

Development of x-Ray Computed Tomography Image Quality Indicators, “IQI”s

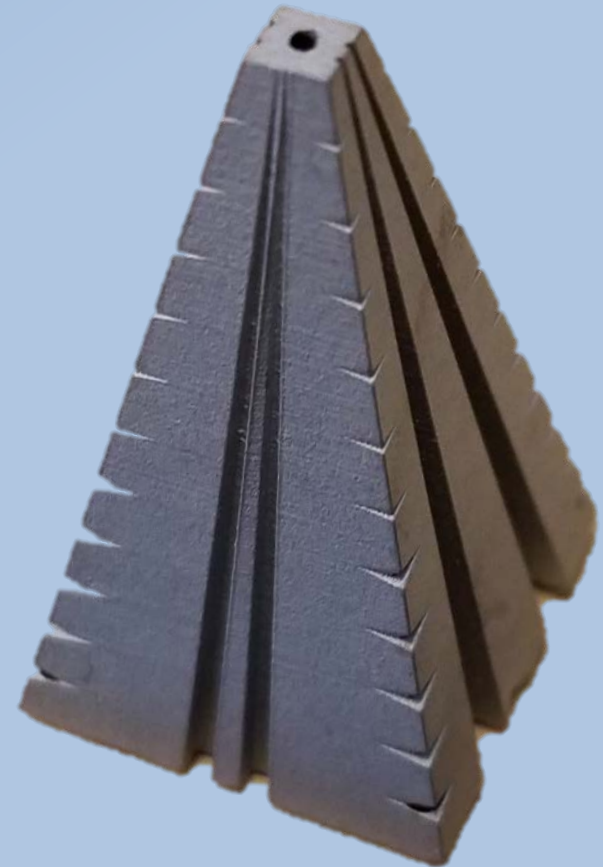
**NASA Goddard Space Flight Center
Materials Engineering Branch
OSMA NDE Program**

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Collaborators: Antonio Moreno, Olivia Landgrover, Grace Fischetti

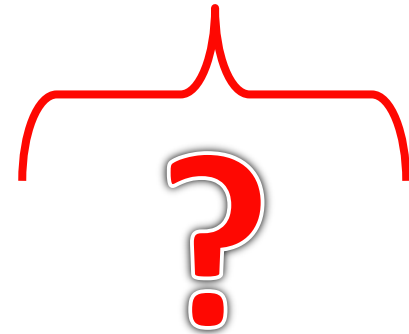
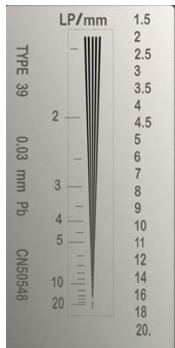
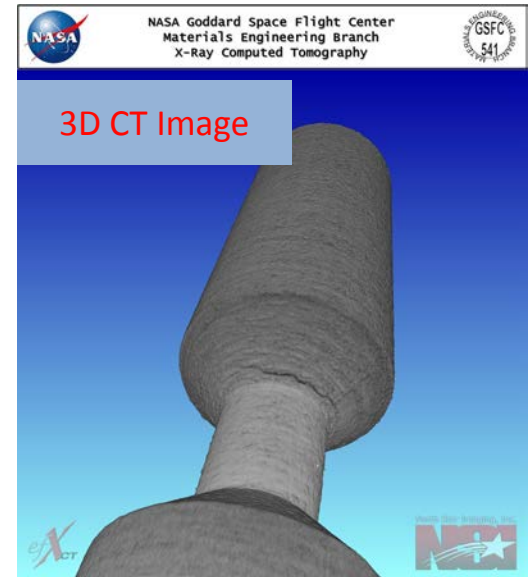
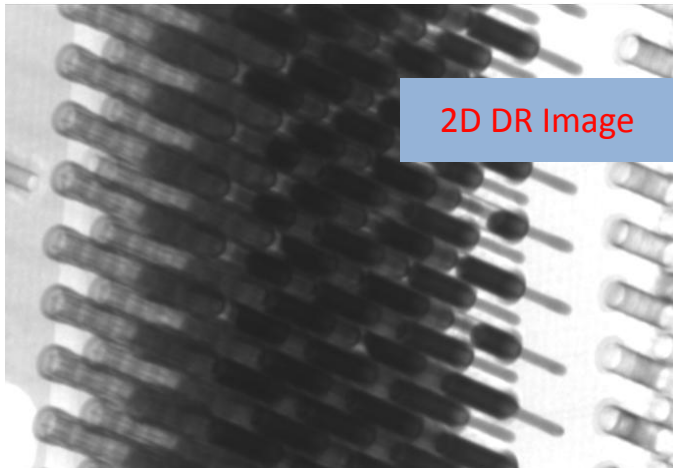
LaRC Additive Manufacturing Mini-TIM

November 9, 2018



Motivation

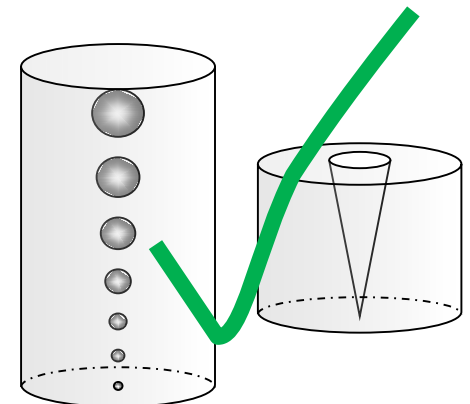
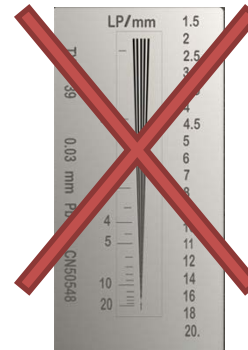
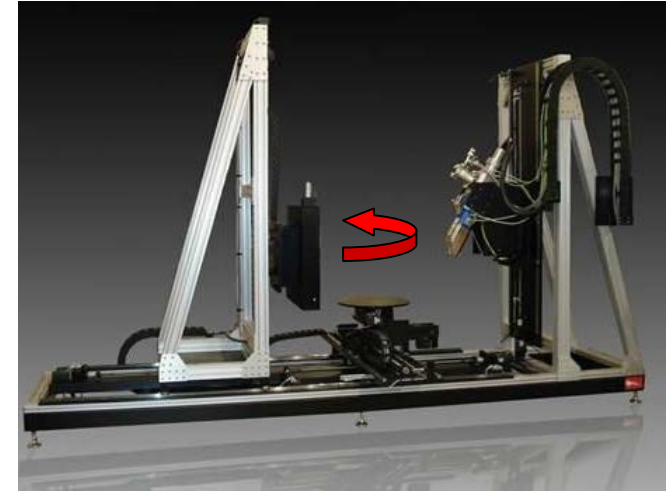
X-Ray Image Quality Indicators



From left: Convergent line pair gauge, duplex line pair gauge, step block, plaque penetrometer [ndtsupply.com]

Program Goals/Initiatives

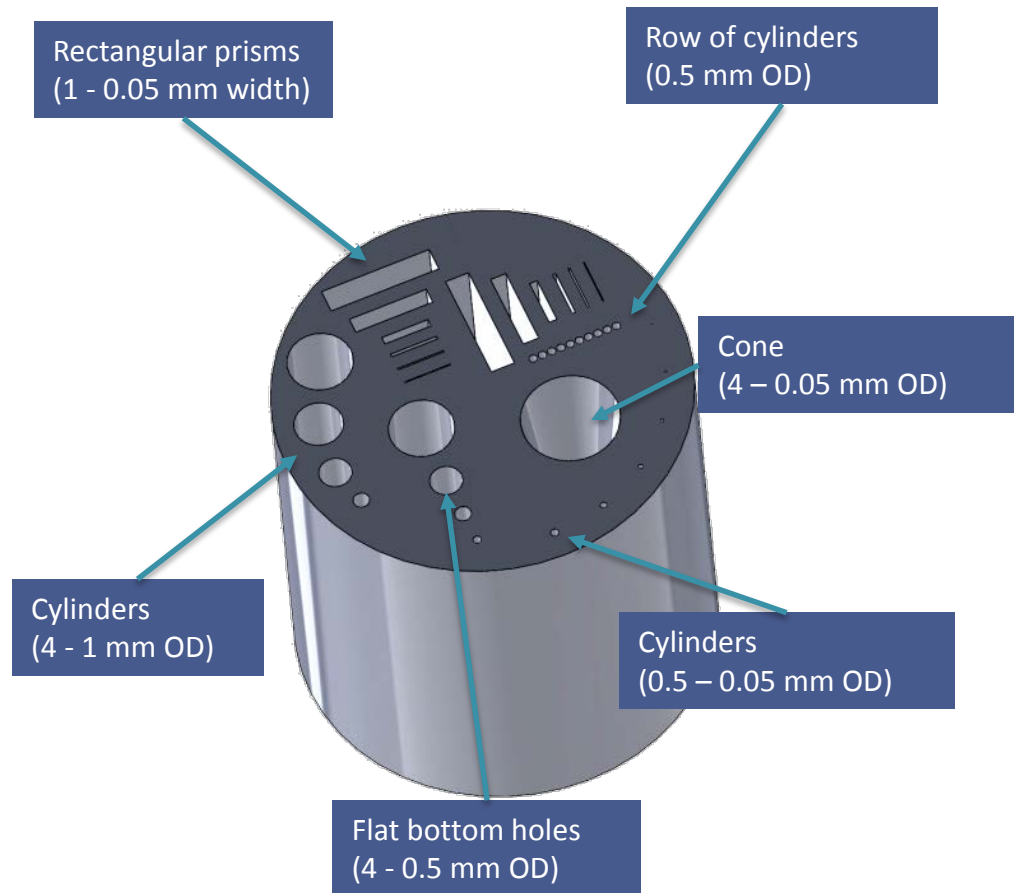
- Develop methodology and tools to assess Computed Tomography (CT) system performance.
 - Fabricate Image Quality Indicators (IQIs) using materials and internal features useful for assessing inspection capabilities.
 - Analyze IQI volume data to assess CT detectability limits, contrast sensitivity, resolution, etc.
 - IQIs conducive to CT should be of more uniform cross-sectional aspect ratio



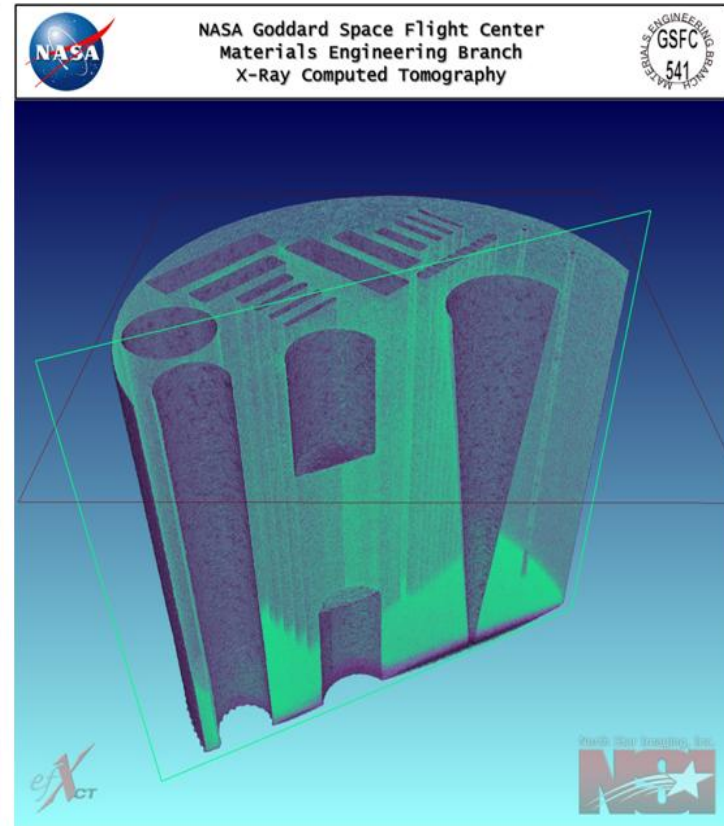
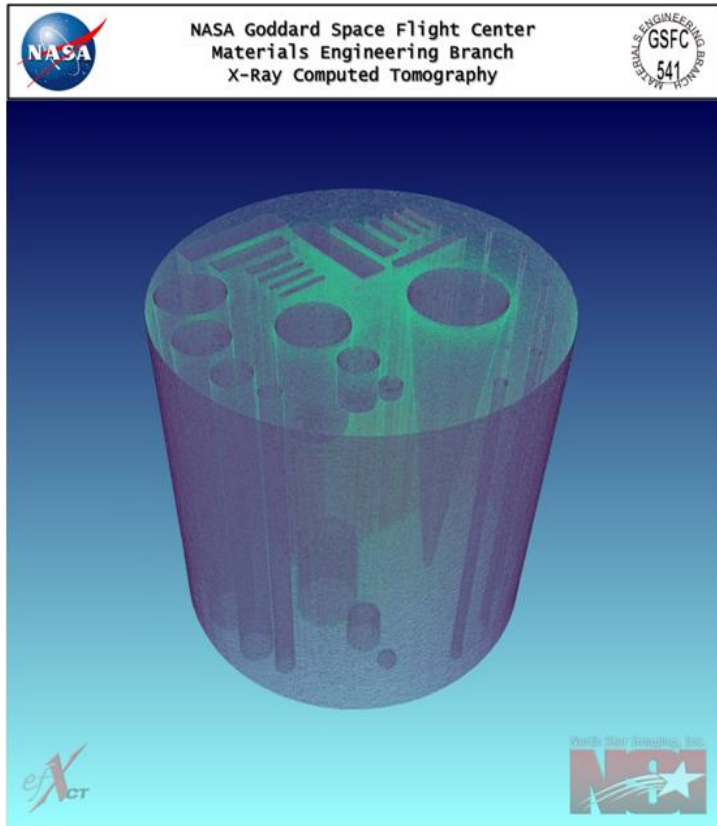
Original Concept: Cylindrical IQI

Cylindrical IQI

Various design features ranging in size to assess both manufacturability (per AM method) and CT inspectability.

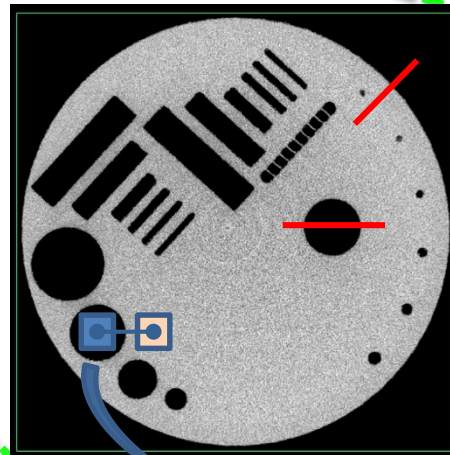
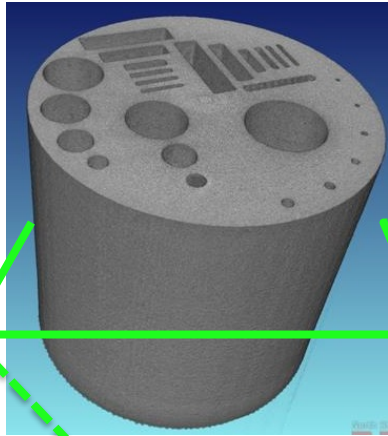


Cylindrical IQI



Cylindrical IQI: Intended Performance Verification Elements

- Resolution
- Contrast Sensitivity
- CT Dimensional Measurement Accuracy (CT metrology relative to conventional measurements)



Edge sharpness/resolution:

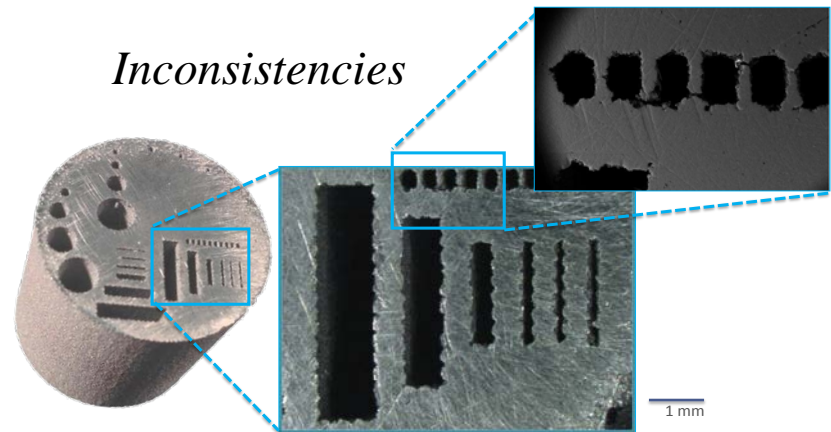
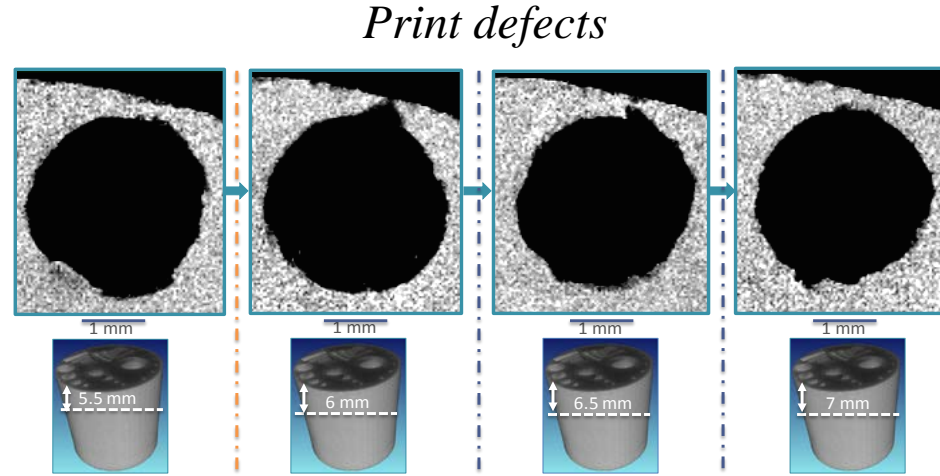
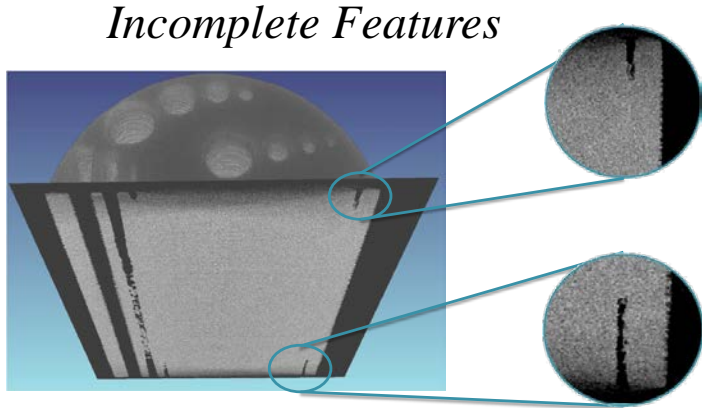
- Modulated transfer function (MTF)
- Convergent features

Contrast to Noise Ratio as function of:

- Geometric shape
- Size
- Location
- Density (using filled powder)

Diameter = 25.4 mm

Cylindrical IQI: as Assessment Tool for AM Process Control



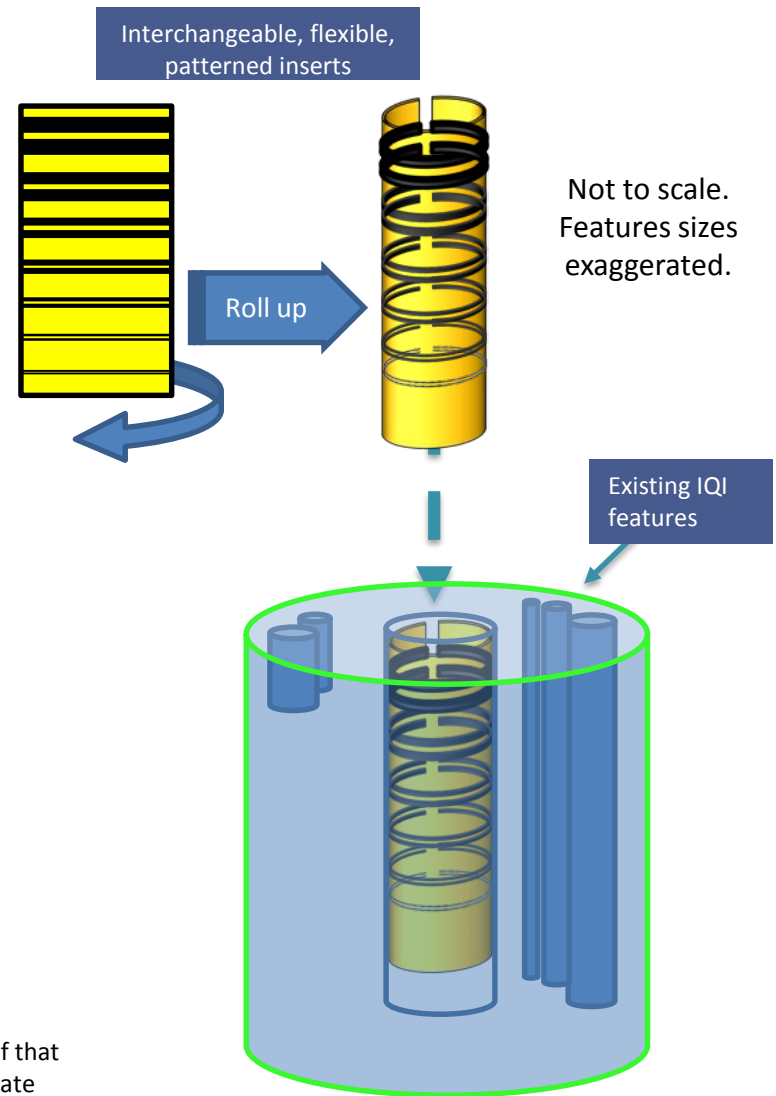
Hybrid Insert IQI

Hybrid IQI with Flexible Lithographic Patterned Inserts

- Redesign to incorporate some existing features, but leave room for other additions:
 - Rod or powder inserts to assess contrast sensitivity to various materials
 - Flexible, rolled up test patterns to assess resolution
- Flexible IQI inserts tested on 100 or 125 micron Kapton substrates using either sputtered or photolithographic deposited gold.

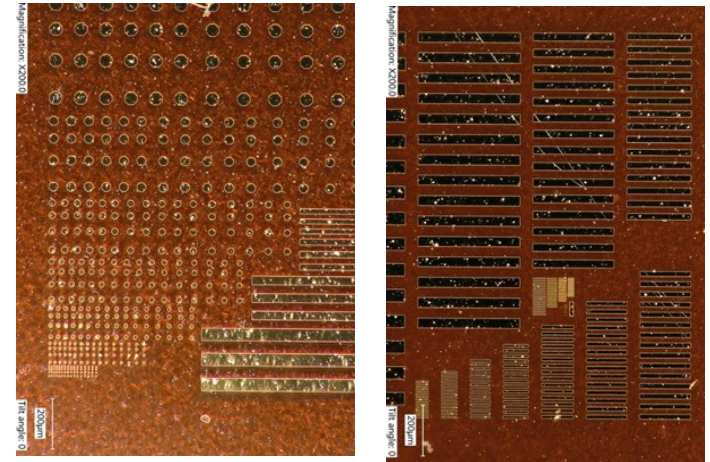


20x25 mm Kapton film, typical of that used for the deposition substrate



Hybrid IQI with Flexible Lithographic Patterned Inserts

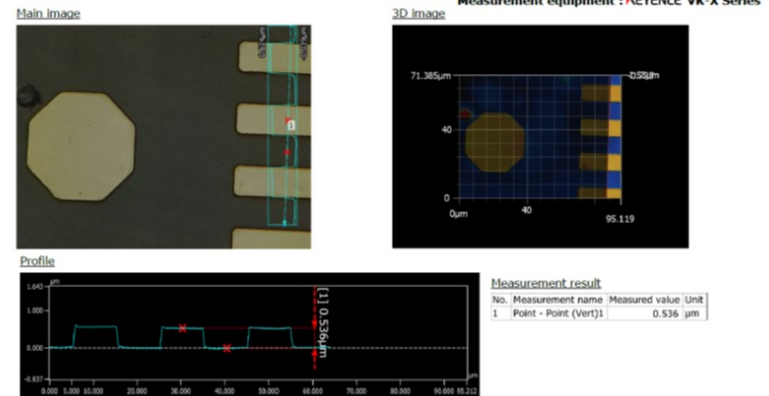
- Patterns came out well on first attempt. Good adhesion of Au to Kapton, though need protective coating for durability (e.g. parylene, polyurethane)
- Some "bubbling" observed on Kapton surface. May be residual from etch process.
- Challenges in dealing with microfabrication facility, high costs, schedules, etc.



Pre-existing photolithography patterns.
~2 mm total pattern length.

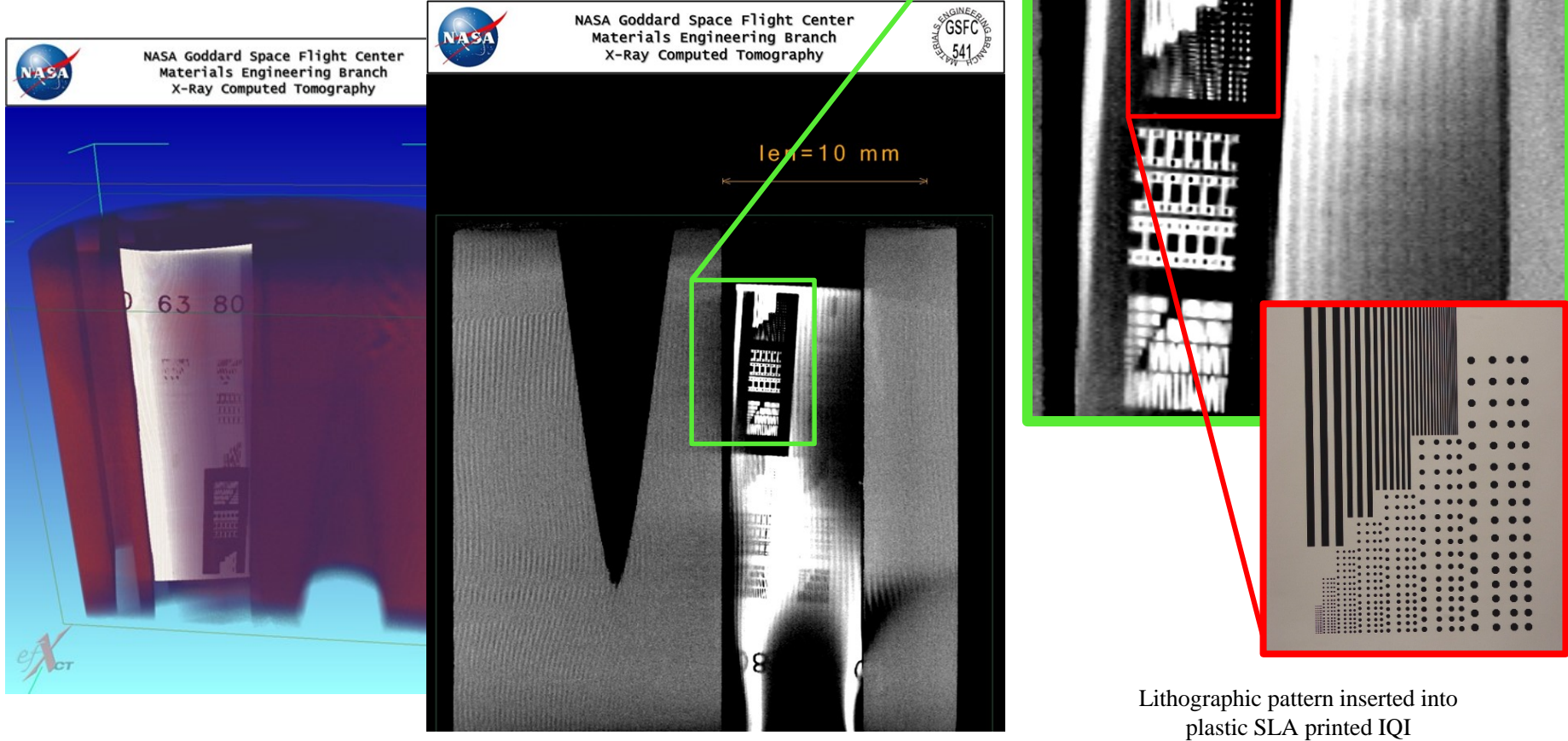
Sample 10 - xray CT line pair gage

Profile measurement



Gold pattern thickness measured via laser confocal microscope: 536 nm

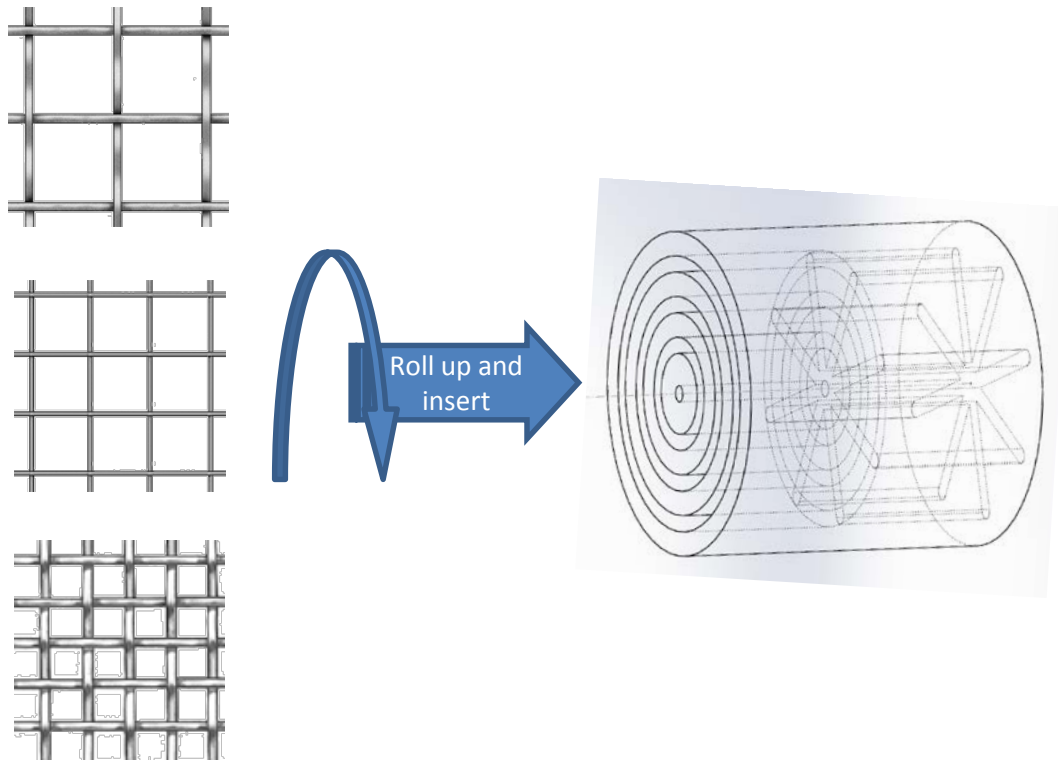
Hybrid IQI with Flexible Lithographic Patterned Inserts



Some other CT IQI concepts

Hybrid IQI with Flexible Wire Grid Inserts

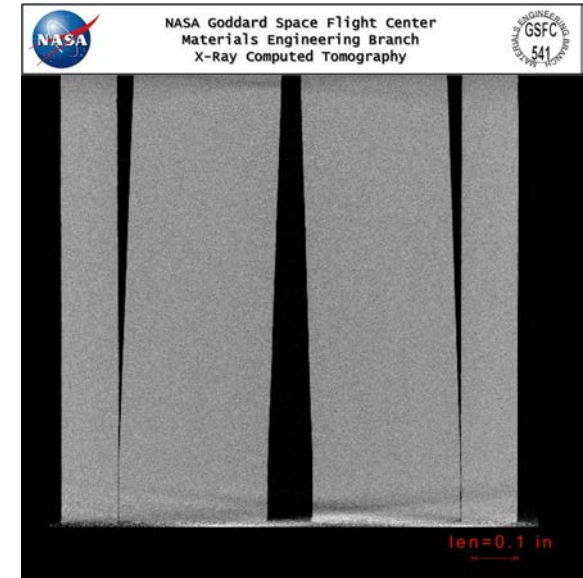
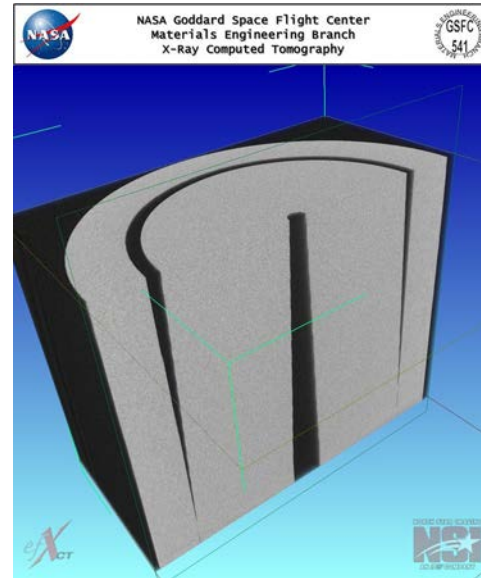
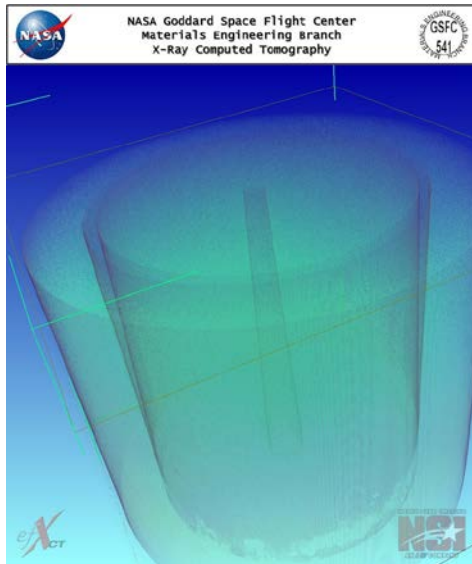
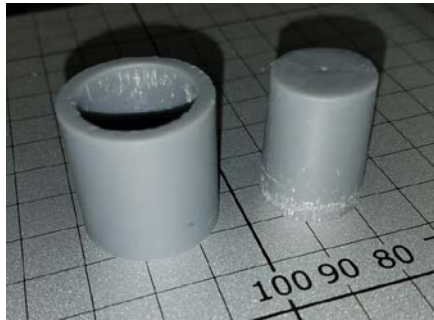
- Other insert materials being explored to avoid costly lithography
- Wire meshes of varying, defined density, formed into screen tubes and placed in concentric pattern IQI



Proof-of-Concept Trial



Taper IQI



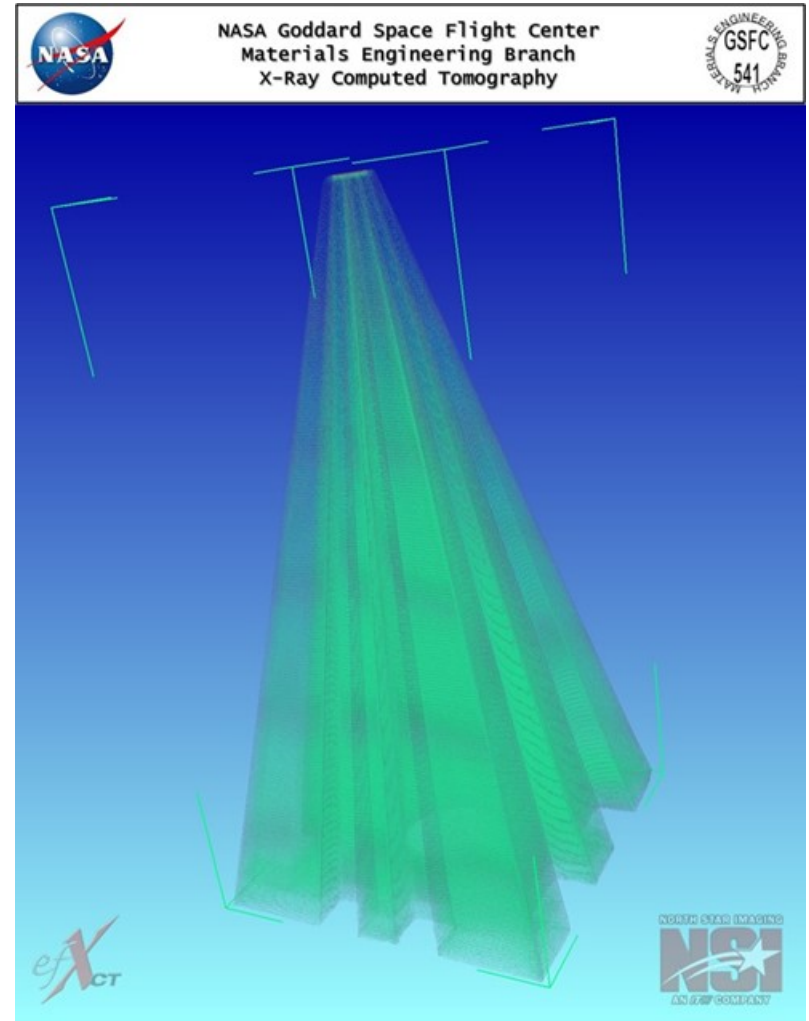
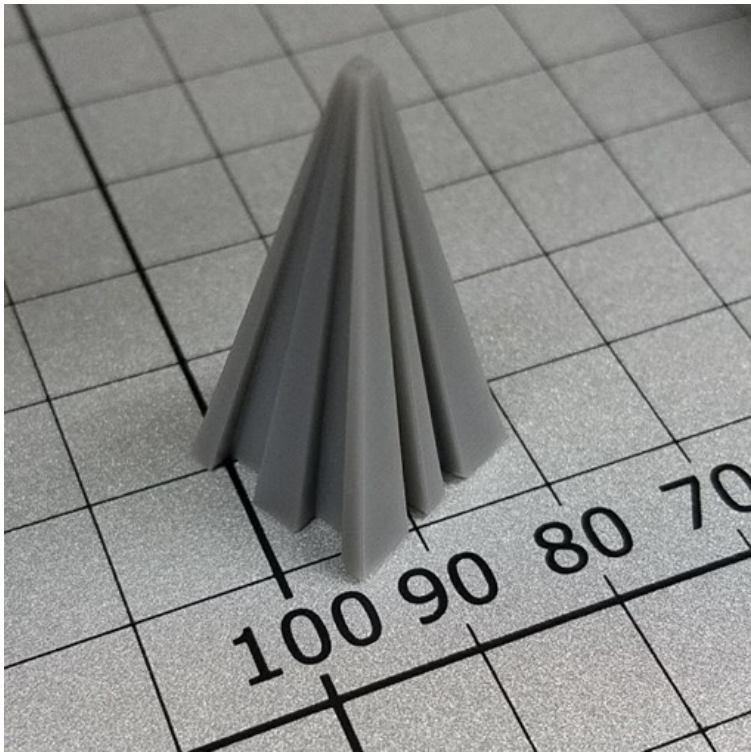
Proof-of-Concept Trial

- Matching shell and insert, with slightly different taper angles.
- Idea is to create very small features within CT where tapers converge using simple design features.
- The above is a first cut proof of concept for more complex varying taper designs.

Most Recent Efforts: Pyramid IQI

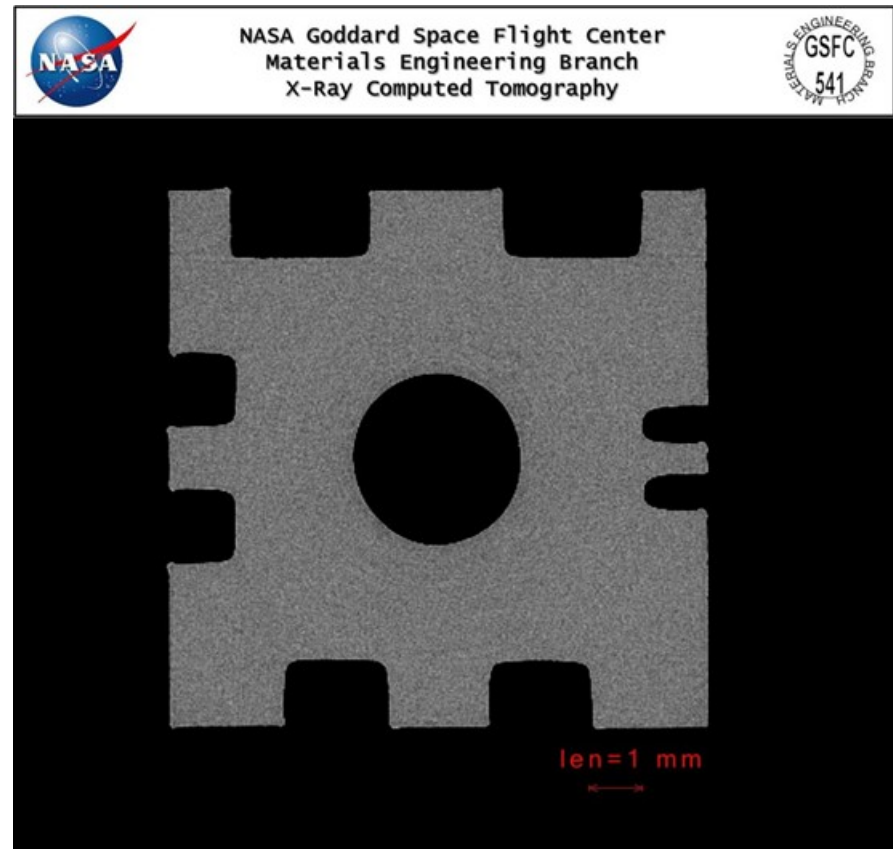
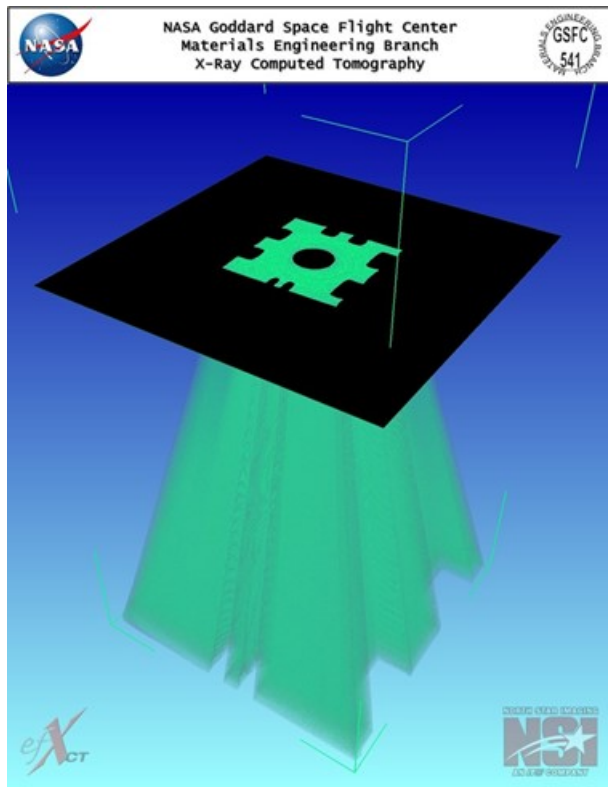
Pyramid IQI

- Original design...



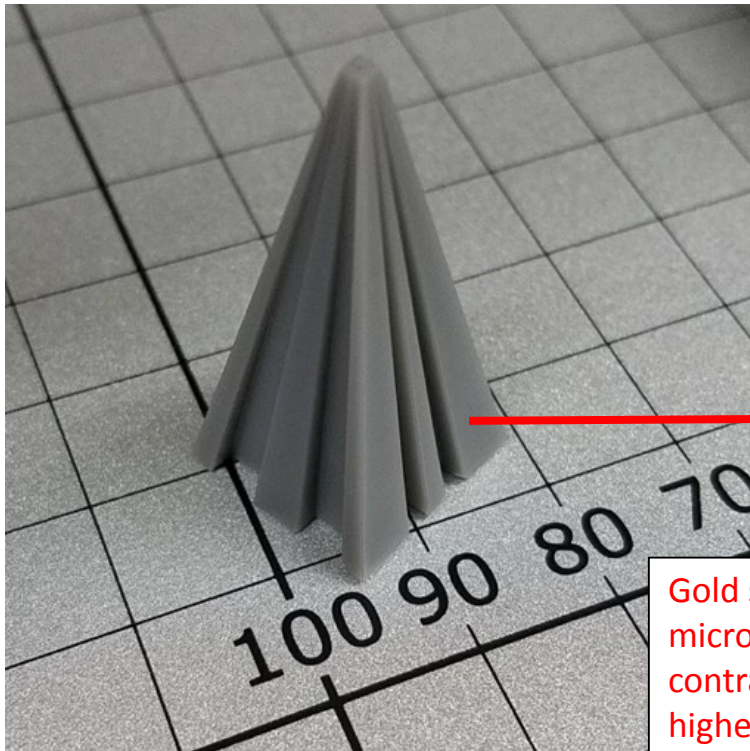
Pyramid IQI

- Original design...

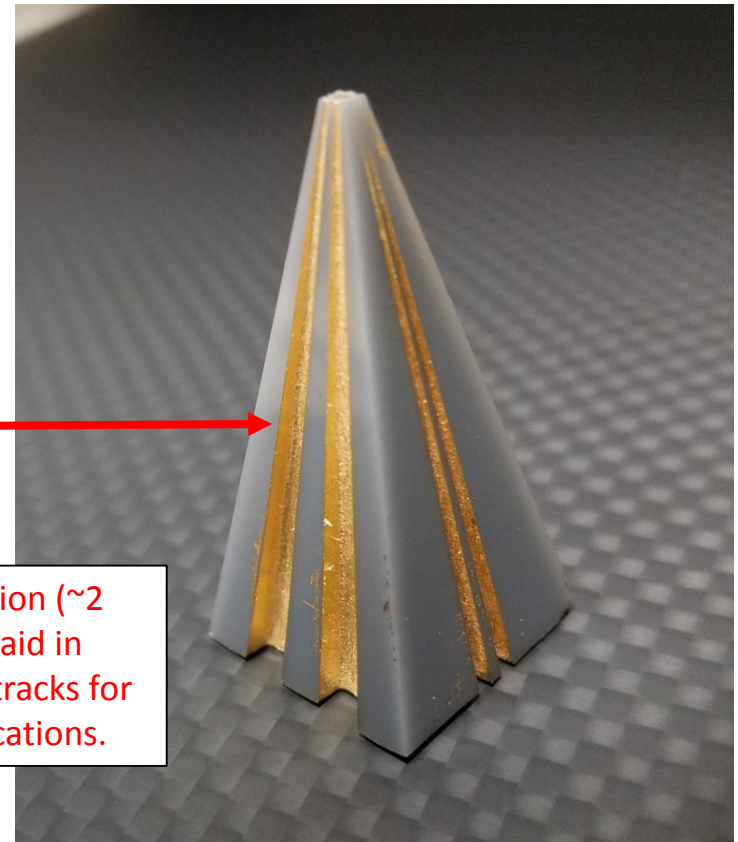


- Pyramid 3D converging line pair gauge consists of a different sized pair of channels on each side
- As you approach top of pyramid, all features scale smaller
- Upon cross-section at any height, 2D slice provides a set of different sized line pairs

Pyramid IQI with sputtered gold inlays

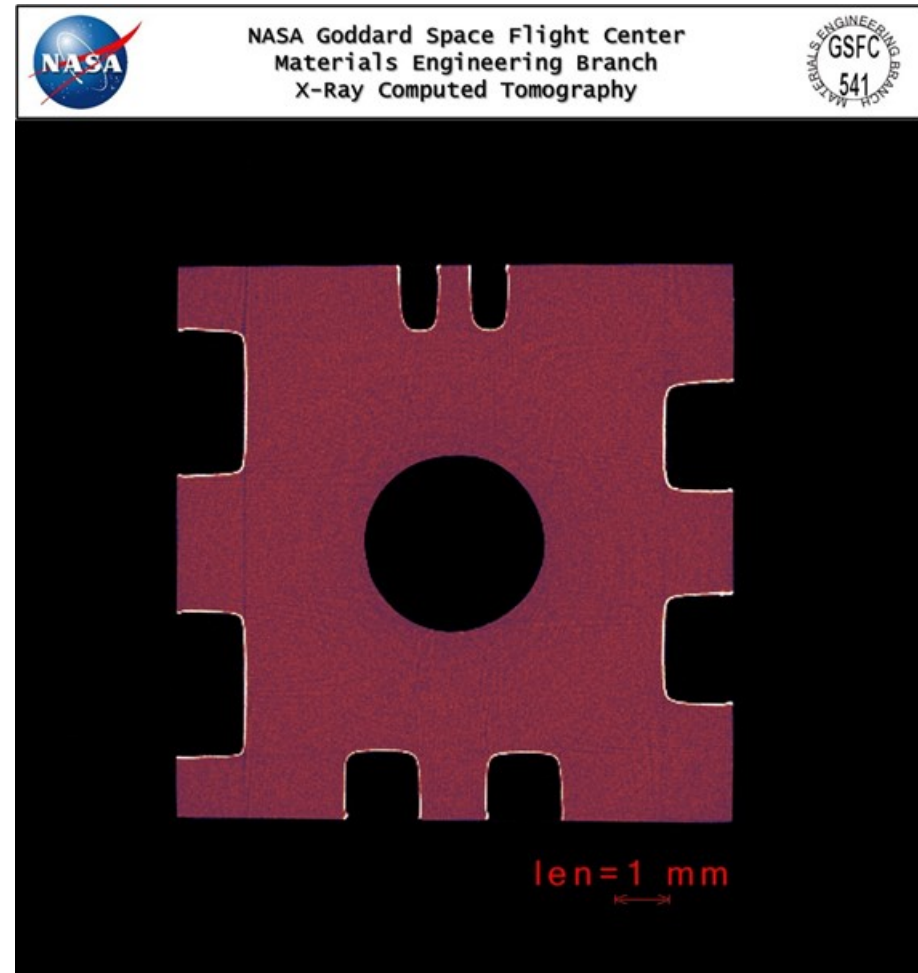
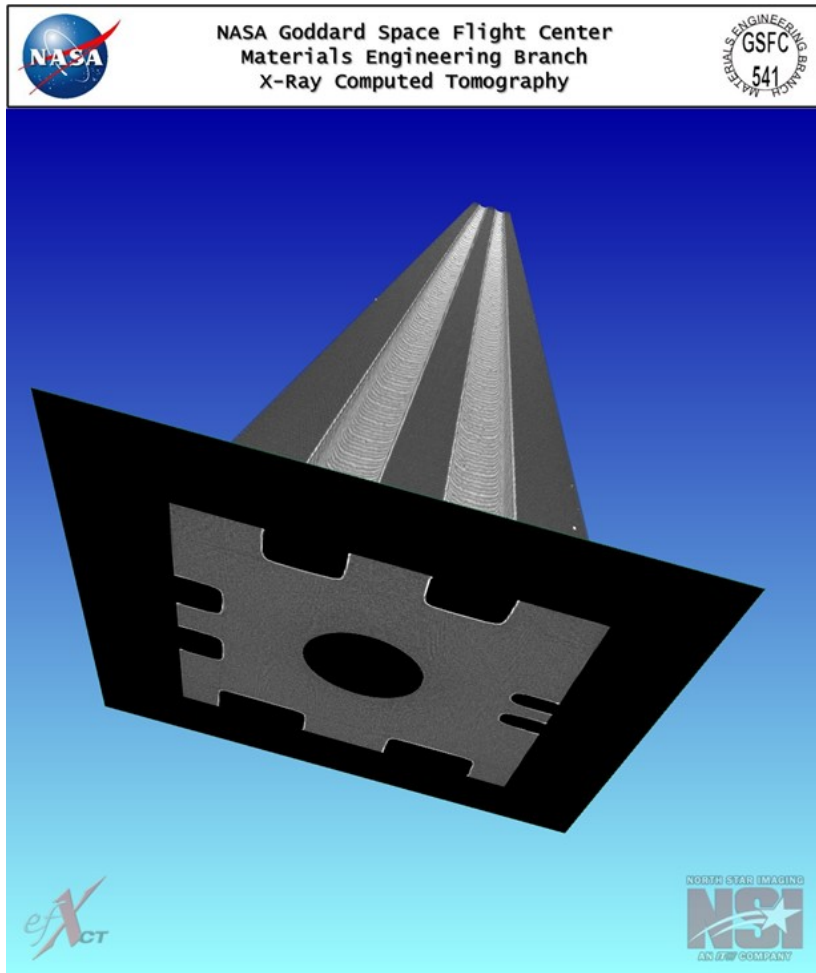


Gold sputter deposition (~2 microns nominal) to aid in contrast of line pair tracks for higher kV scan applications.

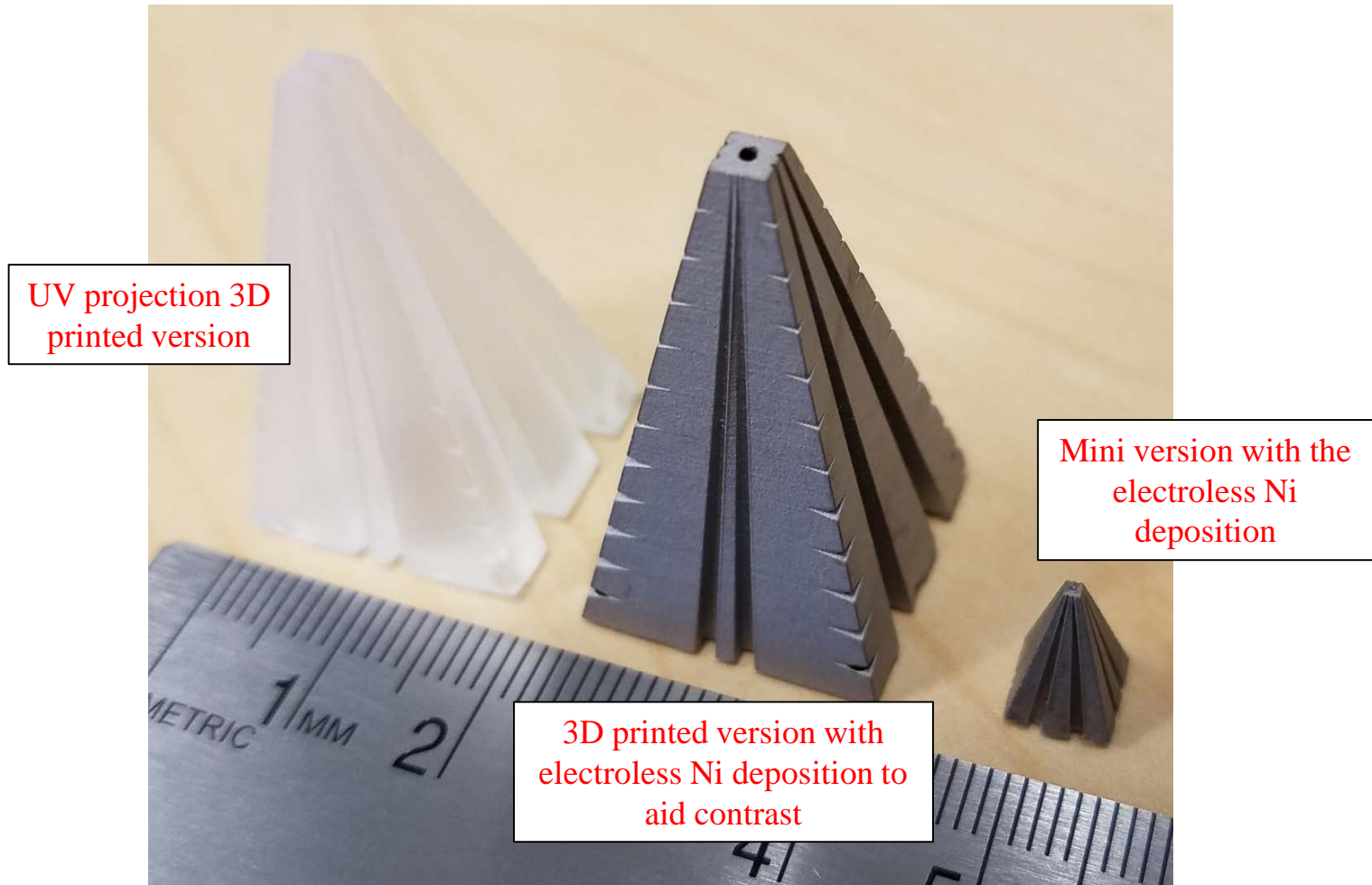


Credit: Stephen Lebar/GSFC/ATA for Au sputter

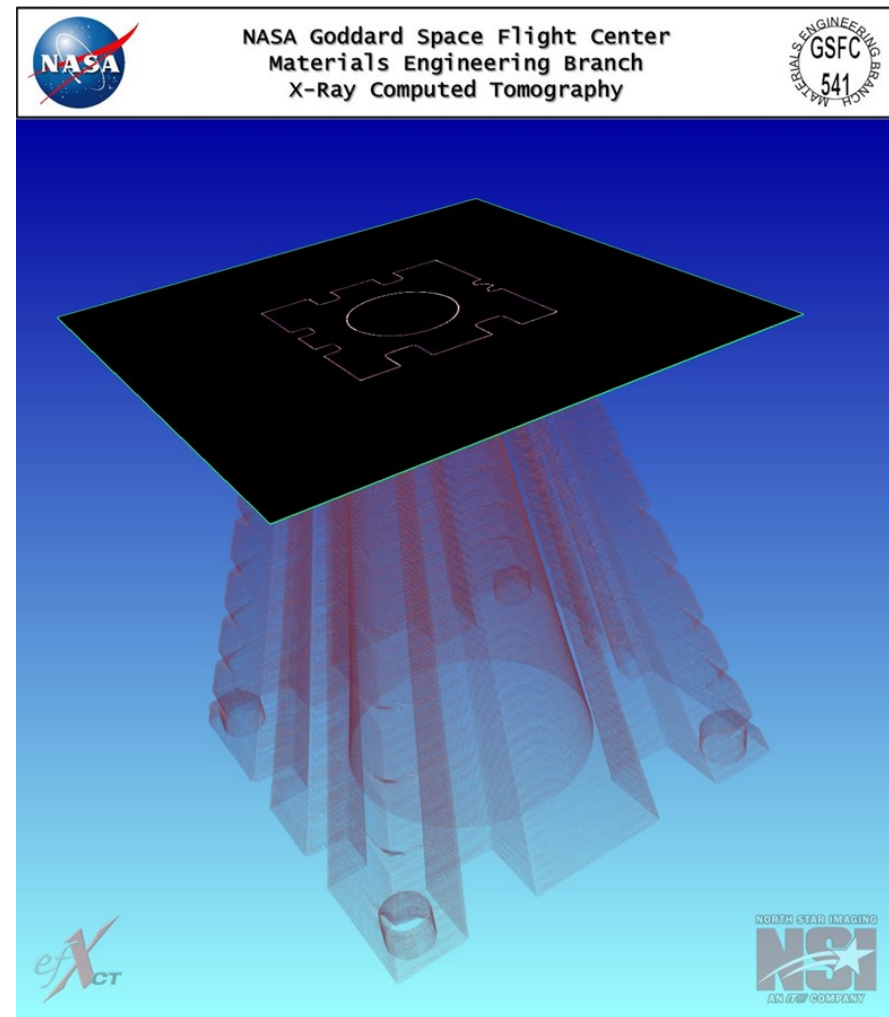
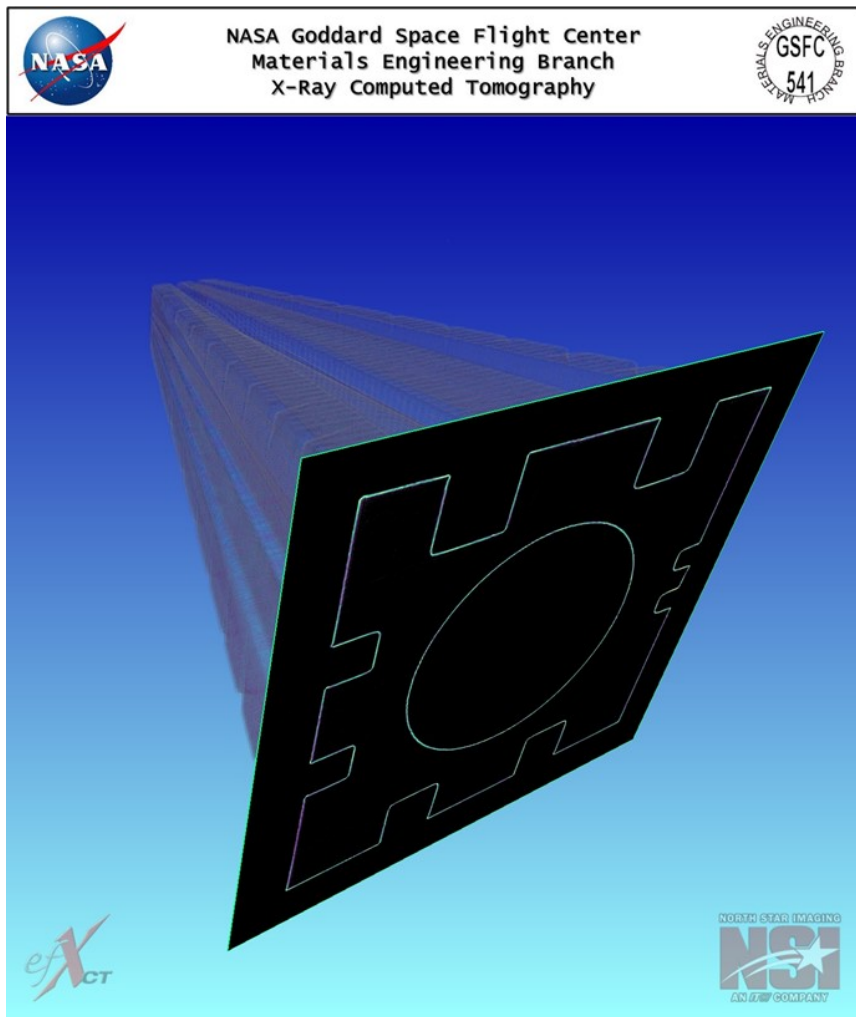
Pyramid IQI with sputtered gold inlays



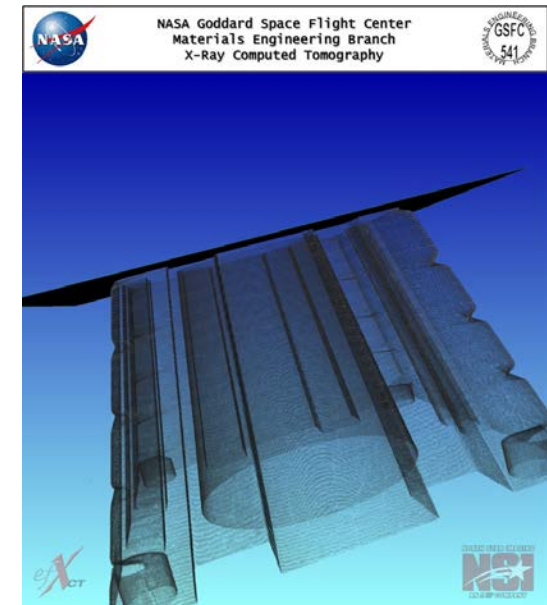
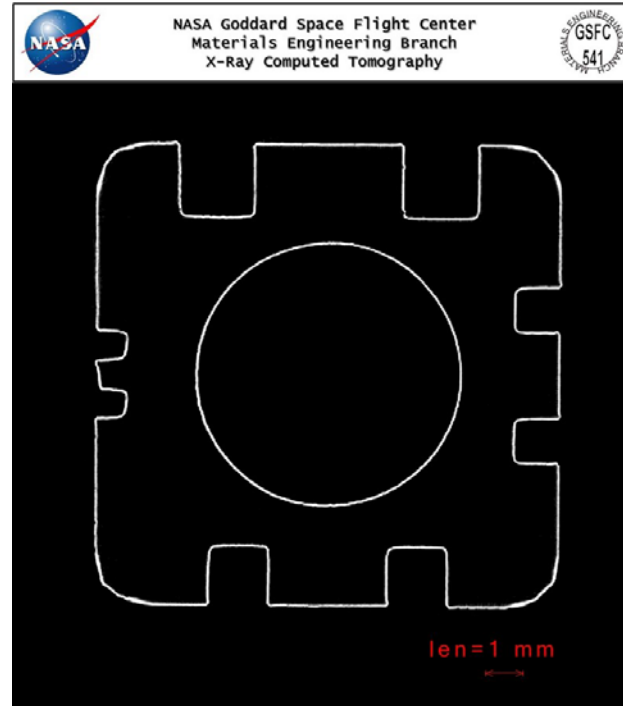
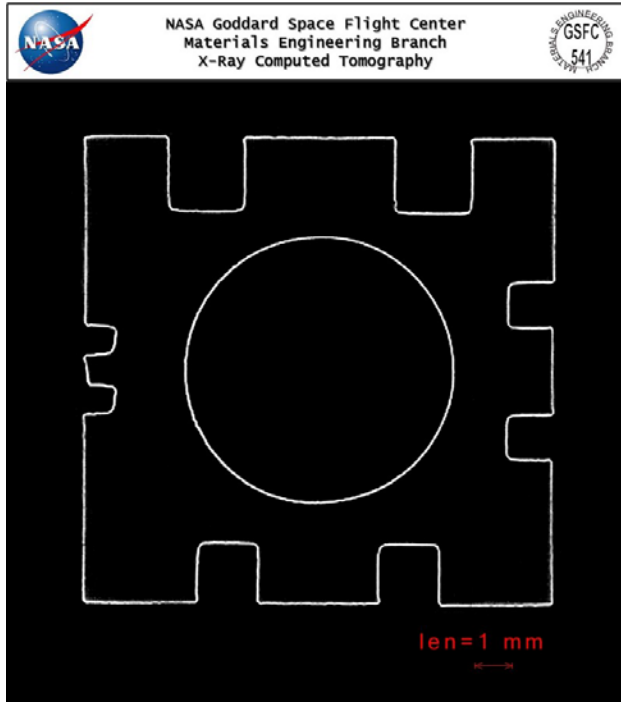
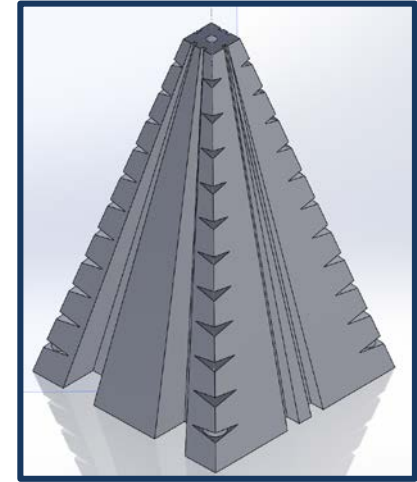
Pyramid IQI: SLA plastic with electroless nickel coating



Pyramid IQI: SLA plastic with electroless nickel coating



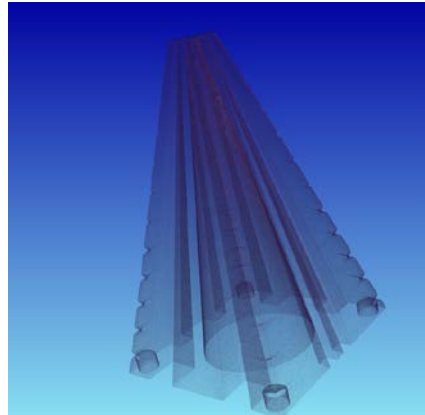
Pyramid IQI: Ni-coated and use of external fiducials for alignment, elevation gauge, and external verification.



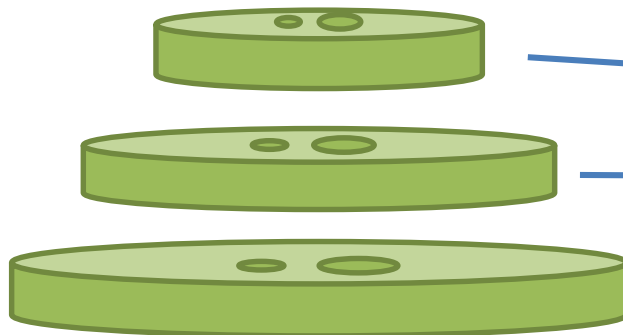
Pyramid IQI: Penetrameter Insert Concept (laser micro-machined discs)



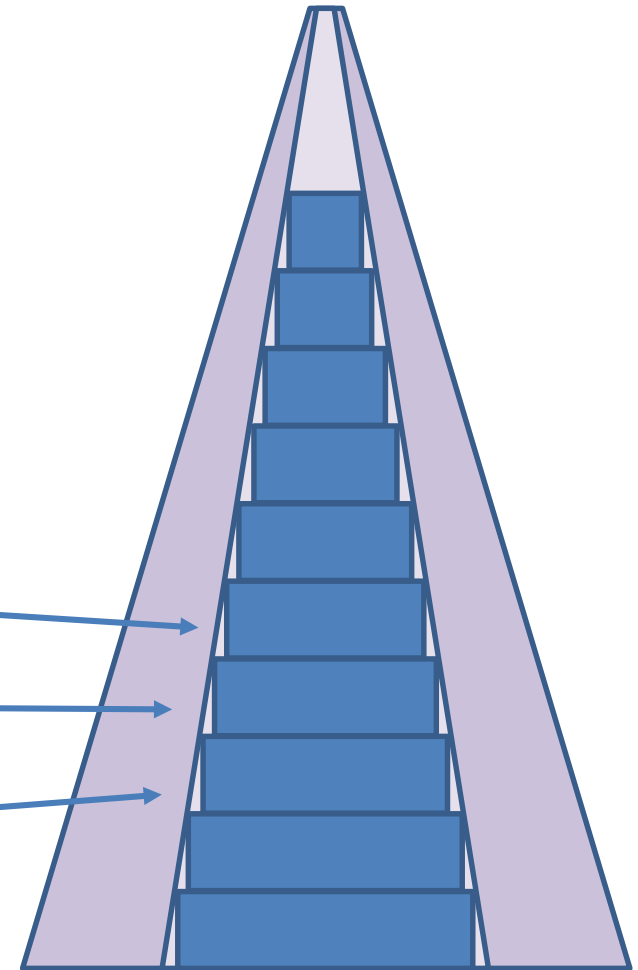
Conventional "2D" radiographic hole penetrameters



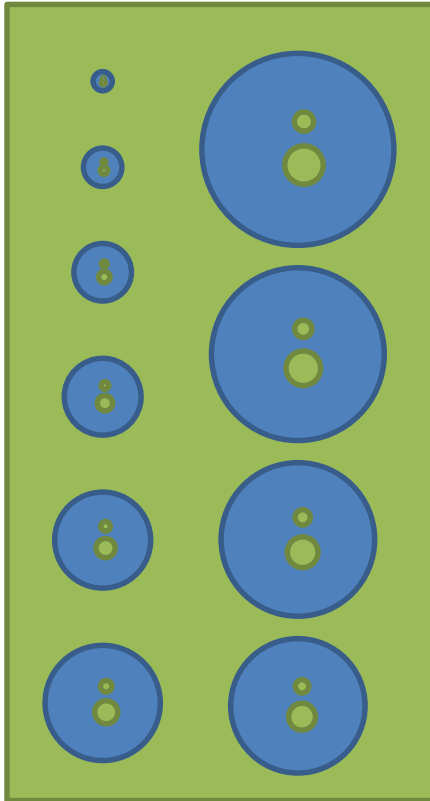
CT of xCT "Pyramid IQI"



Inner hole sizes **not** to scale. Actual holes will be much smaller.

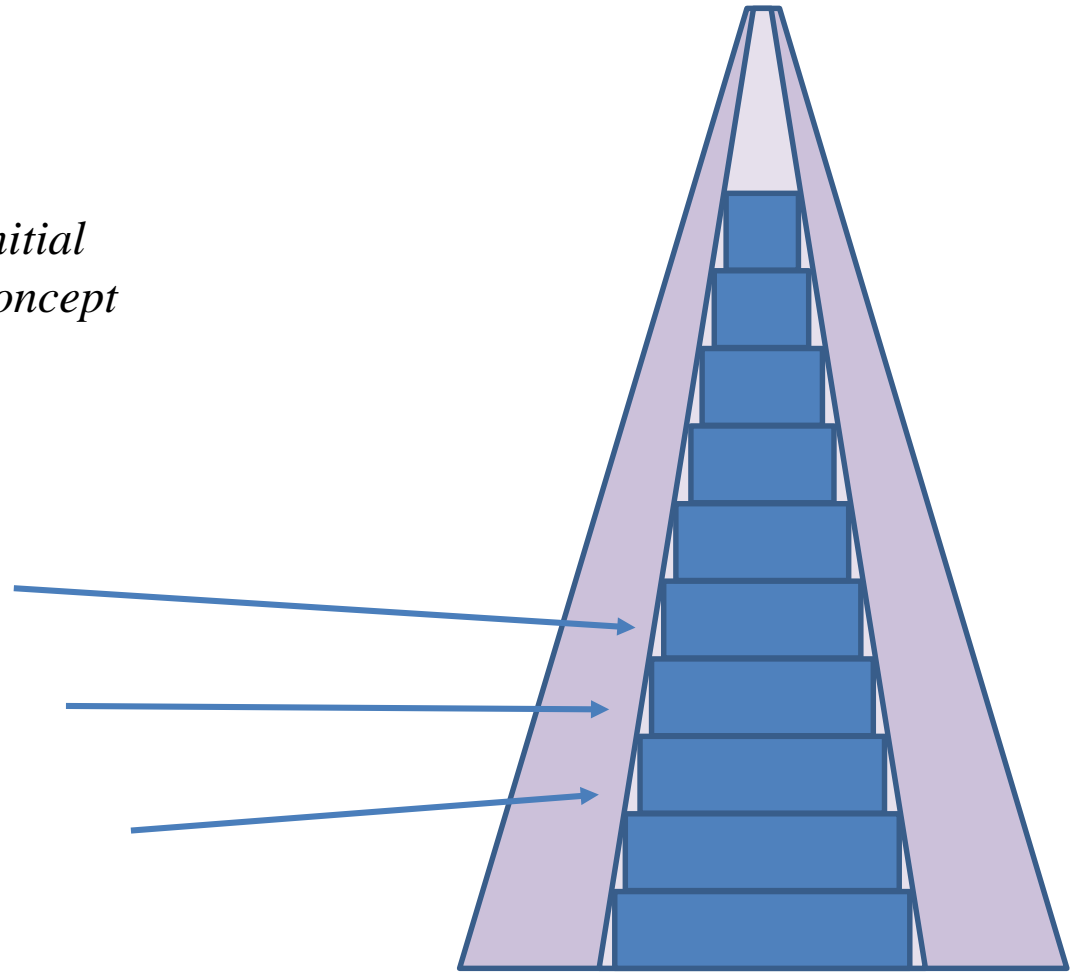


Pyramid IQI: Penetrameter Insert Concept (laser micro-machined discs)



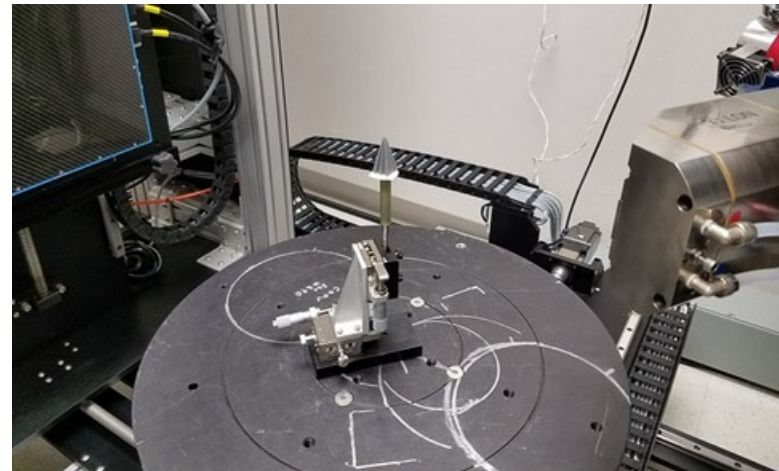
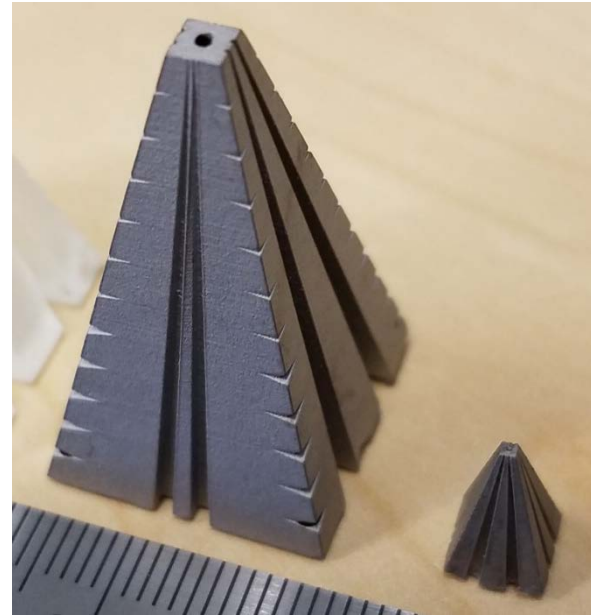
*Initial
concept*

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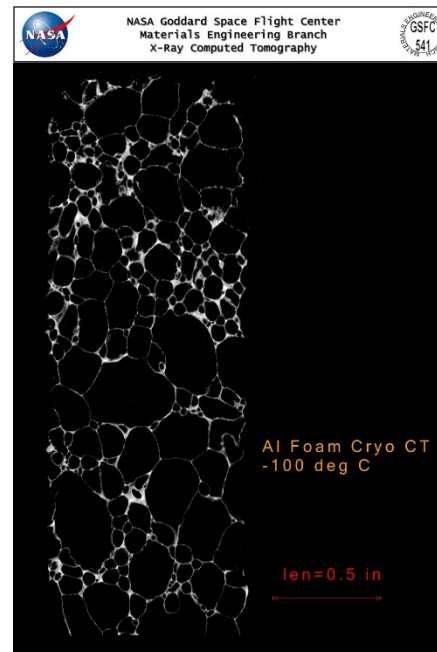
Pyramid IQI, *Next Steps*

- Pursuing full metal version (~2-3x smaller) printed using micro laser sintering (possibly working with Precipart or 3D MicroPrint GmbH)
- Currently incorporating other "internal features" such as disc penetrameters
- Print IQI set to cover range of sizes and run CT system assessments

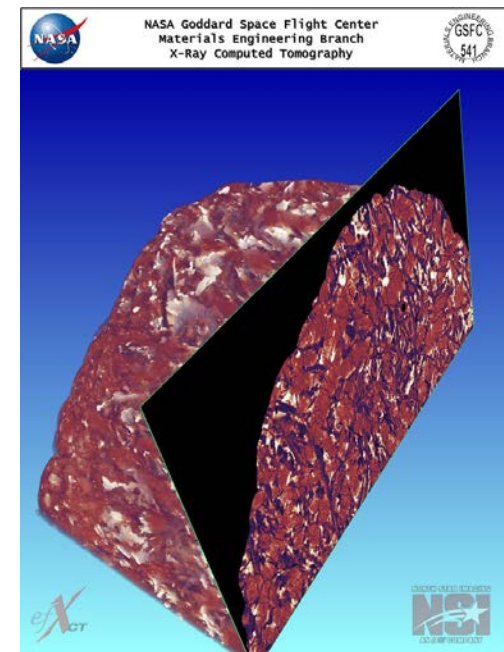


A few other activities in the lab...

- Round Robin testing of the ASTM E07/F42 Inserts and Prisms
 - 9 scans; various combinations of inserts and both the small stepped pyramid and small cone
 - Interested in line defects and contrast sensitivity of defect with increasing wall thickness
- New start proposal (OSMA NDE program) on AM Flaws
 - Assess the key NDE signal-related differences between flaws in AM parts versus conventional parts
 - Looking at 2 key variables: Surface roughness and grain structure
- NESC support for micrometeorite impact assessment for COPVs
- Cryogenic CT scan Capability
- Contrast enhancements for CT and for PT of AM parts
- Various ongoing GSFC Program-related work
- Lunar sample research
- Efforts to push awareness for CT for In-Space Use!



1st cryoCT scan



Lunar meteorite

Thanks for your time!