



## **6-AXIS ULTRAFORM FINISHING PLATFORM A-AXIS CONFIGURATION**

Mirror Technology Days 2016  
Greenbelt, Maryland

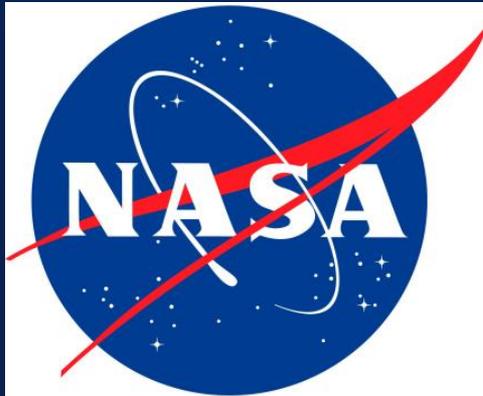
OptiPro Systems, LLC  
Ontario, NY 14519

**Edward Fess, Jayson Tierson,  
Corey Sadlik, Rob Bechtold, Greg Matthews, Frank Wolfs  
Presented by: David Mohring**

OPTIPRO



# SBIR Partners



## NASA SBIR Contracts

NASA Contract Number: NNX16CM33P– Phase I  
Title: UFF Mandrel Fabrication Enhancement  
COTR: Roy Young @ MSFC

**OptiPro Systems, LLC**  
**Ontario, NY**

## INNOVATION

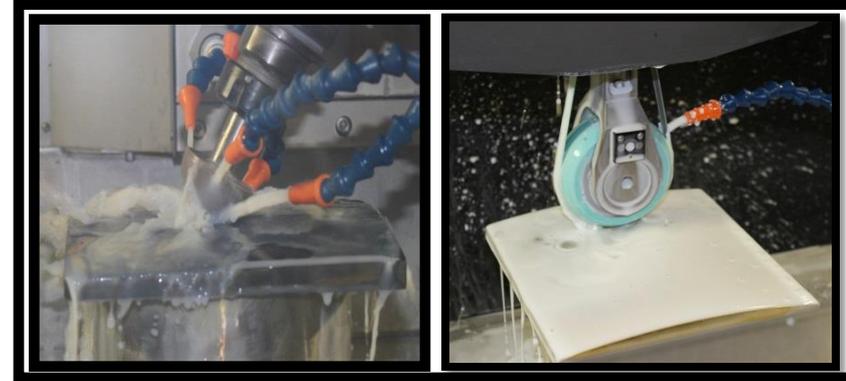
The UltraForm Finishing (6-Axis UFF) and the UltraSurf platforms developed by OptiPro Systems deterministically polish and measure complex aerodynamic and conformal mirror shapes made of difficult to manufacture glass, crystal and ceramic materials.

## ACCOMPLISHMENTS

- ◆ 2008 OSA – Paul Forman “Excellence in Engineering Award” for first affordable Computer Controlled Optical Machining Center.
- ◆ Optical fabrication companies and prime contractor suppliers are embracing the new technology to cost effectively manufacture axisymmetric domes and optics for newly designed defense systems. The technologies developed under the SBIR contracts have provided a cost effective manufacturing solution for DoE, DoD, MDA and NASA components.
- ◆ The integration of the UFF (CNC controlled finishing platform) and the UltraSurf (Automated non-contact measurement device) provides a deterministic fabrication solution for a wide range of newly developed windows, domes and mirrors.

## COMMERCIALIZATION

- ◆ UltraForm Finishing (UFF) : Asphere, Axisymmetric Dome, Freeform Polisher
  - Private Sector installations at Universities, Material manufacturers and Precision optical component manufacturers
  - US Patent No. 7,662,024 B2 : “Method and Apparatus for precision polishing of Optical Components”
- ◆ UltraSurf : Non-Contact Asphere, Axisymmetric Dome measurement platform
  - Private Sector Asphere and Dome Measurement System for production
- ◆ Primary market focus is on companies engaging in the optical fabrication and measurement of spherical domes, aspheres, parabolic mirrors, torics and conformal/freeform shapes.
- ◆ Private sector investment into the UFF and UltraSurf platforms has been through Beta site partners and production level machine purchases.
- ◆ OptiPro Systems, LLC has alliances with material manufacturing firms who require new manufacturing techniques to test and enhance their prototype components and determine the pathway to production level quantities



*Tapered Cylinder Grind and Polish Fabrication*

## GOVERNMENT/SCIENCE APPLICATIONS

- ◆ NASA Contract Numbers NNX12CF49P, NNX14CM21P
- ◆ NASA NNX13CM02C (SBIR 2011-II) (MSFC)
- ◆ DOD Contract Numbers W31P4Q-05-C-R048 and W31P4Q-04-C-R101 awarded by the Defense Advanced Research Projects Agency (DARPA); and Contract Numbers N41756-05-M-1390, N68936-06-C-0010 and N68936-09-C-0079 awarded by the Navy Engineering Logistics Office and NAVAIR.
- ◆ Toric, Acylinder and other freeform geometric shapes made from Si and SiC.
- ◆ Freeform reflective mirror applications for the Department of Energy
- ◆ Materials Include : Spinel, ALON™, CeraLumina™, Si, SiC, ceramics, Fused Quartz & standard optical glasses

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# Outline

- Optical Surface Definition
- Grinding / Diamond Turning
- UltraForm Finishing
- UltraSmooth Finishing
- Software Tools
- Polishing Process
- Surface Metrology
- Nickel Plated Surface Finishing

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# Complex Optical Surfaces

- Off-Axis Aspheres
- Torics
- Aspheric Cylinders
- Parabolics
- Freeforms and Conformal Optics

# Surface Definition

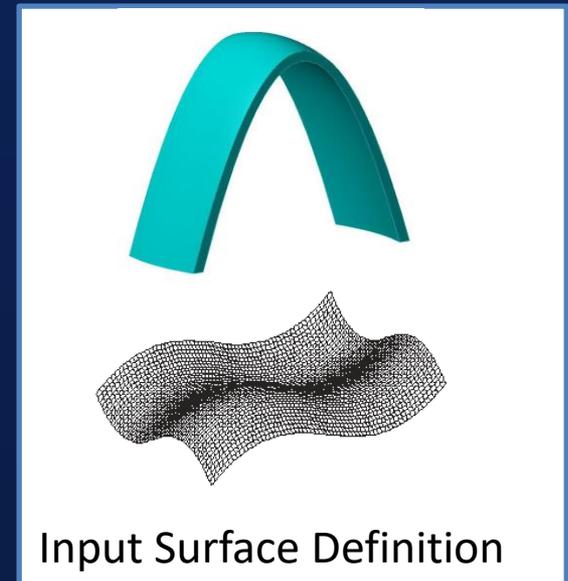
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- Mathematical Equation
  - Basis functions
  - Zernike polynomial
  - Q Polynomial
- Wireframe model
- Solid model
- Cloud of points
- Mandrel definition ...

$$r = \sqrt{h_0^2 + 2ky - py^2} \quad z = \sqrt{r^2 - x^2}$$

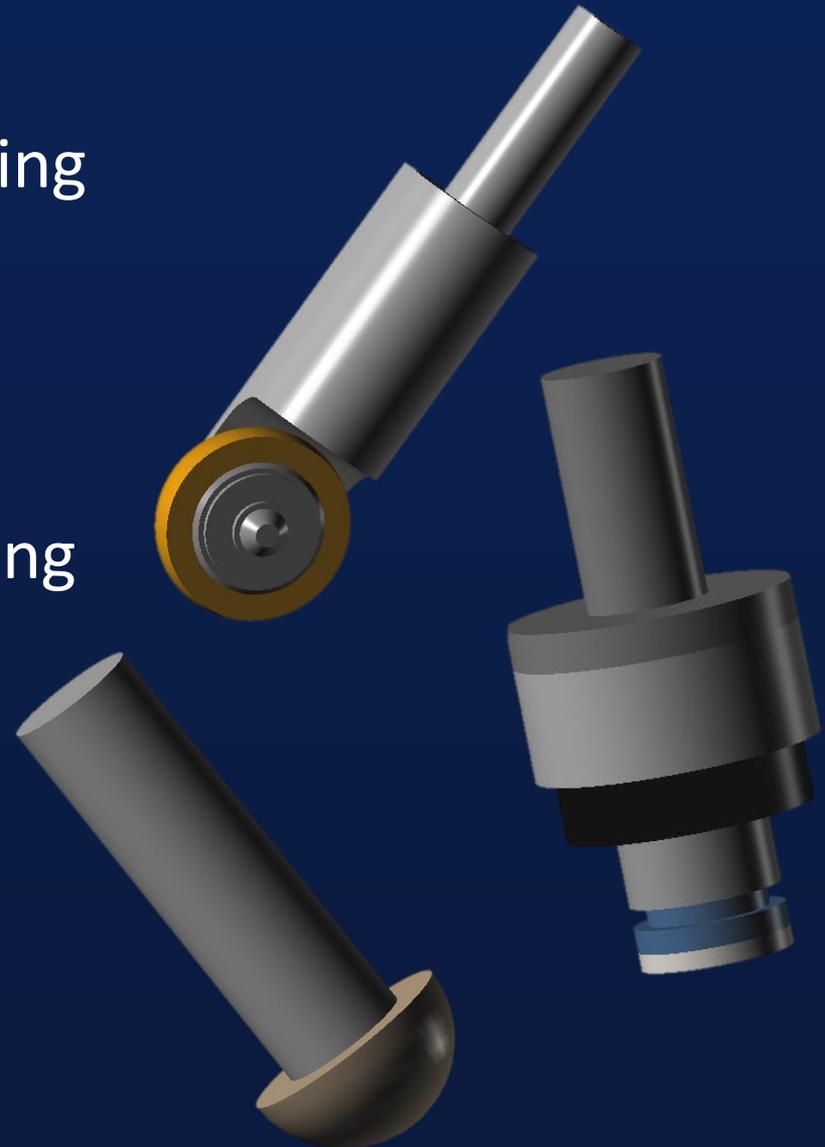
$r$  is the radius of the surface at any given  $y$  coordinate,  $h_0$  is a constant equal to 425 mm,  $k$  is a constant equal to -3.844346977 mm,  $p$  is a constant equal to  $-3.0810743 \times 10^{-04}$



# Manufacturing Tools



- Deterministic Grinding (DMG)
- UltraForm Finishing (UFF)
- UltraSmooth Finishing (USF)



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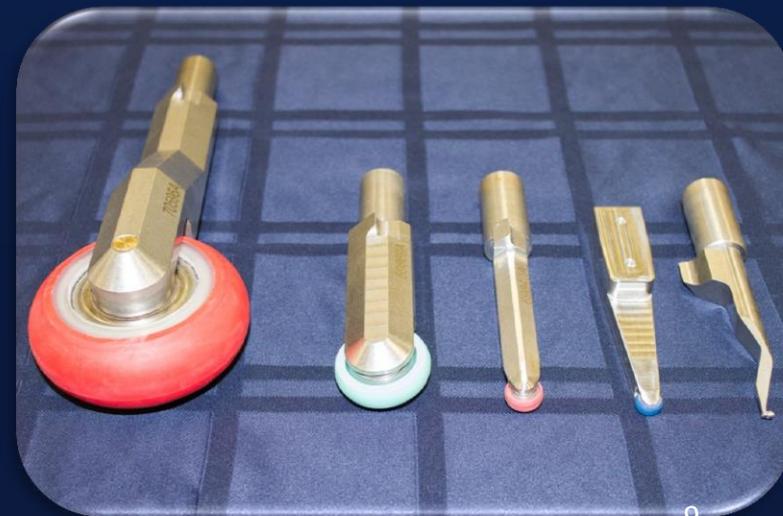
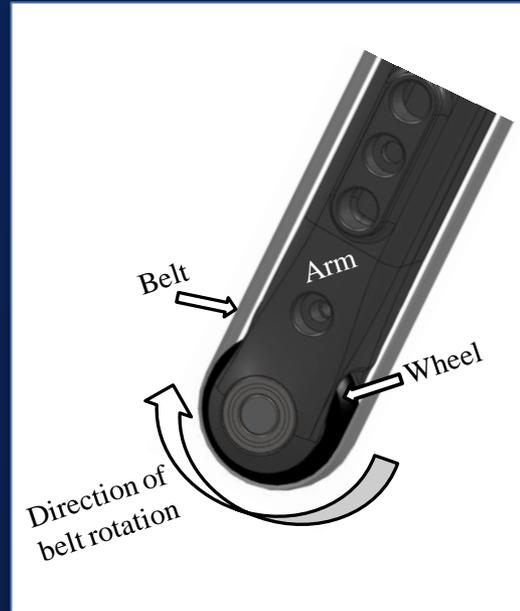
# Ultrasonic Machining Centers



- OptiSonic 3X: 3-axis ultrasonic machining
- OptiSonic 5X: 5-axis ultrasonic machining

# UFF Features

- Wheel size range 6 to 100 mm in diameter
- Wheel nominal hardness range from 30-80 Shore A
- Bound/fixed abrasives or commercial polyurethane belts with slurry
- Capable of finishing a wide range of materials from optical glass to hard ceramics to sub-micron form tolerances



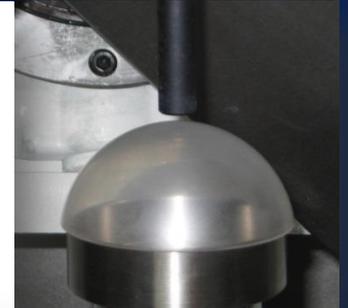
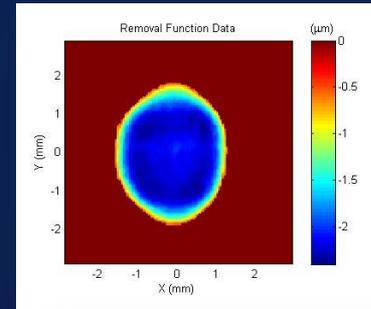
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# UFF

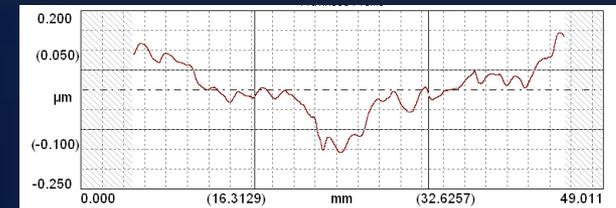
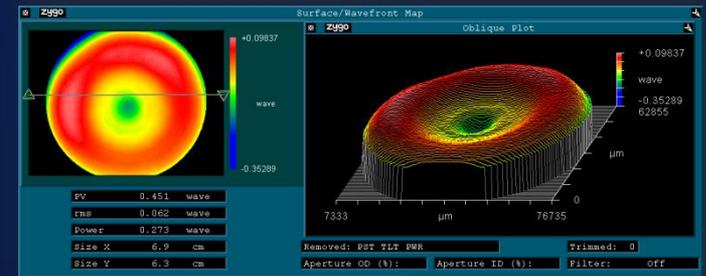
## Measure Removal Function

- Integrated STIL pen
- Onboard metrology



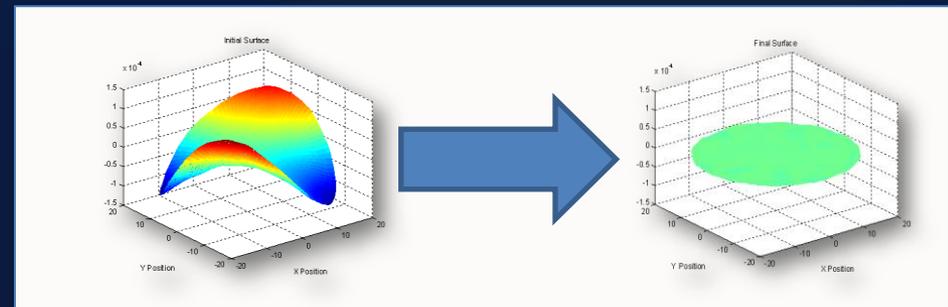
## Input Initial Figure Error

- Zygo Interferometer Input
- Profilometer Input



## Optimize Polishing Tool Path

- Reduce figure error
- Fine control of polishing path



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# USF

- Prepare part for USF correction
  - Lower stock removal will leave less signature
- Smooth MSF post USF
  - Tool design allows for high compression in vertical direction and possesses great torsion stiffness
  - Tooling's compliant layer can be configured with different stiffness materials.
  - Ideal tool design for USF high-pressure, high-speed polishing setup



# 6-Axis UFF @ MSFC

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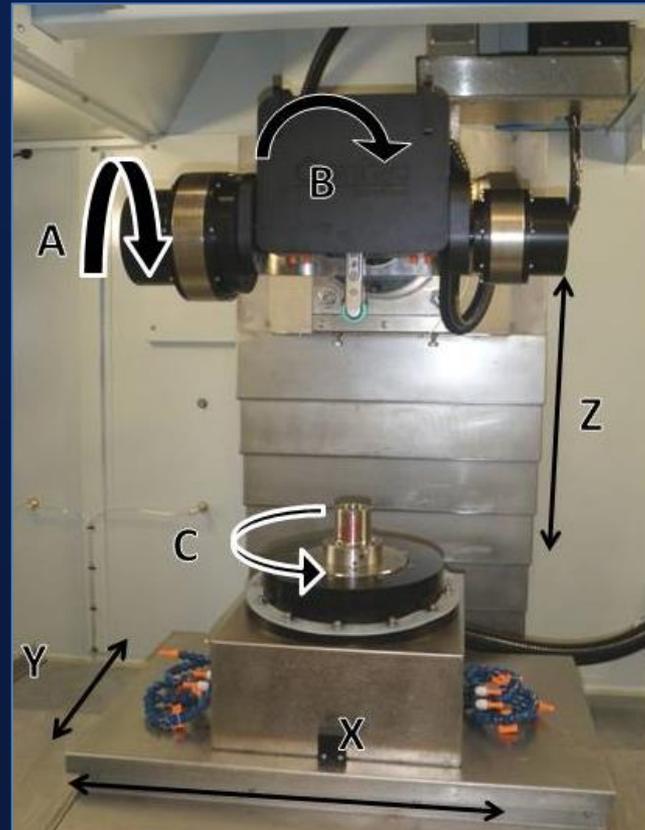
- X,Y,Z linear axis
- A,B,C Rotary Axis
- Tool Rotation motion control
- Work Piece motion control
- Freeform capabilities
- Tool normal -> Surface
- Full CNC Control
- Optical Fabrication software
- Bound and loose abrasives
- Deterministic / corrective



The logo for OPTIPRO, featuring the word "OPTIPRO" in a stylized blue font with a white outline, set against a dark blue background with a white border.

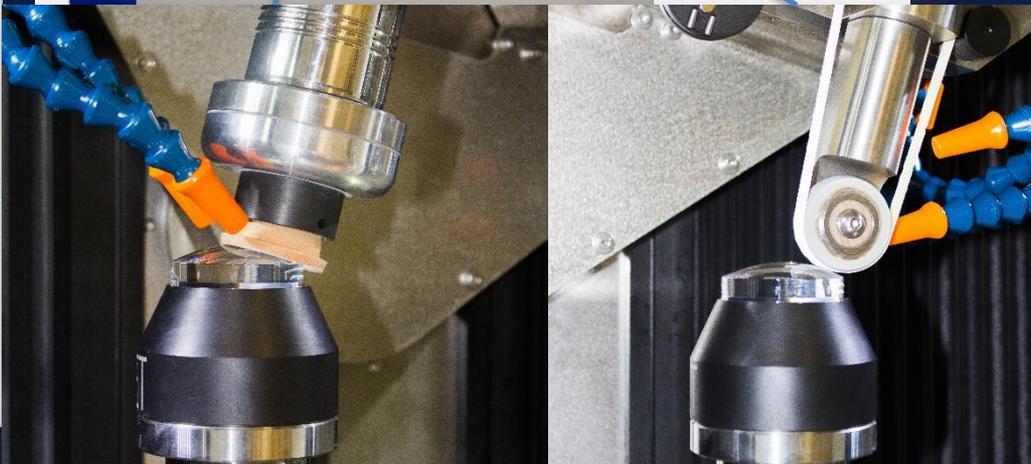
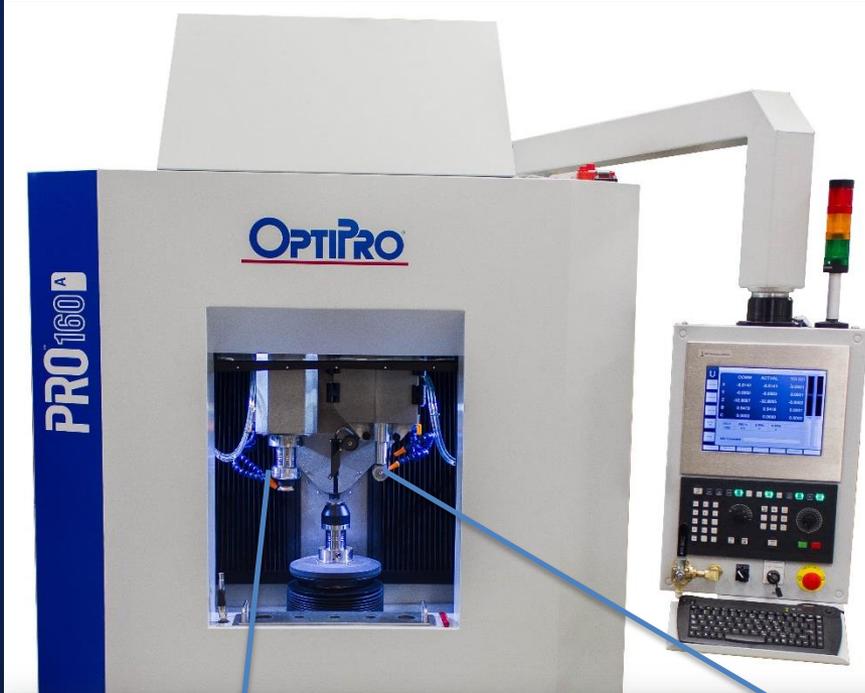
# UFF 300 Platform @ MSFC

The initial platform design was configured with an axis orientation required to polish a rectangular 250 mm x 250mm fused quartz mandrel. The current setup of the 6-axis machine has the A and B axes both on the head with the tool. The useable travel on the x-axis is roughly 430 mm and the useable travel on the y-axis is roughly 315 mm.



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# New 160A(sphere) vs. Triumph



# Tasks



1. Design table mounted precision CNC rotary A-Axis.
2. Rotary Axis and work holding fixture component manufacture and purchase.
3. A-Axis Assembly and Test with calibration standards and measuring equipment.
4. UFF UltraWheel toolpath development incorporating the varied axis configurations.
5. A-Axis Motion Control / Orientation optimization on the CNC test platform at OptiPro.
6. Aluminum Mandrel Fabrication – Nickel Plating.
7. UFF Tooling & Fixture Setup and Design of experiments (DOE) detailed
8. Nickel Plated Aluminum Mandrel Polishing Test with required measurements as detailed in DOE.
9. MSFC Group A ART-XC Mandrels approximate dimensions of 2 inch diameter and 27 inch long.



# Work schedule, milestones, and deliverables

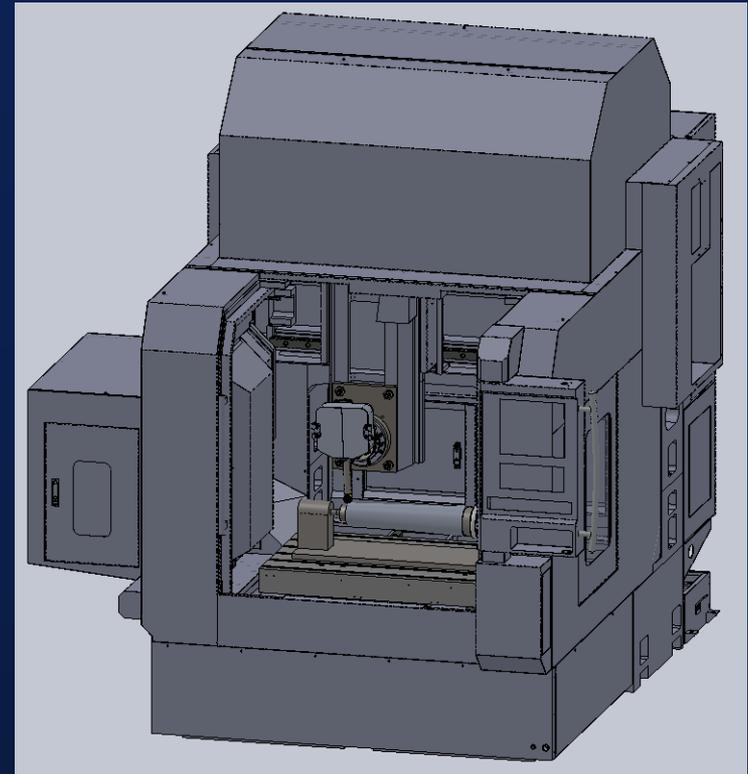
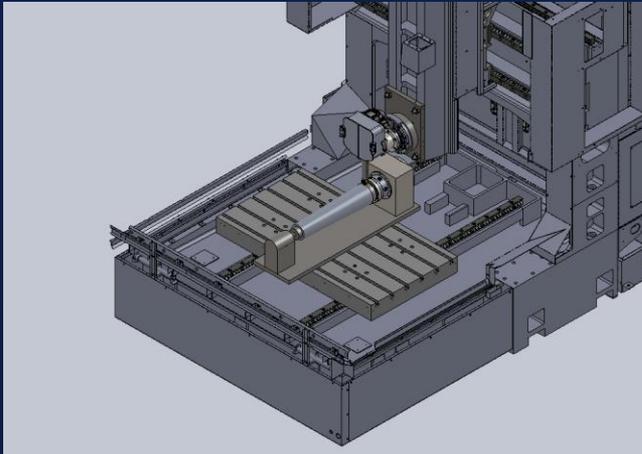
Detailed Phase I work schedule, milestones, and deliverables							
Phase I June 10, 2016 to December 9, 2016							
Task #	Description	June	July	August	September	October	November
1	Design table mounted precision rotary A-Axis	X	X	X			
2	Component Manufacture and Purchase	X	X	X			
3	A-Axis Assembly and Test			X	X		
4	UFF UltraWheel Toolpath Development				X	X	
5	A-Axis Motion Control / Orientation optimization				X	X	
6	Aluminum Mandrel Fabrication				X	X	X
7	UFF Tooling - Fixture Setup				X	X	X
8	Aluminum Mandrel Polishing Test					X	X
	<u>Deliverables</u>						
9	Interim report after 3 months from contract starting date						
10	Final report including project summary documents						
11	Mandrel & A-Axis Assembly						

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# SXL 500 Platform @ OptiPro

Table Mounted Rotary Axis  
XZ Orientation "A-Axis"  
YZ Orientation "B'-Axis"



The 2 Rotary axis orientations ( Along X-axis and then Along Y-axis). The resultant mandrel surface will be measured and analyzed for form errors and mid spatial frequency errors. Process parameter requirements determined.

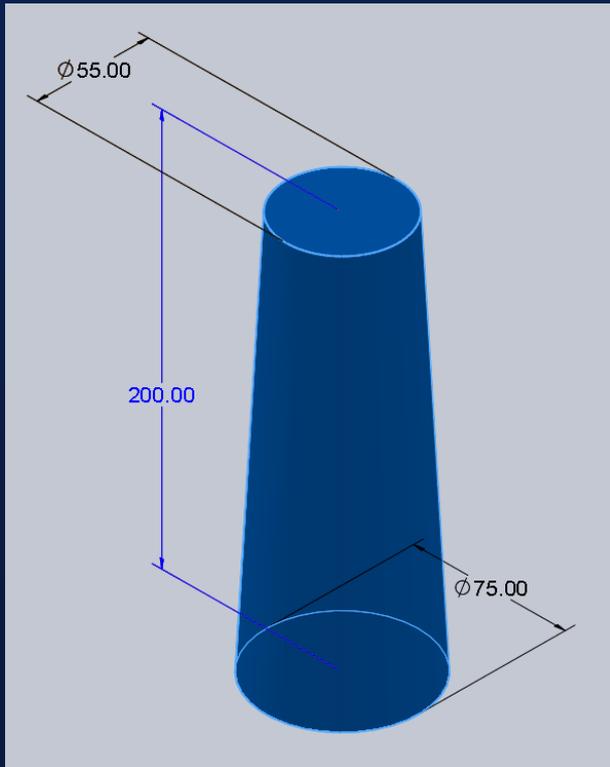
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# Aluminum Mandrel Test Piece

Actual mandrel lengths can extend to 630 mm in length with an average diameter of 100mm.

Proposed work piece size for initial tests shown below....

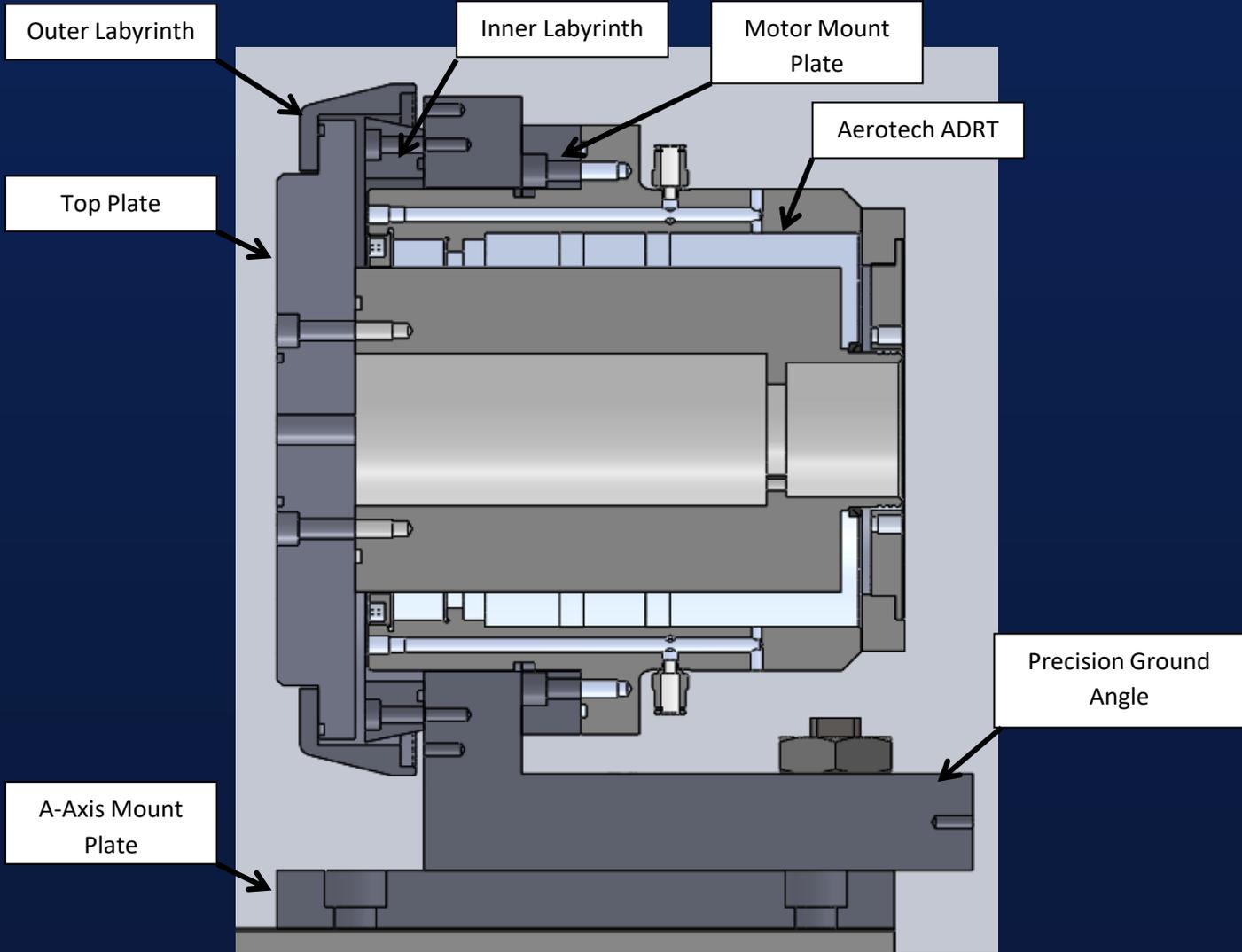


The x-ray optics module alignment station used for the FOXSI project

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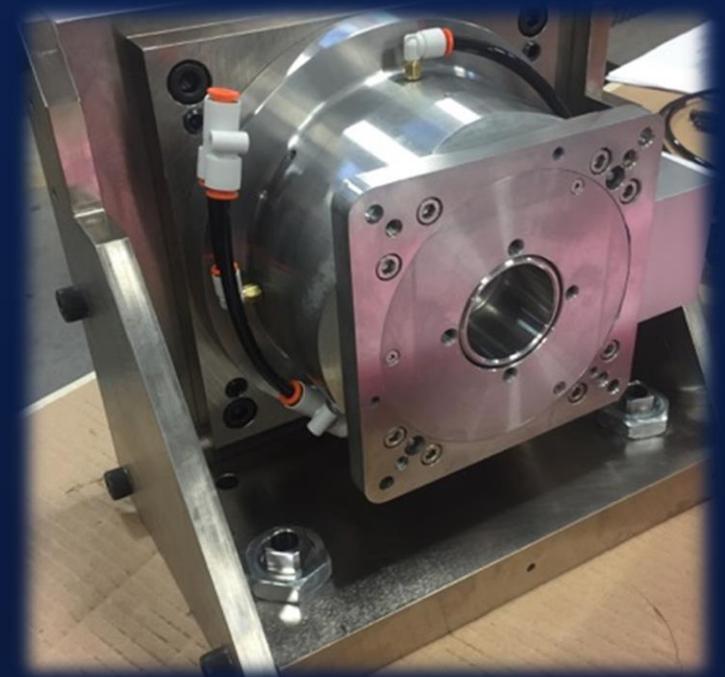
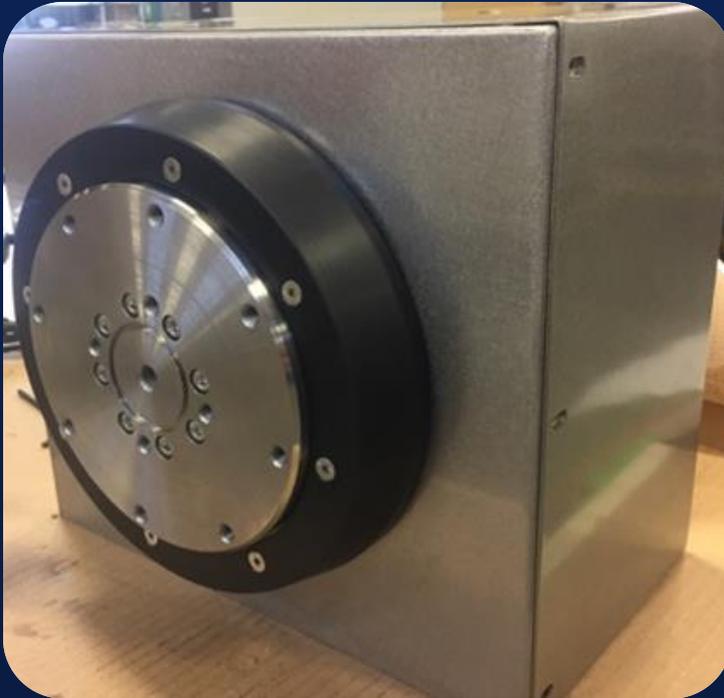


# A-Axis Motor



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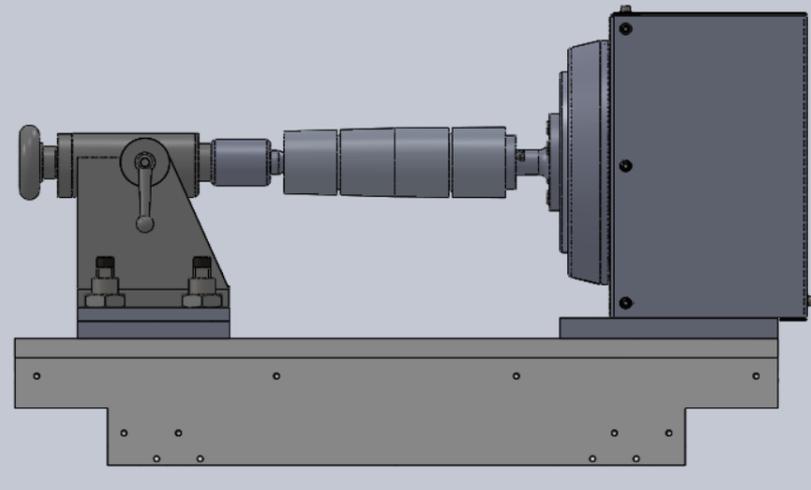
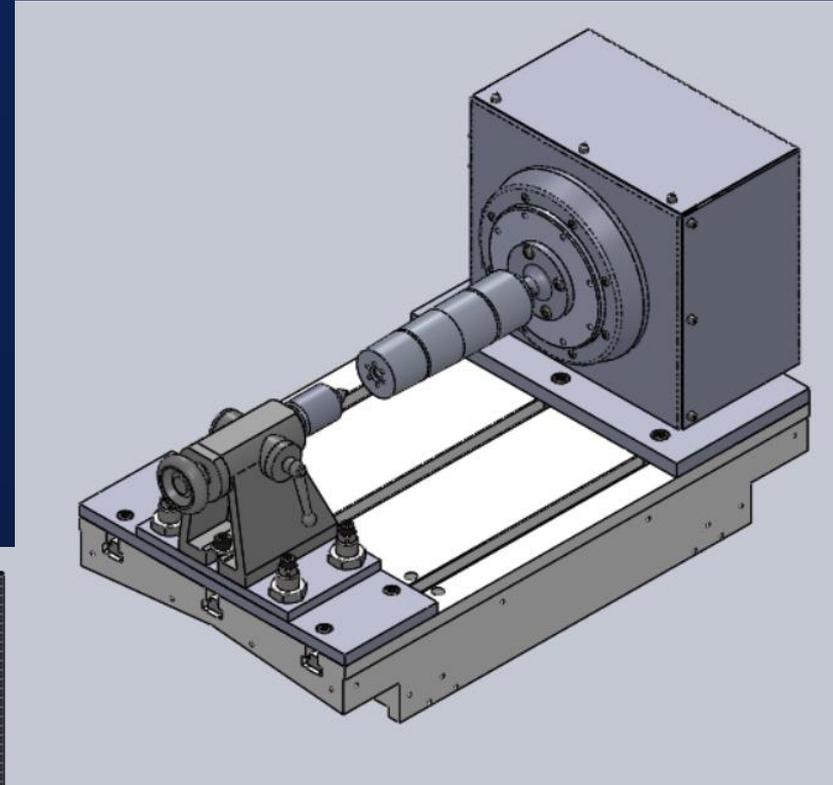
# A-Axis Bearing/Integral Motor Assembly



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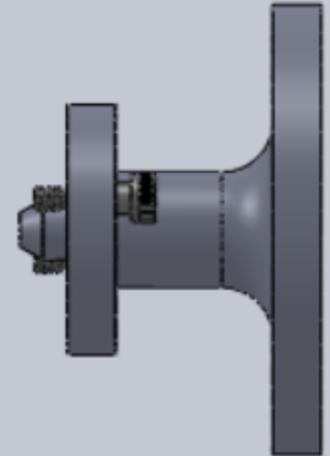
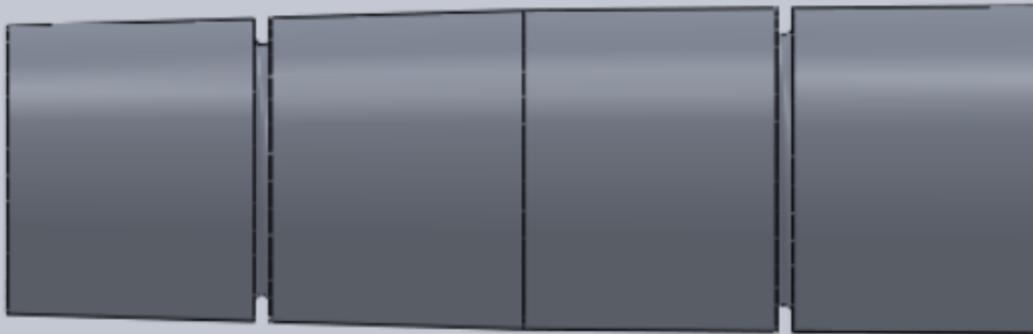


# Part Mounting



# Part Mounting

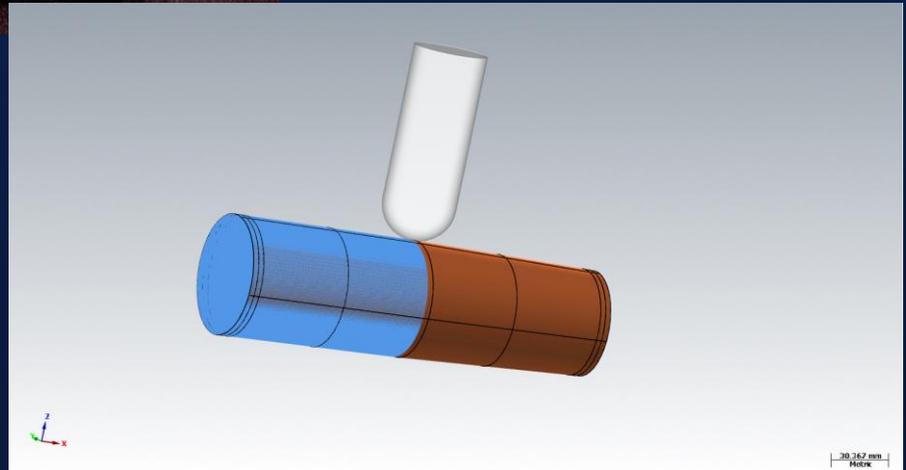
- The part fixture is trammed with the A-Axis motor top plate.
- Shoulder bolts are threaded through the part fixture and into the mandrel to lock rotation.
- The tailstock is then positioned so that the live center puts pressure on the mandrel, securing it in place using tapered features on both ends.



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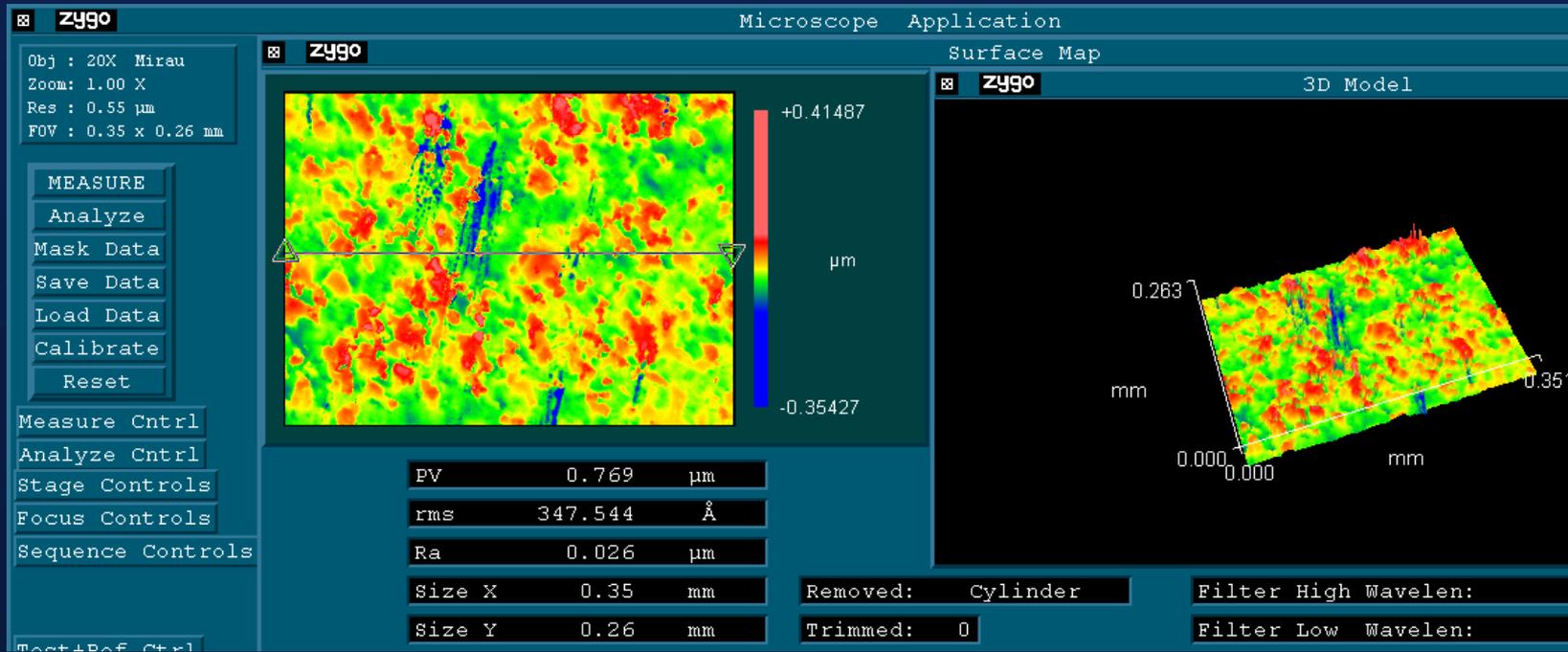


# Nickel Plated Mandrel



# Ni Plating USF Initial Results

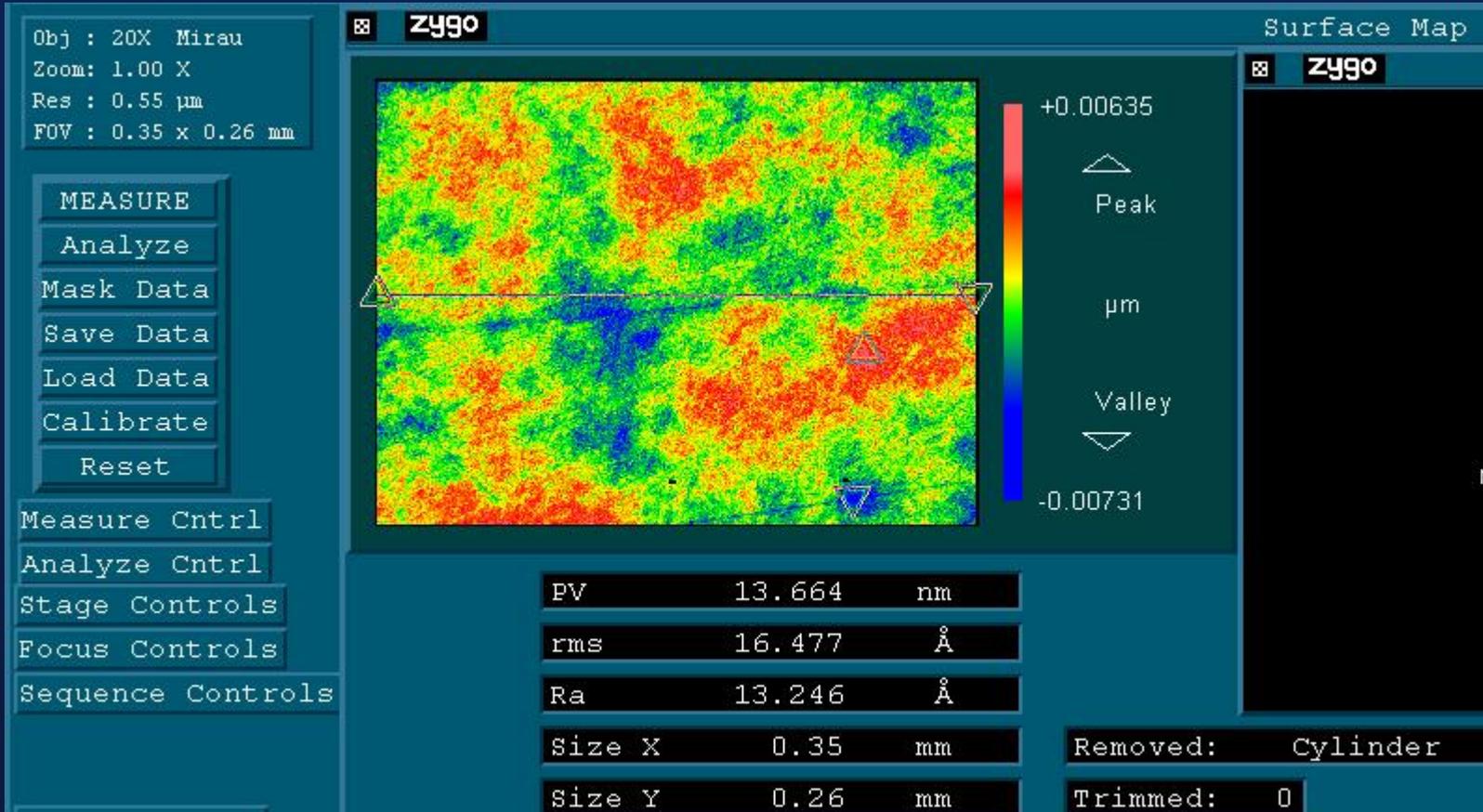
- Silica, Alumina, Diamond Abrasives
- Polish Tool pad materials : Polyurethane, Suba, Felt
- Initial Zygo NewView Surface roughness :
- PV: 769 nm RMS: 347 Angstroms



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# Ni Plating USF Latest Results



# PROSurf USF Toolpath



PROSurf

File Job Process Tool Manage View About

SPINEL USF

Processes Tools Orientation Surface Motion Fixture Correction Tool Path

Coolant  
 Thru Tool Coolant  
 High Speed Cutting  
 C-Axis Brake

Work Coordinates: G54  
Safety Feed Rate: 10

Spindle Rotation:  CW  CCW  
USF Spindle:  S1  S3

Write To Screen  
 Write To Disk

Write

```

    (Tool Name: 50mm USF Pad)
    (Tool Type: USFPad)
    (X-eccentricity: 0 mm)
    (Y-eccentricity: 0 mm)
    (Tool Length B: 100 mm)
    (Axis Align B: 0 mm)
    (B angle compensation: off)
    (Compression: 0 mm)
    (Correction Type: grayOut)
    (Gray Out Time: 0 min)
    (Random Pause: On)
    G01 F300 G7 G40 G90
    G53 Z0.
    G54
    M16
    M8

    #HSC ON [FAST]
    S1=120 M3
    X-98.038
    Y-52.215
    Z11.756
    B8.285
    C69.358
    X-98.038
    G93 G01 X-98.038 F10
    X-98.038 Y-52.215 Z11.756 B8.285 C69.358 F0
    
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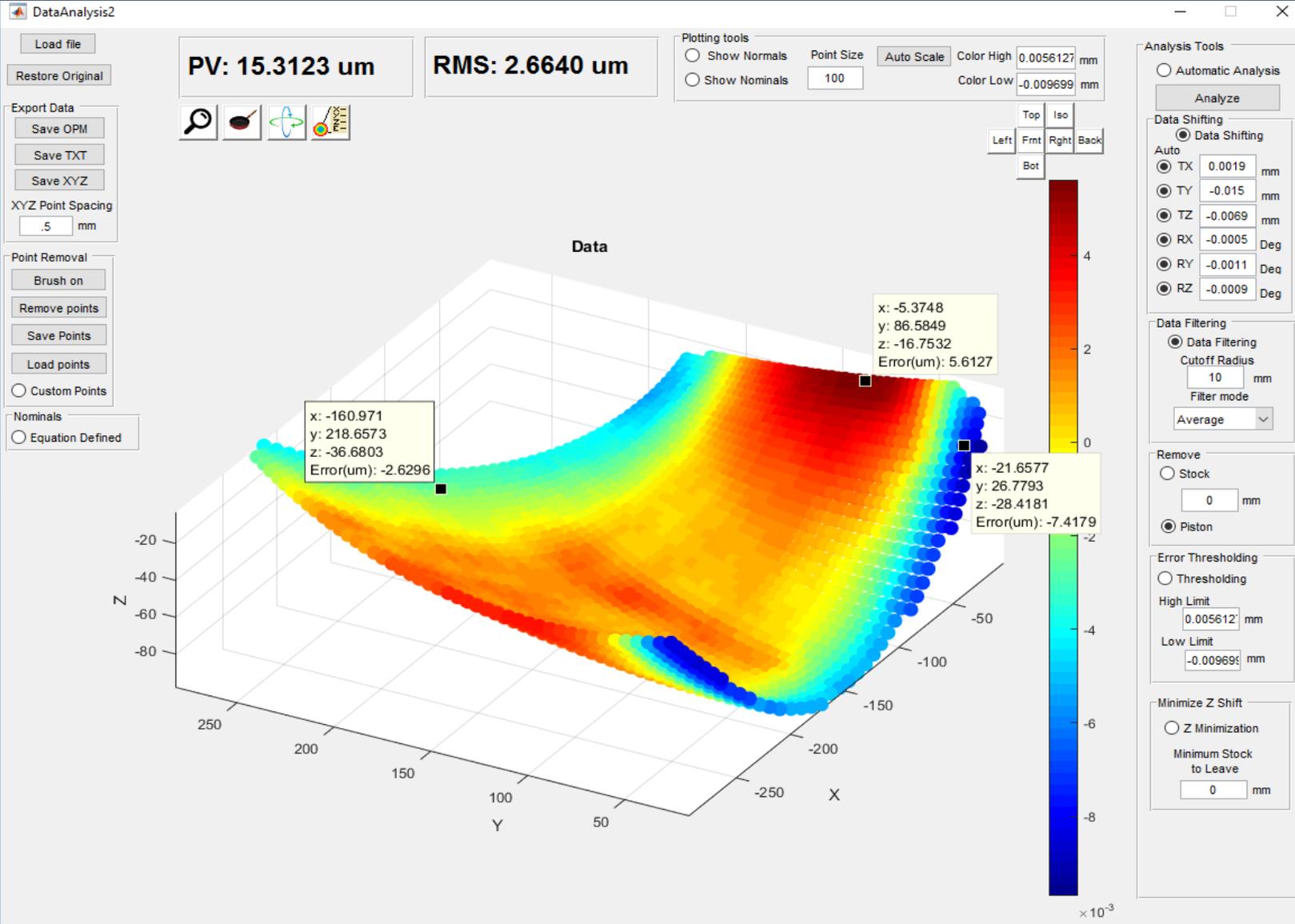
Machine On

Slow Fast  Panels On

Start

1:37 PM 3/30/2014

# Measurement Analysis



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APOMA

American Precision Optics Manufactures Association

# TUCSON TECH

WORKSHOP

NOVEMBER 10th-11th

Don't miss your chance to:



Learn new technologies and  
manufacturing tips



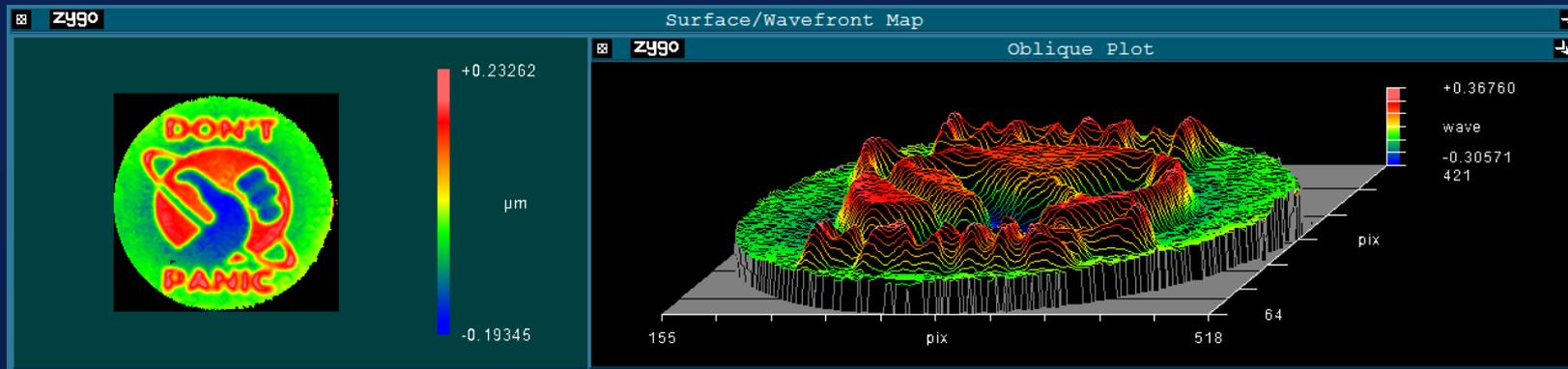
Hear the latest industry  
insights



Connect with leaders of  
the optics community

**BONUS:** Attendee's will be able to tour the University of Arizona Richard F. Caris Mirror Laboratory

# Thank You



The Hitchhiker's guide to the galaxy

- There are many challenges to manufacturing acylinder and freeform optical components, but Don't Panic!
- OptiPro continues to develop technologies in Grinding, UFF, UltraSurf, and ProSurf to deterministically fabricate precise complex optical surfaces.

