

Assessing the Durability of Flow-formed Aluminum 2195-T6 for Aircraft Cryotanks

NAWAMS 25

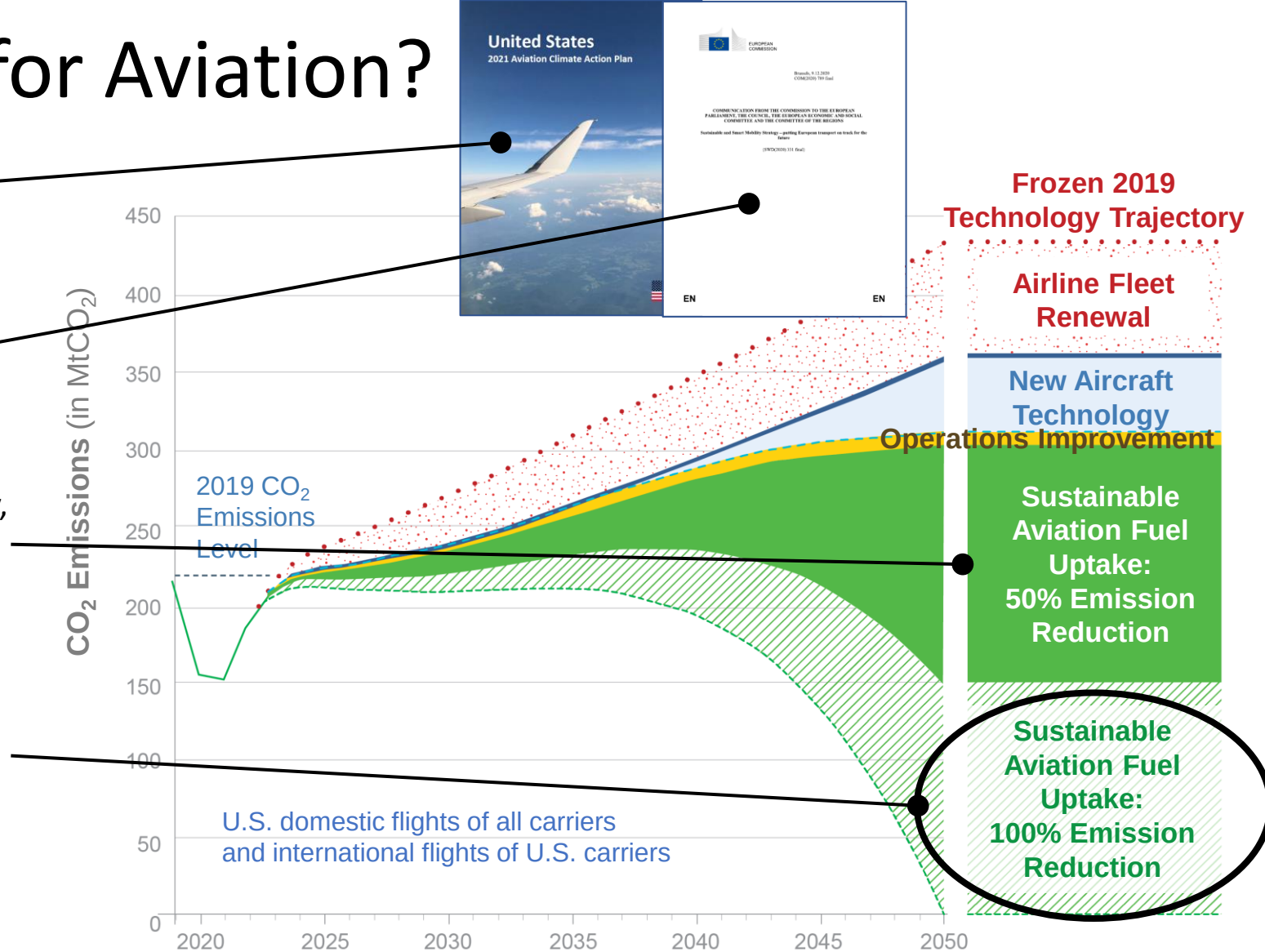
Advanced Manufacturing 1
July 15th, 2025

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Libby Urig (AMA)



Why Cryogenic Fuels for Aviation?

- U.S. Aviation Climate Action Plan has set Sustainable Aviation Net-Zero Carbon Emissions Goals by 2050
- Europe established a strategy in 2020 and is engaging with industry for hydrogen-fueled aviation
- SAF reduces emissions and fossil fuel dependency, but transition to new approach required to achieve 2050 goals beyond SFNP (AACES 2050 study)
- Switch to renewable cryogenic fuels to eliminate carbon emissions from fuel production and aircraft propulsion, (assuming sustainable fuel sources are available)
- **Cryofuel storage for aviation is still an outstanding technological question**



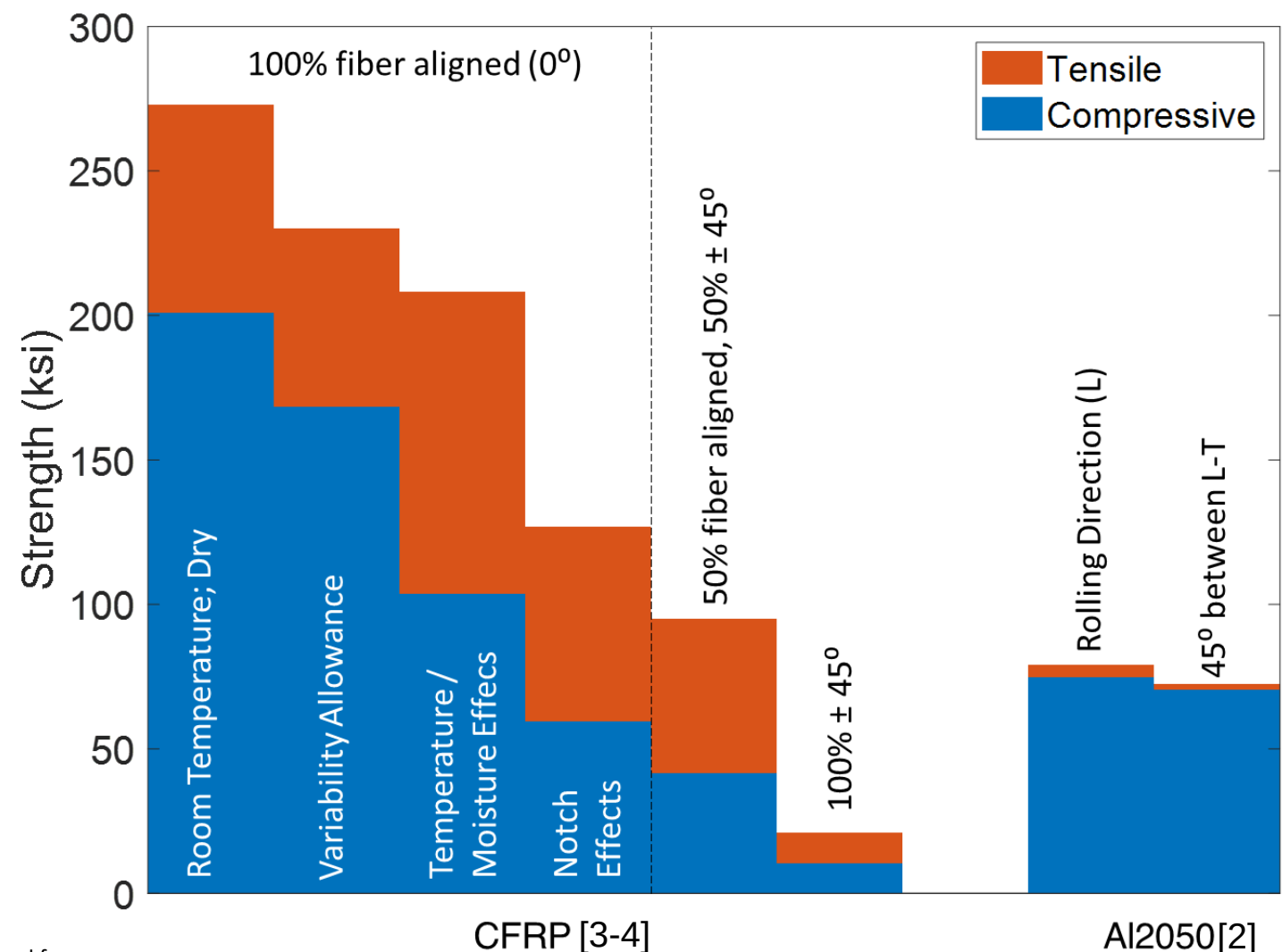
SAF = Sustainable Aviation Fuel; SFNP = Sustainable Flight National Partnership; AACES = Advanced Aircraft Concepts for Environmental Sustainability

Global climate goals by 2050 require new approach to fuels beyond SFNP :
Renewable cryogenic fuels can enable net-zero carbon emissions.

Cryotanks and the State of the Art

- Efforts to create an all-composite tanks are on-going but durability to sustain thermomechanical cycling has not been demonstrated in the literature
- Currently, most cryotanks for stationary storage and for launch vehicles are metallic
 - There are examples of quick, single use composite overwrap pressure vessels used in launch vehicles
- Gaps still remain for metallic cryotanks for aviation that need to addressed [1]
 - (1) minimizing the **weight** of a **durable** tank structure that carries the **required amount of fuel**
 - (2) **surviving the required number of mission cycles** involving fuel fill and drain cycles and their corresponding thermomechanical loading
 - (3) creating a design that can actually be **manufactured, inspected, and used with confidence.**

Accounting for all factors, metals are weight competitive



When accounting for environmental effects and anisotropy, Al2050 (aluminum lithium) are competitive with carbon-fiber reinforced polymer (CFRP) composites in terms of strength and weight:

CFRP Specific Strength: 360.8 ksi*in³/lb
Al2050 Specific Strength: 508.8 ksi*in³/lb

Data used from:
[2] R. A. Hafley, M. S. Domack, S. J. Hales, and R. N. Shenoy, "Evaluation of Aluminum Alloy 2050-T84 Microstructure and Mechanical Properties at Ambient and Cryogenic Temperatures," NF1676L-24863, Jul. 2011. Accessed: Jun. 13, 2025. [Online]. Available: <https://ntrs.nasa.gov/citations/20160010564>
[3] "MIL-HDBK-17-2E COMPOSITE MATERIALS POLYMER MATRIX." Accessed: Jun. 17, 2025. [Online]. Available: http://everyspec.com/MIL-HDBK/MIL-HDBK-0001-0099/MIL-HDBK-17-2E_22709/
[4] "Carbon Fibre Polymer Matrix Structural Composites | SpringerLink." Accessed: Jun. 25, 2025. [Online]. Available: https://link.springer.com/chapter/10.1007/978-981-10-2134-3_14

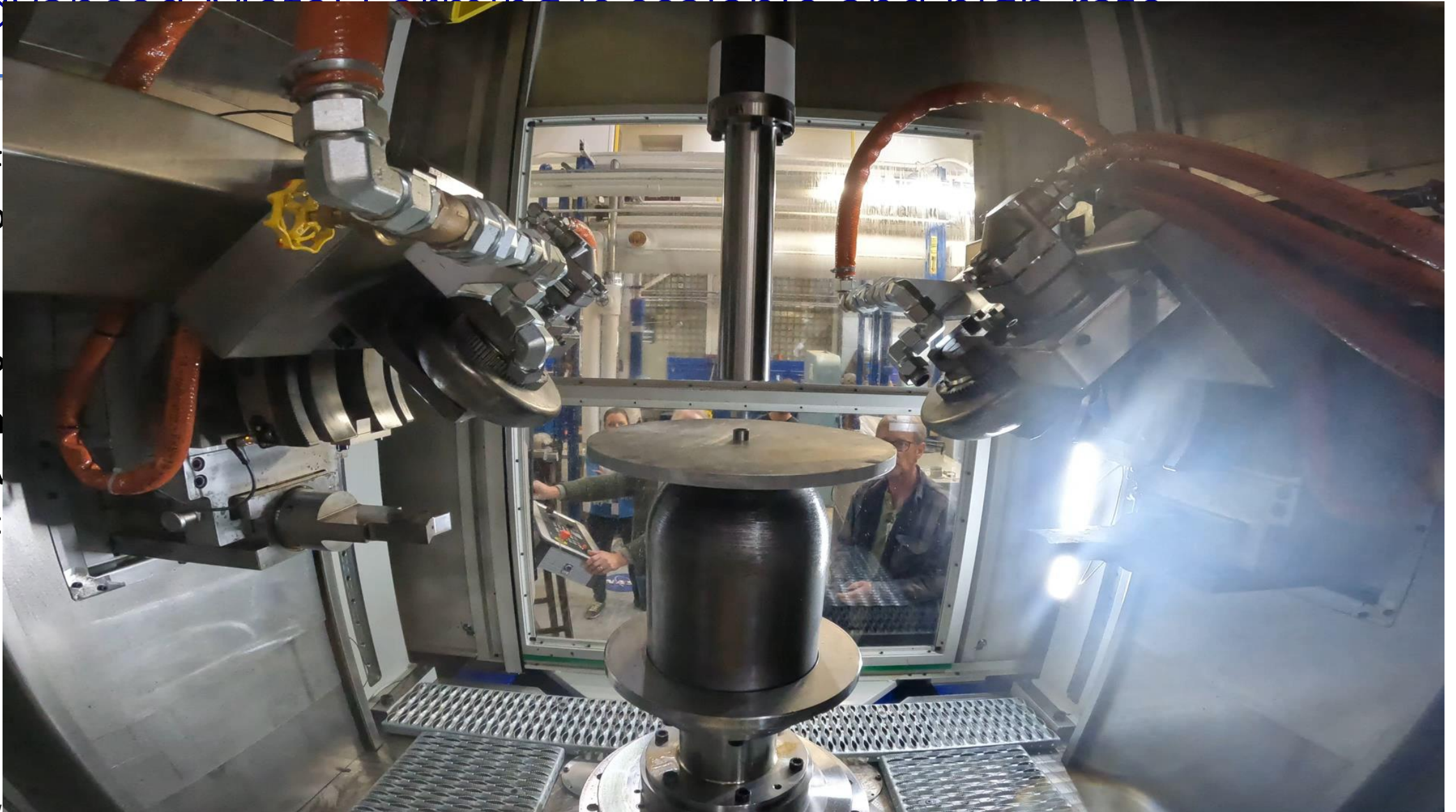
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Advanced Metal Forming

Advanced Metal Fabrication is called high water

- F
- o
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- M
- C



[5] Tayon, W. M., Haddad, W. M., Domack, M. S., & Hirsberger, W. M. (2022). Development of Advanced Manufacturing Approaches for Single Piece Launch Vehicle Structures.

[6] Stoner, M. C., Hehir, A. R., Ivanko, M. L., & Domack, M. S. (2016). *Cost-Benefit Analysis for the Advanced Near Net Shape Technology (ANNST) Method for Fabricating Stiffened Cylinders* (No. L-20600).

[7] Frederic, Peter (2022). *Advanced Metallic Fuselage Cost Study*. Tecolote.

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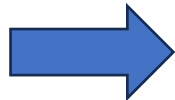
Advanced Metal Forming

DuraCrAFT: fatigue life testing overview

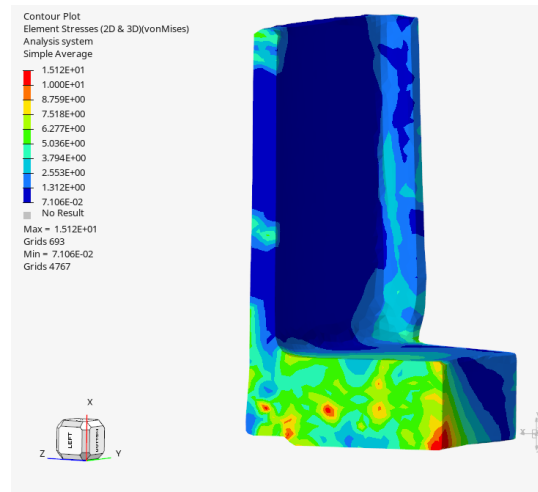
Goals: Compare fatigue life performance of flow-formed Al2195 to wrought product



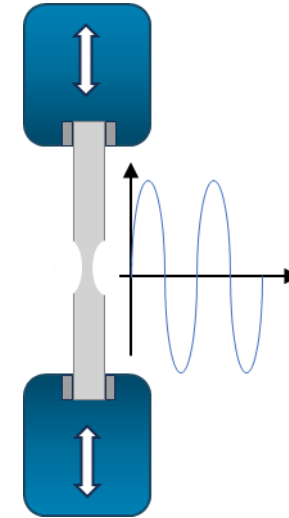
Starting material of wrought (pictured), flow-formed Al2195, and flow-formed Al6061



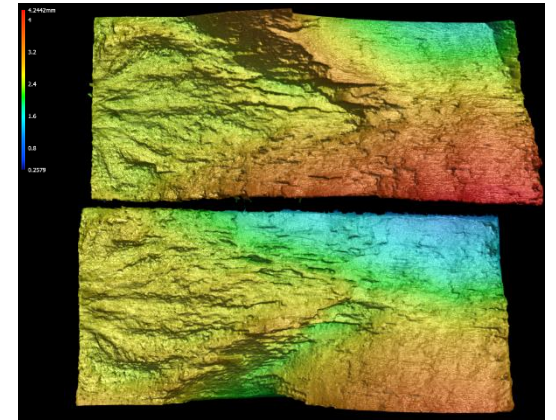
Heat treated to T6



Measure residual stresses via contour method



Perform fatigue life tests

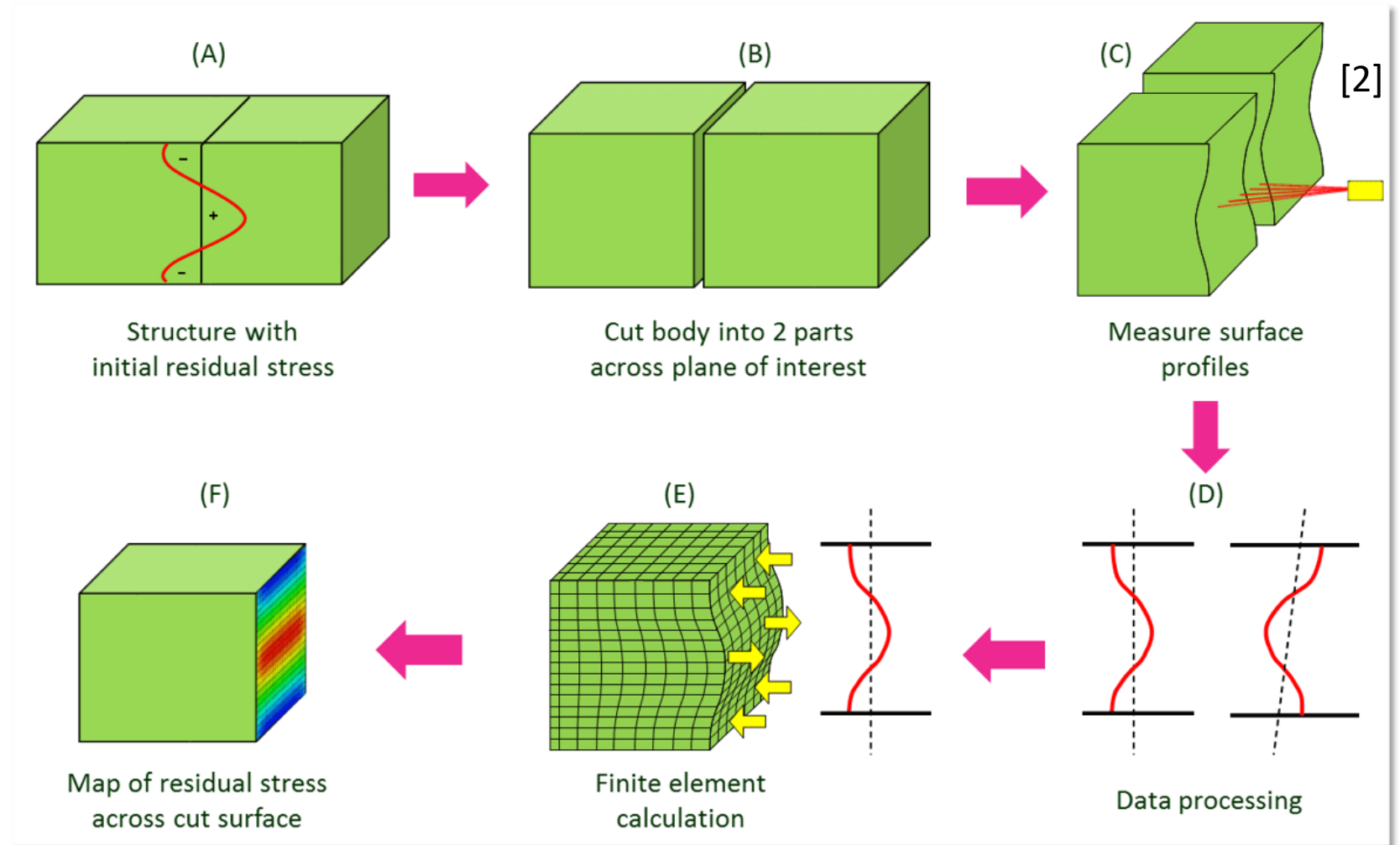


Characterize fracture surface

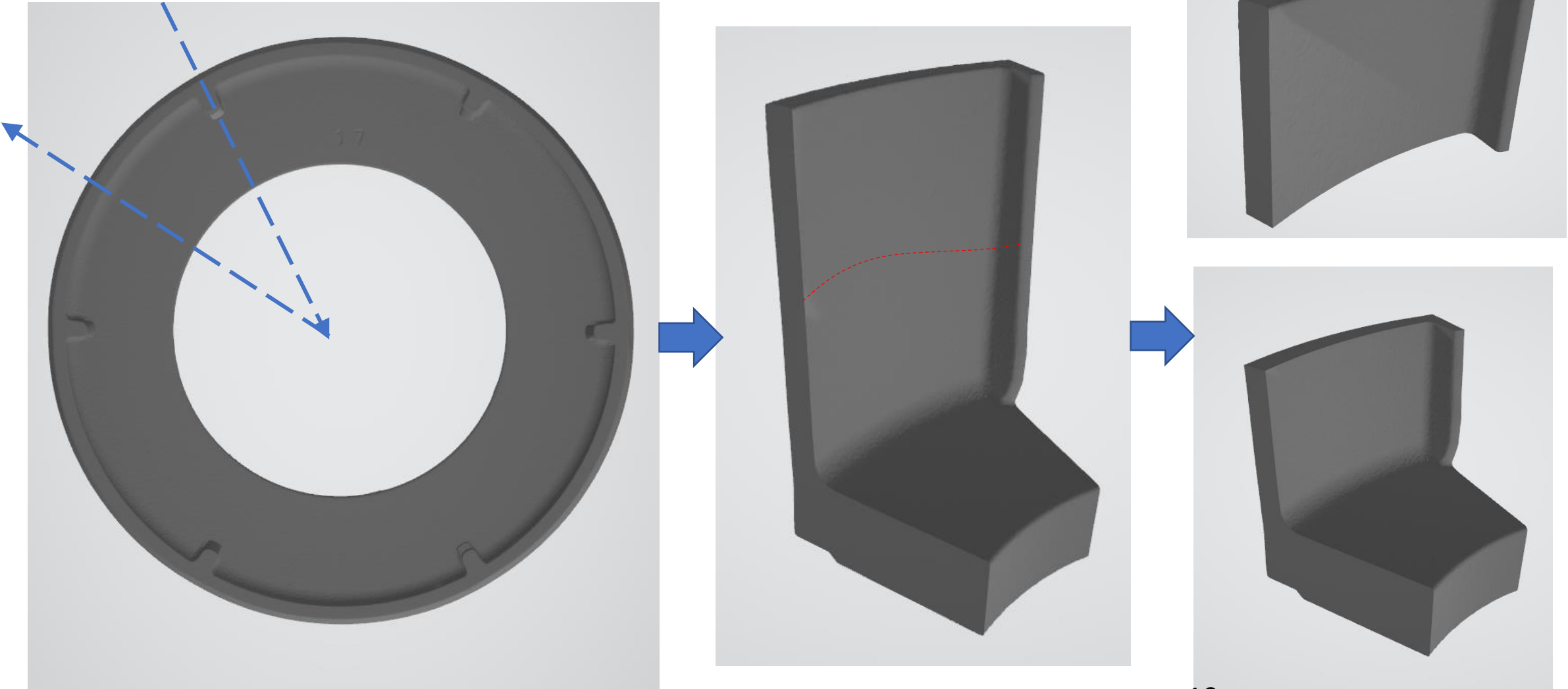
Additional testing performed on flow-formed Al2195 at cryogenic temperatures (-321°F) and on flow-formed Al6061 at room temperature

Contour Method for mapping residual stress

- Linear Elastic Finite Element
- Assumption that any deformation can be attributed to relieving of elastic residual stress
- Los Alamos and University of Manchester



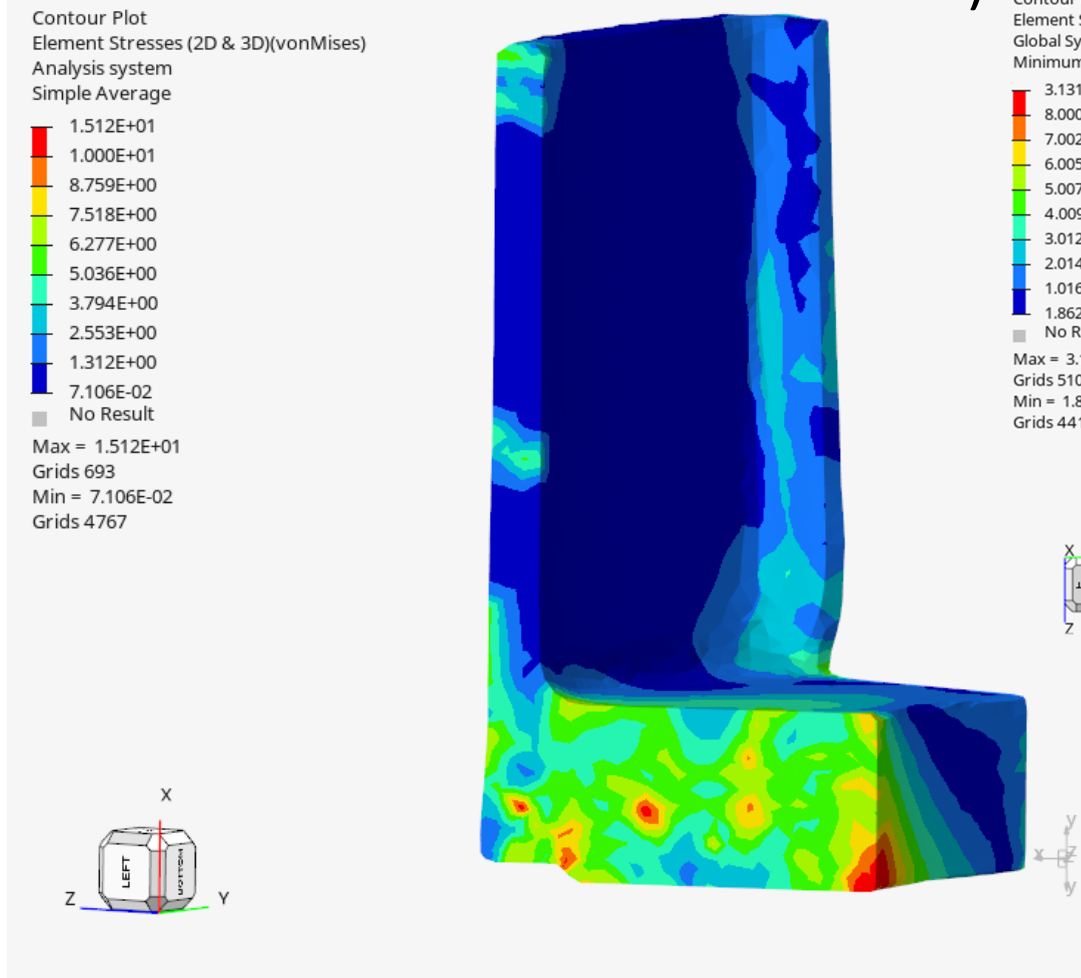
Light scans of initial structure and wire-EDM'ed parts



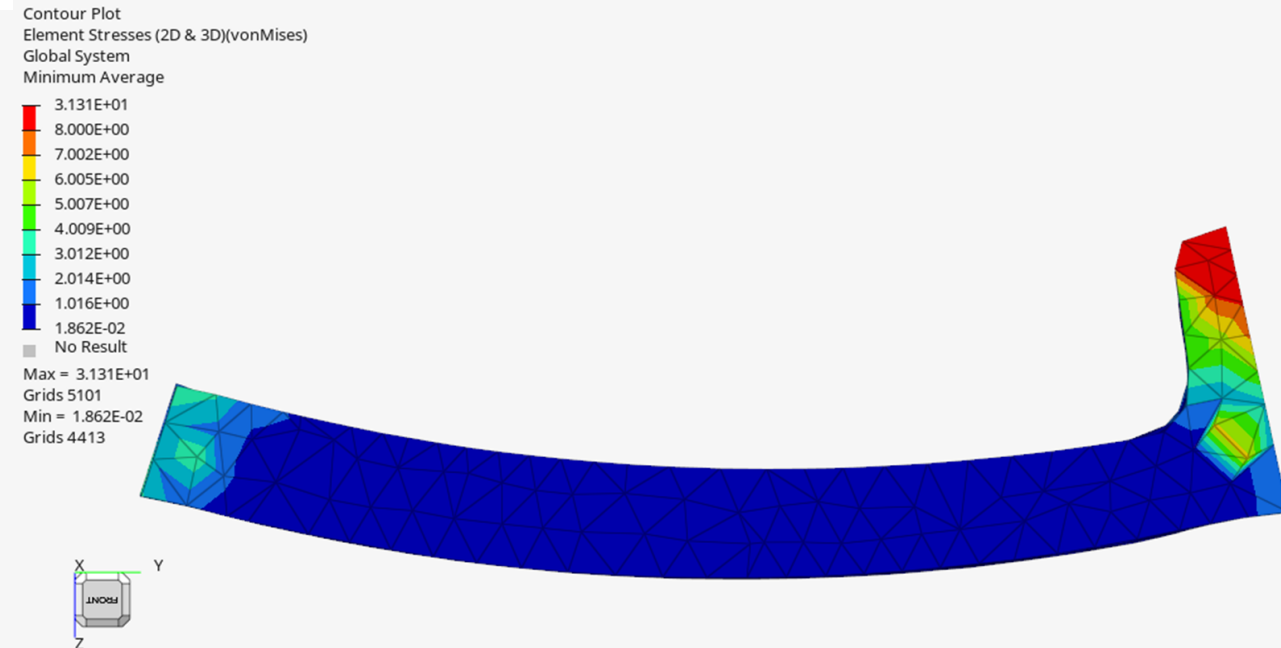
Distortions are minimal, in the range of .140 mm

Residual stresses from 2195 cylinder are small

a)



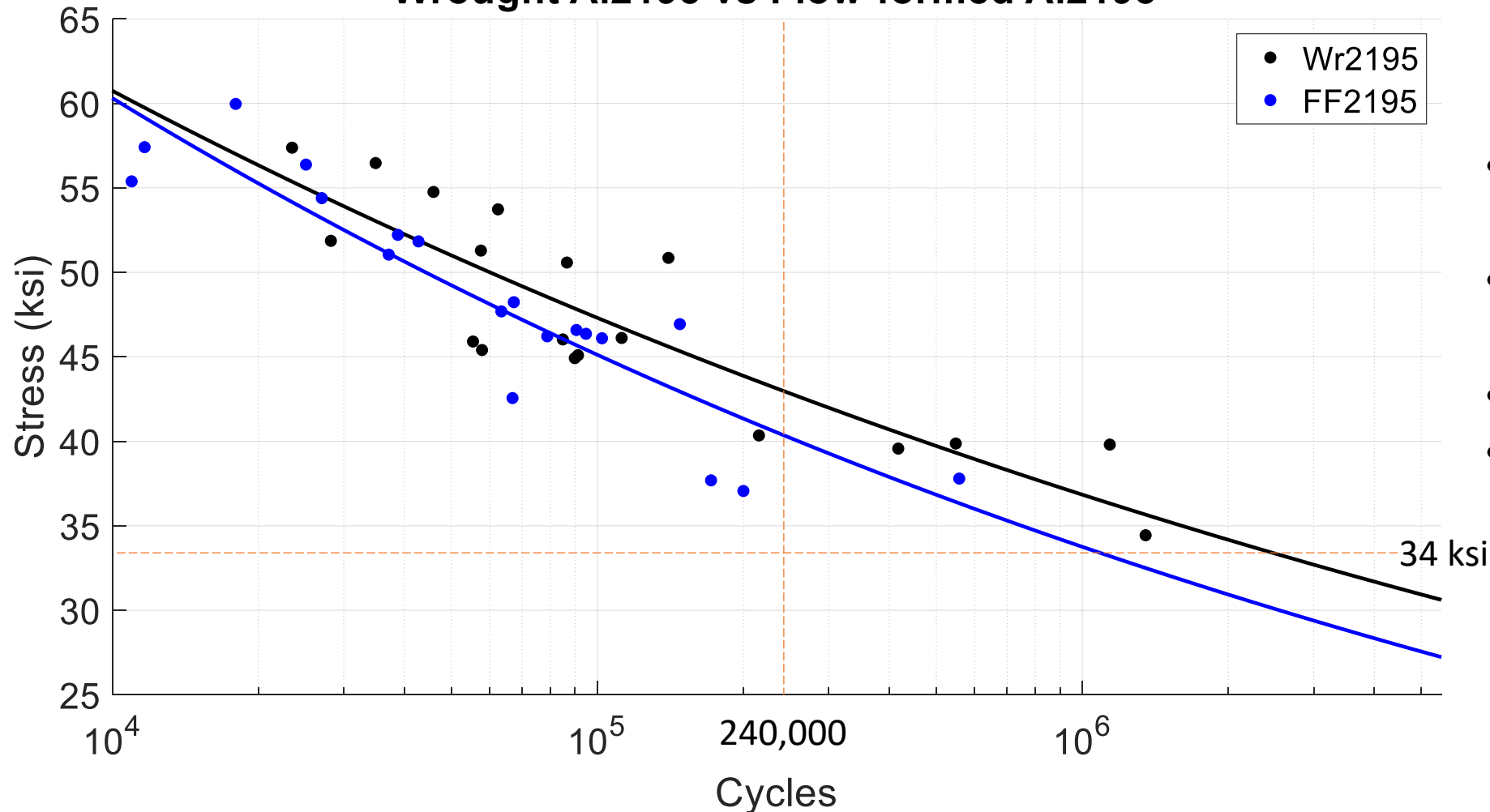
b)



Residual stress maps for the a) wall cross-section (circumferential) and b) stiffened-wall section (axial) show maximum stress of ~15 Mpa (~2 KSI) and ~30 Mpa (4 KSI), respectively

S-N curve shows near equivalent fatigue life for wrought and flow-formed Al2195

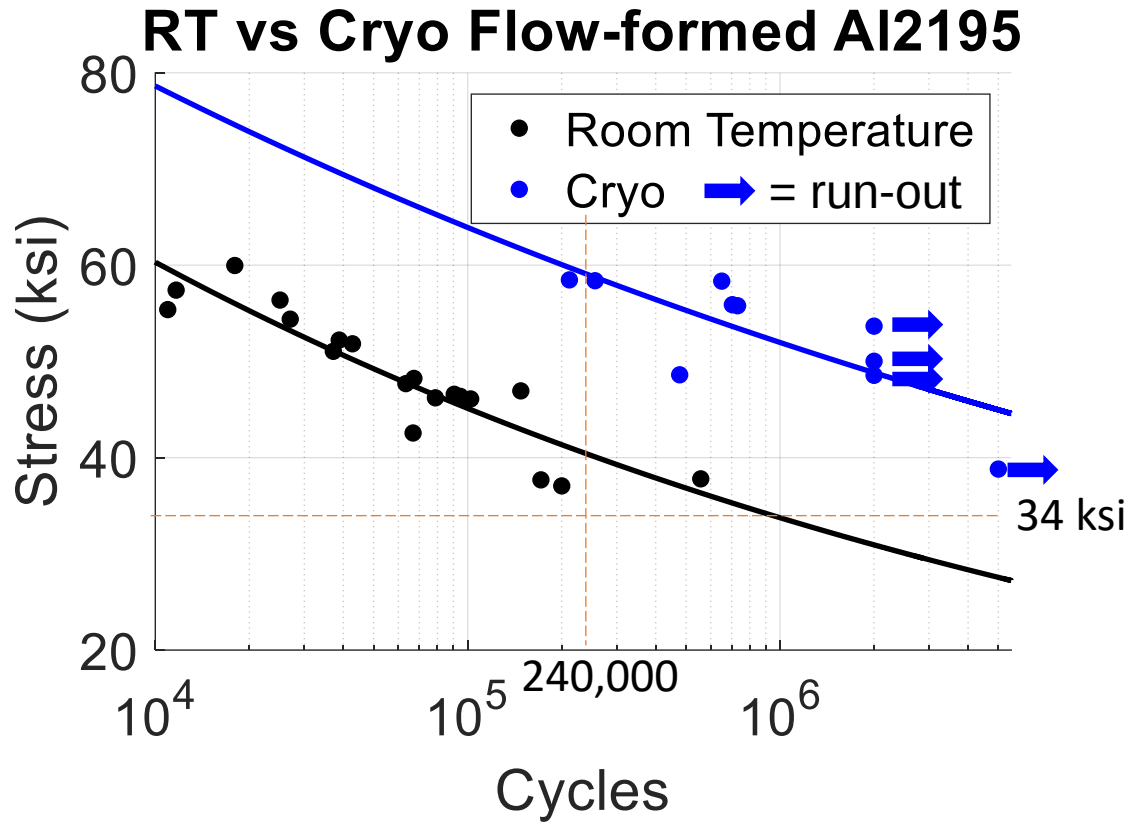
Wrought Al2195 vs Flow-formed Al2195



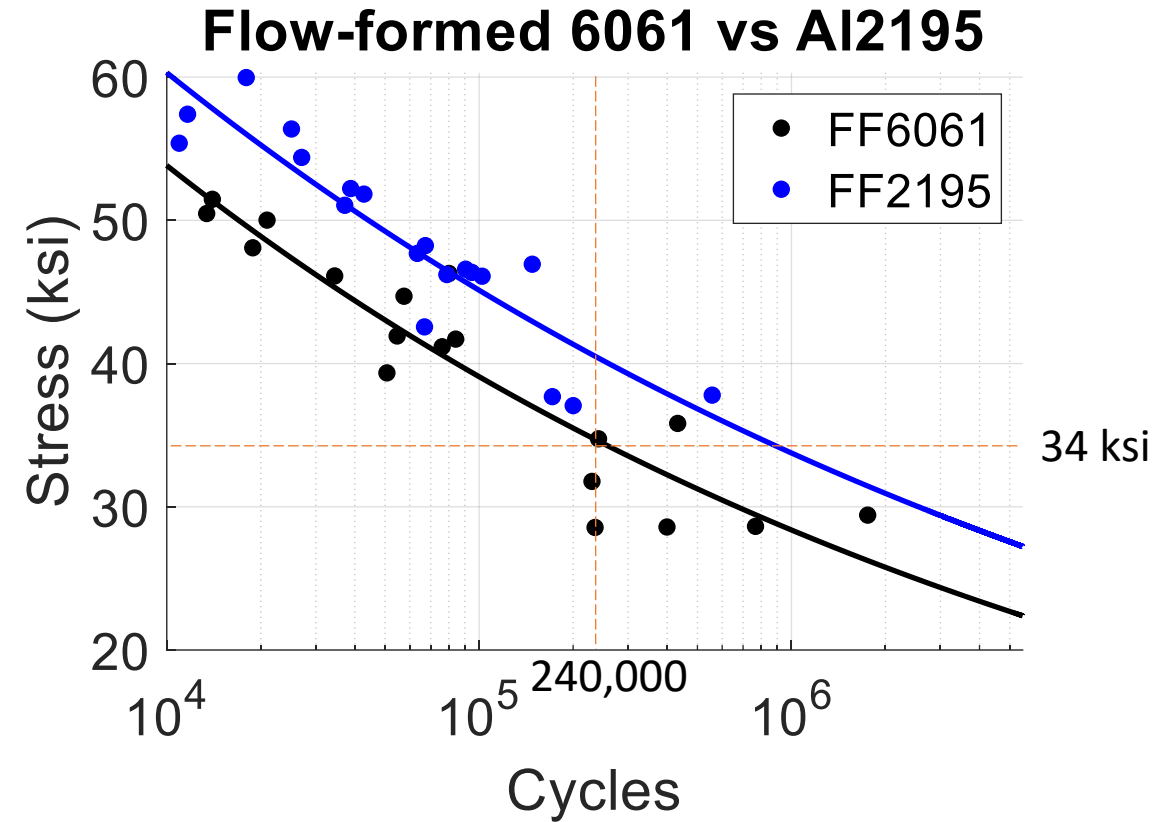
- Fatigue life testing
 - Flat, dog bone samples; R = 0.1; 5 Hz
- Upper range of stress on LH₂ tank is 34 ksi [3]
- Estimated cycles for cryotanks is 240,000 [3]
- Powerlaw fit: $\sigma = c_1 N^b$
- T-test performed on two sets of data
 - Wrought and flow-formed Al2195 fatigue lives are statistically equivalent

Benefit: Flow-forming allows for extremely fast manufacturing rates and the ability to create novel shapes while maintaining near-equivalent fatigue life performance

Additional S-N curves show positive cryogenic performance and alloy comparisons



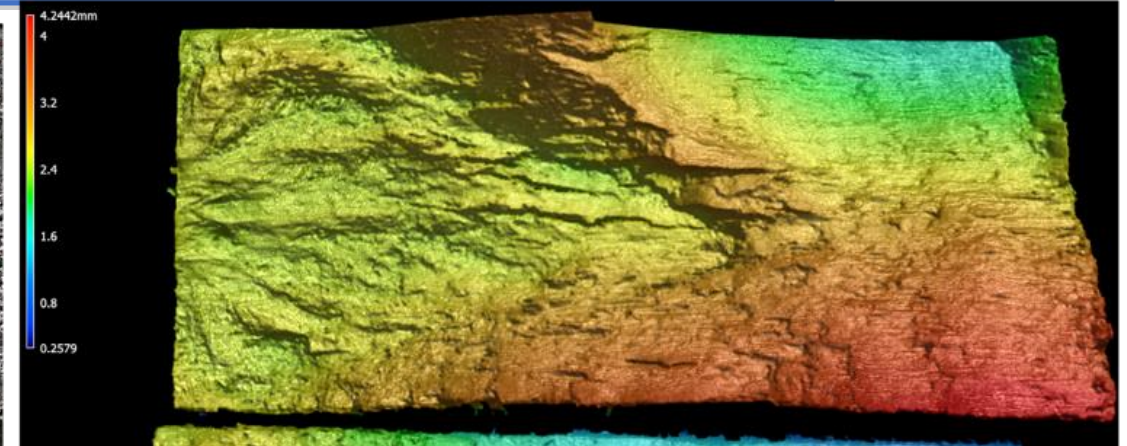
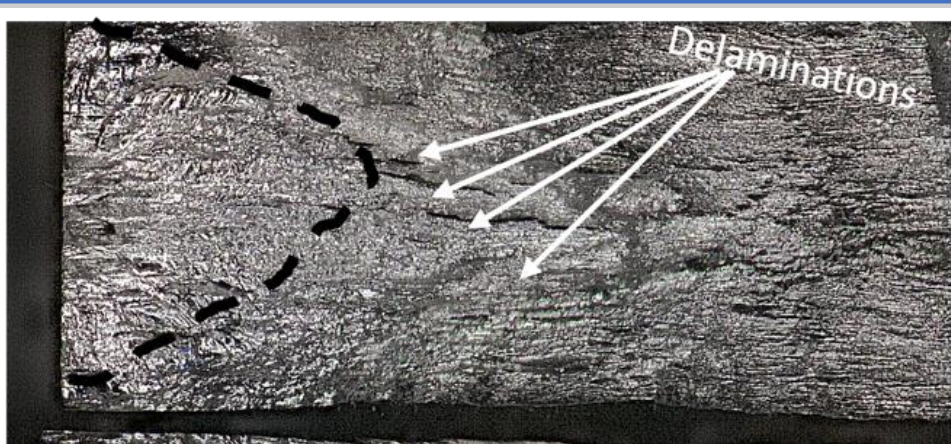
Flow-formed 2195 at cryogenic temperature show predicted ~10x cycles compared to room temperature at 34 ksi



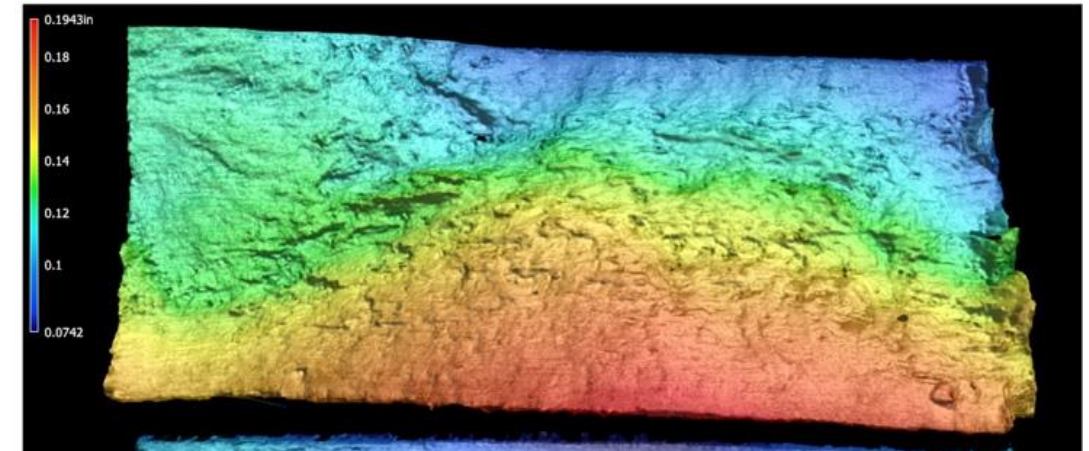
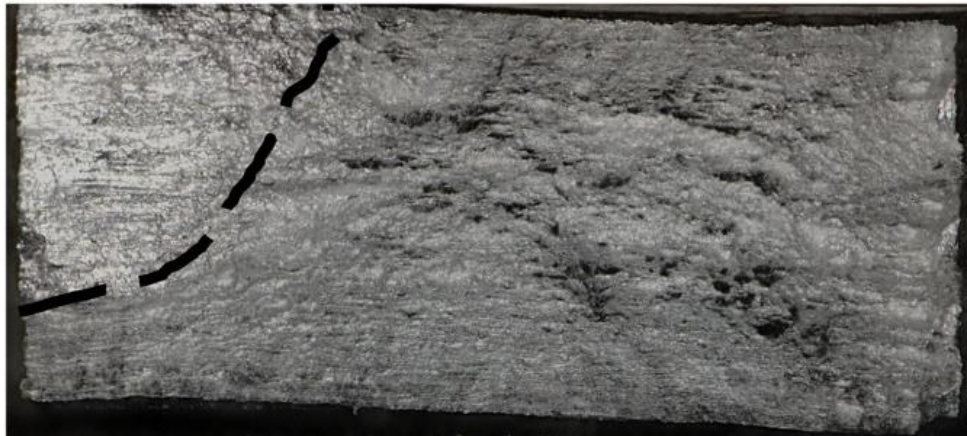
Flow-formed Al2195 shows ability to withstand 944,000 cycles and flow-formed Al6061 withstand 272,000 cycles at 34 ksi

Fractography of flow-formed Al2195 reveals reduced delaminations

Wrought Al2195



Flow-formed 2195



Optical Image of Fracture Surface

Optical Image of Fracture Surface

- Aluminum Lithium alloys (e.g. Al2195) have shown tendency to undergo out-of-plane brittle intergranular failures (delaminations), which has been linked to increased fatigue life
- Delaminations may accelerate crack growth rate in more complex loading conditions
- Flow-formed Al2195 shows reduced delamination and maintains near-equivalent fatigue-life as wrought

Conclusions

(1) minimizing the **weight** of a **durable** tank structure that carries the **required amount of fuel**

(2) **surviving the required number of mission cycles** involving fuel fill and drain cycles and their corresponding thermomechanical loading

Al2195-T6 shows:

- Low residual stresses
- Near equivalent fatigue life to wrought product
 - Flow-formed Al2195-T6 exhibits less delaminations than wrought
- S-N cryogenic properties show positive performance compared to room temperature

(3) creating a design that can actually be **manufactured, inspected, and used with confidence.**

Future work: Design and fabricated test article

Acknowledgements to Libby Urig, Andy Newman, and Wes Tayon for their contributions to this work!

Questions?

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