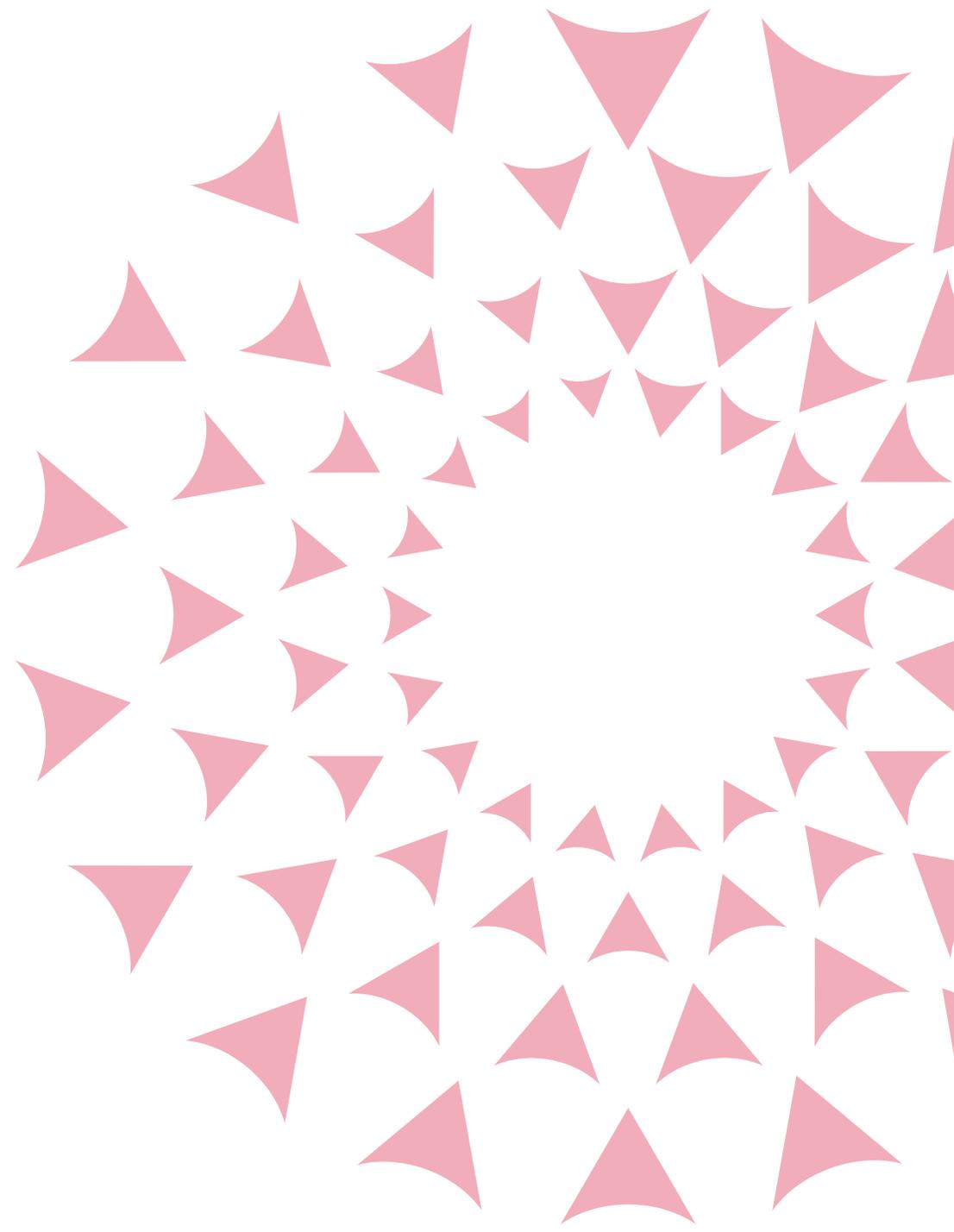


Design, Manufacture and Testing of 3D Printed Phantoms for CT Scanner AEC Testing

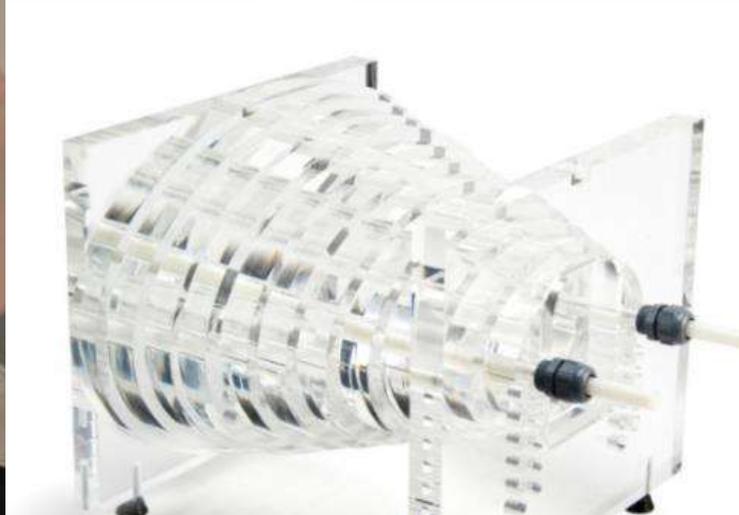
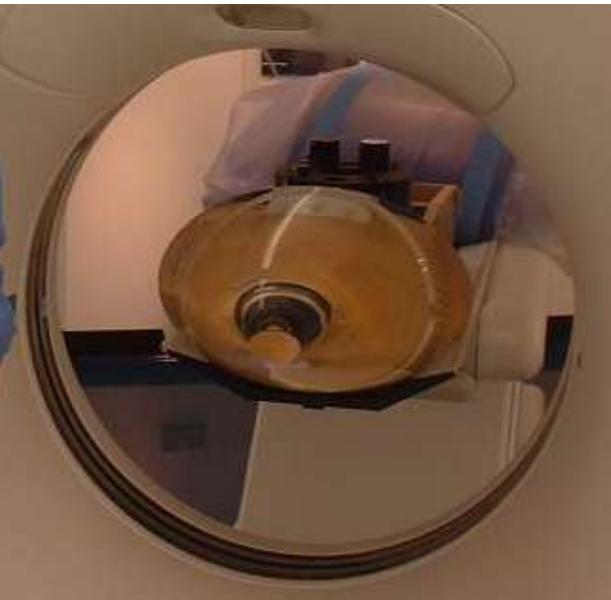
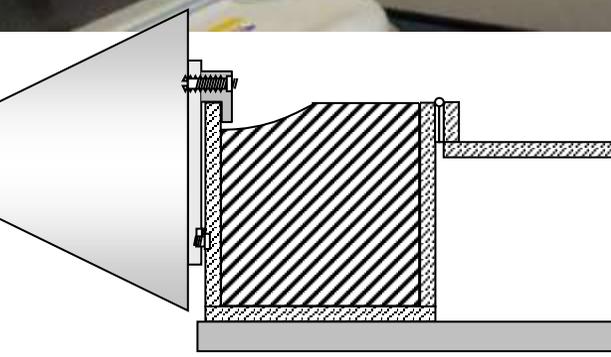
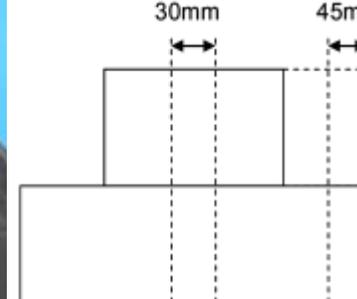
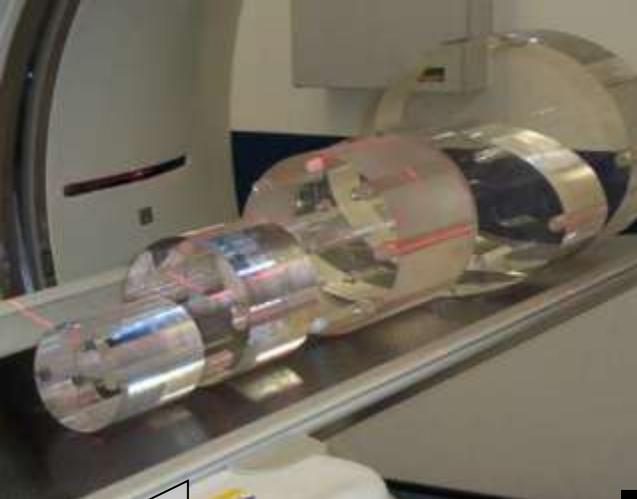
Nick Keat, PET-CT Physicist
Perceptive Discovery, London



Previously on ctug.org.uk

Year	Presenter	Phantom	Link	Title
2004	Elly Castellano	Various PMMA stacked	🔗	The Auto mA feature on the latest wave of GE scanners
2004	Gareth Iball	Anatomically Shaped PMMA		The Assessment of Siemens Caredose software for pelvic CT
2004	Nick Keat	ImPACT	🔗	Assessment of automatic exposure control systems on CT scanners using a custom made phantom
2007	David Platten	Patients	🔗	Setting up the AEC on a GE LightSpeed 16 CT scanner
2008	Geraldine Revill	ImPACT	🔗	Investigation into the dose & image quality of Siemens Caredose 4D during clinical use: A comparison of 3 centres
2008	Lynn Bateman	BOD	🔗	A simple anthropomorphic phantom used to demonstrate the effectiveness of CT dose modulation functions
2008	Katie Howard	Patients	🔗	Use of CT automated exposure control and image quality in PET-CT
2010	Emily Field	ImPACT	🔗	Comparison of the function and performance of CT AEC systems
2012	Tim Wood	Rando, Elliptical PMMA	🔗	Optimisation of the Philips automatic exposure control system
2012	Tim Wood		🔗	CT AEC characterisation and optimisation using a noise-power spectra analysis framework
2012	Gareth Iball	Rando	🔗	CT AEC Techniques in PET/CT scanning
2012	Supawitoo Sookpeng	Five elliptical cross sections		New designed phantom to test CT ATCM systems
2012	Colin Martin	Perspex Ellipse		A study of CT dose distributions in an elliptical phantom and the influence of automatic tube current modulation
2013	Ruth Nicol	UHCW phantom "Bertie"	🔗	Assessing AEC performance of CT scanners using a custom-designed phantom Focus on positioning and centering of the patient
2013	Lynn Bateman	CeLT	🔗	'One Stop CT QA'; Routine QA with the CeLT phantom
2015	Deborah Merzan	3 section PMMA	🔗	A novel phantom to evaluate longitudinal and angular automatic tube current modulation (ATCM) in CT
2018	Debbie Harries	Mercury 4.0	🔗	First Experiences with the Mercury 4.0 AEC Phantom
2018	Gareth Iball	CTDI Phantom	🔗	Six years of AEC testing – what have we learned?
2020	Emily Seymour	CeLT, GE Water	🔗	Intra-Scanner Detector and AEC Study
2024	Laurence King	Nested CTDI, Leeds, Mercury	🔗	Experiences of TCM testing



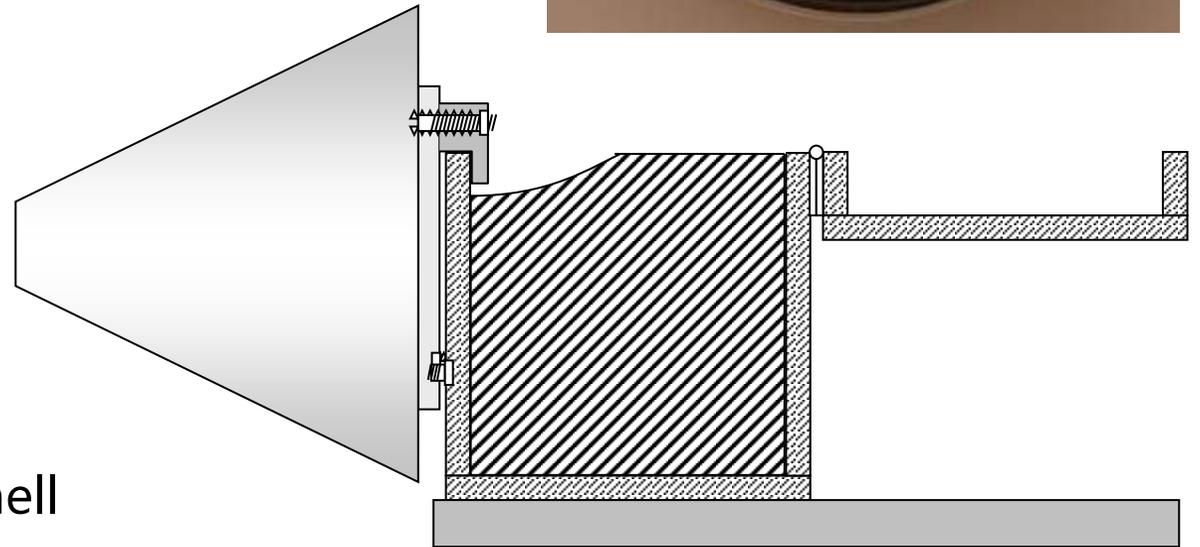


Motivation for this presentation

- Plenty of CTUG AEC presentations over the years
- A lack of standardisation of AEC testing methodology
 - Scanners have different capabilities / approaches
 - Everyone has different phantoms
 - Report 32 update reflects this diversity
 - Easier to recommend approaches to testing than a protocol
- This talk isn't really about AEC performance!
- Aim to 3D print a more practical AEC phantom

What is needed from an AEC phantom?

- Something anatomically relevant
 - Approximately tissue equivalent
 - Typical patient cross section size range
 - Typical patient cross section shape range
 - Gradual change / steps in z-axis
 - Repeatability
- Something practical
 - Not too heavy
 - Not too delicate
 - Not too expensive
- Use ImPACT phantom as basic design
 - 3:2 ellipse cross section
 - Replace solid acrylic with water fillable shell



3D Printing a solution

- Fused Deposition Modelling (FDM)
 - Most used consumer 3D printing technology
 - Melted plastic filament extruded onto build plate layer by layer to build model



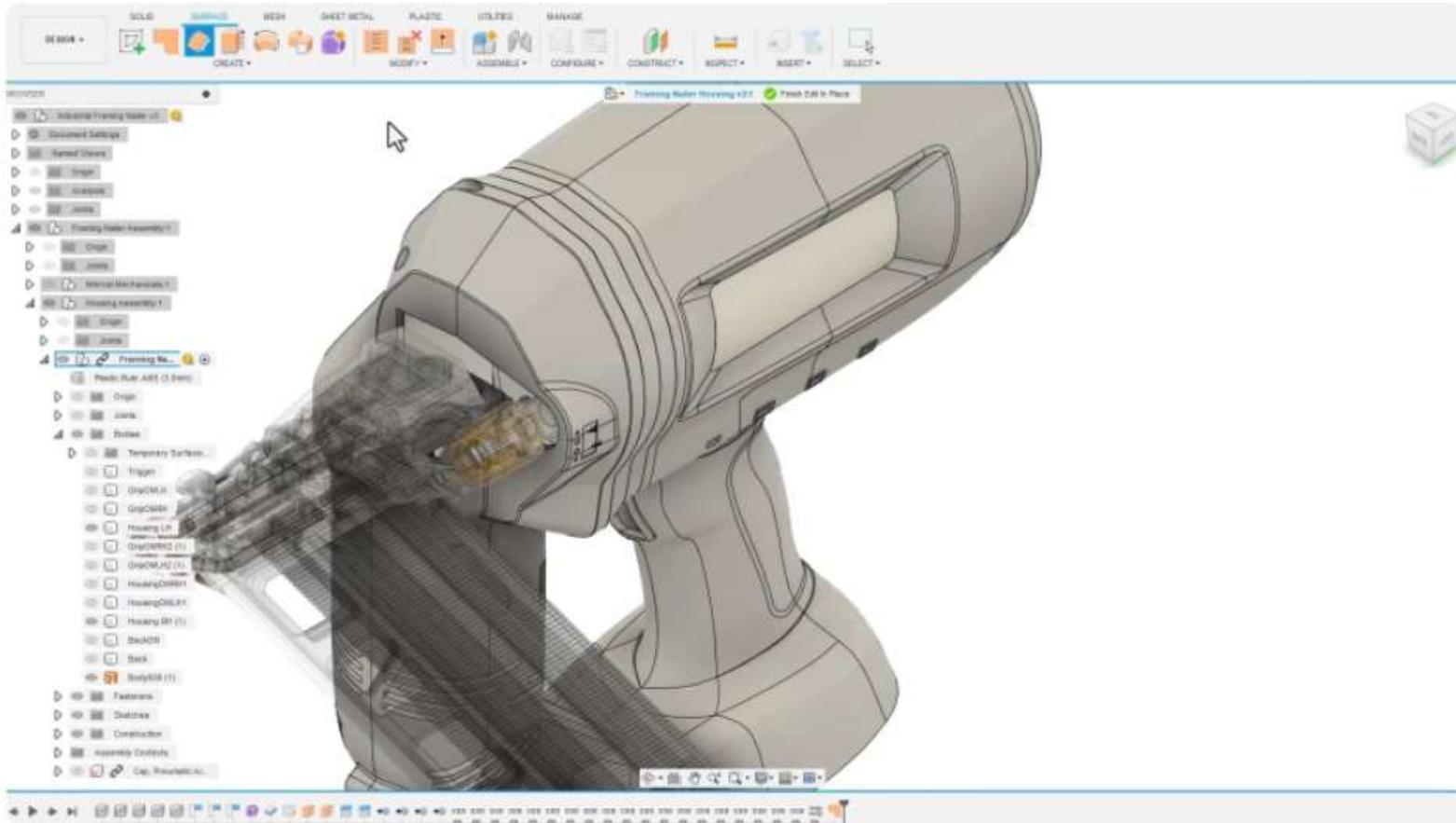
FDM printers

- Consumer FDM e.g. Bambulabs A1 Mini
 - 180 x 180 x 180 mm build volume
 - £170, 1 kg filament ~ £15-20
 - Print head moves left-right (x) and up (z)
 - Bed moves back and forwards (y) "bed slinger"



3D modelling software

- Autodesk Fusion: CAD/CAM with huge capabilities for design, testing, assembly

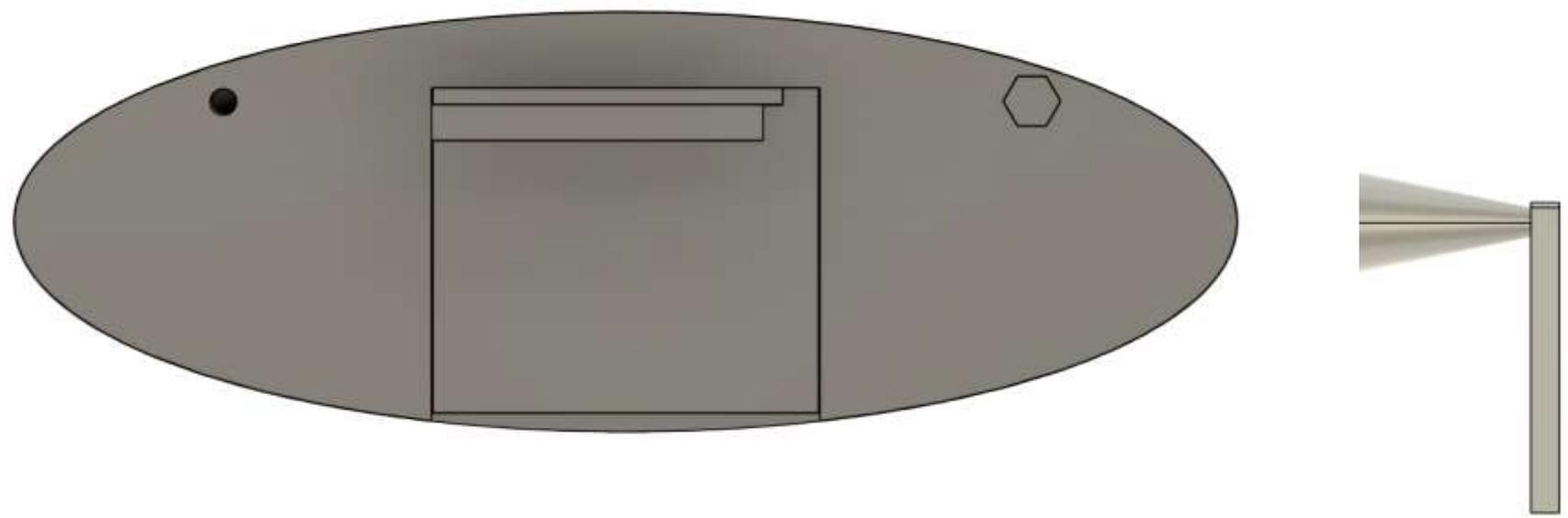


DESIGN - SOLID SURFACE MESH SHEET METAL PLASTIC MANAGE UTILITIES

CREATE • MODIFY • ASSEMBLE • CONFIGURE • CONSTRUCT • INSPECT • INSERT • SELECT •

BROWSER

- AEC Phantom Parametric v14
 - Document Settings
 - Named Views
 - Origin
 - Analysis
 - Section1
 - Section4
 - Section6
 - Construction
 - Cone.1
 - Origin
 - Bodies
 - Sketches
 - Base Sketch
 - Top Sketch
 - Base.1
 - Origin
 - Bodies
 - Base
 - Top.1
 - Origin
 - Bodies
 - Body.1
 - Prop.1
 - Origin
 - Bodies
 - Sketches
 - Bolt.1
 - Origin
 - Bodies
 - Sketches
 - Catphan Box Mount.1
 - Origin
 - Bodies



COMMENTS

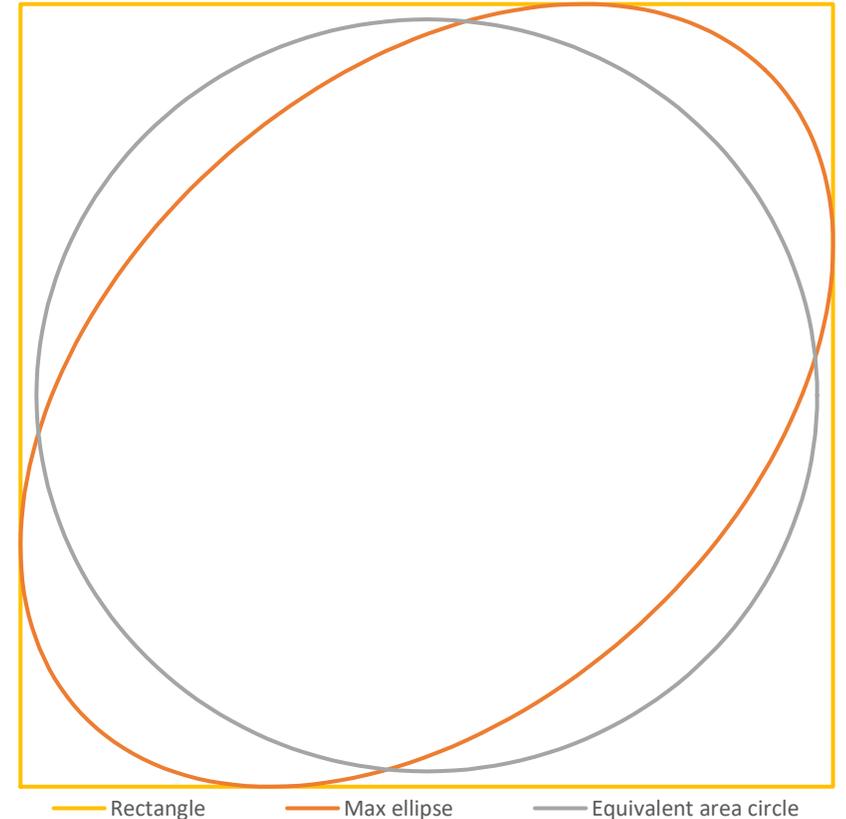
Navigation icons: pan, rotate, zoom, fit, etc.

Main toolbar with various CAD tools: create, modify, assemble, etc.



Preparing V1

- 180 * 180 mm build plate, 3:2 major to minor ratio
 - Ellipse 211*141 mm
 - Same Water Equivalent Diameter (WED) as 173 mm circle
- Maximum area of an ellipse of given eccentricity on a rectangular build plate:
 - An obscure question!
 - Ask ChatGPT...
 - Rectangle width and height W, H
 - $e =$ eccentricity of ellipse with diameters $a, b = \sqrt{1 - \left(\frac{b^2}{a^2}\right)}$
 - Max area, $A_{max} = \frac{\pi\sqrt{1-e^2} (W^2+H^2)}{4(2-e^2)}$
 - Optimal rotation, $\theta = \arcsin(\sqrt{s})$
 - $s = (W^2 - H^2(1 - e^2))/(e^2(W^2 + H^2))$



Slicing, supports, infill

Support Settings:

- Enable support:
- Type: normal(auto)
- Style: Default
- Threshold angle: 30
- On build plate only:
- Remove small overhangs:

Raft Settings:

- Raft layers: 0

Filament for Supports:

- Support/raft base: Default
- Support/raft interface: Default

Advanced Settings:

- Initial layer density: 90 %
- Initial layer expansion: 2 mm
- Support wall loops: 0
- Top Z distance: 0.2 mm
- Bottom Z distance: 0.2 mm
- Base pattern: Default
- Base pattern spacing: 2.5 mm
- Pattern angle: 0 °
- Top interface layers: 2 layers
- Bottom interface layers: 2 layers
- Interface pattern: Default
- Top interface spacing: 0.5 mm

Line Type	Time	Percent	Used filament	Display
Inner wall	36m40s	9.8%	16.85 m 53.48 g	<input checked="" type="checkbox"/>
Outer wall	1h4m	16.9%	15.59 m 49.50 g	<input checked="" type="checkbox"/>
Overhang wall	8s	<-0.1%	0.01 m 0.02 g	<input checked="" type="checkbox"/>
Sparse infill	1h43m	27.5%	21.44 m 68.06 g	<input checked="" type="checkbox"/>
Internal solid infill	45m7s	12.0%	17.97 m 57.06 g	<input checked="" type="checkbox"/>
Top surface	5m44s	1.5%	1.76 m 5.58 g	<input checked="" type="checkbox"/>
Bottom surface	7m26s	2.0%	1.24 m 3.94 g	<input checked="" type="checkbox"/>
Bridge	25m10s	6.7%	3.35 m 10.62 g	<input checked="" type="checkbox"/>
Gap infill	2s	<-0.1%	0.00 m 0.00 g	<input checked="" type="checkbox"/>
Support	20m3s	5.3%	3.93 m 12.47 g	<input checked="" type="checkbox"/>
Support interface	12m32s	3.3%	1.42 m 4.51 g	<input checked="" type="checkbox"/>
Custom	5m32s	1.5%	0.02 m 0.06 g	<input checked="" type="checkbox"/>
Travel	50m23s	13.4%		<input checked="" type="checkbox"/>
Retract				<input type="checkbox"/>
Unretract				<input type="checkbox"/>
Wipe				<input type="checkbox"/>
Seams				<input type="checkbox"/>

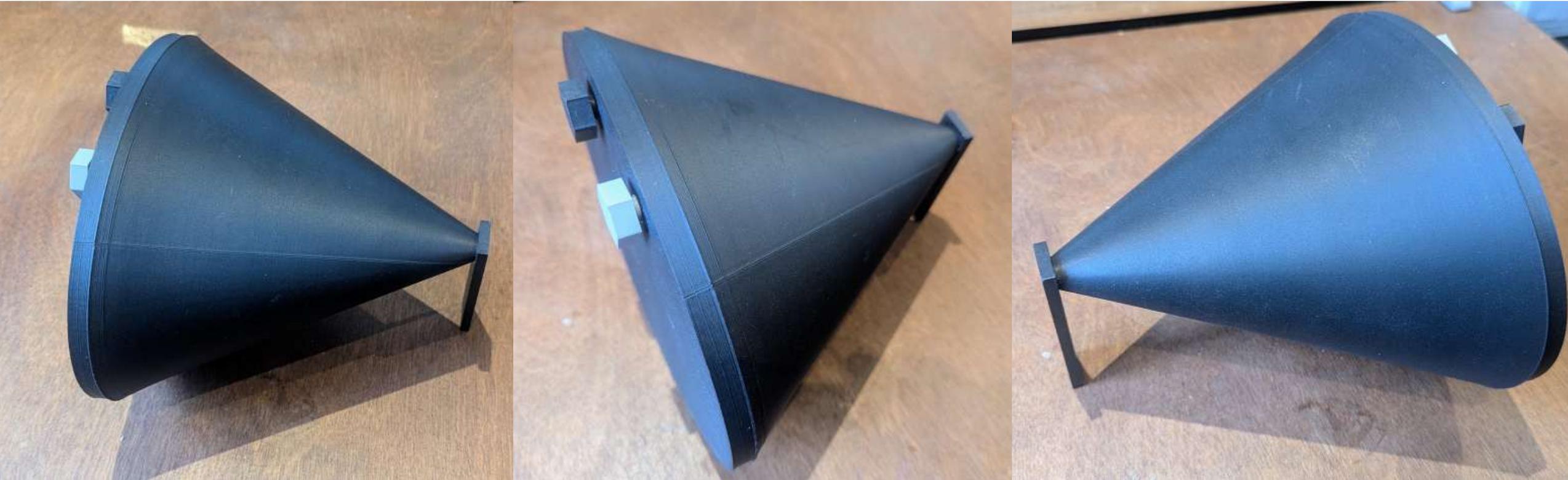
Total Estimation:

- Total Filament: 83.57 m 265.33 g
- Model Filament: 78.22 m 248.34 g
- Cost: 6.63
- Prepare time: 5m27s
- Model printing time: 6h10m
- Total time: 6h15m



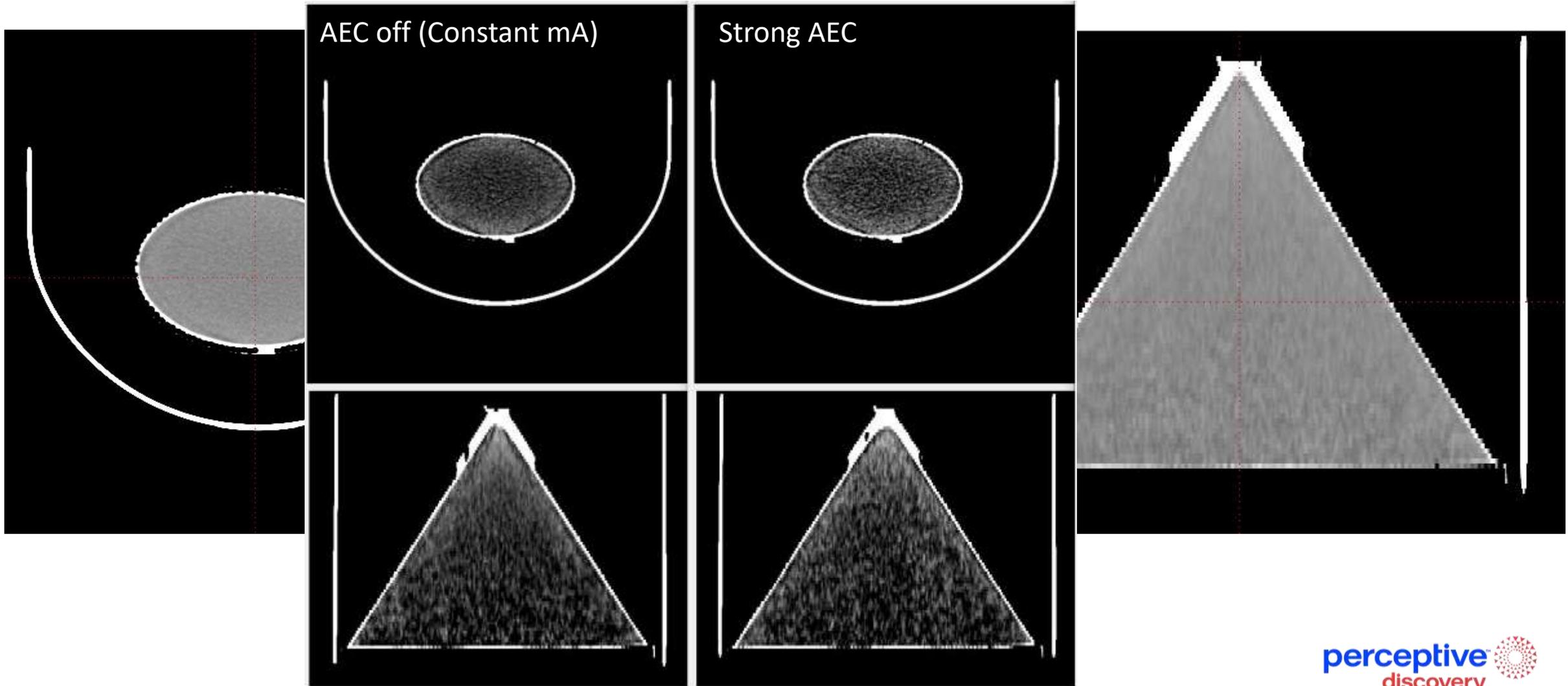
The result

- Printed with PLA (Polylactic Acid) filament
- ~ 6 hour print
- ~ 1 hour for prop and bolts

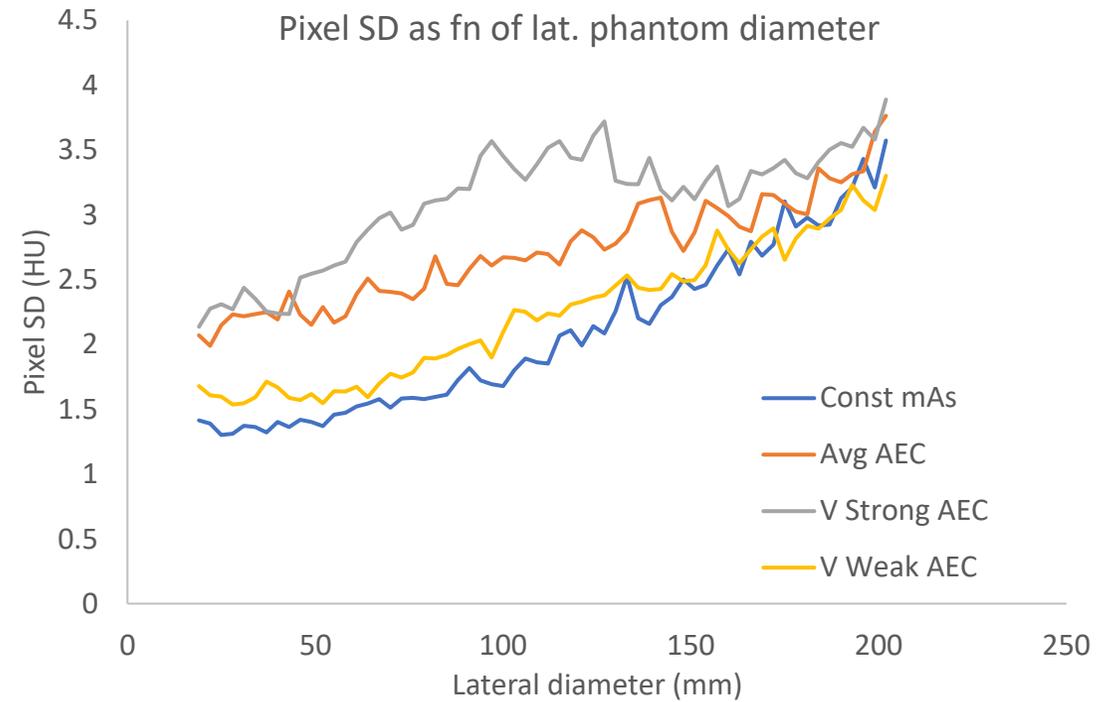
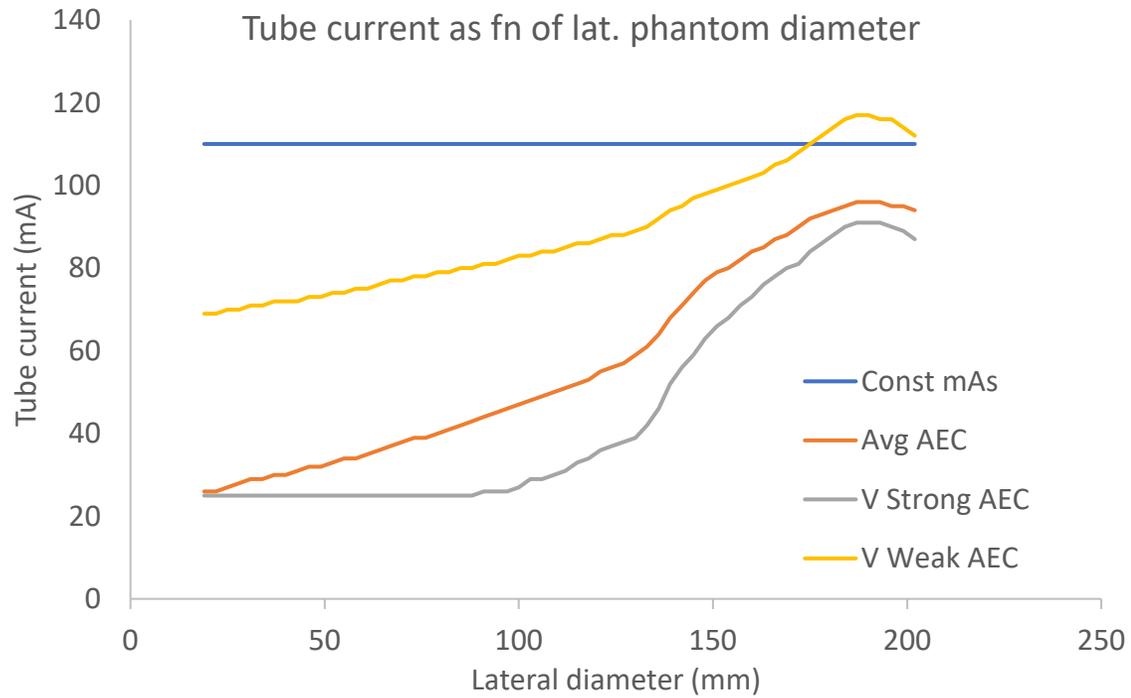


Scanning

- Siemens Horizon PET-CT: scanned as a head, phantom too small for body AEC

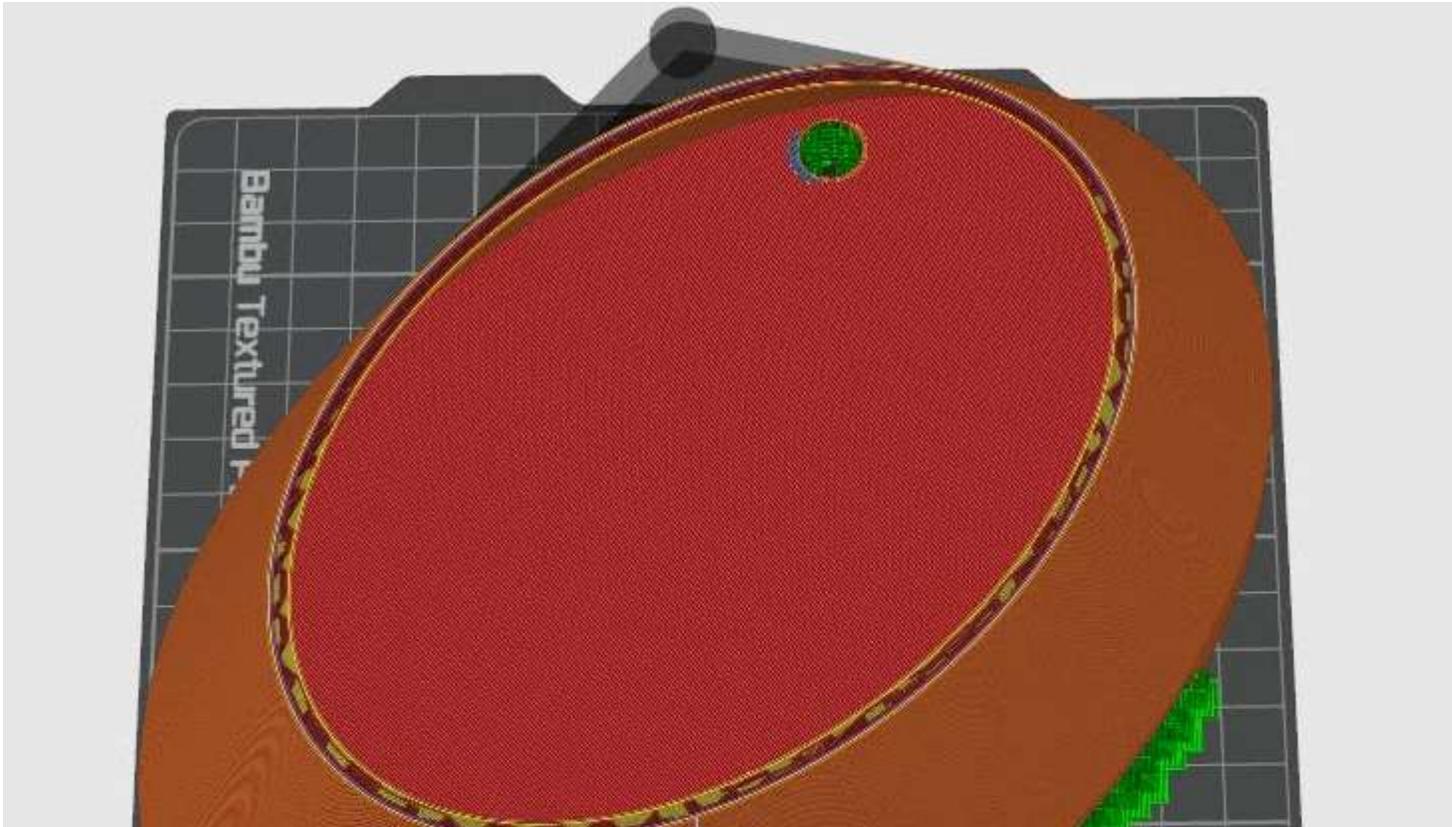


Analysis



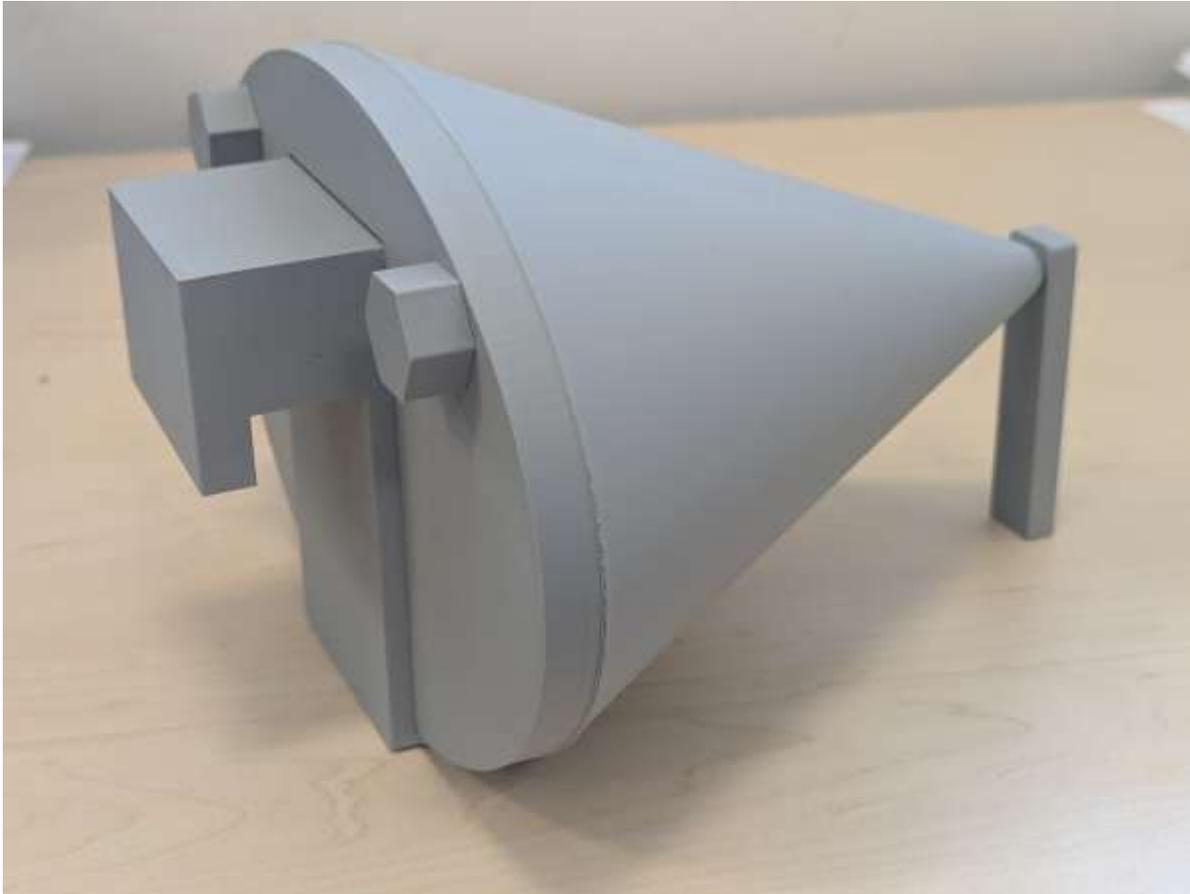
Thoughts from V1

- Phantom proves the concept
 - Light, strong, simple to fill and position, rapid prototyping
- Some ingress of water within phantom walls
- Larger printer needed for body phantom



V1a

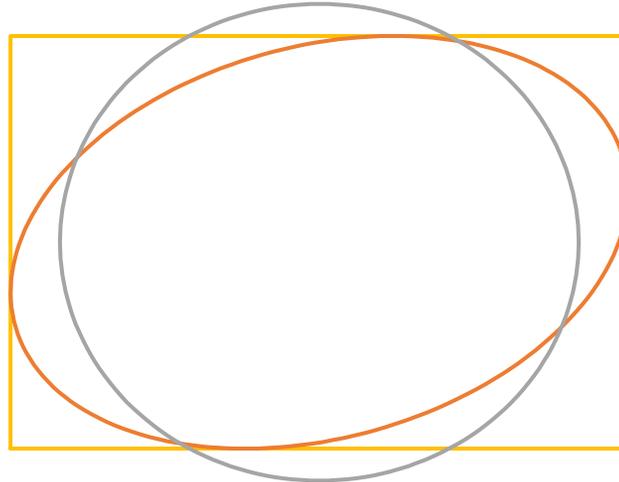
- Added Catphan mount



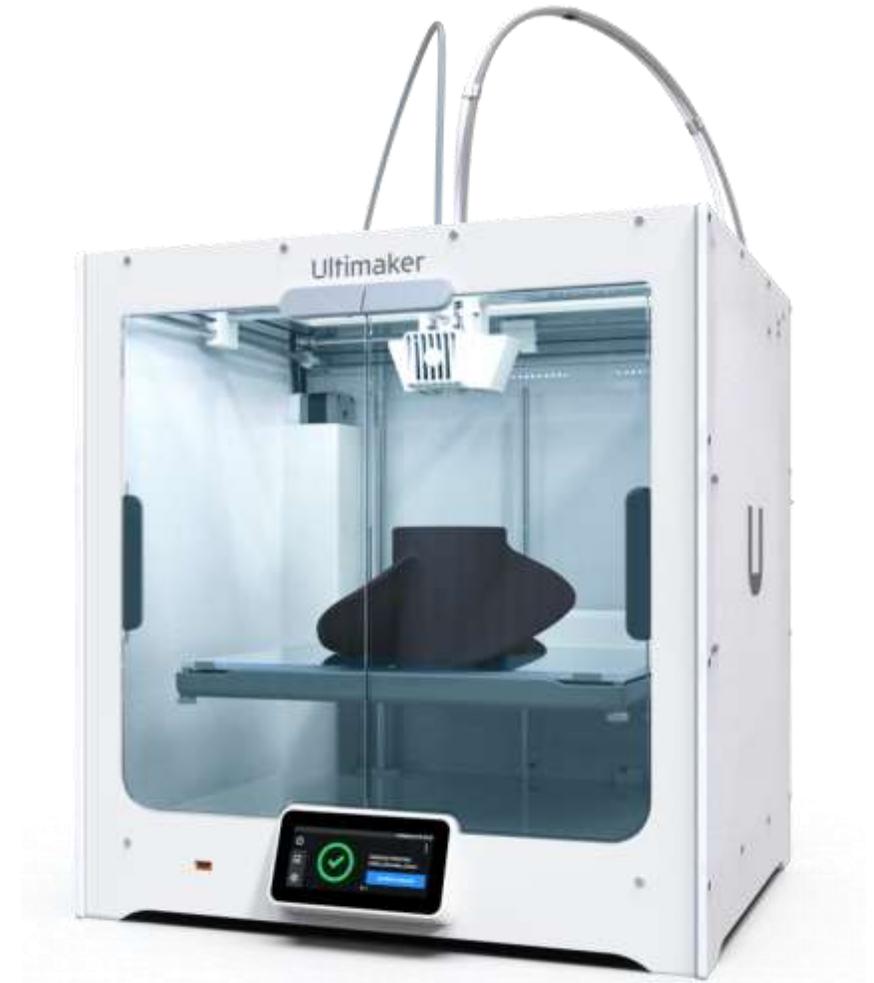
V2: Larger Phantom

- Bigger printer: UltiMaker S5: 330 * 240 * 300 mm
 - Phantom base ellipse 324 * 216 mm
 - Equivalent WED: 265 mm
- Printed in ABS: finished with acetone
 - Acrylonitrile Butadiene Styrene
 - Acetone smooths surface
 - Seals against ingress

Max area ellipse of given eccentricity on rectangular plate

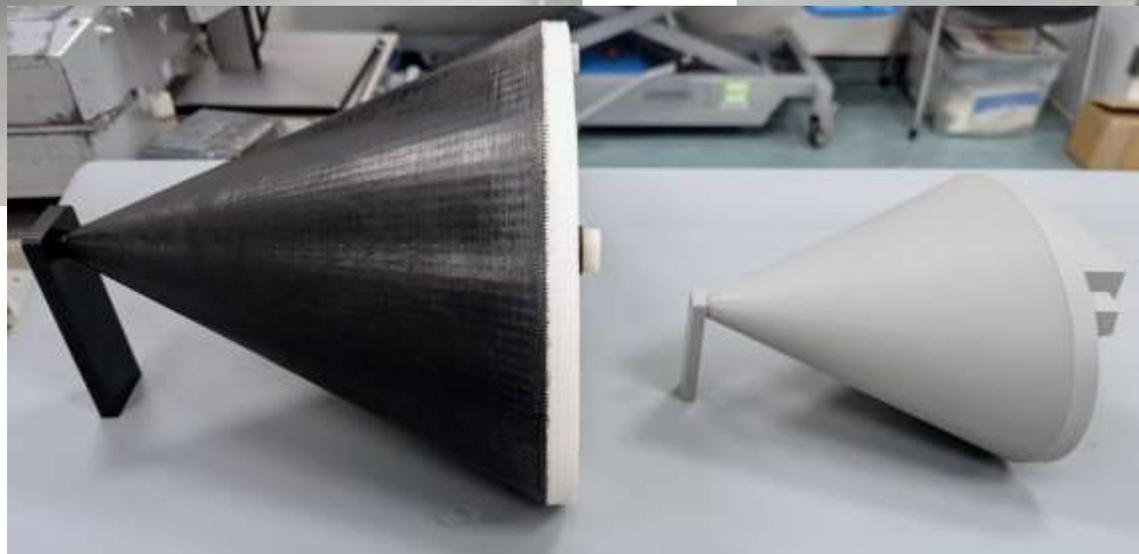
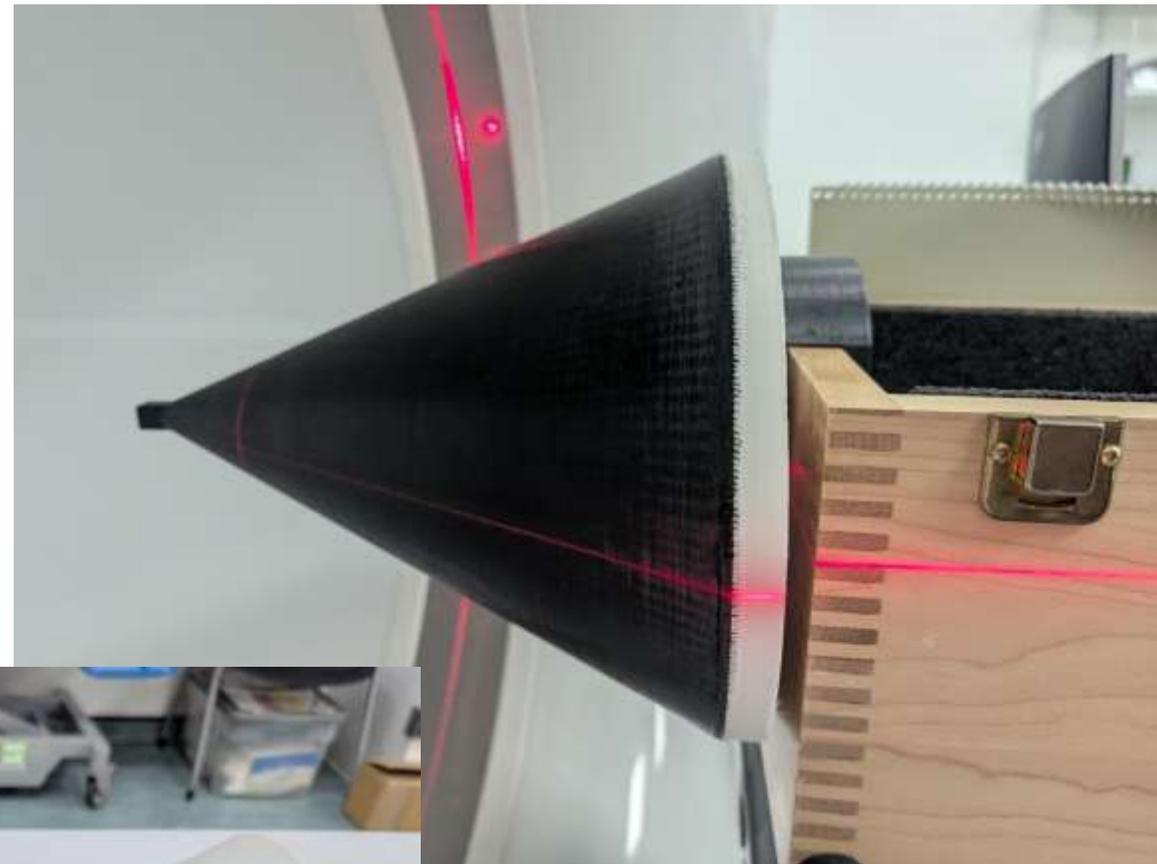


— Rectangle — Max ellipse — Equivalent area circle



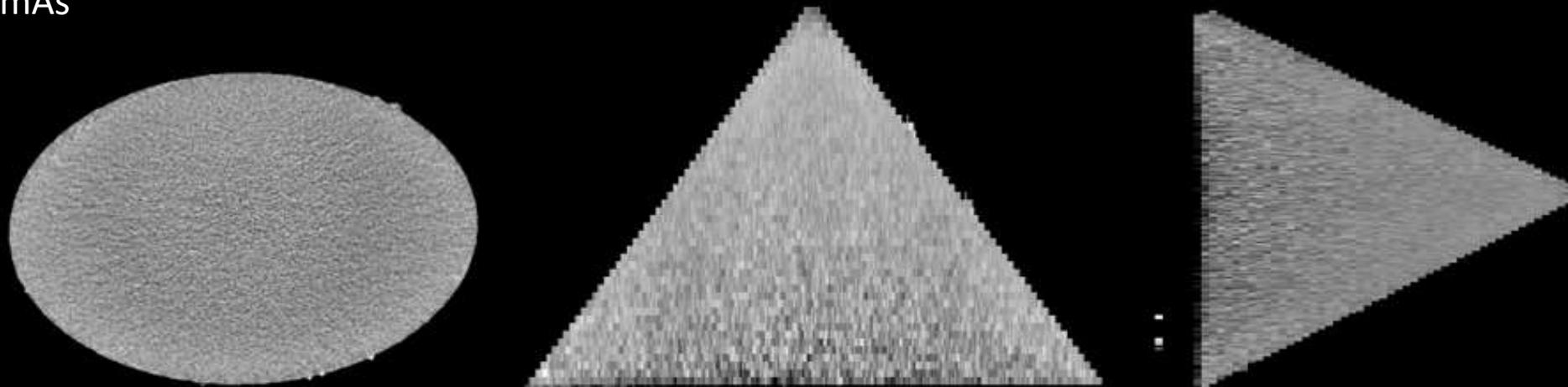
Thanks to Jon Howard!

V2 phantom

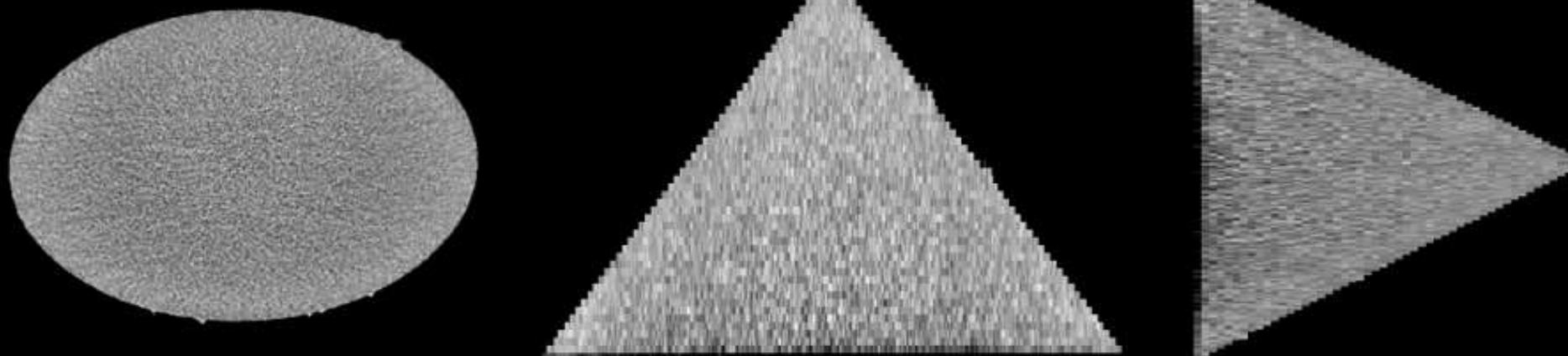


V2 Images

200 mAs

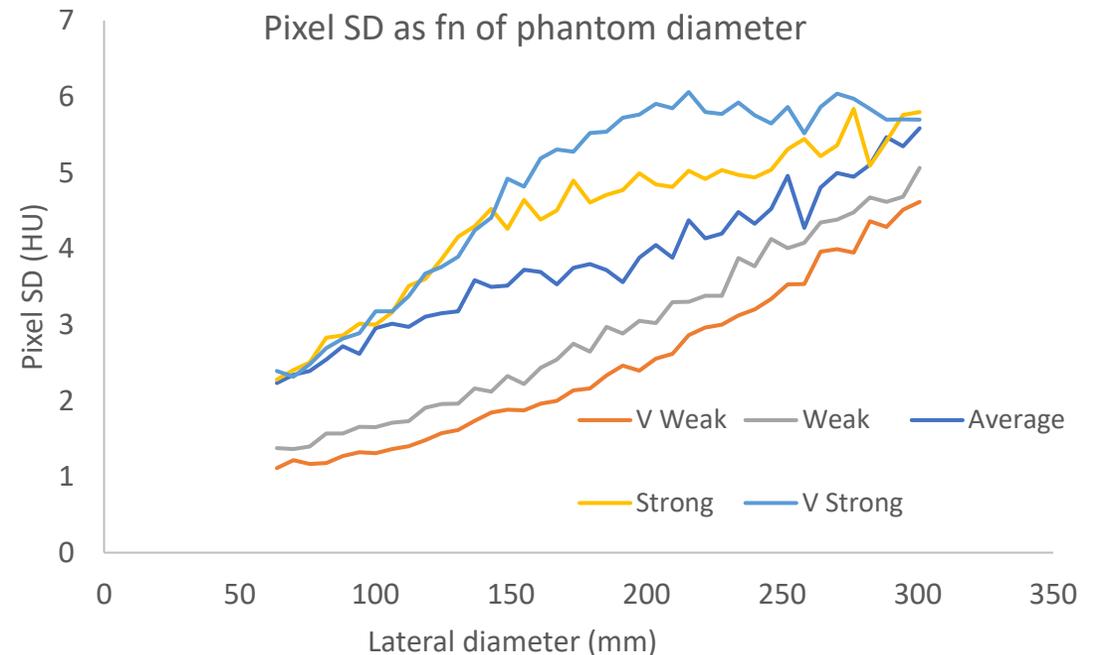
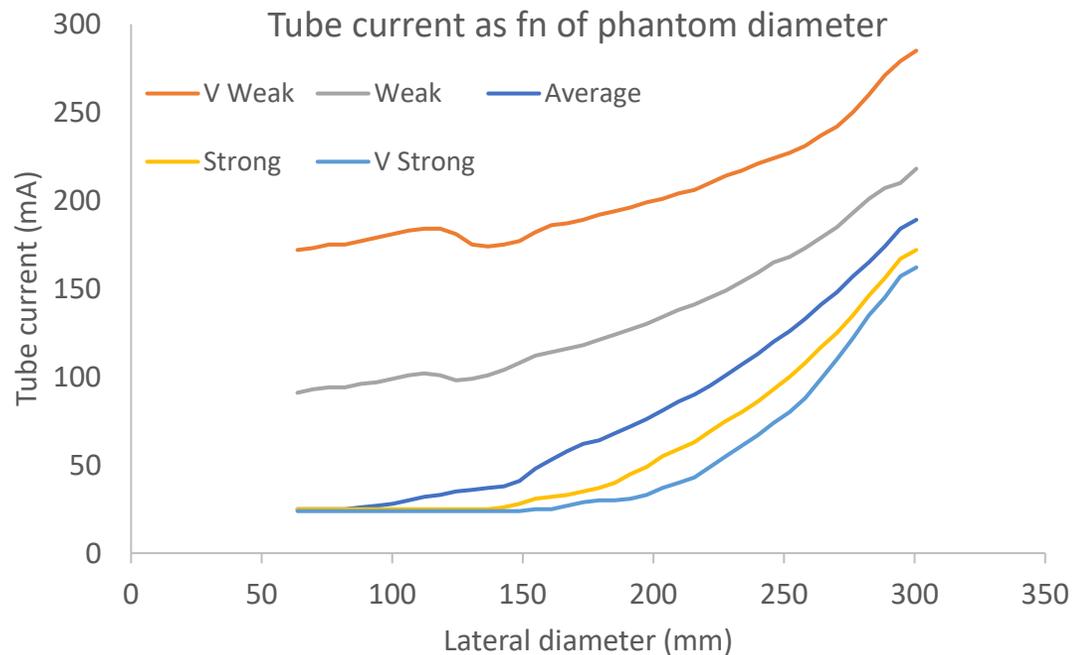


400 Reference mAs, V Strong AEC



Results from V2 cont.

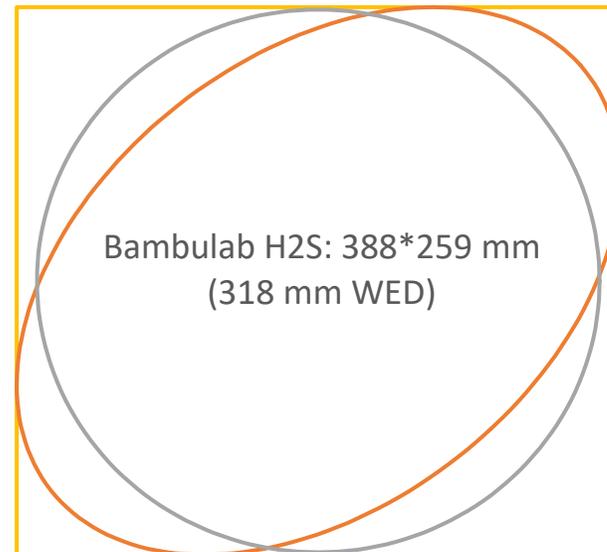
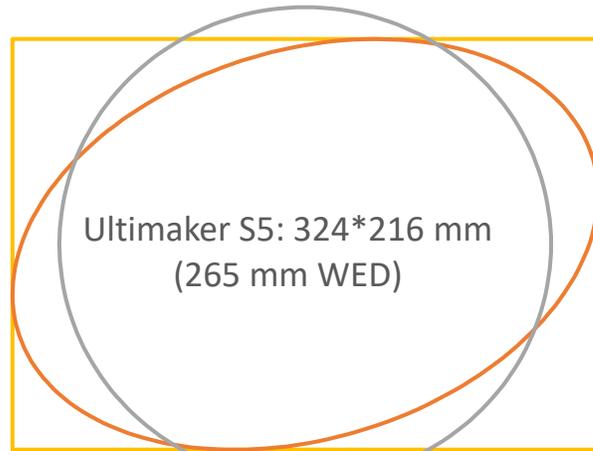
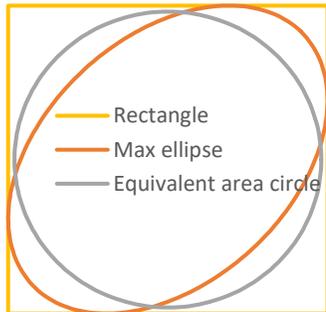
- Vary CAREDose adaptation strength
- 400 mAs reference dose to avoid minimum mA



Larger phantoms still?

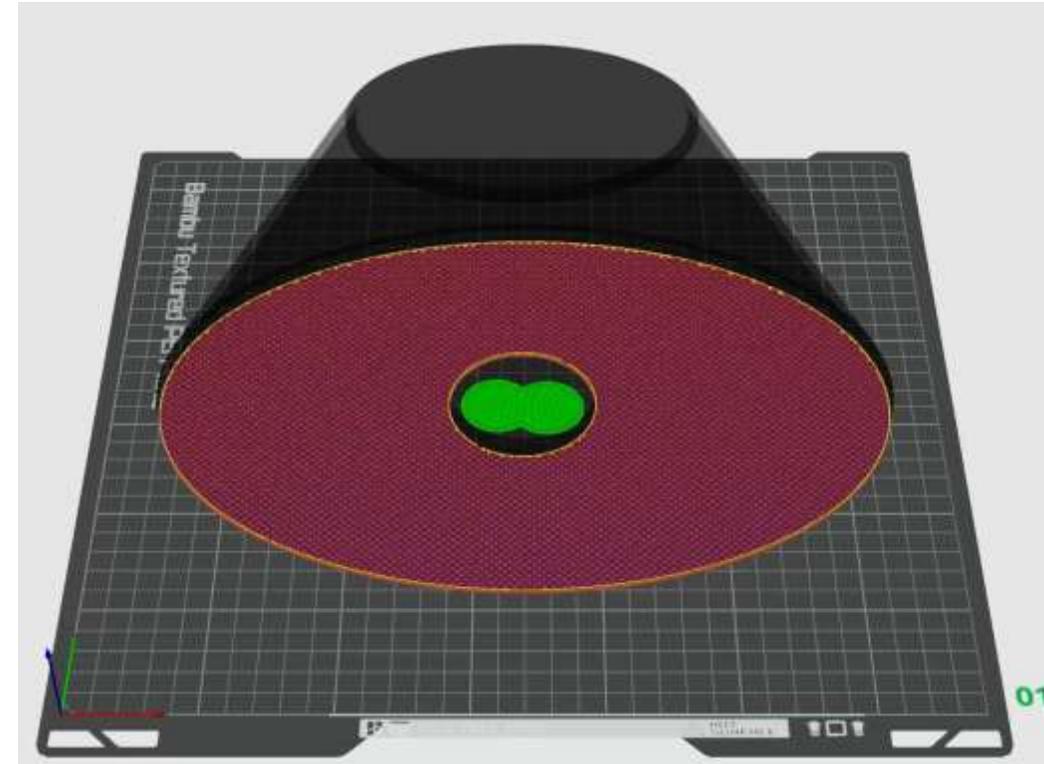
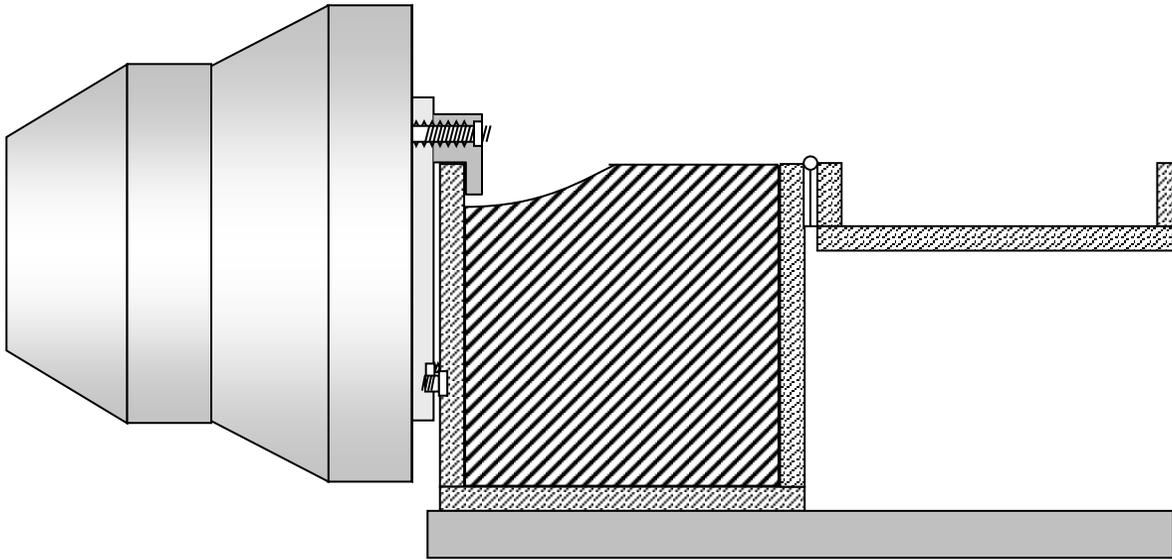
- Bambulab H2S – 340*320*340: large for a consumer printer
 - 388*259 mm ellipse (WED 318 mm)
 - Automatic Material System: AMS (multi material and/or colour printing)
- Beyond: commercial printers with large volumes

Bambulab A1 mini: 211*141 mm
(173 mm WED)



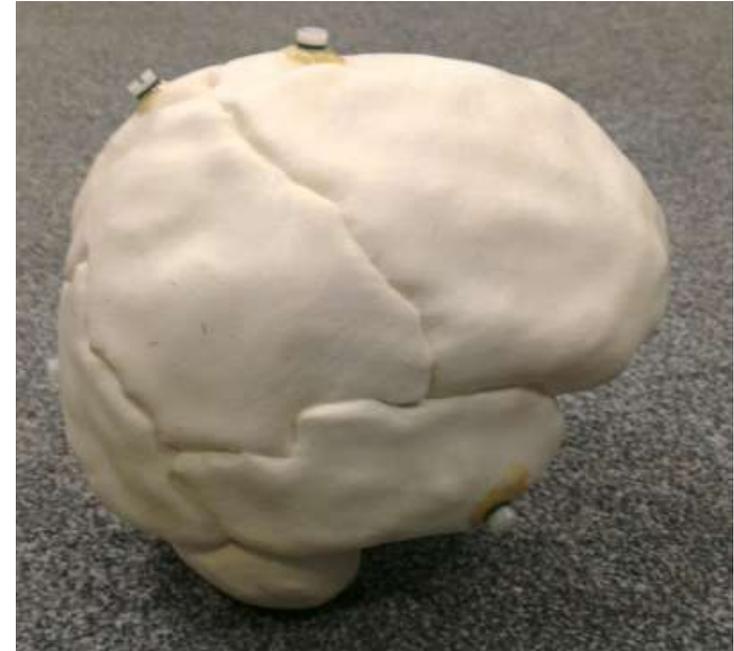
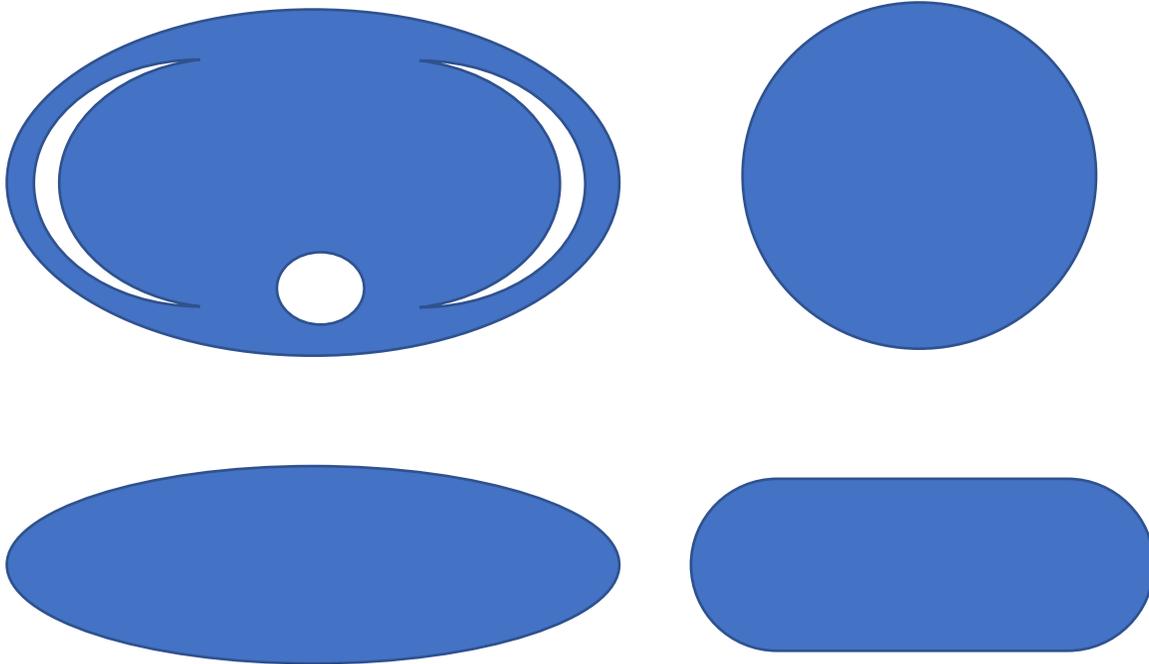
Design developments

- Add stepped regions for repeatable measurements
- Smaller cross sections less interesting
- Overhanging regions become a problem
 - Dissolvable supports with PVA filament
 - Would need larger base holes



Design developments (cont)

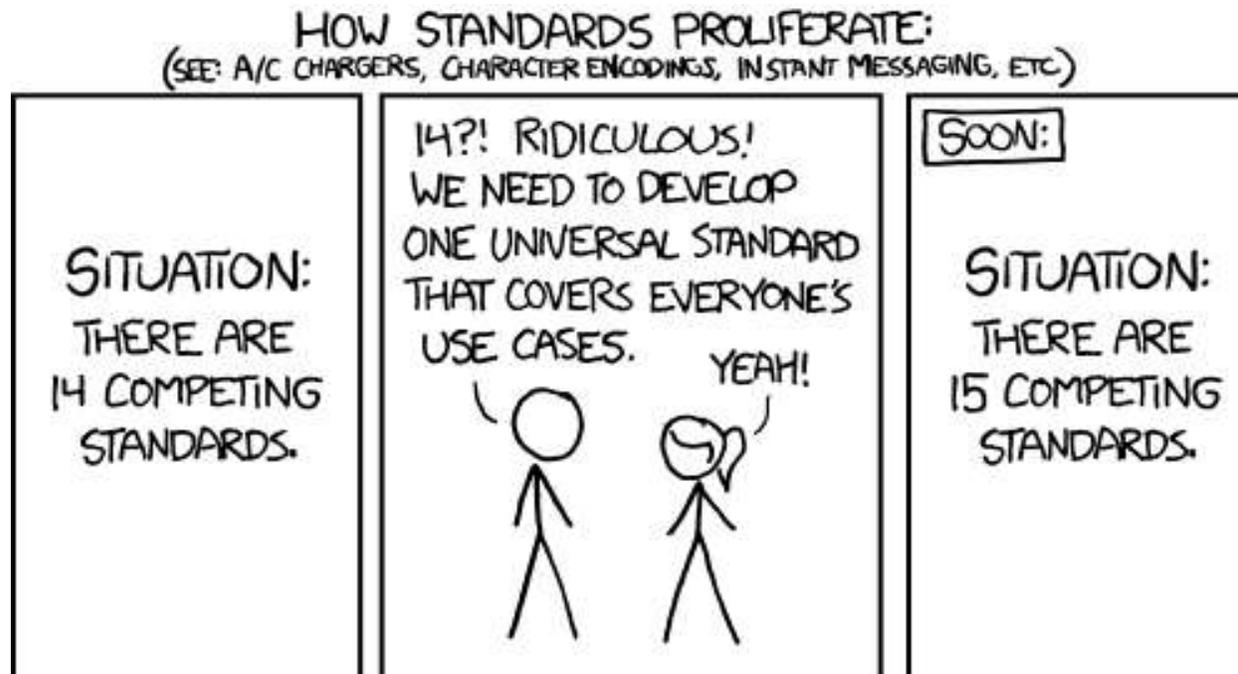
- Variable / different cross section shape
- PBF: Powder Bed Fusion for bone inserts: CaCO_3 printing, ~ 1200 HU



Conclusions

nicholas.keat@perceptive.com

- Successfully designed and produced fillable 3D printed phantoms for AEC testing
- Rapid prototyping allowed iterative design without extra expense
- Larger printer would help to simulate larger cross sections
- Potential for different shapes / sizes / materials
- Hope to see more standardised testing phantoms/methodology



<https://xkcd.com/927/>