Demise Testing and Modelling of Glass Materials and Demisable Bipod Concepts

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Objectives

- Three Separate Areas of Interest

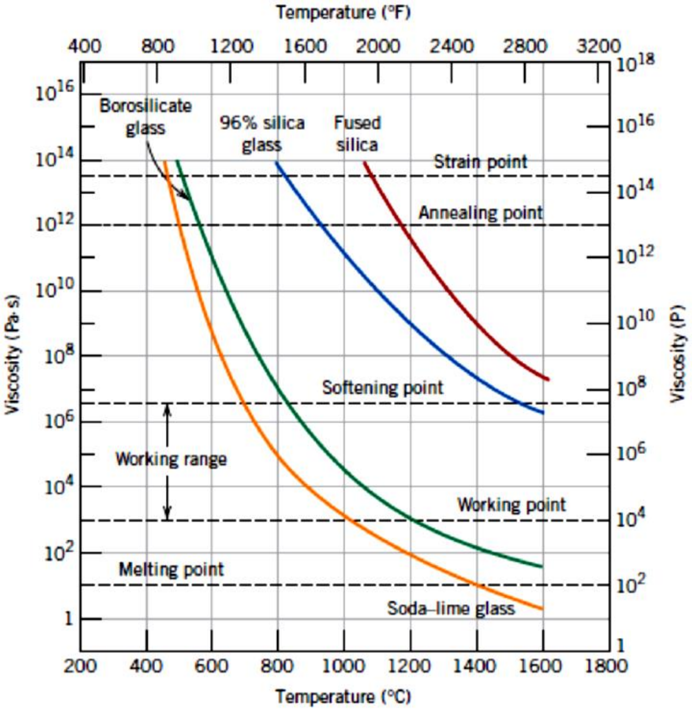
- Glass Modelling
  - Specific investigation of fused silica and Zerodur
  - Development of ‘glass’ model for destructive re-entry tools

- Ejecta Interaction
  - Does the impact of aluminium on hot titanium/steel surfaces enhance demise?
  - Splashes seen on recovered tanks
  - Nothing of interest seen in testing (but tests were quite cool)

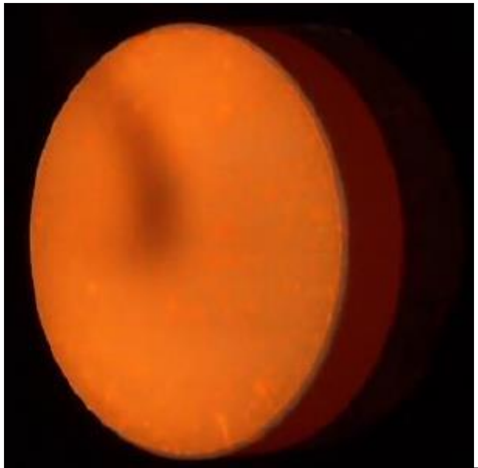
- Bipod Demisability and Design-for-Demise
  - Critical part of optical payloads
  - Often titanium or CFRP, so can provide casualty risk

Glass Materials

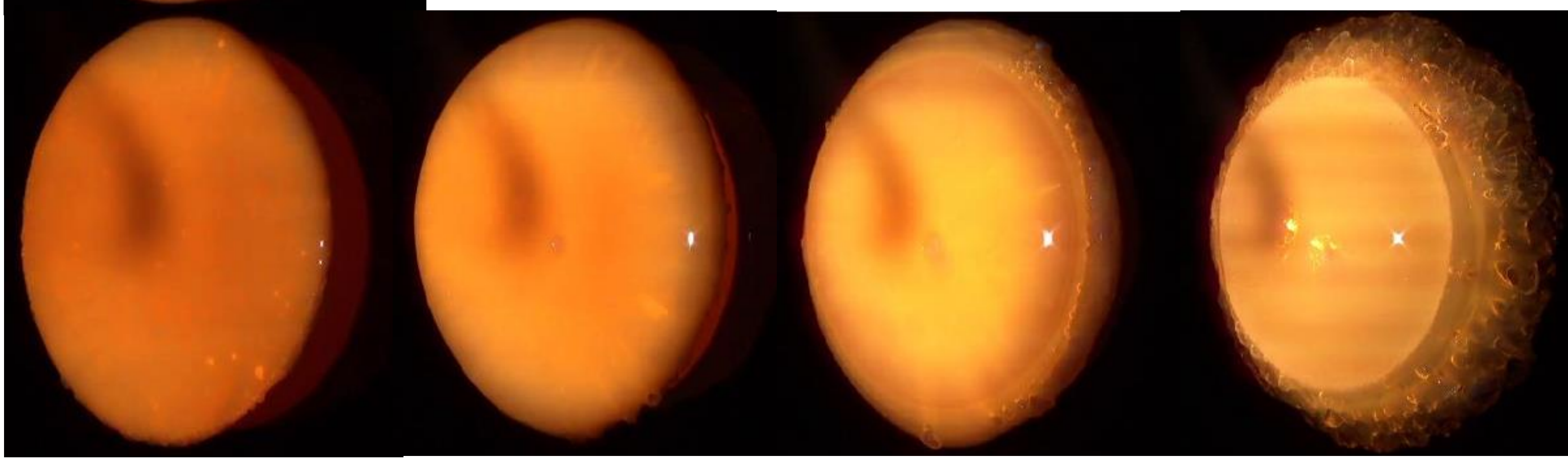
- How do Glass Materials Demise?
  - Glasses do not have melting point
  - Reduction in viscosity with increasing temperature
    - Different profiles for different glasses
  - Hypothesis: shear failure when hot
- Characterisation of Zerodur, Fused Silica
  - Basic properties (OGI)
  - Temperature-viscosity curve (SHU)
  - Post-test analysis (SHU)
- Testing of Materials
  - Confirm (or deny) shear failure
  - Consolidate modelling approach
- Construct/Verify Models
  - Data from testing
  - CNES data on Zerodur



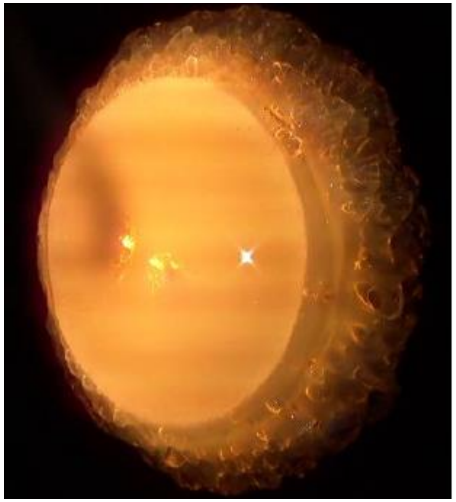
Zerodur Stagnation



- Stepped Flux Approach
  - No demise at first three conditions
  - ~600kW/m^2 fully catalytic, some rim deformation
    - Late if catalytic surface, early if non-catalytic
  - ~700kW/m^2 glassy surface, clear motion
  - ~800kW/m^2 visible waves of material motion
  - Clear reduction of viscosity with temperature



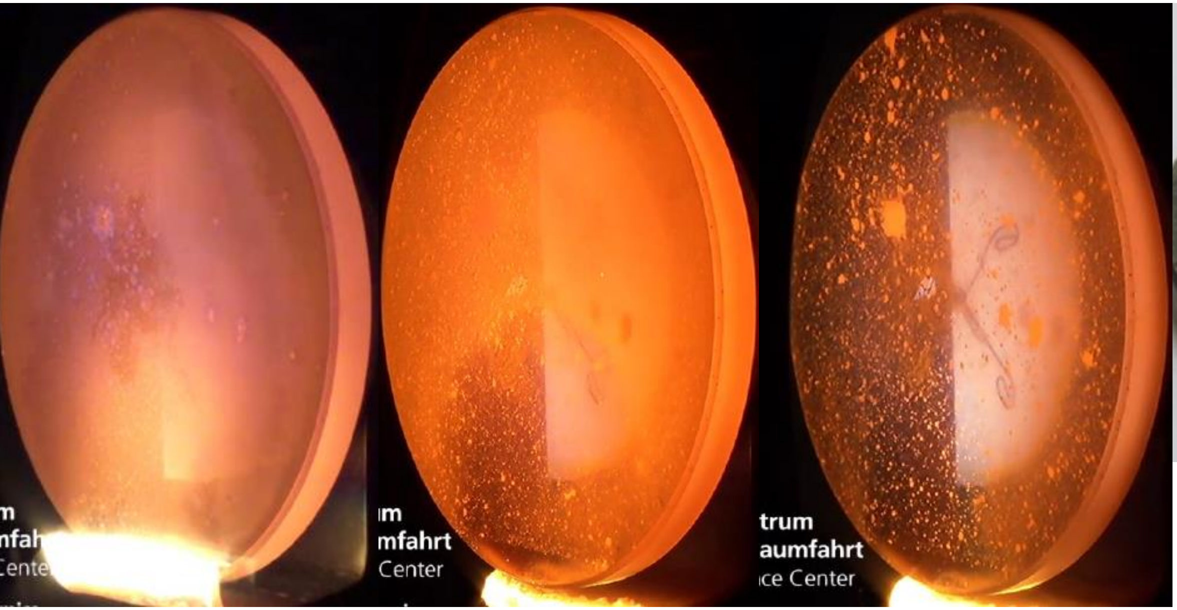
Zerodur



- Zerodur material motion clearly observed
  - Thermocouple data to about 1200^0C
  - Pyrometer data suggests this is a minimum
  - Higher than DEBRISK melt, in line with SAMj
  - Data suggests viscosity quite high at these temperatures
  - State-of-melt tests suggest that material is close to amorphous
- Sample remains
  - Glassy layer majority amorphous
  - Opaque layer majority crystalline
- Rebuilding
  - Demonstrates very low catalycity of glasses
  - Input heat flux is about half of fully catalytic
  - Models massively overpredict the heating

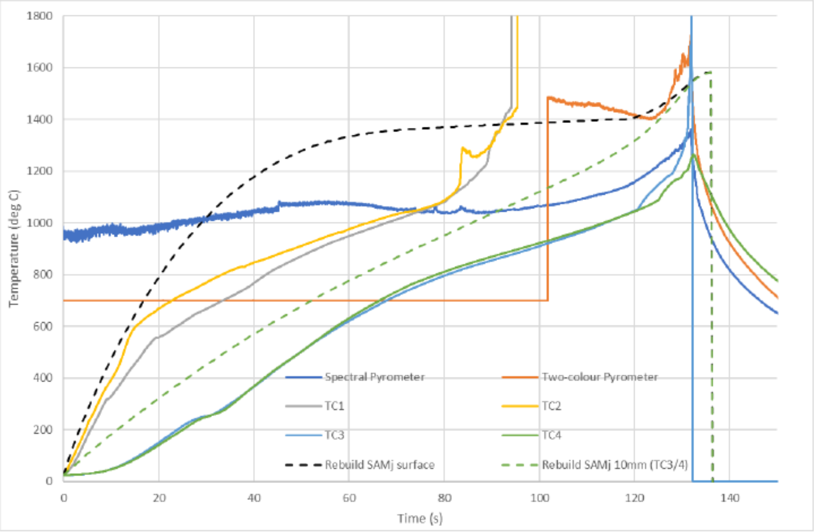
Fused Silica Stagnation

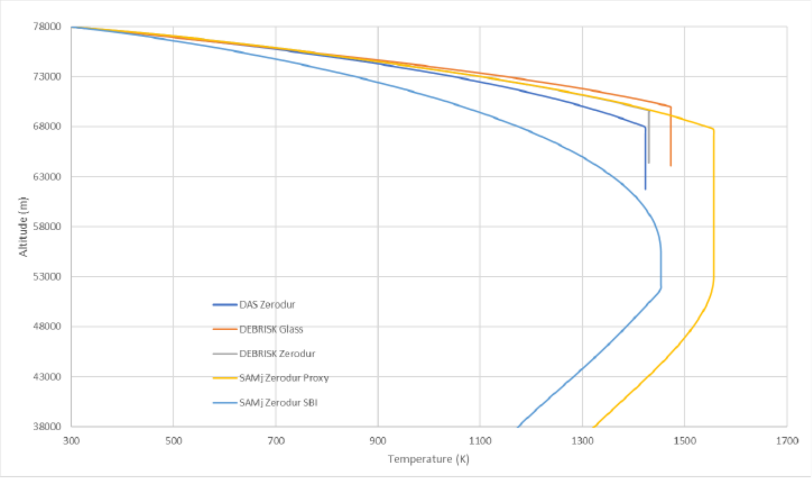
- Stepped Flux Conditions
  - Obtain steady states to gain energy balance
  - No demise observed
- Rebuilding
  - Very low catalycity confirmed – must be included in models



Glass Material Demise Modelling

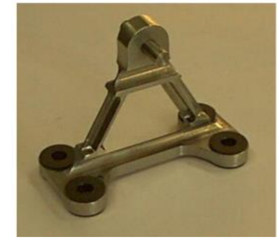
- SAMj Model Updated
  - Use of simplified HBI model
  - Surface energy balance; bulk energy
  - Provide temperature profile across material
- Viscosity-shear Model
  - Shear from hot outer layer
  - Material loss rate function of surface viscosity
    - Fit to experimental data
    - General to viscosity
    - Can be used for range of glasses
  - Based on understanding of hot outer layer
- Low Demisability of Zerodur
  - Less than previous models
  - Driven by low catalycity; viscosity model

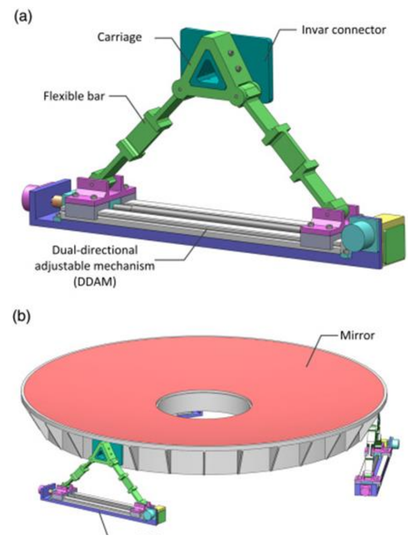


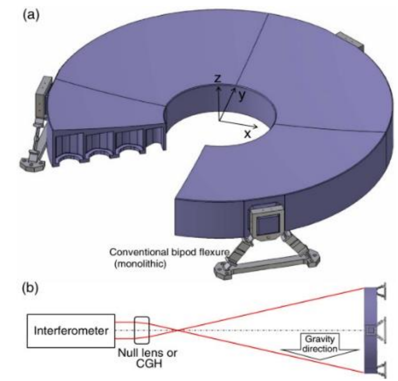


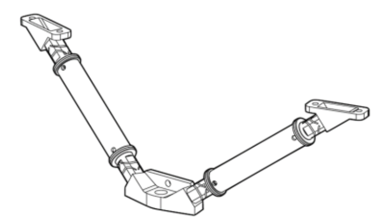
Bipods

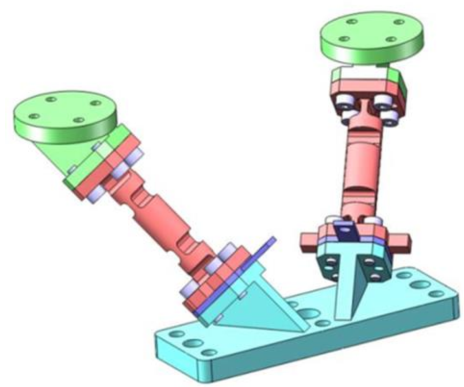
- Support Optical Payloads
  - And other things…
- Often Low Demisability
  - Titanium, CFRP, Invar
  - Huge variety
- Test Nominal Bipod
  - ‘Standard’ design, titanium
- Design ‘Demisable’ Bipod
  - Lightweighting
  - 3D printing (flow paths?)
  - Test and assess
- Modelling

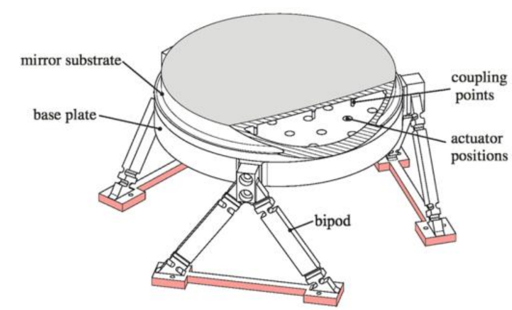




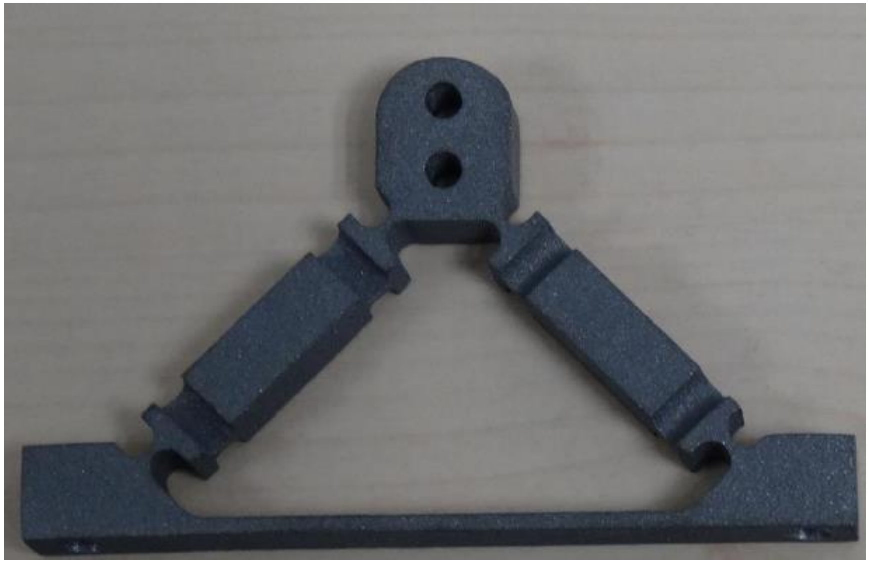




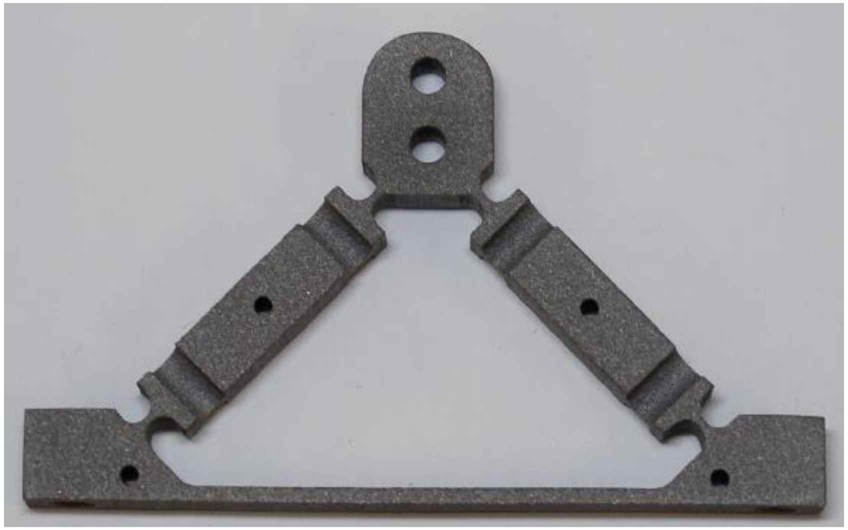


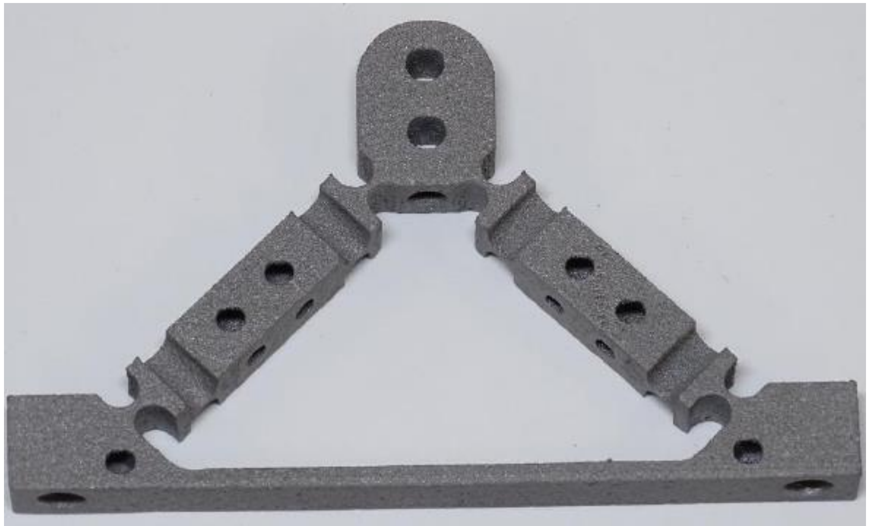


Bipod Investigation

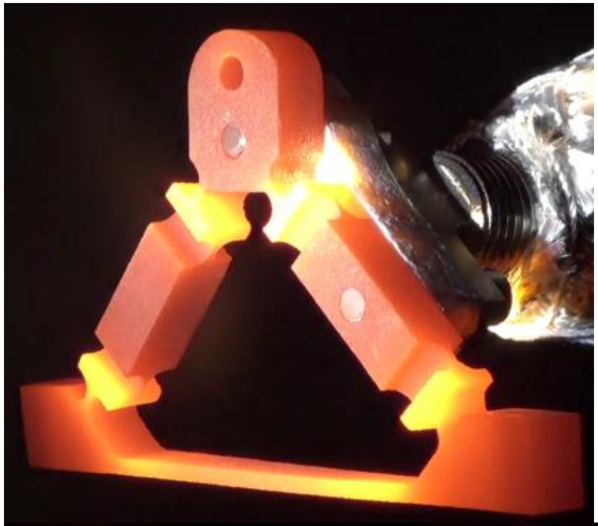


- Strawman Bipod Designed (UCL)
  - 22g
- Designed to Support 8kg
- Single solid A-frame
- Demisable Versions
  - Hollow
  - Flow Holes

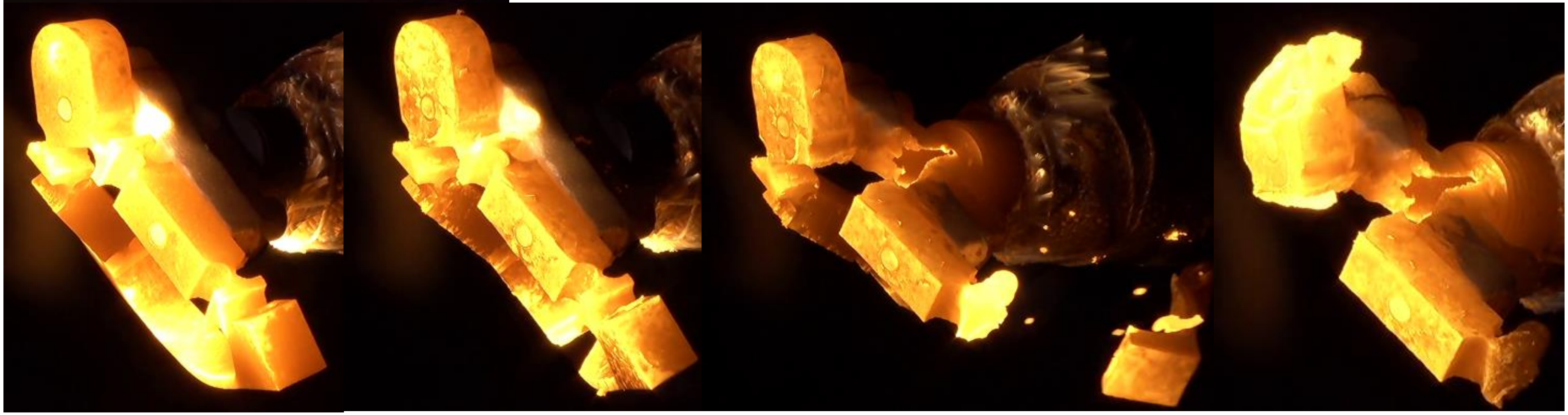




Baseline Bipod



- Stepped Flux Approach
  - Length scale dominates heating
    - Captured well in predictions/rebuilds
  - Bipod bends as it gets hot
  - Melt start at predicted condition
  - Fragmentation at predicted locations
  - Head melts early – due to high fluxes around hole

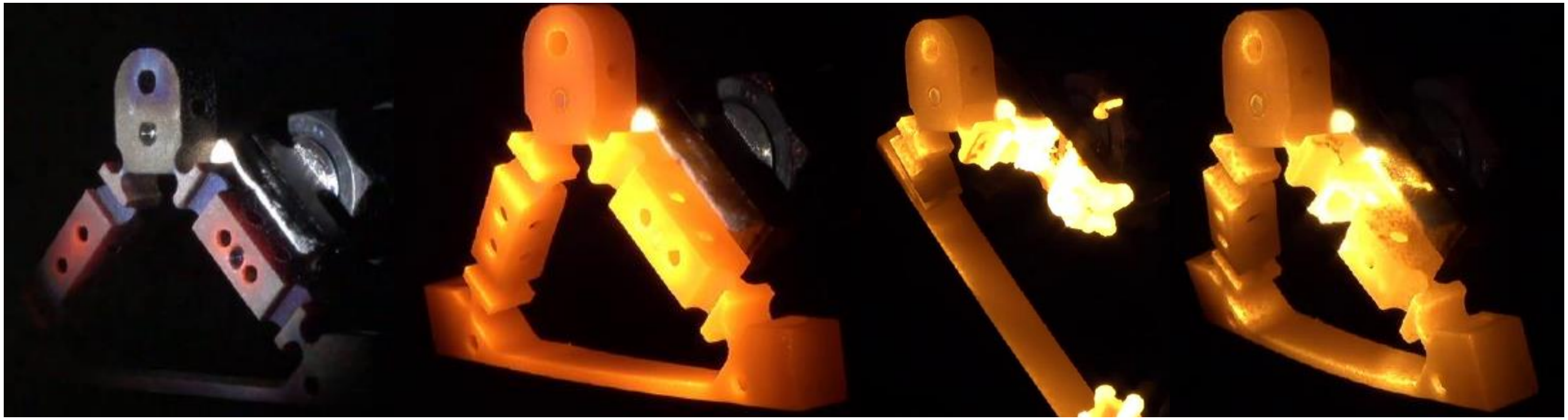


Hollow Bipod

- Stepped Flux Approach
  - Length scale dominates heating
    - Increased heating around hole for powder removal
  - Bipod bends as it gets hot; similar to baseline
  - Sample removed from flow on gas mixture change
    - Some oxide residue
  - Melt start at predicted condition; same as baseline
  - Melt of attached leg much earlier than baseline

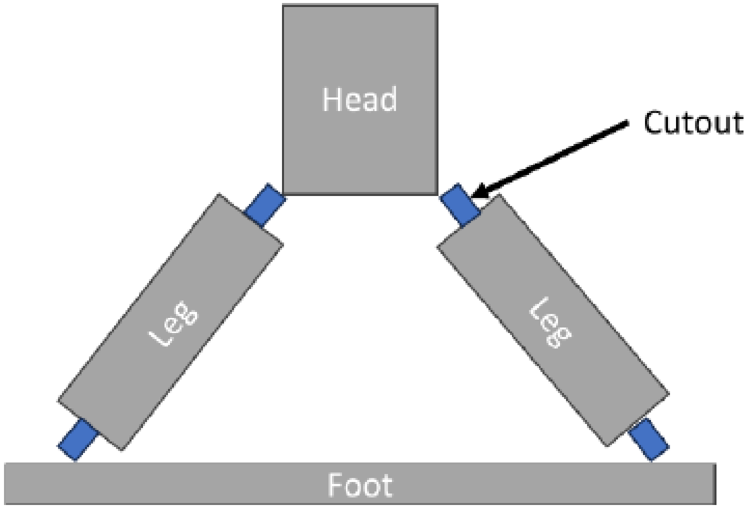
Flow Holes Bipod

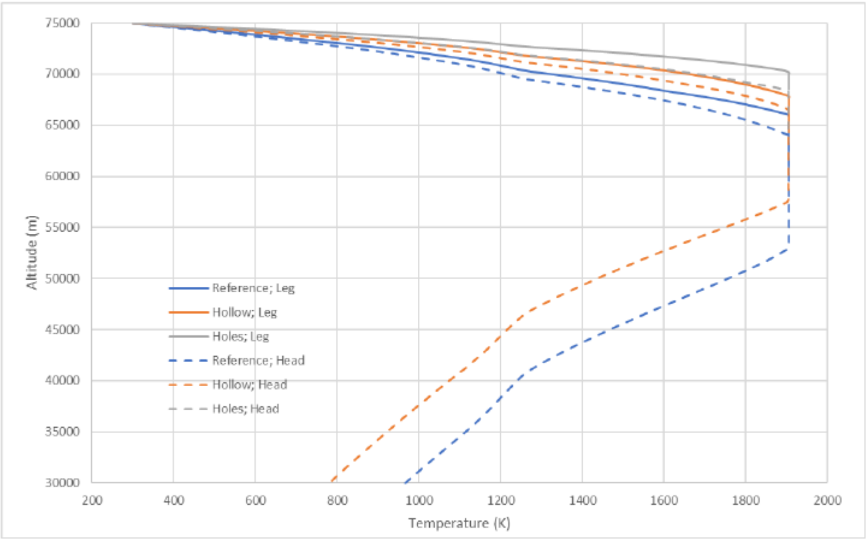
- Stepped Flux Approach
  - Length scale dominates heating
    - Heating to holes faster than heating to cutouts!
    - Highly successful D4D technique
  - First melt is at hole on attached leg
    - Before cutout melt
  - Melt of legs at condition prior to head melt
  - Head not melted as test stopped



Bipod Modelling

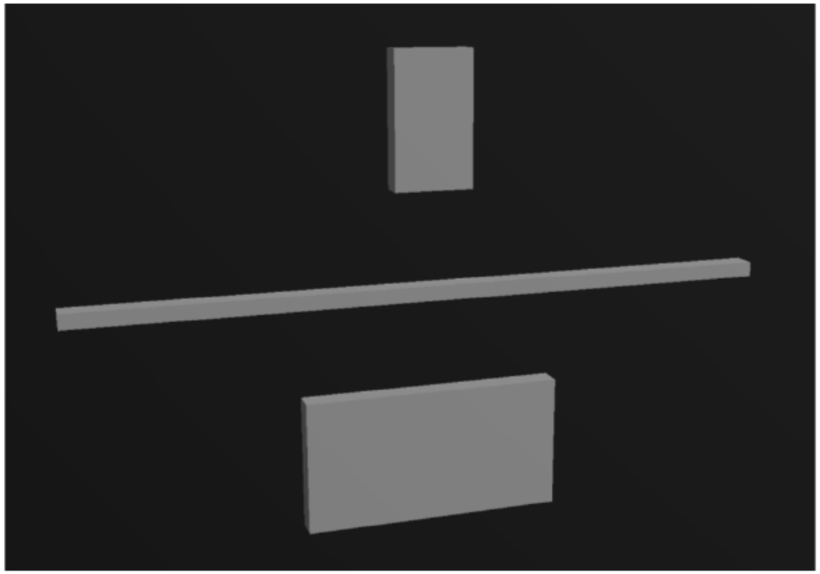
- Assess Model with Length Scales
  - Three bipod sizes
    - Test object (~35g)
    - Medium bipod (~250g)
    - Large bipod (~1.5kg)
  - Hollow and holes versions assessed
    - Different length scales
- Results
  - Cutouts fail (fragmentation)
  - Parts can demise
  - Medium bipod demises (78km)
  - Impact of D4D clear at 75km release





Bipod Modelling

- Simplified Models
  - Volume envelope
  - Match volume
  - Match length scale
- Models Underpredict
  - Length scale model is good
  - Issue with interference on S/C
    - Can pass through parts
- DRAMA Recommendations
  - Multi-component model
  - Include small length scales
  - Ring model (joint connections)
  - Mass-loss fragmentation
  - Titanium melt emissivity



Bipod	Model	78km Release	75km Release	70km Release
Small	Reference	Demise	Demise	Demise
	Envelope	Demise	Demise	Demise
	Volume	Demise	Demise	Demise
	Length Scale	Demise	Demise	Demise
	Adjusted Length	Demise	Demise	Demise
Medium	Reference	Demise	Demise	Demise
	Envelope	No Demise	No Demise	No Demise
	Volume	Demise	Demise	No Demise
	Length Scale	Demise	Demise	Demise
	Adjusted Length	Demise	Demise	Demise
Large	Reference	Demise	Head Only	4 Parts
	Envelope	No Demise	No Demise	No Demise
	Volume	No Demise	No Demise	No Demise
	Length Scale	Demise	Demise	No Demise
	Adjusted Length	Demise	No Demise	No Demise

Conclusions

- Glasses
  - Viscosity measurements and demise testing of Zerodur
  - Demonstration of low surface catalycity – critical for reasonable modelling
  - Improved glass model for demise based on balance integral
    - Demise driven by viscosity
    - Suggests current models are highly optimistic
- Bipods
  - Thin structure is generally good for demisability
    - Most models miss this aspect – underpredict demisability
  - Demonstrated importance of length scales in tests
    - Must capture thin parts to get good fragmentation and demise simulations
  - Excellent performance of D4D techniques
    - Hollow version had low thermal inertia; melted quickly
    - Flow holes provided massively more heating (~40%, half length scale)
  - Flow holes recommended for investigation in other D4D fields