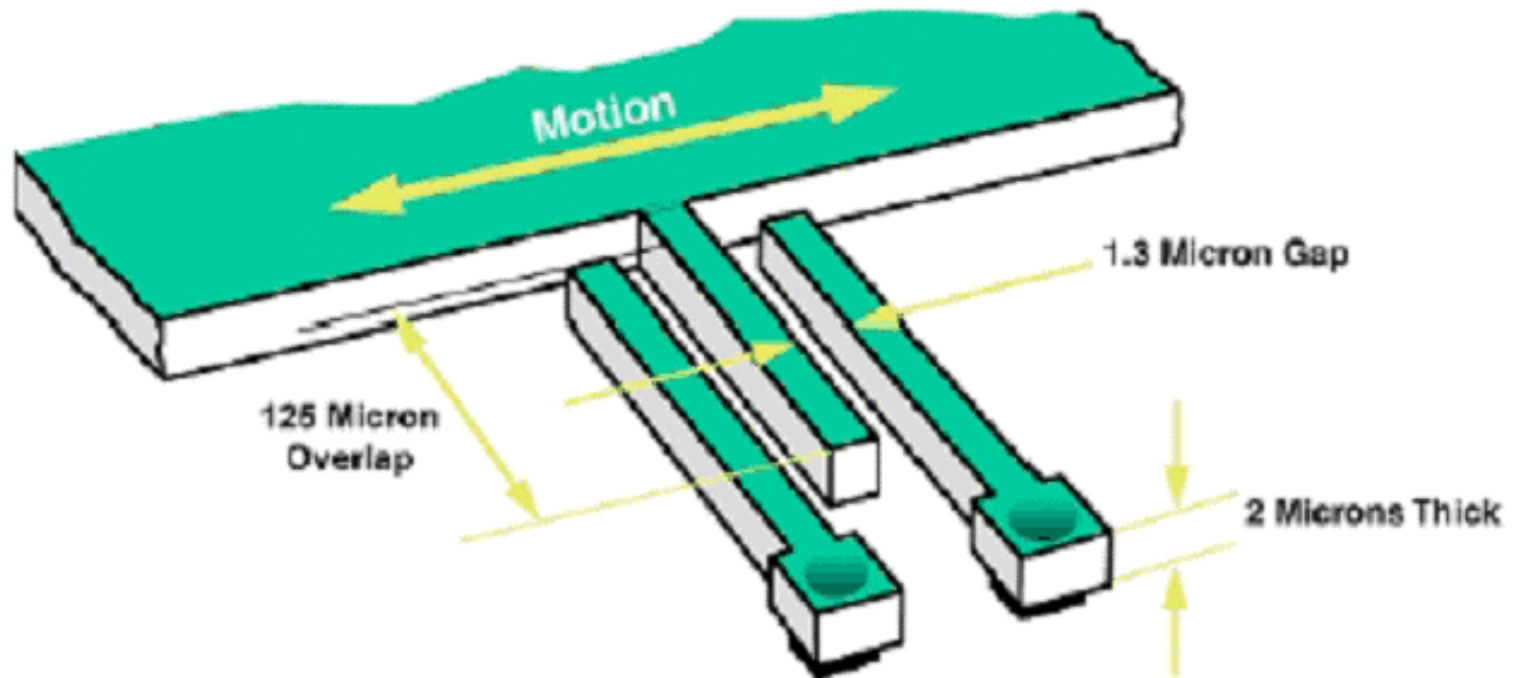
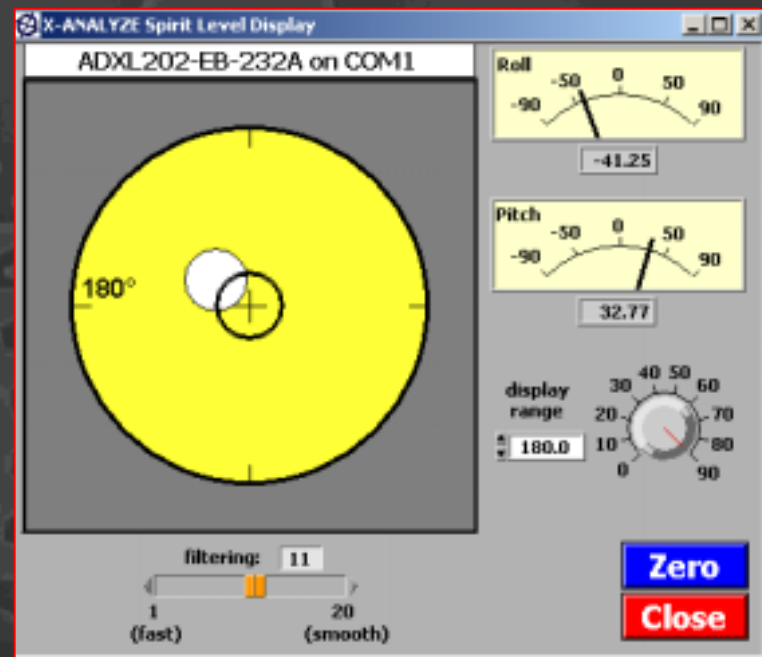
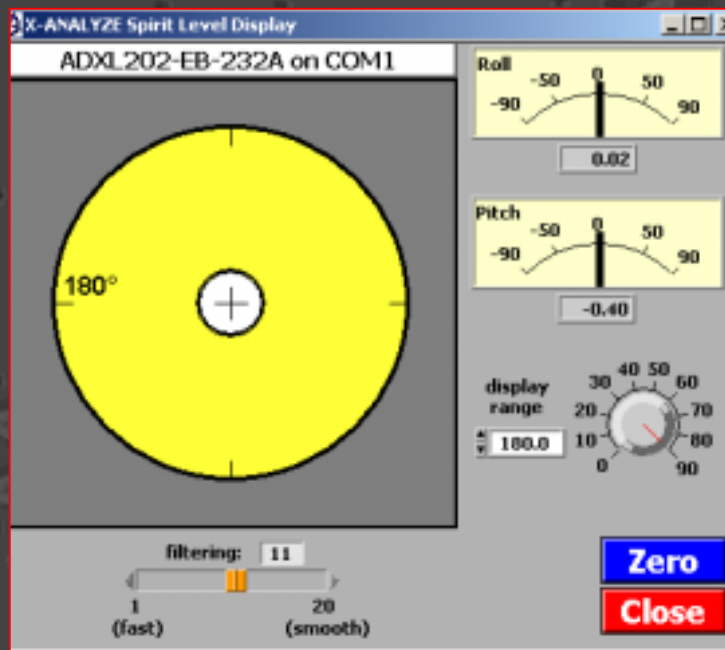


Figure 1. Beam Dimensions for a Single Finger.

How does Kirby's MEMS work?

- When the device is tilted:
- The mass moves
- The springs expand/compress
- The capacitor combs “sense” a change in voltage.
- The circuitry processes.

Computer Image of Accelerometer MEMS



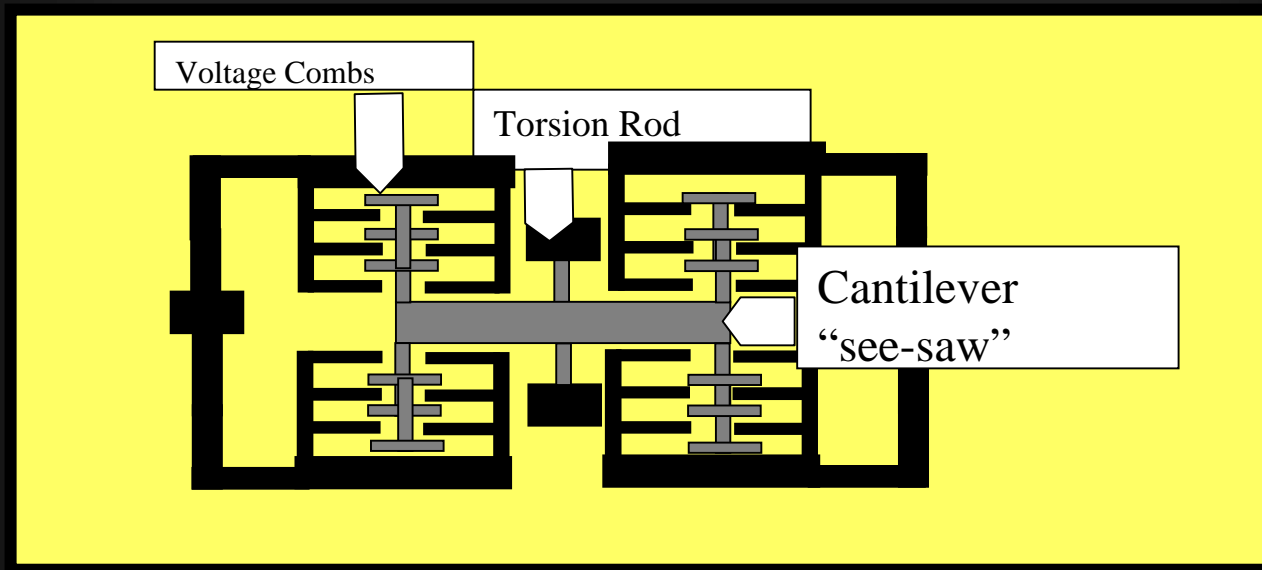
The image on the right is when the game is tilted.

Methods



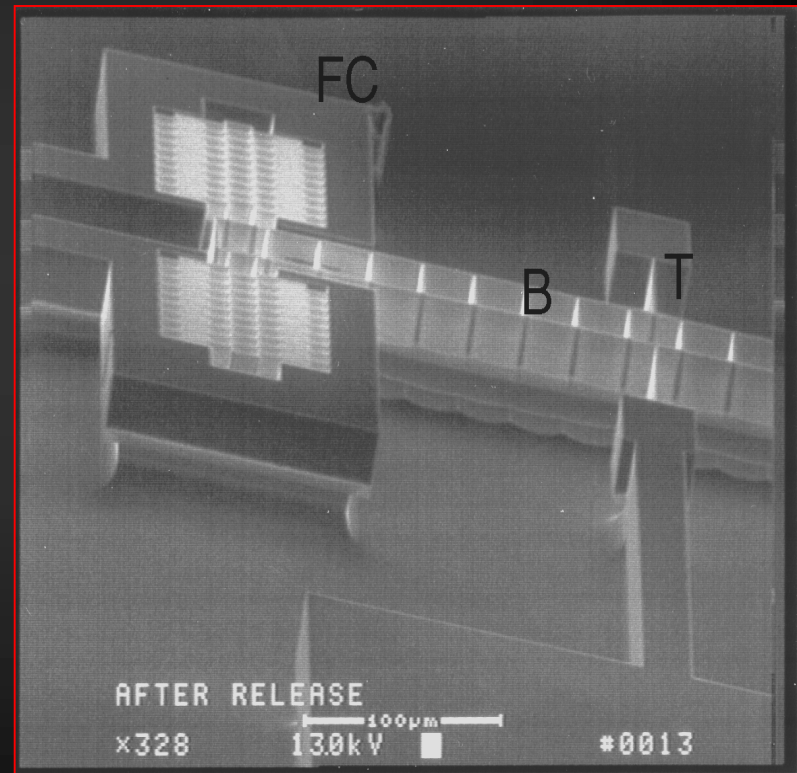
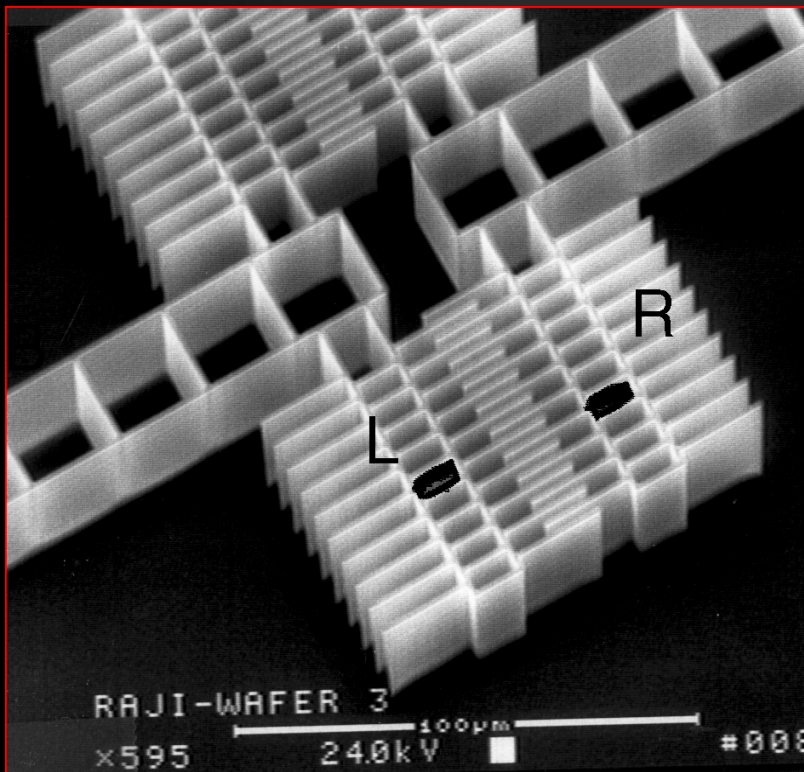
- The device we are testing is designed to vibrate when voltage is applied.
- Our tests are to determine what the highest velocity of vibrations will be for selected voltages.

Overview of Testing Device “C2”



A torsional oscillator. The black parts are fixed to the substrate, and the gray parts are movable. The length of the cantilever is approximately $144\mu\text{m}$ (micro meters).

Scanning Electron Micrographs of Coupled Oscillators



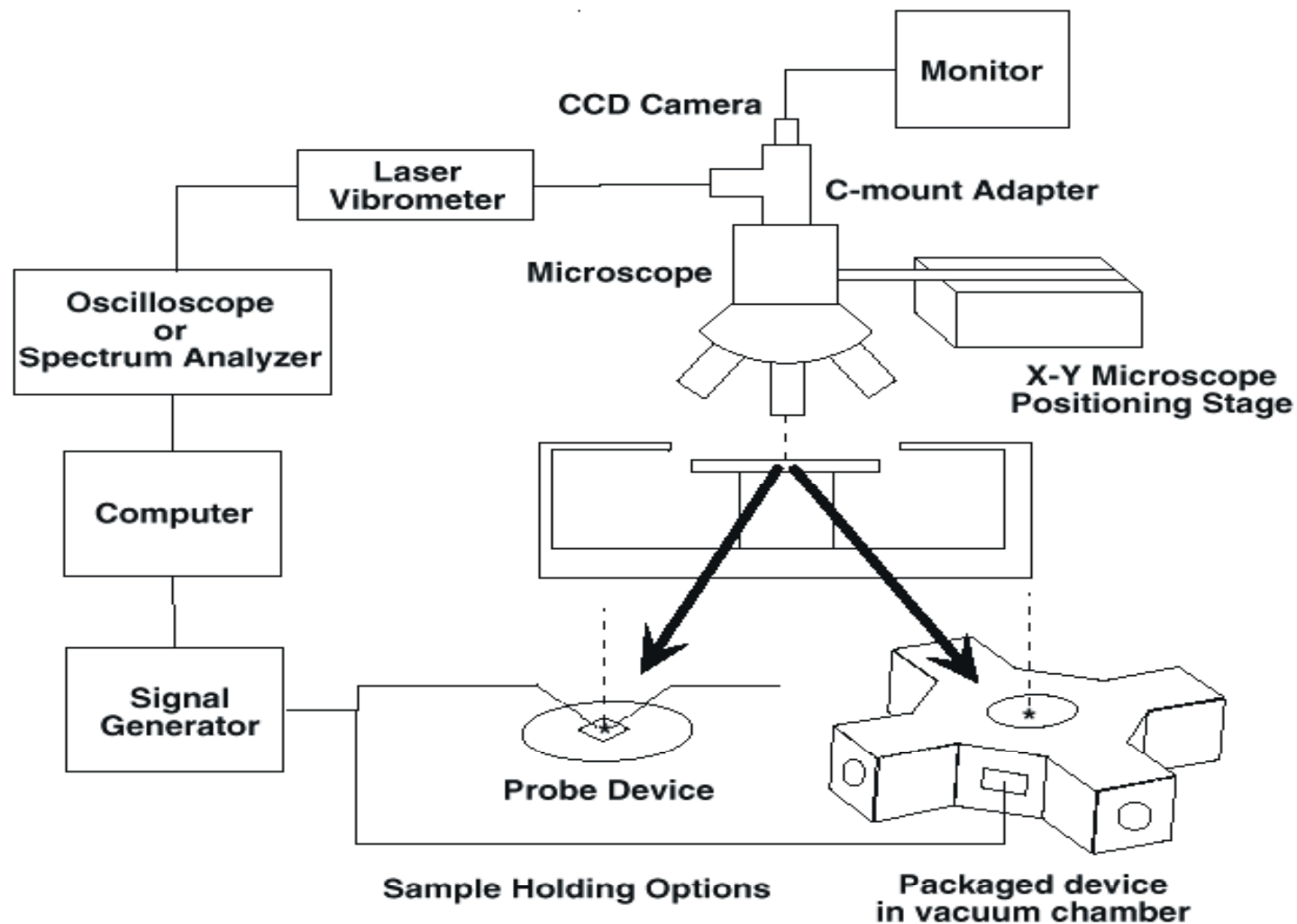
The Math Behind the Device

The formula below is the differential equation for motion and its solution. Raji uses this to calculate the resonance frequency of the device before it is built. The results of the test data are compared to the initial calculations.

$$m \frac{d^2 x}{dt^2} + c \frac{dx}{dt} + kx = -k_e V_A \cos(\omega t)$$

$$\text{Velocity} = (m_1/x) / \sqrt{(m_2)^2 - x^2} + 4(m_3)^2 x^2$$

Laser Vibrometer Characterization Suite



Tektronix Oscilloscope Computer Interface: Testing at 3.6 Voltage


The screenshot shows the Tektronix Oscilloscope Computer Interface software. The window title is "Loop1_output_in_one_mie". The menu bar includes "File", "Edit", "Operate", "Project", "Windows", and "Help". The toolbar contains icons for file operations and a font setting of "13pt Application Font".

Wave Form: SQRTCOS
Mode: Arb Waveform

Max A: 3.6
Min A: 3.6
Step A: 10.00

Max F: 74500
Min F: 75500
Step F: 10

Current Amplitude: 3.6
Current Frequency: 74500

Power Indicator: 
Power Switch: ON

Result Array

Parameters	A	F
	60.100000	9400.000000
	60.100000	9450.000000
	60.100000	9500.000000
	60.100000	9550.000000
	60.100000	9600.000000

Testing at 5.6 Voltage

Loop1_output_in_one_file

File Edit Operate Project Windows Help

13pt Application Font


Wave Form: SQRTCOS Mode: Arb Waveform

Max A: 5.6 Max F: 74500

Min A: 5.6 Min F: 75500

Step A: 10.00 Step F: 10

Current Amplitude: 5.6 Current Frequency: 74500

Power Indicator: 

Power Switch: ON

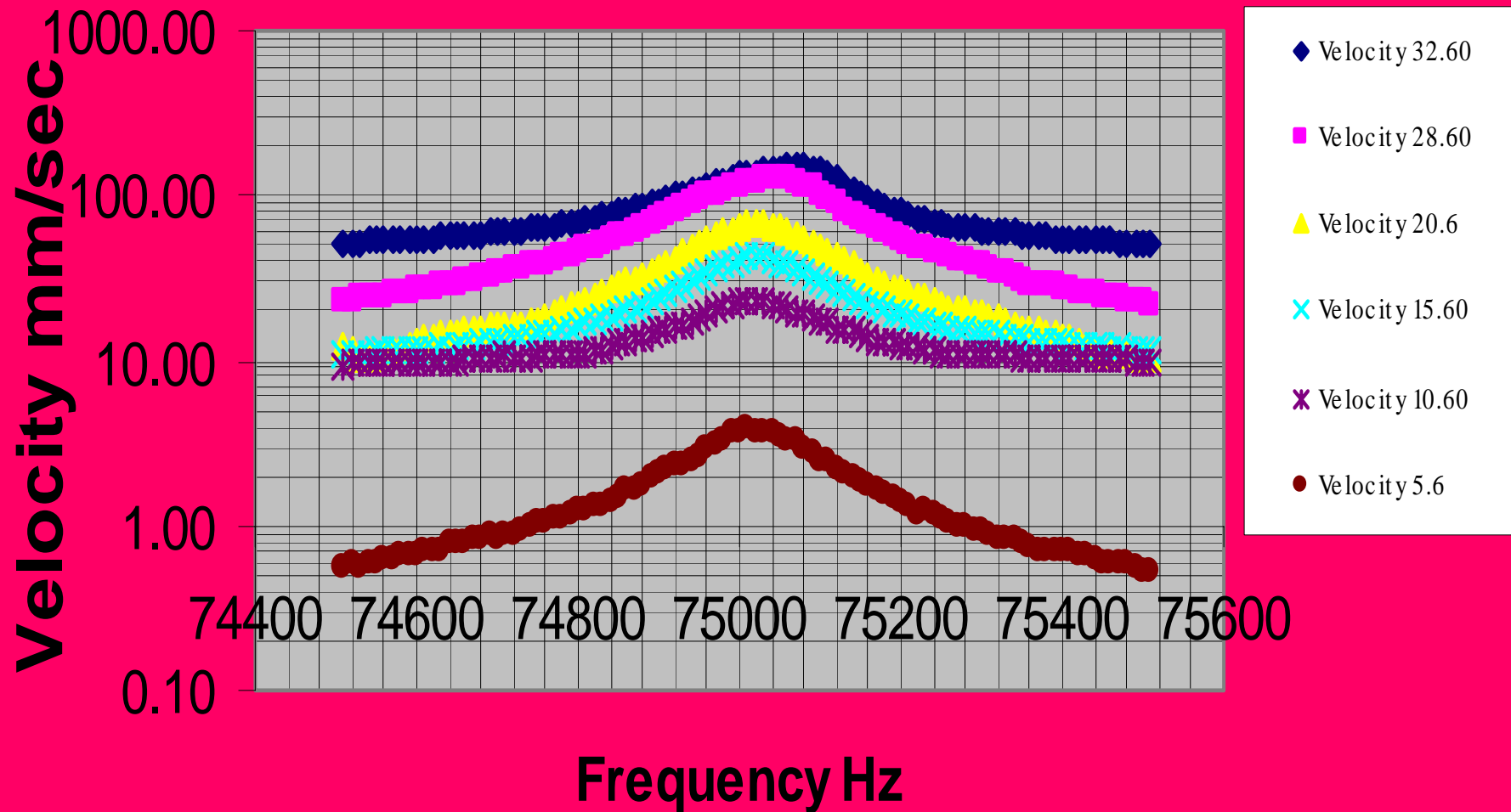
Result Array

Parameters	A	F
	60.100000	9400.000000
	60.100000	9450.000000
	60.100000	9500.000000
	60.100000	9550.000000
	60.100000	9600.000000

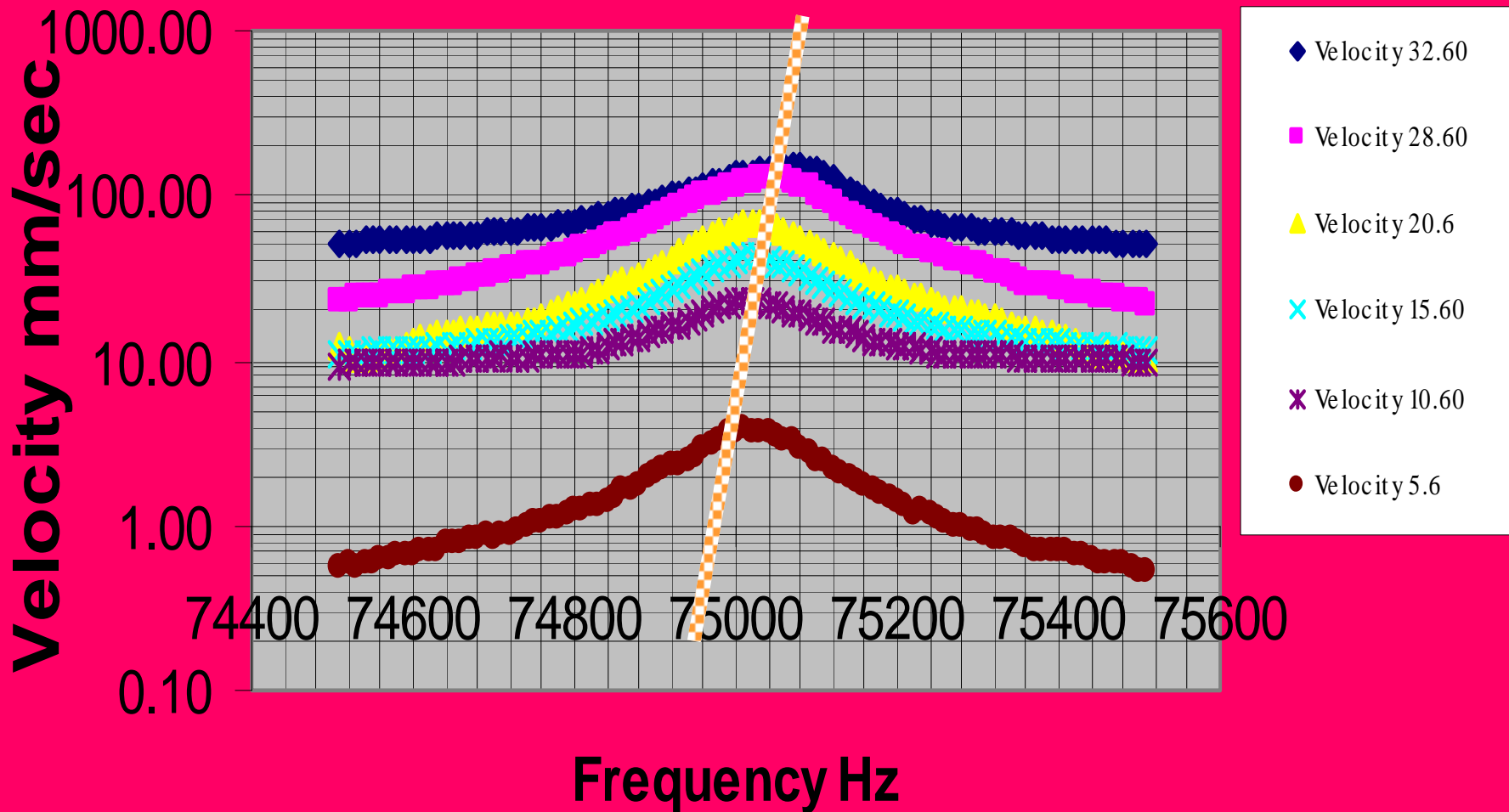
Peak Velocities are highlighted

Frequency of Input Voltage	Velocity 32.60	Velocity 28.60	Velocity 20.6	Velocity 15.60	Velocity 10.60	Velocity 5.6	Velocity 3.6
74970	119.00	103.50	56.75	35.50	20.1	3.104	1.122
74980	123.50	107.88	59.60	37.50	21.2	3.326	1.22
74990	127.50	112.63	62.38	39.30	22	3.596	1.353
75000	131.50	116.38	64.75	40.70	22.5	3.724	1.362
75010	135.00	120.88	66.13	41.80	22.80	3.84	1.43
75020	138.50	123.00	67.00	42.20	22.8	3.612	1.424
75030	141.50	126.50	66.63	41.90	22.4	3.642	1.362
75040	144.50	125.63	65.63	40.80	22.2	3.6	1.402
75050	146.50	127.48	64.00	39.30	21.5	3.392	1.318
75060	148.00	124.13	61.13	37.30	20.76	3.254	1.202
75070	148.50	121.63	58.00	35.40	19.6	3.206	1.164
75080	148.00	114.88	54.63	33.60	19	2.964	1.112
75090	146.00	111.13	51.63	31.70	18.2	2.818	1.048

C2 Frequency v. Velocity



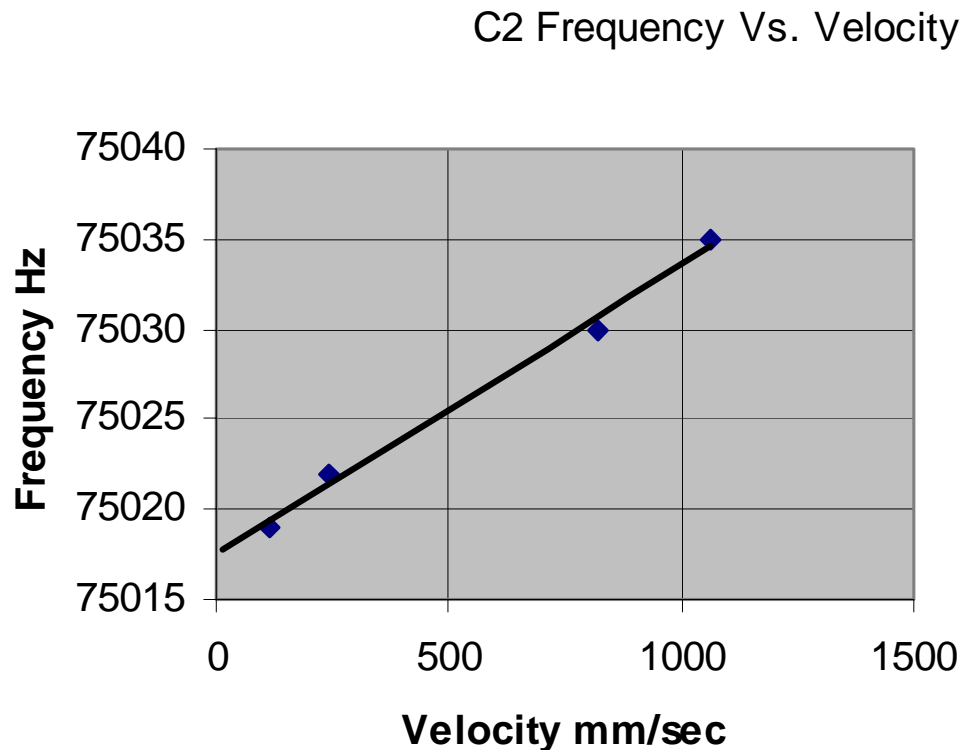
C2 Shift of Peak Velocity



C2 Frequency Vs. Velocity

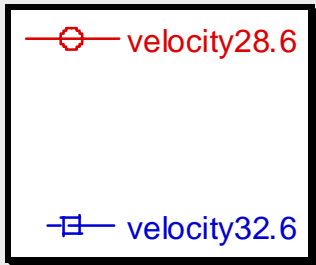
The linear equation calculated by Raji fits almost perfectly into the data collected.

When $R^2 = 1$, the fit is perfect.

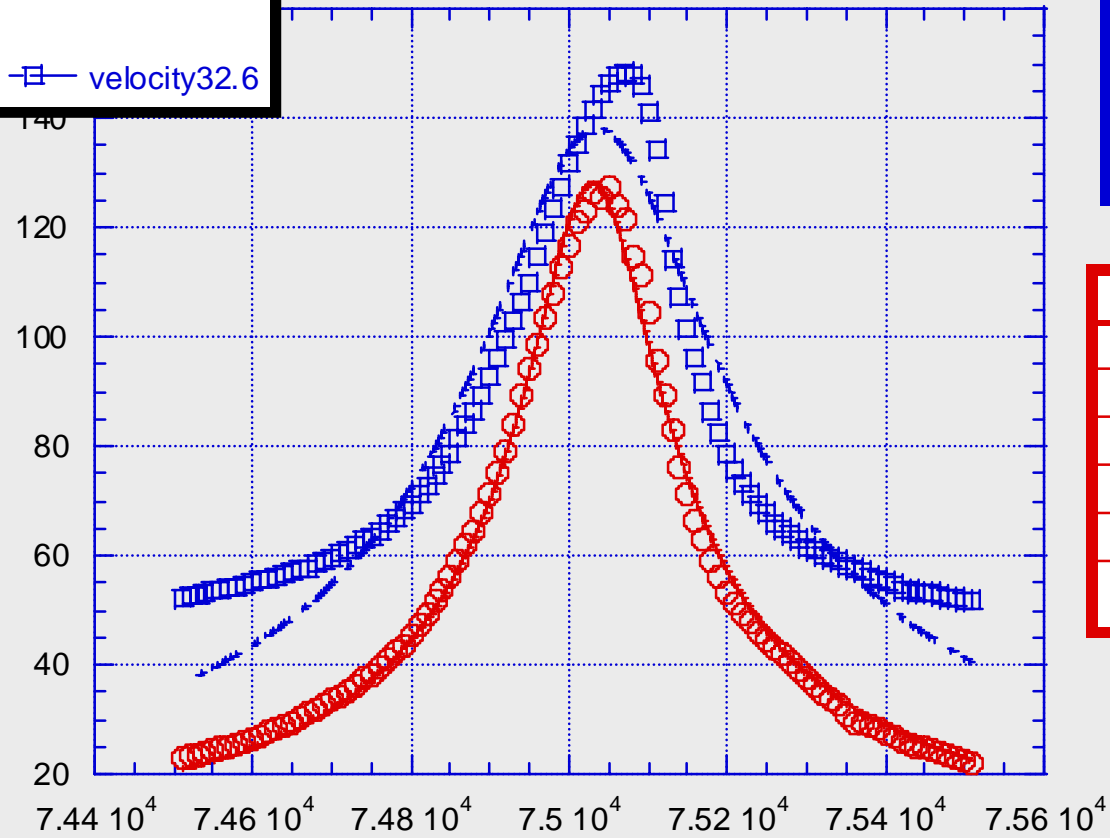


$y = 0.0161x + 75018$
 $R^2 = 0.9936$

- ◆ m2=res. Frequency
- Linear (m2=res. Frequency)



Data 1 4:44:19 PM 7/16/2002



$$y = m1 \cdot M0 / \sqrt{(m2 \cdot m2 - m0 \cdot m0)} \dots$$

	Value	Error
m1	40096	912.16
m2	75035	3.9297
m3	145.27	4.9165
Chisq	7282.1	NA
R ²	0.91978	NA


$$y = m1 \cdot M0 / \sqrt{(m2 \cdot m2 - m0 \cdot m0)} \dots$$

	Value	Error
m1	21828	157.91
m2	75030	0.86549
m3	85.323	0.96636
Chisq	503.8	NA
R ²	0.99506	NA

The top curve does not fit well into the solution because at this voltage, the velocity is not linearly related.

What did I learn this summer?

- Engineering is cool.
- Engineers solve problems for people.
- When you test something, you test all your variables millions of times against the control.
- Engineers write **everything** down in numbered log books.

A photograph of a woman with her hair in a bun, seen from behind, looking out from the deck of a boat. The boat's interior, including a dashboard with a screen, is visible on the left. The background shows a vast blue body of water and distant mountains under a clear sky. A red rectangular border is drawn around the text area.

Thanks to Raji and Kim for
the time you gave me, and
the opportunity to
learn...time to go fishing.