



NEW NAFEMS WORKING GROUP MEMBER INTRODUCTION

James G. Ratcliffe

NASA Langley Research Center, Hampton, Virginia

NAFEMS Composites Working Group Meeting, October 12, 2022

- 1. Introduction**
- 2. Background**
- 3. Analysis Input Fracture Properties**
- 4. Discussion**



Education: Mechanical Engineering and Materials Science-
Liverpool University, UK

Experience: NASA Langley Research Center – 22 years

Current Position: Senior Researcher, Durability and Damage
Tolerance of Composites

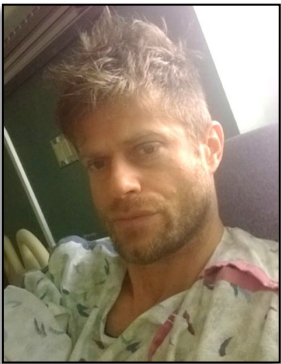
Expertise/Research Contributions:

- Fracture characterization
- Validation test article design/test method development
- Damage tolerance of sandwich structure
- ASTM standard test development

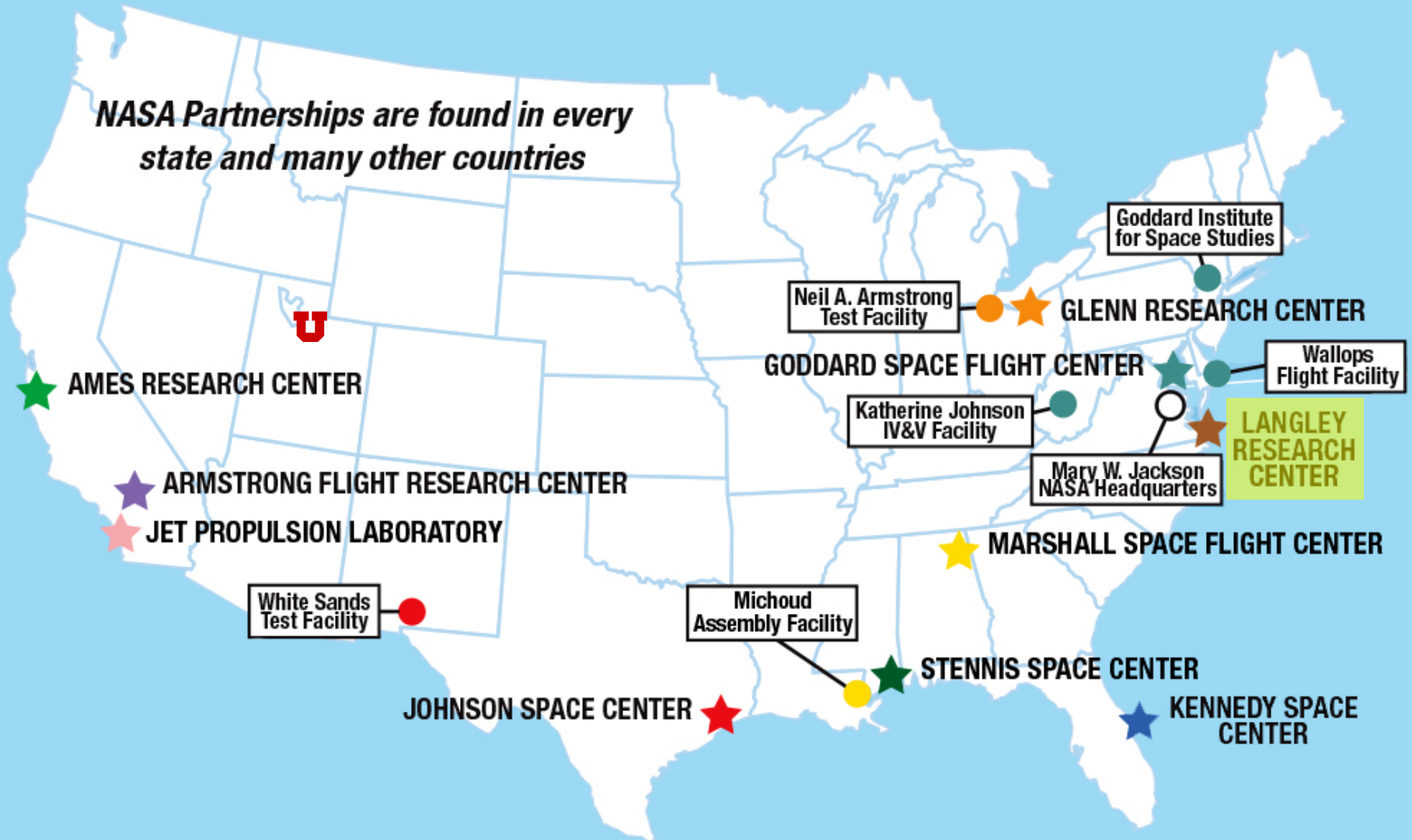
James Ratcliffe Bio



- First-hand experience with fracture
- Fiber reinforced femur



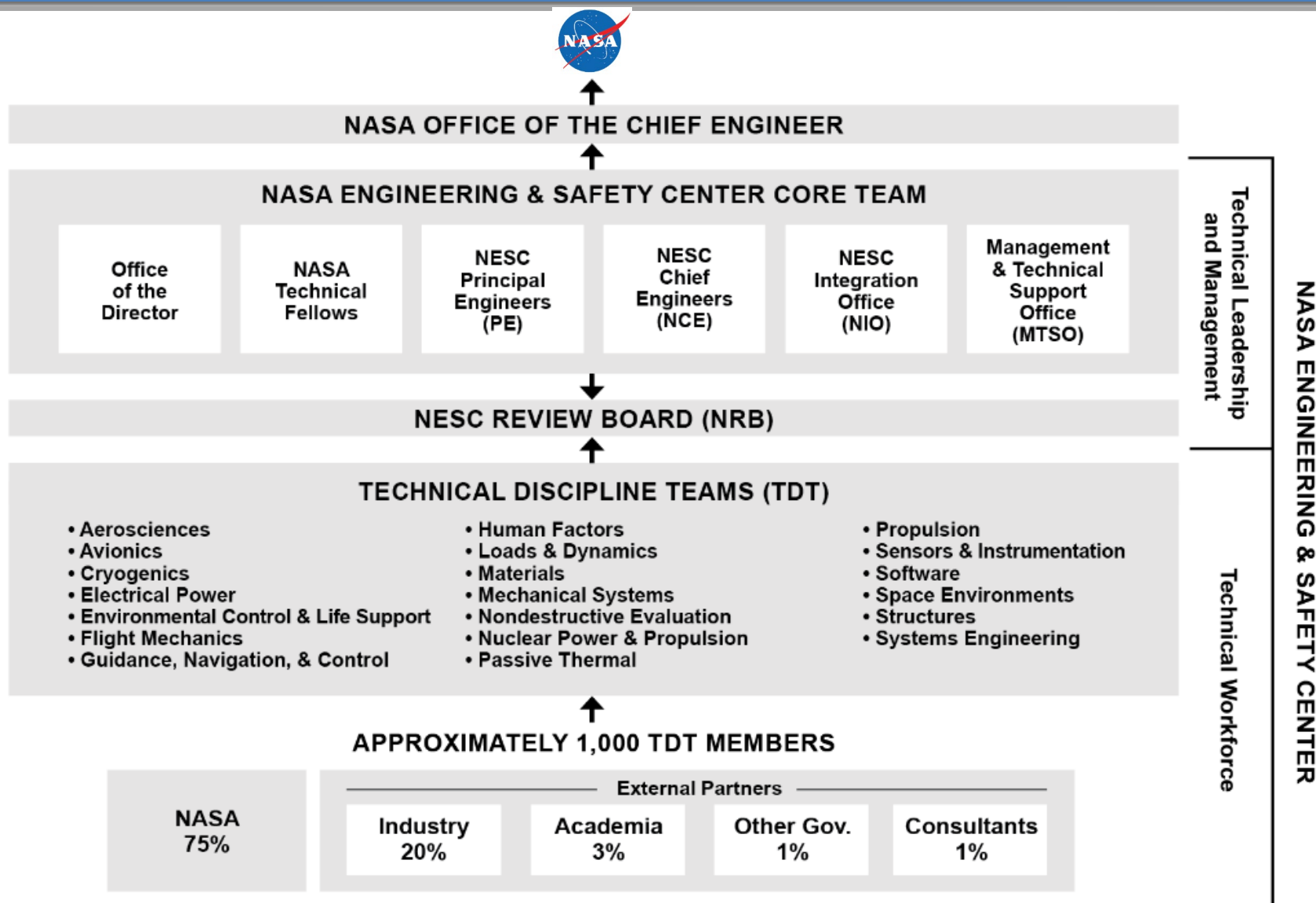
NASA Locations





- Established 1917 by the National Advisory Committee for Aeronautics (NACA)
- Approximately 1850 Civil Servants and 1700 Contractors
- Present/past accomplishments
 - First of three research centers
 - Established the National Aeronautics and Space Administration (NASA), a civilian agency responsible for coordinating America's activities in space, on **July 29, 1958**
 - World's first transonic wind tunnels
 - Gantry to simulate lunar landings
 - Orion crew module development
 - Future vehicles (autonomy)
- Mission directorates and agency functions, including:
 - Research Directorate (RD)
 - Engineering Directorate (ED)
 - Science Directorate (SD)
 - NASA Engineering and Safety Center (NESC)
- Main activities
 - Aeronautics: Wake vortex, fixed-wing and rotary wing aircraft, air safety, human factors, aerospace engineering, materials processing
 - Astronautics: Moon, Mars, Earth sciences

NASA Engineering Safety Center

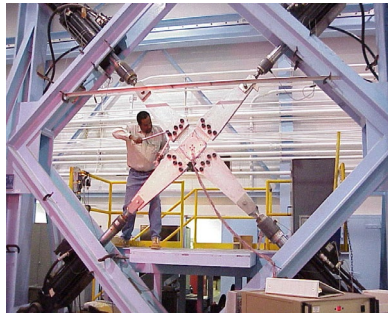


Durability, Damage Tolerance, and Reliability Branch Experimental Equipment

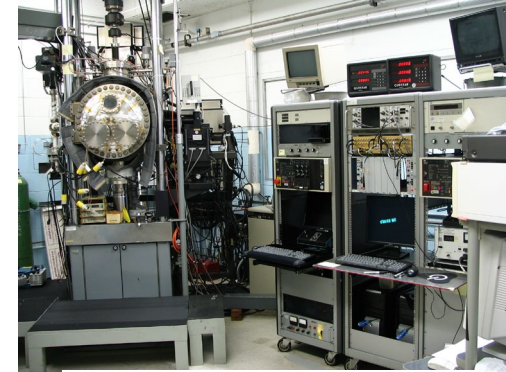


- Over 50 servo hydraulic load frames
- >1 lb to 400 kip capacities
- Multiple screw driven load frames
- Close quarters....

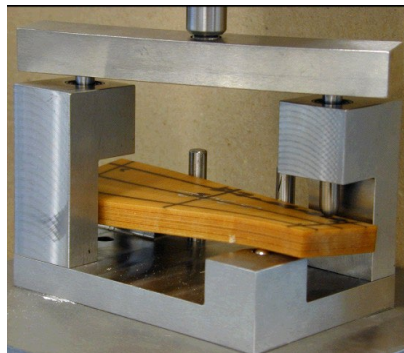
Materials Research Laboratory



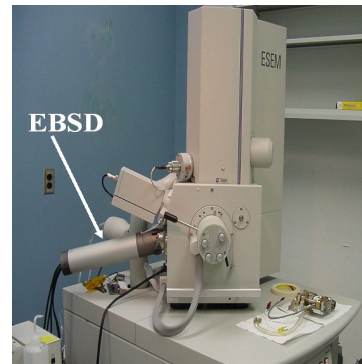
Bi-Axial Load Frame



Environmental Testing



Materials Characterization



Inspection equipment
Microscopy, UT, X-ray/CT



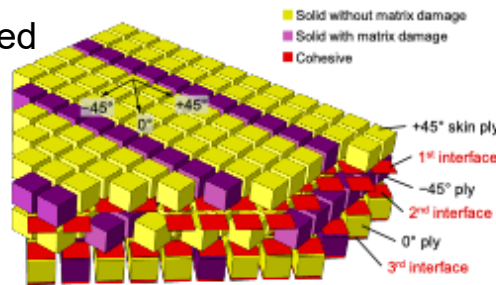
Temperature chambers

Progressive Damage Analysis Tool: CompDam*

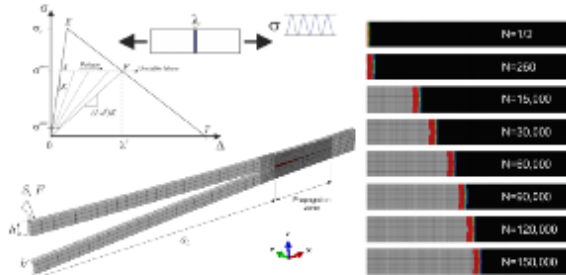
Description:

- Continuum damage mechanics method for predicting damage in Carbon-Fiber-Reinforced Plastic (CFRP) under large deformations
 - User material in Abaqus/Explicit
 - Matrix crack orientation defined and tracked
 - 3-D fiber kink band model
 - Cohesive fatigue law based on S-N data
 - Static strength and fatigue life prediction

Modeling Approach



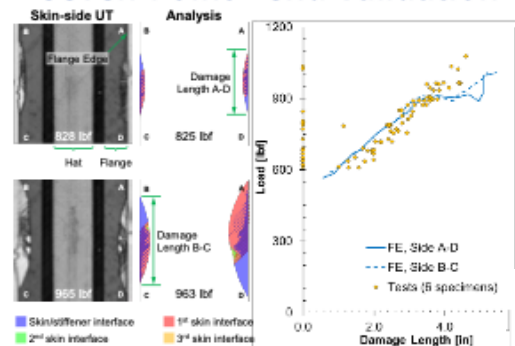
Cohesive Fatigue Modeling



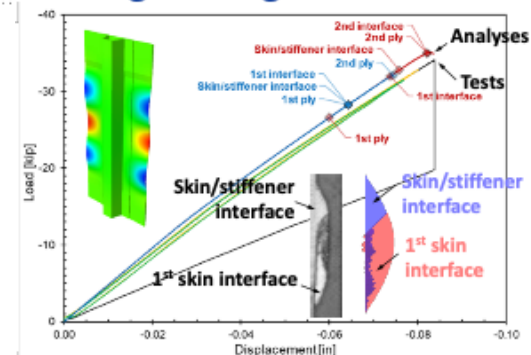
Verification / Validation / Demonstration of Capability:

- Quasi-static interlaminar damage
- Static sub-component test articles
 - Accurate prediction of matrix crack-delamination interaction
 - Correct damage evolution sequence
 - Predicted peak loads within 15% of test loads

Seven-Point Bend Validation



Single Stringer Validation



Transition Path:

- Open-source release via NASA Open Source Agreement
- Publication of theory and applications

Progressive Damage Analysis Tool: Floating Node Method*

Description:

- Discrete crack approach for predicting intra- and inter-laminar damage
 - Abaqus/Standard User Element (UEL)
 - Floating nodes: multiple crack interactions
 - No crack spacing limit
 - Explicit capture of matrix crack/delamination interaction kinematics
 - Static strength and fatigue life prediction

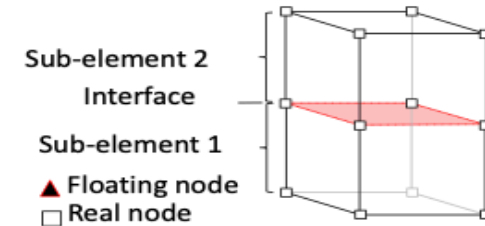
Verification / Validation / Demonstration of Capability:

- Static and fatigue Intra- and inter-laminar benchmarks
- Sub-component test articles
 - Residual strength of impact-damaged skin-stringer panels
 - Fatigue life prediction of beam sub-elements
 - Correct damage evolution sequence
 - Predicted peak loads within 15% of test load

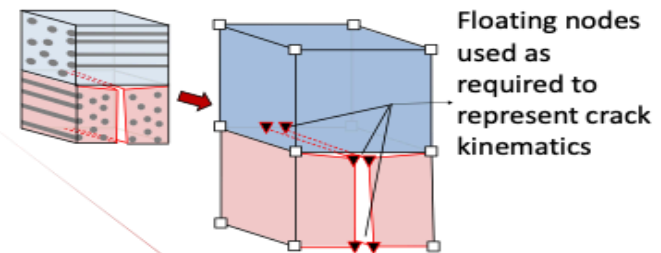
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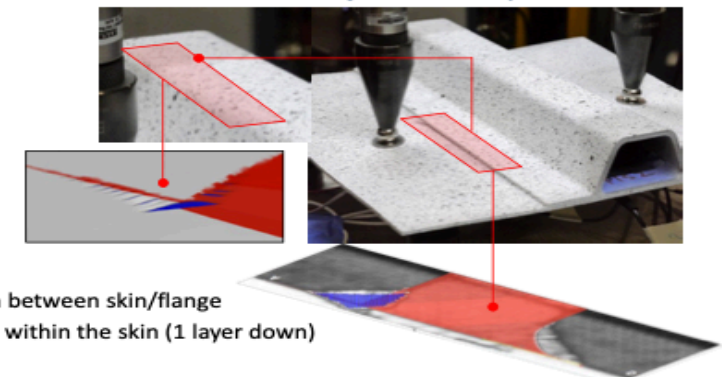
One extended interface element



Explicitly represents crack networks (delamination/matrix crack interaction)



Validation example: Seven point bend

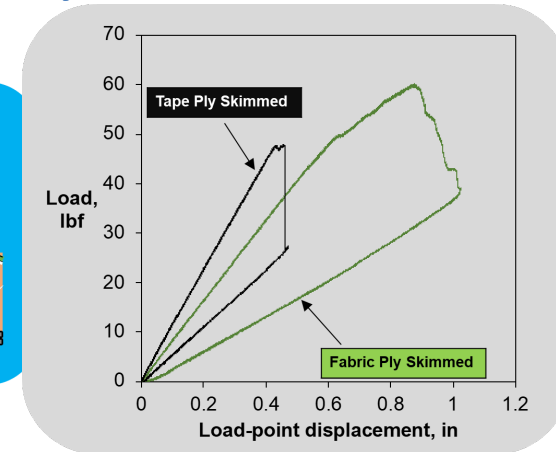
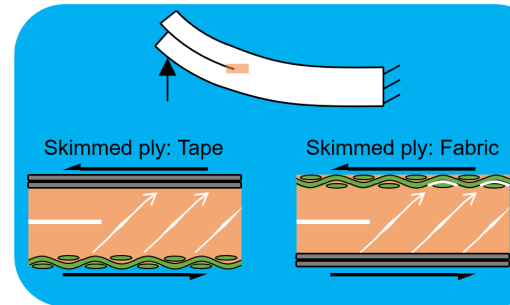


* Chen, B.Y., Pinho, S.T., De Carvalho, N.V., Baiz, P.M. and Tay, T.E., 2014. A floating node method for the modelling of discontinuities in composites. *Engineering Fracture Mechanics*, 127, pp.104-134.

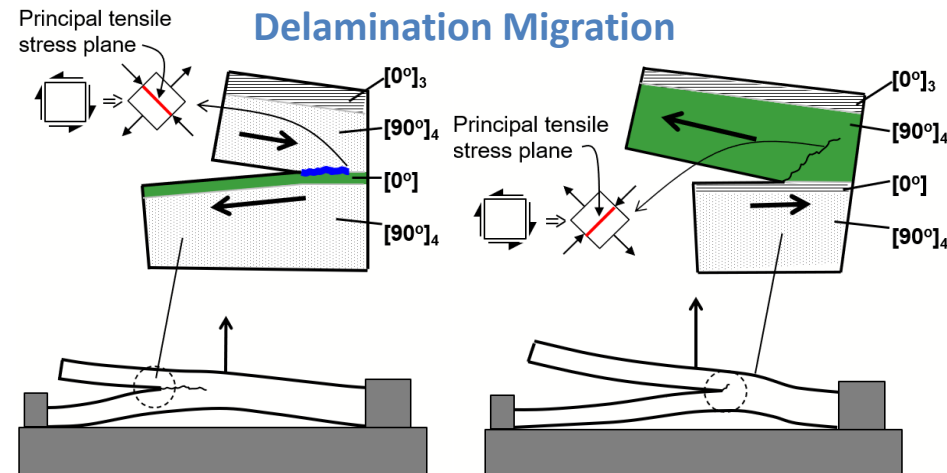
Materials Characterization

- Material systems
 - Polymer-matrix composites (thermoset- and thermoplastic-based materials)
 - Adhesives
 - Woven fabric Carbon/Carbon composites
 - Ceramic-matrix composites
 - Ablative materials
- Interlaminar fatigue and fracture:
 - Non-unidirectional tape laminates
 - Hybrid laminates (e.g., tape/fabric interfaces)
 - Adhesives
- Elastic-plastic bondline Interfacial fracture
 - J-integral measurement procedures
 - ASTM standard test method development
- Effect of processing defects (bond line thickness variation, porosity, ply waviness, etc.) on material properties (toughness, strength, etc.)
- Effect of fracture history on apparent fracture properties

Delamination in Hybrid Laminates



Delamination Migration



Analysis Input Fracture Properties

Problem

Progressive damage analysis (PDA) tools for simulating damage in laminated composites rely on certain empirical input data. Established standardized test methods not equipped to provide information necessary for PDA input:

- Crack growth resistance and fatigue delamination growth rates at non-unidirectional ply interfaces and in hybrid laminates
- Strength components subjected to volumetric scaling effects
- Traction separation law measurements

Action

Modify existing standard test methods and develop new standards to provide reliable PDA input property data



Thank you for your
attention