OptiPro Systems

Grinding, Polishing and Non Contact Metrology of PolyCrystalline Alumina Missile Domes

Mirror Technology SBIR/STTR Workshop

June 18, 2009

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Facility in Ontario, NY

- 12,500 sq. ft. building
- Engineering Department
- Technical Training Center
- Optical Fabrication Research & Development area
- Temperature Controlled Machine Build & Assembly
- Technical Service Center
- CNC Manufacturing (milling turning and grinding)
- Metrology Lab
- Marketing & Sales
- Product Show Room

Optical Fabrication History

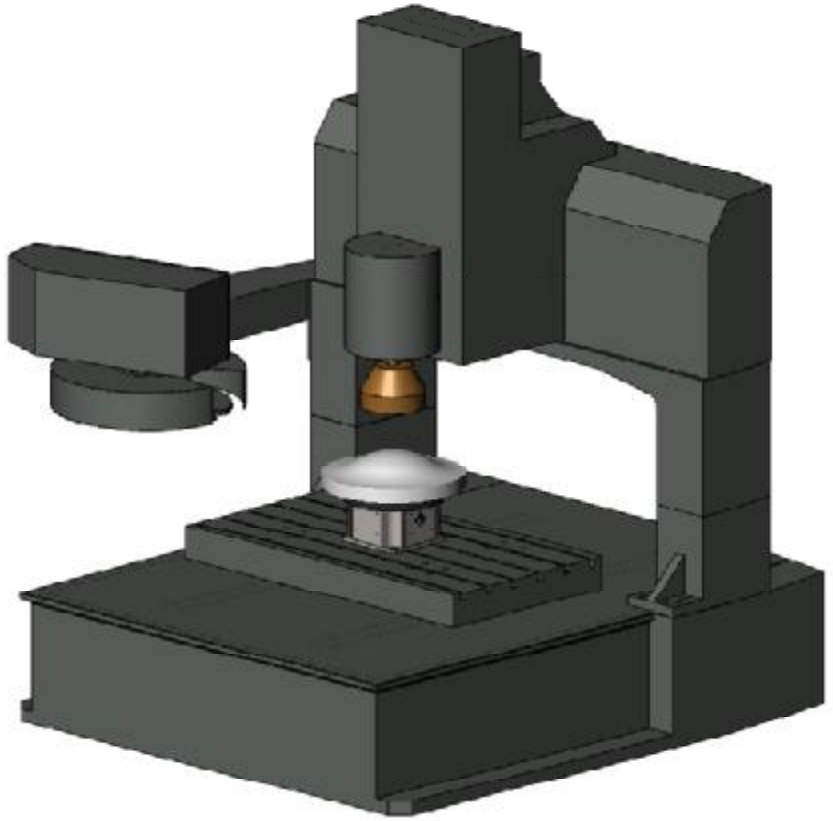
- SX Optical CNC Machining Centers
  - Defense Advanced Research Projects Agency, DARPA
  - Developed with the Center for Optics Manufacturing, Kodak and DARPA
  - Machines sold to many fabrication companies and DOD Prime Contractors
- PX Optical Spherical High Speed Polisher
- UFF UltraForm Finishing
  - Initial prototype developed with Army Contract DAAE30-95-C-0091 SBIR
  - PCA Ogive production with Navy Contract N41756-05-M-1390 SBIR
  - Machines sold in fabrication companies and DOD Prime Contractors
  - Materials include: Glass, PCA, ALON, Spinel, SiC, IR Material
  - Shapes include: Domes, Aspheres, Ogive, Non-Axisymmetric freeform
- UltraSurf 5-Axis Non Contact Metrology System
  - Development with Naval Air Systems Command Contract N68936-07-C-0046 SBIR
  - Prototype platform for Dome, Ogive, Asphere and Freeform surfaces

eSX 150 Optical Machining Center

- Capacities from 5 mm to 150 mm
- 1,000 to 24,000 Liquid Cooled, Air Purged, Ceramic Hybrid Grinding Spindle
- Highly repeatable HSK 63 quick change tool holders
- EZ to use Graphical User Interface
- Fagor 8070 5 Axis CNC Control
- B-Axis Travel -95 to +95 Degrees
- Automatic Curve Correction
- Automatic Tool Changer
- Tool Setting probe /Work Probing System
- Built in electronic spherometer
- Ethernet communications

SXL 500 Optical Machining Center

- Workpiece Diameter Range of 10-500mm, max weight of 170 kg
- Work Spindle 1-250 rpm
- Tool Spindle 100-12,000 rpm
- Quickchange Tooling
- Vacuum Workholding
- 48” x 28” x 20” XYZ Axes travels
- B-Axis ±90°, C-Axis 0° to 360°
- Automatic Tool Changer
- Tool/Workpiece Probe
- User Friendly Operator Screens
- Built in Electronic Spherometer
- Ethernet communications
- Fagor 8070 5-axis CNC Control

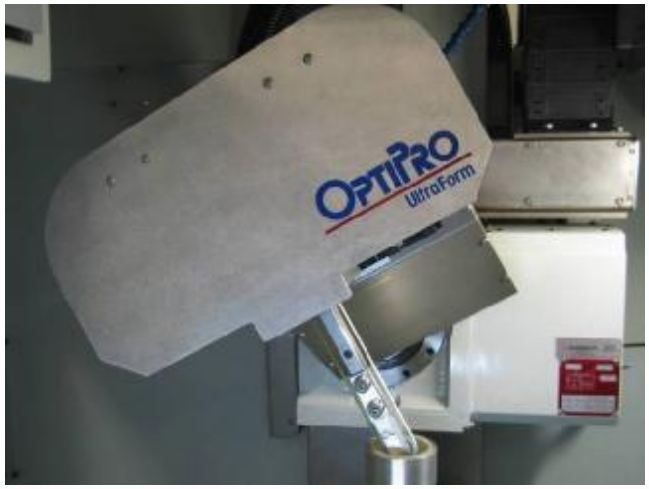


ePX150 Hi Speed Spherical Polisher

- Fagor 8070 CNC Controlled polisher with Graphical User interface for fast process setup and adjustment
- In process monitors to determine process requirements for new materials
- Hydro expansion chucks for versatility and compatibility of tooling and setups
- Quick slurry change over system and containment cleaning cart
- Special features for hemispherical Dome polishing

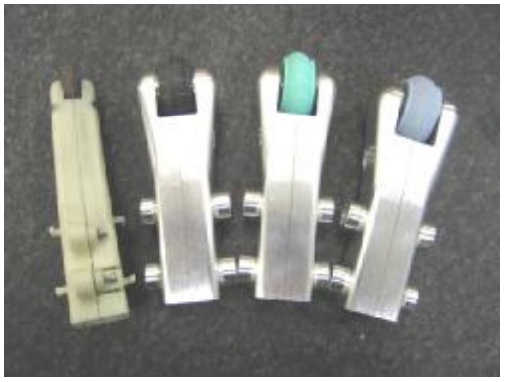
UltraForm Finishing

- §5 axes – 3 Linear X,Y,Z and 2 Rotary B and C
- §Fagor 8070 CNC Control with User Friendly GUI
- §On-Board metrology for removal function and preliminary part measurement
- §Bound/Fixed abrasive with Coolant / Slurry Options



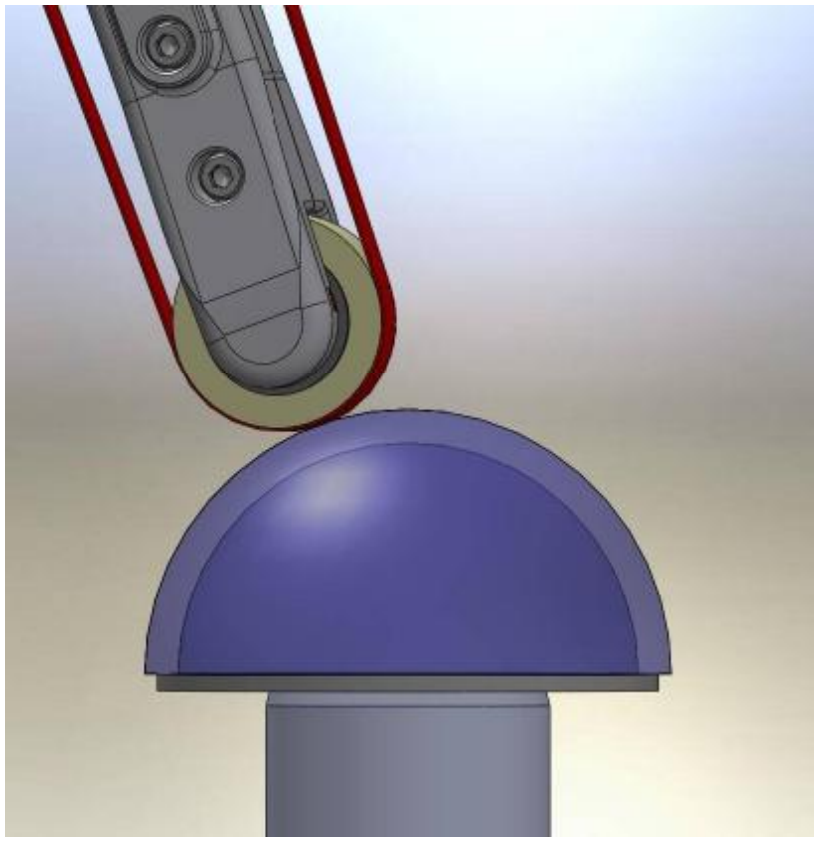
UFF Solution

- Polish, fine ground spherical, aspheric, freeform and plano surfaces (No pre-polishing requirements)
- 2 different length arms, the long extension arm of the wheel allows finishing inside deep concave ogive missile domes geometries
- Wide variety of wheel durometers and diameters and abrasive belts
- Long belt lengths with a variety of finishing materials and slurries allows for a more deterministic polishing process
- On-board metrology for work piece and removal function analysis
- Intuitive Graphical User Interface



UltraForm Finishing: How it Works

- UltraForm Finishing polishes using a precision controlled belt
- Fixed abrasive cerium oxide, alumina and diamond belts
- Conventional polyurethane pad belts with abrasive slurries



Laser Probe of UltraWheel

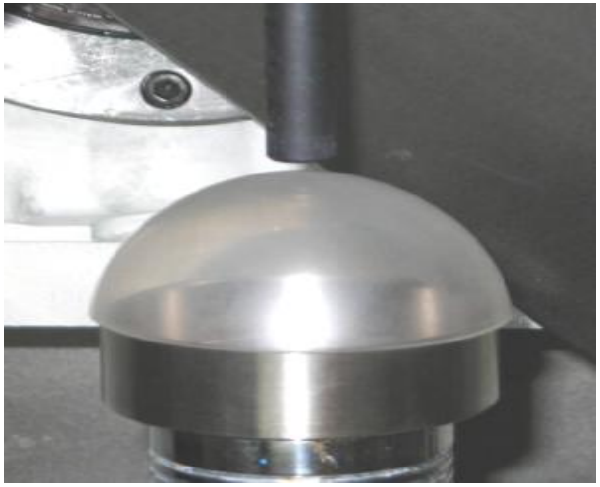
- Laser Probing the tool gives us valuable information
  - The exact location of the tool in the X and Y axis
    - This allows for the best possible centering
  - The exact size and shape of the tool
    - This allows for the tool to be modeled as accurately as possible

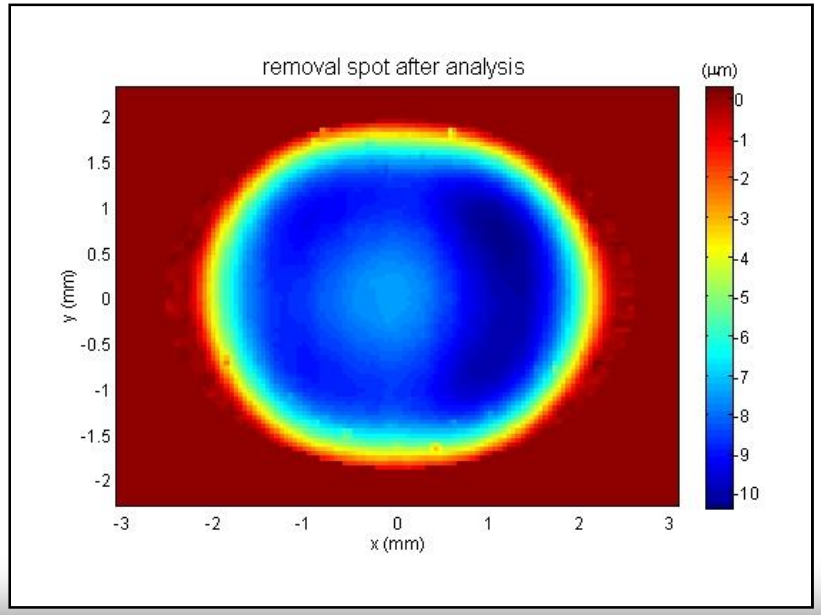
UFF Process Flow

Measure Removal Function

- Integrated STIL pen
- Onboard metrology

INPUTS	SPOT ANALYSIS RESULTS
inputted part form: PLANO	volume: 0.0992 mm^3
	depth average: 7.06 µm
	maximum depth: 10.4 µm
	spot length: 4.91 mm
	spot width: 3.64 mm
inputted spot shape: NON-FRAGMENTED	spot area: 14 mm^2
spot dwell time: 15 s	volumetric removal rate: 0.397 mm^3/min

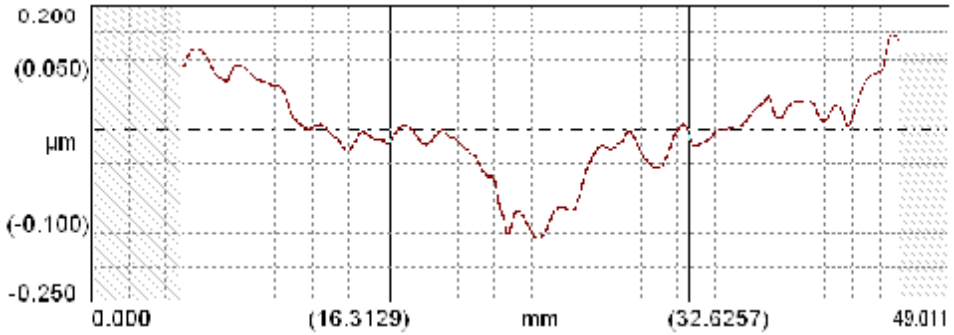




UFF Process Flow

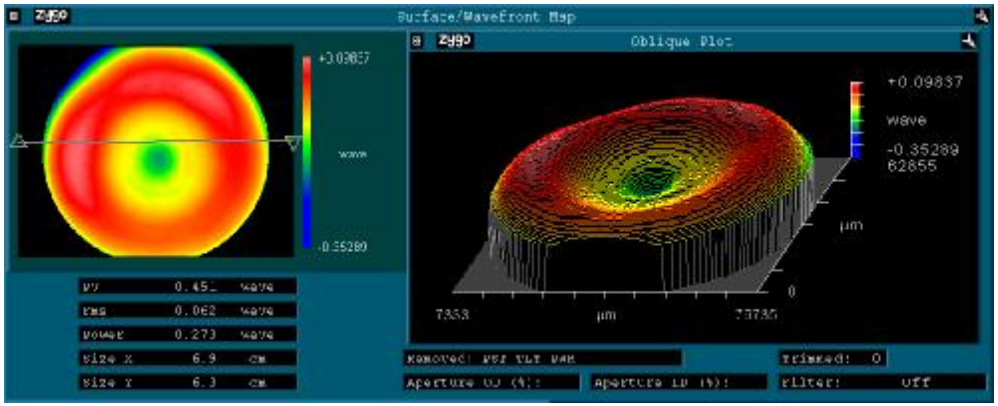
Measure Removal Function

- 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

Many different metrology options

UFF Process Flow

Measure Removal Function

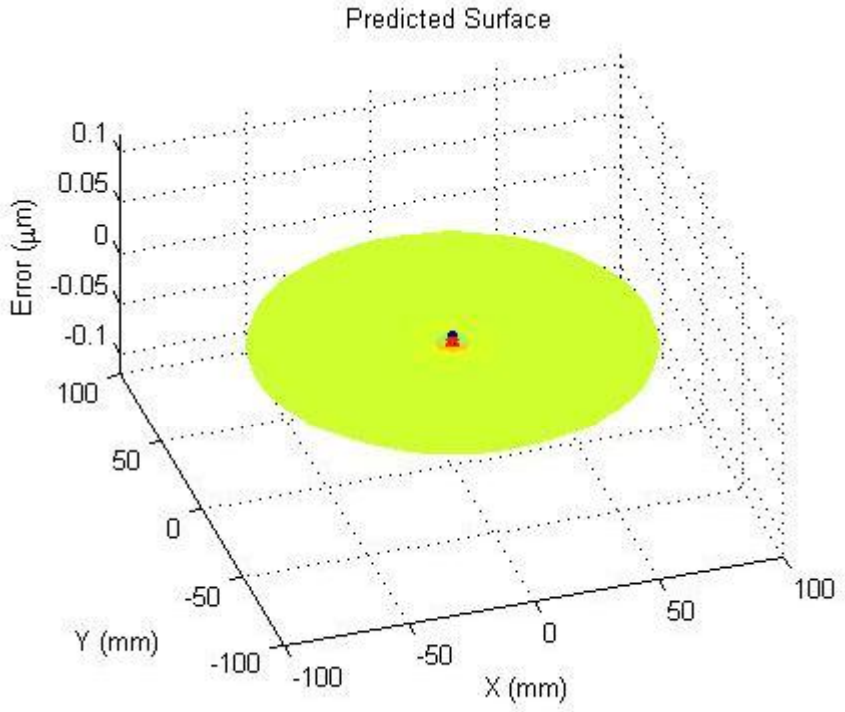
- Integrated STIL pen
- Onboard metrology

Input Initial Figure Error

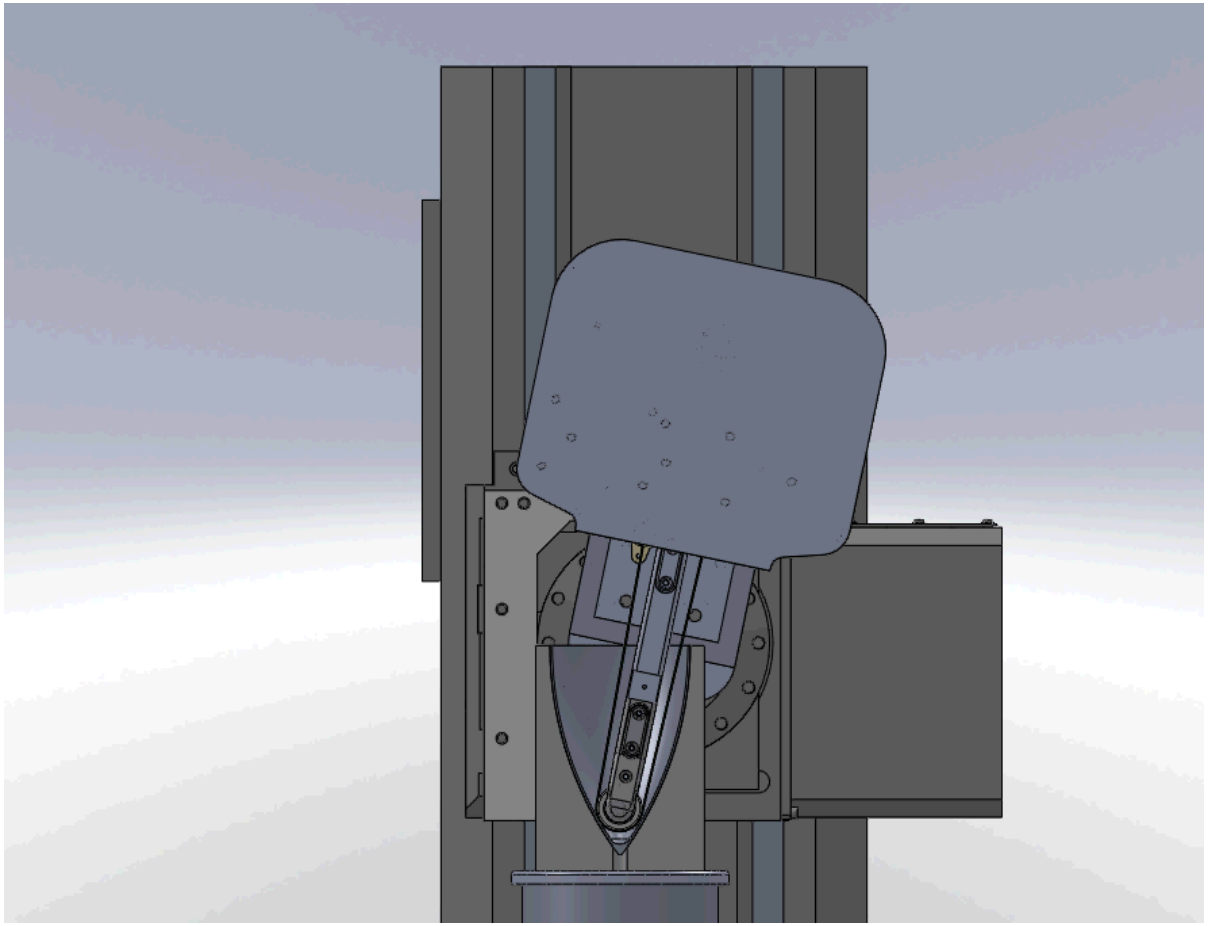
- Zygo Interferometer Input
- Profilometer Input

Optimize Polishing Tool Path

- Reduce figure error (PV) and roughness (RMS)
- Fine control of polishing path



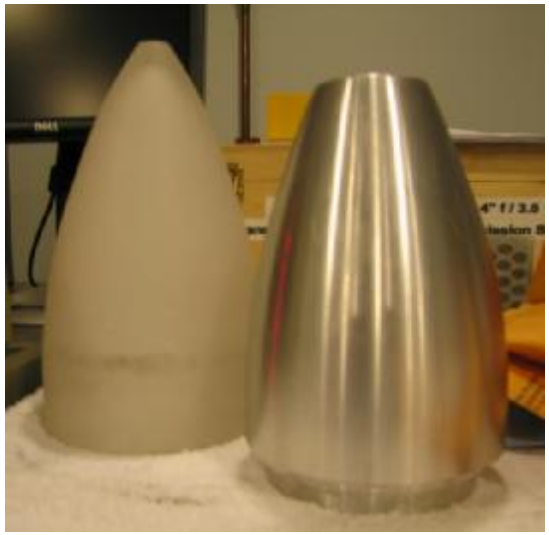
UltraForm Finishing of Ogive Missile Dome



Deep Concave Missile Dome finished on the UltraForm Finishing platform

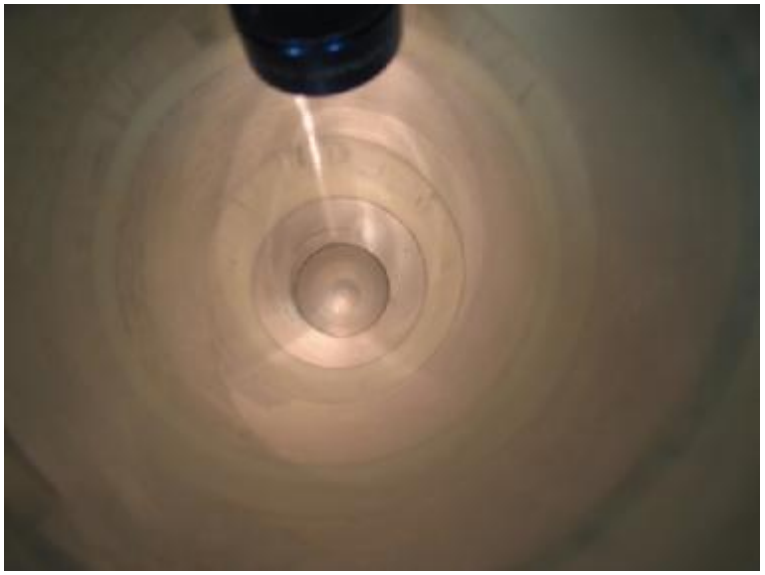
AlON Ogive Pre-Forming

Block Raw Blank On ID → Rough Grind OD → Remove Plug From Part



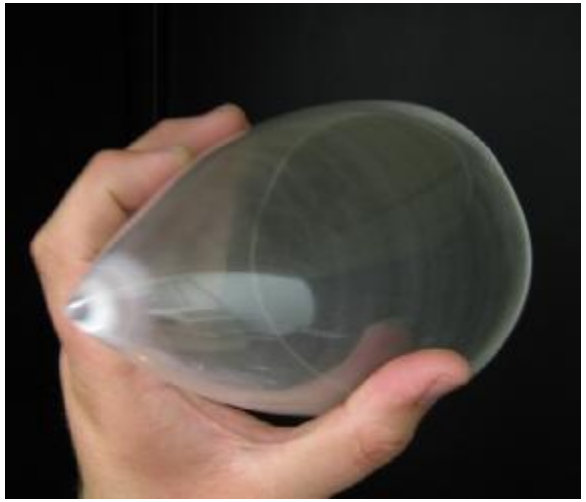
AlON Ogive Inner Surface Process

Block on OD Fixture → Rough and Fine Grind ID → Move Fixture with Ogive to UltraForm Polishing Machine Polish ID De-block

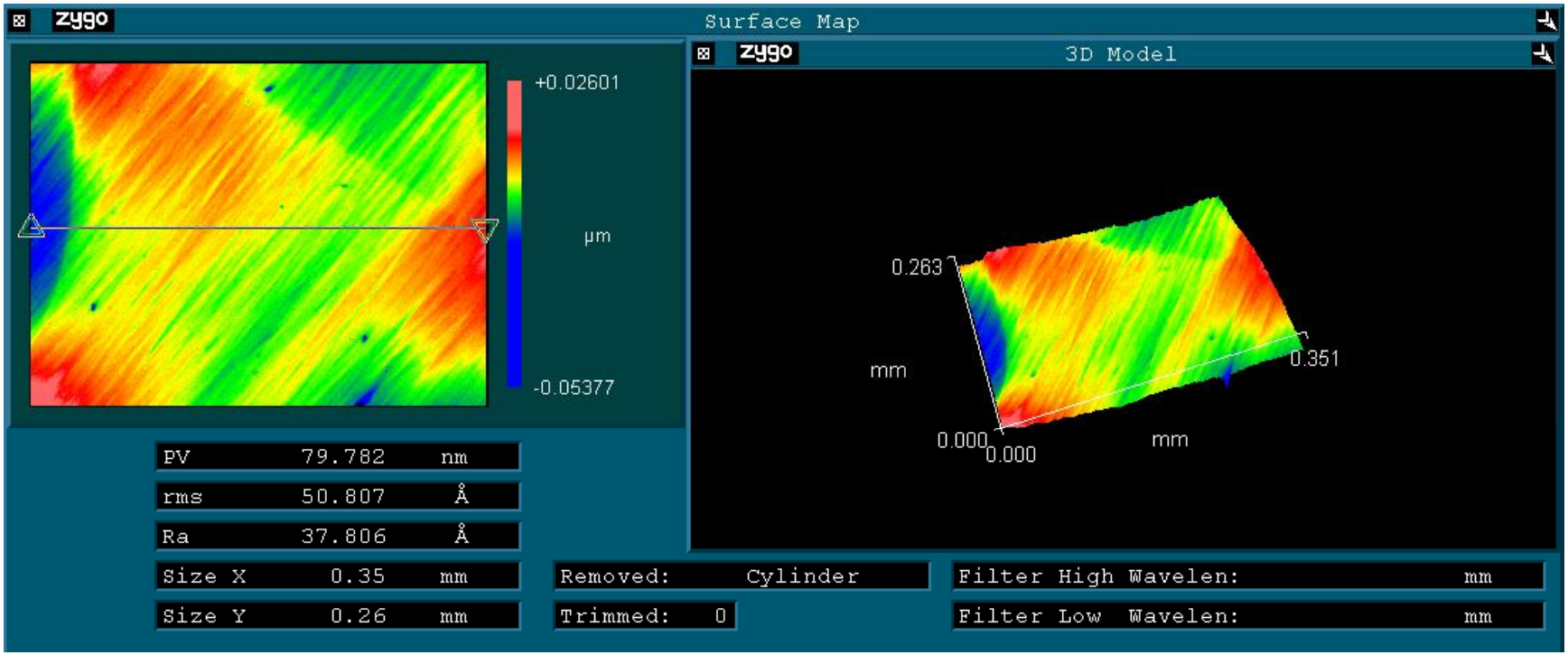


AlON Ogive Outer Surface Process

Block on ID Fixture → Rough and Fine Grind OD → Move Fixture with Ogive to UltraForm Polishing Machine → Polish OD → De-block



Results - ALON

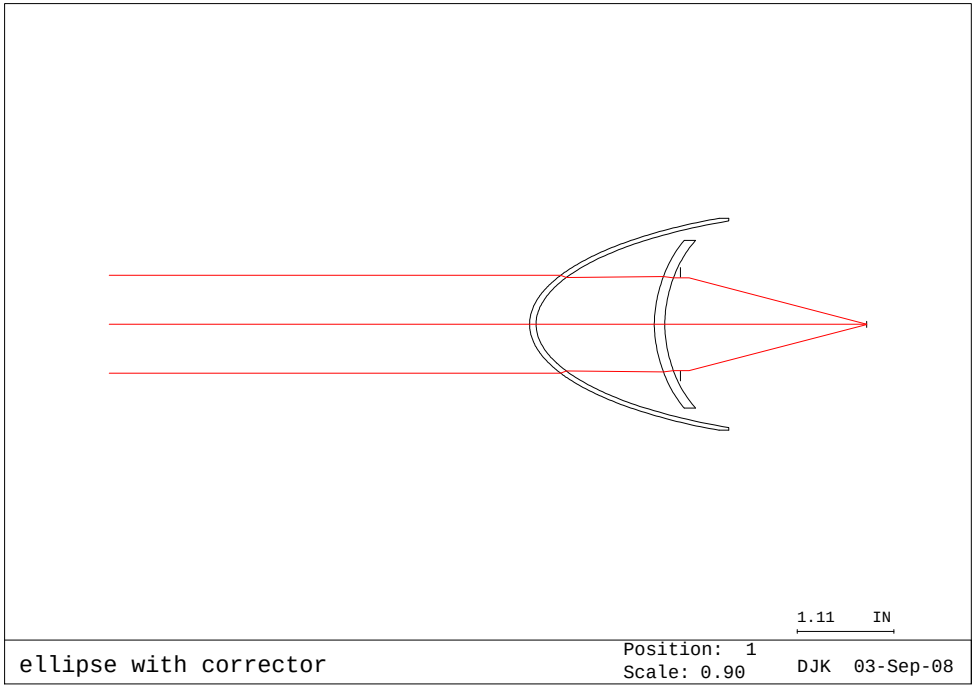


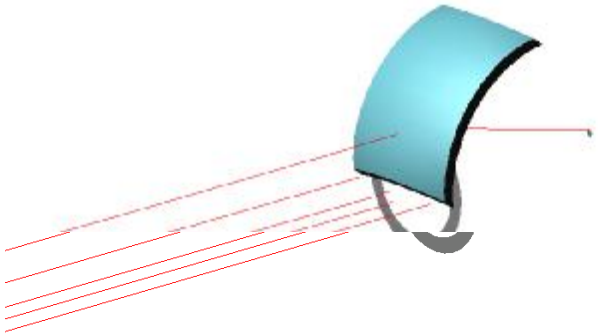
Fast Removal Rate

Bound Abrasive – No Clean Up

50 Angstrom rms finish - Reduced Grain Highlighting

Why FreeForm / Conformal?



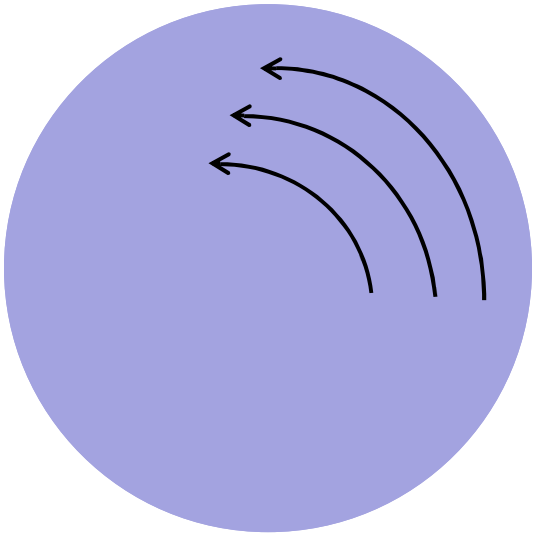


§ Corrector Optics for Ogive Domes will not have rotational symmetry

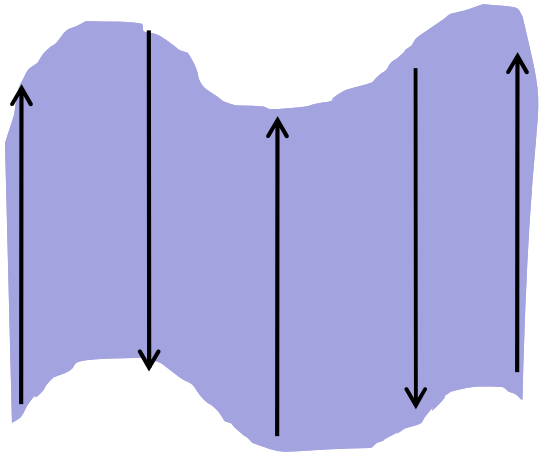
§ Conformal Optics = Aerodynamics / Stealth (ie.wing of a jet fighter)

Why Raster?

The R-Theta solution works well for rotationally symmetric material removal. However, this solution will not work as well for conformal and free-form optics.

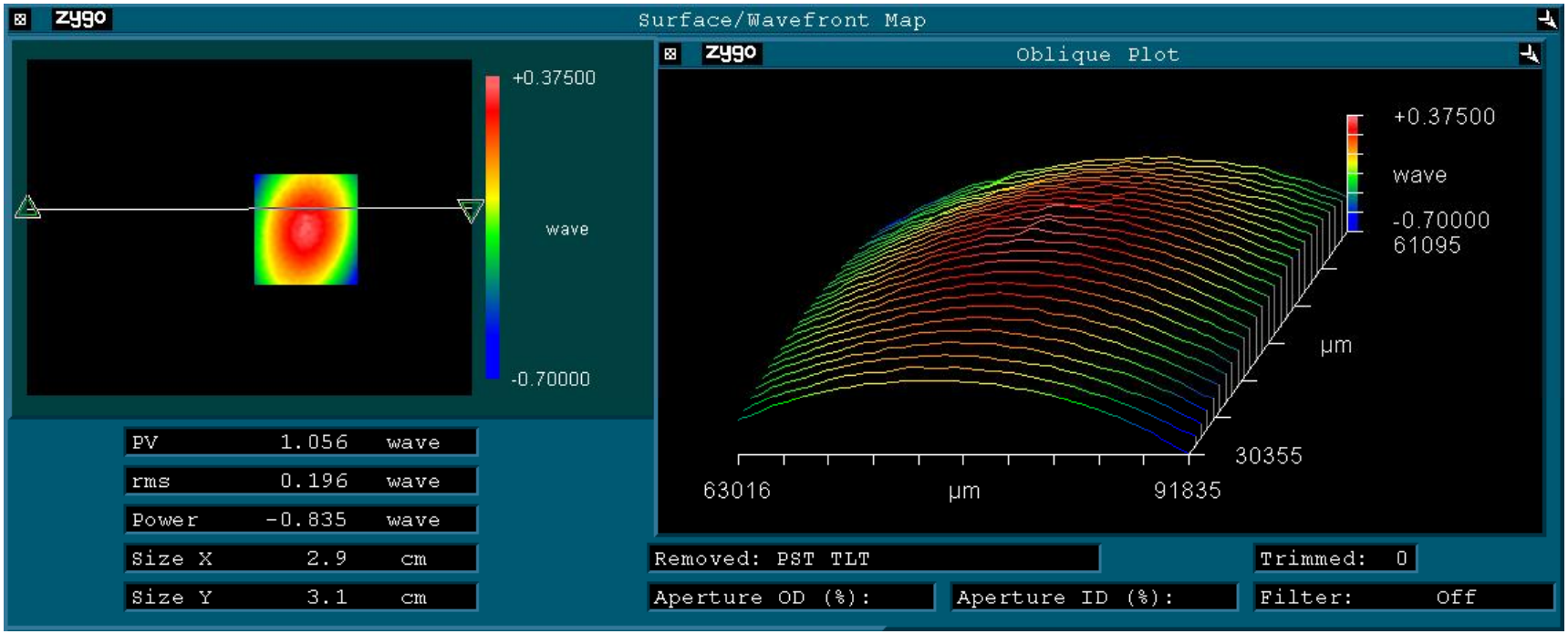


R-Theta



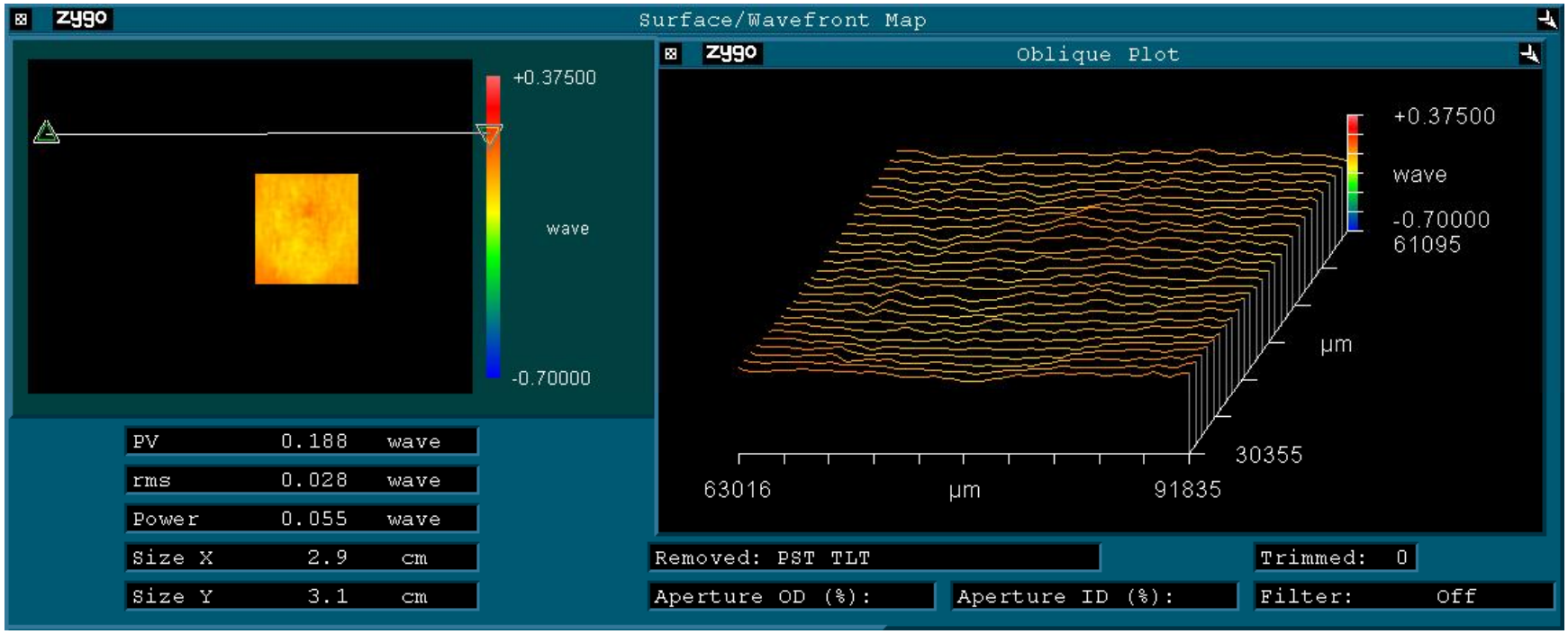
Raster

BK7 – Plano Raster Polish



Initial 30mm diameter surface had 1 wave PV error

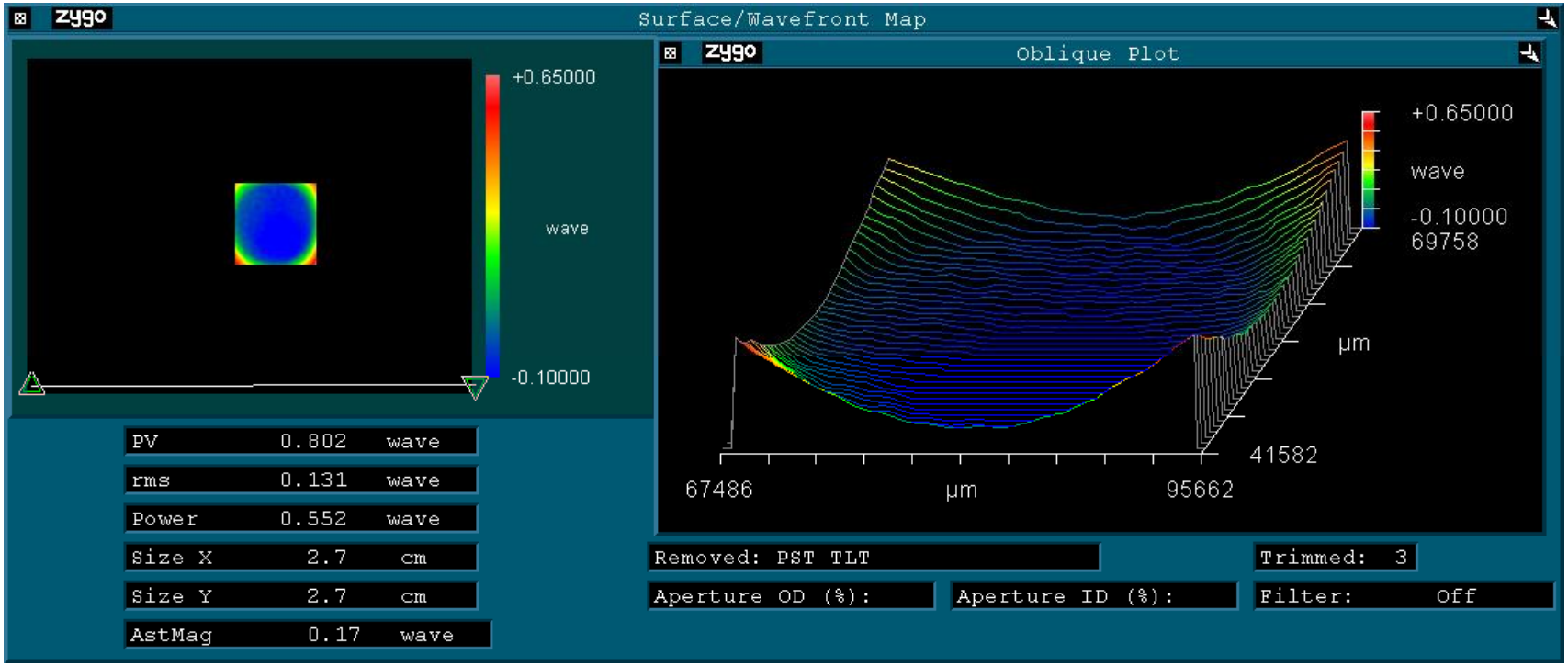
Results – Plano Raster



5X improvement in PV

7X improvement in RMS

Plano Raster Toolpath

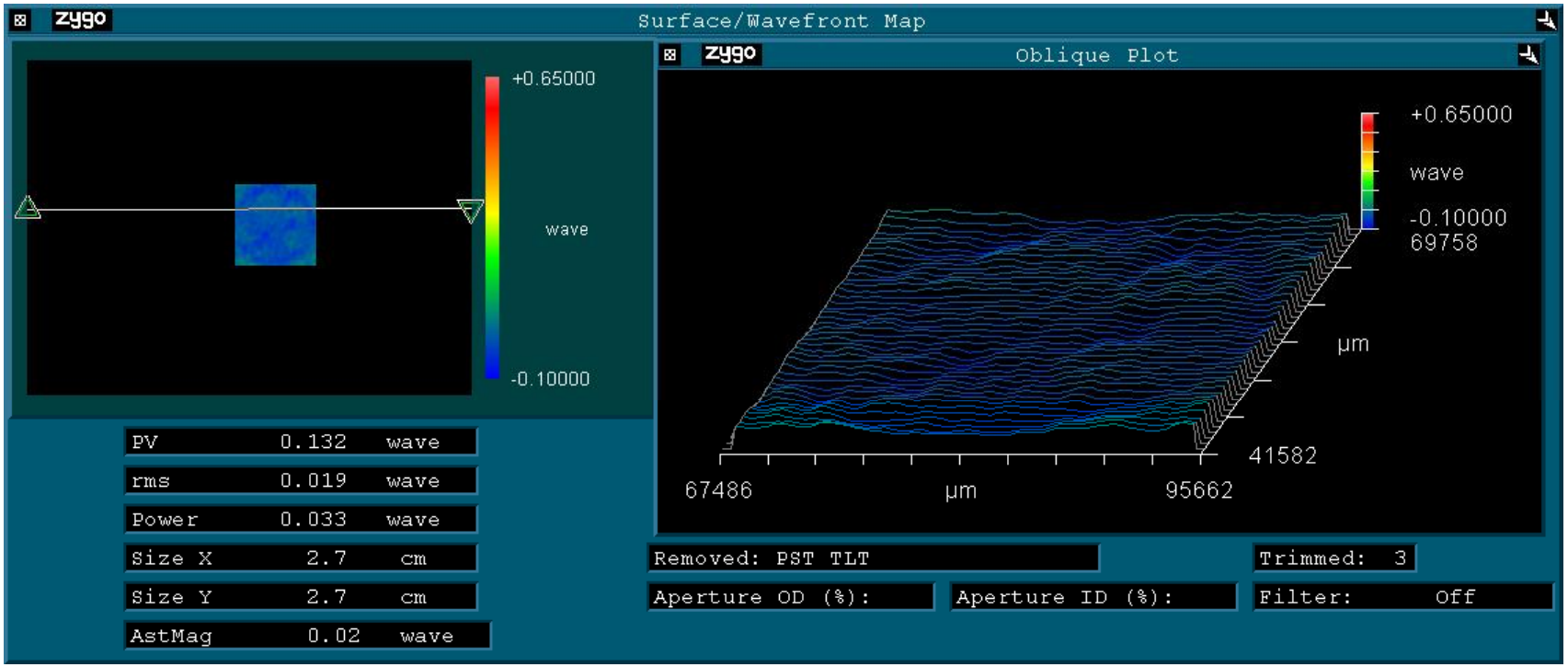


Initial surface had significant error

PV = .8 wave

RMS = .13 wave

Results – Plano Raster

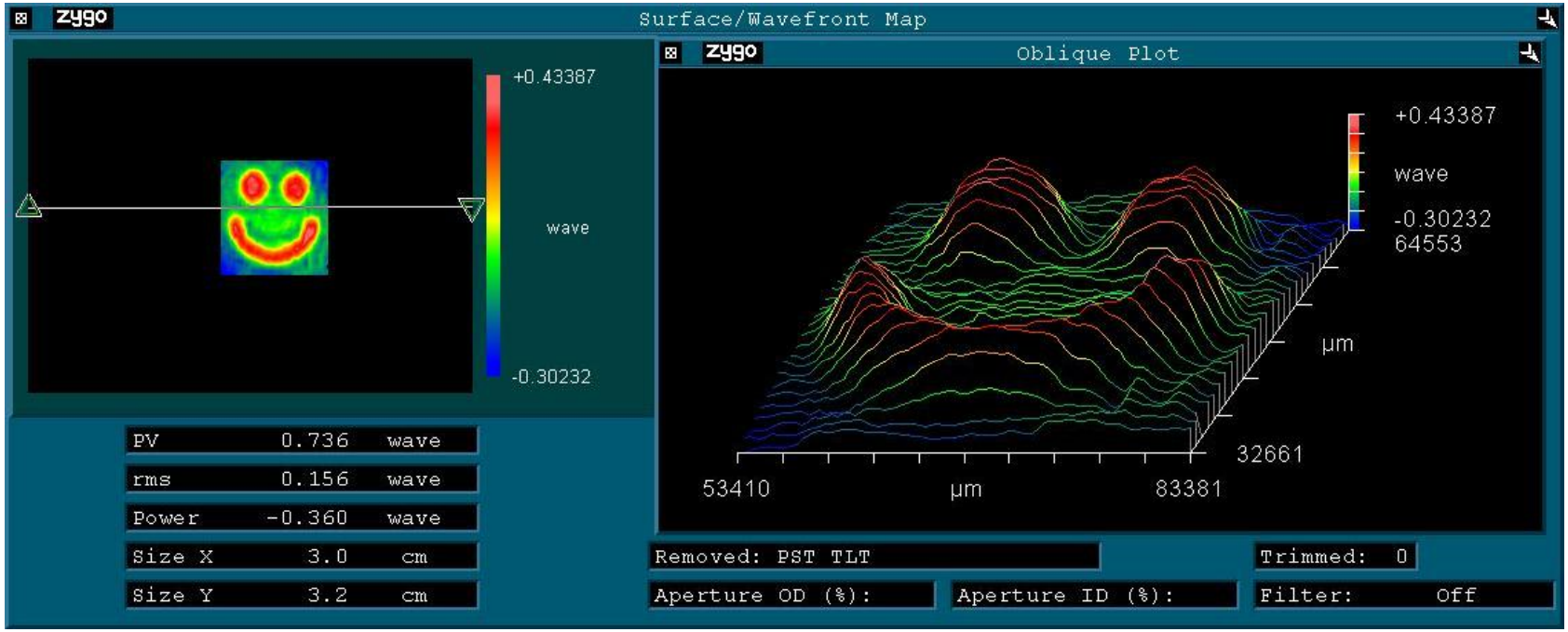


Corrected Surface Results

PV = .13 wave

RMS = .02 wave

Results - Plano Raster

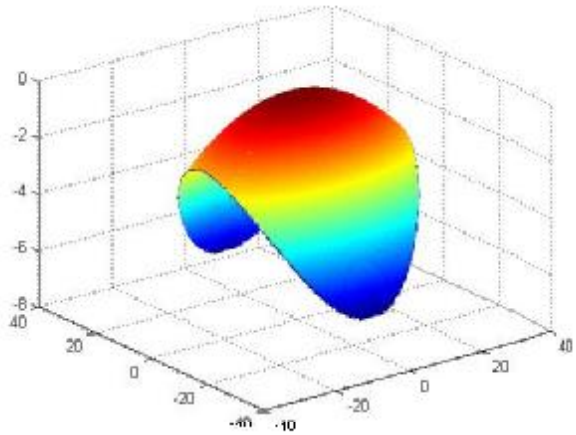


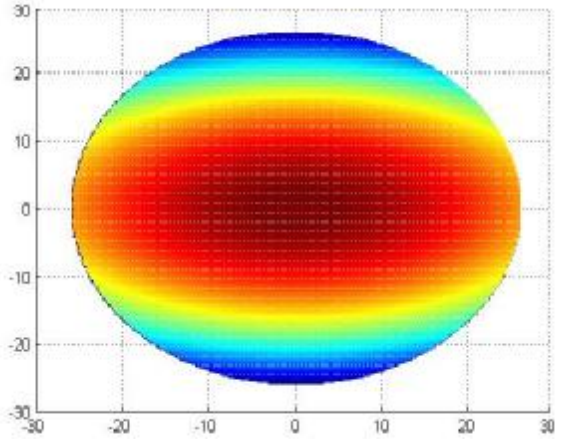
0.7 Wave PV of Controllable Happiness

Initial Results - Ellipse Raster

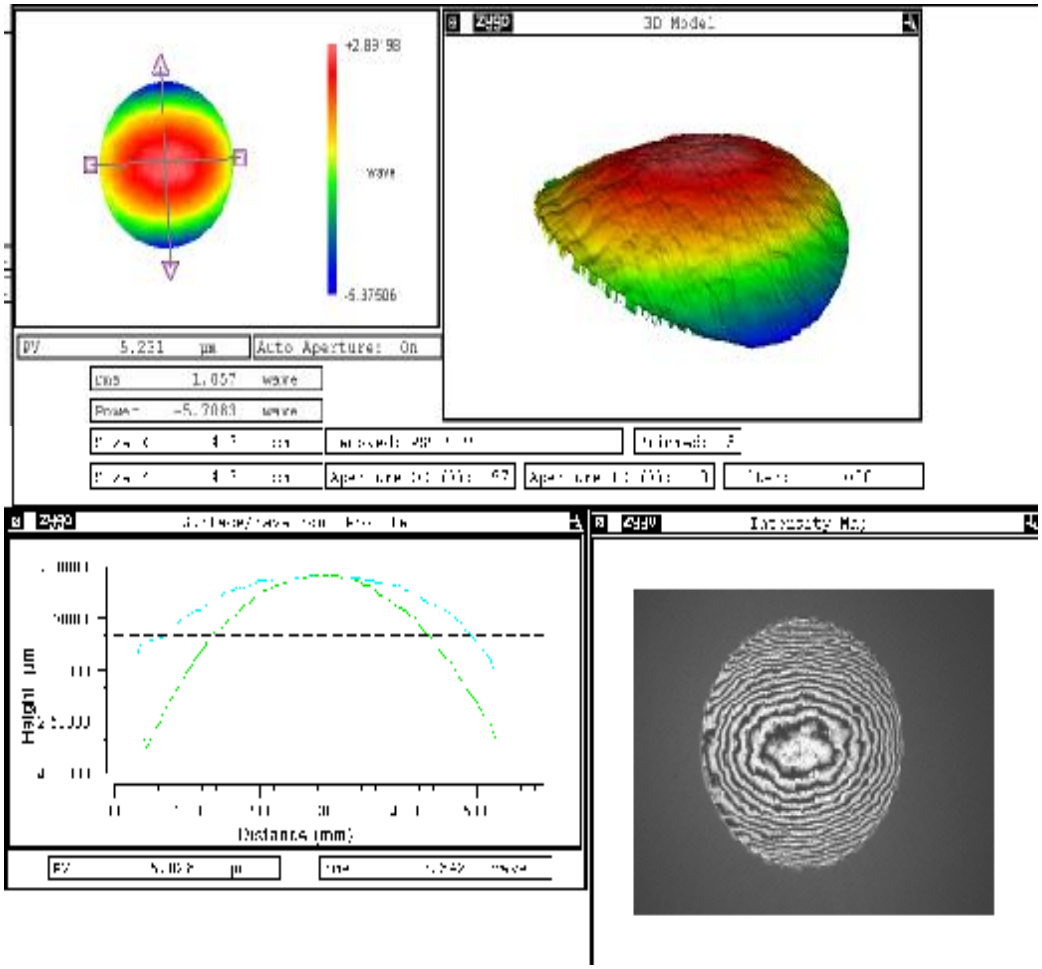
Generate and polish an elliptical surface that could be measured on an interferometer.

Non – rotationally symmetric

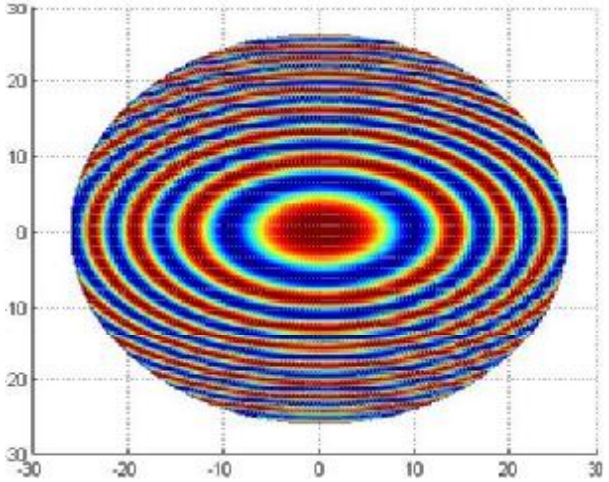




Results – Ellipse Raster

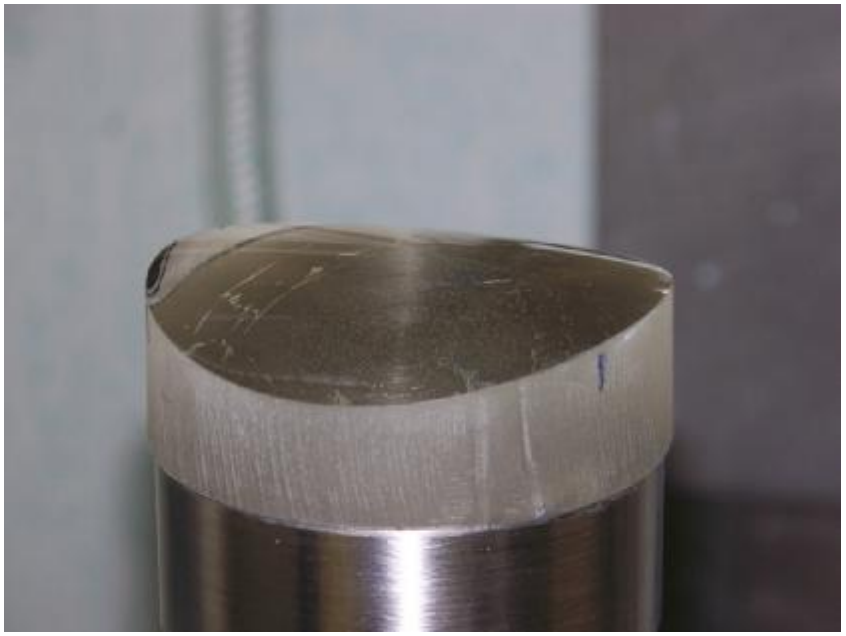


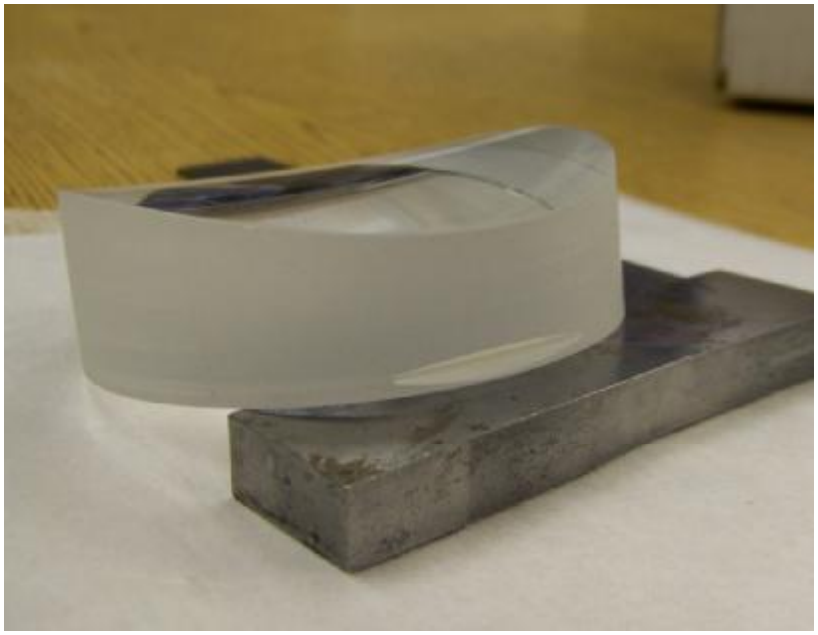
GPI PV:5.23µm



Simulation:5.1µm

Results – Ellipse Raster



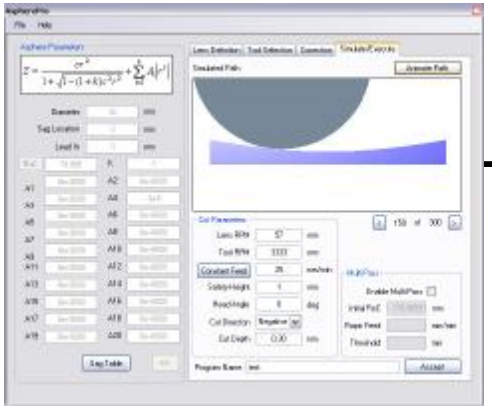


Radical departure ellipse done with the UltraForm Finisher

UltraForm Finishing of Aspheres!

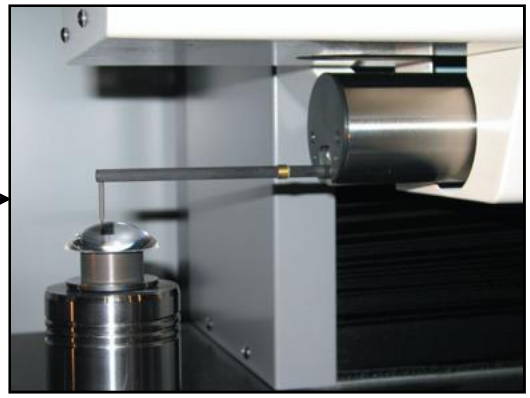
- Light weighted Optical Systems for the War Fighter
- Improved Heads up displays, rifle scopes etc.
- More accurate guidance systems for missiles
- Potential for improving the diamond turned “record grooving” in night vision infrared optics
- Fast polishing times = Reduced costs for aspheres!

OptiPro's Asphere / Freeform Fabrication Process

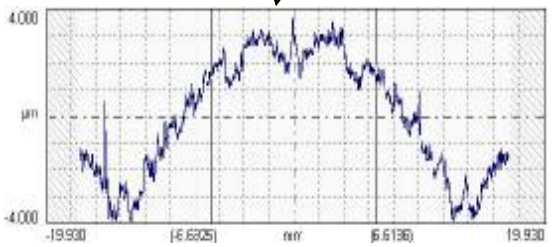


Define-AspherePro

Grind-eSX or SXL 5 axes grinder

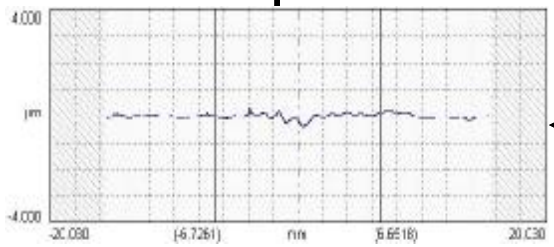


Measure-OptiTrace S5000



Transfer measured data to UFF

Polish- UltraForm Finishing (UFF)



1-2 polishing iterations and ship!

Finished Asphere

AspherePro Grinding Software

§ AspherePro creates tool path program all OptiPro grinding platforms

§ Auto toolpath correction with profilometer or MetroPro measurement data

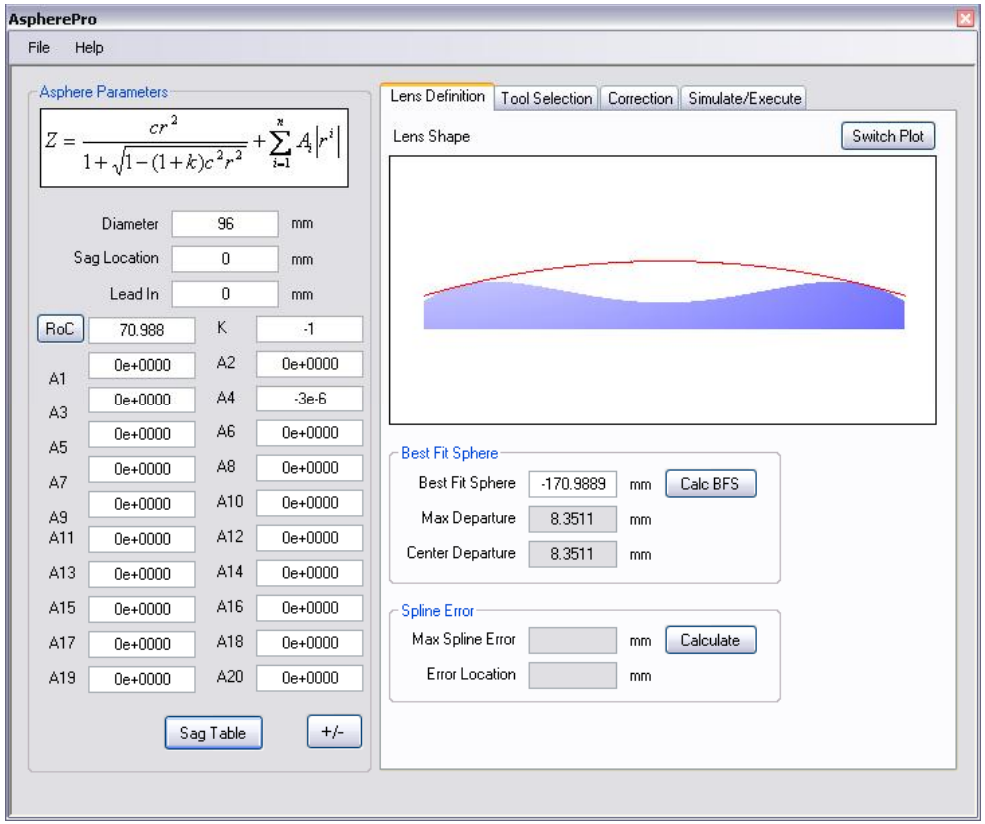
§ 2 Versions

  § Integrated CNC Control

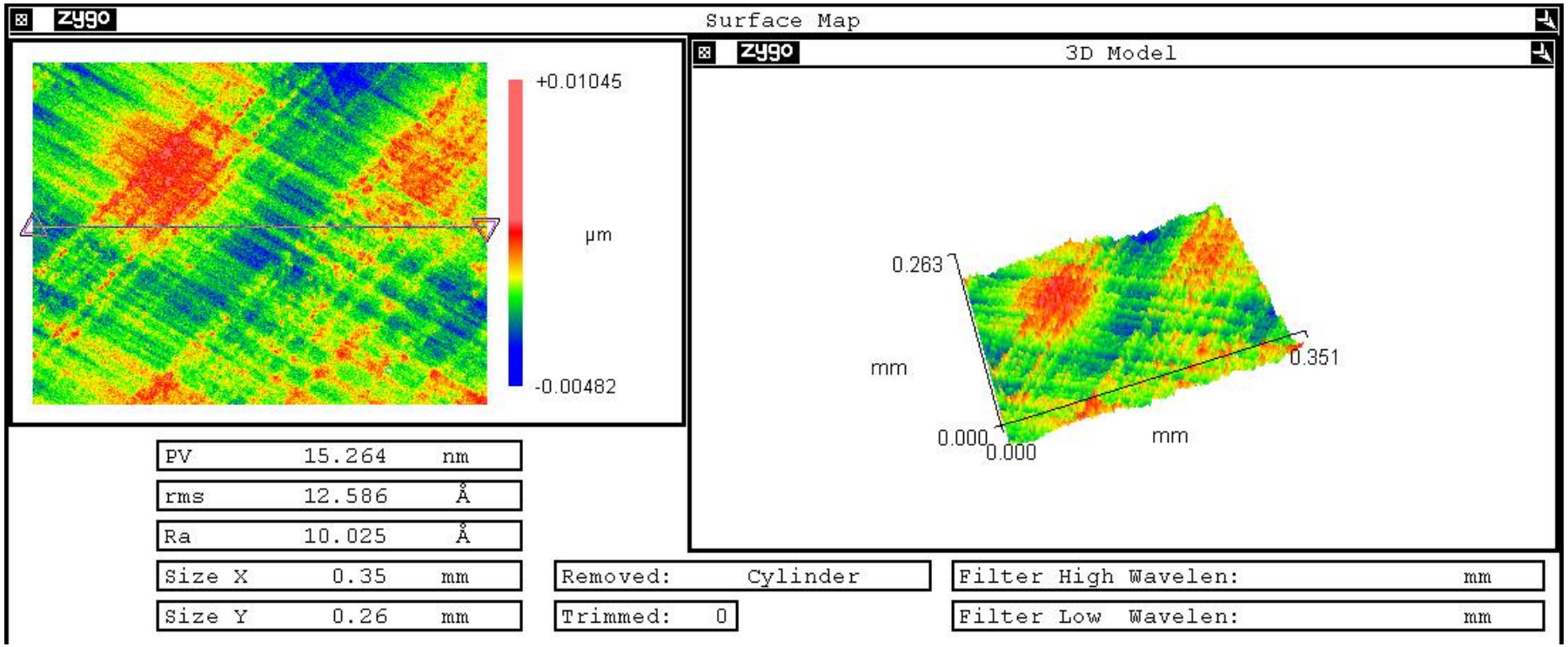
  § Standalone PC

§ Automated tool selection and definition dependant on aspheric geometry and tool type

§ Process verification with tool path simulation



Results – BK7



Fast Removal Rate

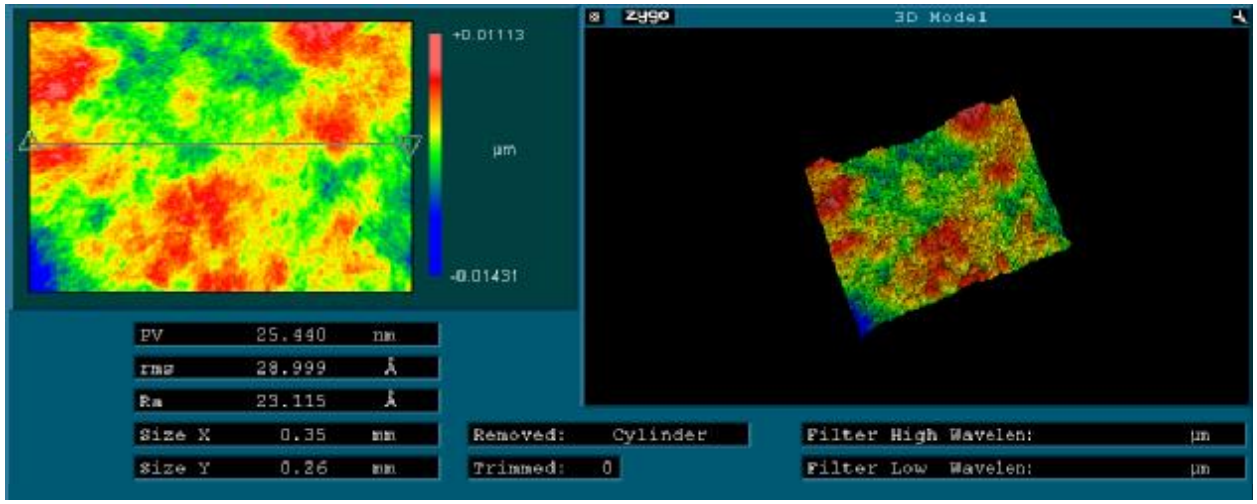
Bound Abrasive – No Clean Up

13 angstrom finish

UFF Process SiC Asphere

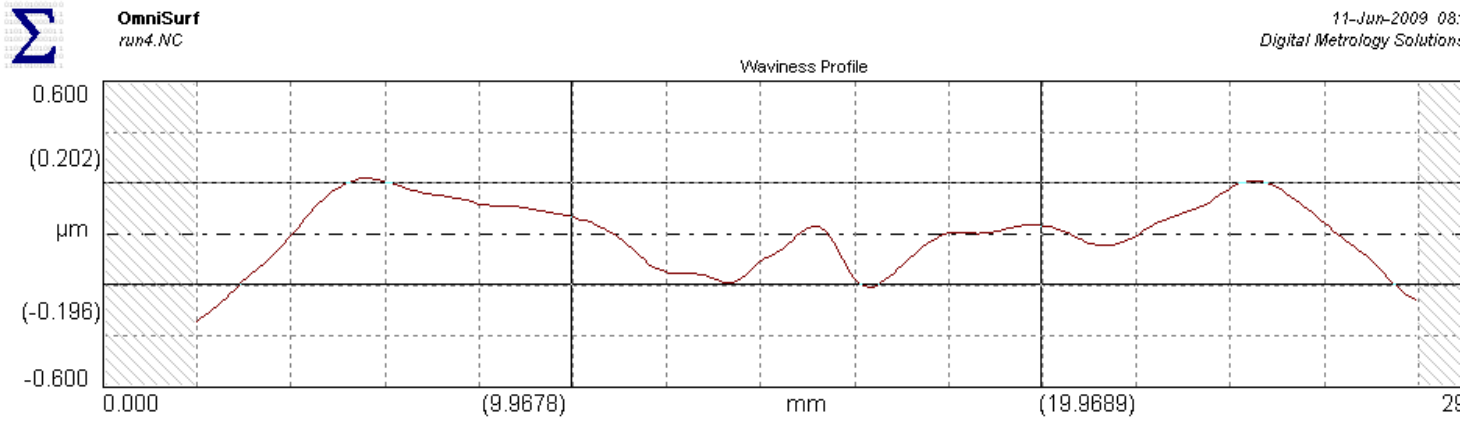
- UFF Polishing using 3µm and ½µm diamond belts
- Polishing runs: ~15 minutes to remove 2µm on 30mm diameter part
- Removal rates are very high (up to ~0.5mm^3/min.) for 3µm diamond belts at 120rpm, 100µm of compression

Results SiC Asphere



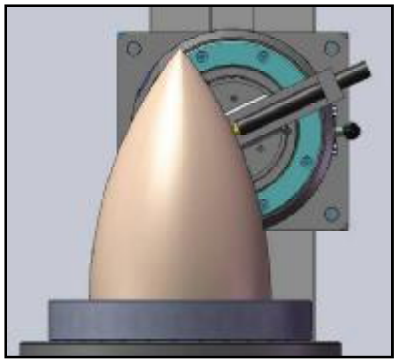
Roughness: 29 Angstrom rms

Form Deviation: 0.5 microns



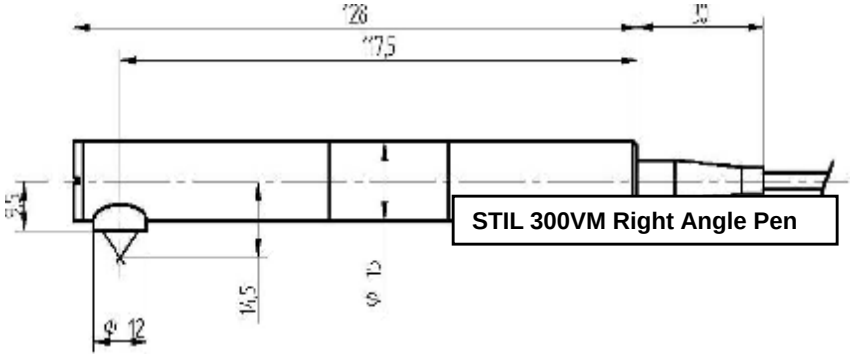
UltraSurf Metrology

- Non Contact surface and thickness measurement of spheres, aspheres and freeform geometries
- Compact design with 5 air bearing axes of motion, 3 linear and 2 rotary
- Granite, ceramic and steel materials and Invar linear scales for thermal stability
- Accuracy: +/- 1 µm over 8” linear travel with 25 Nanometer resolution in X, Y and Z directions
- Rotary error motion: +/- .1 arc second total over 360° move
- Renishaw linear and rotary encoders and dual Signal 5 nm resolution read heads eliminates error harmonics
- 2 Optical non-contact optical pen choices, STIL and Lumetrics



STIL's CHR 150 Sensor

- Non-contact collimated white light sensor
- Implementation of controlled axial chromatic aberration
- STIL probe selection: Range vs. Accuracy
  - 300 um range -> 100 nm accuracy
    - 4 um spot size
  - 20 um range -> 10 nm accuracy
    - 1 um spot size
- Optical pen with 0°,45° and 90° measure



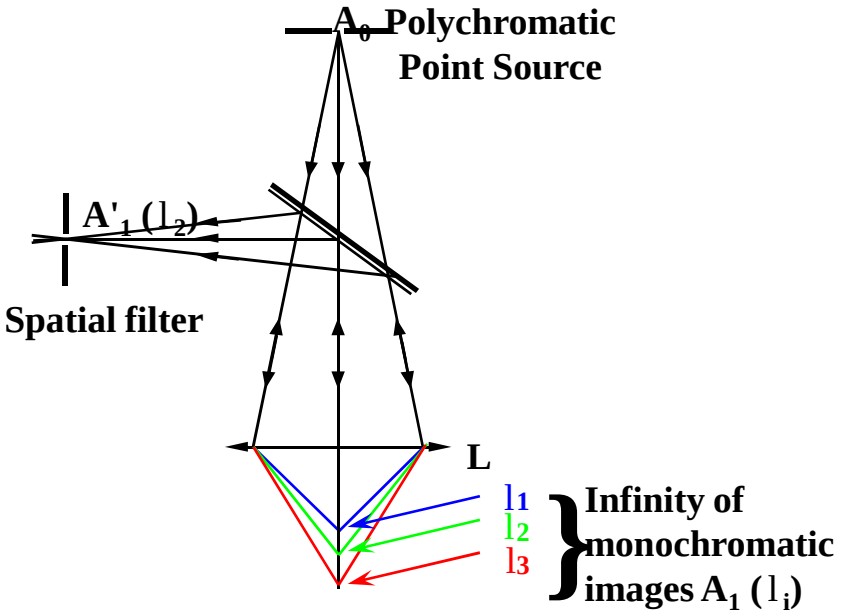
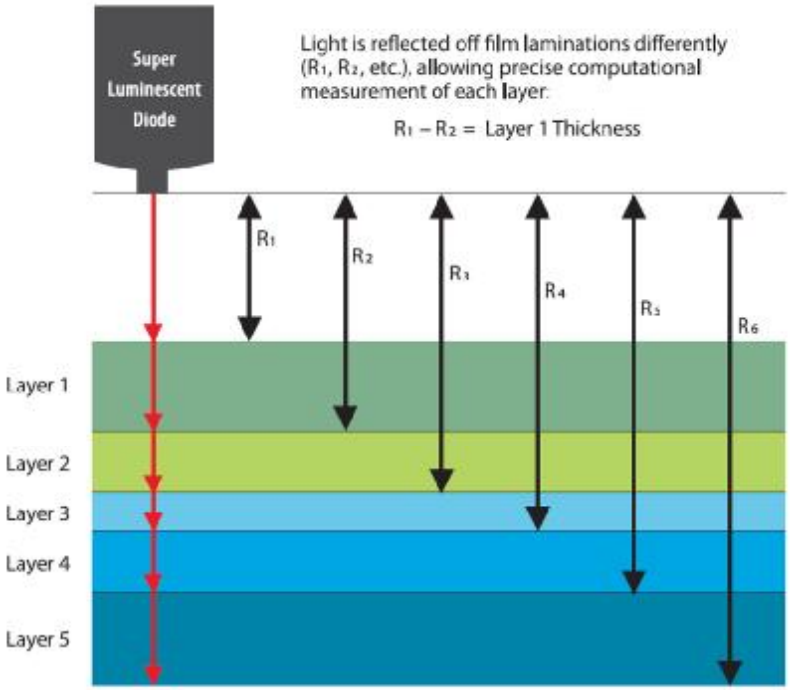


Diagram of the STIL pen reflecting different wavelengths (colors) based on distance

Lumetrics OptiGauge Probe

- Measures material thickness
- Able to measure one surface relative to another
  - Simplifies fixturing for measurement purposes
  - Not dependant on operator fixturing skill
- Has been successfully tested with:
  - ALON, PCA, Sapphire
  - Standard optical glasses



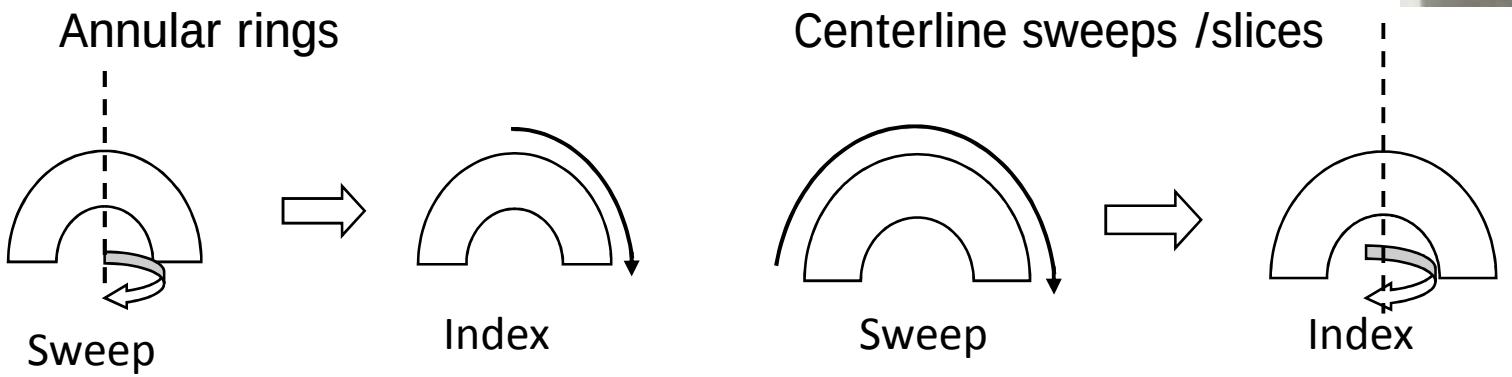
Analysis of Five-Part Film

OptiGauge Specifications

Measurement Range	12µm–12mm (.00047–.472")
Accuracy	±0.1µm (.000004")
Resolution	0.03µm 1.1 (.000001")
Scan Rate	30–100Hz
Control Module Dimensions	18"W x 17"D x 5.5"H
Control Module Weight	14 Lbs./6.35 Kg.
Power Requirements	110VAC 50/60Hz (220V available)
PC Operating System	Windows XP Professional

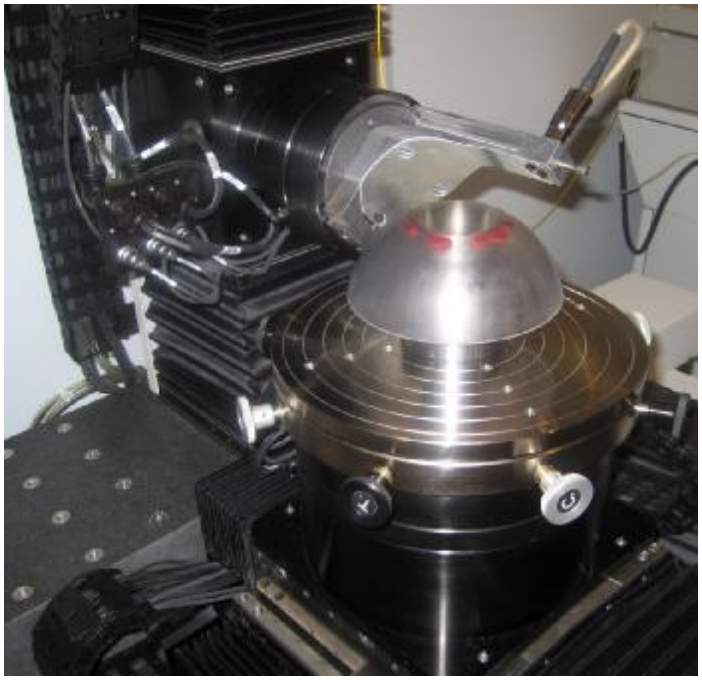
UltraSurf Modes

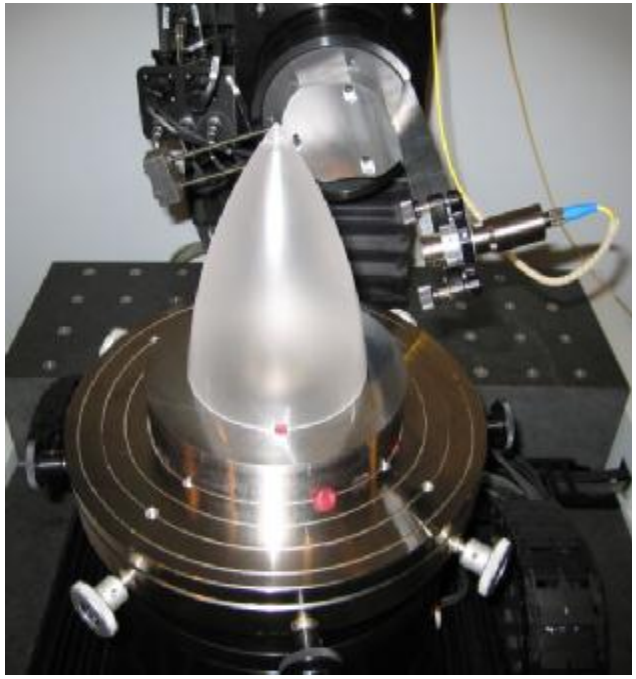
- Rotationally Symmetric Geometry

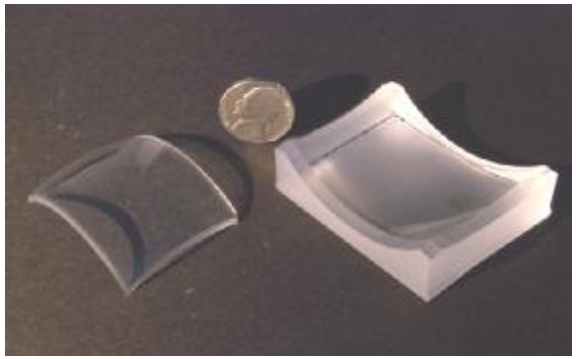


- Freeform
  - Raster, 2 to 5-Axis Freeform scans
  - Dependent on surface departure from plano/sphere

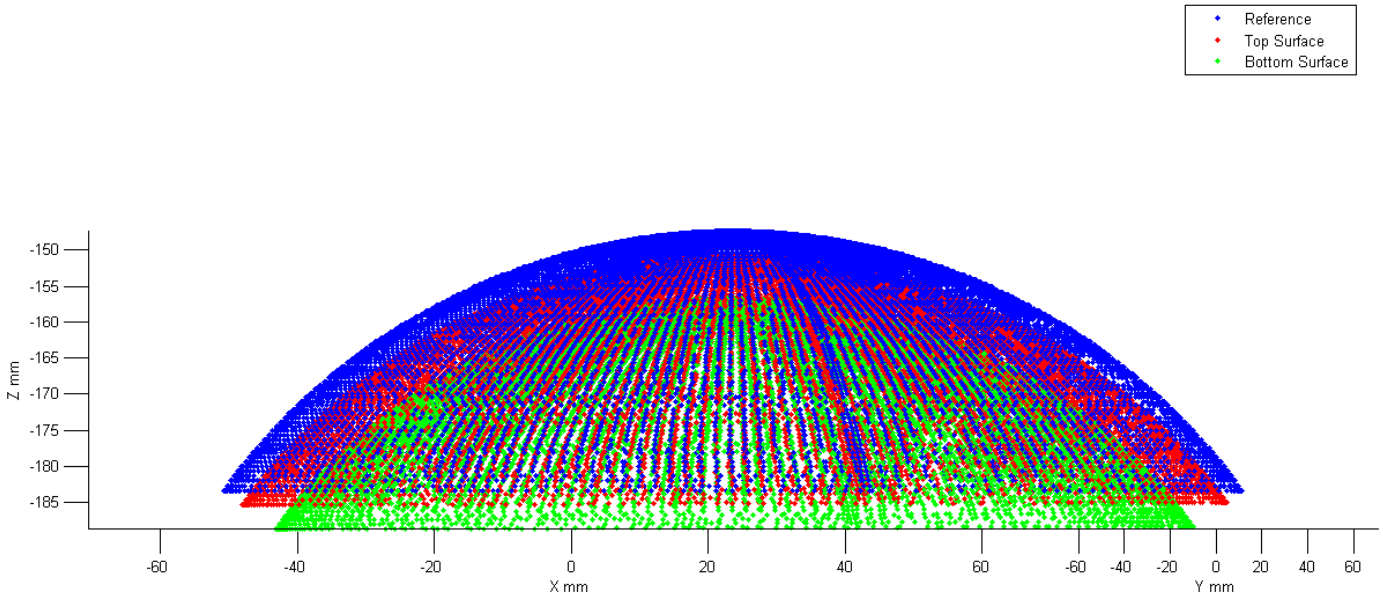
UltraSurf Dome, Ogive and Freeform







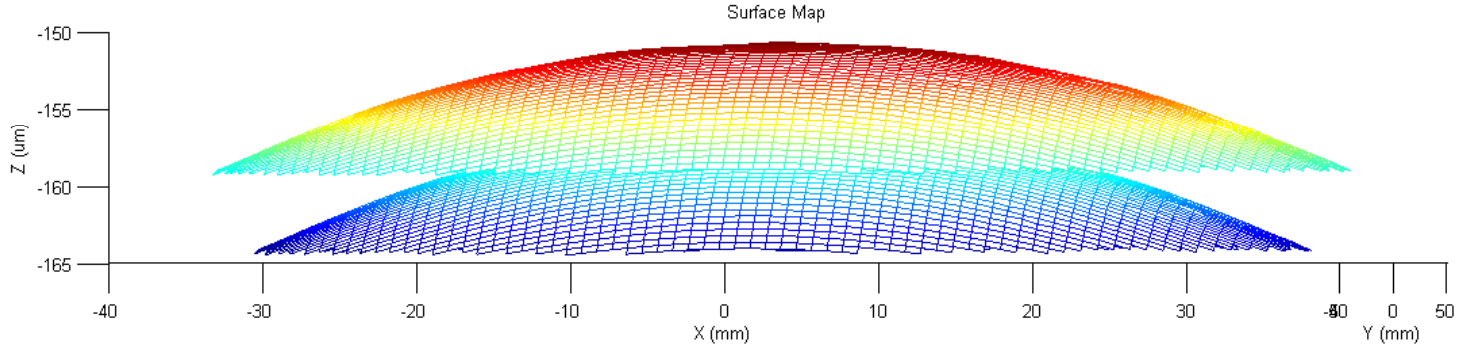
Measured Cloud of Points



3 Separate Clouds Taken Simultaneously

1. Reference Surface, used to rebuild surfaces in 3-D
2. Top Surface (Red)
3. Bottom Surface (Green)

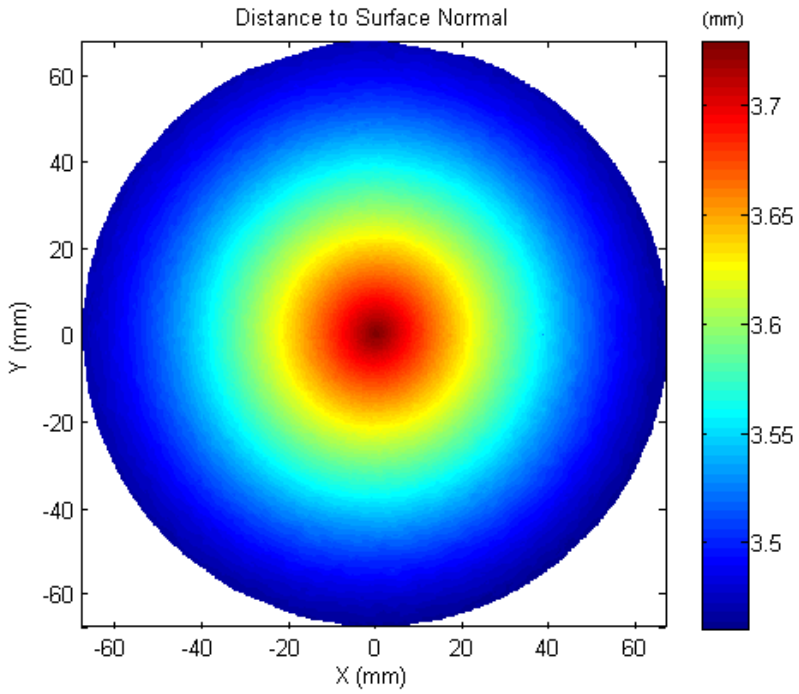
Reconstructed Surfaces



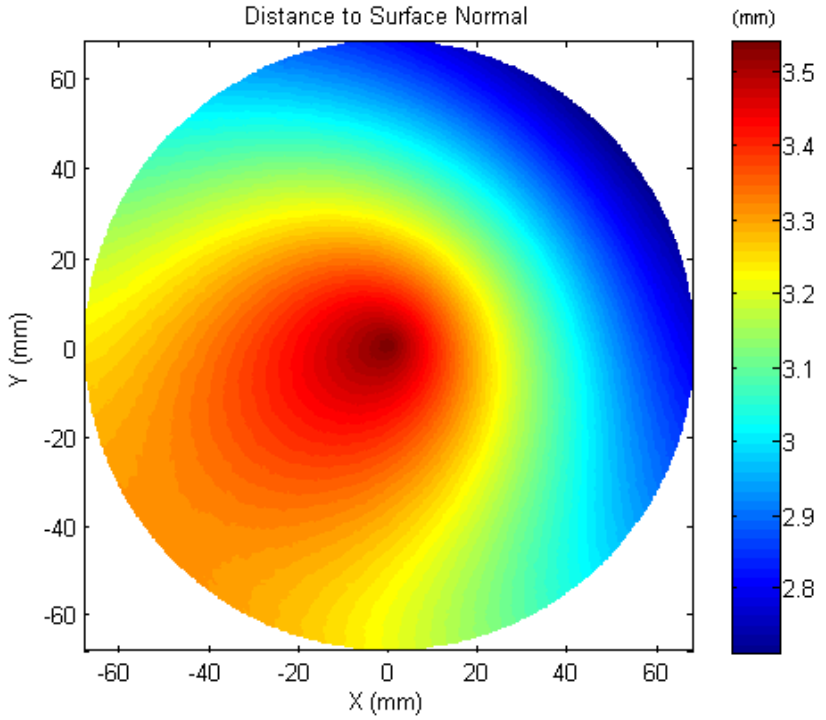
Top and Bottom Surfaces Constructed From Cloud of Points (Cubic Interpolation)

Comparison of Data

Distance From Reference Surface to First Surface Can Be Used to Identify Part Blocking Errors



Tip/Tilt, and Centering Errors Removed, Radius Error Exists



Tip/Tilt, Centering and Radius Errors

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Thank-you!