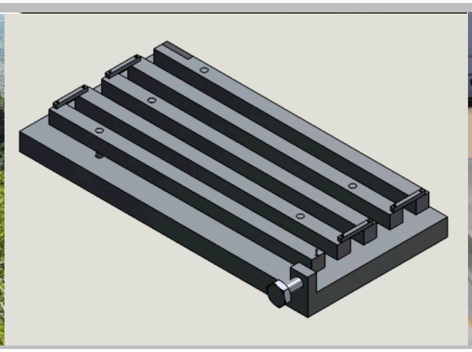
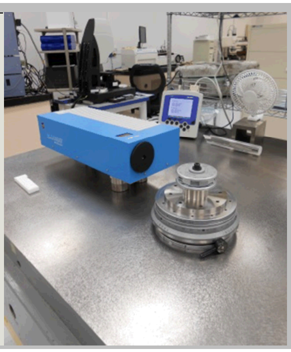
SAND2015-5622PE

Sandia National Laboratories





MAC 2015: Autocollimator Calibration

C1C Kaylee Kostka, USAFA

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Overview

- Desired Project Outcomes
- Research and Development
- Conclusions and Future Improvements
- Work and Play

What Happened?

Civil Engineering
Structures/Steel Design
Angles, Customary Units

?

Mechanical Engineering
Metrology in Length, Mass, and Force Lab
Radians, Nanometers

Let’s start from the Beginning…

Sandia National Laboratories

- Arrived at Sandia National Labs on 1 June
- Worked with Hy Tran and Rick Mertes in the Primary Standards Lab
  - Length, Mass, Force Lab

OFFICE PICTURE

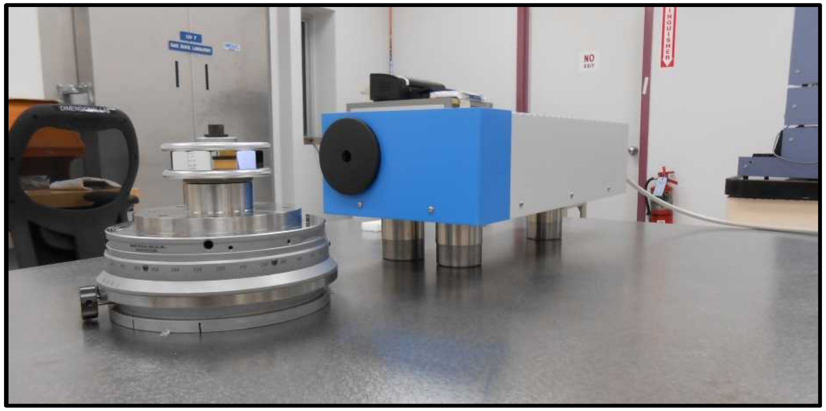
Why is this important?

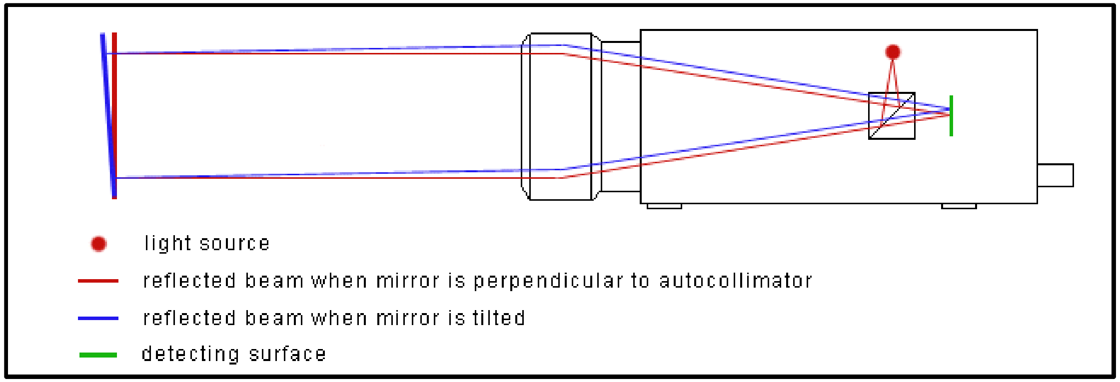
Metrology: the science of measurements and weights

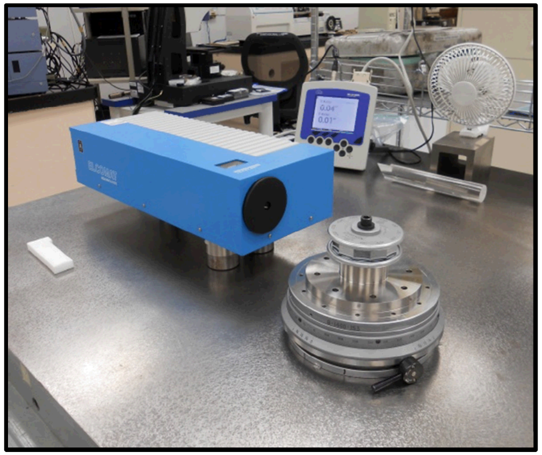
- In lab setting, sets measurement standards and ensure proper calibration of machines
- At the PSL
  - Set standards compatible with national standards
  - “Anticipates future measurement needs of the nuclear weapons complex”
  - Check abilities of new technology
- PSL has maintenance, calibration, and engineering, among others.

Autocollimator 101

- Emits light, measures deviation of reflected angles
- Two types capable of measuring changes in X and Y direction
- Autocollimator at PSL capable of measuring deviations of 0.005 arc-sec (~25 nanoradians)





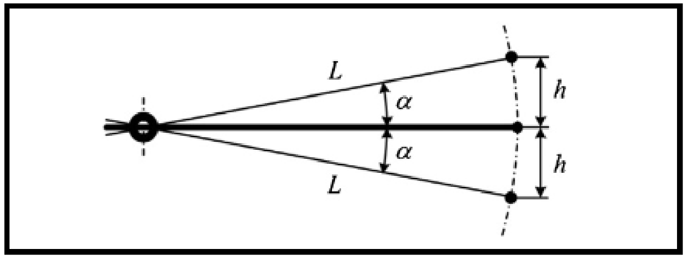


The Project

Designing a system capable of calibrating Sandia National Laboratories' Primary Physical Standards' autocollimator to 0.001 arc-second resolution

- Relationship between length (L) and displacement (h)
- Putting it in perspective
  - 0.001 arc-second is about 5 nanoradians (angle made with 5 nanometers over a 1 m span)
  - Angle created by a hair at 20 km away

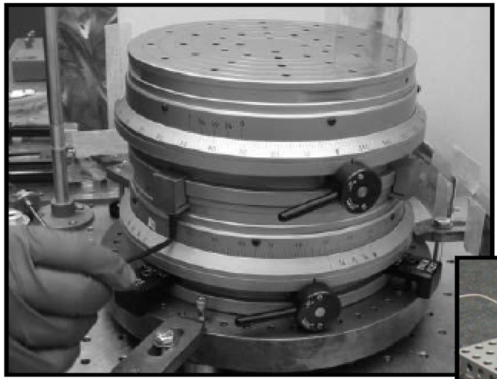
$$\alpha = \frac{h}{L}$$



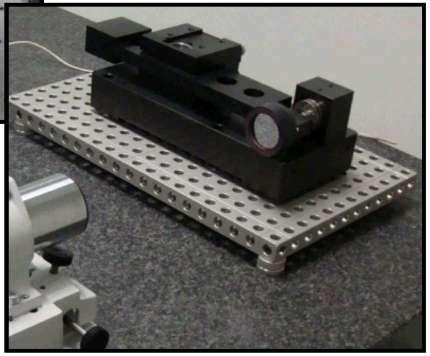
Previous Developments and Ideas

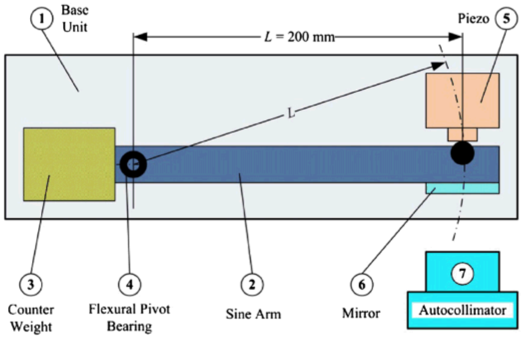
- Sine Bar
  - High Precision Small Angle Generator (HPSAG) by Turkey's National Metrology Institute
- High-performance circle dividers
  - Computer controlled or manually adjusted
    - Advanced Automated Master Angle Calibration System at NIST
    - Moore 1400 Precision Index Tables

Circle Divider



Sine Bar





Photos courtesy of IOP Publishing, Measurement Science and Technology section, SPIE Digital Library

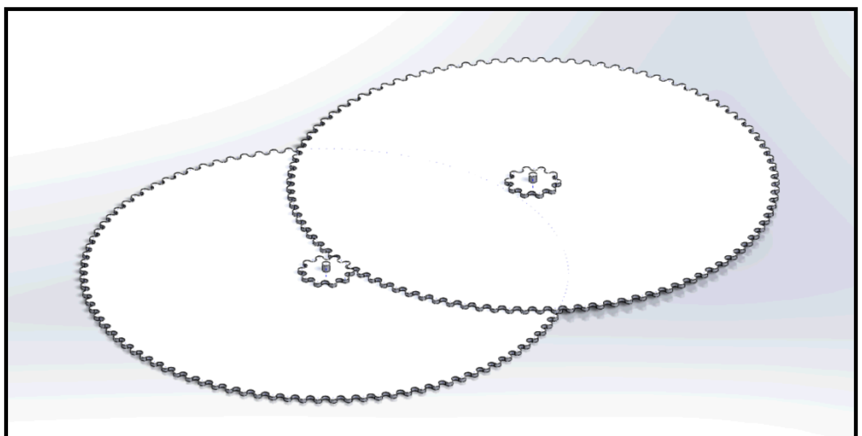
Proposed Ideas

- Gear system
  - Gear reduction of 1:10
  - Space constraints huge flaw
- Lever system
  - Would need 5 arms to reduce angles to within 5 nanometer limits
  - Developed three ideas
    - Vertically Applied Weight system
    - Gauge Blocks
    - Actuators

Gear System

- Used gears with 6 teeth vs. 60 teeth
  - Reduction factor of 1:10
- Problem: too much variability in angle measurement due to the spacing between the gears.

10 Teeth: 20 Teeth		10 Teeth: 100 Teeth		1 Tooth: 100 Teeth	
Ratio: 1/2		Ratio: 1/10		Ratio: 1/100	
Gear Set	Reduction	Gear Set	Reduction	Gear Set	Reduction
1	0.5	1	0.10	1	0.01
2	0.25	2	0.01	2	0.0001
3	0.125	3	0.001	3	0.000001
4	0.0625	4	0.0001	4	1E-08
5	0.03125	5	0.00001	5	1E-10
6	0.015625	6	0.000001		
7	0.0078125	7	1E-07		
8	0.0039063	8	1E-08		
9	0.0019531	9	1E-09		
10	0.0009766	10	1E-10		
11	0.0004883				
12	0.0002441				
13	0.0001221				
14	6.104E-05				
15	3.052E-05				
16	1.526E-05				
17	7.629E-06				
18	3.815E-06				
19	1.907E-06				
20	9.537E-07				
21	4.768E-07				
22	2.384E-07				
23	1.192E-07				
24	5.96E-08				
25	2.98E-08				
26	1.49E-08				
27	7.451E-09				
28	3.725E-09				
29	1.863E-09				
30	9.313E-10				



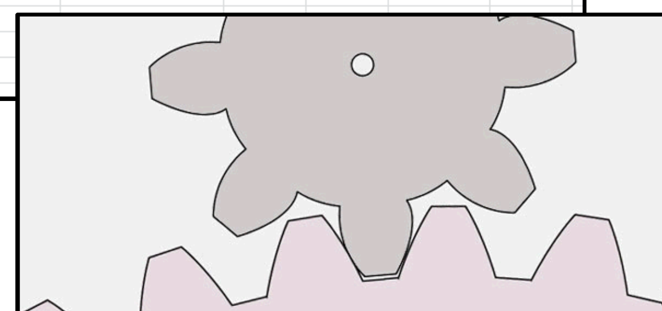
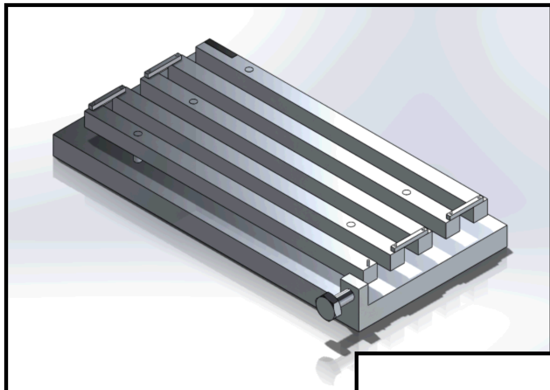
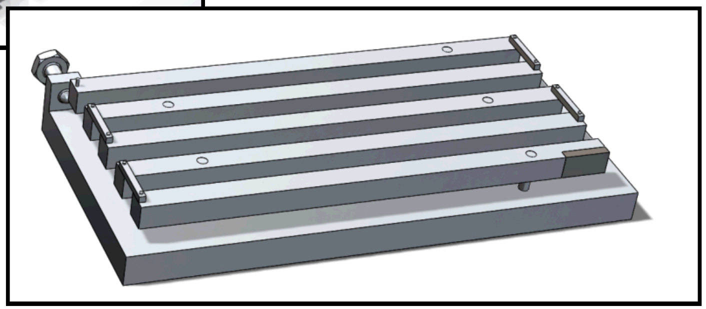


Photo courtesy of Robives.

Developed Concept





	A	B	C	D
1	Lever Arm:	250	mm	
2	Initial Deflection from Gage Block	5	mm	
3	Beyond Flexure:	50	mm	
4		Beyond Flexure Displacement	Angle (rad)	Nanoradians
5	Arm 1	1	0.02	20000000
6	Arm 2	0.02	0.0004	400000
7	Arm 3	0.0004	0.000008	8000
8	Arm 4	0.000008	0.00000016	160
9	Arm 5	0.00000016	3.2E-09	3.2
10	Arm 6	3.2E-09	6.4E-11	0.064
15				
16–19		*Calculation of displacment on the opposite side of the flexure (solve*	*Calculate angle on side beyond flexure*	*Convert radian to nanoradians*
20–23		$\frac{5\ mm}{250mm} = \frac{x\ mm}{50\ mm}$	$\alpha = \frac{h}{L}$ $Angle = \frac{Displacement}{Lever\ Length}$	$nano = rad * 10^9$
24				

Final Design Specifications

5 Lever Arm Design

Base: 330 mm x 150 mm

Lever Length: 300 mm
250 mm, 50 mm ratio

Angle Accuracy: 3.2 nanoradians

Flexure: 0.25 in outside diameter with 0.0143 $\frac{in-lb}{Degree}$

Material: 1060 Aluminum Alloy

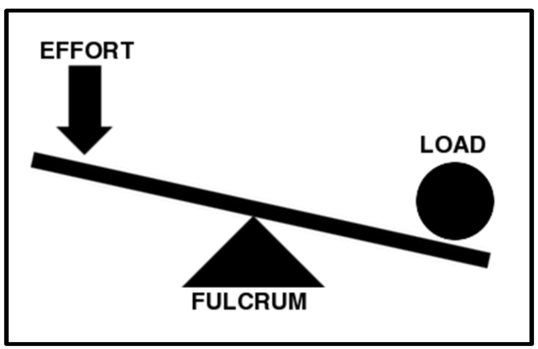
Actuator: rounded top, similar to New Focus picomotor from Motus Mechanical

Photo courtesy of Motus Mechanical

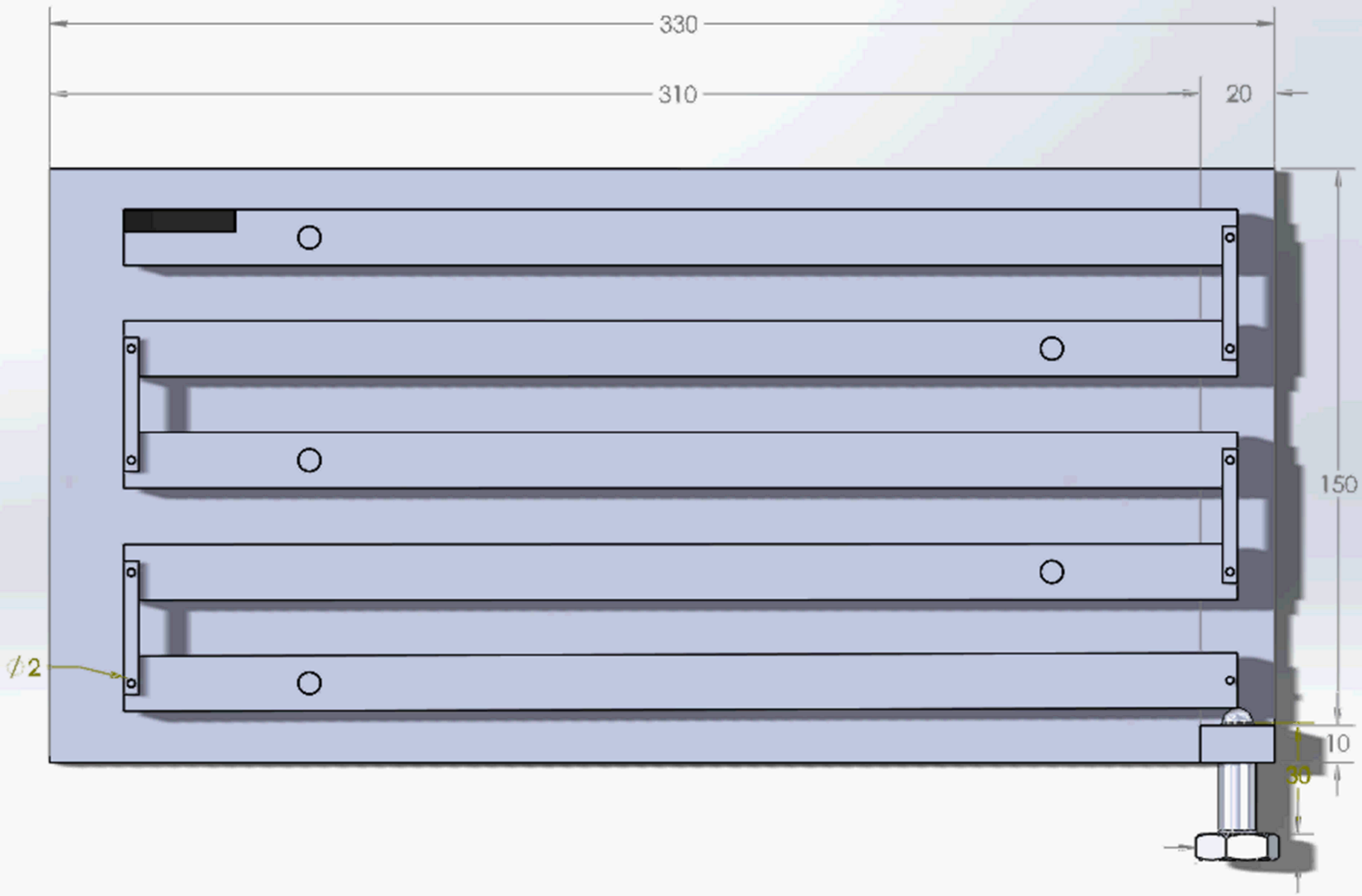
Lever System

- Would have a "teeter totter" system, displacement reduction through 5 different lever arms
- Use flexure system at fulcrum, cross flex hinge

300 mm system with
250 mm lever arm



	A	B	C	D
1	Lever Arm:	250	mm	
2	Initial Deflection from Gage Block	5	mm	
3	Beyond Flexure:	50	mm	
4		Beyond Flexure Displacement	Angle (rad)	Nanoradians
5	Arm 1	1	0.02	20000000
6	Arm 2	0.02	0.0004	400000
7	Arm 3	0.0004	0.000008	8000
8	Arm 4	0.000008	0.00000016	160
9	Arm 5	0.00000016	3.2E-09	3.2
10	Arm 6	3.2E-09	6.4E-11	0.064
15				
16–19		*Calculation of displacment on the opposite side of the flexure (solve*	*Calculate angle on side beyond flexure*	*Convert radian to nanoradians*
20–23		$\frac{5\ mm}{250mm} = \frac{x\ mm}{50\ mm}$	$\alpha = \frac{h}{L}$ $Angle = \frac{Displacement}{Lever\ Length}$	$nano = rad * 10^9$
24				


330
310
20
150
10
30
⌀2

Other Considerations

- Angle calculations assumed no deflection in arms
- Calculated deflections in each lever arm
  - Max deflection was 0.0187 mm in long arm of first lever
  - Deflections did not have major effect on angle output

Torsional Spring Rate	Calculation: $\frac{0.0145\ lb-in}{1\ degree} * \frac{1\ degree}{0.0174\ radians} * \frac{1\ N-m}{8.85076\ lb-in} = \frac{N-m}{radians}$				
		0.0145	57.47126437	0.112984648	0.094153873
Calculation of Torque Applied by Screw	Ratio, angles from APPDX B: $\frac{X\ N-m}{radians} = \frac{0.094154\ N-m}{radian}$				
	X=	0.0018831			
Conversion to N-mm	Ratio: $\frac{N-m}{radian} * \frac{1000\ N-mm}{N-m}$				
	τ (N-mm):	1.8830775			
Calculation of Force Applied by Displacement	Equation: $\tau = F * r * sin\theta$ r= 250 mm, θ=90*				
	F (N)=	0.0084254			
Deflection of Long Portion of Lever	Assuming that the lever arm works like a cantilever with point load applied at end				
	Moment of Intertia		**Assuming rotation around x axis, rectangular shape		
	Mass of Entire Lever		$Mass = Density * Volume$		
	Density (d) (g/mm^3)	0.0027		Mass (g)=	182.25
	Volume (mm^3)	67500			
	Moment of Inertia		$I_x = \frac{1}{12} * m * (h^2 + w^2)$		
	Height (mm)	15			
	Width (mm)	15		MoI (g-mm^2)=	3417.1875
	Deflection of a Cantilever		$\Delta_{max} = \frac{PL^3}{3EI}$ at the free end		
	P (g)	0.8593943			
	L (mm)	250		Deflection (mm)=	0.018712179
	E (N/mm^2)	70000			
Deflection of Connection Piece, Axial Loading and in Tension	Assuming that the point load applied by the actuator is the same felt by the connection piece, causing axial loading and deflection				
	Deflection of an Axial Member		$\delta = \frac{PL}{AE}$		
	P (g)	0.8593943			
	L (mm)	36		Deflection (mm)=	2.76234E-05
	E (N/mm^2)	70000			
	A (mm^2)	16			
Deflection of Short Portion of Lever	Assuming that the load applied by the connection piece is the same as applied by the actuator				
	Deflection of a Cantilever		$\Delta_{max} = \frac{PL^3}{3EI}$ at the free end		
	P (g)	0.8593943			
	L (mm)	50		Deflection (mm)=	0.000149697
	E (N/mm^2)	70000			

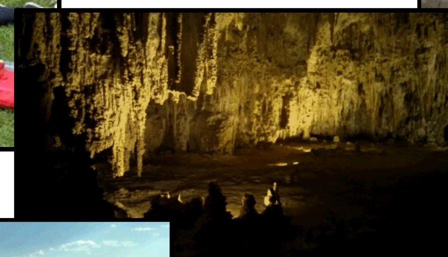
Future Developments

- Calibrator will need a stand
  - Autocollimator laser is 3.5” above the table level, can use stands to raise calibrator
- Computer-driven belt attached to actuator
  - More accurate assessment of the output distance of the actuator
- Improved flexure design
  - Try different types rather than cross rotary

Work and Play

- Grand Canyon
- Great Sand Dunes, CO
- Roswell, Carlsbad, White Sands NP
- Climbing La Luz, riding Sandia Tram
- Hot Air Ballooning
- Isotopes Baseball Game with MAC interns






Sandia National Laboratories

Lessons Learned And Take-Aways

Academic

- Broadened my academic "lane" by adding mechanical engineering elements
  - Working with deflections and structural analysis, but had review of simple machines
- The Academy gives you a broad education, enables you to understand general ideas and not worry about technical details
  - Explosives tour, touring PSL with Delta and Y connected power
- People with a variety of degrees but all passionate about their jobs
  - Degree matters, but your passion matters more

"Real Life"

- Have greater appreciation for airmen who work at PMEL (Precision Measurement Equipment Laboratory)
  - Saw first-hand what they do daily
- Officer experience– I won't know everything
  - My airmen are the technical experts
  - Trust that they know their jobs, I need general understanding
- Work isn't just about work
  - Working with the people in my office, tours around Sandia, using free time to expand knowledge and gain experiences

Sources and Further Information

Actuators. Motus Mechanical. 2015. Web. 22 June 2015.

Double-Ended Pivot Bearings. Riverhawk Flex Pivots, 2015. Web 22 June 2015.

Micro-Radian Autocollimator Principles of Operation. Micro-Radian Instruments, 2015. Web. 18 June 2015.

Pekelsky, James R, Loren E. Munro. "Bootstrap calibration of an autocollimator, index table, and sine bar ensemble for angle metrology." *Recent Developments in Traceable Dimensional Measurements III* 5879 (2005): 1-17. Web.

"Physical Properties" and "Mechanical Properties." *Aluminum/Aluminum 1060 Alloy (UNS A91060).* AZO Material. 11 June 2013. 18 June 2015.

Primary Standards Laboratory. Primary Standards Laboratory at Sandia National Laboratories, New Mexico. Web. 18 June 2015.

Yandayan, Tanfer, Bulet Ozguer, et. all. "High precision small angle generator for realization of the SI unit of plane angle and calibration of high precision autocollimators." *Measurement Science and Technology* 23 (2012): 1-12. Web.

QUESTIONS?