High-Performance Micropositioners for Opto-Electronic Manufacturing

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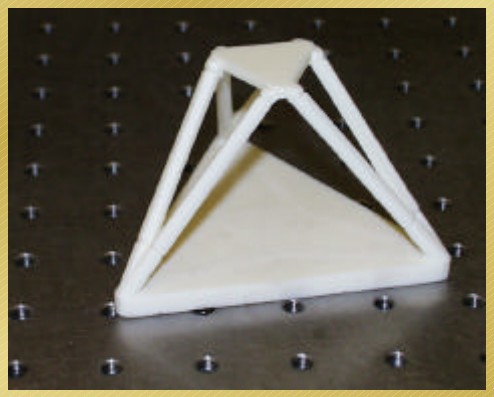
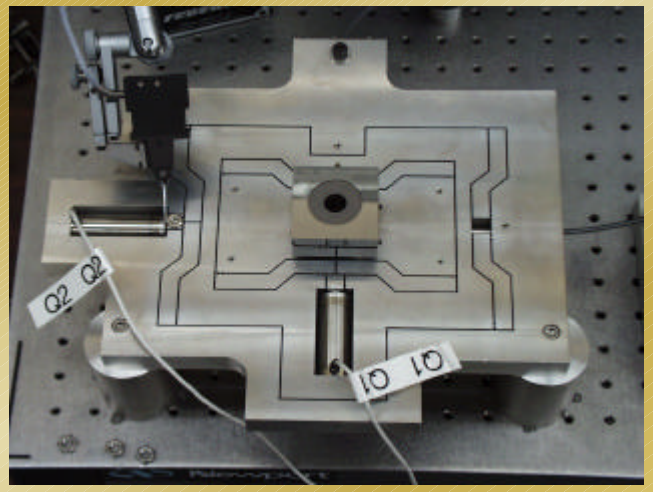
SPIE/New England Chapter
CORNING Lasertron, Bedford, MA

Intelligent Systems Division
Manufacturing Engineering Laboratory
National Institute of Standards and Technology

NIST



Outline

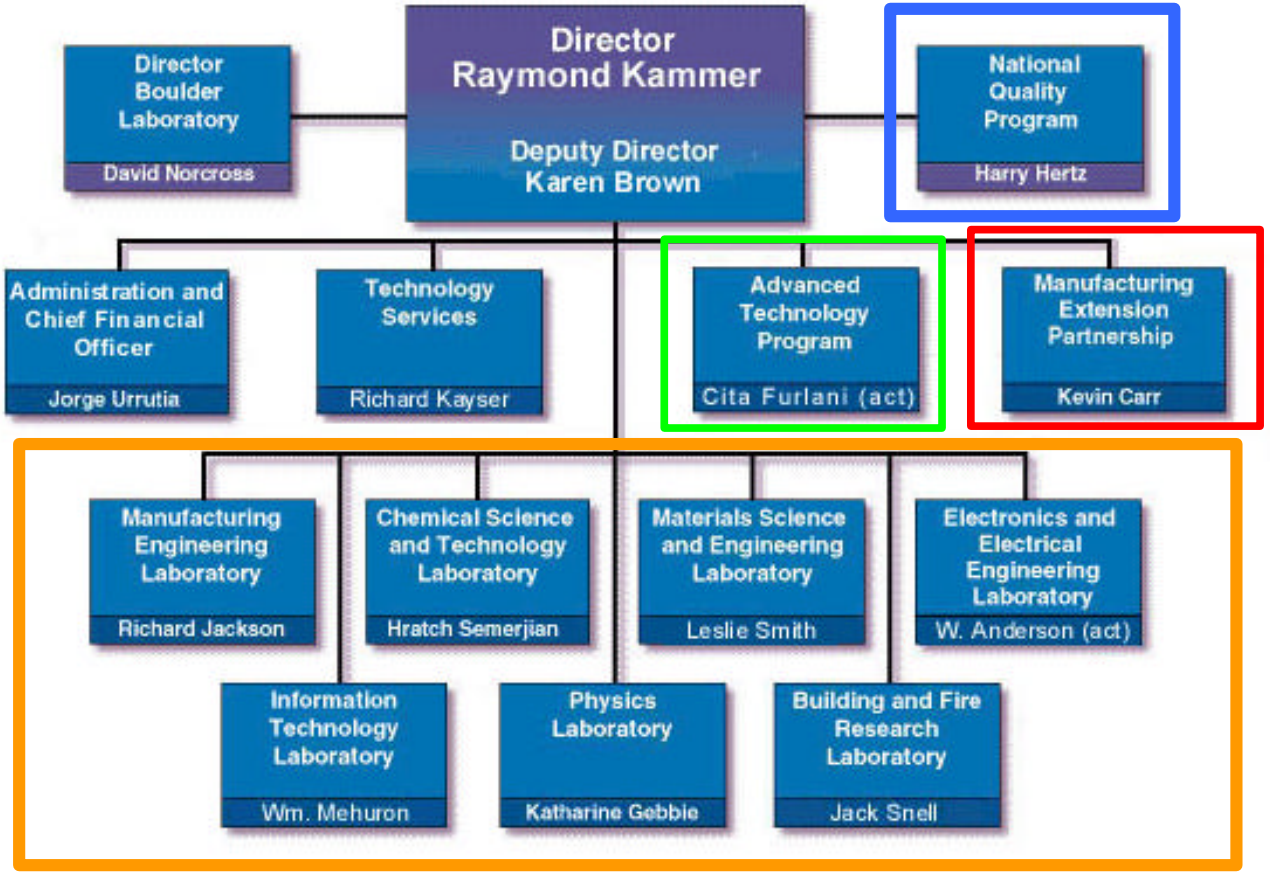


- Historical Background (NIST, ATP, MM, MMN)
- Research Objectives
- Planar Micro-Positioners Designs
- Planar Micro-Positioners: Models, Performance Testing, and Calibration
- 3-D Space Micro-Positioners Designs
- 3-D Space Micro-Positioners Models

Historical Overview

National Institute of Standards and Technology

NIST Organizational Chart



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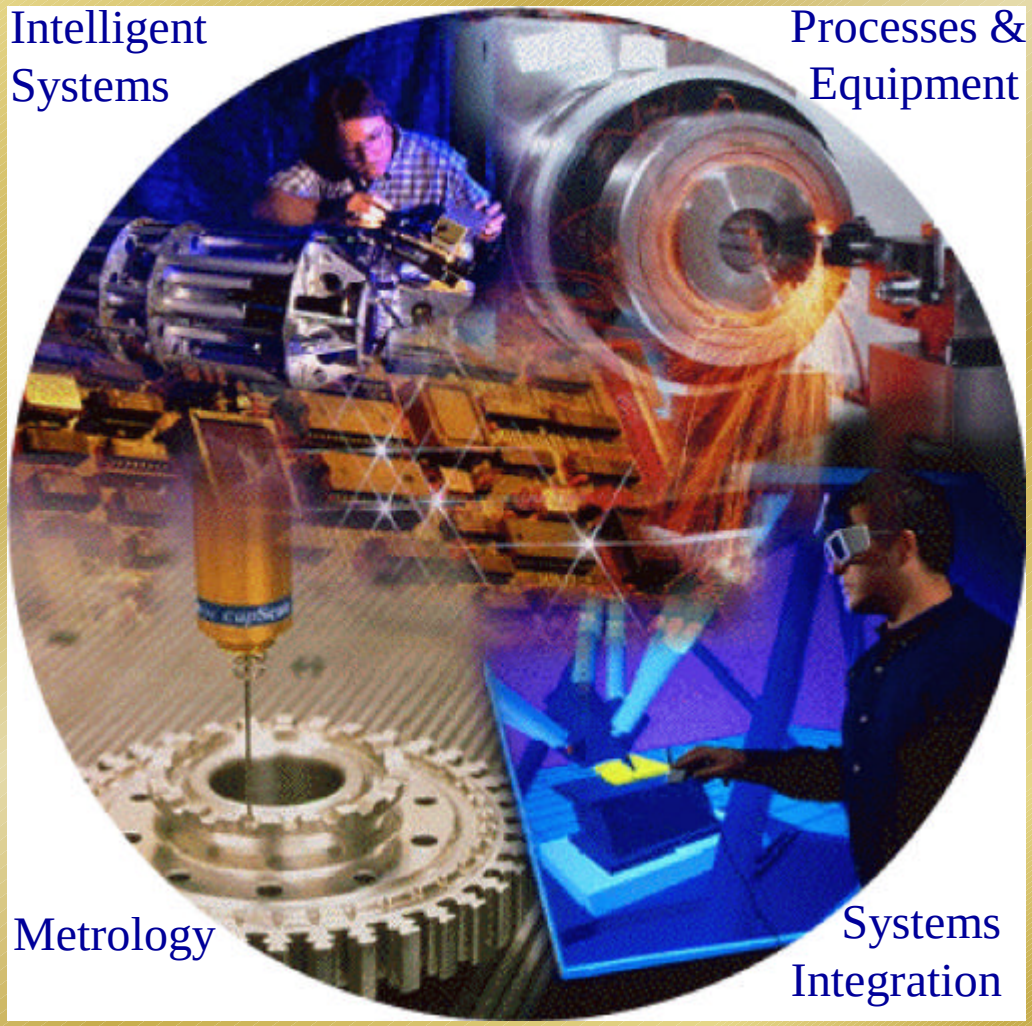
Manufacturing Engineering Laboratory
Intelligent Systems Division

MEL Overview

Intelligent Systems Division

Automated Production Technology Division



Fabrication Technology Division

Precision Engineering Division

Manufacturing Systems Integration Division

NIST

Precision Optoelectronics Assembly Consortium

Adept Facility, September ‘99, Final POAC Meeting

NCMS, Adept Technology, Inc. , Boeing Co. , Corning, Inc. , Focused Research, Inc. , SRI International , NJIT, NIST/MEL, NIST ATP present for final meeting.

FY99 Micro-Meso Scale Manufacturing Exploratory Project

- Visited 20+ companies and laboratories
  - Specific Measurements, Standards and Data Needs
- Co-sponsored Two Workshops
  - One with DARPA and one with NSF
- Attended conferences in MEMS, Nanotechnology, Photonics...
- Developed a final report / trip report

MEL Strategic Program: Nano Manufacturing

MEL Program Goal

To provide the measurements and standards needed by industry to measure, manipulate, and manufacture *nano-discrete part products.*

Nano-Discrete Part Product

a product having critical part features with dimensions of <= 100 nm
either a single discrete part or an assembly of discrete parts

Objective: Performance Testing and Calibration of Micro-Positioners

- Develop performance tests, including quick and simple tests, in order to improve the reliability of micro-positioners.
- Develop calibration procedures in order to improve the accuracy of operation of micro-positioners.
- Measure the performance of various micro-positioner configurations, couplings and calibration fixtures.

Planar Micro-Positioner Designs

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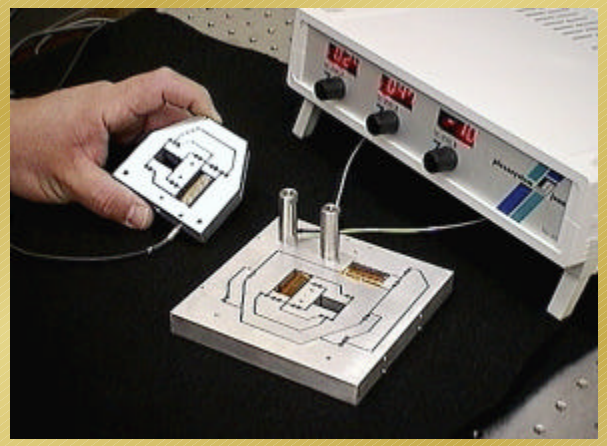
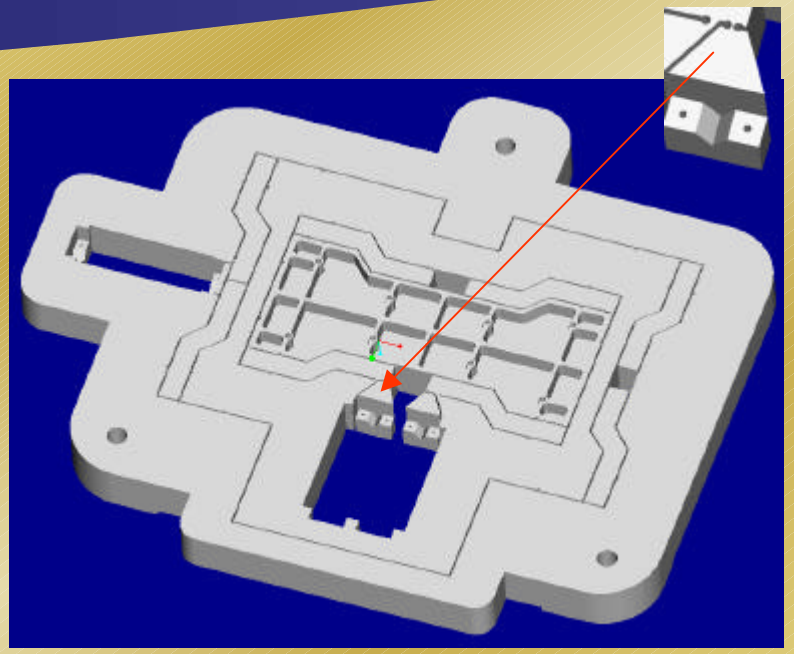
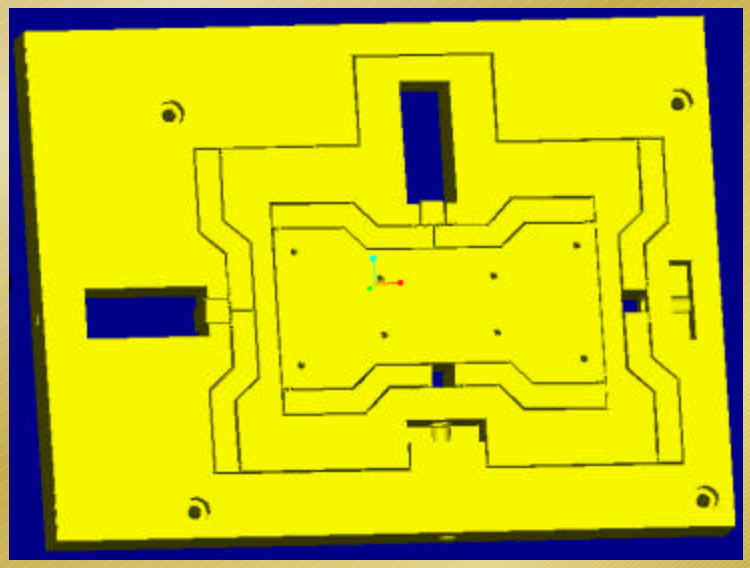




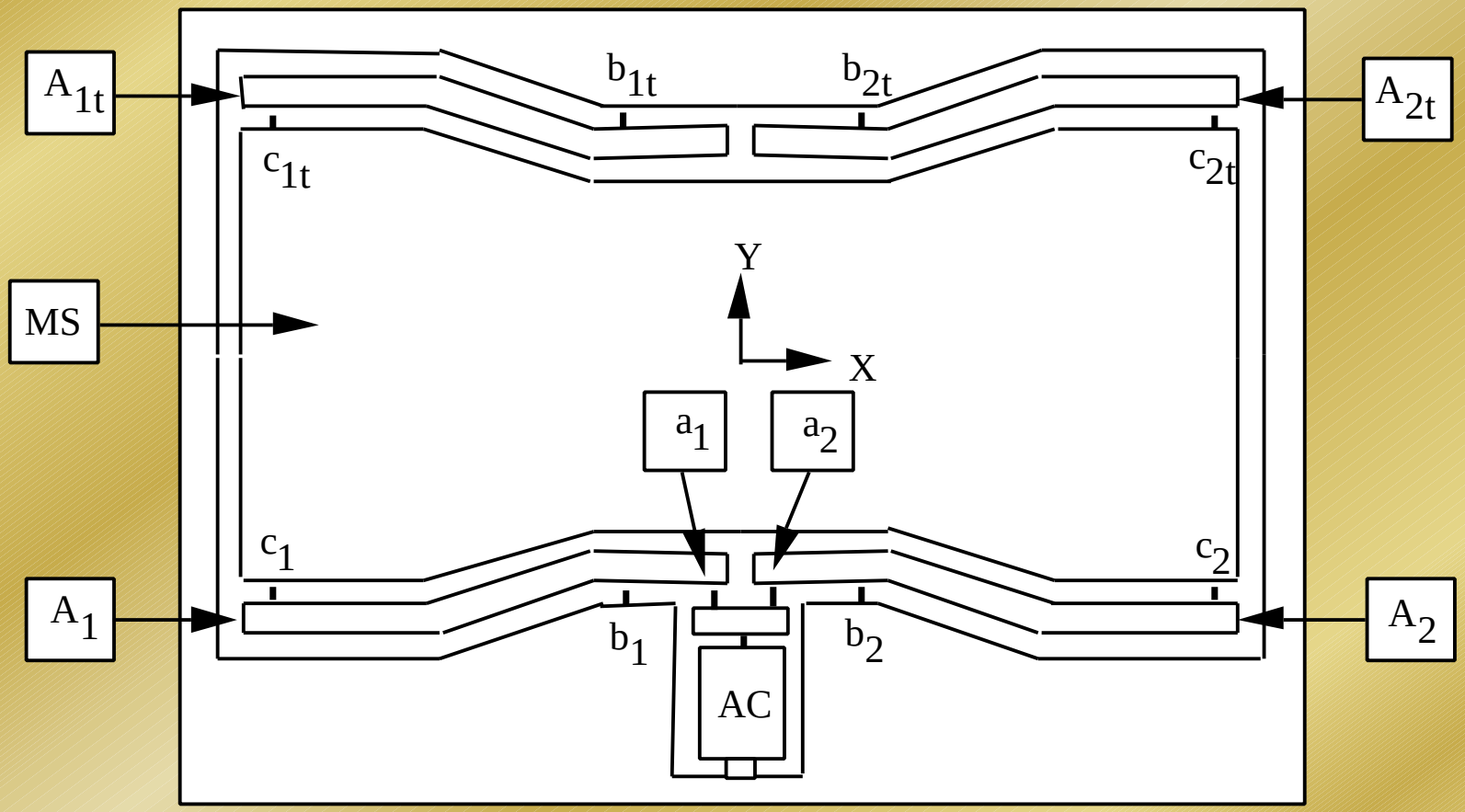
Wye Creek Instruments

Fred Scire, NIST

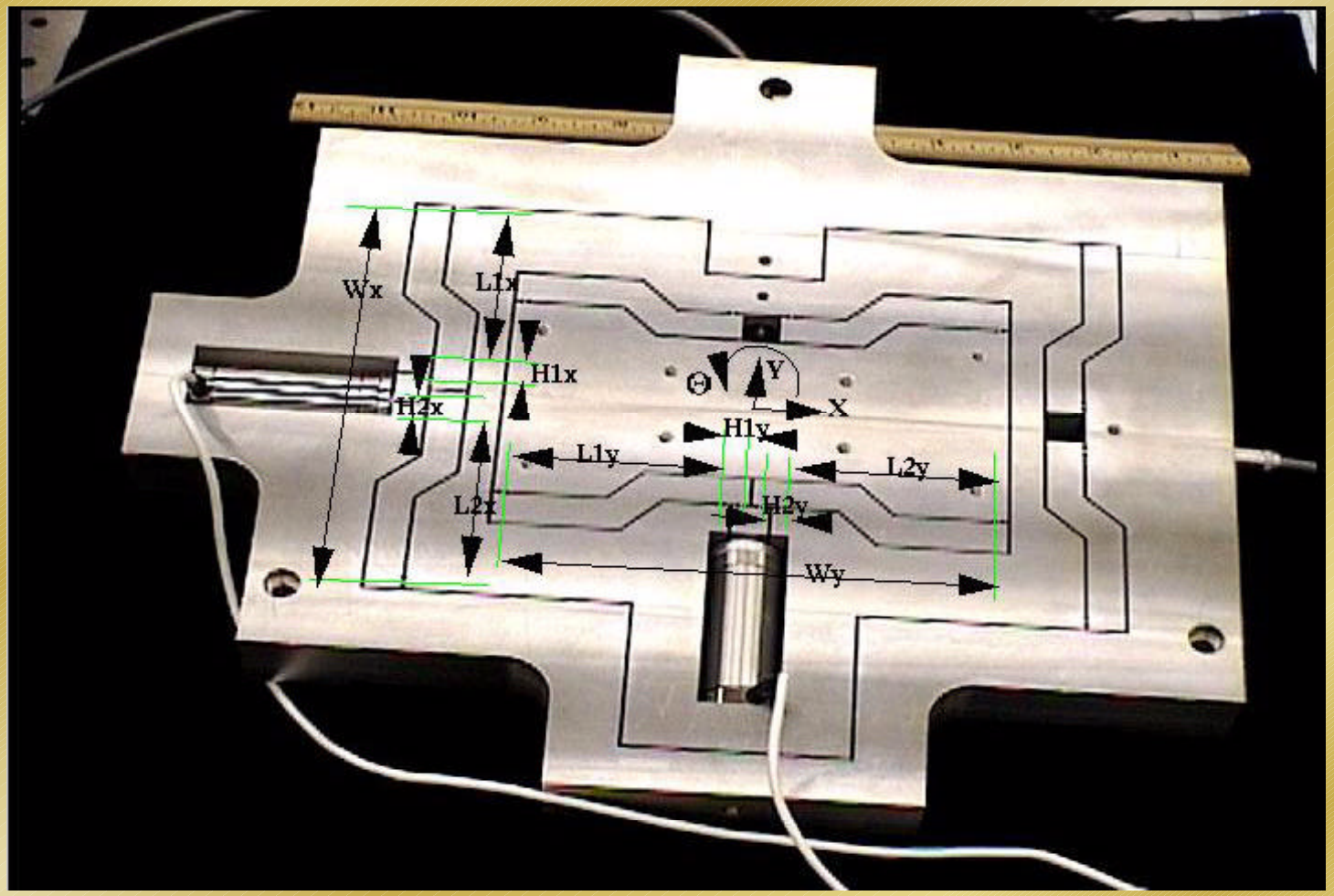


NIST

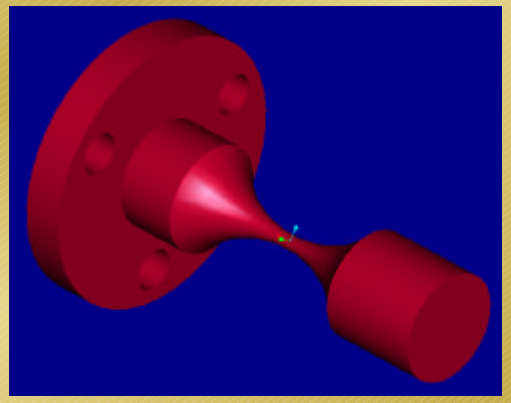
Schematic of Y axis

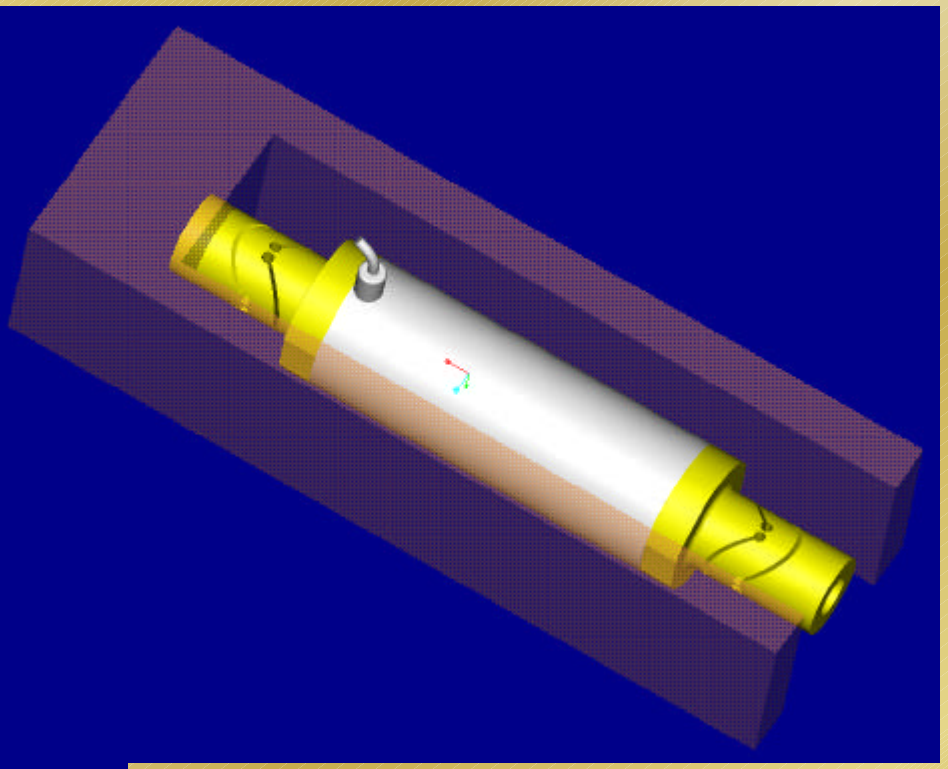


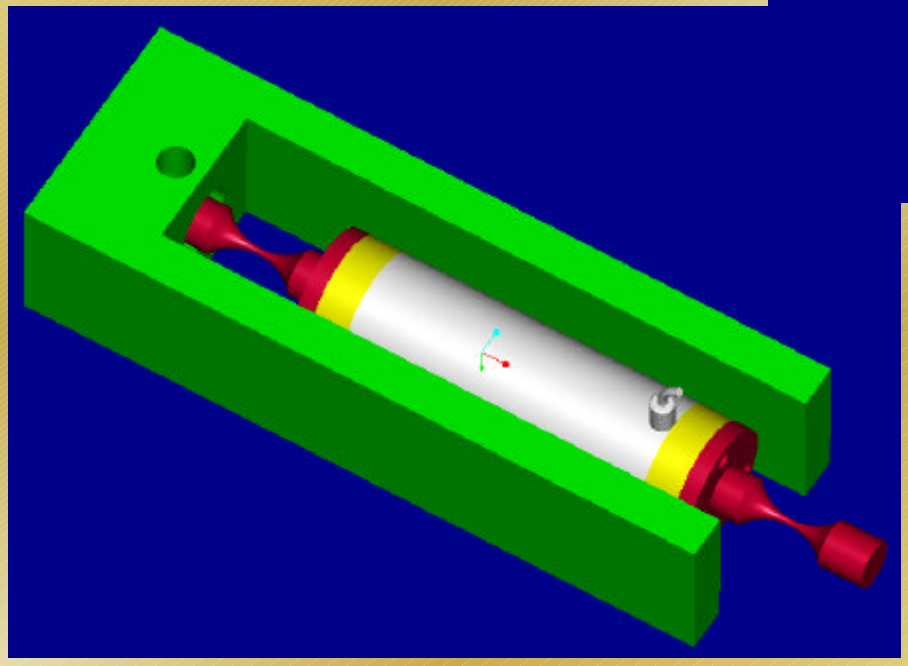
Parallel Cantilever Geometry

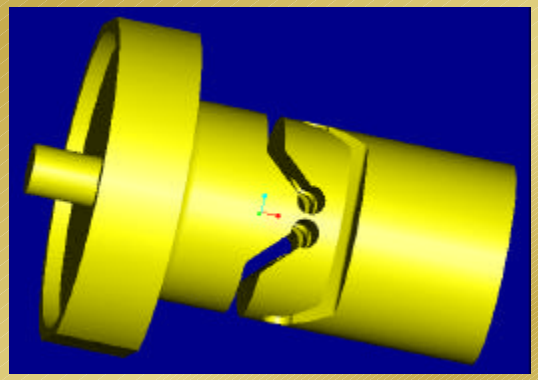


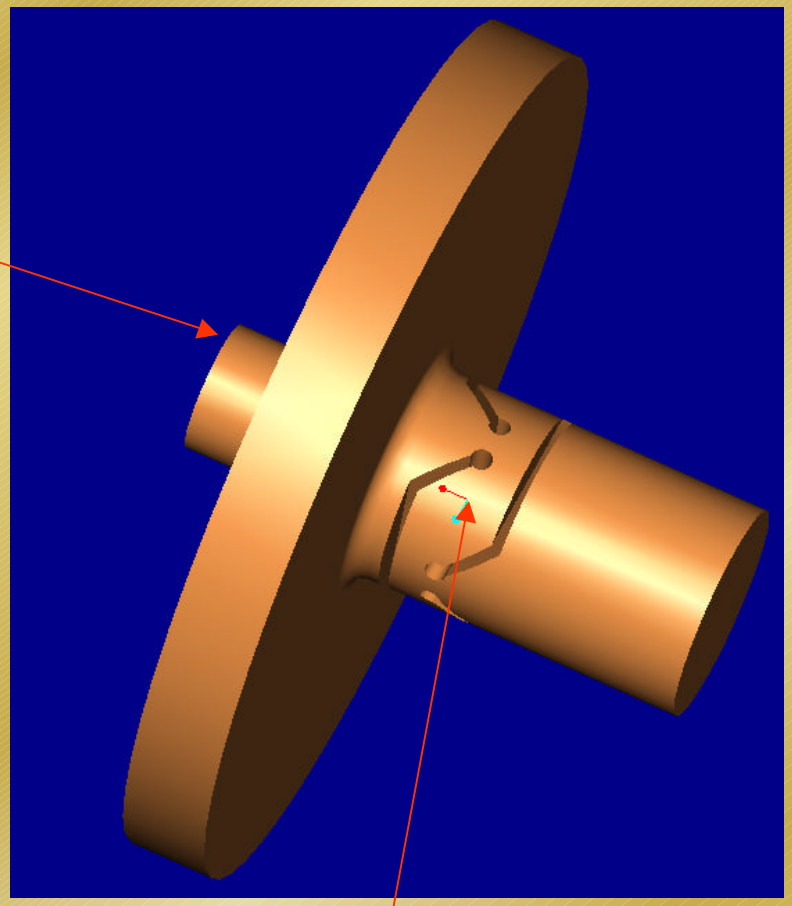
Monolithic Coupler Designs

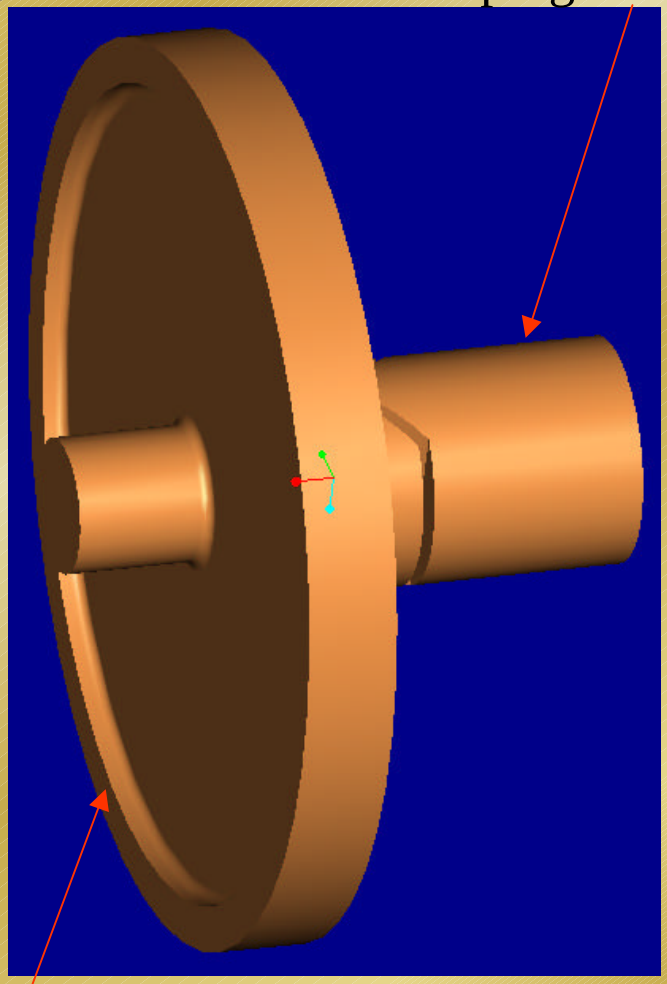












Optimized Coupler for PZTs on X-Y Stage

Flexure Analysis

Assumptions:

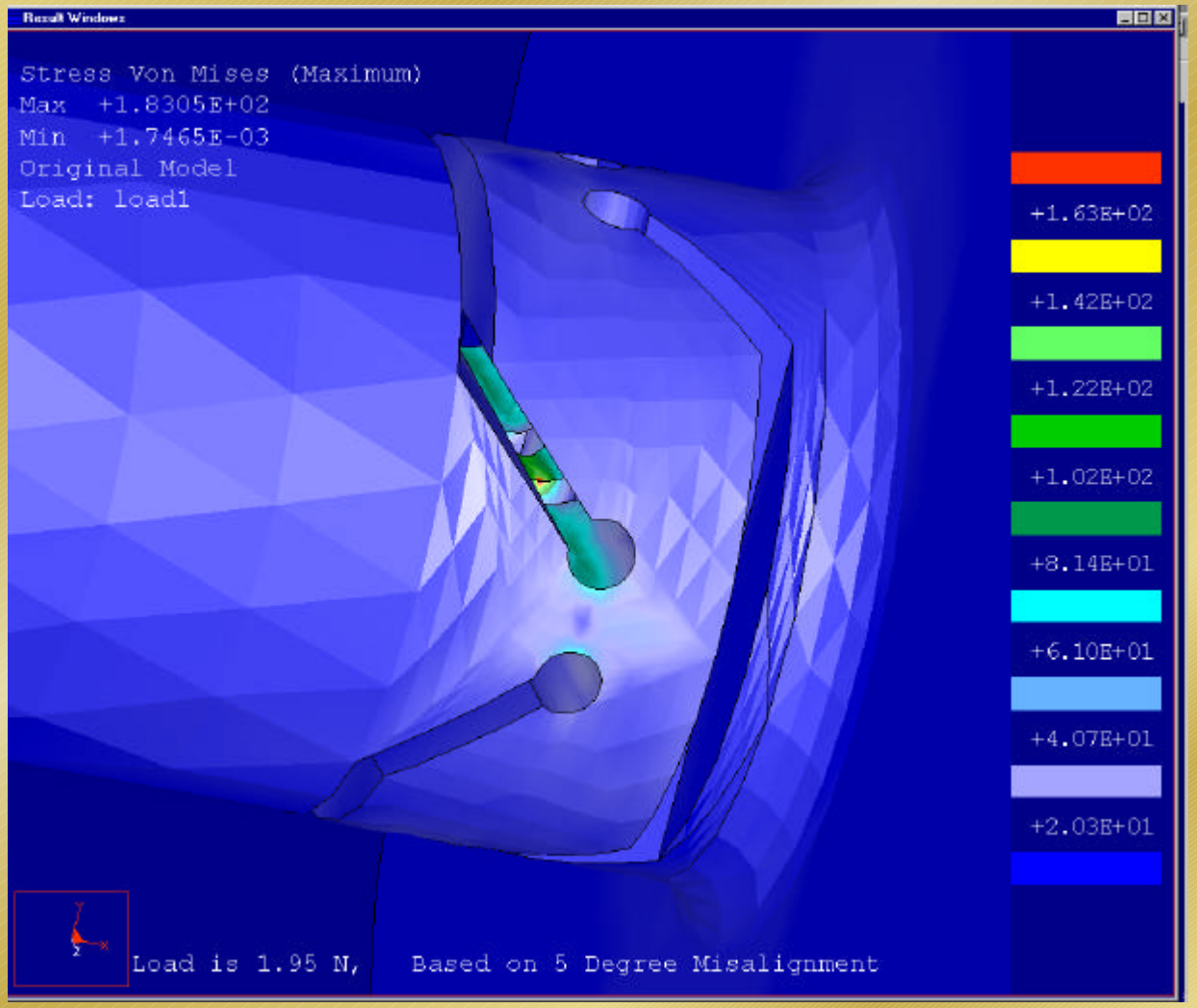
5 Degree Misalignment

40 Ounce of Force (11.12 N) per 10 Micrometer

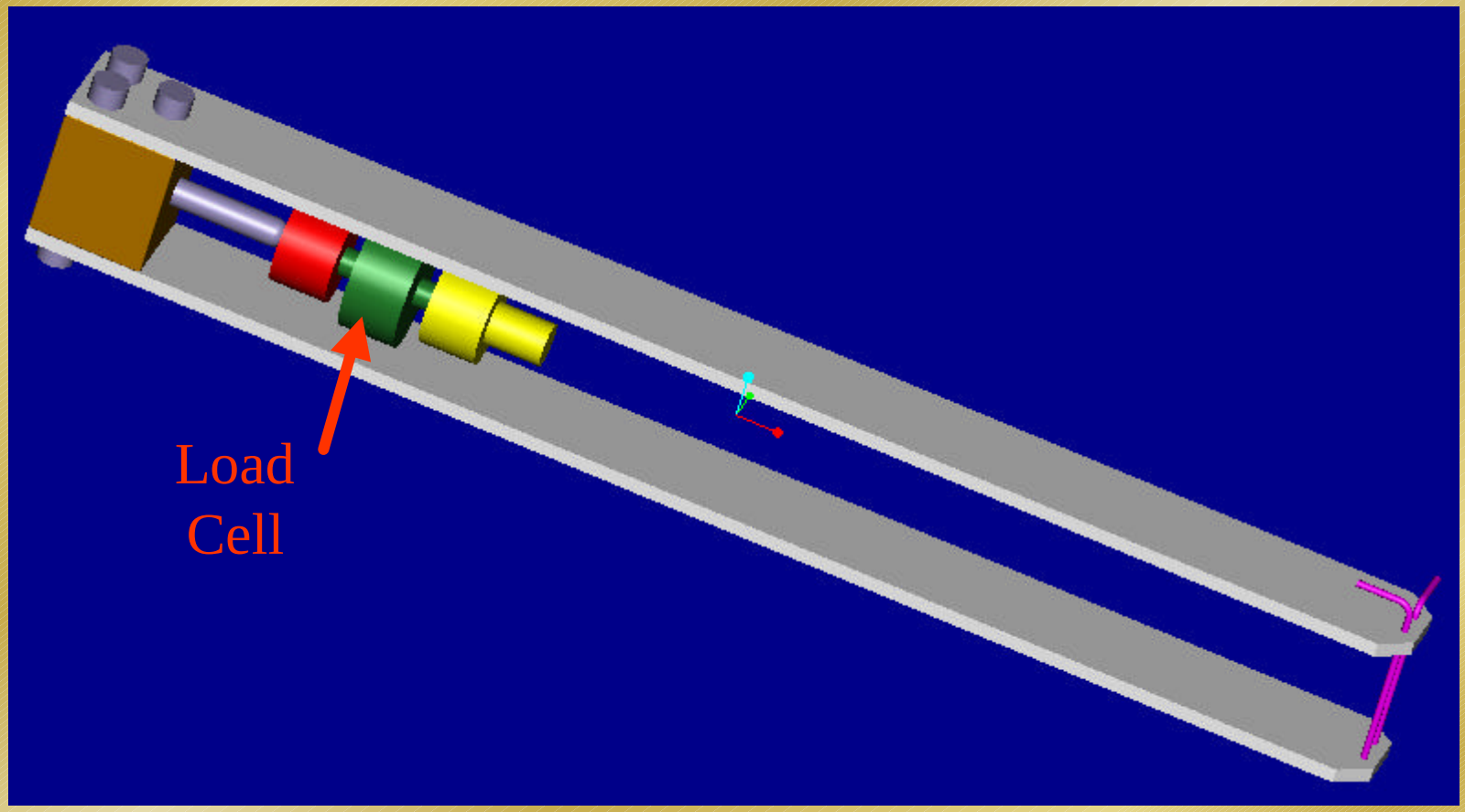
F axial ~ 22.24 N

Fy ~ 1.95 N

Result: 183 MPa < 255 MPa for AL 6061-T6



Pre-Load Mechanism for PZT Assembly



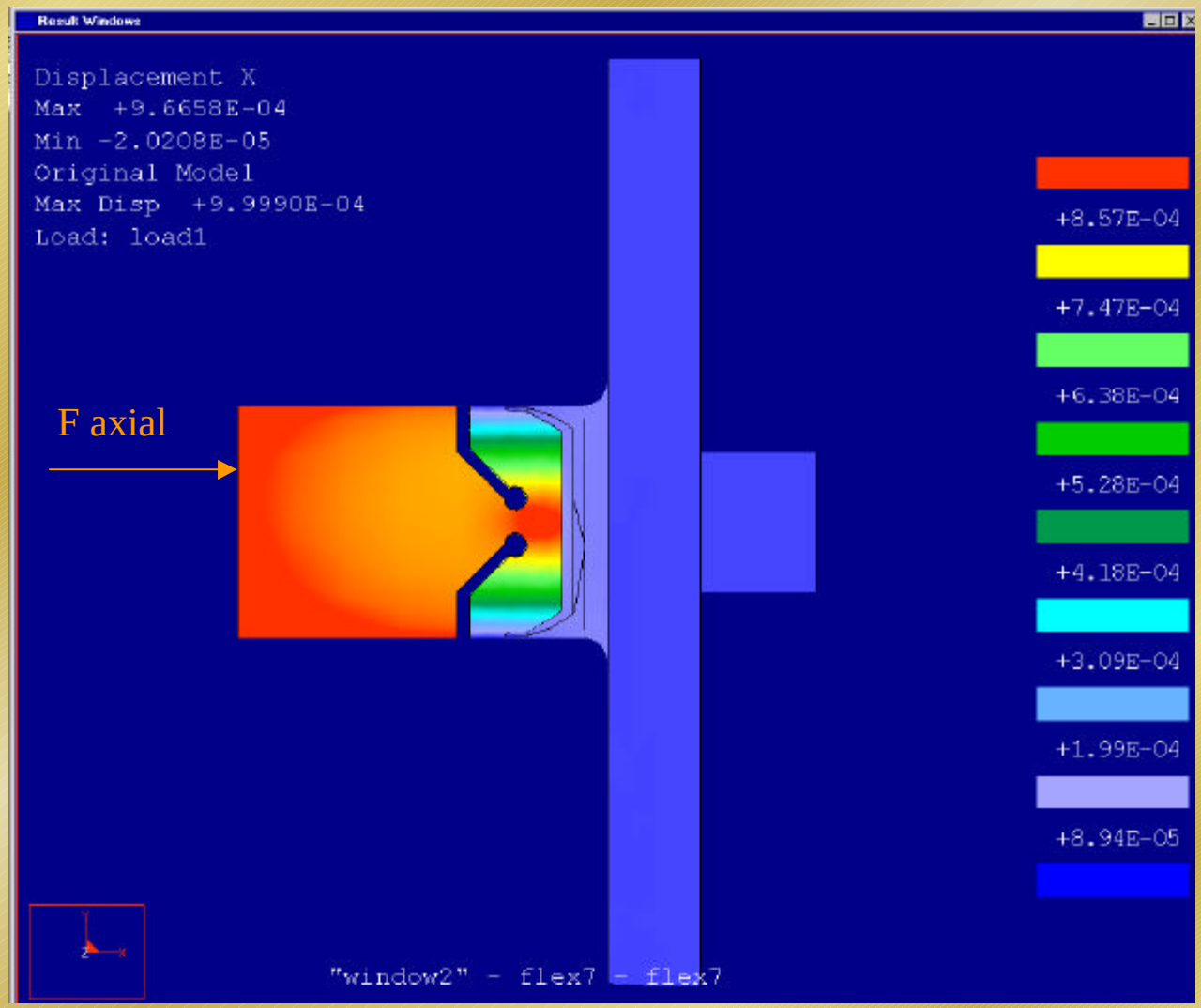
Axial Flexure Displacement

F axial ~ 22.24N

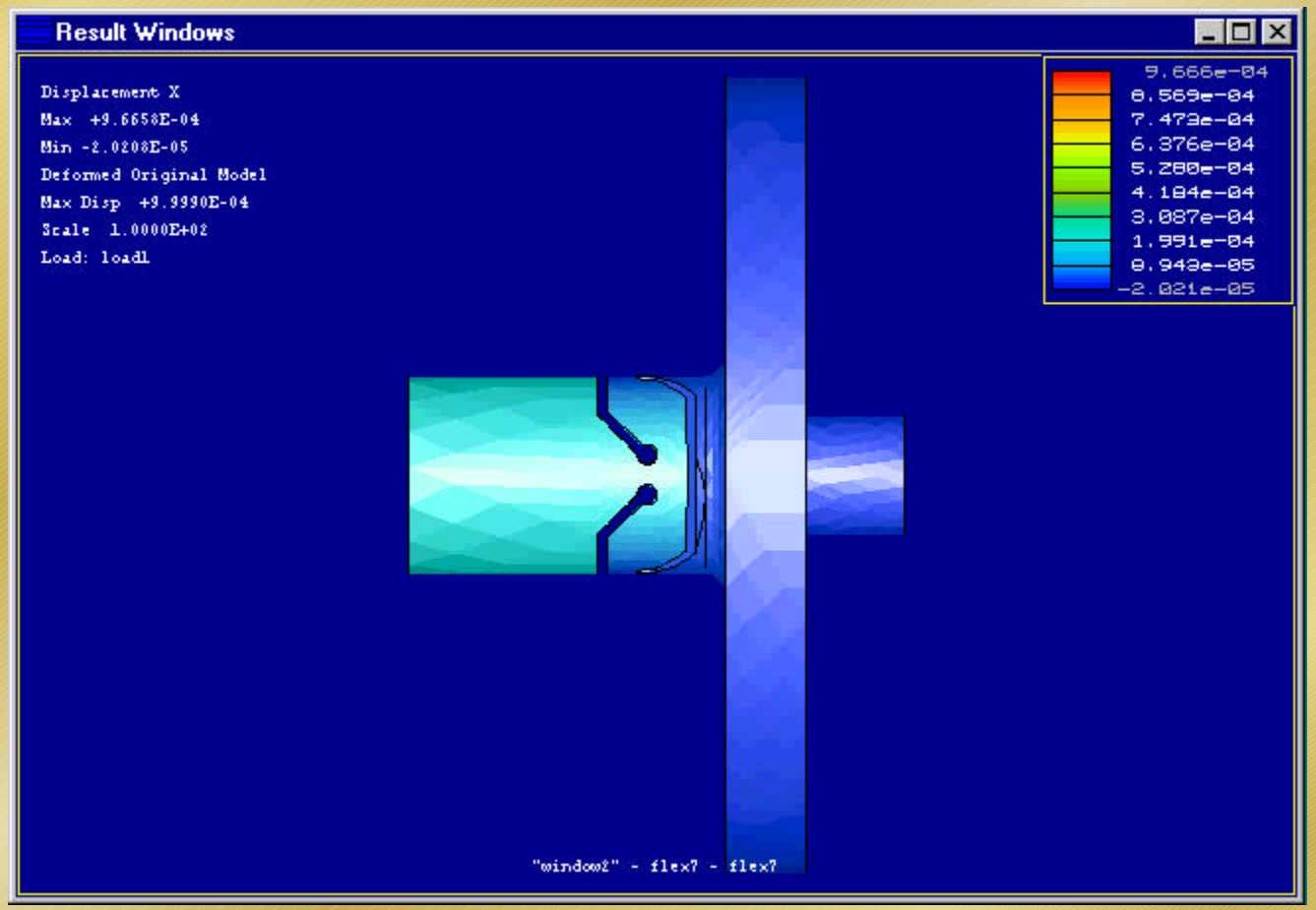
Displacement

~ 0.00097

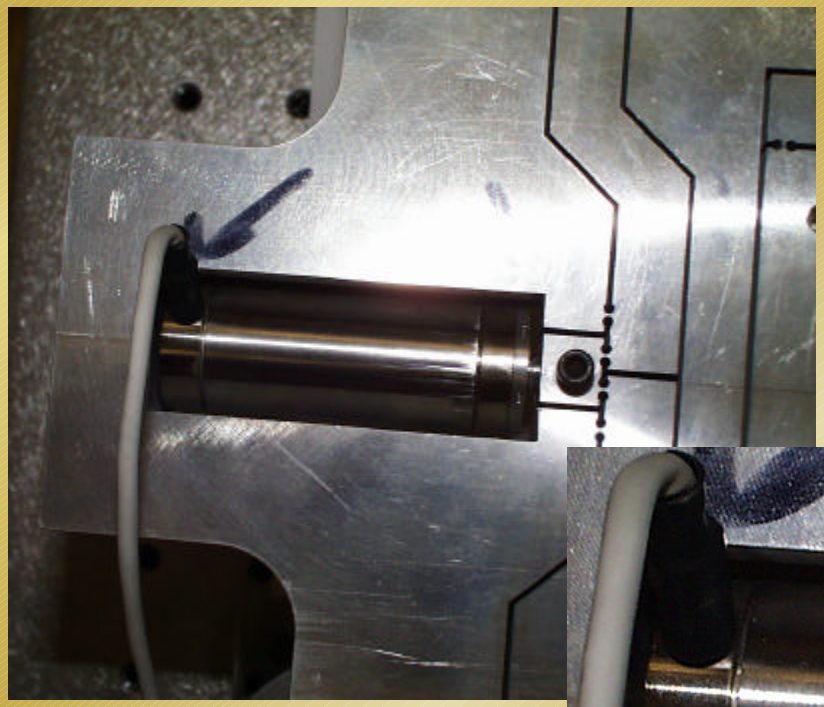
or 1 micrometer

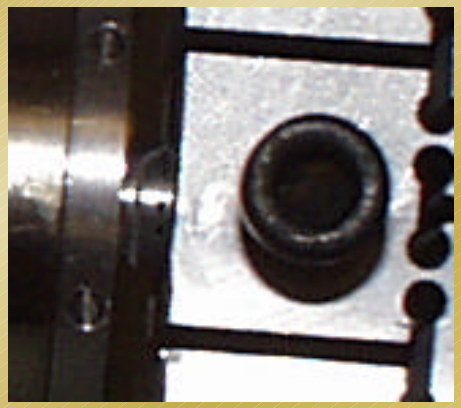


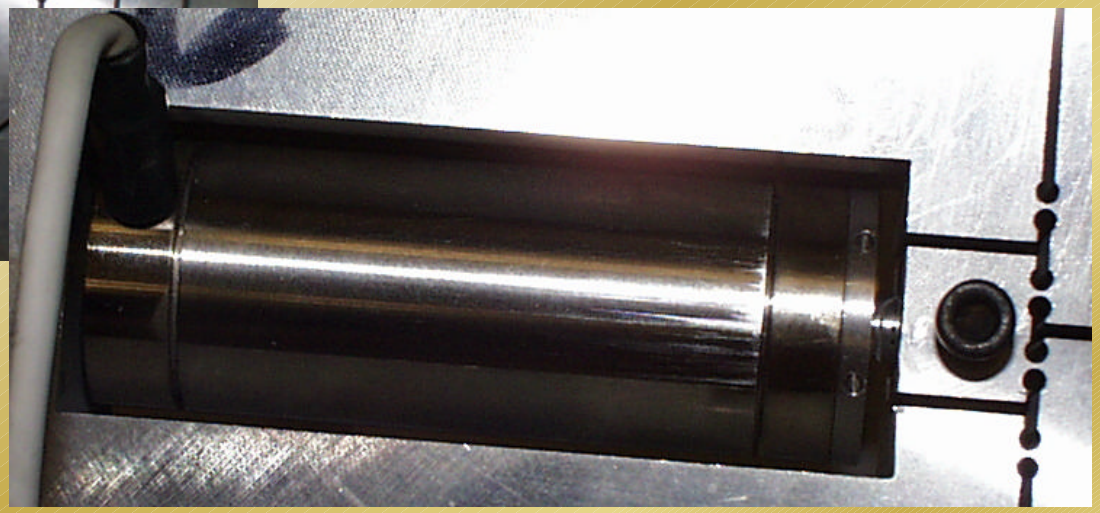
Displacement Errors of Coupler



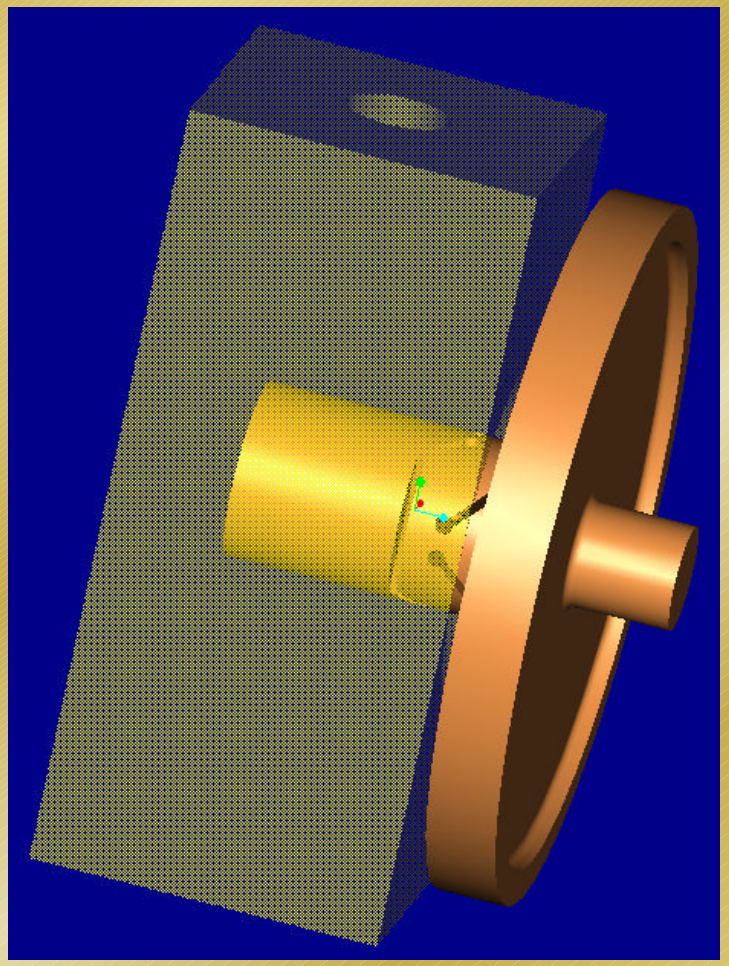
Views showing current coupler



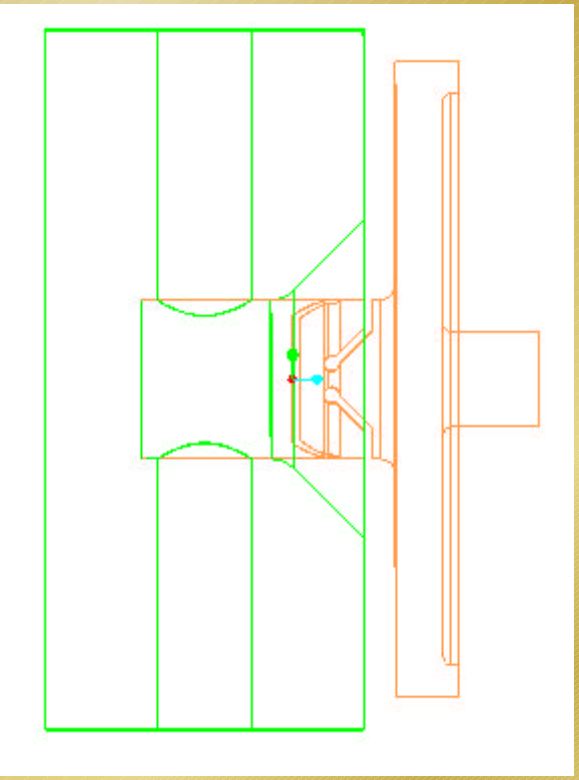


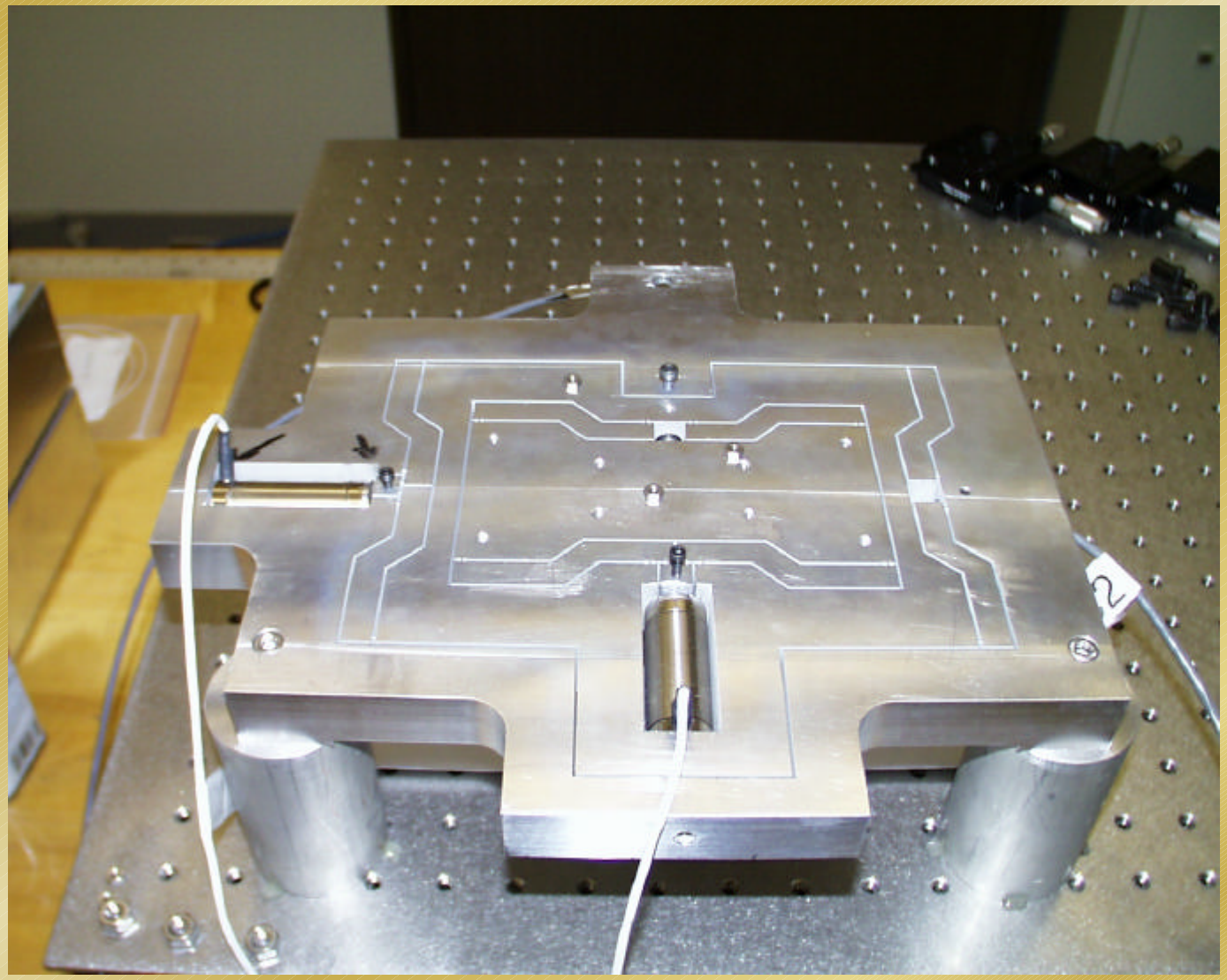


Coupler Design for X-Y Stage

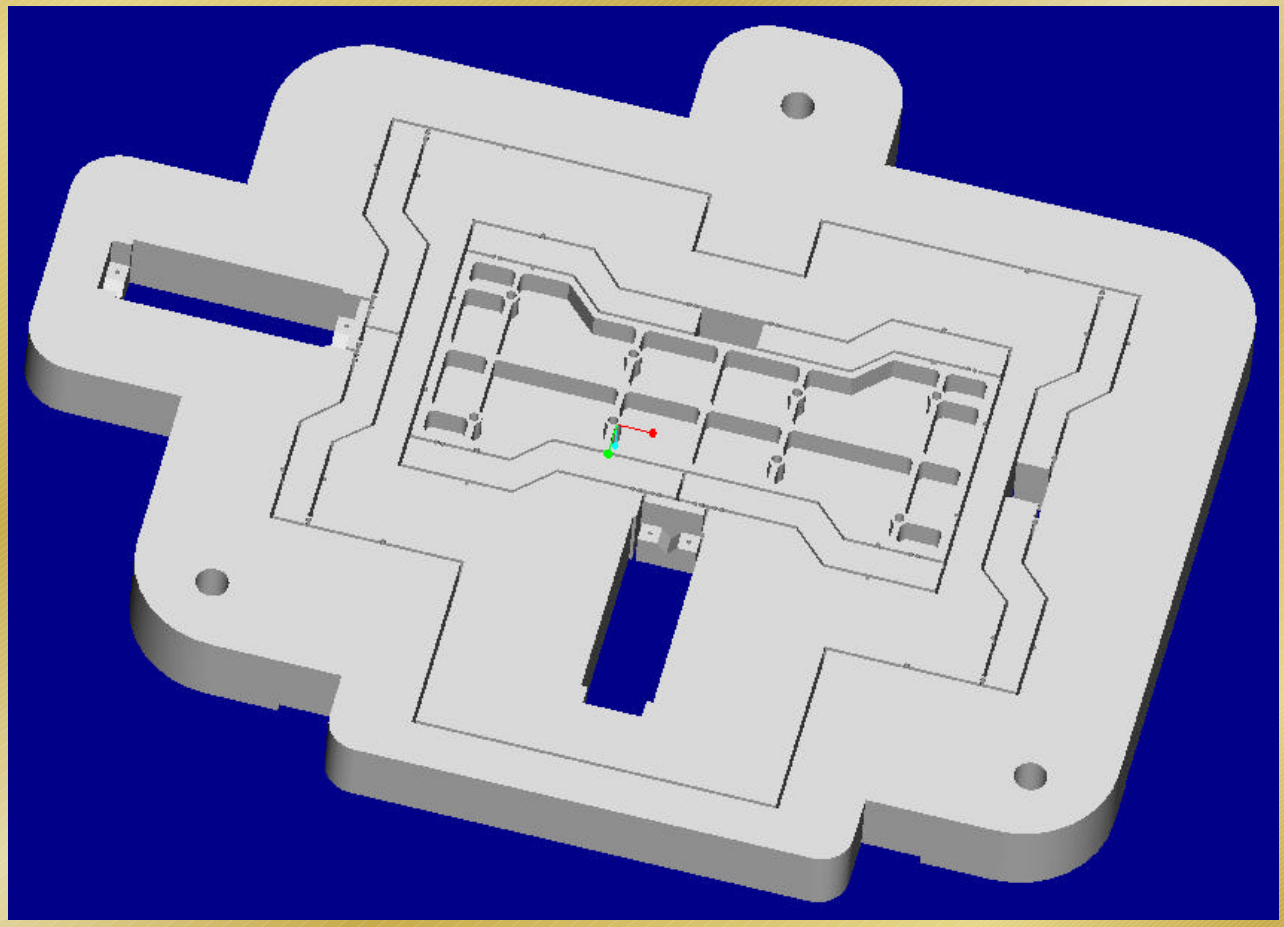


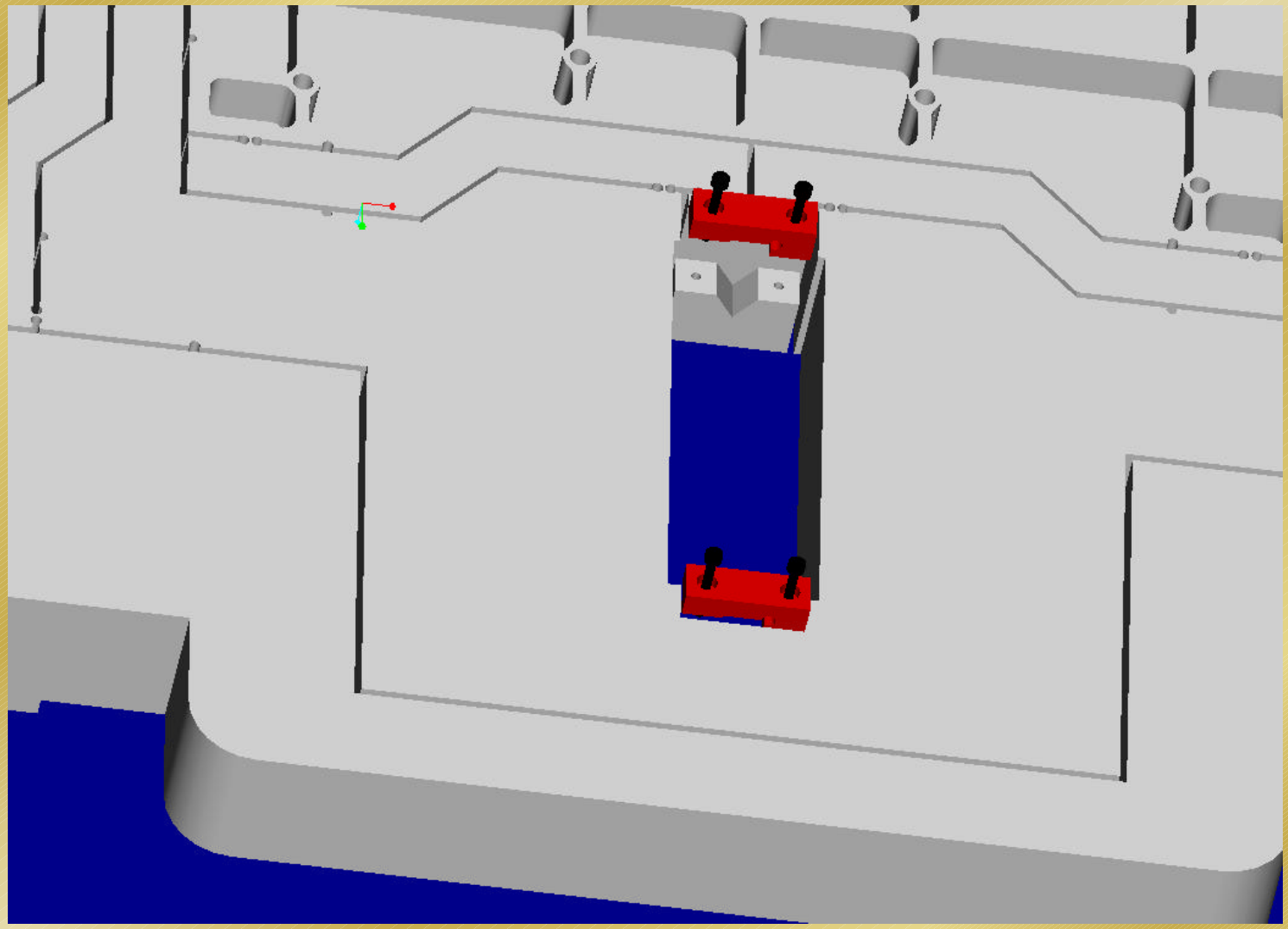
Set Screw Clamp, Top and Bottom - NOT Ideal



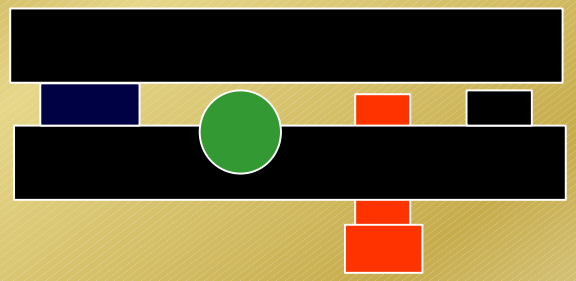


X-Y Microstage Revision

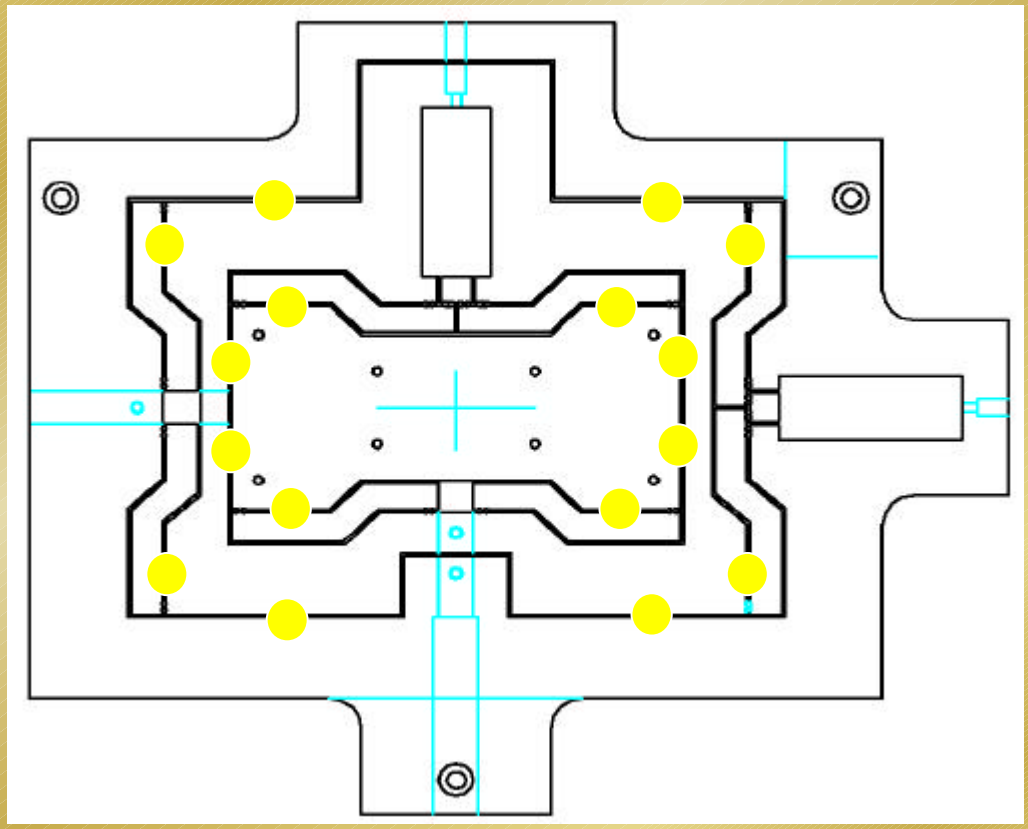




Safety Stops

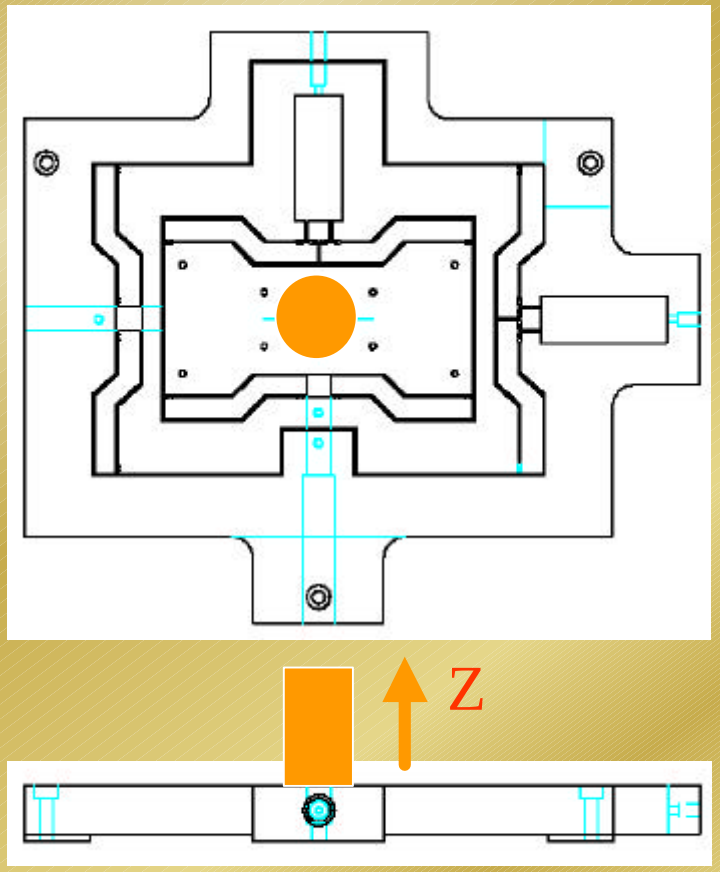


- Elastomer
- Plastic or Steel Rod
- Stop Screw
- Designed/Machined Stop

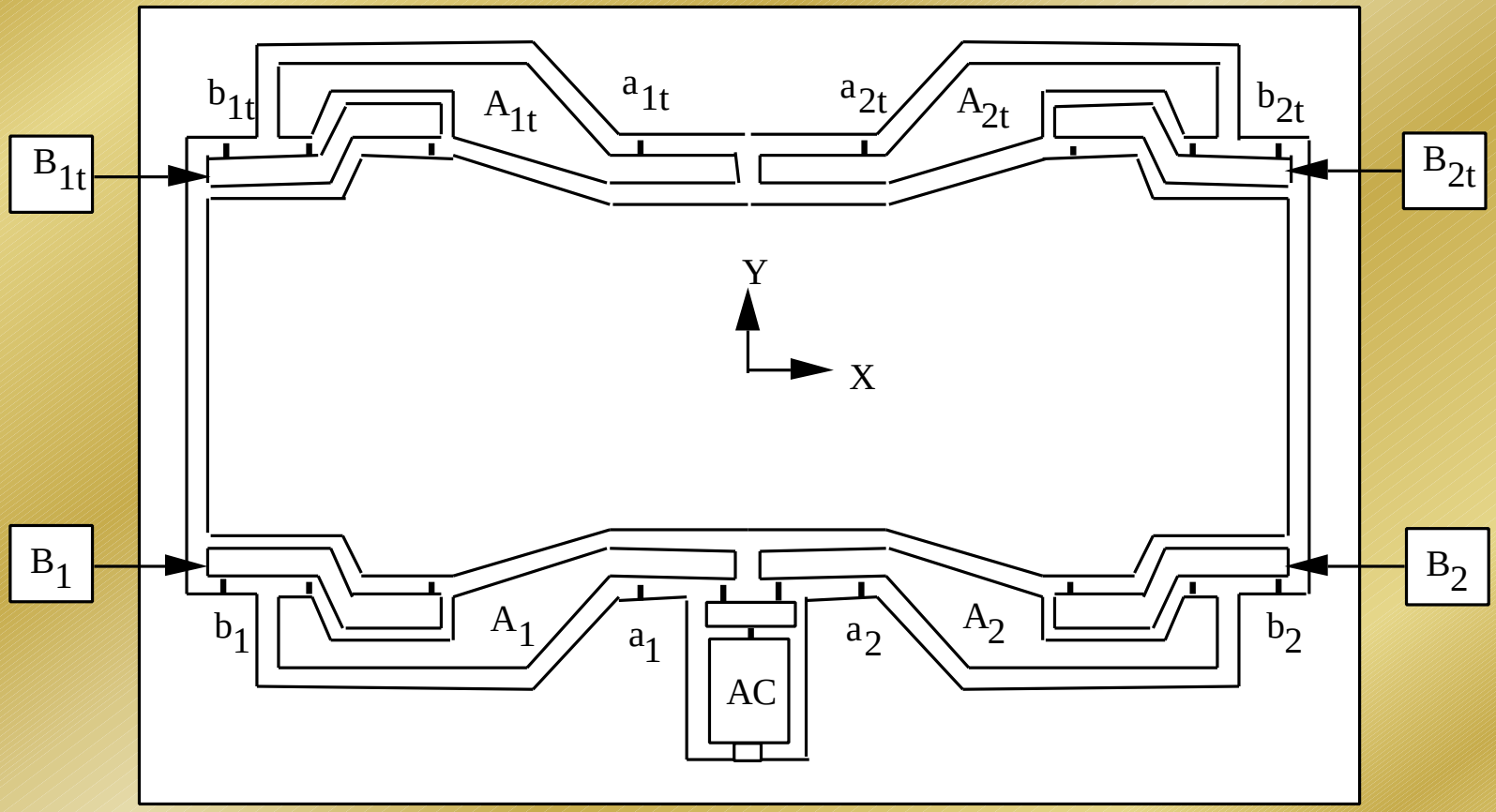


Z-Axis Concepts

- Commercial PZT Actuator
- Additional Linear Flexure Stage, similar to current X and Y axis.
- Calibration more difficult.



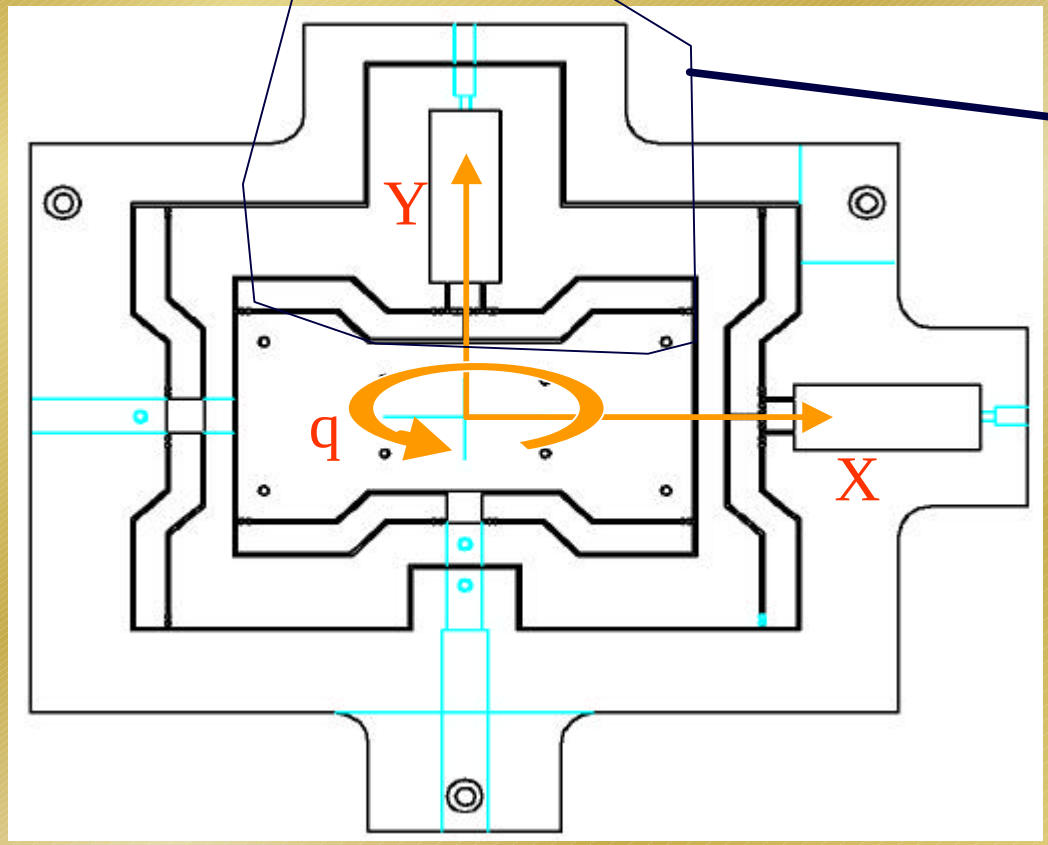
Reduce Size with Compound Cantilevers

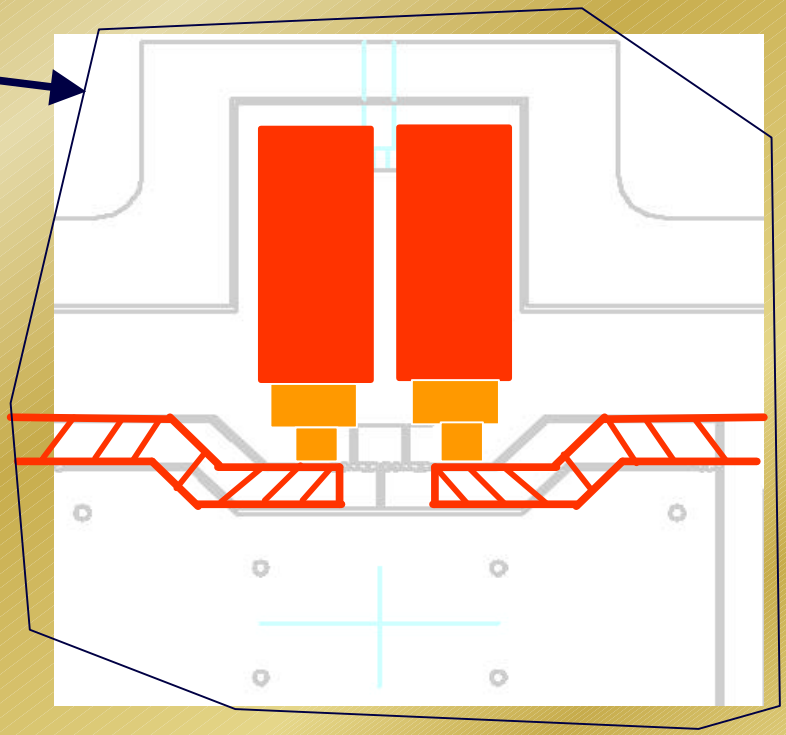


Only shows Y-axis

X-Y- θ Micro Positioning Platform Concept

Add two actuators on one axis.





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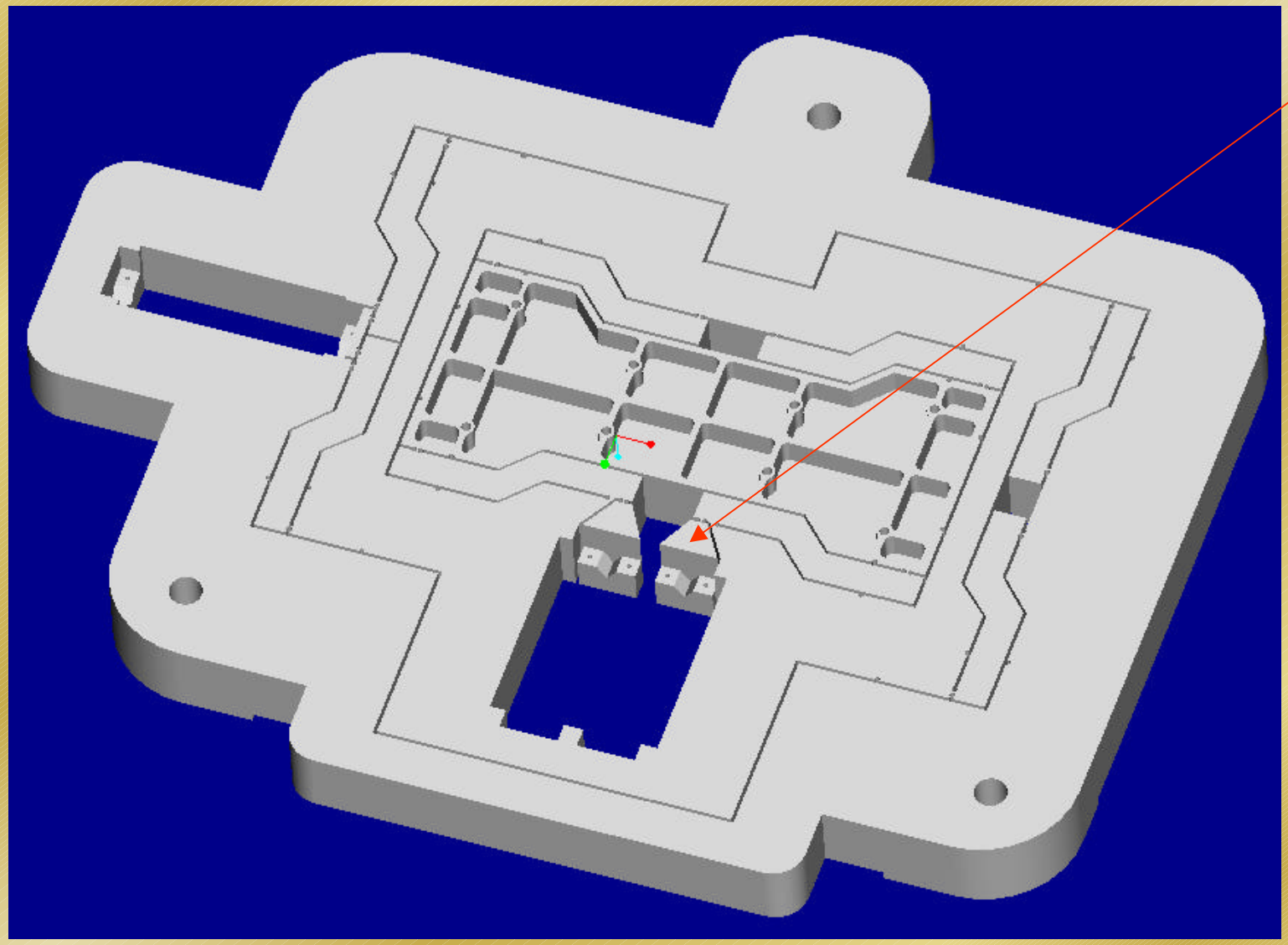
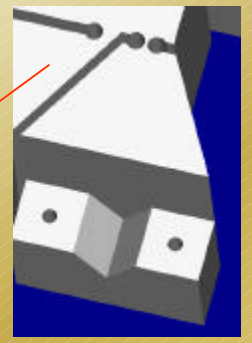


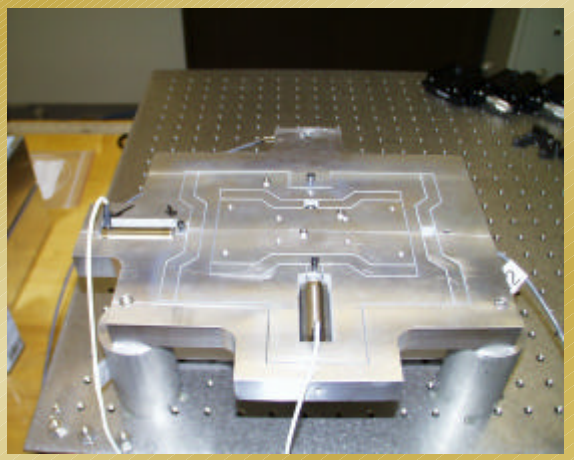


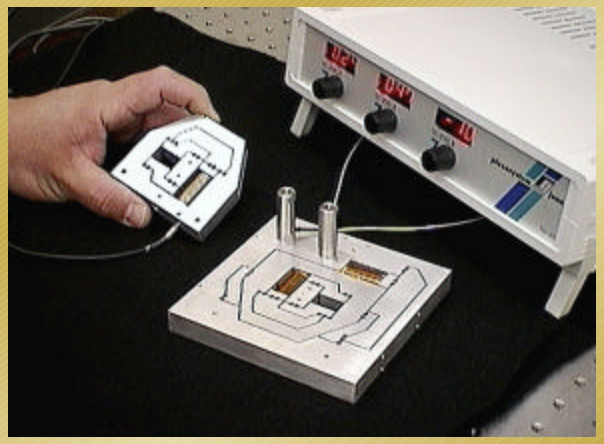
NIST

Microstage Fabrication Costs

Original "Wye Creek" Stage

- $500 per stage to machine
- Batch process for cutting stages - 4" thick
- Fabricated custom PZT's - inexpensive





NIST Microstage

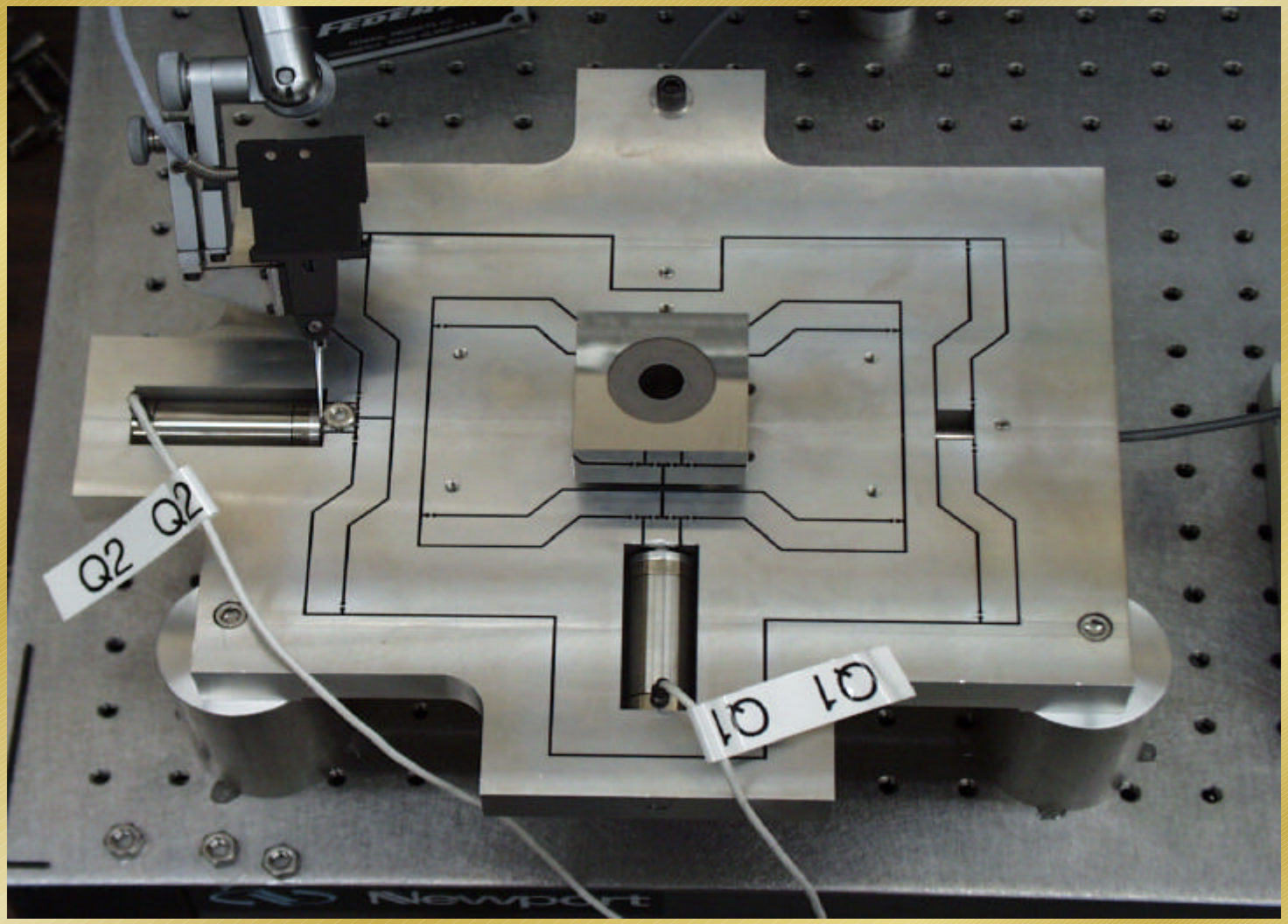
- EDM Machining approximately $2,000 ($65 dollars per hour - about 31 hours)
- Total Machining cost $4,000
- Per unit costs approx. $1,000

Approx. Batch Costs for Stage

- Machining $500-$1,000
  - Process batch of four or five at a time on EDM Machine
- Actuators $800-$1200
  - Cheaper if PZT actuator is fabricated in house
- Sensors $1000 - $2400
  - Could be installed based on customer specifications
- **Total $2300 - $4600**
- **Open-Loop $1300 - $2200**

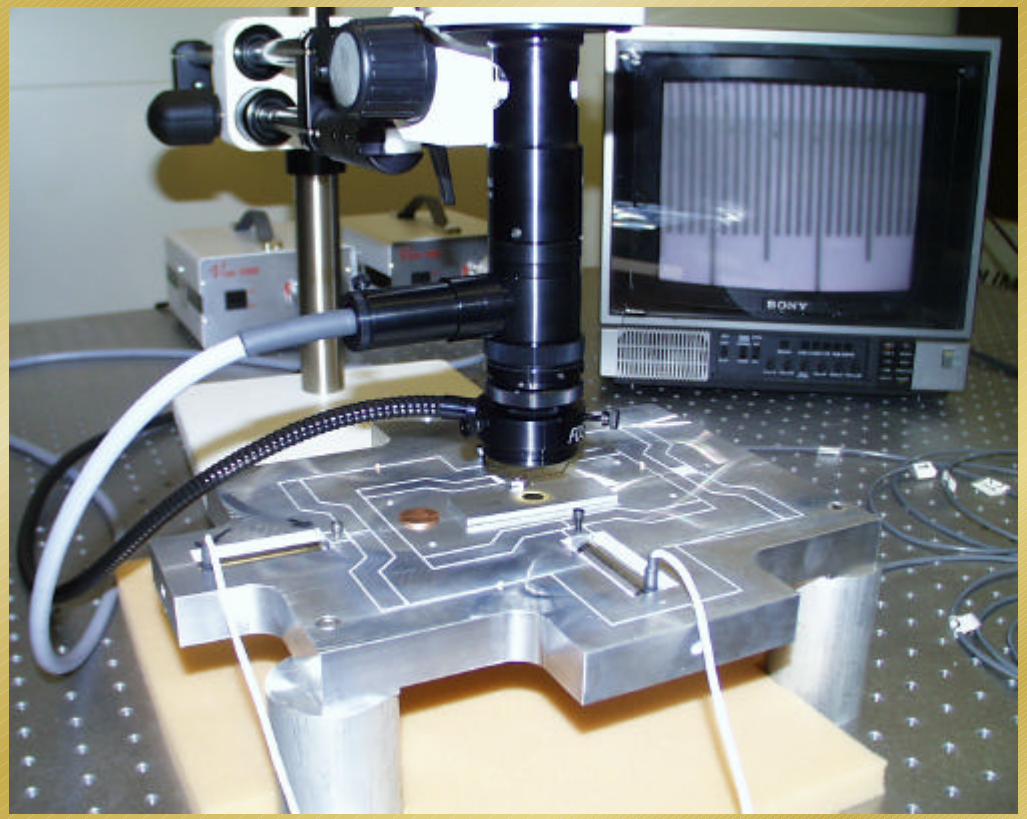
Planar Micro-Positioners: Models, Performance Testing, and Calibration

NIST X-Y Microstage

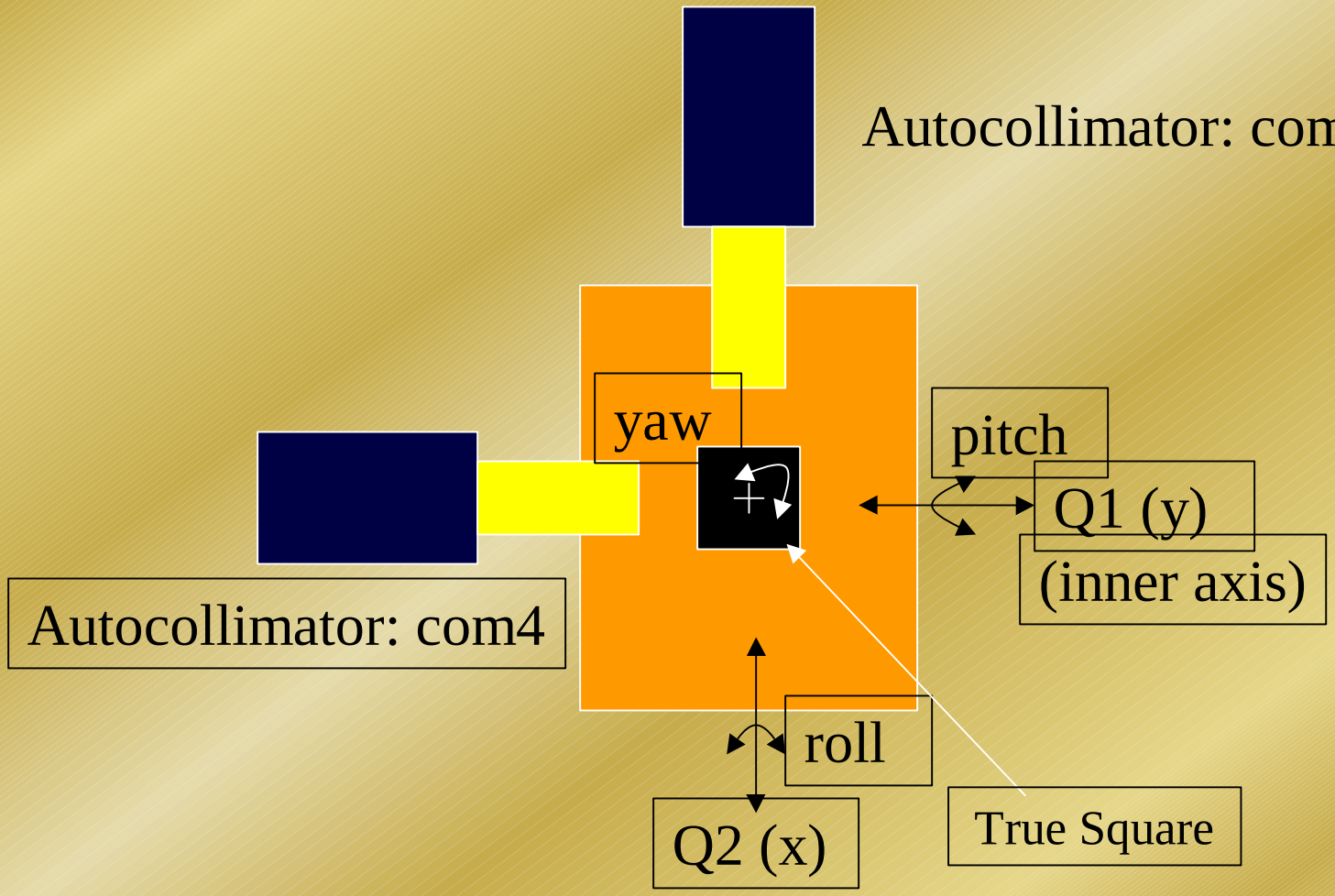


Stage Motion Performance Tests

- X-Y Axes Cross Talk
- Angular Error Measurements
- Stage Linearity
- Mechanical Coupling Transmission Ratio

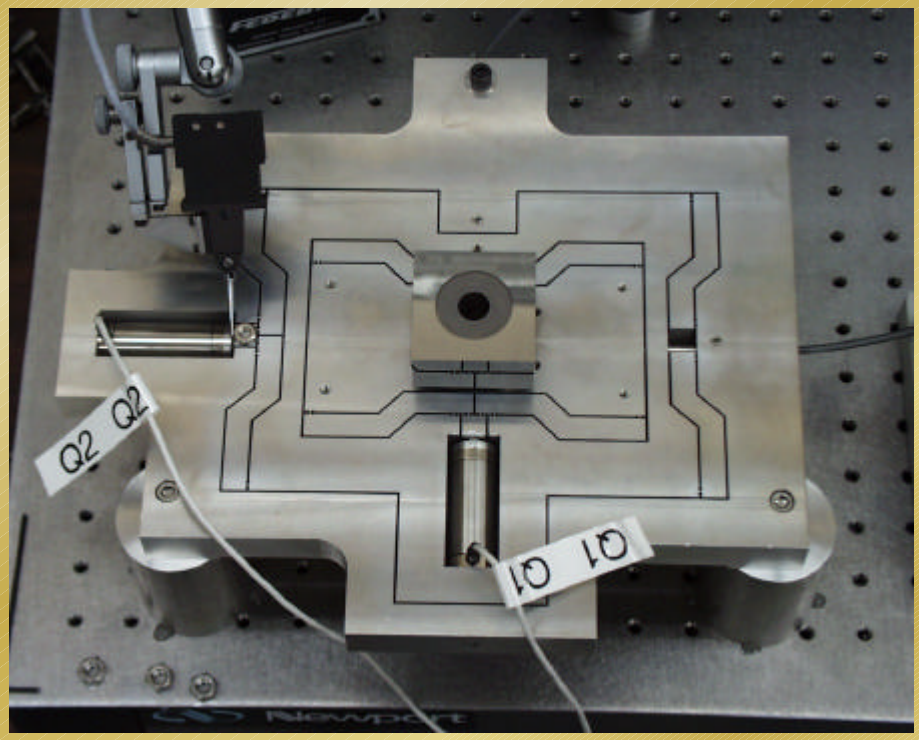


Measurement Setup



Axis Crosstalk

- Static checks indicate crosstalk to be approximately one part in 4000 (25 nm over 100 micrometers)



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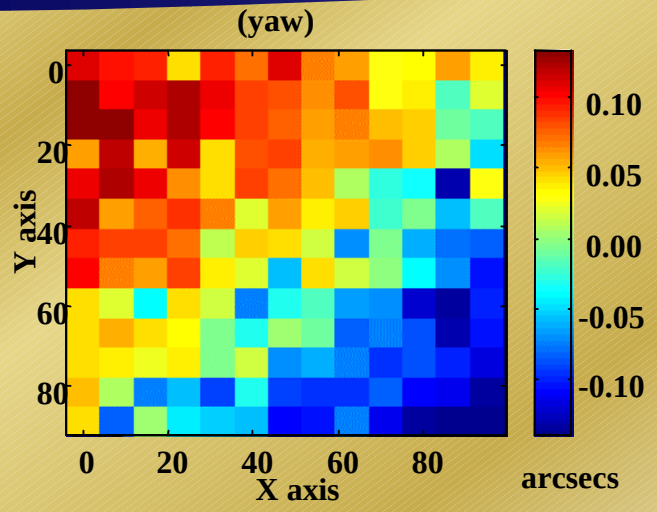
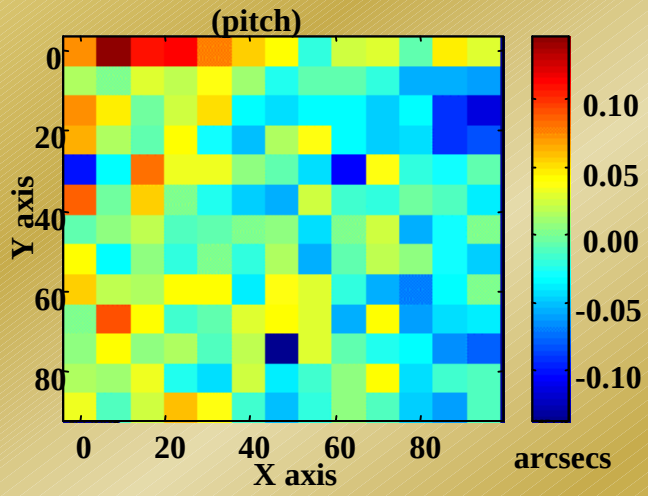
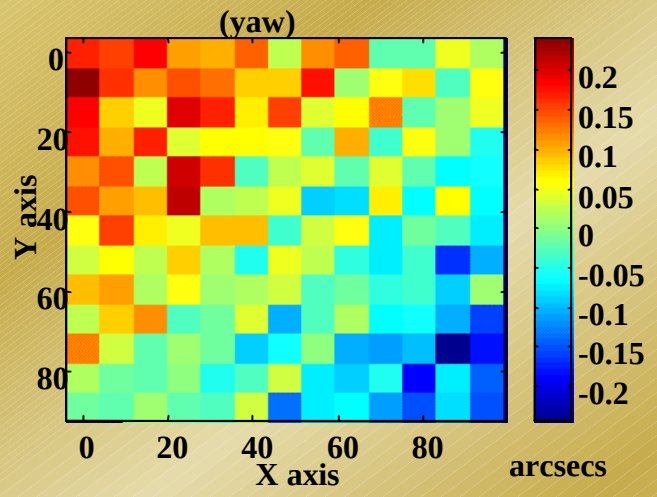
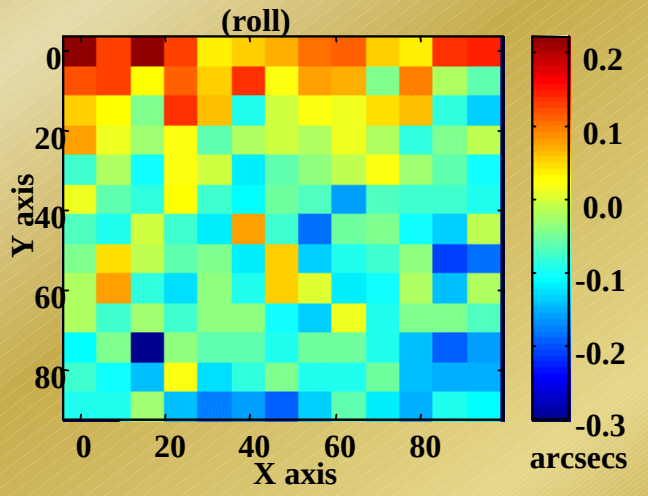




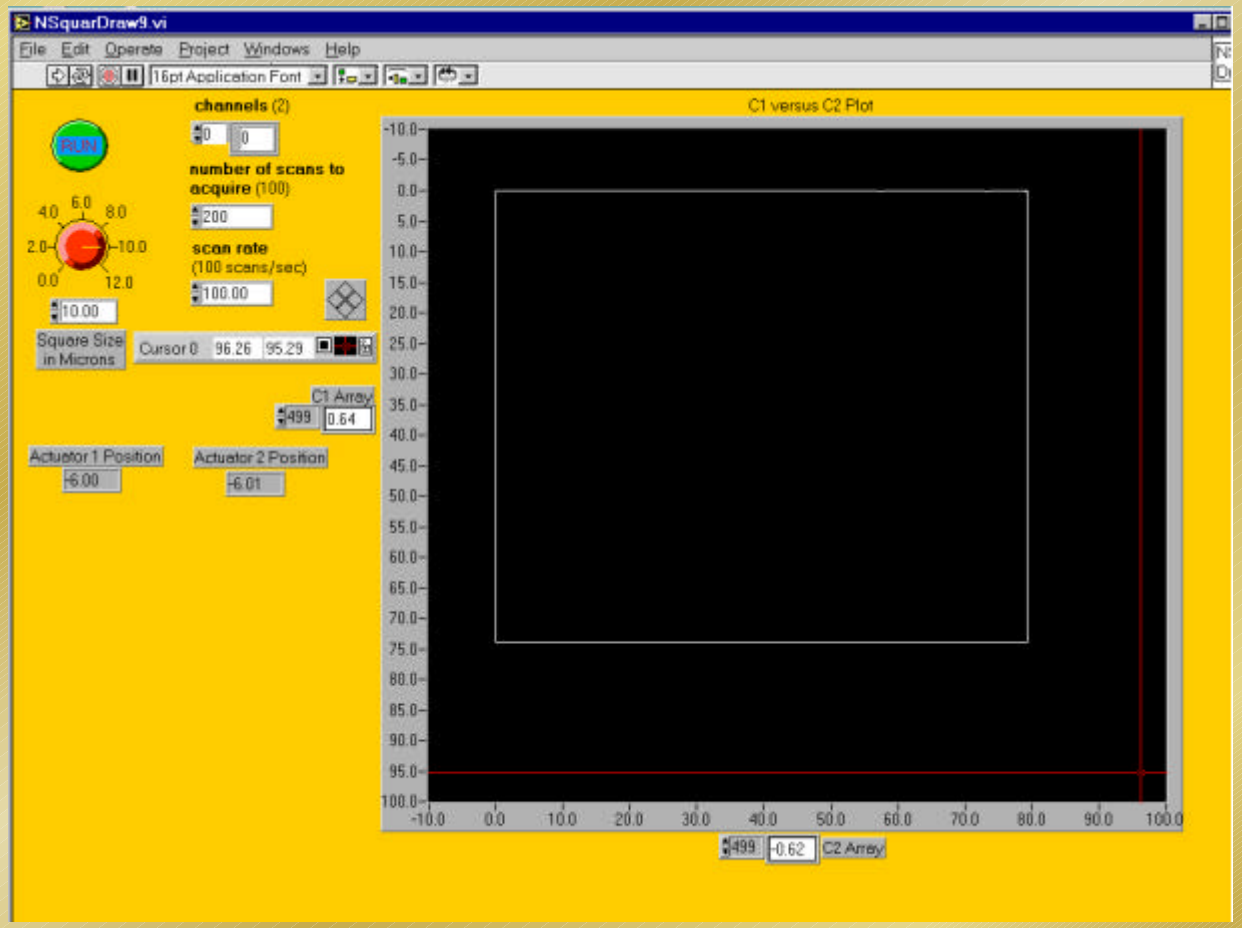




Colormap of micro-positioner stage pitch, roll and yaw error taken on a 10 x 10 position grid. All XY axis units are in micrometers. The measured angular error ranged from 0.3 to 0.4 arcseconds (0.11 mdegrees).

NIST

Baseline Control Trajectory



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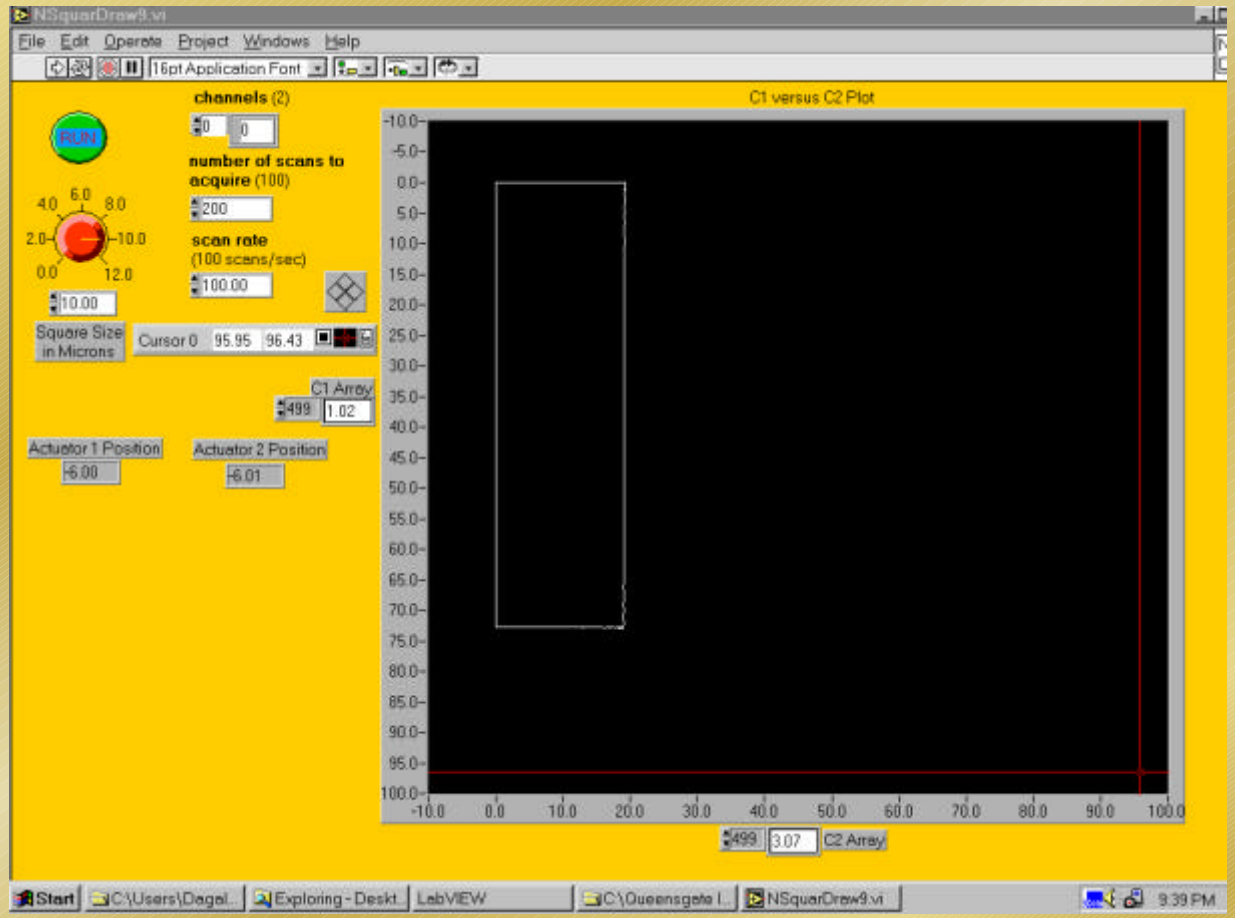
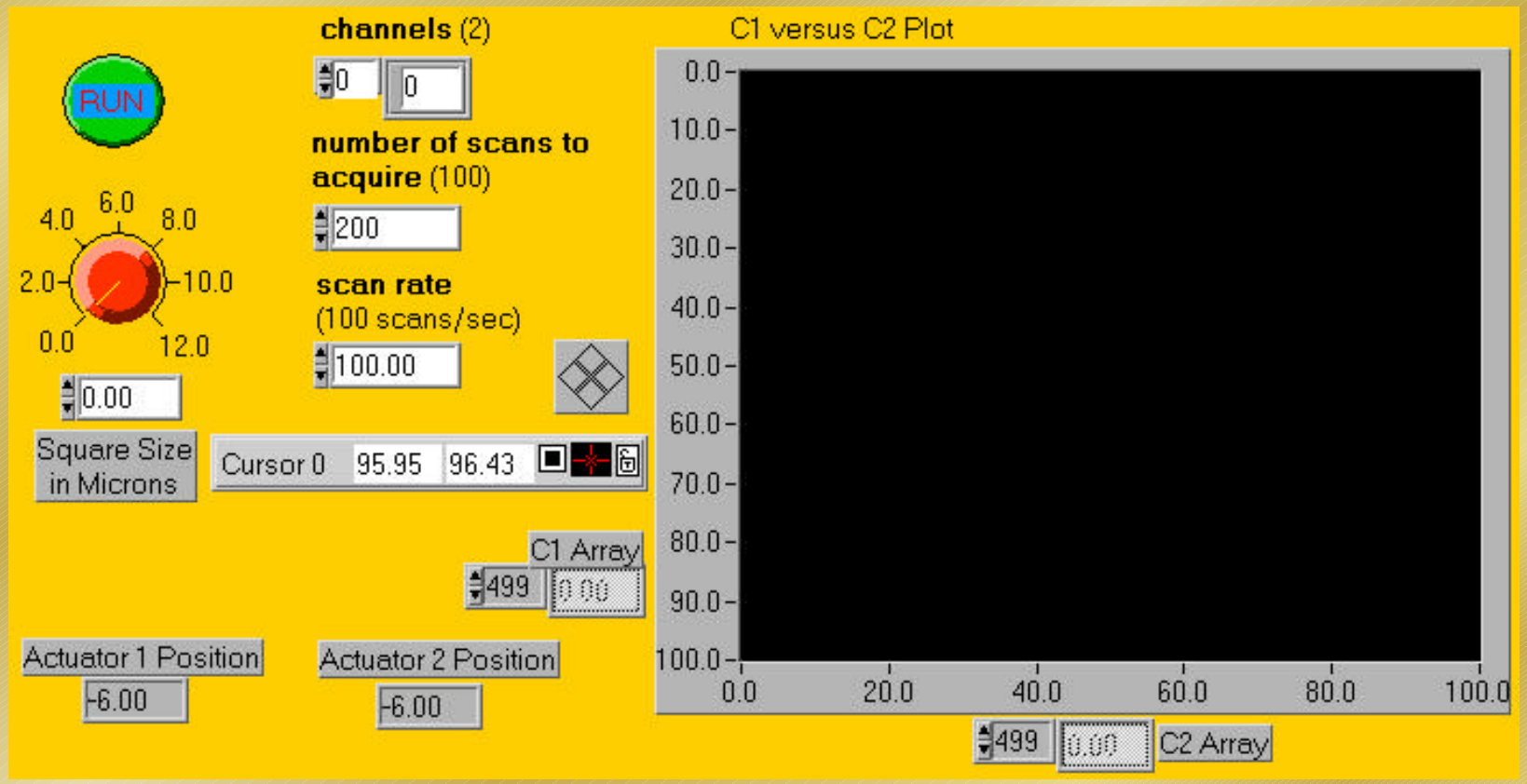
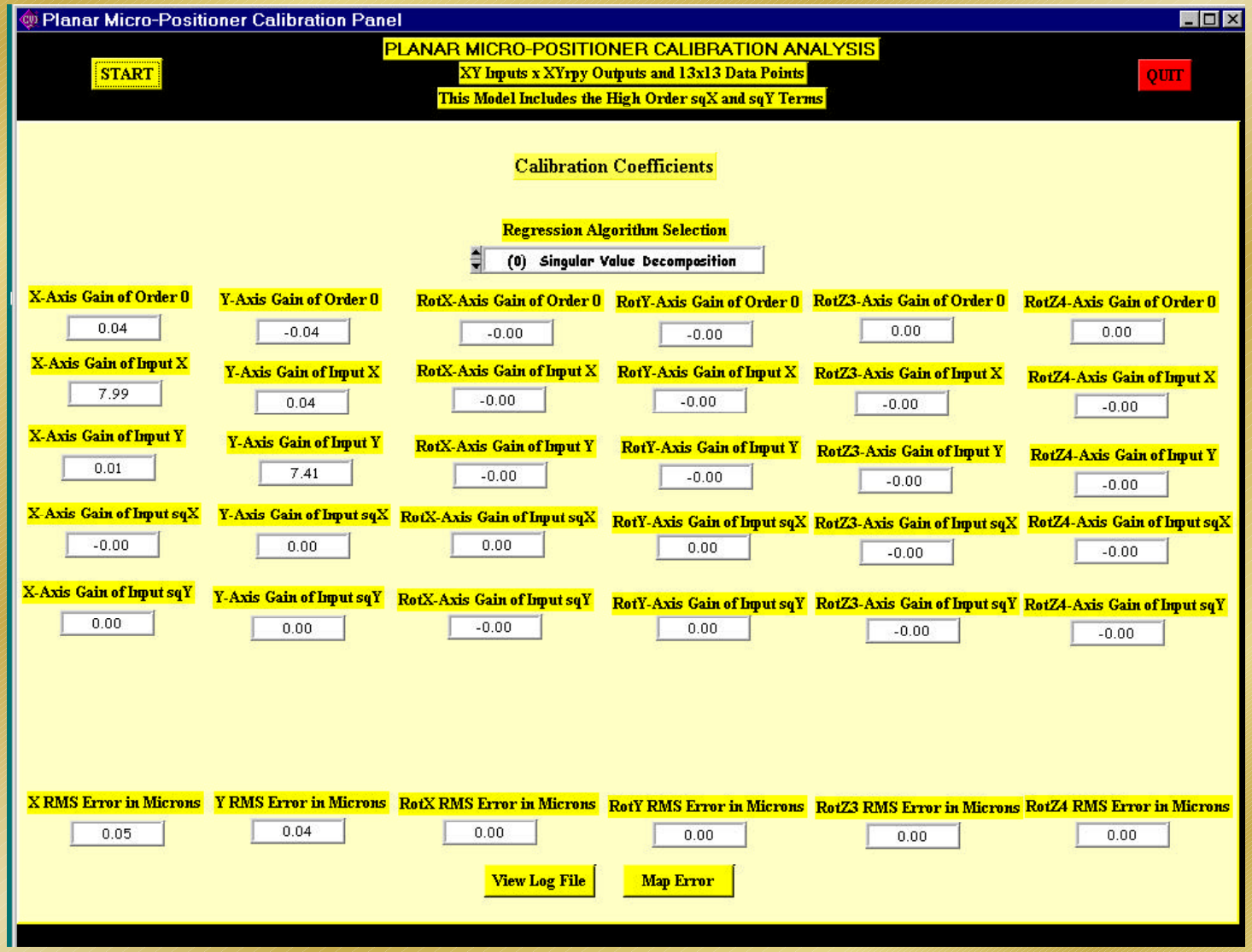
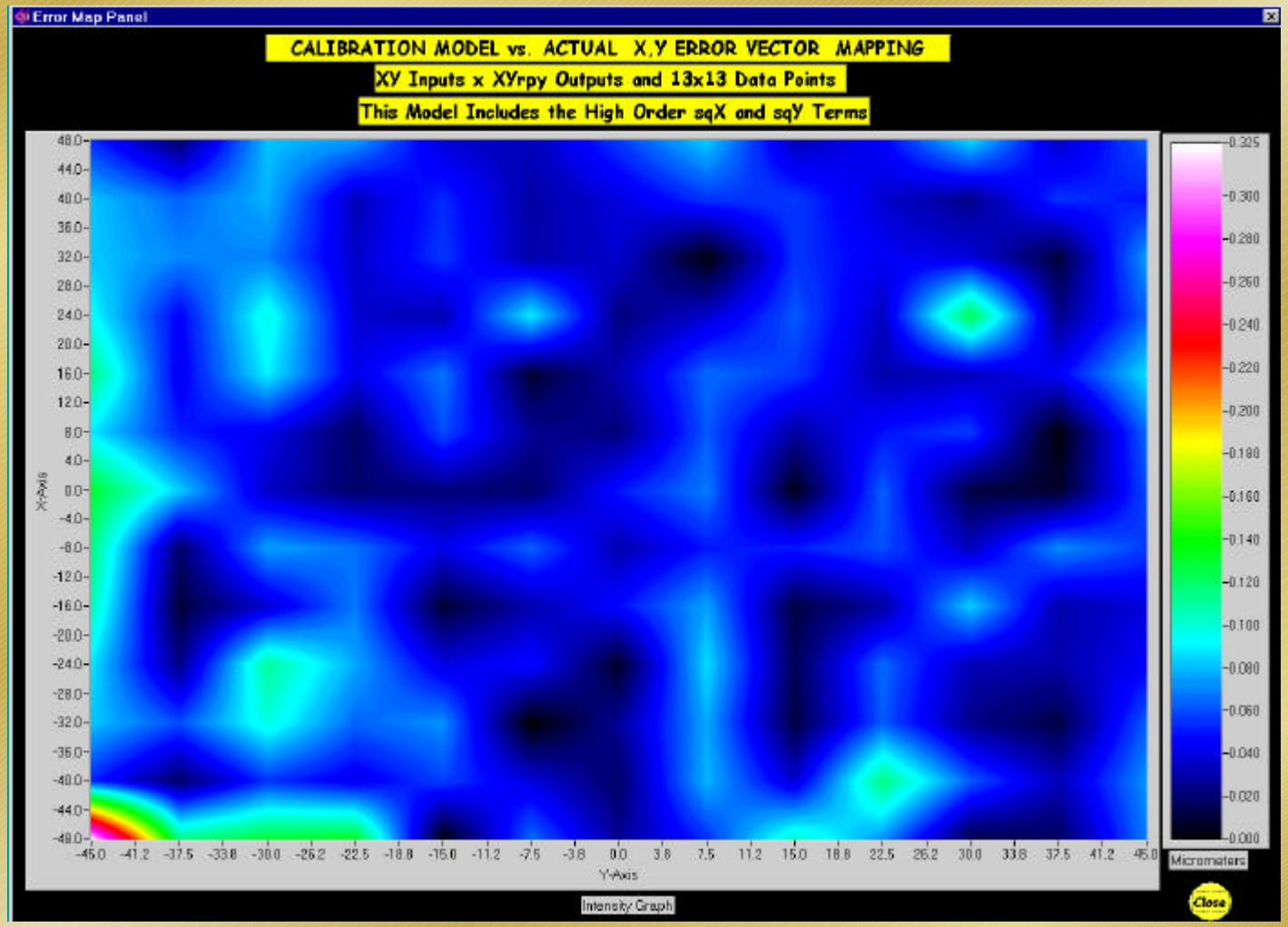
Defective Coupling Control Trajectory

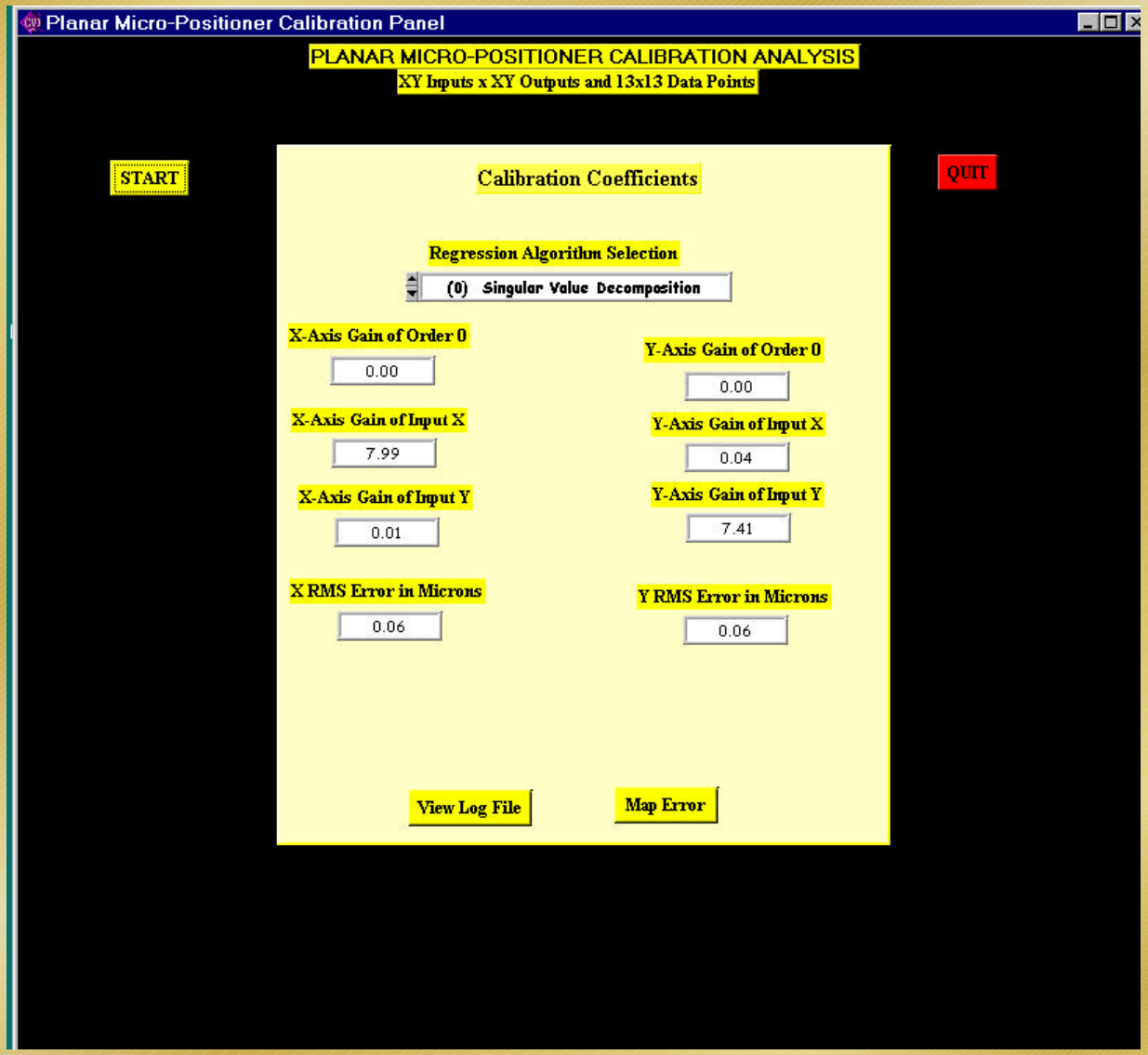


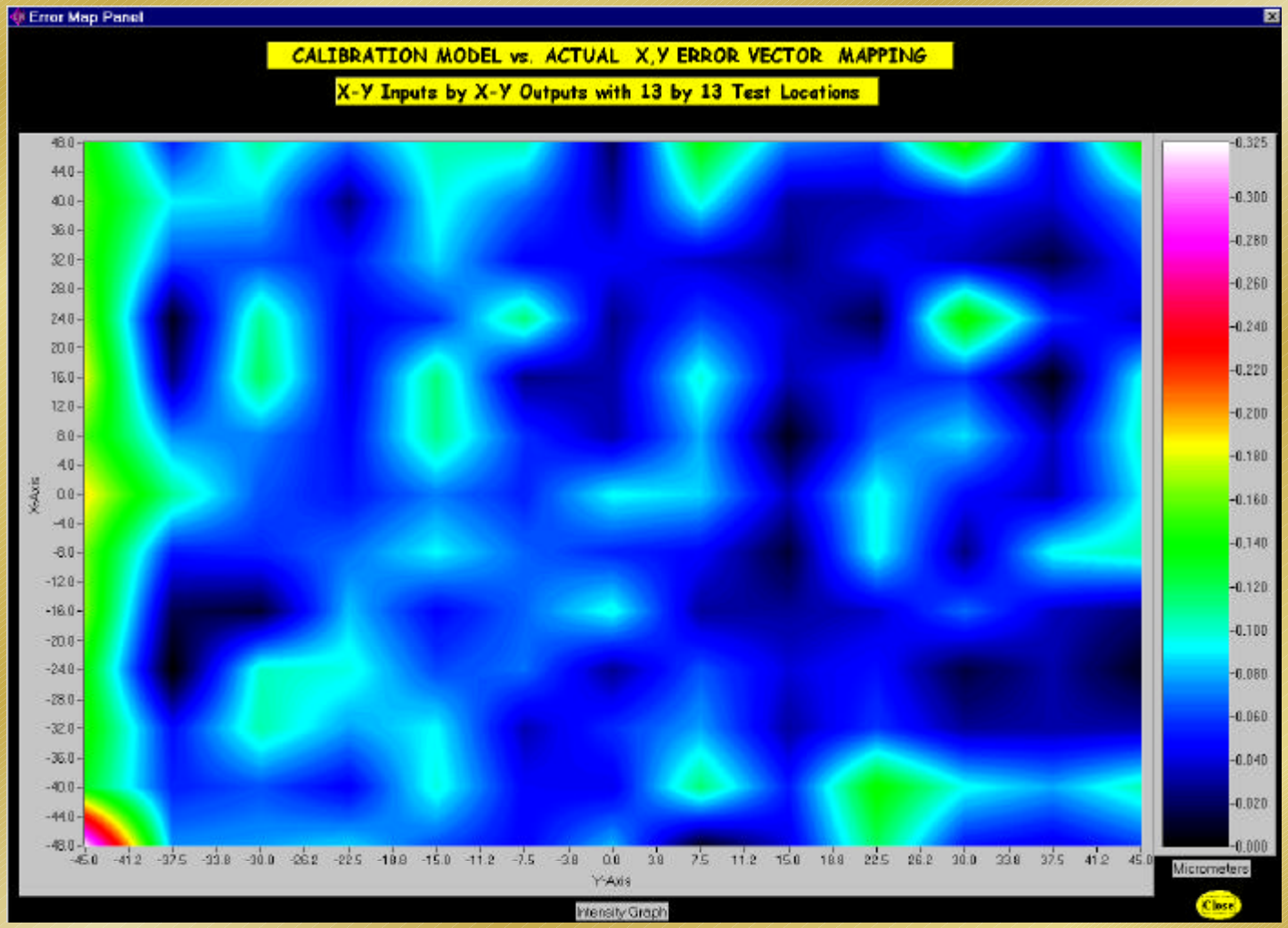
Baseline Control Trajectory




Planar Micro-Positioner Calibration Panel
PLANAR MICRO-POSITIONER CALIBRATION ANALYSIS
XY Inputs x XYrpy Outputs and 13x13 Data Points
This Model Includes the High Order sqX and sqY Terms
START
QUIT
Calibration Coefficients
Regression Algorithm Selection
(0) Singular Value Decomposition
X-Axis Gain of Order 0
0.04
Y-Axis Gain of Order 0
-0.04
RotX-Axis Gain of Order 0
-0.00
RotY-Axis Gain of Order 0
-0.00
RotZ3-Axis Gain of Order 0
0.00
RotZ4-Axis Gain of Order 0
0.00
X-Axis Gain of Input X
7.99
Y-Axis Gain of Input X
0.04
RotX-Axis Gain of Input X
-0.00
RotY-Axis Gain of Input X
-0.00
RotZ3-Axis Gain of Input X
-0.00
RotZ4-Axis Gain of Input X
-0.00
X-Axis Gain of Input Y
0.01
Y-Axis Gain of Input Y
7.41
RotX-Axis Gain of Input Y
-0.00
RotY-Axis Gain of Input Y
-0.00
RotZ3-Axis Gain of Input Y
-0.00
RotZ4-Axis Gain of Input Y
-0.00
X-Axis Gain of Input sqX
-0.00
Y-Axis Gain of Input sqX
0.00
RotX-Axis Gain of Input sqX
0.00
RotY-Axis Gain of Input sqX
0.00
RotZ3-Axis Gain of Input sqX
-0.00
RotZ4-Axis Gain of Input sqX
-0.00
X-Axis Gain of Input sqY
0.00
Y-Axis Gain of Input sqY
0.00
RotX-Axis Gain of Input sqY
-0.00
RotY-Axis Gain of Input sqY
0.00
RotZ3-Axis Gain of Input sqY
-0.00
RotZ4-Axis Gain of Input sqY
-0.00
X RMS Error in Microns
0.05
Y RMS Error in Microns
0.04
RotX RMS Error in Microns
0.00
RotY RMS Error in Microns
0.00
RotZ3 RMS Error in Microns
0.00
RotZ4 RMS Error in Microns
0.00
View Log File
Map Error


Error Map Panel
CALIBRATION MODEL vs. ACTUAL X,Y ERROR VECTOR MAPPING
XY Inputs x XYrpy Outputs and 13x13 Data Points
This Model Includes the High Order sqX and sqY Terms
X-Axis
Y-Axis
Intensity Graph
Micrometers
Close


Planar Micro-Positioner Calibration Panel
PLANAR MICRO-POSITIONER CALIBRATION ANALYSIS
XY Inputs x XY Outputs and 13x13 Data Points
START
QUIT
Calibration Coefficients
Regression Algorithm Selection
(0) Singular Value Decomposition
X-Axis Gain of Order 0
0.00
Y-Axis Gain of Order 0
0.00
X-Axis Gain of Input X
7.99
Y-Axis Gain of Input X
0.04
X-Axis Gain of Input Y
0.01
Y-Axis Gain of Input Y
7.41
X RMS Error in Microns
0.06
Y RMS Error in Microns
0.06
View Log File
Map Error

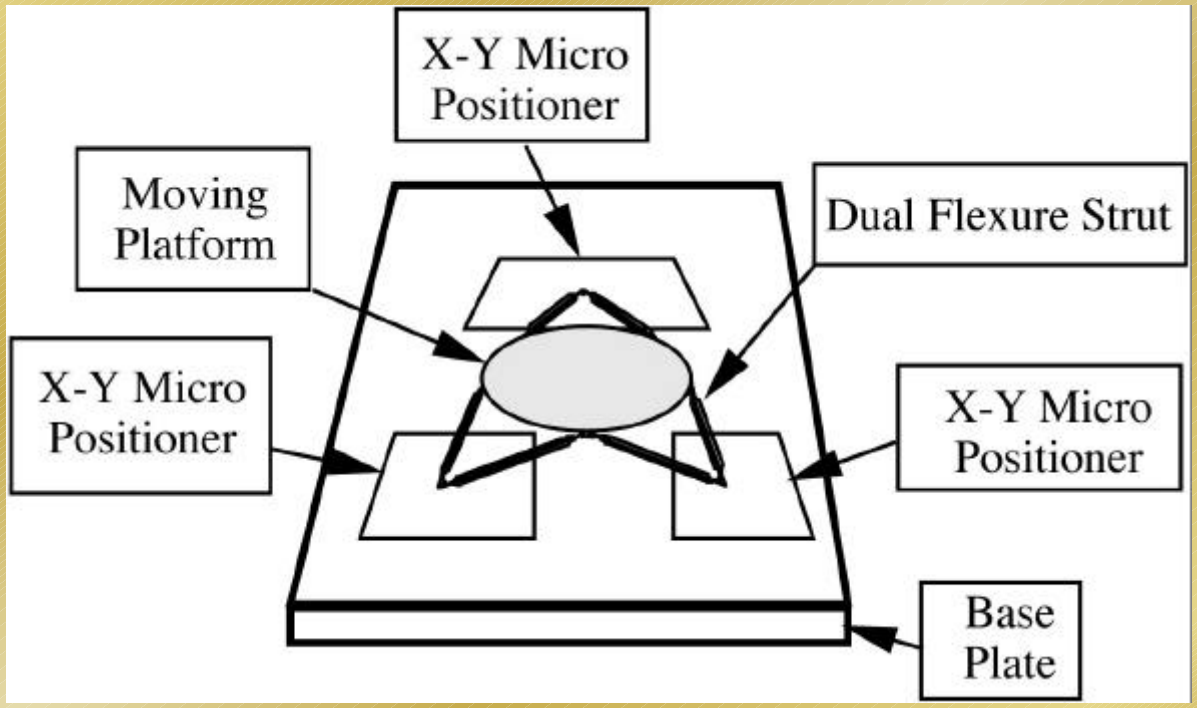

Error Map Panel
CALIBRATION MODEL vs. ACTUAL X,Y ERROR VECTOR MAPPING
X-Y Inputs by X-Y Outputs with 13 by 13 Test Locations
X-Axis
Y-Axis
Micrometers
Close
Intensity Graph

3-D Space Micro-Positioners Designs

3-D Space Micro-Positioners Designs

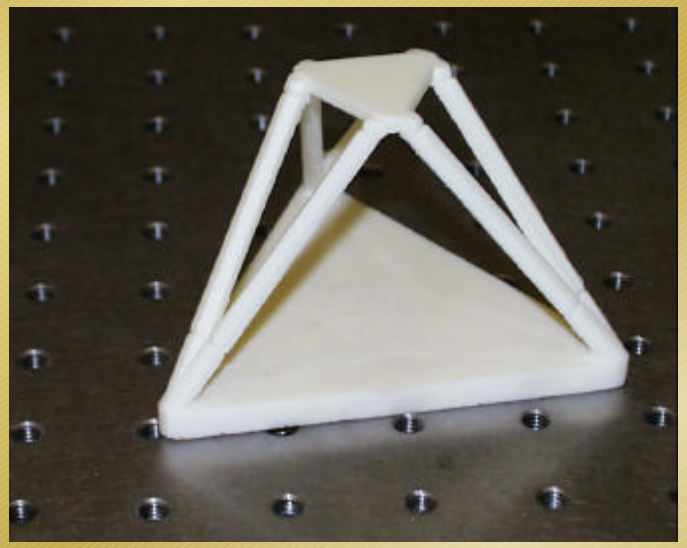
- 6-Degree of Freedom Tri Stage Micro-positioner (Stewart Mechanism)
- ADM Fine Stage 6 DOF Micro-positioner
  (Built in collaboration with UNC Charlotte Precision Engineering)

6-Degree of Freedom Tri Stage Micro-positioner



Modeling of 3-D Space Micro-Positioners

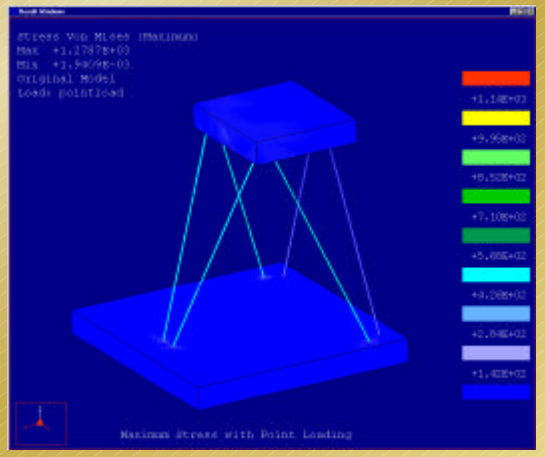
MicroDevices - Performance Measures

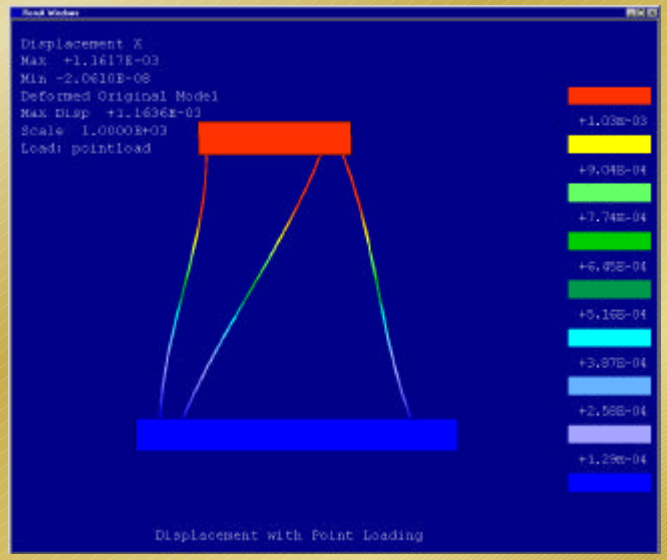


6 Degree of Freedom

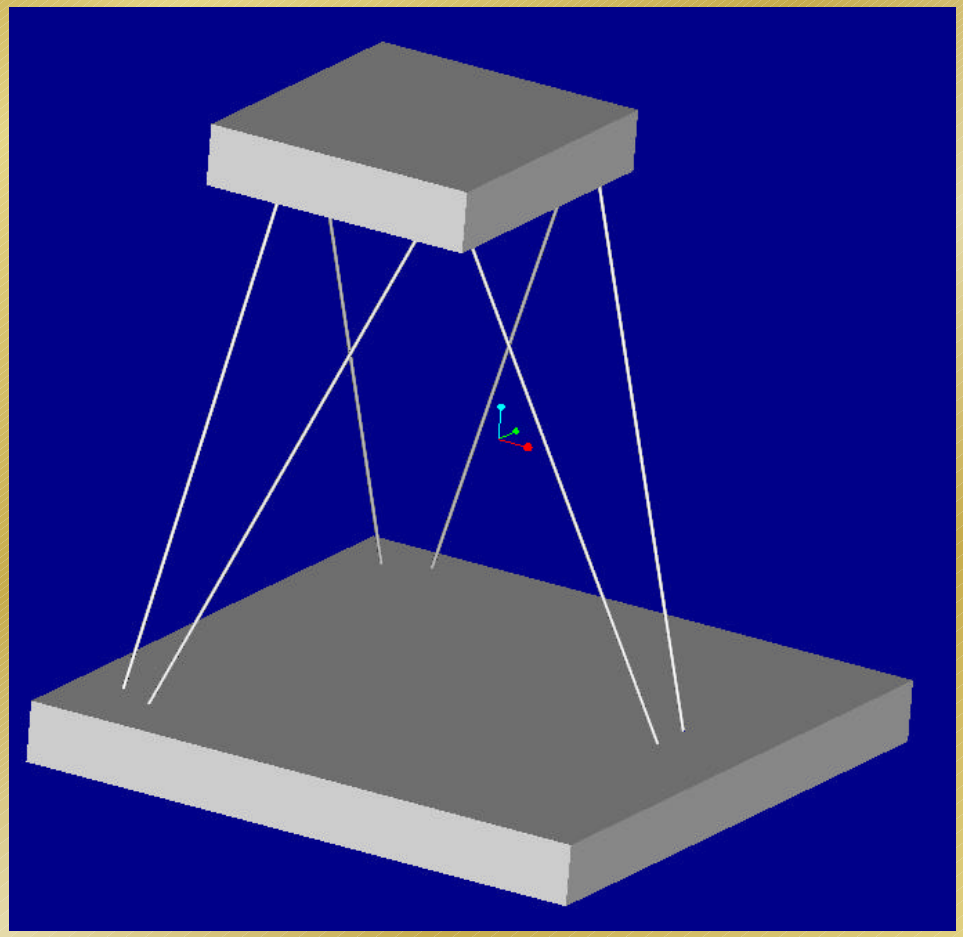
Microstage Prototype

Advanced Performance Measures and Design Tools





6D Microstage Test Structure

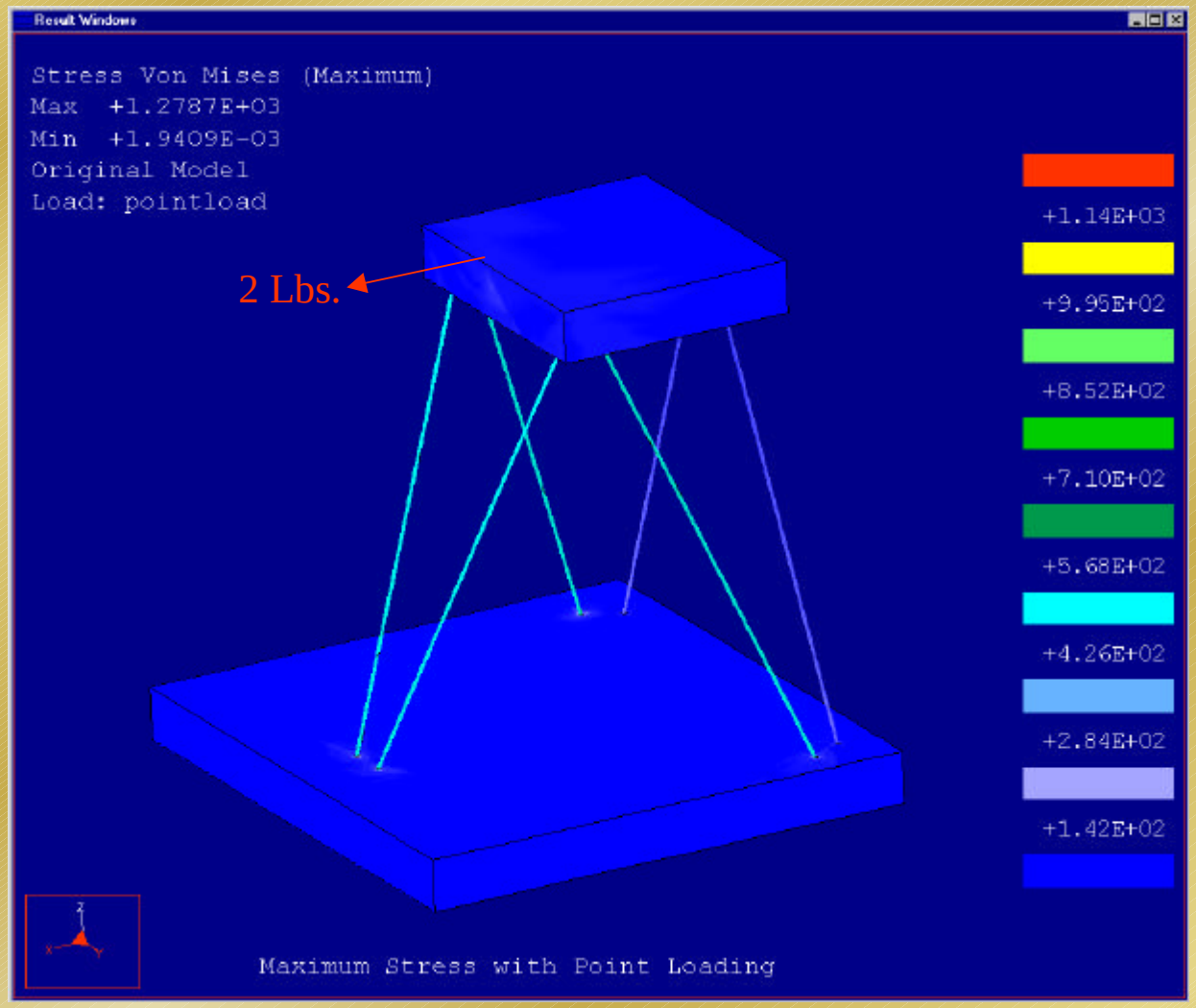


rel.ptd - Notepad

File Edit Search Help

```
d=0.7874
b=3.937
a=1.9685
h=5

D3=b+d
D5=D3
D4=0.57735*D3
D1=1.1547*D3
D2=0.57735*D3

ratio=4

D215=1.1547*b+0.288*d
D216=0.5*d
D222=0.5*d
D221=D215
D227=0.57735*b-0.289*d
D228=b+0.5*d
D233=D227
D234=D228
D239=0.577*b+0.577*d
D240=b
D245=0.577*b+0.577*d
D246=b

D263=0.5+h


D267=0.57735*a+0.57735*d
D268=a
D272=0.57735*a+0.57735*d
D429=0.25+D272
D273=a
D277=0.57735*a-0.289*d
D278=0.5*d+a
D282=D277
D283=D278
D287=1.1547*a+0.288*d
D288=0.5*d
D292=D287
D293=D288

D302=0.25
D303=0.25
D304=D278+0.25
D305=D304
```

NIST



Pro/Mechanica

FEA Analysis

Conditions:

AL6061 T-6

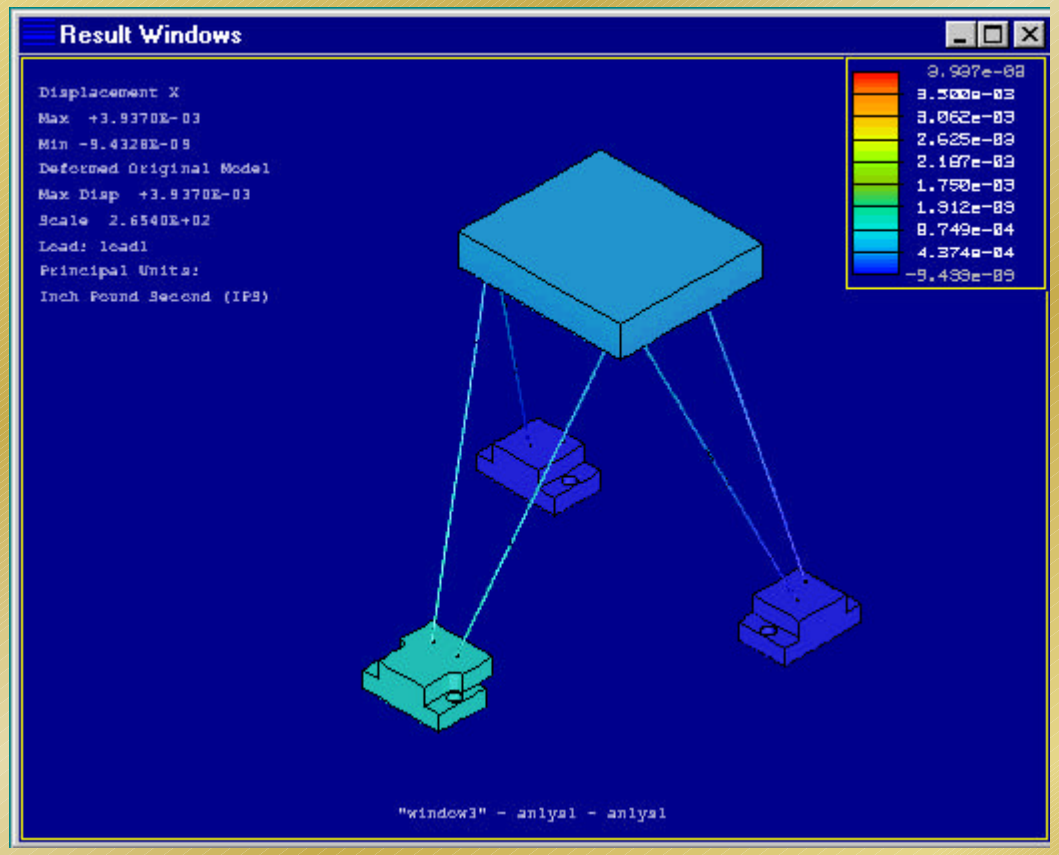
Maximum Yield Stress =

40,000 psi

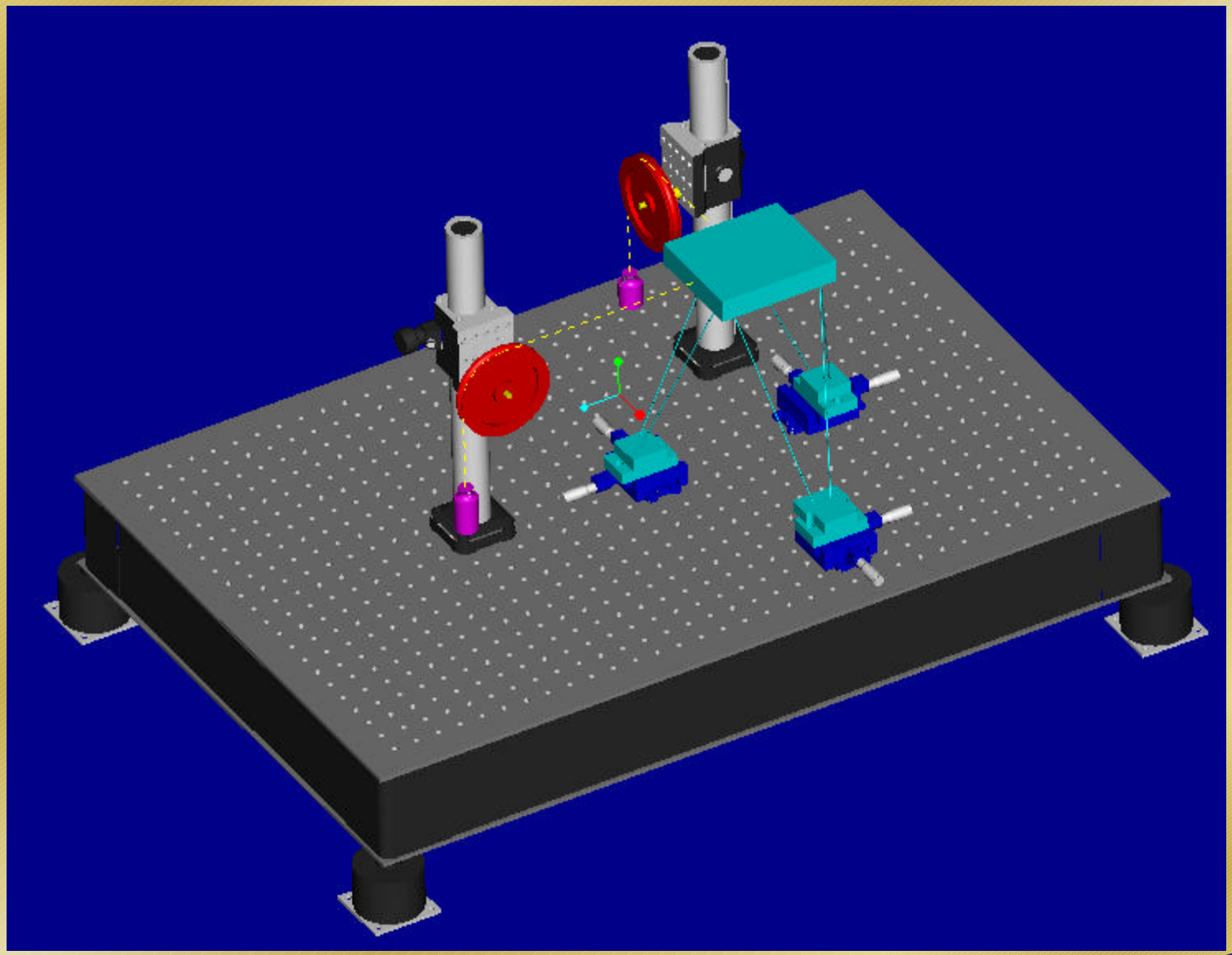
Maximum of Model = approx. 1,300 psi

NIST

MicroDevices - Performance Measures

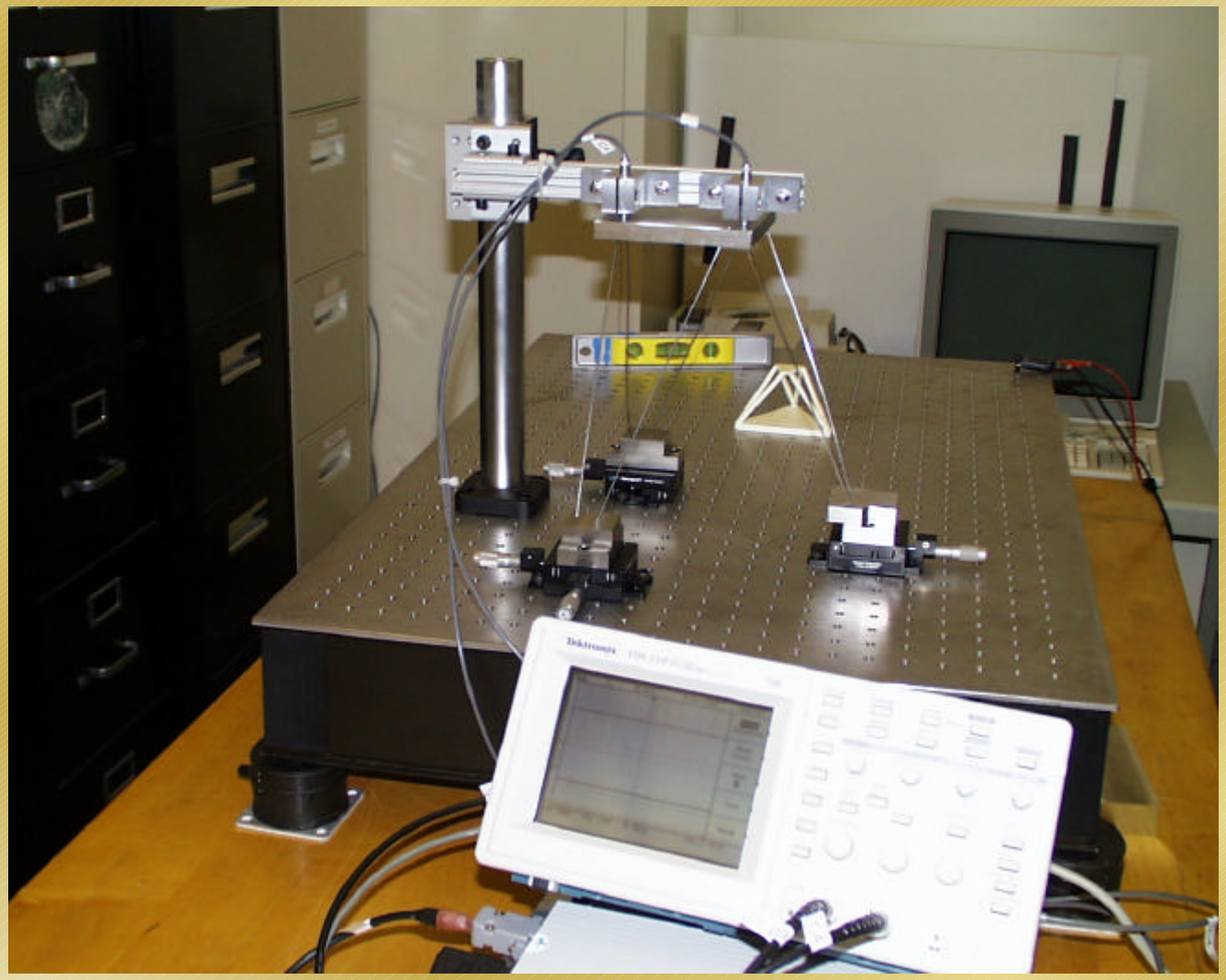


Manufacturing Engineering Laboratory
Intelligent Systems Division



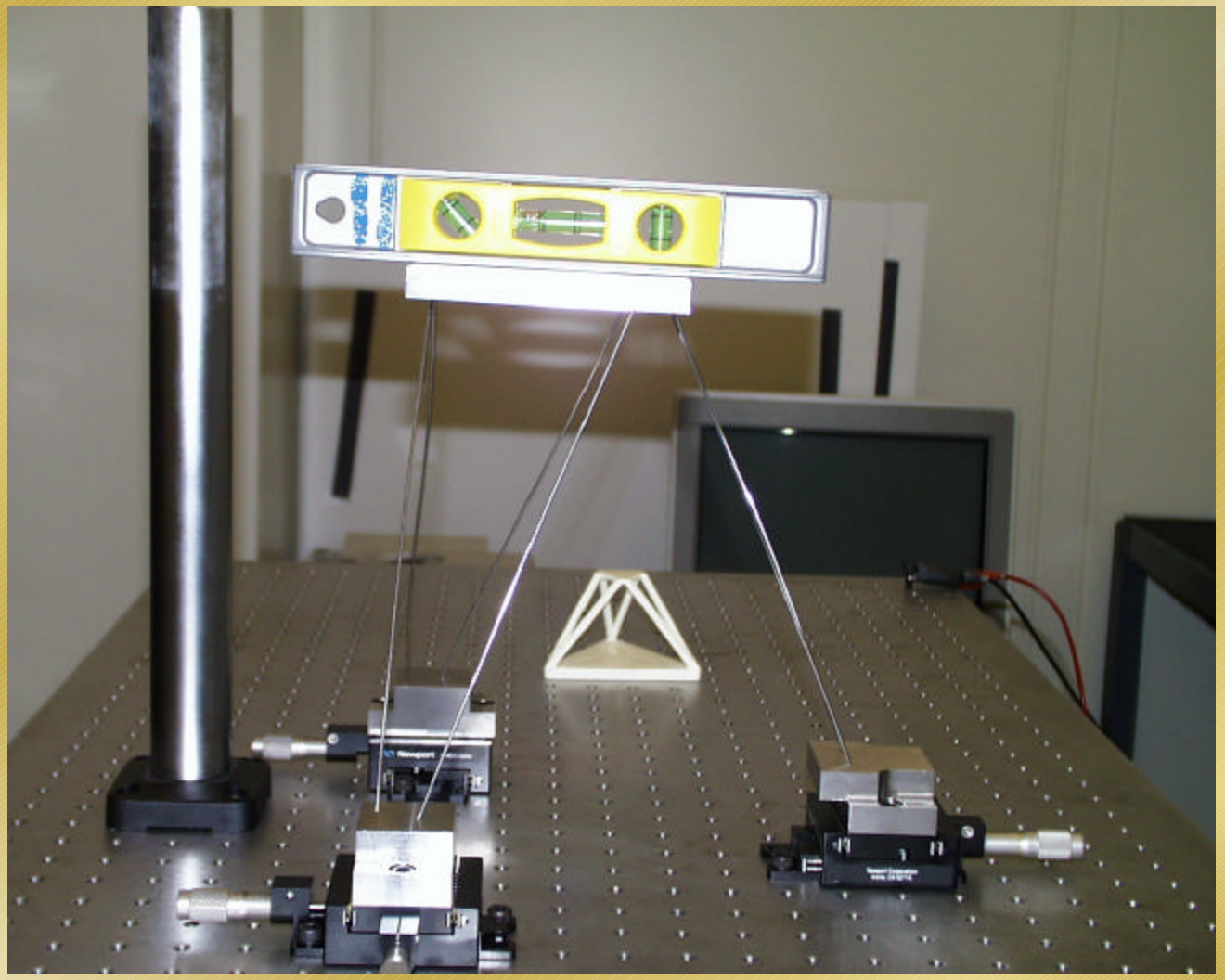
NIST

Manufacturing Engineering Laboratory
Intelligent Systems Division



NIST

Manufacturing Engineering Laboratory
Intelligent Systems Division



NIST

List of Participating NIST Staff

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Dr. Nicholas Dagalakis

Mr. Edward Amatucci

Mr. Robert Bunch

Mr. James Gilsinn

Mr. Brian Weiss

Summary

- X-Y Micro-positioners performance measures and testing software
- Beginning to apply performance measures and testing to 6DOF micro-positioners
- Dissemination of current Research Results - Submitted Abstracts for Publication

For more information:

- Information posted on our website:
  - Final Report on Micro-Meso Scale Manufacturing Exploratory Project and Workshop proceedings:
    - Manufacturing Technology for Integrated Nano- to Millimeter (In2m) Sized Systems, March 1999
    - Manufacturing Three-Dimensional Components and Devices at the Meso and Micro Scales, May 1999

http://www.isd.mel.nist.gov/meso_micro/

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