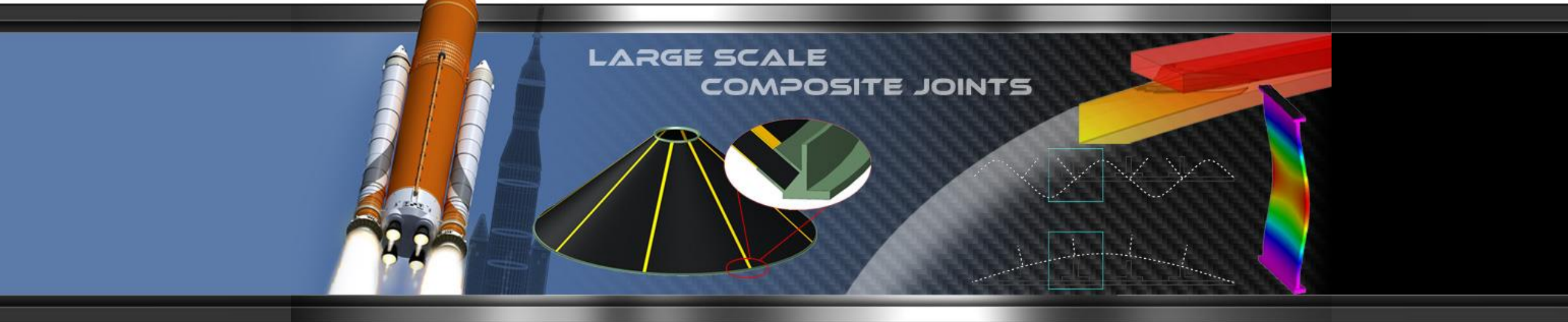




## **COMPOSITE TECHNOLOGY for EXPLORATION**



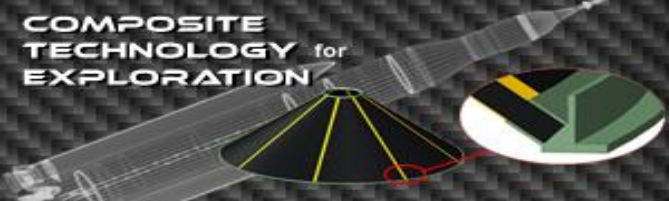
# **Finite element based design tool for the CTE longitudinal lap joint**

Andrew Bergan

*Durability, Damage Tolerance, and Reliability Branch*

Seventh NASA Structures, Loads and Dynamics, and Mechanical Systems (SLaMS) Early Career Forum (ECF)

NASA Goddard Space Flight Center, August 21-24, 2018

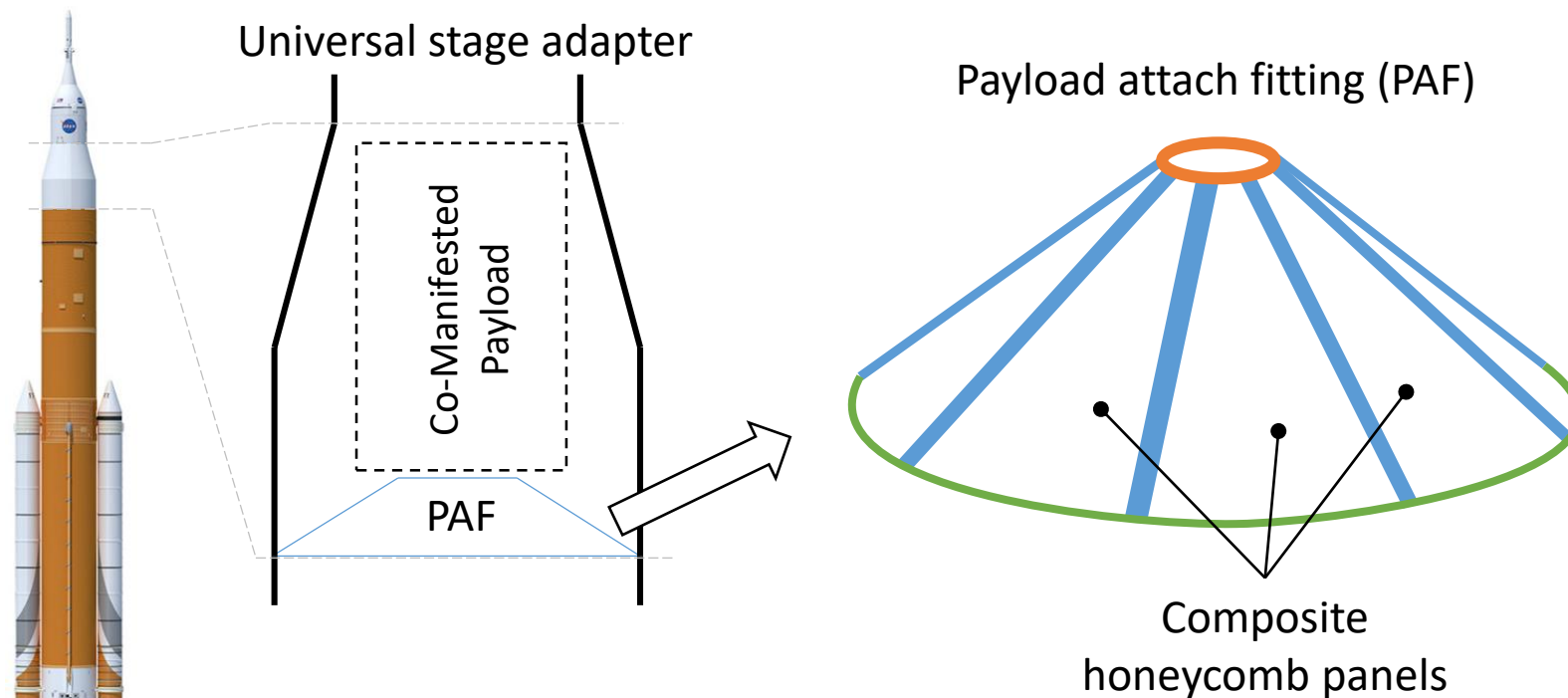


# Composite Technology for Exploration (CTE) Project



- Objectives

- Demonstrate weight-saving, performance-enhancing bonded joint technology for Space Launch System (SLS)-scale composite hardware
- Advance the state of the art in the detailed analyses of composite bonded joints and the interactions of their stress-strain fields with local design features

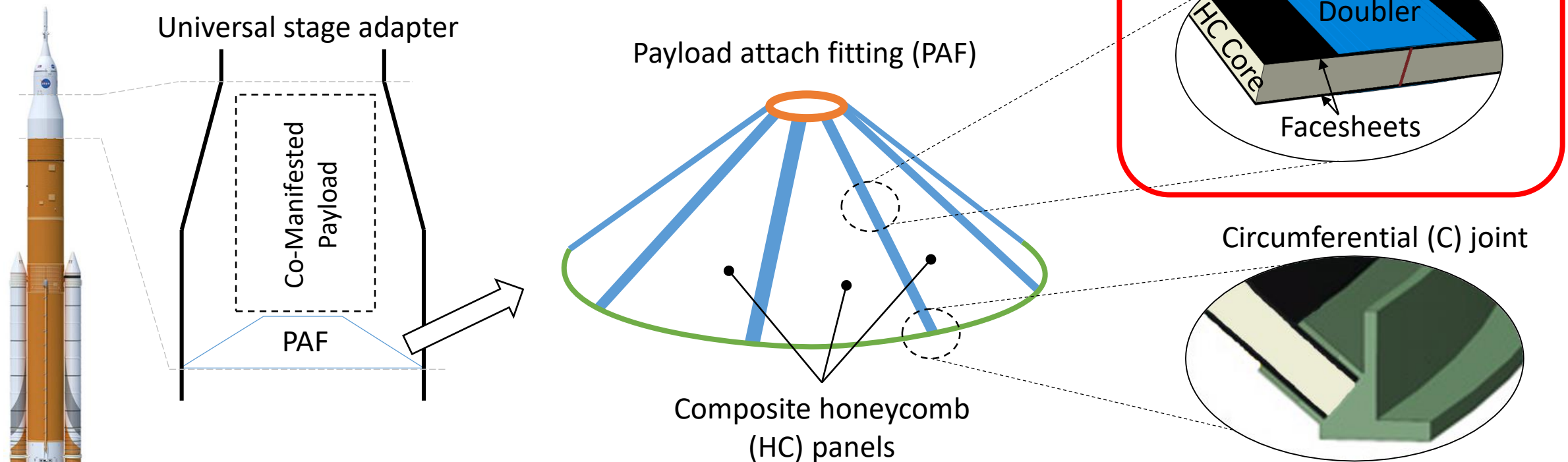


# Composite Technology for Exploration (CTE) Project

- Objectives

- Demonstrate weight-saving, performance-enhancing bonded joint technology for Space Launch System (SLS)-scale composite hardware
- Advance the state of the art in the detailed analyses of composite bonded joints and the interactions of their stress-strain fields with local design features

- Focus on 2 types of joints: Longitudinal and Circumferential





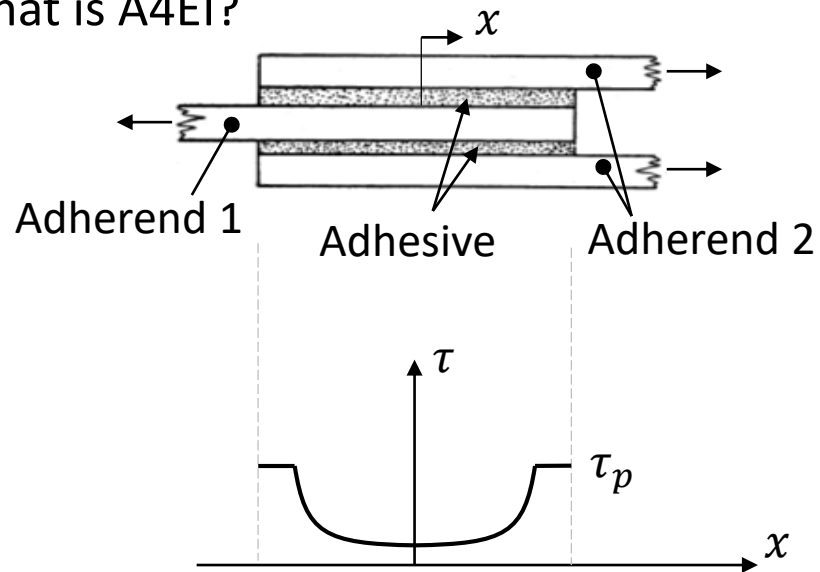
# Outline



- Industry standard design tool: A4EI
- Alternative approaches
- Parametric finite element model for CTE L-Joint
  - Objectives
  - Model features
- Comparison of analysis tools
- Concluding remarks

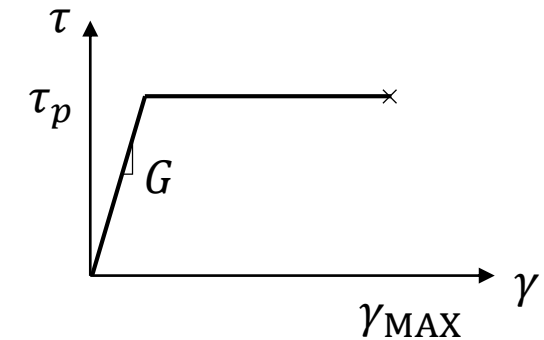
# Industry Standard Approach to Sizing Bonded Joints: A4EI

## • What is A4EI?



$$\frac{d^2\gamma}{dx^2} - \frac{\tau}{t_a} \left( \frac{1}{E_2 t_2} + \frac{2}{E_1 t_1} \right) = 0$$

$$\tau = \tau(x)$$



## • How is A4EI used?

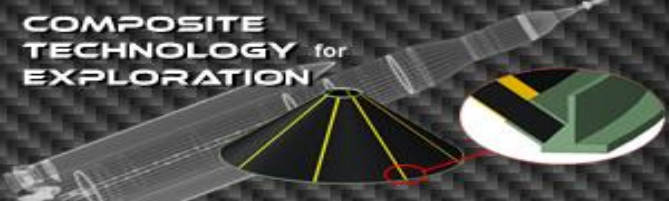
- Margins calculated at a characteristic distance
- Peel stress is often ignored (against recommendation from Hart-Smith)

### Advantages

Simple  
Fast  
Proven/trusted

### Limitations

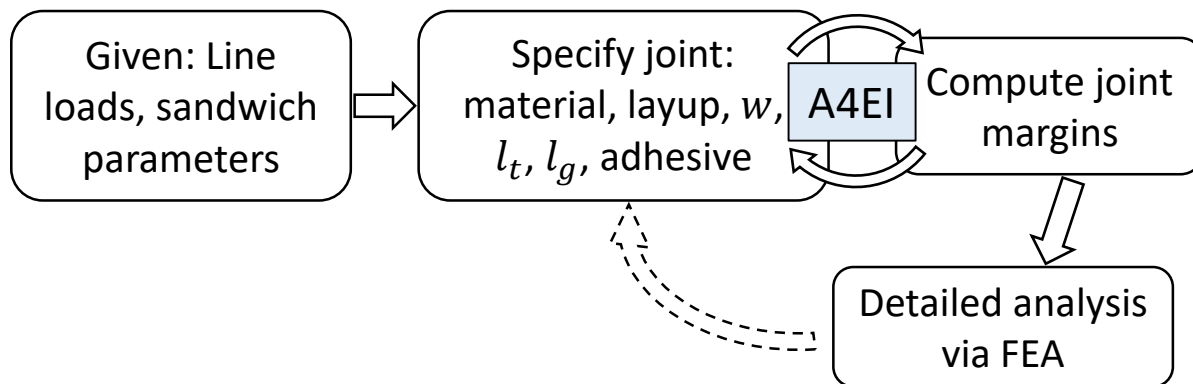
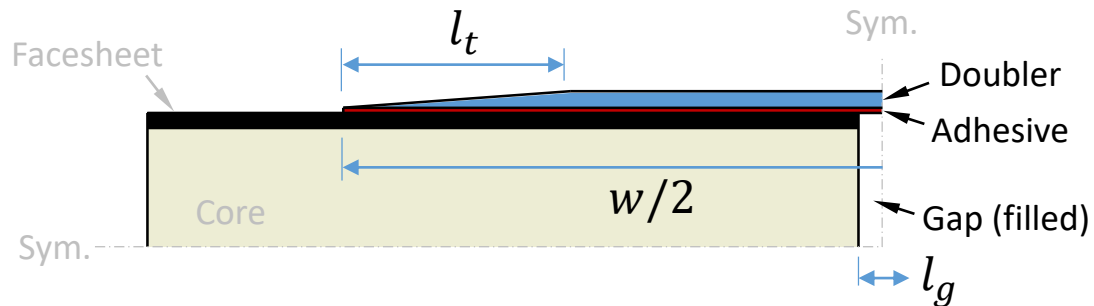
Does not consider peel stress  
Requires characteristic distance  
Does consider loading along joint axis  
Core modeled as a 'ply' using CLT



# CTE's Experience Using A4EI Highlighted Several Limitations



## Design process



## Outcomes

Three iterations to design

1. A4EI --> 8 ply doubler:  $w = X, l_t = Z$
  2. FEA → 6 ply (+ margins with FS = )
  3. FEA → 4 ply (+ margin with FS = )
- A4EI would not converge for 4 ply case!

Not addressed in preliminary structural analysis

- Adherend delamination
  - Design without adhesive
- } Detailed analysis

Not address in structural analysis

- Panel gap  $l_g$ , filler material (mfg)
- Ply drop off sequence (heuristics, mfg)

## Conclusions

- **SUCCESS:** Initial estimate for joint size
- **LIMITATION:** Inability to evaluate **combined loads** and **full-field stresses** produced overly conservative design



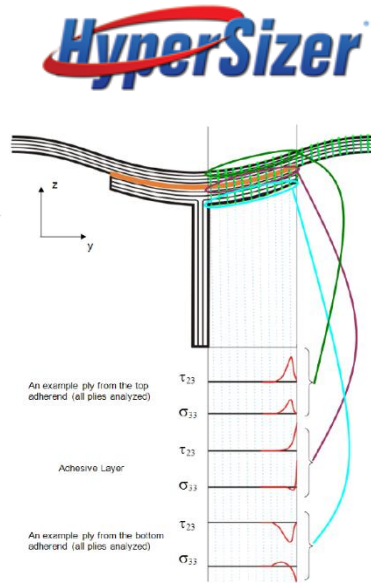
# Outline



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# Alternatives to A4EI

## Hypersizer BondJo



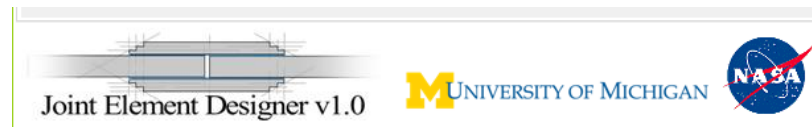
### Advantages:

- Full field stresses
- Many options for loading

### Limitations:

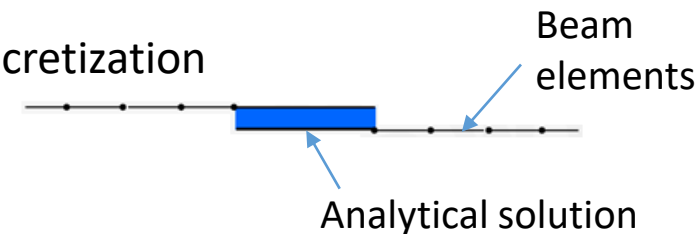
- No consideration for sandwich
- Sizing iterations are manual

## Joint Element Designer (JED)



### Idealization

### Discretization



### Advantages:

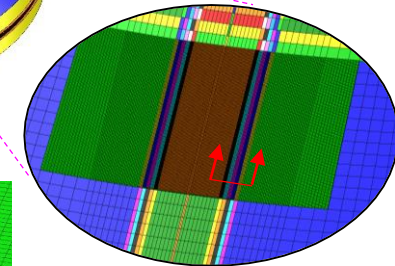
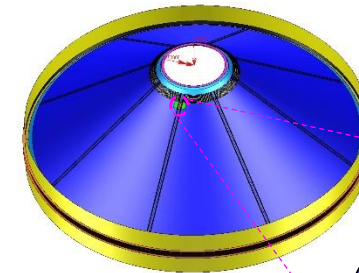
- Special 'adhesive' elements for adhesive and sandwich
- Geometric nonlinearity

### Limitations:

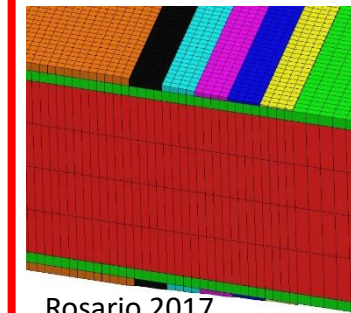
- 2-D
- Sizing iterations are manual

## Finite element (FE)

### Global



### Local



Rosario 2017

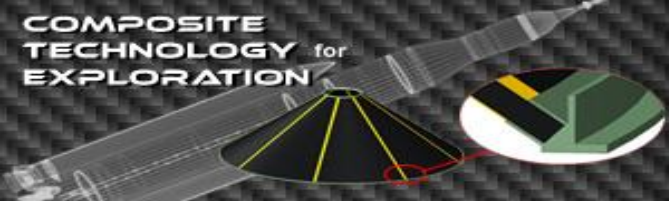
### Advantages:

- Tailored to specific configuration

### Limitations:

- Time consuming
- Highly refined mesh required

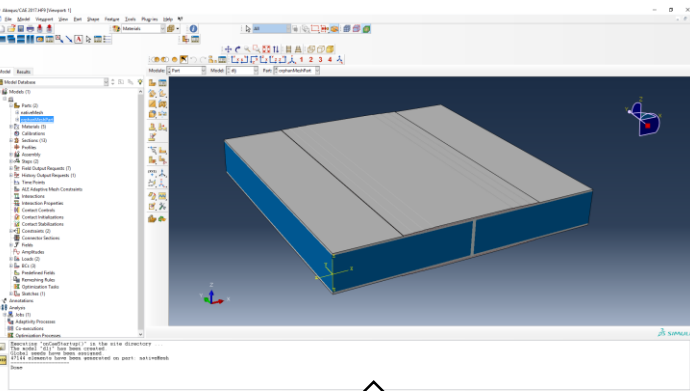
***CTE is working with developers of these tools to address limitations!***



# Parametric Finite Element Modeling as a Design Tool



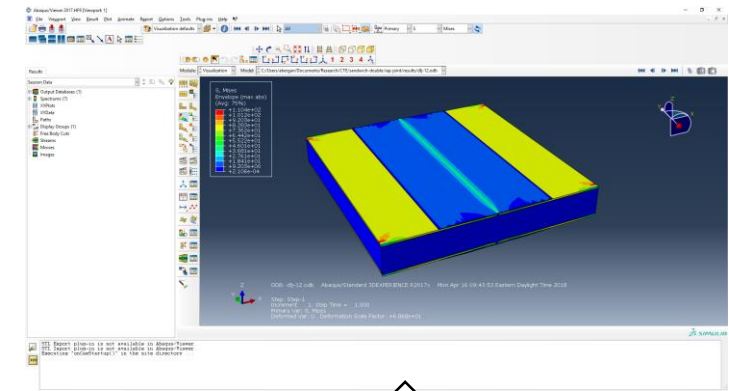
## Pre-processor



## Solver



## Post-processor



*Iterate/Optimize*



## Benefits:

- Flexibility of finite element modeling
- Save analyst time building & processing similar models
- Enables more opportunities to iterate

## Limitations:

- Initial time to build scripts > time to build model
- Need to establish structural configurations up front

***Goal: Develop a parametric model of the CTE L-Joint for design***



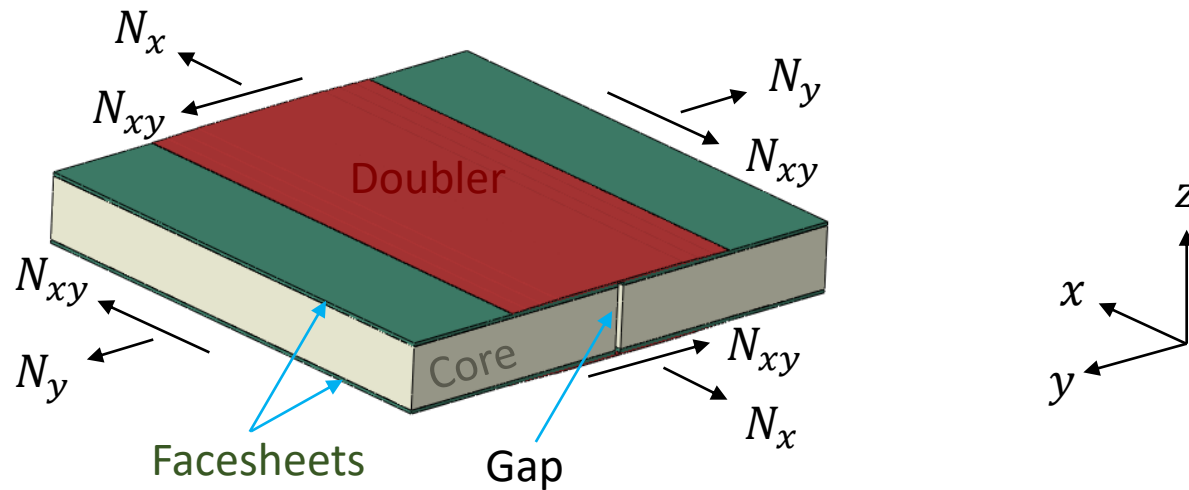
# Outline

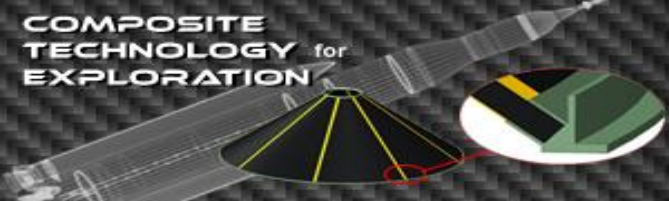


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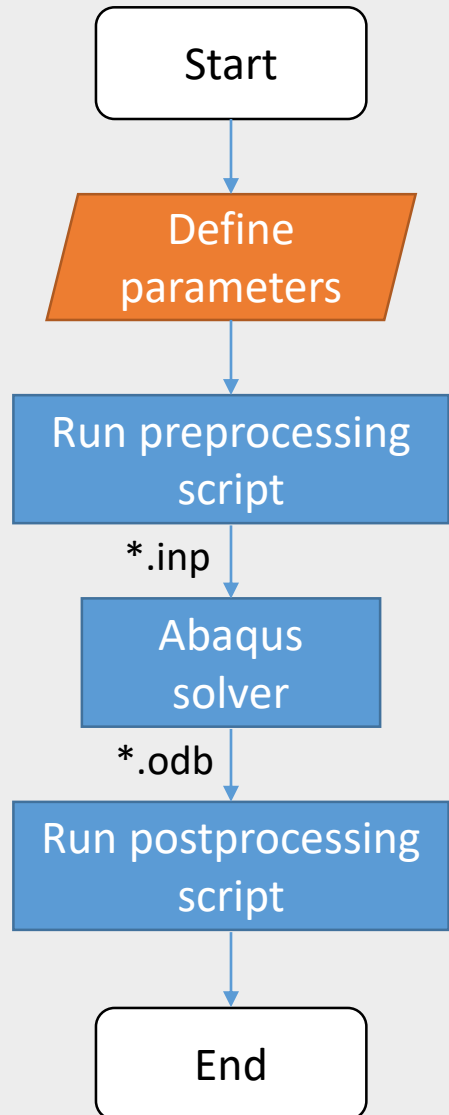
## Objective: Parametric FEA design tool to size double lap joints

- Focus on key doubler sizing parameters (material, layup,  $w$ ,  $l_t$ ,  $l_g$ , adhesive)
- Consider any combination of in-plane line loads ( $N_x$ ,  $N_y$ ,  $N_{xy}$ )
- Include 3-D stress state in core, facesheets, and doublers
- Consider design features not typically included in preliminary design: ply drop off sequence, adherend delamination, and panel gap filler



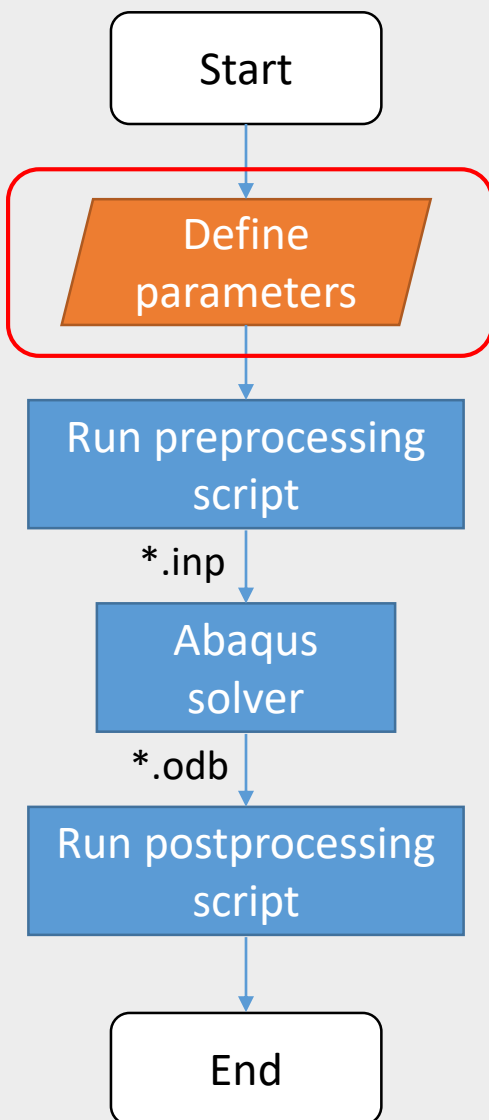
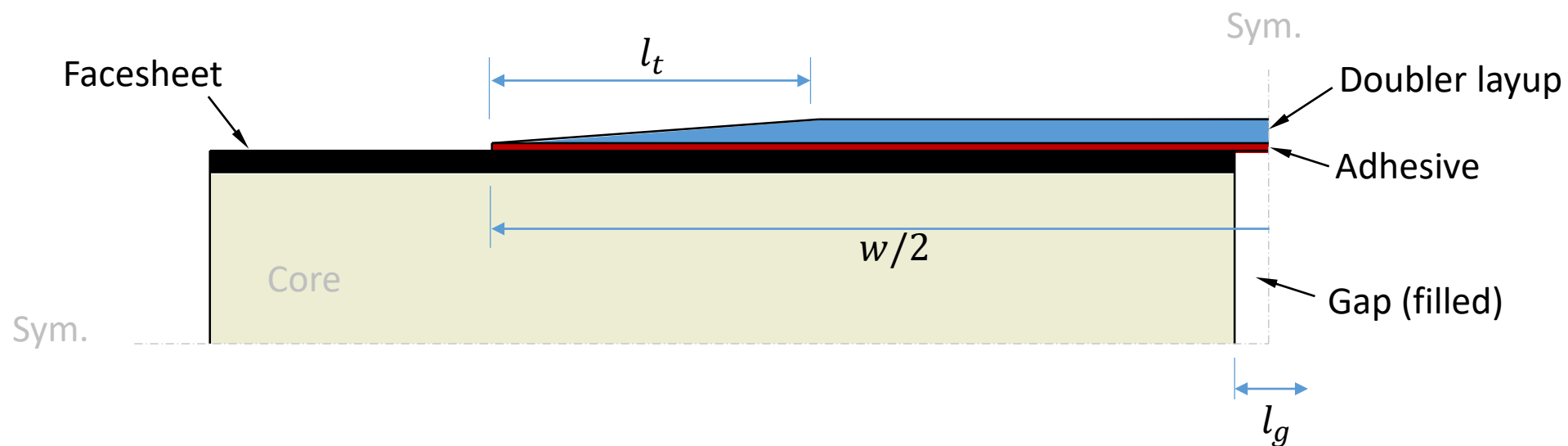


# Parametric Model for CTE L-Joint

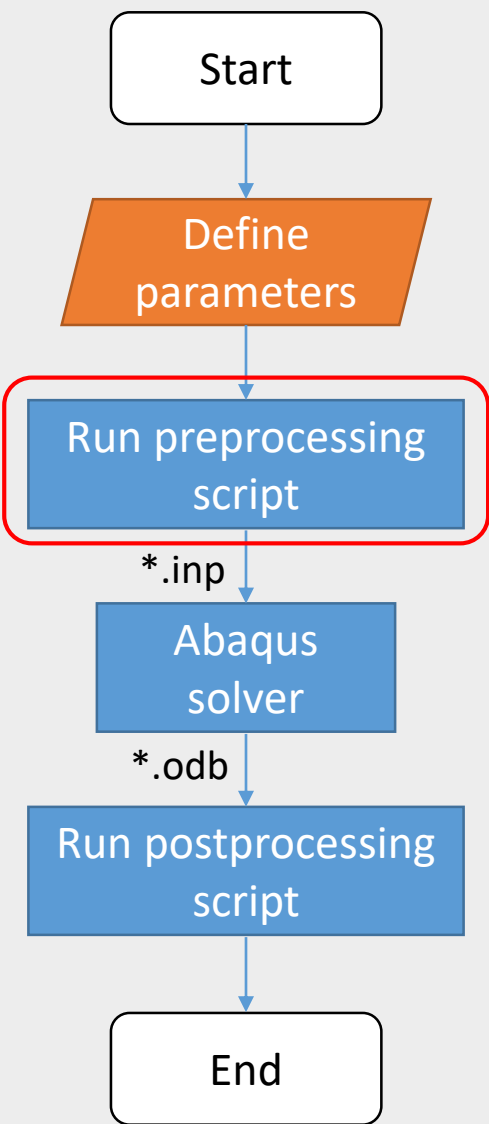


# Parametric Model for CTE L-Joint

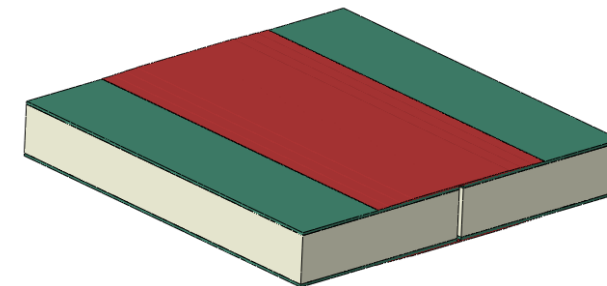
- 32 parameters that can be defined
  - Dimensions
  - Mesh size, local refinement
  - Loads
  - Material properties
- Key parameters for doubler:
  - $l_t$
  - $w/2$
  - $l_g$



# Parametric Model for CTE L-Joint



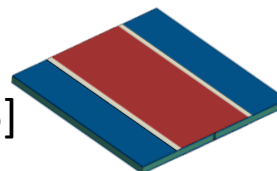
1. Generate mesh
2. Define and assign materials
3. Define loads and boundary conditions



Examples:

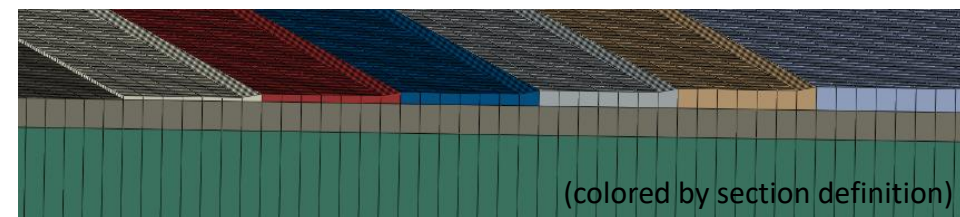
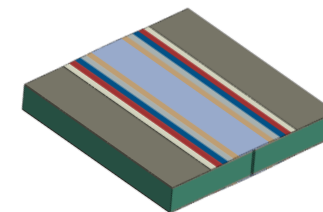
Case 1:

- Doubler layup: [45/-45]
- Core thickness 0.25 in



Case 2:

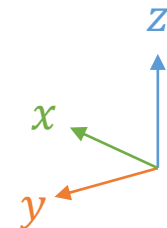
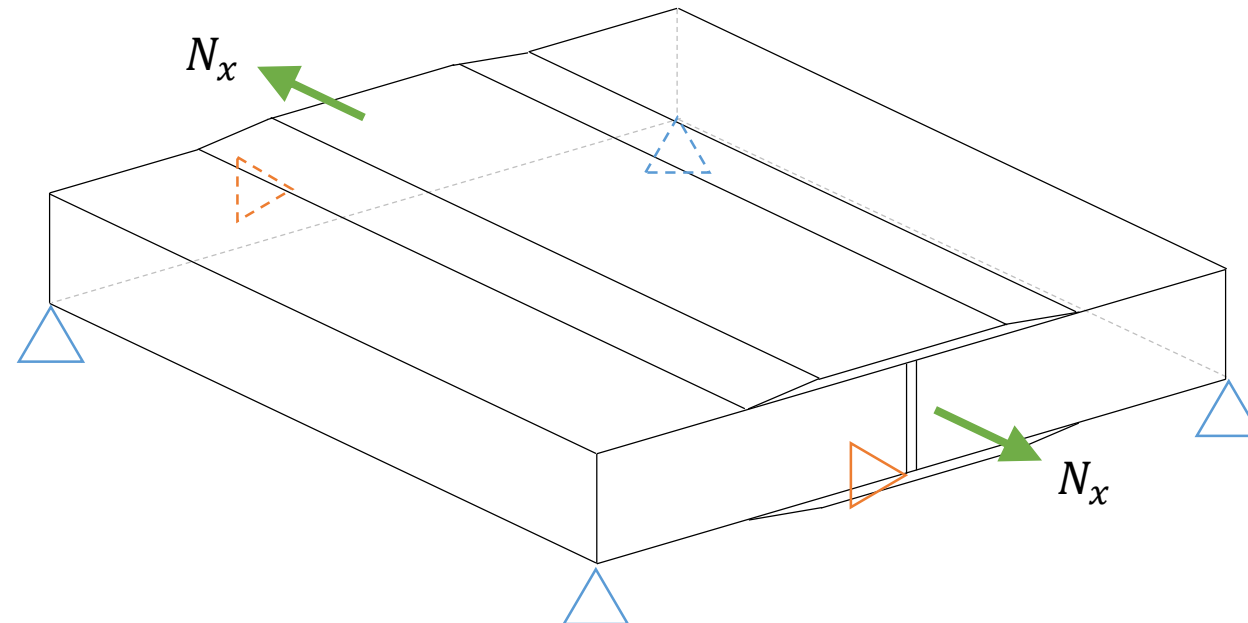
- Doubler layup: [45/-45]<sub>3</sub>
- Core thickness: 1.0 in



| <u>Region</u>       | <u>Element</u> | <u>Elements through-thickness</u> |
|---------------------|----------------|-----------------------------------|
| Core                | C3D8           | ≥4                                |
| Facesheets/Doublers | CSS8           | 1                                 |
| Adhesive            | C3D8           | 1                                 |

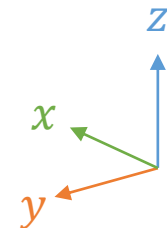
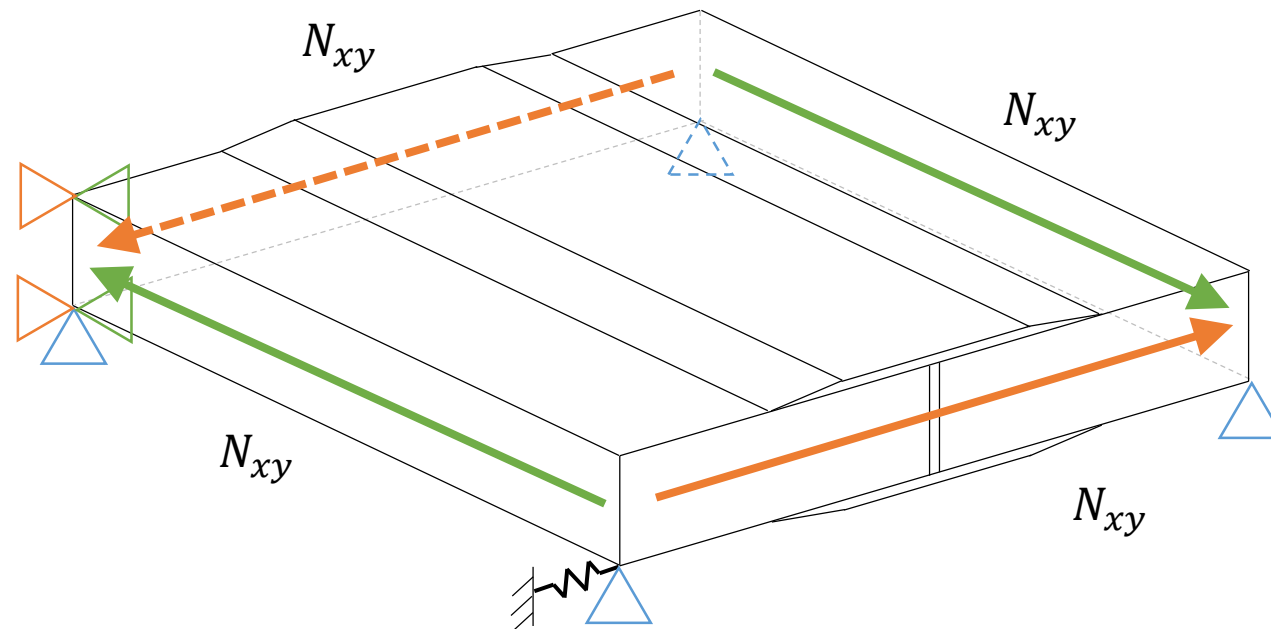
# Parametric Model for CTE L-Joint

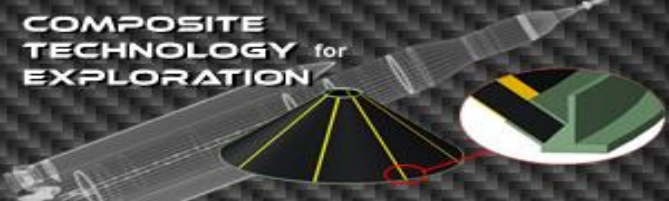
1. Generate mesh
2. Define and assign materials
3. Define loads and boundary conditions
  - Concentrated force + constraint
  - $N_x$ ,  $N_y$ ,  $N_{xy}$ , or any combination



# Parametric Model for CTE L-Joint

1. Generate mesh
2. Define and assign materials
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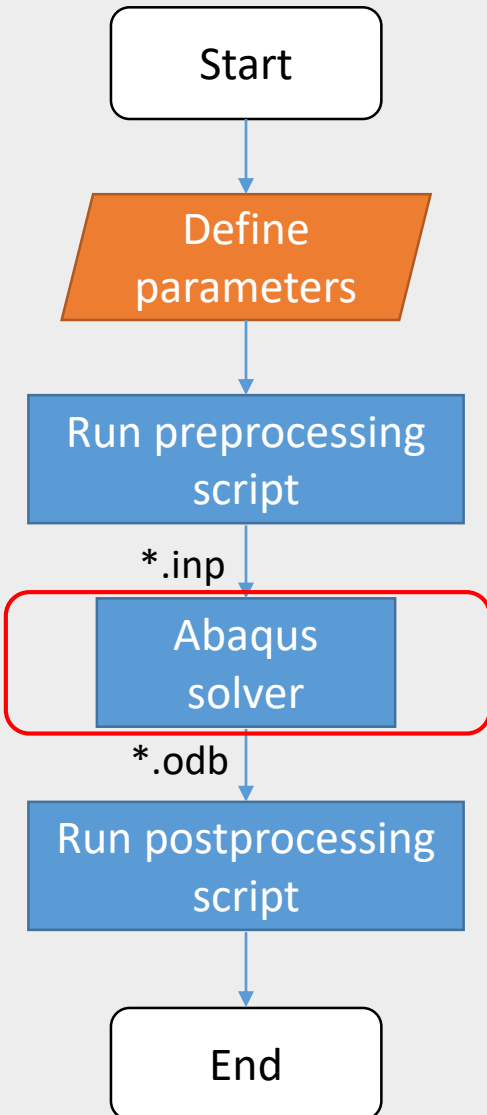




# Parametric Model for CTE L-Joint

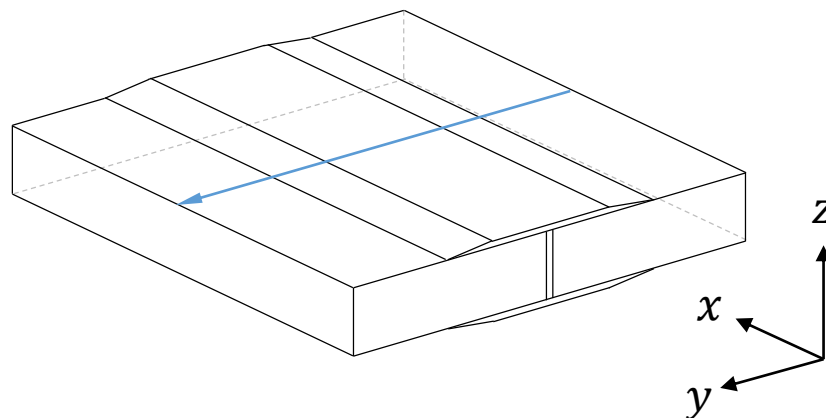
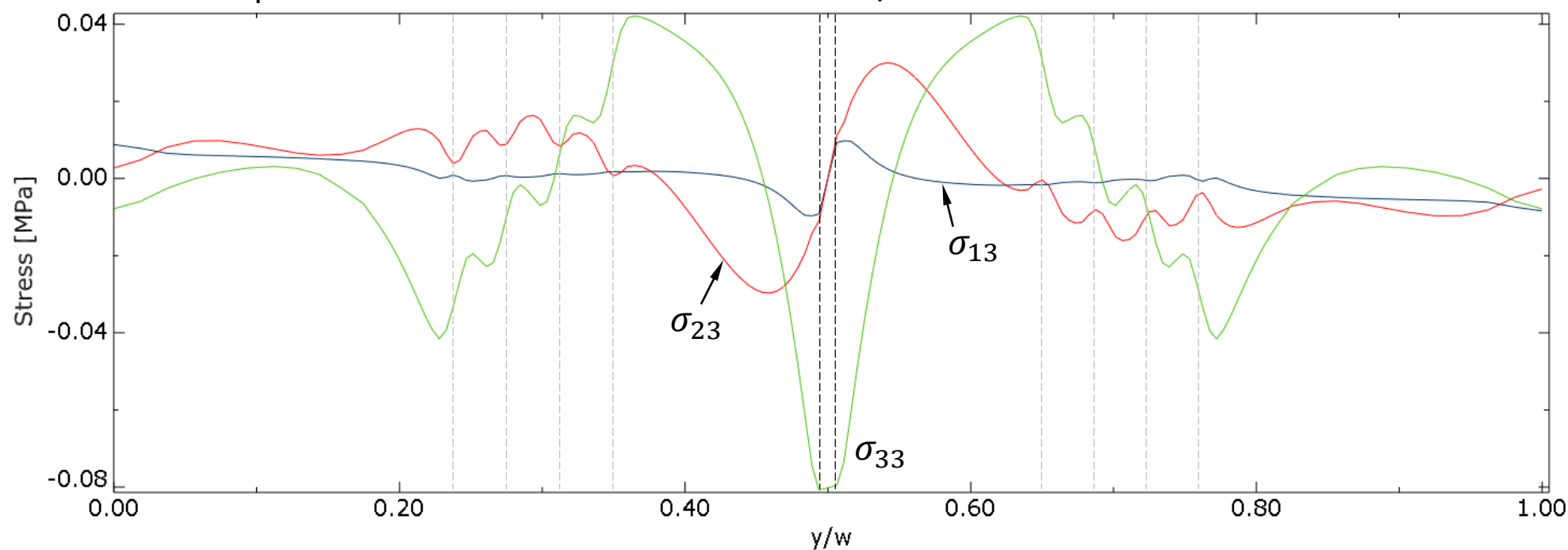


- Static step
- Linear analysis\*
- Abaqus 2017
- Typical run time: ~5 minutes



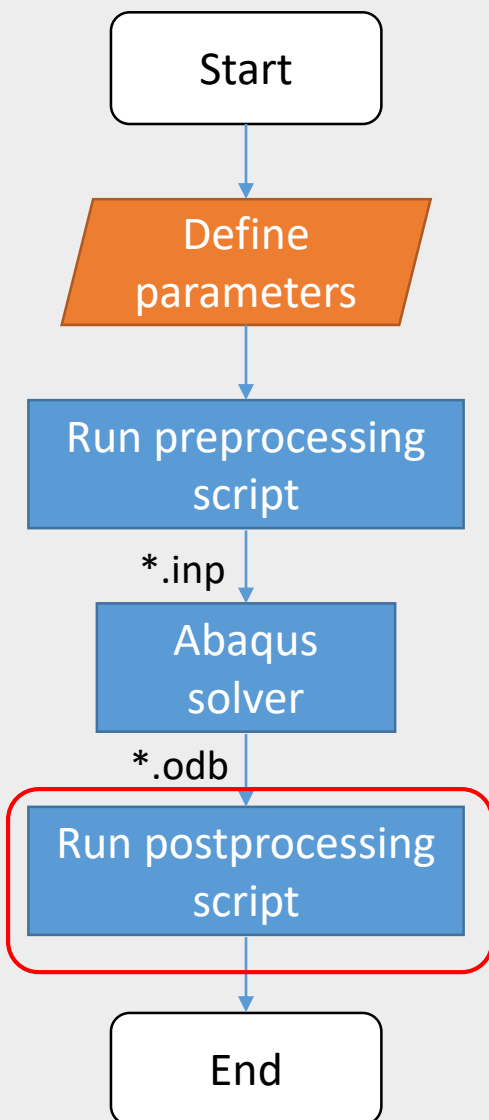
# Parametric Model for CTE L-Joint

Example result: stress in the core at facesheet/core interface



For each ply, core, and adhesive:

- Stress extracted
- Margins calculated

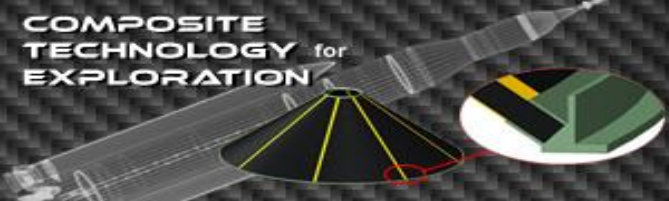




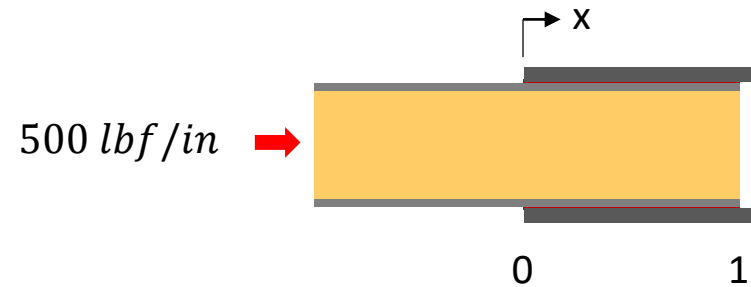
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# Comparison of Analysis Methods



IM7/8552-1

Top Facesheet:  $(-45/0/45/90)_s$   
 $t_{ply} = 0.0072$  in

T650/5320-1

Top Doubler:  $(0/90/0/90)$   
 $t_{ply} = 0.0077$  in

Materials

IM7/8552-1

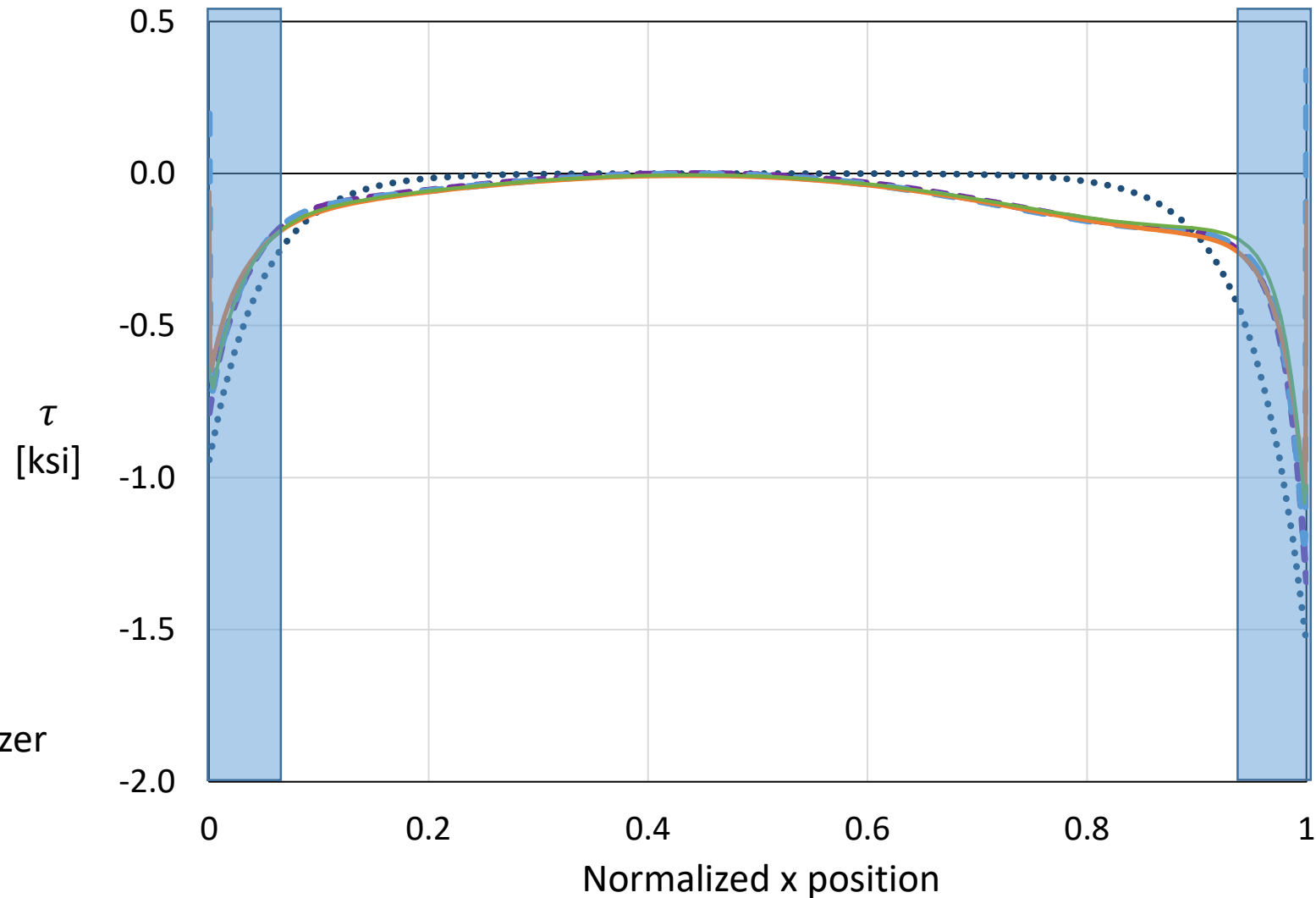
T650/5320-1

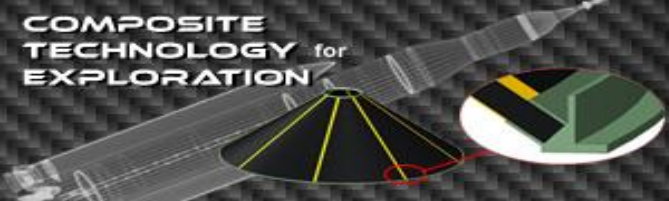
Plascore 3/16" 3.1 pcf

Film Adhesive

..... A4EI  
 - - - JED  
 - - - Hypersizer  
 — HFFE  
 — LFFE

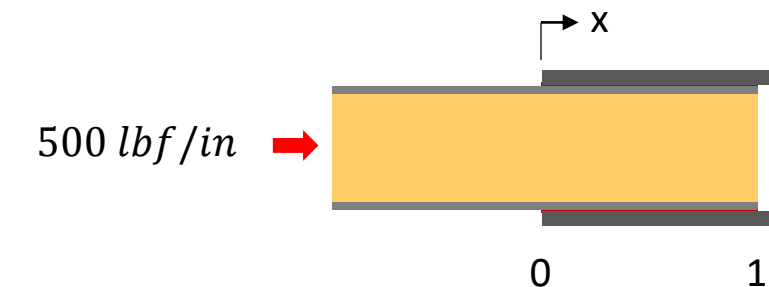
Shear stress in the adhesive layer





# Comparison of Analysis Methods

Shear stress in the adhesive layer



IM7/8552-1

Top Facesheet:  $(-45/0/45/90)_s$

$t_{ply}=0.0072$  in

T650/5320-1

Top Doubler:  $(0/90/0/90)$

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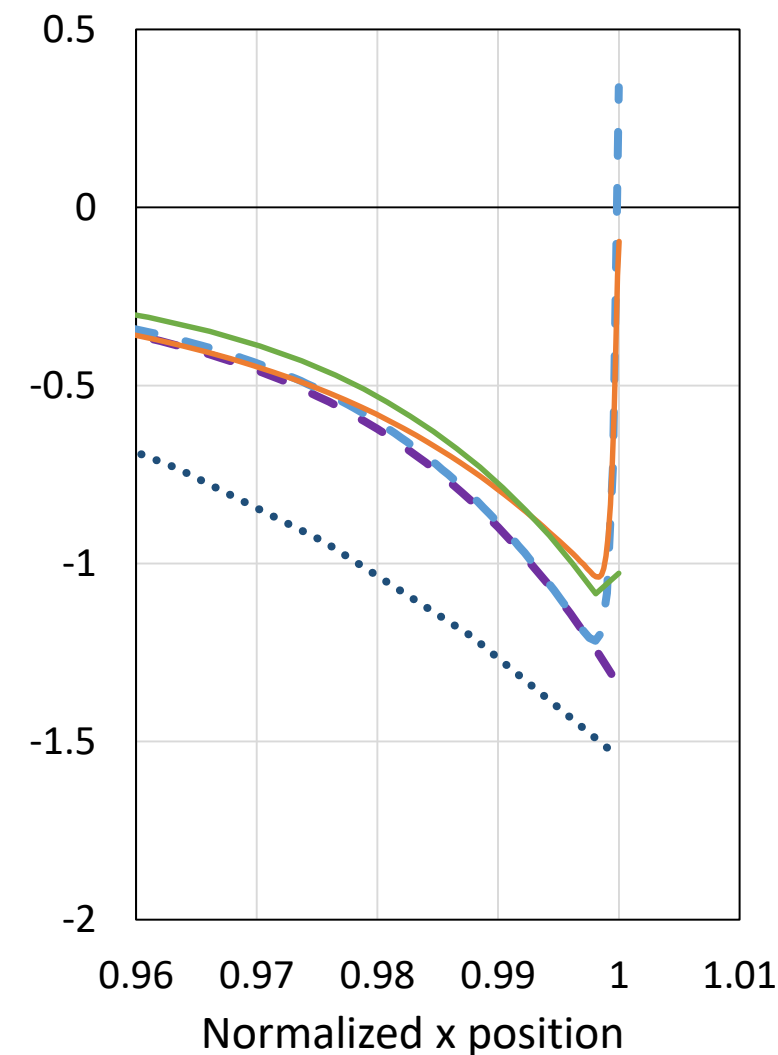
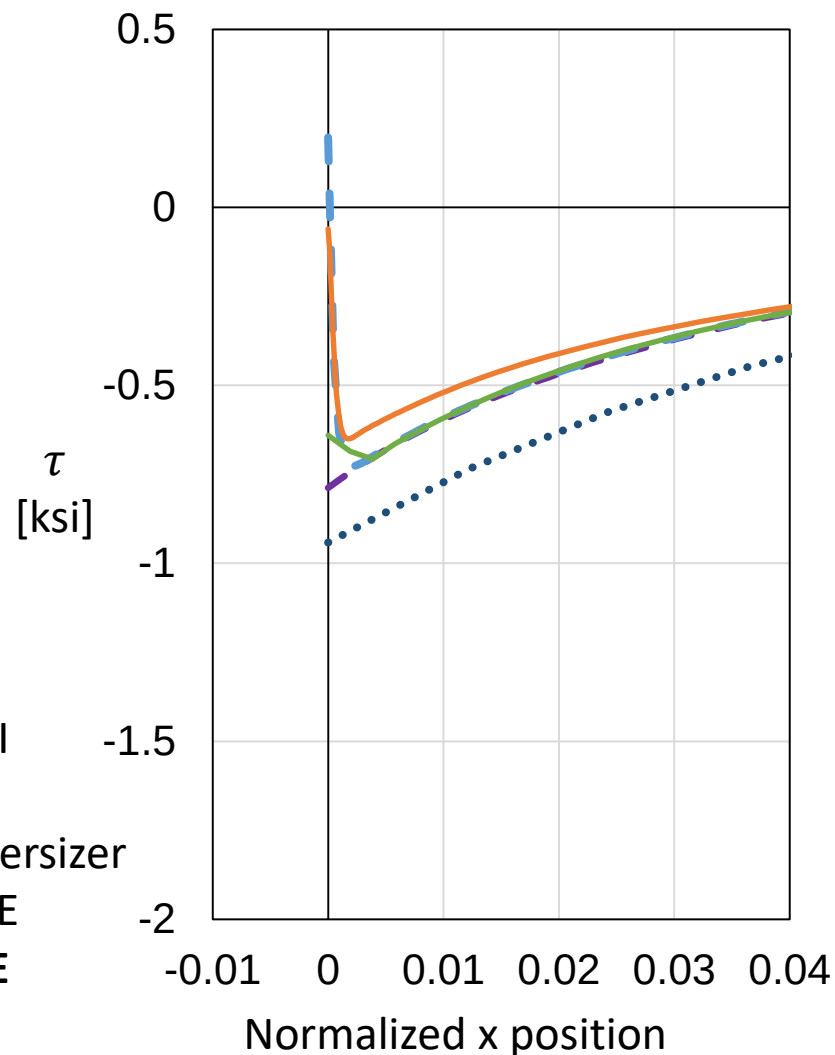
IM7/8552-1

T650/5320-1

Plascore 3/16" 3.1 pcf

Film Adhesive

..... A4EI  
 - - - JED  
 - - - Hypersizer  
 — HFFE  
 — LFFE



# Concluding Remarks

- Summary

- Better analysis tools for bonded joints are needed
- A set of parameterized scripts were created to automate FEA of the CTE L-joint
- The parametric finite element model enables more thorough analysis earlier in the design phase

- Path forward

1. Validation with element-scale test data:



2. Integration with design optimization tool for automatic sizing



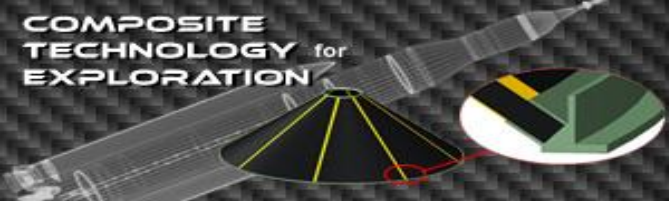
**Call to action: Consider using parametric finite element modeling tools!**

## Finite element based design tool for the CTE longitudinal lap joint

Andrew Bergan

[andrew.c.bergan@nasa.gov](mailto:andrew.c.bergan@nasa.gov)

*Durability, Damage Tolerance and Reliability Branch*



# References



1. B. A. Bednarczyk, J. Zhang, C. S. Collier, Y. Bansal, and M.-J. Pindera, "Analysis Tools for Adhesively Bonded Composite Joints, Part 1: Higher-Order Theory," AIAA Journal, vol. 44, no. 1, pp. 171–180, 2006.
2. L. J. Hart-Smith, "Adhesive-bonded double-lap joints," NASA Langley Research Center, Hampton, VA, NASA CR-112235, Jan. 1973.
3. D. M. Hoyt and S. Ward, "Composite Bonded Joints Analysis, Data, and Substantiation," presented at the FAA Composite Bonded Joints Workshop, Seattle, WA, 2004.
4. H. Kim and K. Kedward, "Stress analysis of in-plane, shear-loaded, adhesively bonded composite joints and assemblies," DOT/FAA/AR-01/7, Apr. 2001.
5. F. Mortensen, "Development of tools for engineering analysis and design of high-performance FRP-composite structural elements," PhD Thesis, Aalborg Universitet, 1998.
6. S. E. Stapleton, "The analysis of adhesively bonded advanced composite joints using joint finite elements," PhD Thesis, The University of Michigan, Ann Arbor, MI, 2012.
7. J. Zhang, B. A. Bednarczyk, C. S. Collier, P. W. Yarrington, Y. Bansal, and M.-J. Pindera, "Analysis Tools for Adhesively Bonded Composite Joints, Part 2: Unified Analytical Theory," AIAA Journal, vol. 44, no. 8, pp. 1709–1719, 2006.