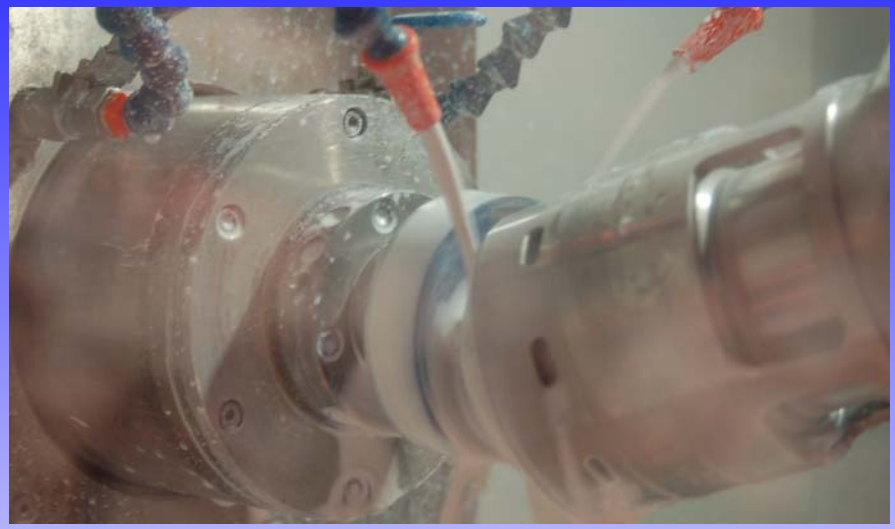

Approach to Polishing Edges Using Zeeko Polishing Technology

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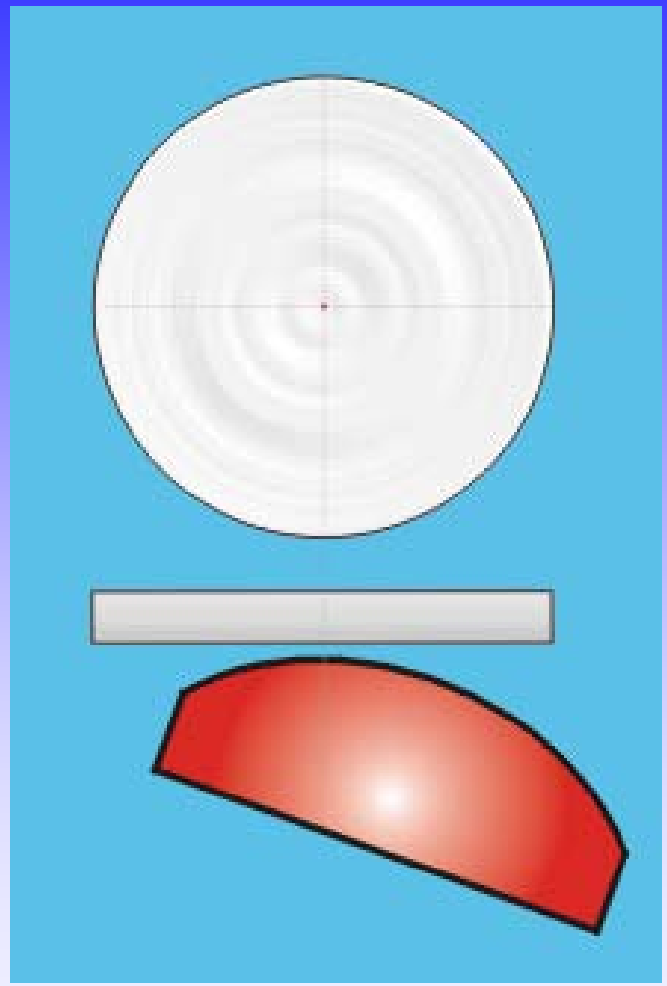
Basis of the Zeeko Polishing Process

- Spherical membrane “bonnet” creates a localized area of material removal of variable size (“influence function”)
- Spot size is controlled independently by varying:
  - The axial position of the tool WRT the part, and therefore the degree to which the membrane is compressed against the part
  - The internal pressure of the working fluid within the tool is controlled separately



Tooling

The spherical bonnet tooling:

- is covered with standard polishing pads (e.g. polyurethane)
- is pressed into the surface of the workpiece by displacement Δz, creating a contact spot of known diameter
- is worked with standard polishing consumables (e.g. cerium oxide)
- delivers volumetric removal rates up to a few cubic millimeters per minute

The Zeeko Optics Machine Range

Seven CNC-controlled axes:

- x, y, z
- Tool rotation (‘H’)
- Tool inclination (‘A’ and ‘B’)
- Workpiece rotation (‘C’)

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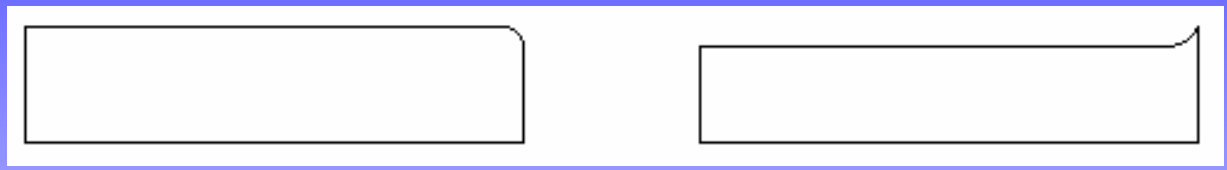
Zeeko Polishing Advantages

The Zeeko Classic polishing process:

- Uses standard polishing pads and slurries
- Pre-polishes from the ground blank condition
- Capable of polishing complex freeform geometries
- Able to polish a plethora of materials including optical glasses, ceramics and metals
- Is deterministic, resulting in reduced production times due to its high removal rate and repeatability
- Numerical optimization gives great flexibility in incorporating “physics” such as edge-effects.

Edge Effects in Optics Finishing

- The ‘edge effect’ refers to an edge on an optic that is turned up or down with respect to the ideal form:



edge down edge up

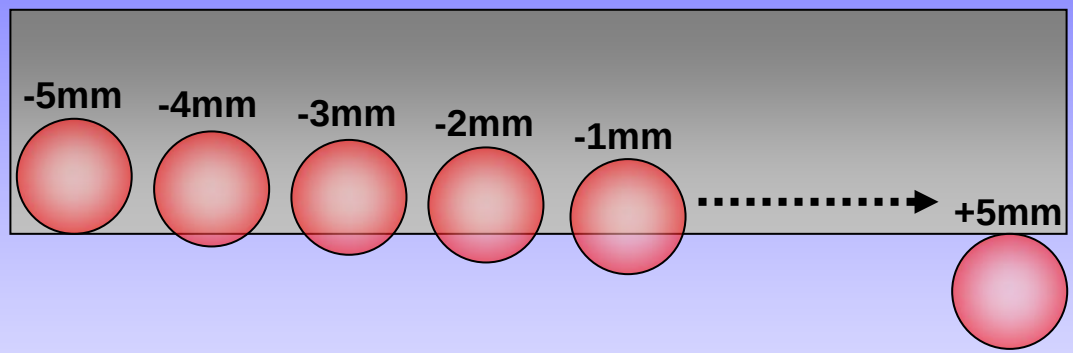
- Large segmented mirrors must have minimal or no edge exclusion
- Like other sub-aperture polishing processes, the Zeeko process is prone to edge effects
- Zeeko can currently control form up to ~2-3mm from the edge of a part
- Primary goal of the Phase I project was to determine the effect of polishing an edge had on the shape of an influence function and account for the evolution of its shape

Meeting Edge Requirements

- James Webb Space Telescope flight mirrors: no edge effect within ~5mm of the edge
- Terrestrial Planet Finder Chronograph (TPFC) to measure size, temperature and placement of earth-like planets
  - Current baseline calls for monolithic primary mirror to avoid diffraction effects associated with edge effects
  - Improvement in edge polishing could make mirror segmentation more attractable for this NASA future project
- Improvements to edge polishing technology provide critical input to NASA studies of the TPFC, TPFI, SAFIR and TMST missions

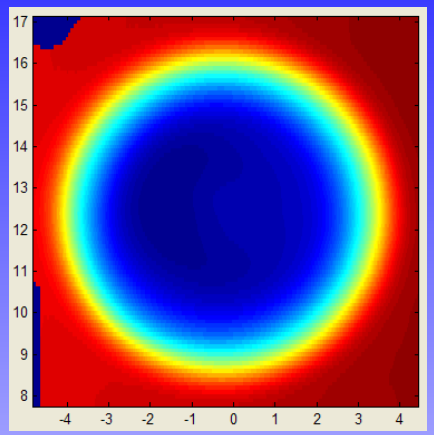
Edge Effects on Influence Functions

- Influence functions were created on a flat rectangular piece of BK7 glass
- 10mm diameter spots were created with center tool overhang values from -5mm to +5mm:

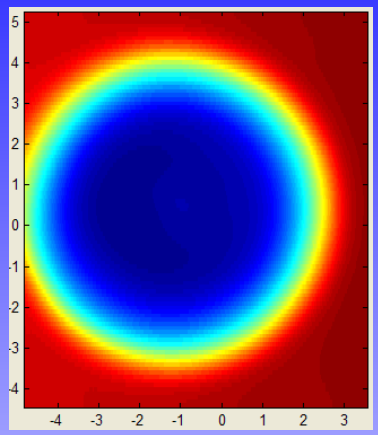


- In order to capture as much data as possible at the edge, a Form Talysurf was used in 3D mode to measure the influence functions

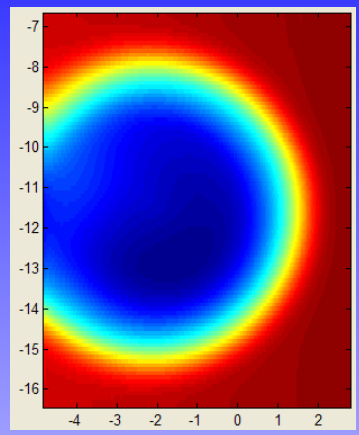
Measurements of Spots



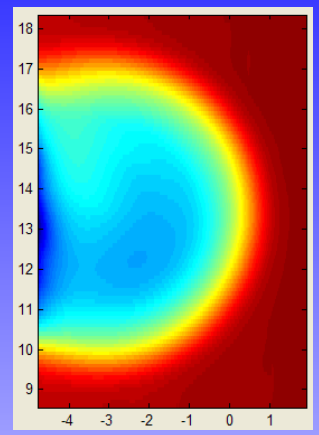
-5mm



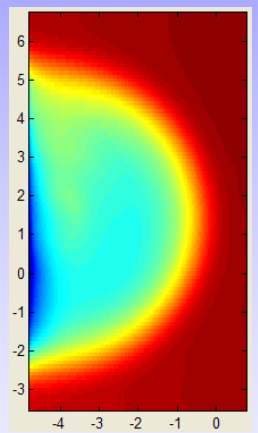
-4mm



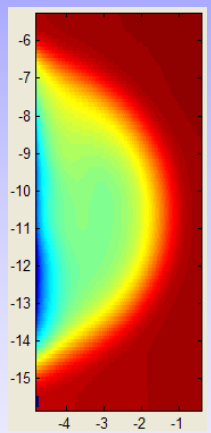
-3mm



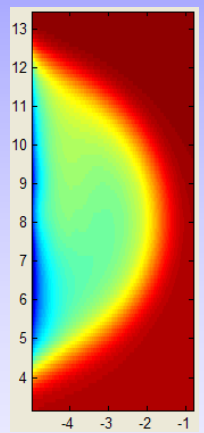
-2mm



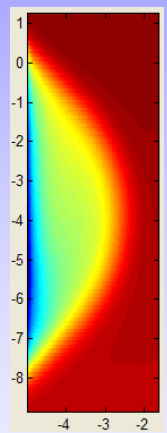
-1mm



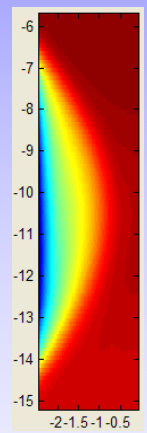
0mm



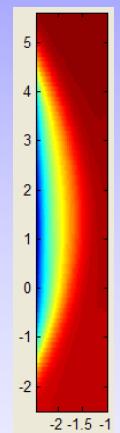
+1mm



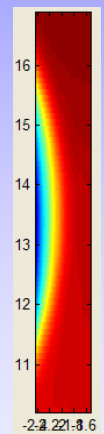
+2mm



+3mm



+4mm



+5mm

There was a roll-off zone of 0.35mm present in the workpiece. This data was subtracted when the spots were analyzed.

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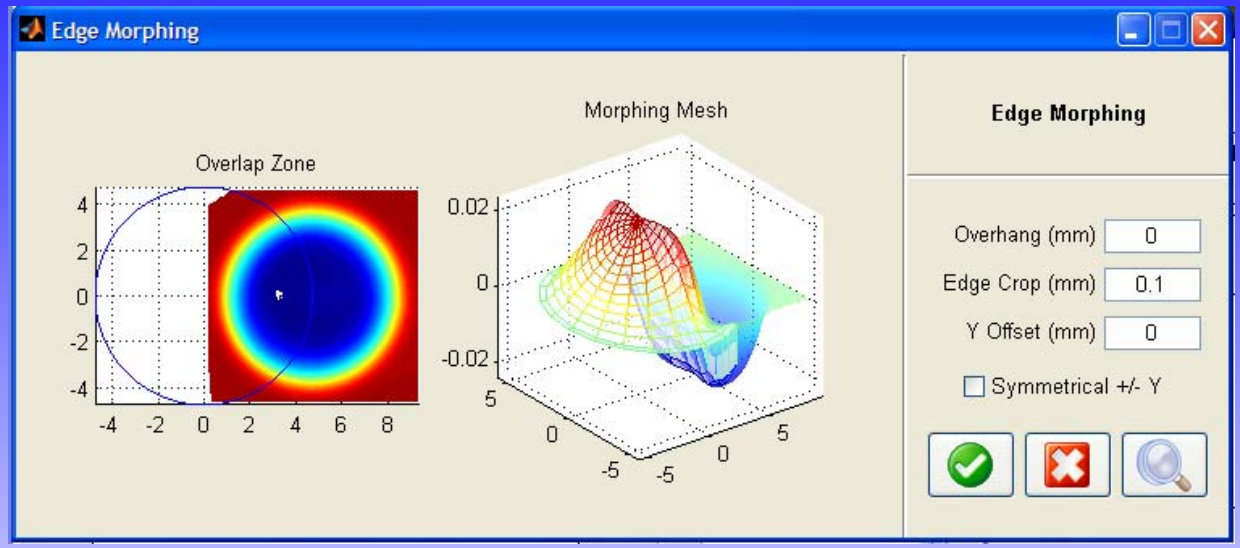
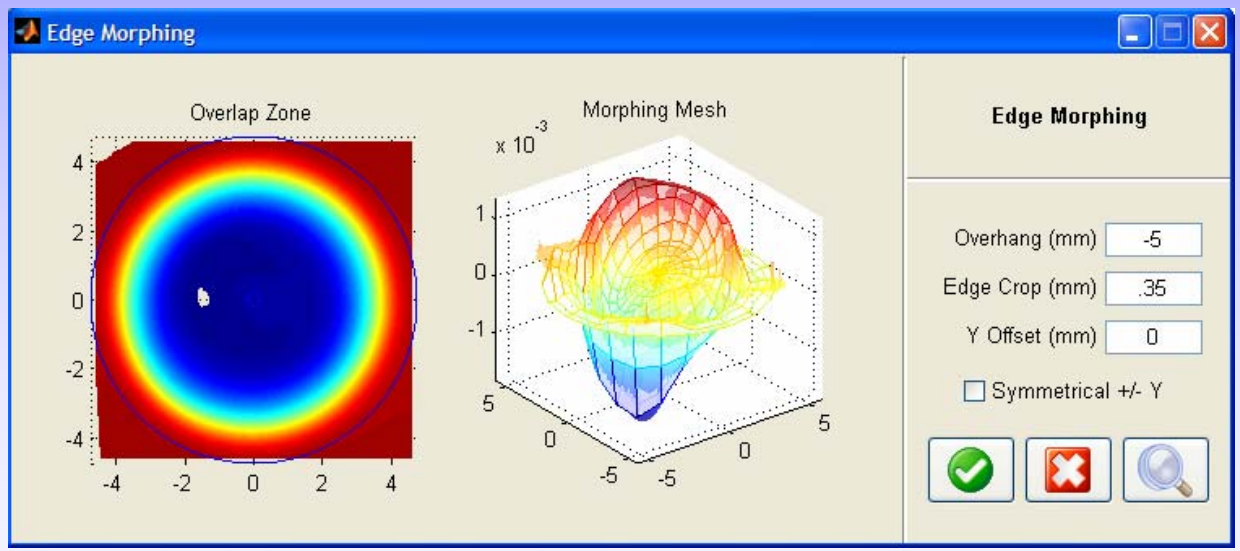
‘Morphing’ of Influence Functions

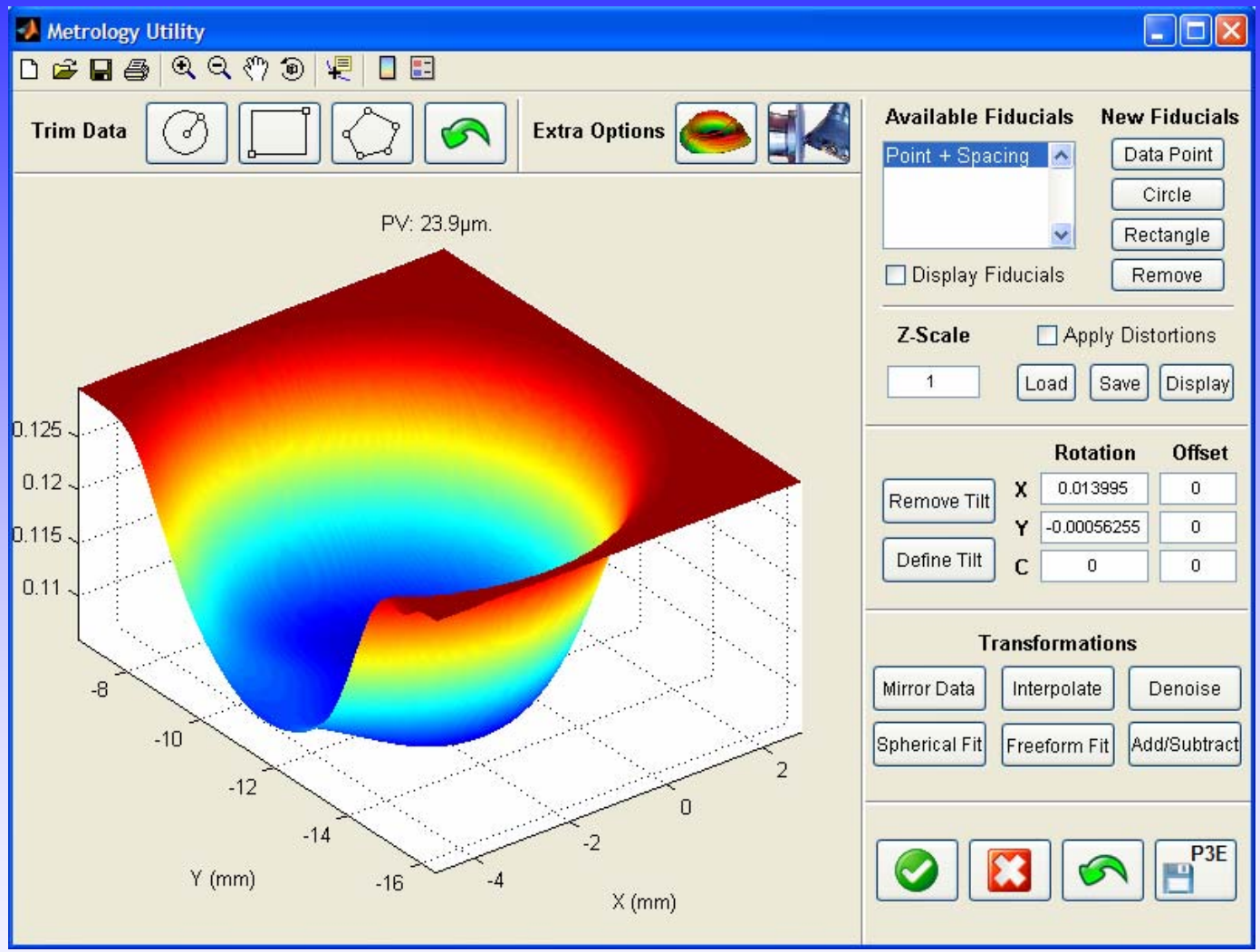




CTO = -5mm

- Define Overlap Zone
- Enter Overhang value (-5mm)
- Subtract edge roll-off zone data by defining ‘edge crop’ (0.35mm)
- Enter y-offset if necessary
- Define symmetry in y-plane
- ‘Morphing Mesh’ is then defined
- Repeat for all other influence functions

Morphing of Spot #4 (CTO = -2mm)



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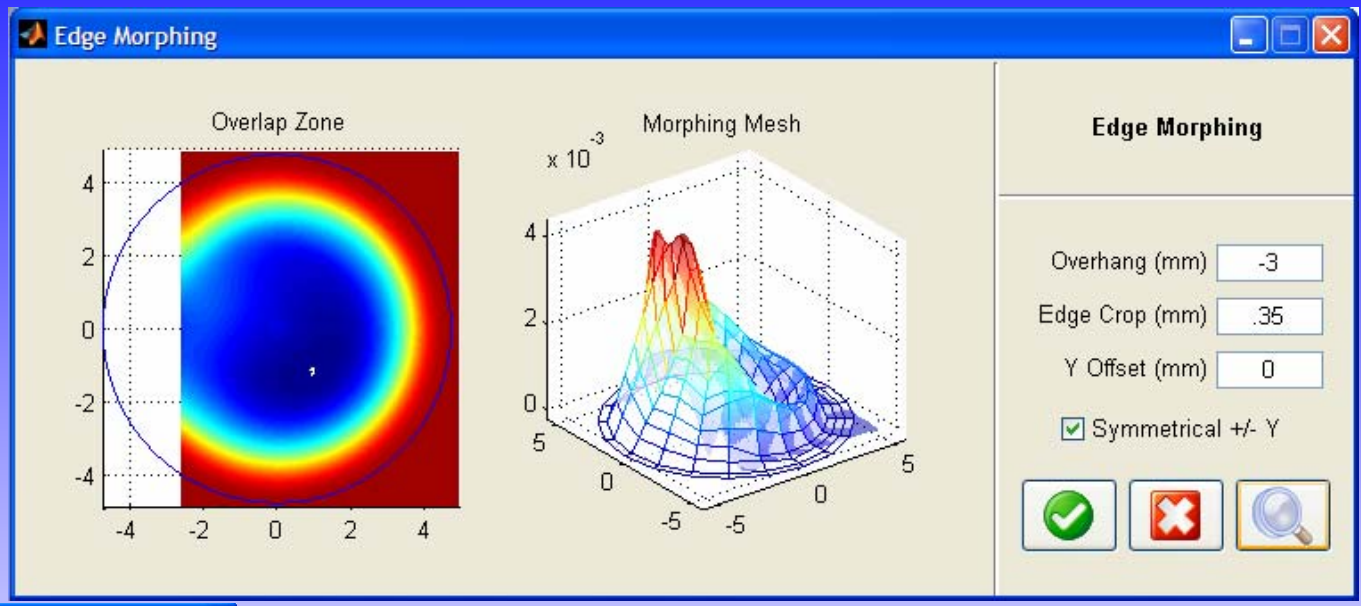
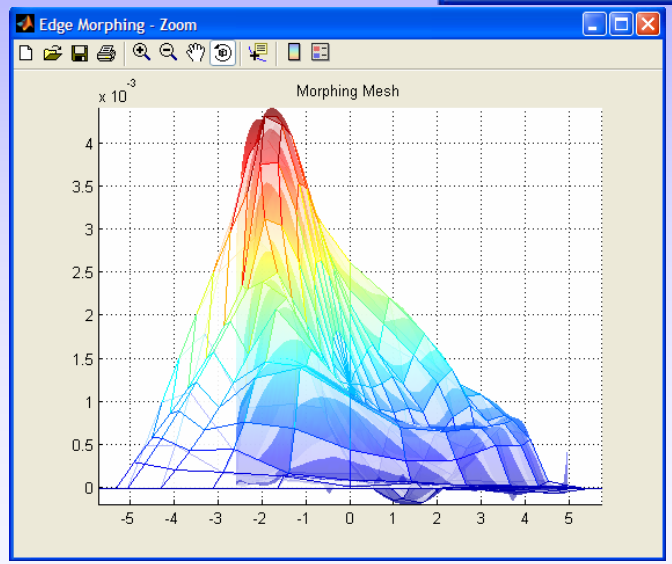
Spot #4 Continued





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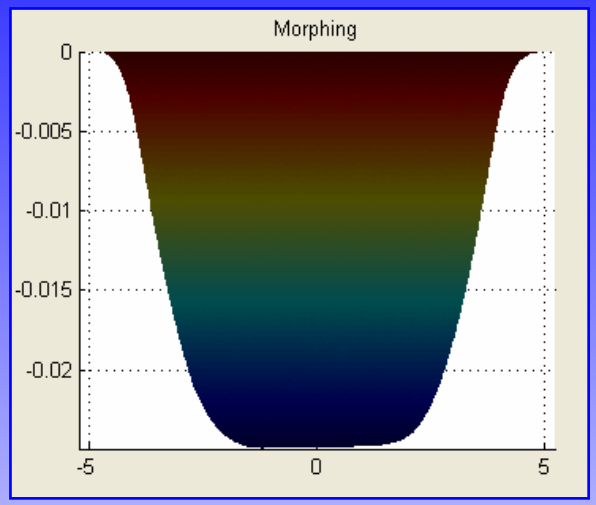
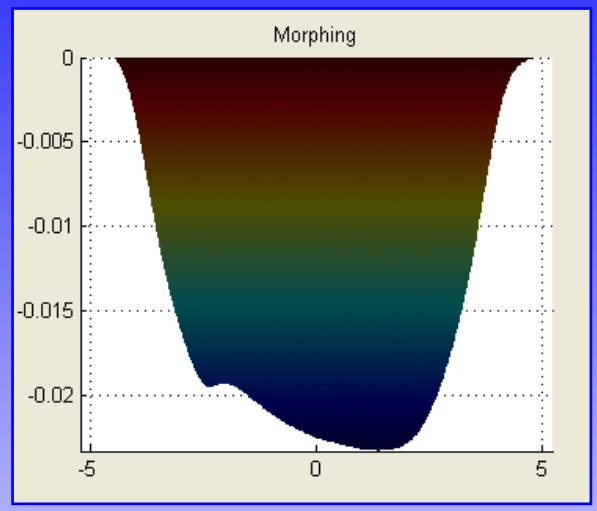
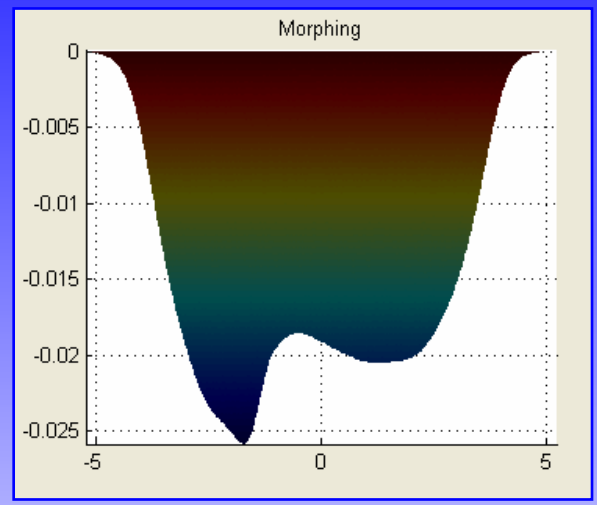
2D Profiles of 'Morphed' Influence Functions



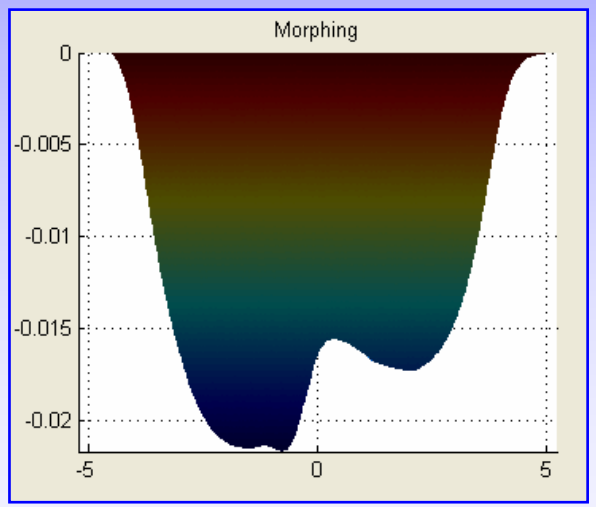
-4mm



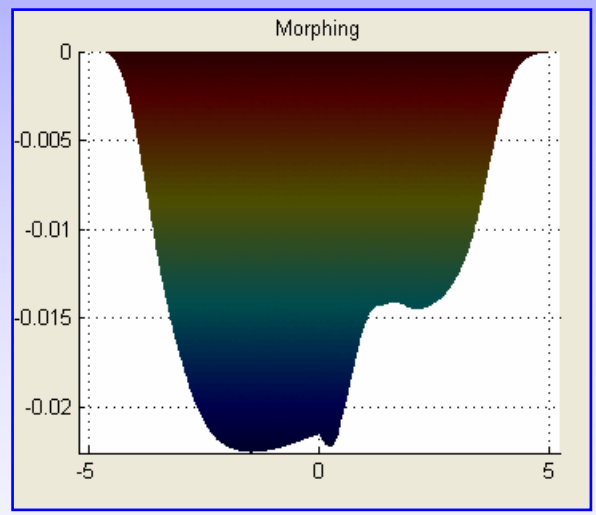
-3mm



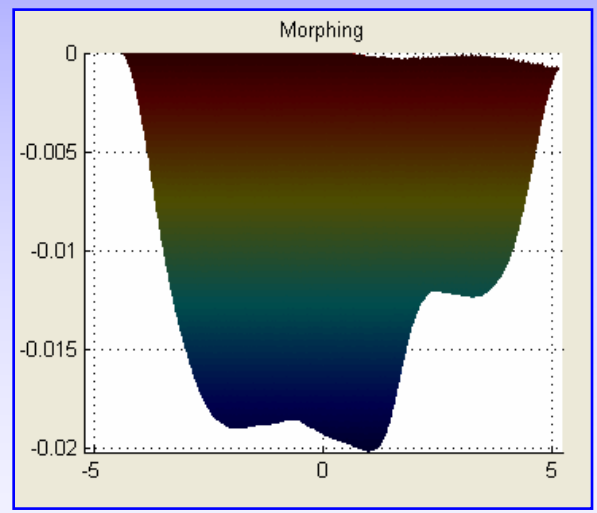
-2mm



-1mm



0mm



+1mm

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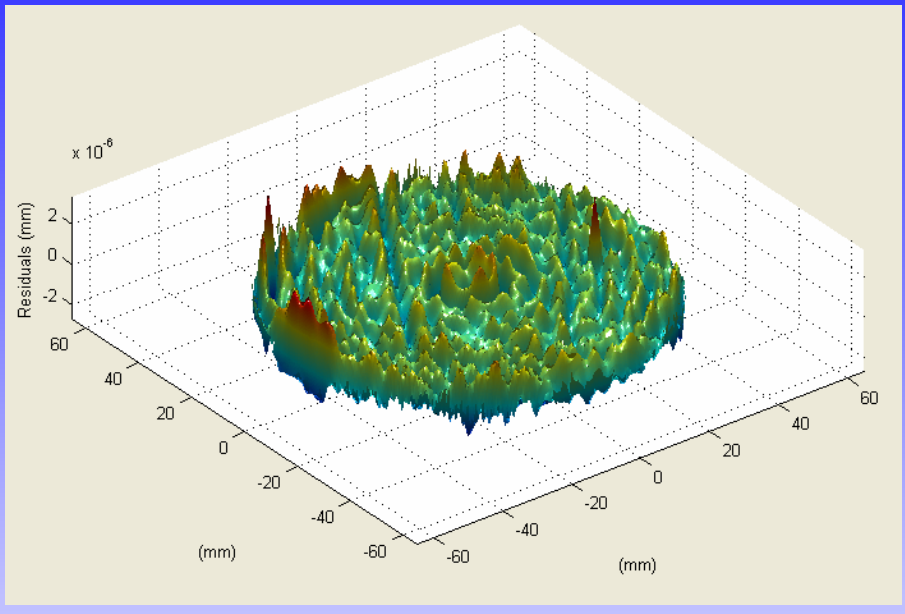
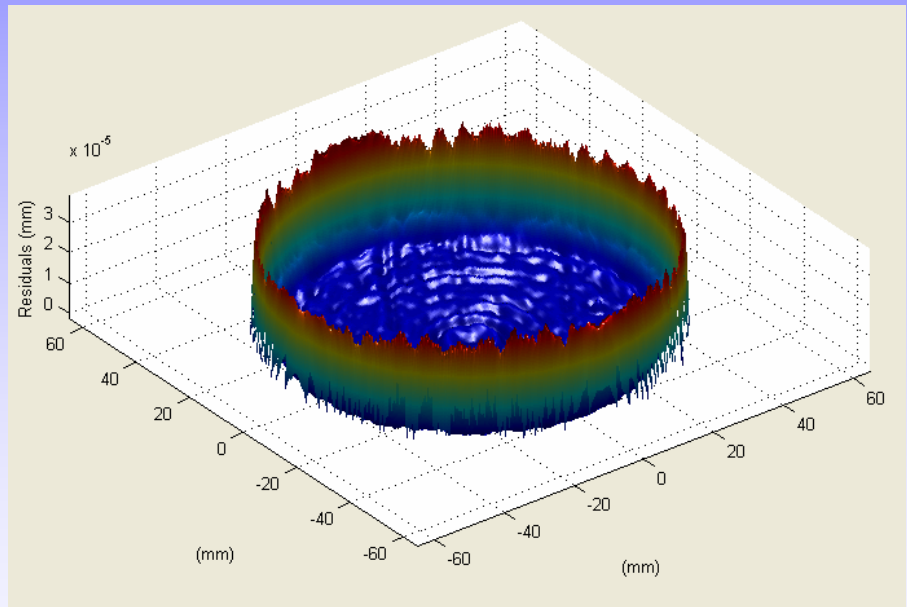
Simulation Comparison



Corrective polishing simulation run without edge control modification on.
CTO = 4mm



Corrective polishing simulation run with edge control modification on.
CTO = 4mm

Conclusions

- Precessions software was modified to account for the effect of polishing an edge on the shape of an influence function
  - Data used for modification included center tool overhangs ranging from -5 mm to +5 mm
- Corrective polishing simulations were run for 2 cases:
  - Simulation accounting NOT for edge effects
  - Simulation accounting for edge effects
- Results from simulation without edge modification display a part polished all the way to the edge
  - However, the simulation did not account for edge effects and therefore does not display the edge roll-off that is known to occur when a tool extends beyond the edge of a part

Conclusions

- Results from simulation with edge modification display the presence of a lip that was formed close to the edge which has been rolled off
  - The edge roll off was expected since the tool was allowed to extend beyond the edge of the part (4 mm)
  - The presence of the lip adjacent to the edge was an unexpected consequence. However, when examining the evolution of the shape of the influence function as the tool moves beyond the edge of a part, it makes ‘physical sense’ and was likely a result of ‘pad rebound’
  - As a side note, we have in the past observed the formation of this lip near the edge of a part when the tool was allowed to extend beyond the edge (we just didn’t know why it happened)

Future Work

- The Precessions code has been modified to account for edge effects on influence functions.
- The Precessions optimizer must now be modified to account for edge effects as well. Then it will be possible to polish parts effectively very close to the edge.
- Varying the size of the influence function as the tool approaches the edge of a part will be explored.

Acknowledgements

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