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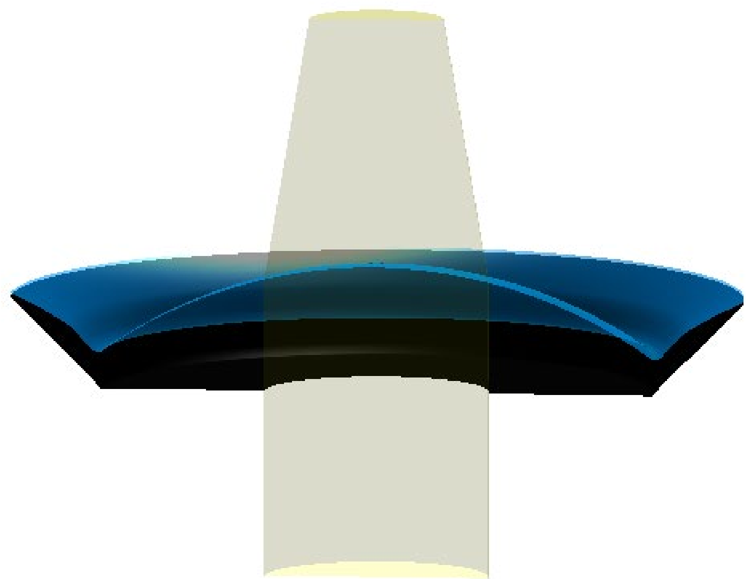


Tunable Optofluidic Aperture

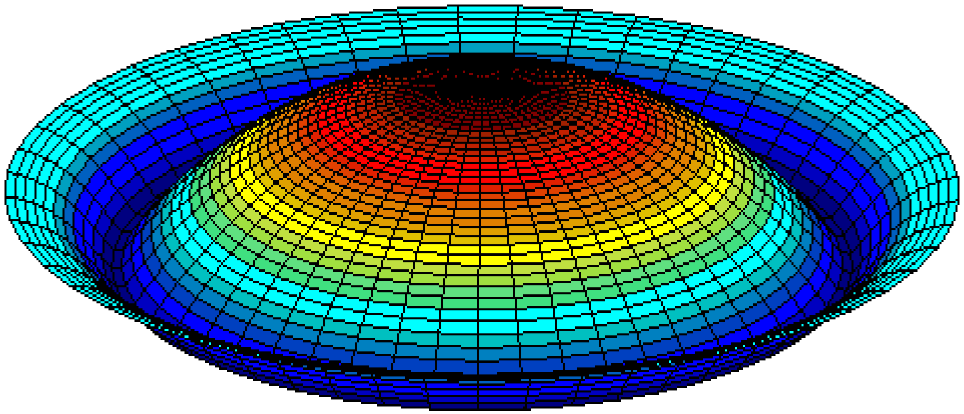
Master thesis presentation

Zürich, February 4th 2011

Joep Mutsaerts

Content

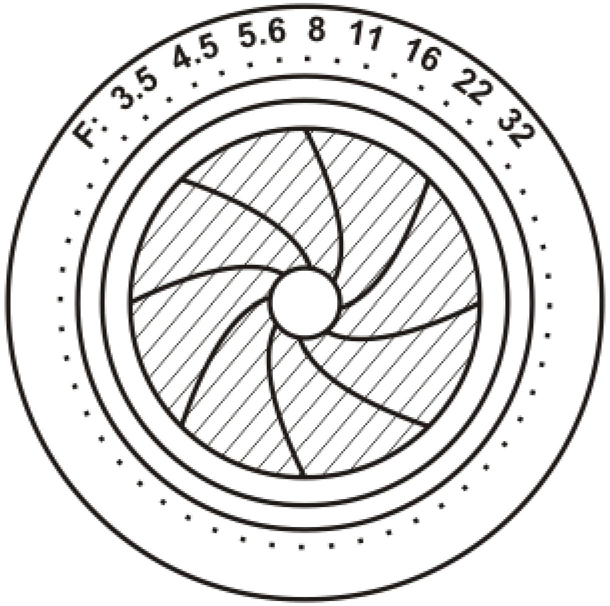
- Tunable aperture
  - Concept
  - Trapped liquid
  - Conclusion
- Membrane model identification
  - Experiments
  - Analysis
  - Simulations



What is a tunable aperture?

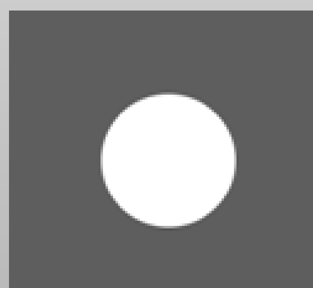
- Most common: Leaflet structure

- Control of:
  - Light
  - Depth of Field
  - Optical quality
  - F number

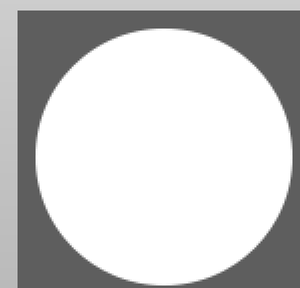


What is a tunable aperture?

f/32 – slow shutter



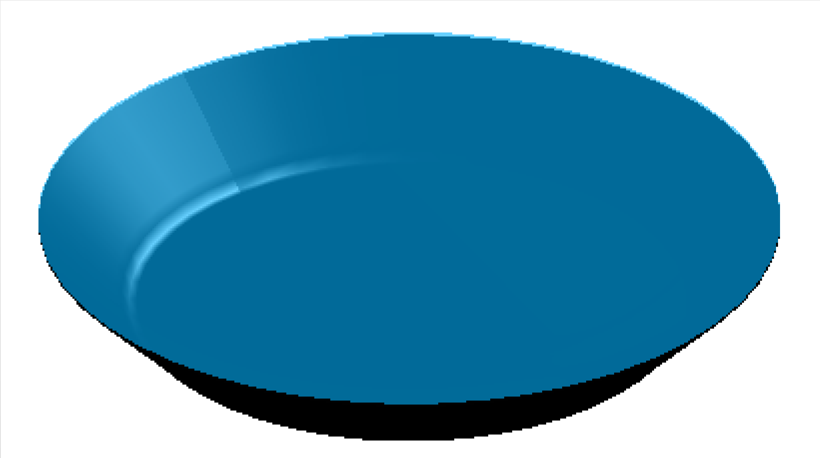
f/5.6 – fast shutter

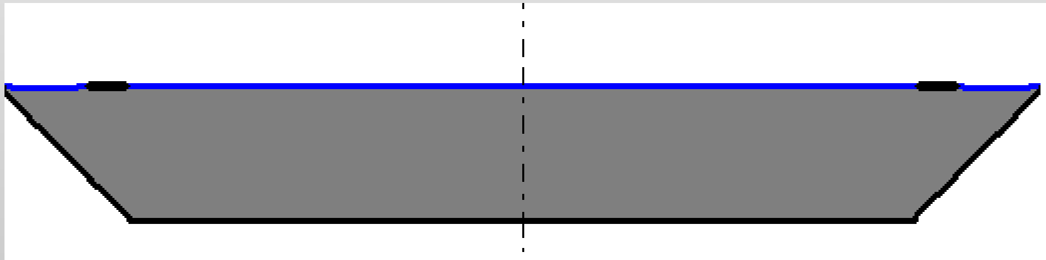


Why create a tunable aperture?

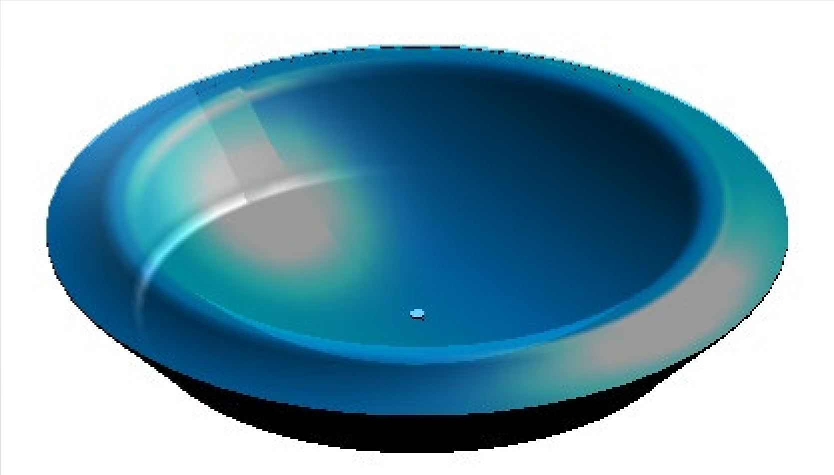
- Optical quality in mobile phone market
- Small size
- Low part count
- Available design

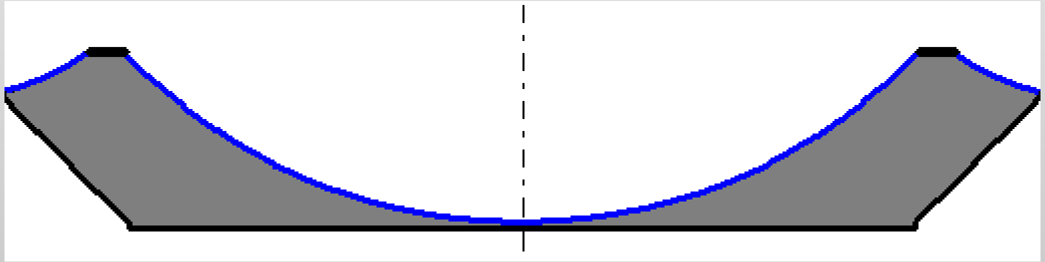
Aperture design



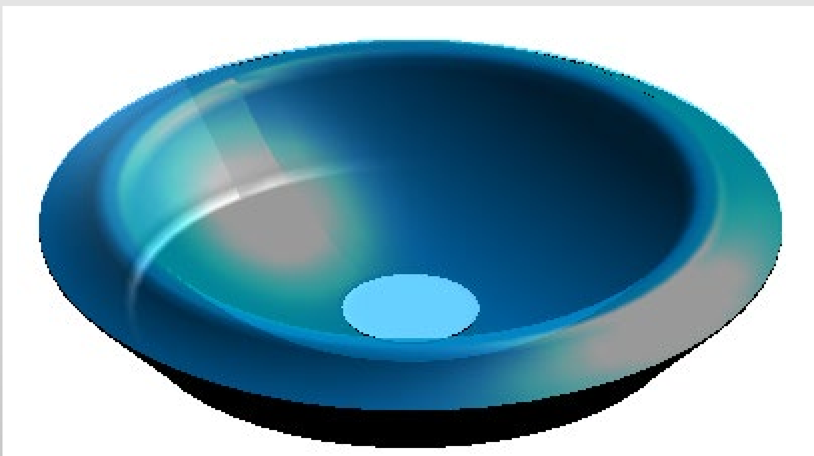


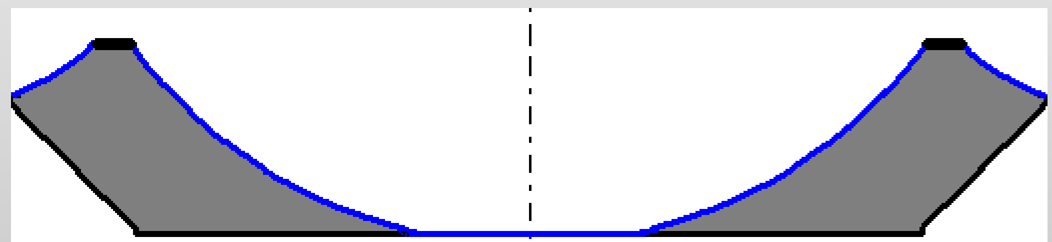
Aperture design



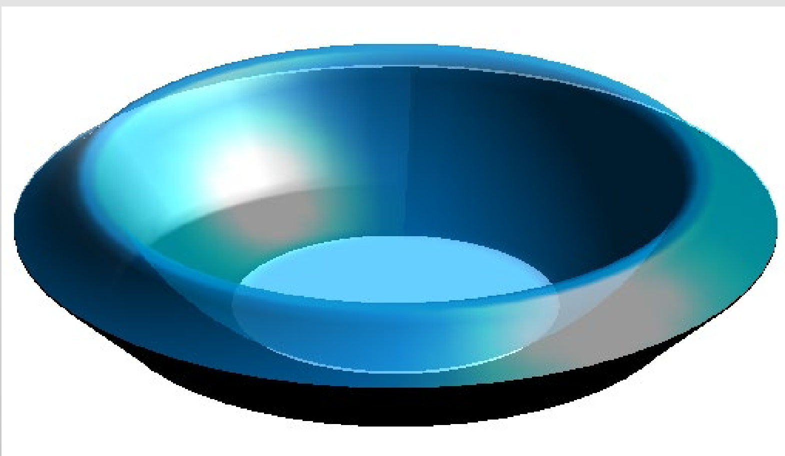


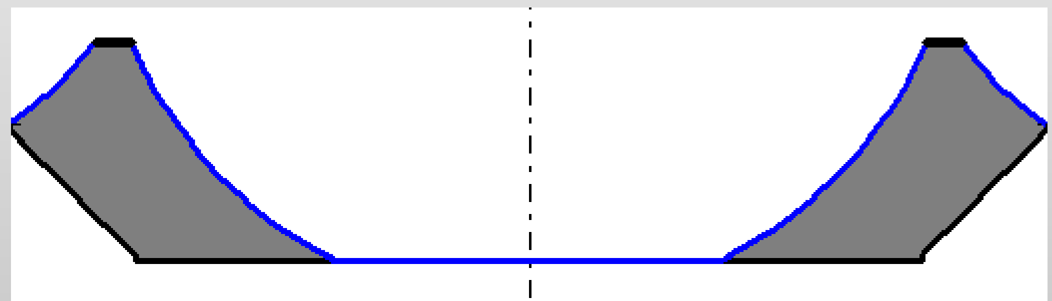
Aperture design





Aperture design

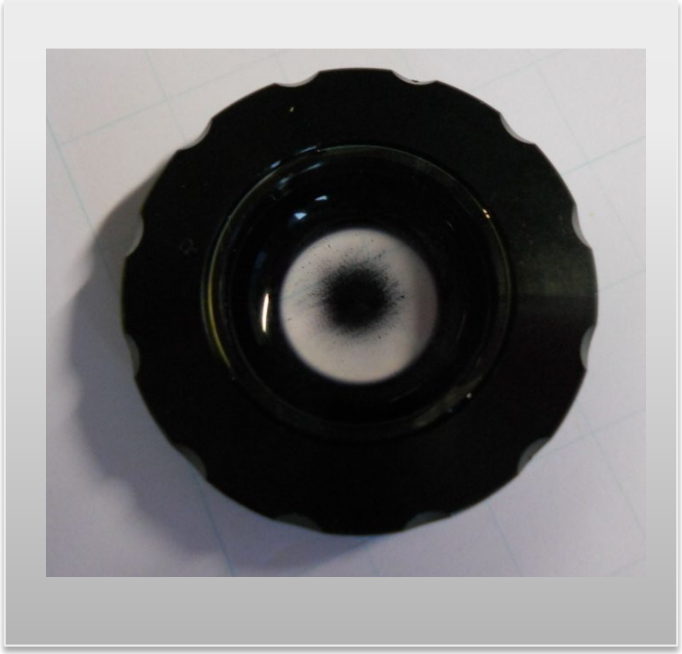




ML Demonstrator 1

- Trapped fluid problem
  - Spot depends on speed

- Identified possible causes
  - Particle size
  - Concentration



"trapped fluid" analysis

Possible solution	Argument pro	Contra
Low concentration	Less aggregation	
Small particle size	Less aggregation	

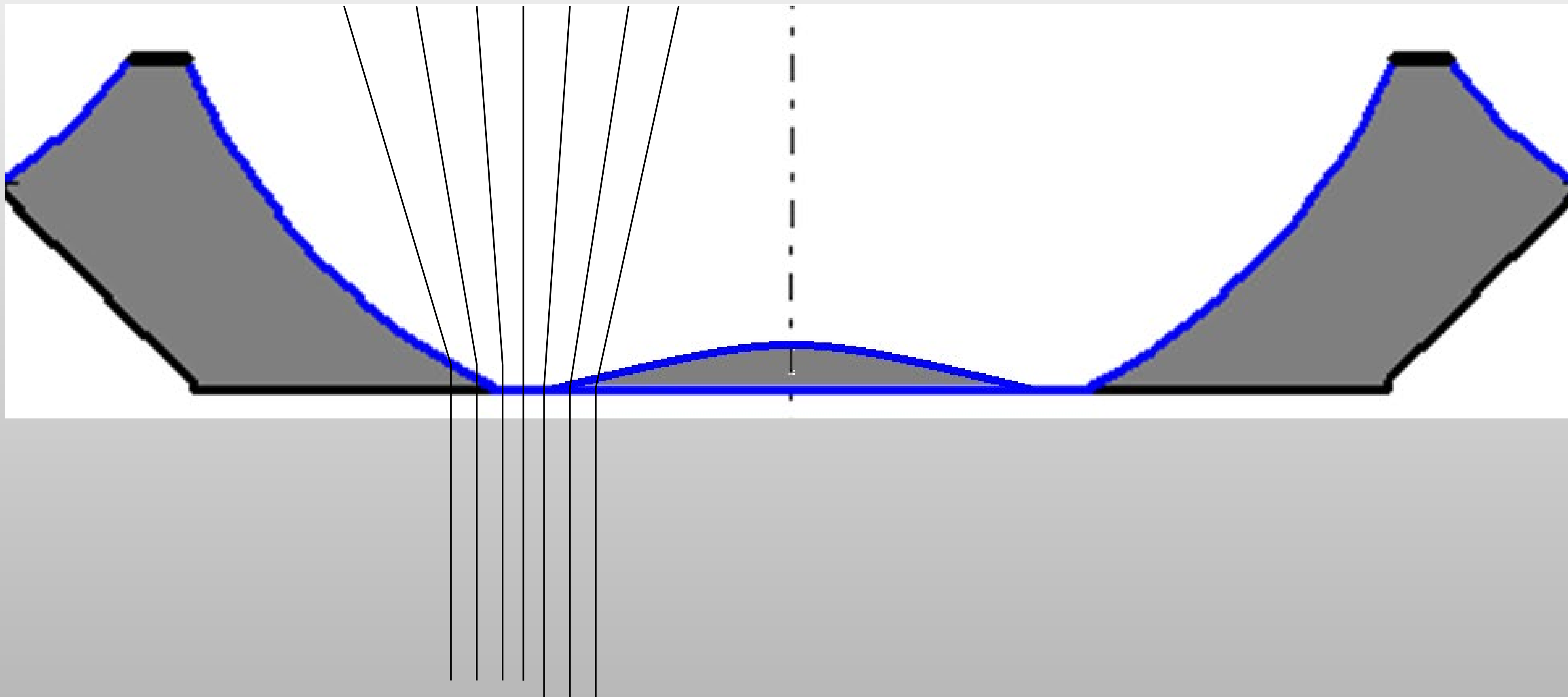
ML Demonstrator 2

- Goal: test lower concentration, filtered particles (< 1 μm)

- Aperture seems clear, but:
  - Lens effect caused by remaining fluid
  - Optical quality depends on speed
  - Lens effect on aperture edge

- Identified possible solution
  - Surface tension
  - Coated glass

Lens effect

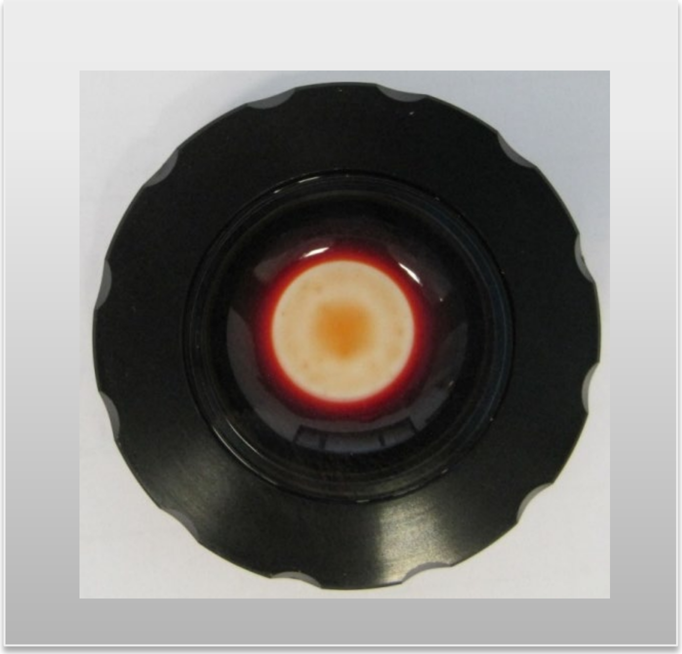


“trapped fluid” analysis

Possible solution	Argument pro	Contra
Low concentration	Less aggregation	Lens effect in soft edge
Small particle size	Less aggregation	Lens effect in soft edge
High surface tension	Less wetting	
Glass coating	Less wetting	

ML Demonstrator 3

- Goal: Test influence of
  - Surface tension of water
  - Glass silicon coating



- Trapped fluid problem
  - High surface tension is not enough
  - Speed dependent

- Identified possible solution
  - Increase contact angle

Fluid	Surface Tension
Mercury	470
Water	73
….	<< 60

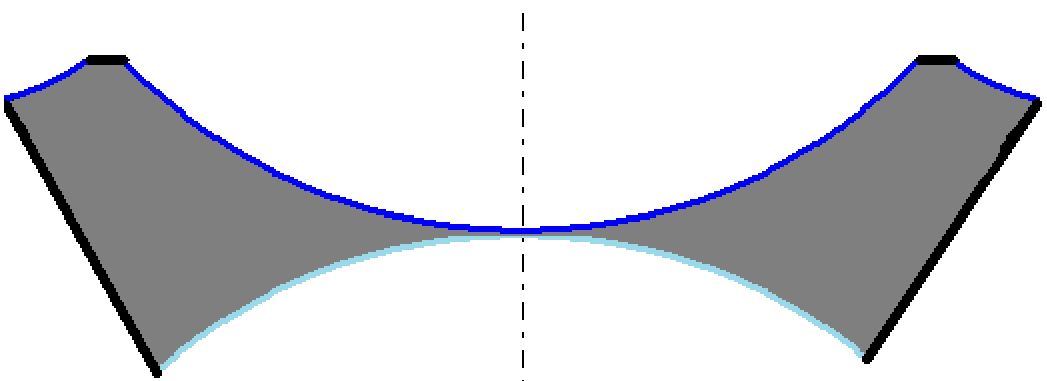
“trapped fluid” analysis

Possible solution	Argument pro	Contra
Low concentration	Less aggregation	Lens effect in soft edge
Small particle size	Less aggregation	Lens effect in soft edge
High surface tension	Less wetting	Does not solve problem
Glass coating	Less wetting	Does not solve problem
Contact angle	Less wetting	

ML Demonstrator 4

- Goal: test influence of contact angle

- Trapped fluid problem
  - Soft edge with lens effect



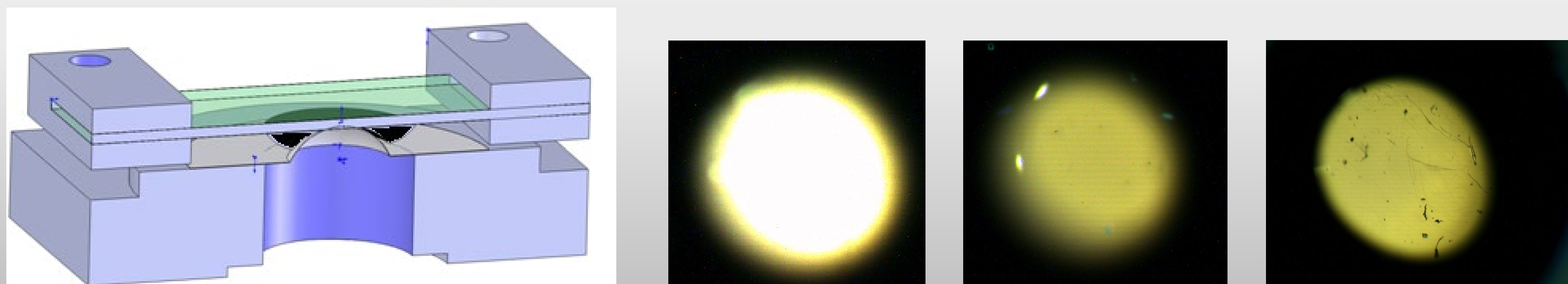
TUDelft optotune

“trapped fluid” analysis

Possible solution	Argument pro	Contra
Low concentration	Less aggregation	Lens effect in soft edge
Small particle size	Less aggregation	Lens effect in soft edge
High surface tension	Less wetting	Does not solve problem
Glass coating	Less wetting	Does not solve problem
Contact angle	Less wetting	Does not solve problem
Positive pressure	Force pushes liquid away	

Positive Pressure Test

- Air pressurized bulge pushes fluid away.
- Particles < 5µm: Clear aperture result but soft edge
- Particles > 5µm: trapped fluid problem

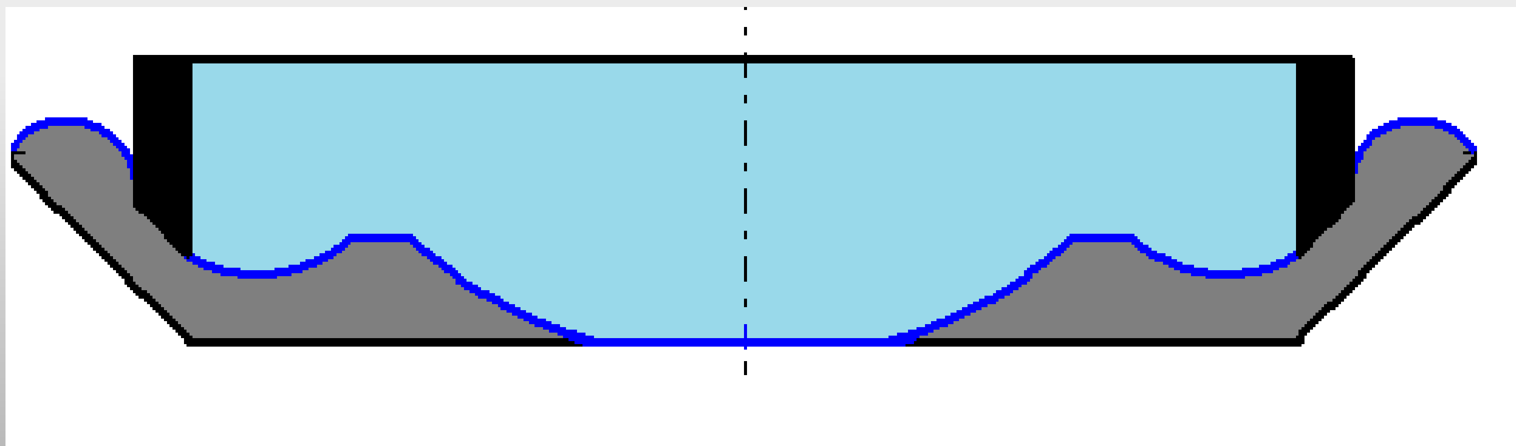


“trapped fluid” analysis

Possible solution	Argument pro	Contra
Low concentration	Less aggregation	Lens effect in soft edge
Small particle size	Less aggregation	Lens effect in soft edge
High surface tension	Less wetting	Does not solve problem
Glass coating	Less wetting	Does not solve problem
Contact angle	Less wetting	Does not solve problem
Positive pressure	Force pushes liquid away	Potential Solution

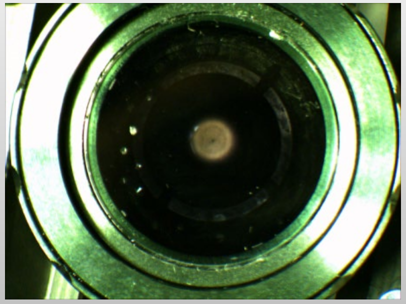
Double liquid positive pressure prototype

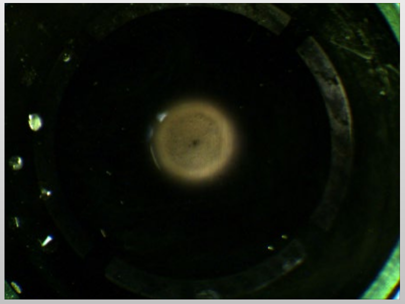
- Optotune lens design with two liquid compartments

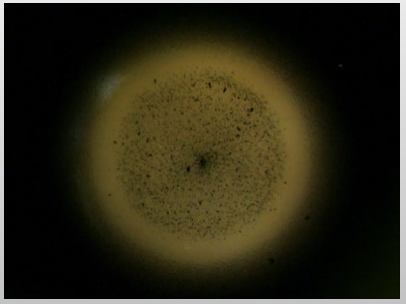


Double liquid positive pressure prototype

- Prototype results: trapped fluid appears again (speed dependent)
- Over time, pigments migrate through membrane into transparent fluid
- Particles were not filtered small enough

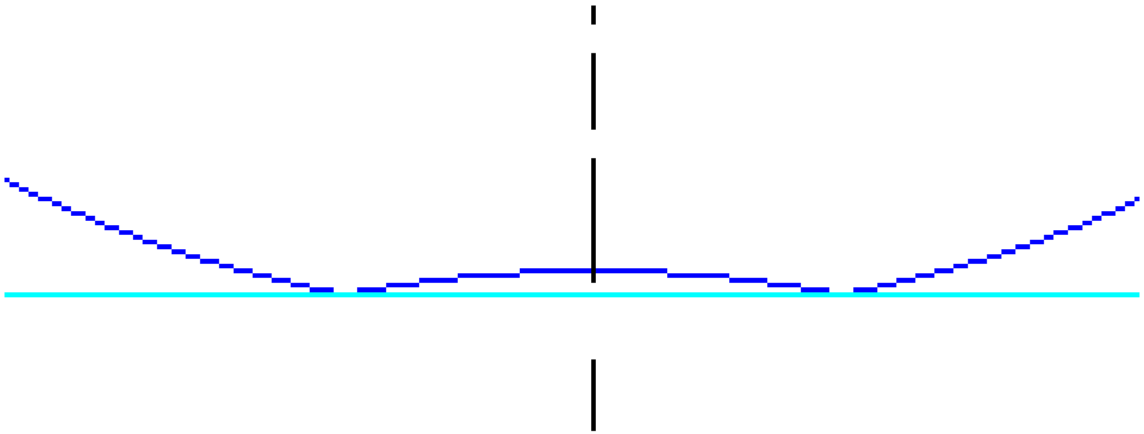






Feasibility of concept

- Use transparent fluid
- Is concept pigment dependent?



Aperture: Conclusions and Outlook

- Trapped fluid problem has not been solved
  - Surface profile of transparent lens should be measured
  - Particle size and concentration play a large role
- Lens effect can be solved by double fluid
  - Bigger and more complicated to produce
  - Pigments leak through the membrane

- Feasibility study advises to put the project on hold
  - Uncertainty of product quality and costs
  - *Not the lowest hanging fruit*

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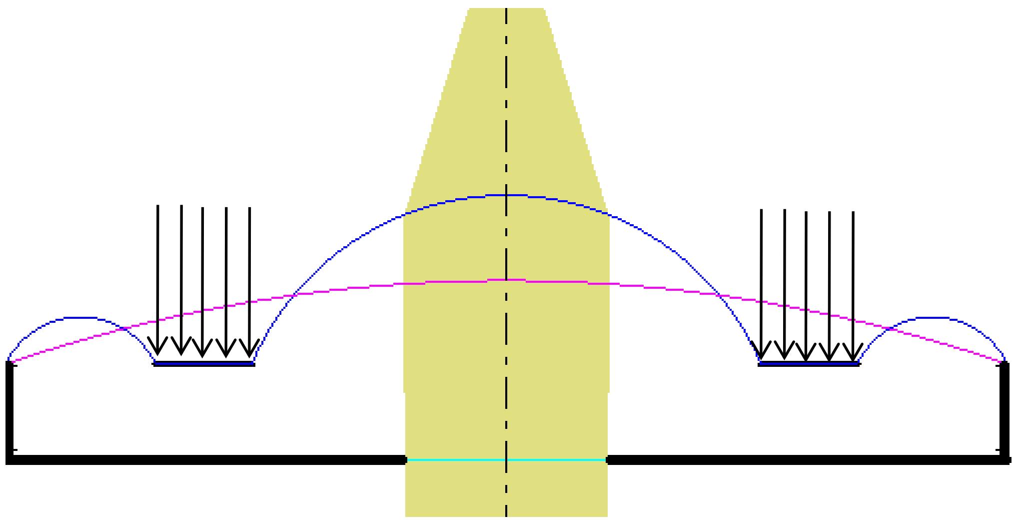


Membrane model identification

Input: Membrane	Process: Model	Output: Deflection
• Material SE0904 • t Thickness • ε_0 Prestrain • r Aperture radius • p Pressure	• Bulge test results • Linear model • Mooney Rivlin model	• Center • Ring • Visualisation tool

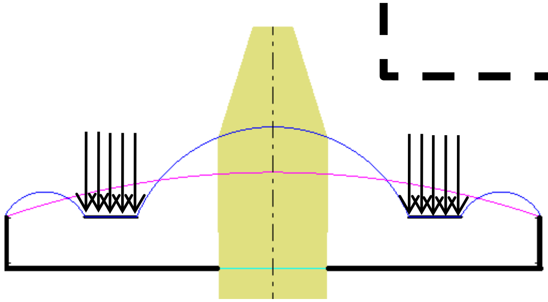
Membrane model identification

Actuation force

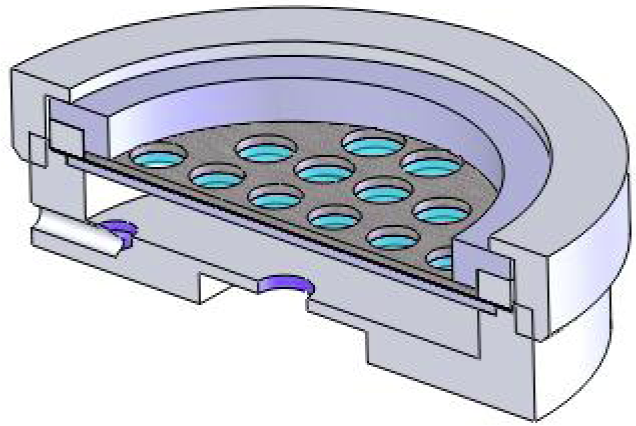
Pressure

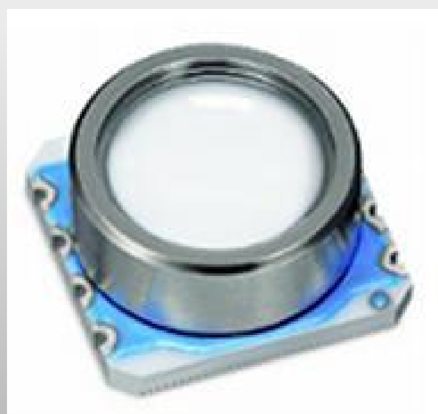
Deflection

Focal length

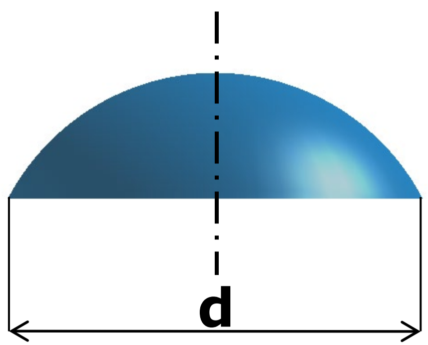


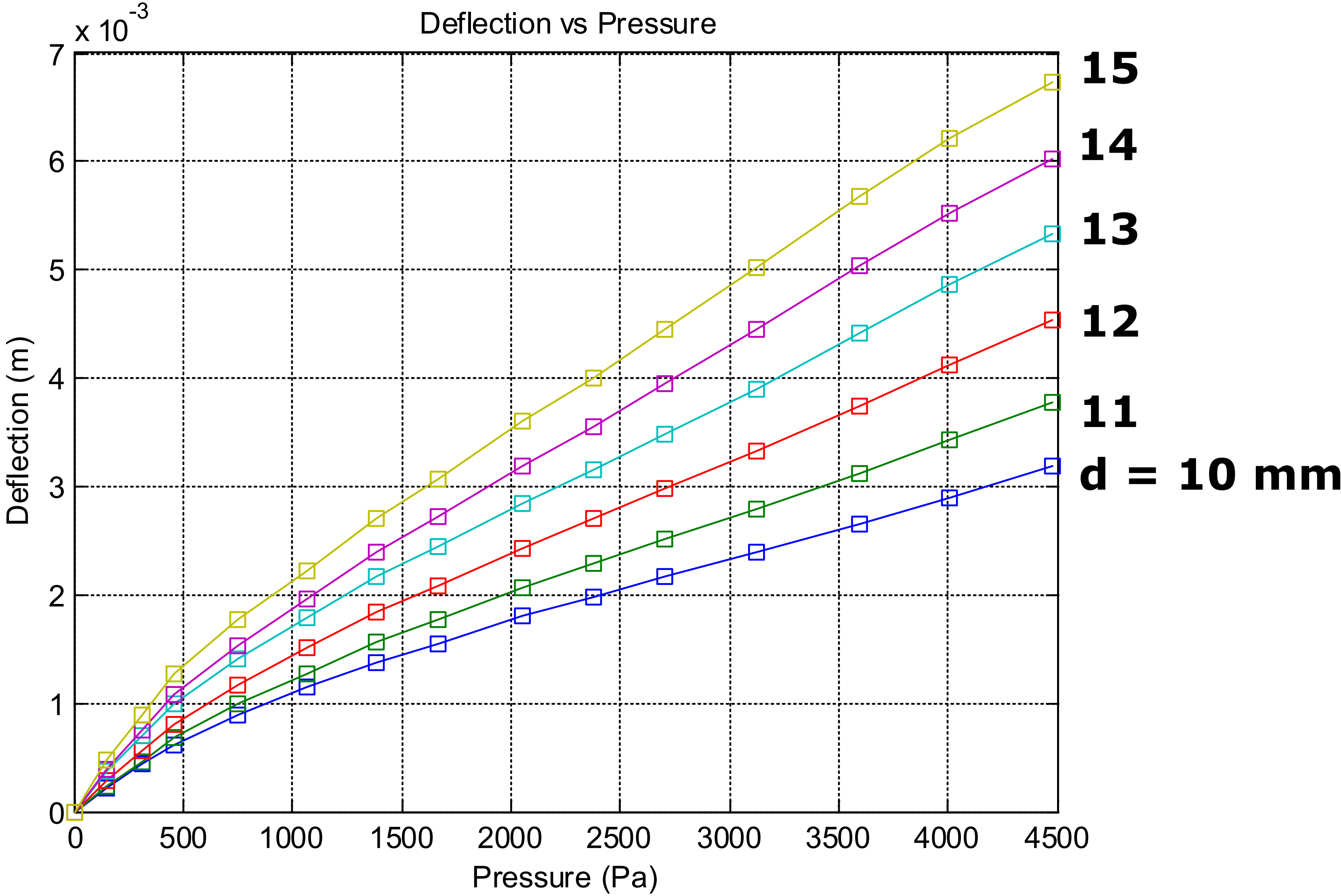
Design of experiment



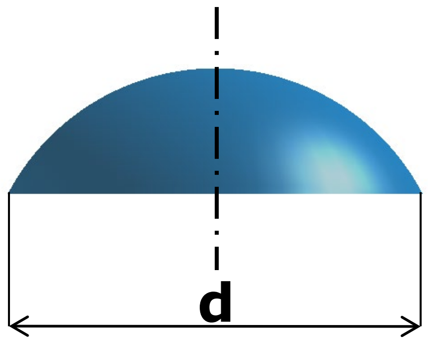


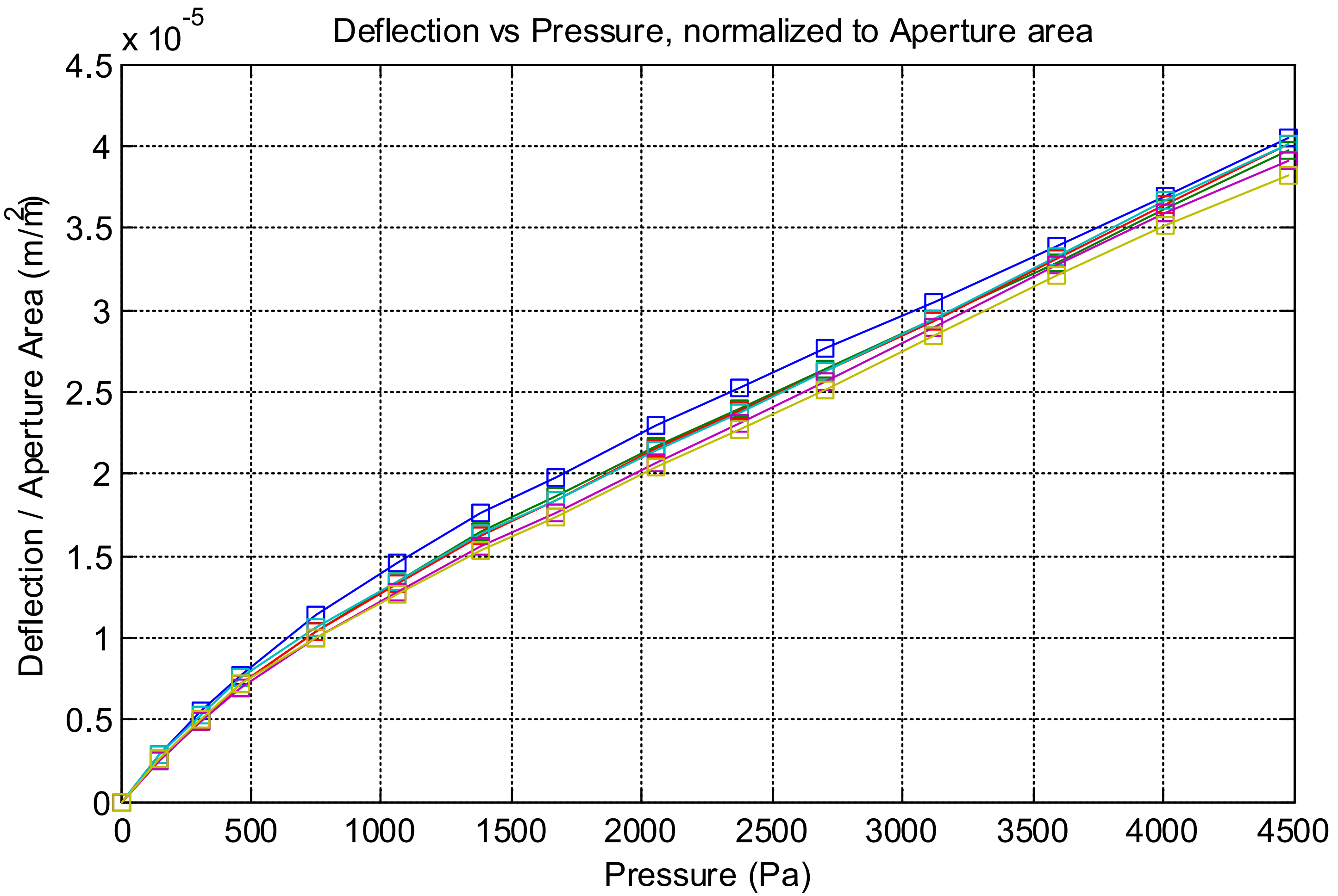
Deflection versus pressure - radius



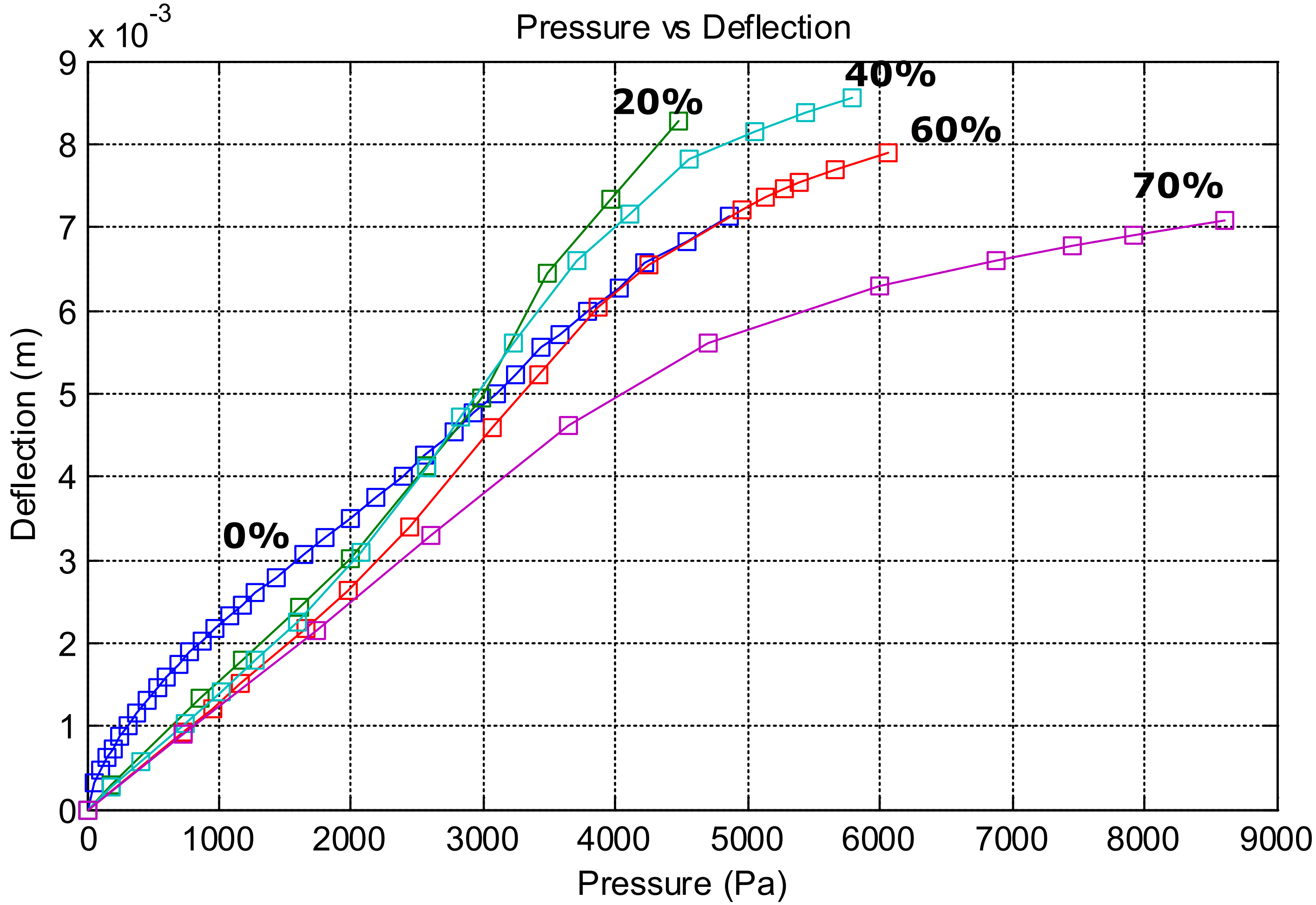


Deflection versus pressure - radius

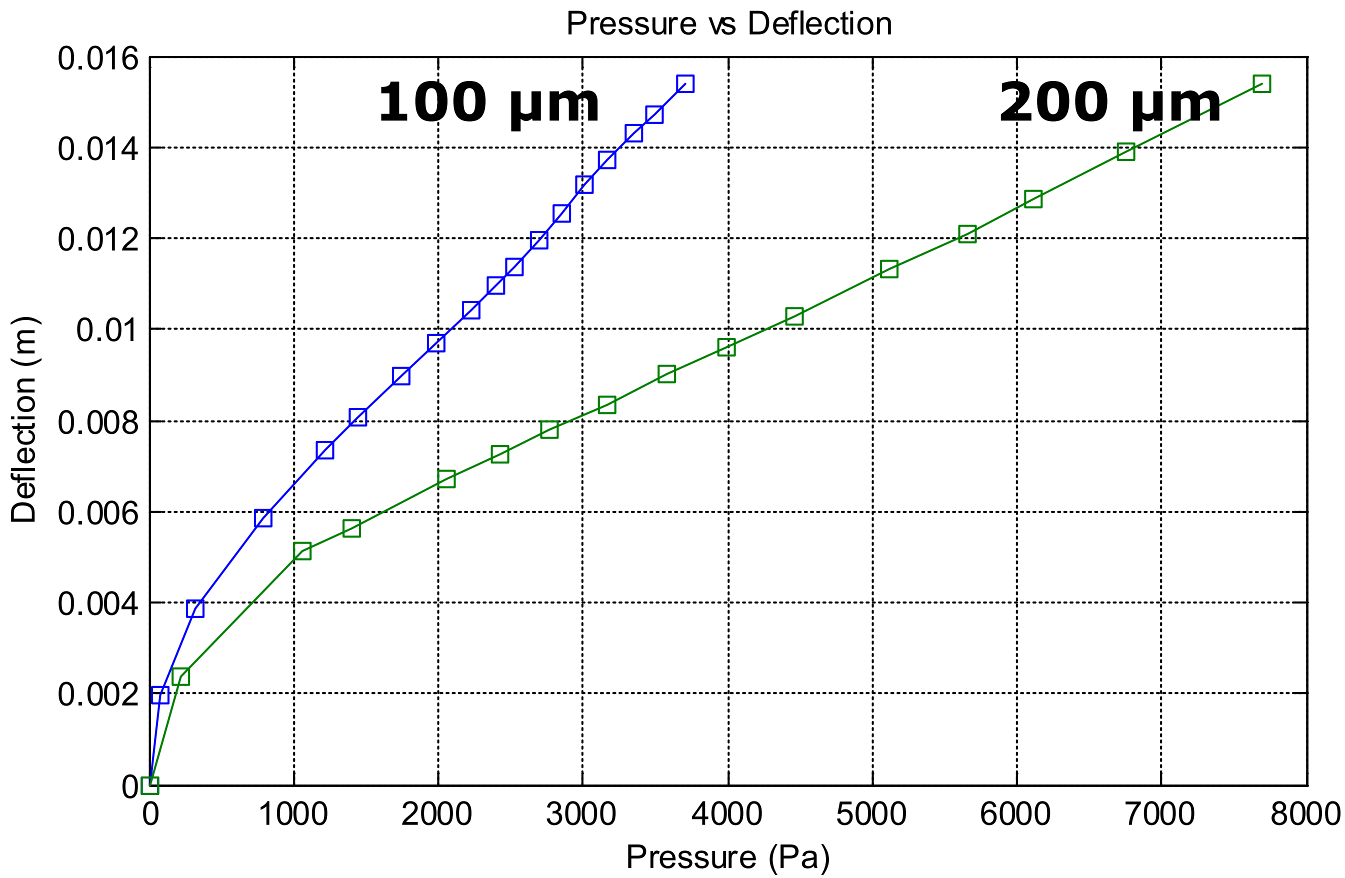




Deflection versus pressure - Prestrain



Deflection versus pressure - Thickness



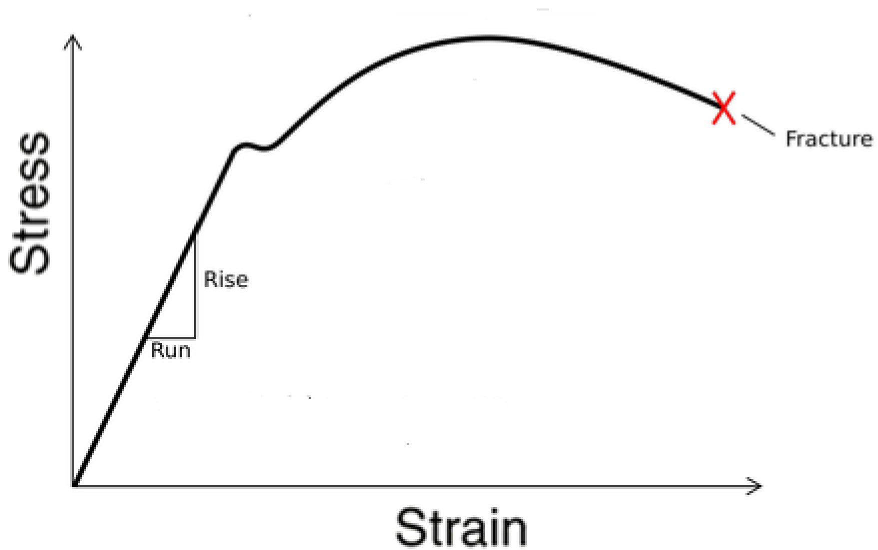
Measurements statistics

- 148 bulge measurements done

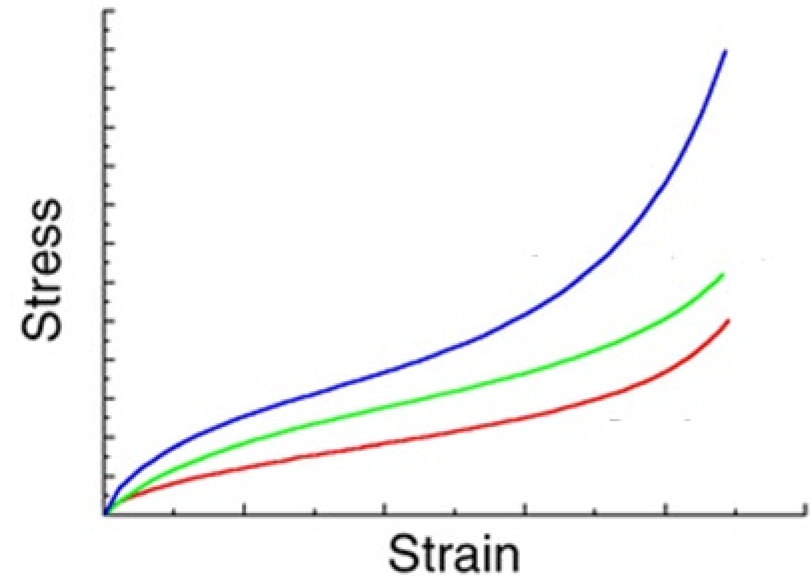
- Thickness 10 – 200 μm
- Radius 5 – 40 mm
- Pressure 0 – 30000 Pa

Modelling

Isotropic – constant Youngs



Non Isotropic – variable Youngs

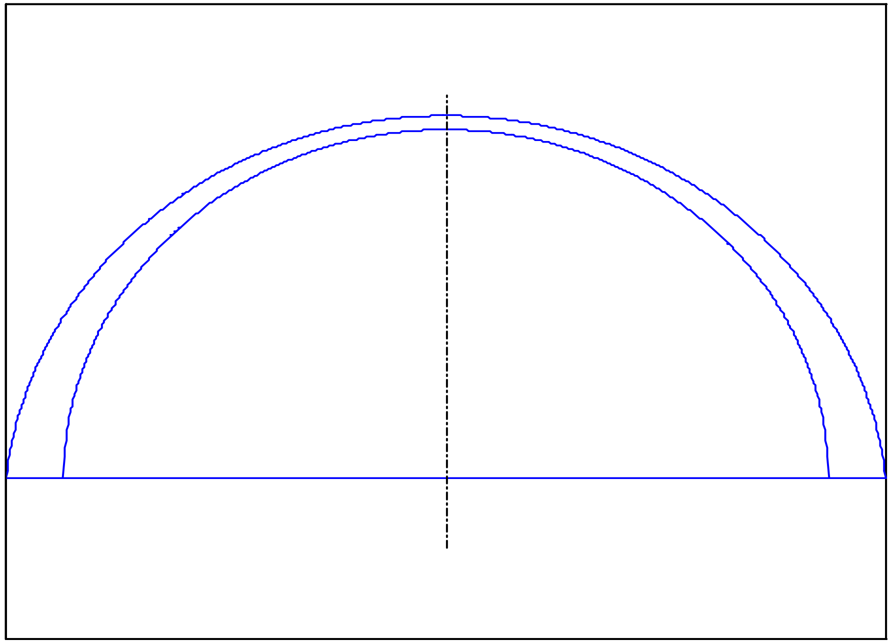


Further challenges

- **Bulge loading**
- **Material model might change**

Bulge loading

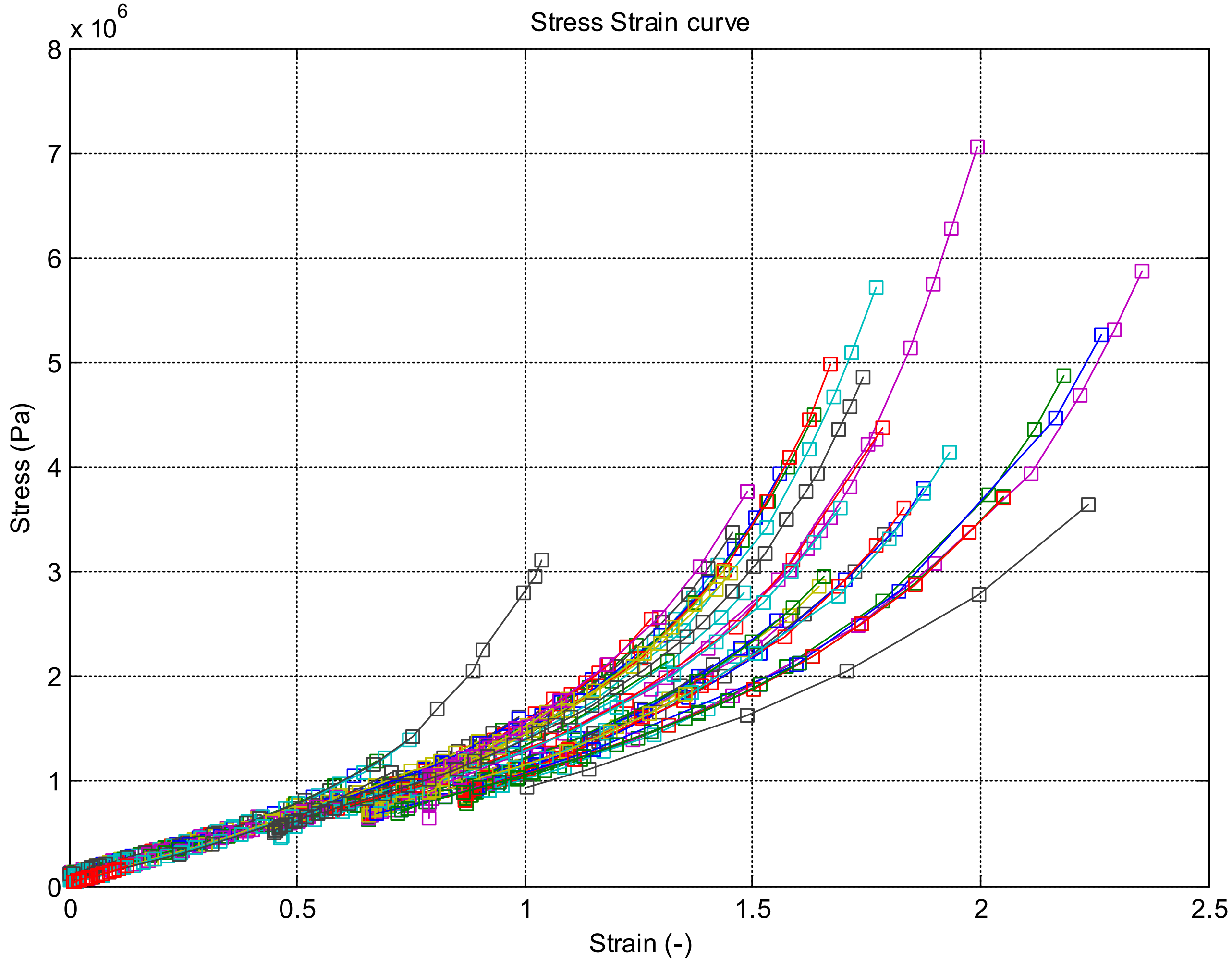
- Thickness not constant
- Thickness proportional to stretch
- Where to measure thickness / stretch?



Stress calculation

- 'Math slide'

Stress Strain calculated



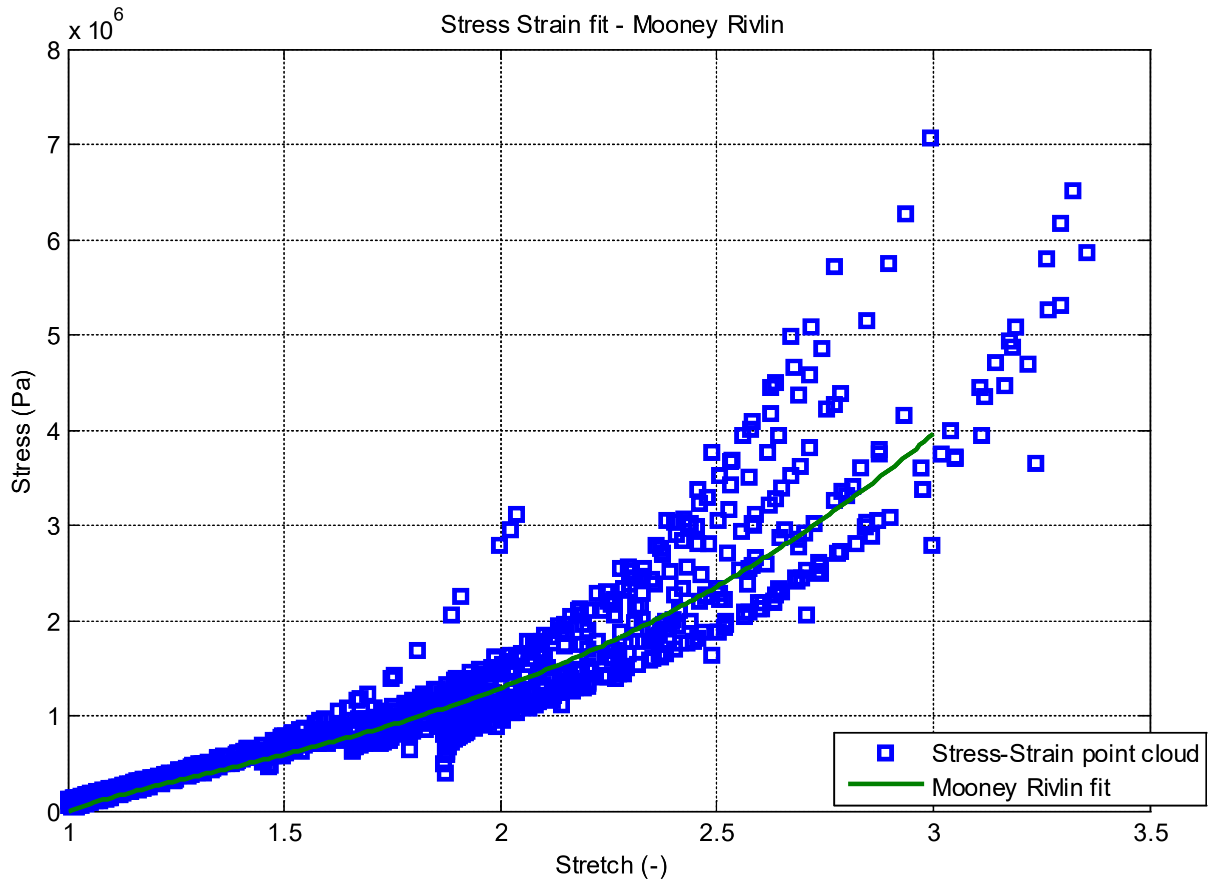
$$\lambda_p = \lambda_{pre}\lambda_{meas}$$

Stress strain fit

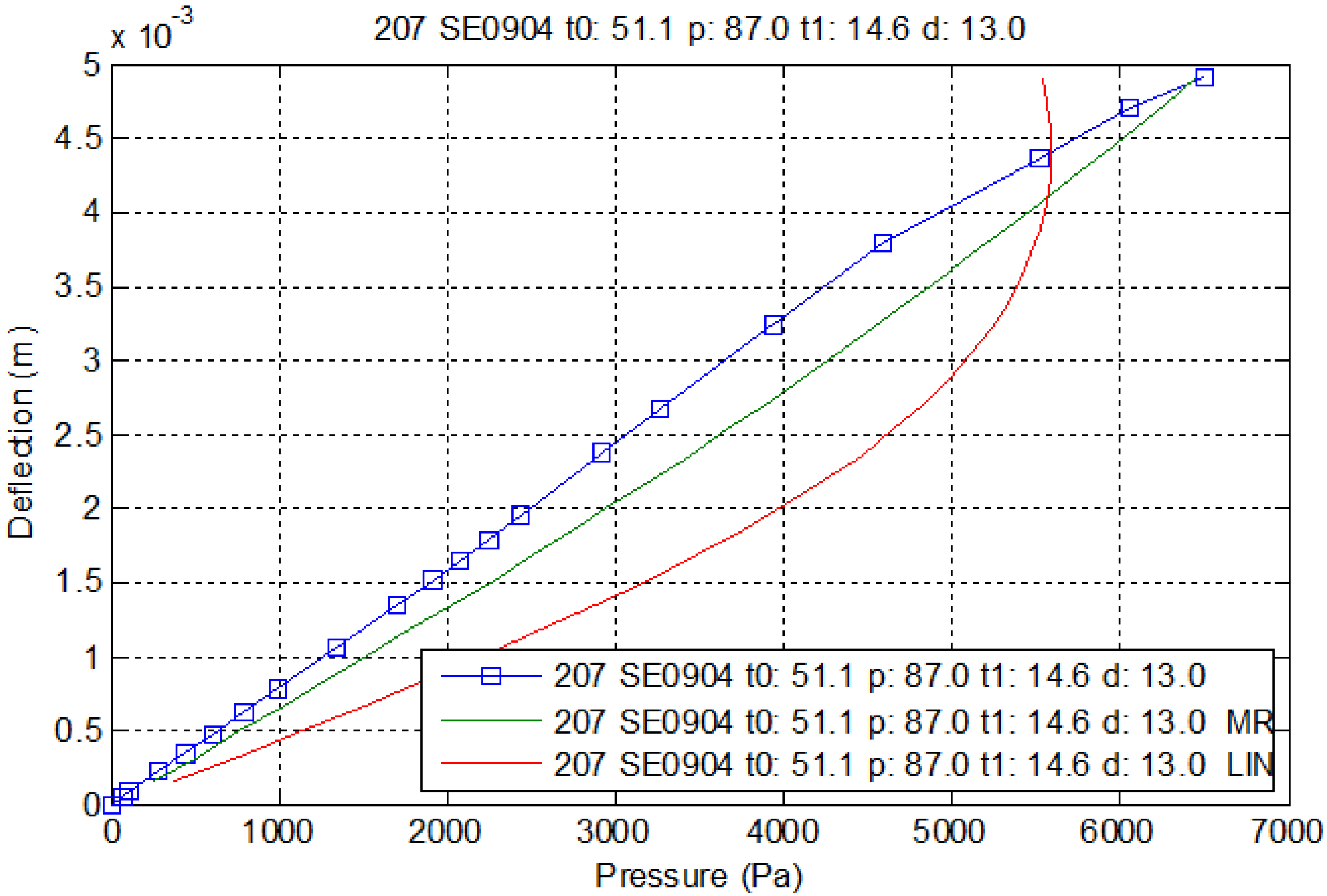
C10 = 210400 Pa

C01 = 16005 Pa

$$\sigma_{MR} = c10 * (\lambda^2 - \lambda^{-4}) - c01 * (\lambda^{-2} - \lambda^4)$$



Deflection versus Pressure - Simulation



Error model	RMS
Mooney Rivlin	0.0549
Linear model	0.1146

Membrane model identification

Input: Membrane

- Material SE0904
- *t* Thickness
- ε_0 Prestrain
- *r* Aperture radius
- p Pressure

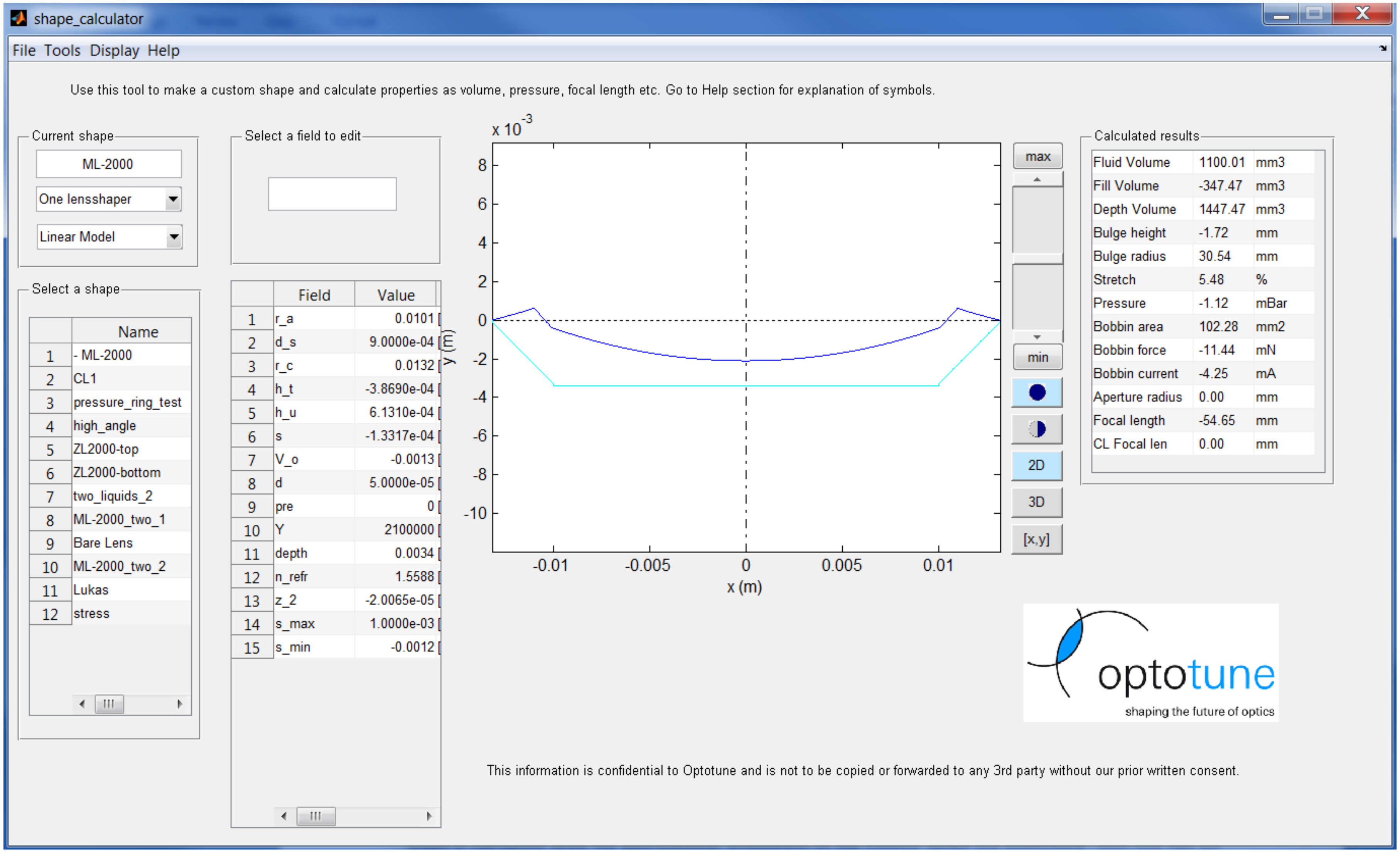
Process: Model

- Bulge test results
- Linear model
- Mooney Rivlin model

Output: Deflection

- Center
- Ring
- Visualisation tool

Shape Predictor



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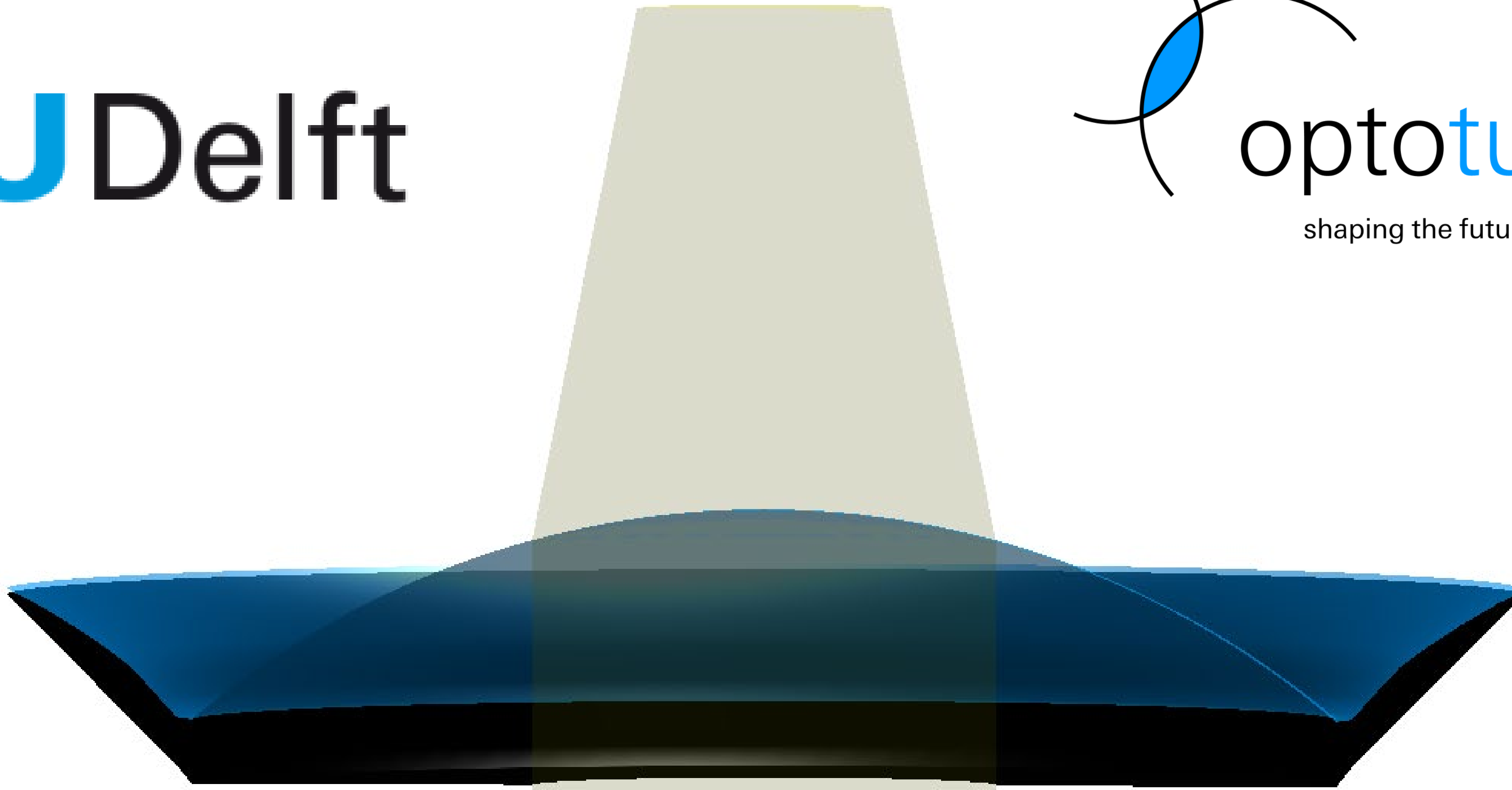
shaping the future of optics



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