Sizing and Margin Methodology for Dual-Layer Thermal Protection Systems

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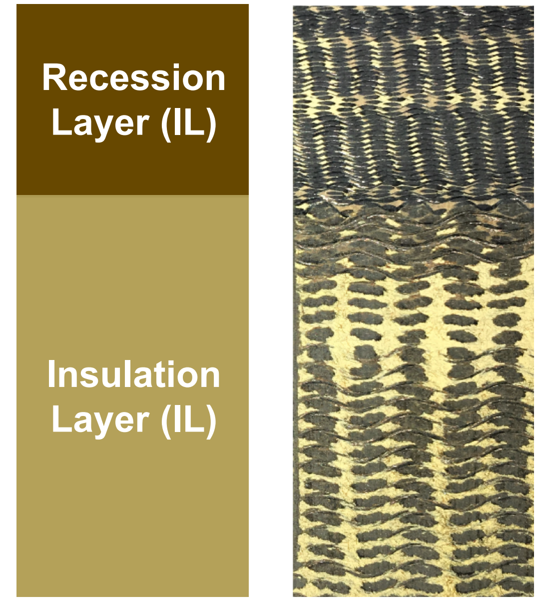
Thanks to Grant Palmer and Dinesh Prabhu for Aeroheating Simulations

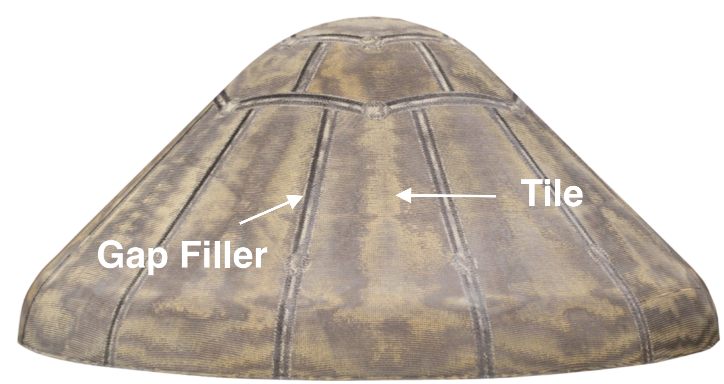
15th International Planetary Probe Workshop

2018-06-12

Dual-Layer TPS Material (HEEET)

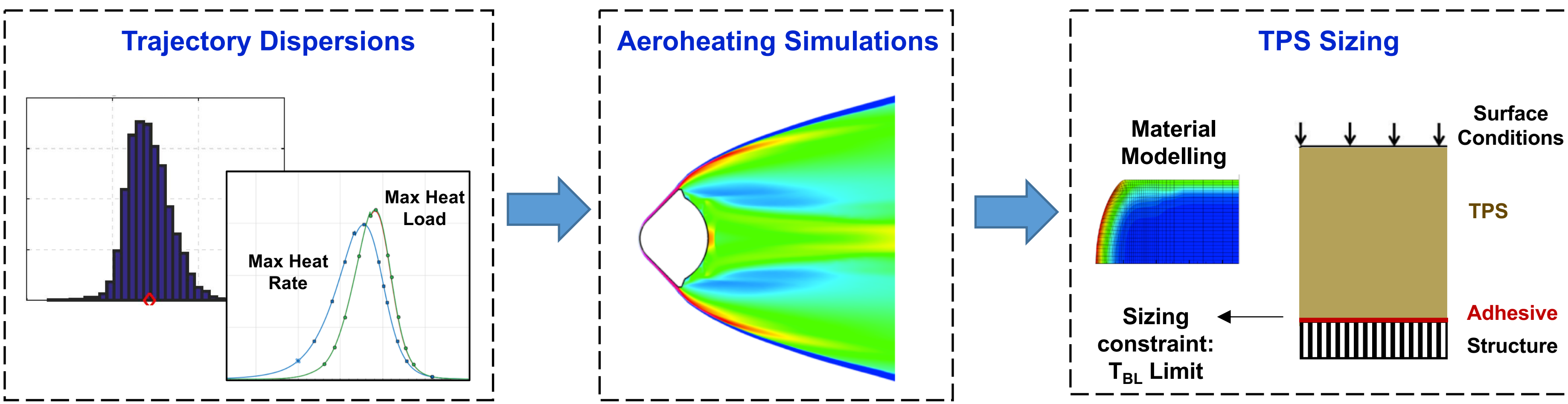
- Increased mass efficiency of dual-layer materials allows mission designers to select shallow entry trajectories
  - Integrate a top layer with good recession performance with a bottom layer with good insulation performance
- NASA is maturing a dual-layer 3D-woven TPS called **HEEET**
  - Top layer made of densely woven carbon fibers (**Recession Layer, RL**)
  - Bottom layer made of carbon and phenolic yarns (**Insulation Layer, IL**)
- Need to **develop a sizing process**
  - Project has developed and validated a one-dimensional thermal response model based on material property and arcjet testing
  - Adapt the conventional NASA ablator sizing process for application to dual-layer materials
- Weaving width limitation drives need for a tiled system
  - This talk focuses on **acreage material sizing**
  - Full sizing process has been developed and accounts for the gap filler thermal response uncertainties





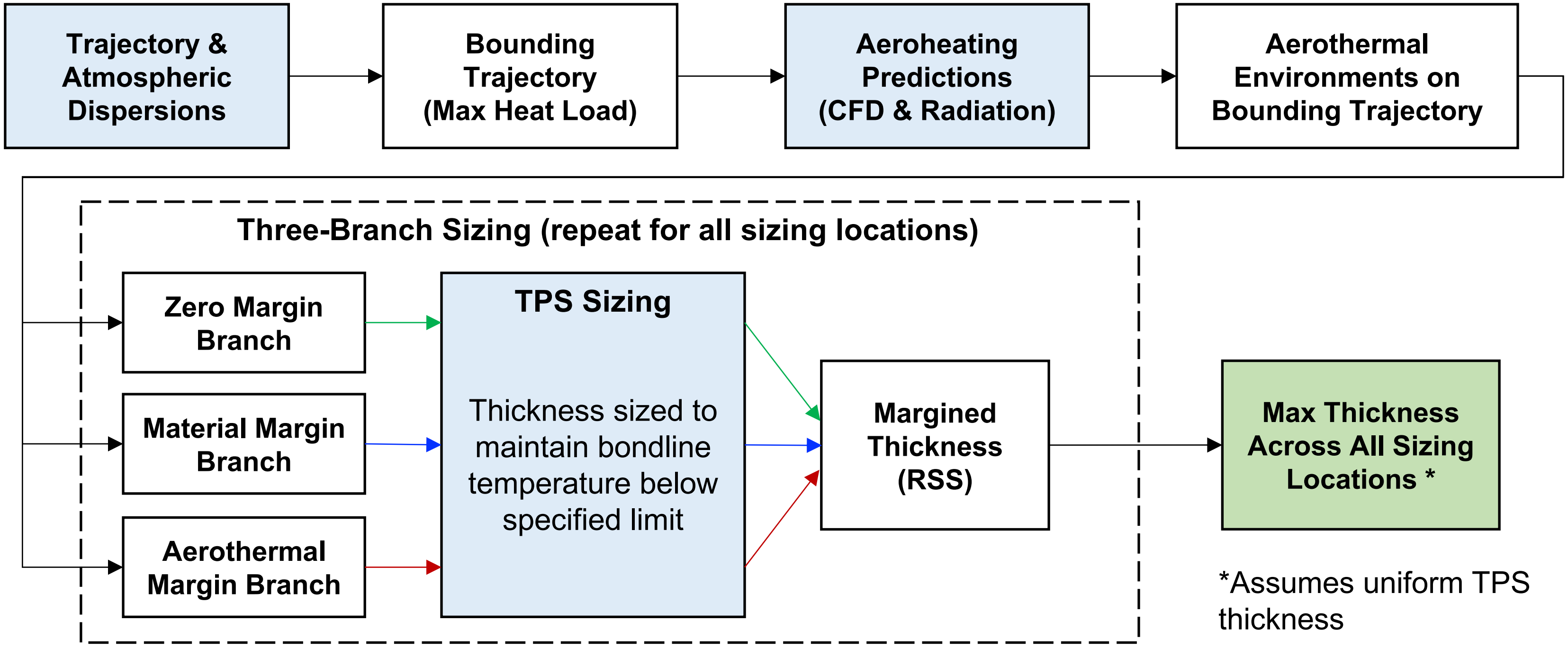
TPS Sizing and Modelling Uncertainties

- TPS thickness is sized to satisfy certain mission-dependent design constraints
  - Typically for single-layer materials, the constraint is a not-to-exceed bondline temperature driven by adhesive or structure temperature limits
- There are uncertainties associated with models used in TPS sizing process
  - Trajectory dispersions
  - Uncertainties in aerothermal environments (ground-to-flight traceability)
  - Uncertainties in thermal response modelling (properties, models, initial conditions)
- TPS sizing process must include margins that protect against uncertainties in modelling
  - Margins can be applied to initial conditions, boundary conditions, design constraints or sized thickness
  - Margins are selected based on testing, uncertainty propagation or engineering judgement



Conventional NASA Ablator Sizing Process

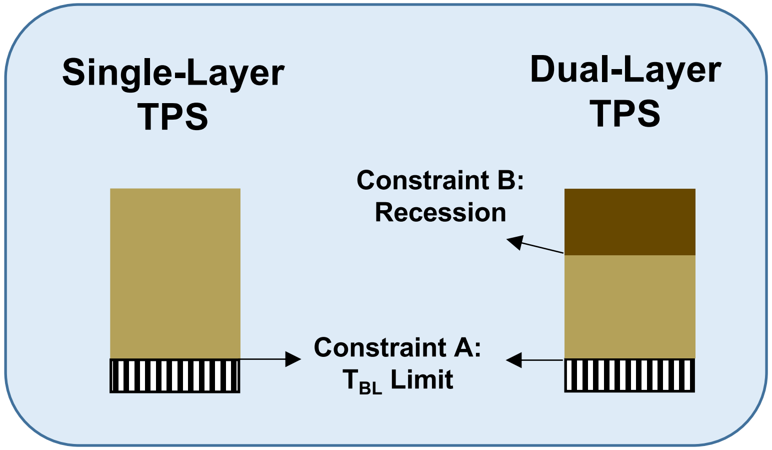
- Aerothermal environments are computed on the bounding trajectory (typically max heat load)
- At each sizing location, TPS thickness is sized along three branches and combined in a root-sum-square (RSS) process
  - Zero margin: apply nominal environments and size thickness to bondline temperature limit
  - Material margin: account for material modelling uncertainties (typically done by reducing bondline temperature by a margin informed through Monte Carlo analysis)
  - Aerothermal margin: account for uncertainty in aerothermal environments (multiplying factors)
- Other considerations: manufacturing tolerance, factor of safety, recession margin



*Assumes uniform TPS thickness

Dual-Layer Sizing Nuances

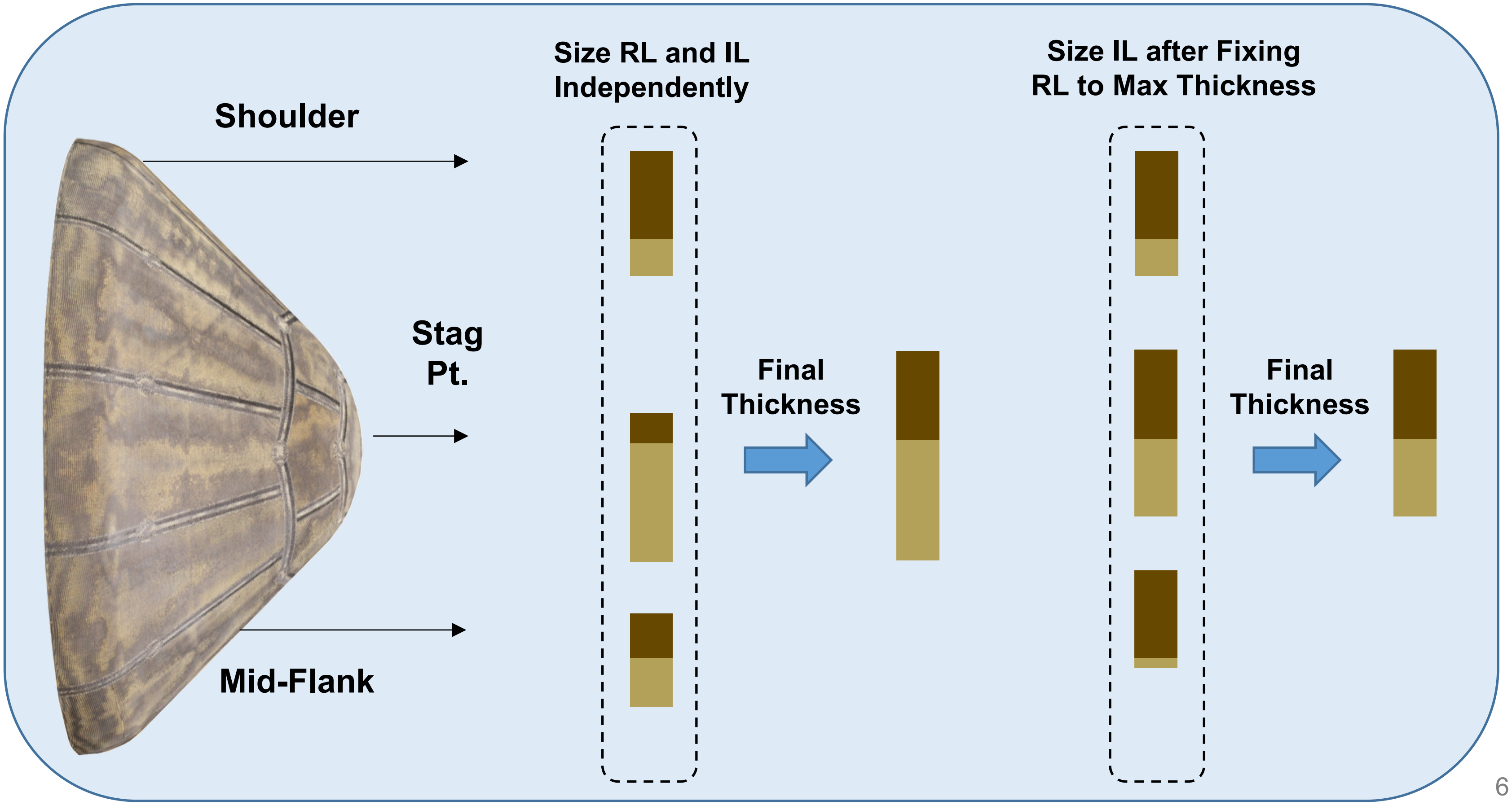
- New constraint at the interface between two layers
  - HEEEET insulation layer should not be exposed to flow
  - Arcjet testing scope limited to RL
- RL is sized to be equal to the predicted recession; IL is sized to bondline temperature limit
  - Material margin must be considered for both interfaces



- Current HEEET implementation requires uniform TPS thickness for both layers
  - Need to find max required thickness for each layer across all body points and trajectories
- Max thickness for each layer may occur at different body points and trajectories
  - Higher ablation leads to lower heat conduction into TPS

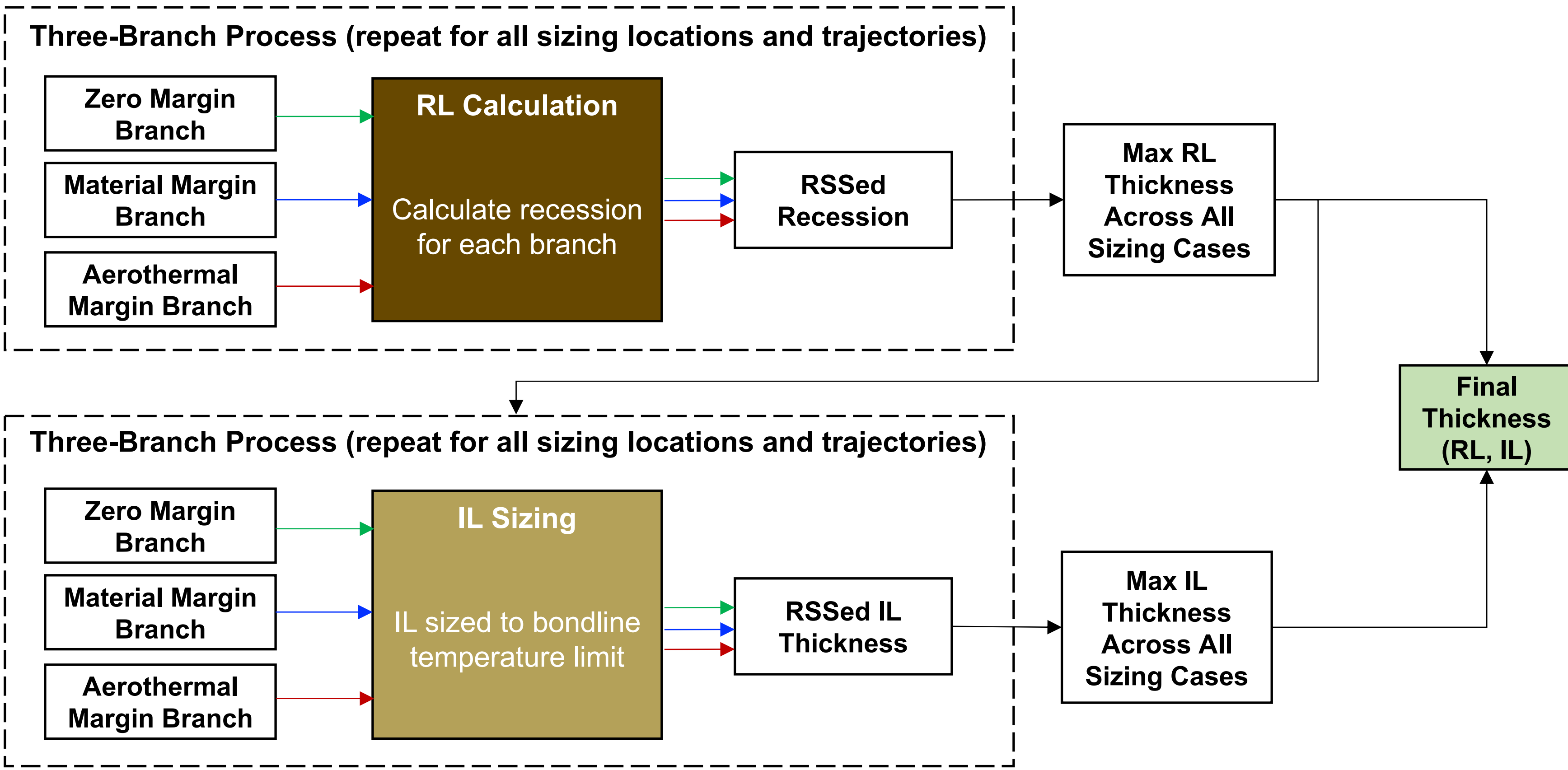
Dual-Layer Sizing Nuances

- Sizing RL and IL independently and then stacking max RL thickness from one location on max IL thickness from another location is not mass efficient
  - Excess RL at some locations can serve as insulation
- More mass efficient to size IL after fixing RL to max sized thickness across all locations



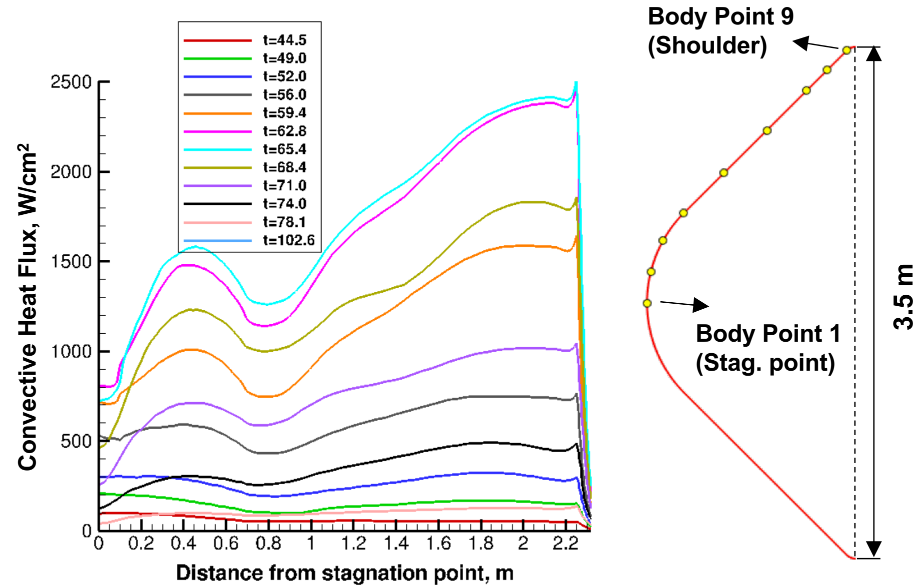
Dual-Layer Sizing Process

- Proposed sizing process takes advantage of the nonessential portion of RL thickness at locations that don't drive RL sizing
  - RL-alone calculation to determine recession for each sizing case; fix RL thickness to maximum RSSed recession across all cases (body points, bounding trajectories)
  - IL is sized for all sizing cases to bondline temperature limit using the fixed RL thickness; Final IL thickness is the maximum thickness across all cases

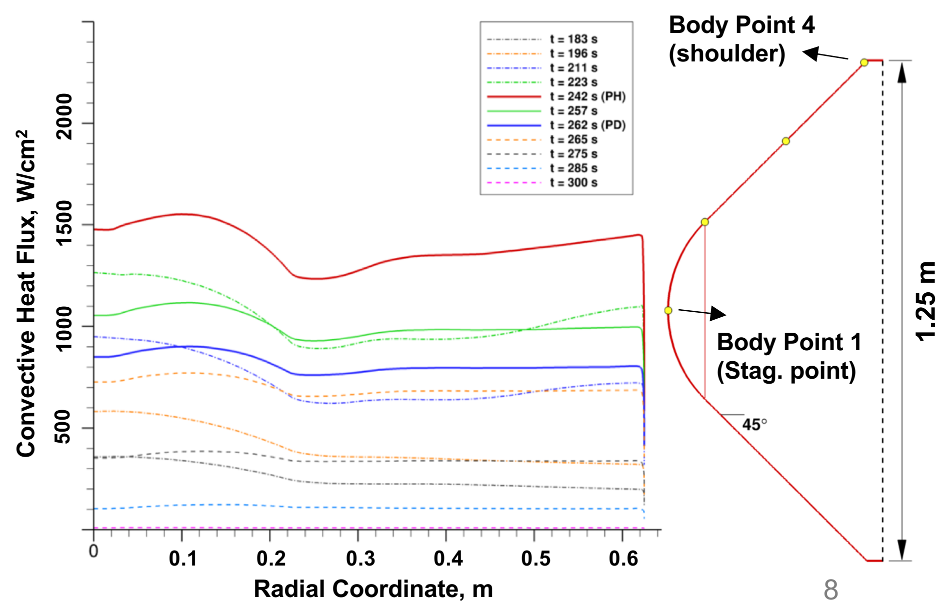


Reference Missions

- **Venus Lander**
  - 2010 NASA study VITaL (shallow)
  - 45-deg spherecone
  - D=3.5m, M_E= 2750kg
  - V_E= 11.3 km/s, γ_E= -9 deg
  - Aeroheating simulations by Grant Palmer
  - 9 sizing cases (9 body points, 1 trajectory)
  - **Highlights location impact on sizing**

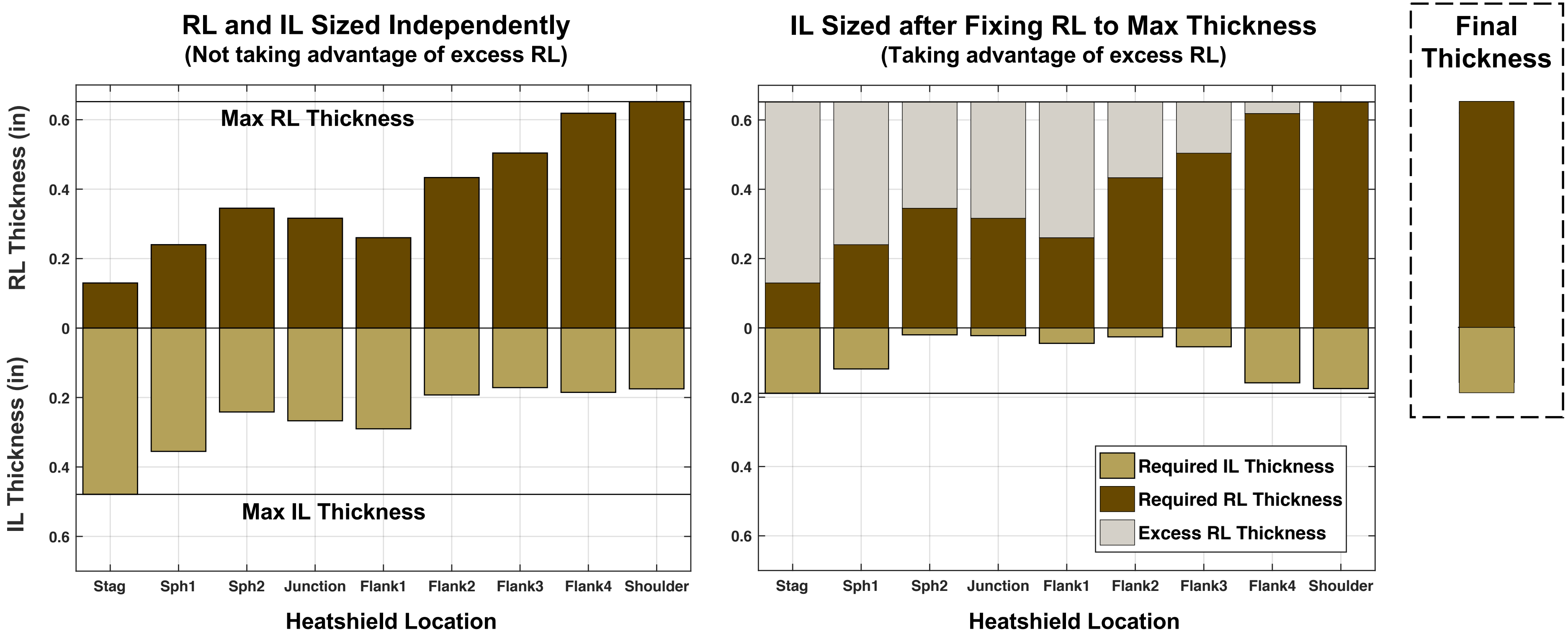


- **Saturn Probe**
  - NF-4 proposal (SPRITE), PI: Amy Simon (GSFC), managed by JPL
  - 45-deg Spherecone, 1.25m diameter, 447kg entry mass
  - V_E= 26.9 km/s, γ_E= -14 deg
  - Aeroheating simulations by Dinesh Prabhu
  - Total of 8 sizing cases (4 body points for max heat rate and load trajectories)
  - **Highlights trajectory impact on sizing**



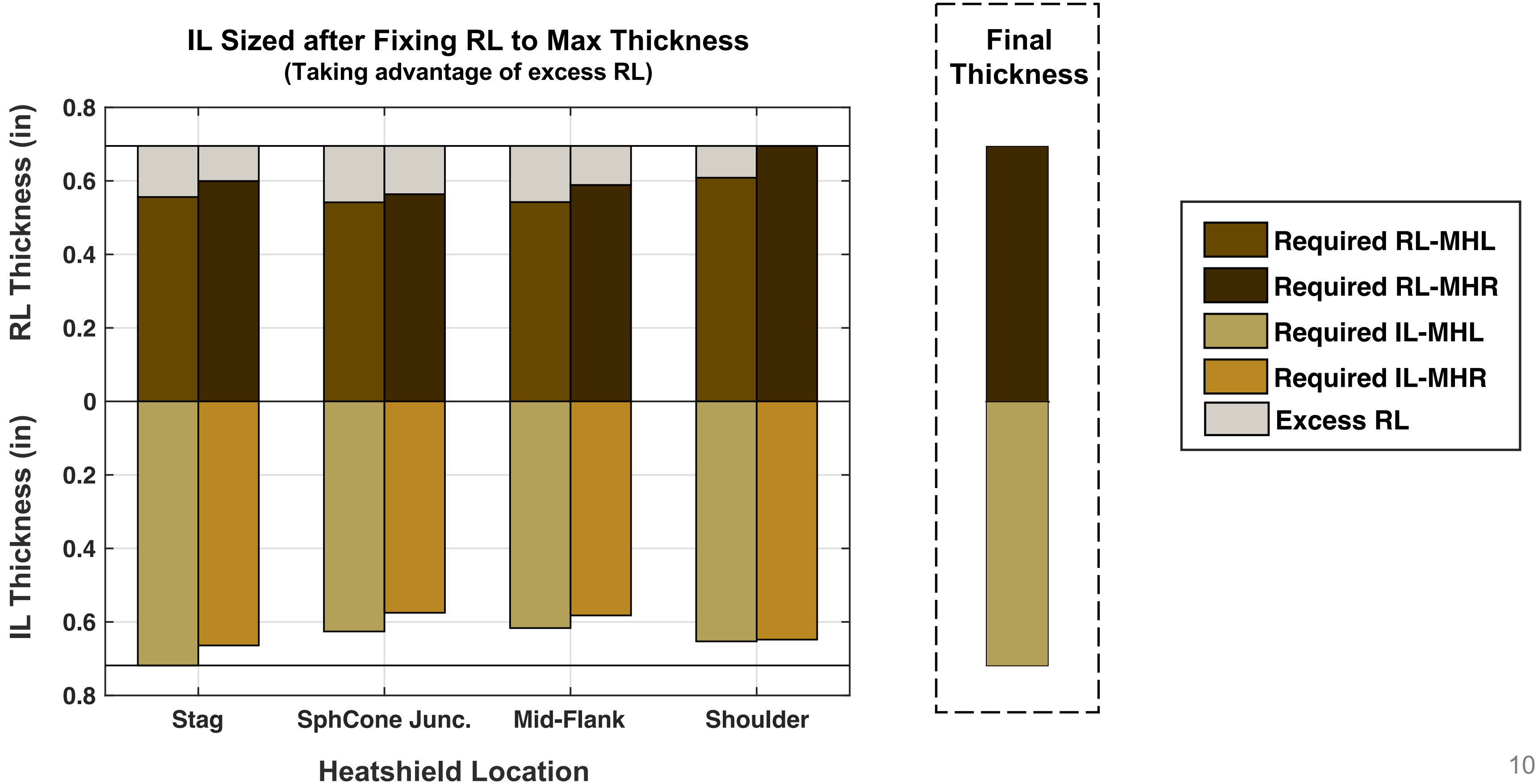
Sizing for Venus Reference Mission

- Sizing done at 9 locations on the heatshield
  - Figure on left: RL and IL sized independently
  - Figure on right: RL sized first; then IL sized while for fixed RL thickness
- Taking advantage of the nonessential portion of RL thickness at locations that don't drive RL sizing provides mass benefits
  - 62% reduction in IL thickness, 19% reduction in areal mass



Sizing for Saturn Reference Mission

- Sizing done at four locations on the heatshield and for two bounding trajectories, Max Heat Rate **(MHR)** and Max Heat Load **(MHL)**
- Maximum RL thickness occurs at shoulder for max heat rate trajectory
- Maximum IL thickness occurs at stagnation point for max heat load trajectory
- Independent RL and IL sizing would have resulted in 21% increase in IL thickness and 9% increase in areal mass

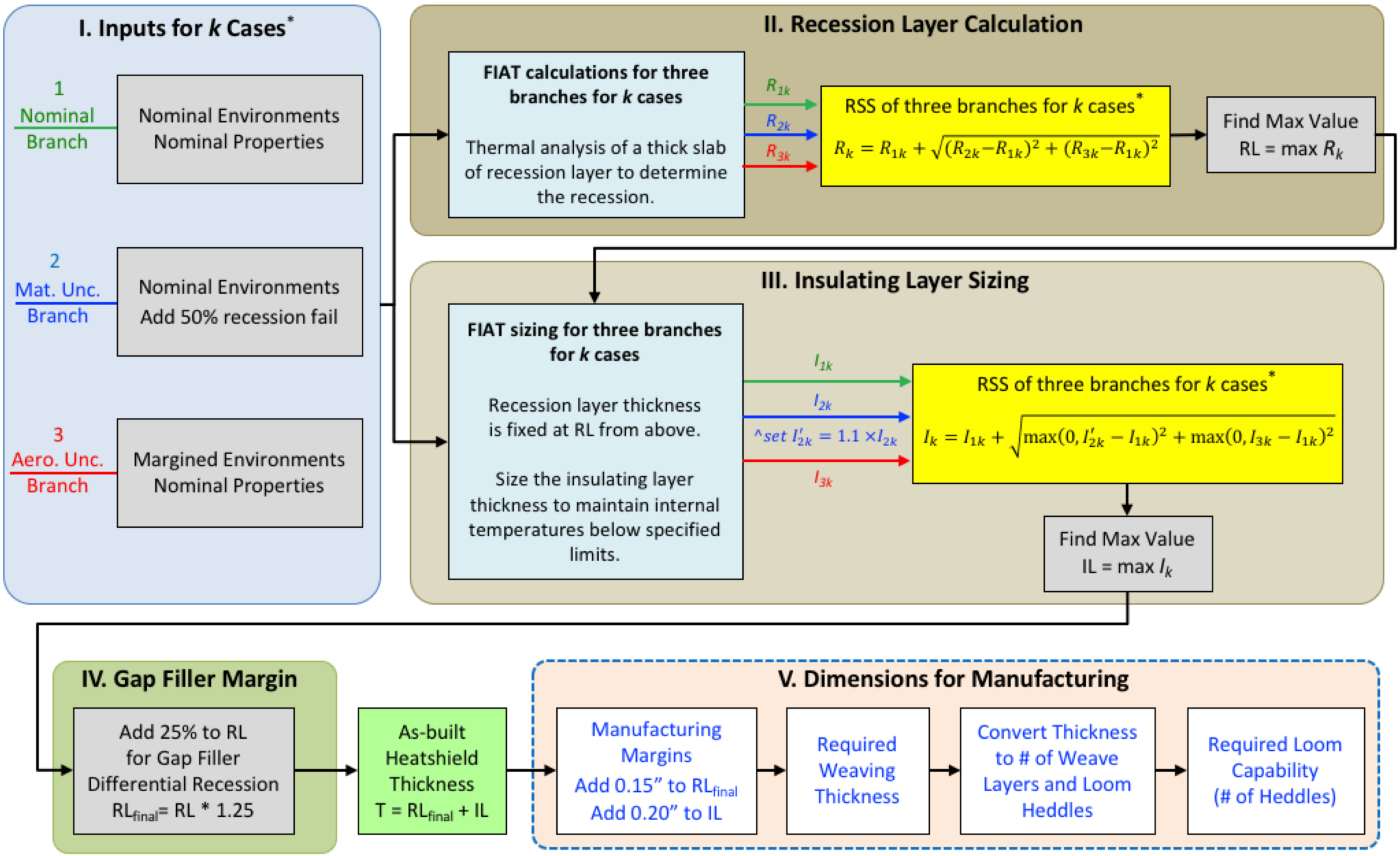


Summary and Conclusions

- Sizing based on only stagnation point environments in early mission phases may not bound required thickness
  - Both for single-layer and dual-layer materials
  - The size of impact is likely larger for dual-layer materials if each layer has to be constant thickness across the heatshield
  - In applications where off-stagnation environments are suspected to be higher, utilizing CFD simulations early in the design is highly recommended
- Proposed sizing methodology takes advantage of the insulation properties of the excess recession layer at locations that don't drive RL thickness
- Allowing the insulation layer to be exposed to flow will provide more flexibility in TPS sizing and design
  - Requires arcjet testing of insulation layer to establish its max capability
  - Sizing process needs to be modified for a different interface constraint (ex. limit on combined aerothermal environment experienced by insulation layer)
- Allowing varying TPS thickness across the heatshield will offer mass benefits
  - Manufacturing challenges should not be underestimated

Backup

Complete HEEET Sizing Process (Including Gap Filler and Manufacturing Considerations)



* Each case represents a single location on the heatshield for a single trajectory. To capture the maximum required thickness for each layer, calculations are performed for bounding trajectories and at multiple locations on the heatshield.

^ Factor of 1.1 is inserted on branch 2 in lieu of a bond line margin.

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