National Aeronautics and Space Administration

Advanced Composites Project: Executive Summary

2019 ACP Fall Final Review
NASA Langley Research Center
Oct. 1, 2019

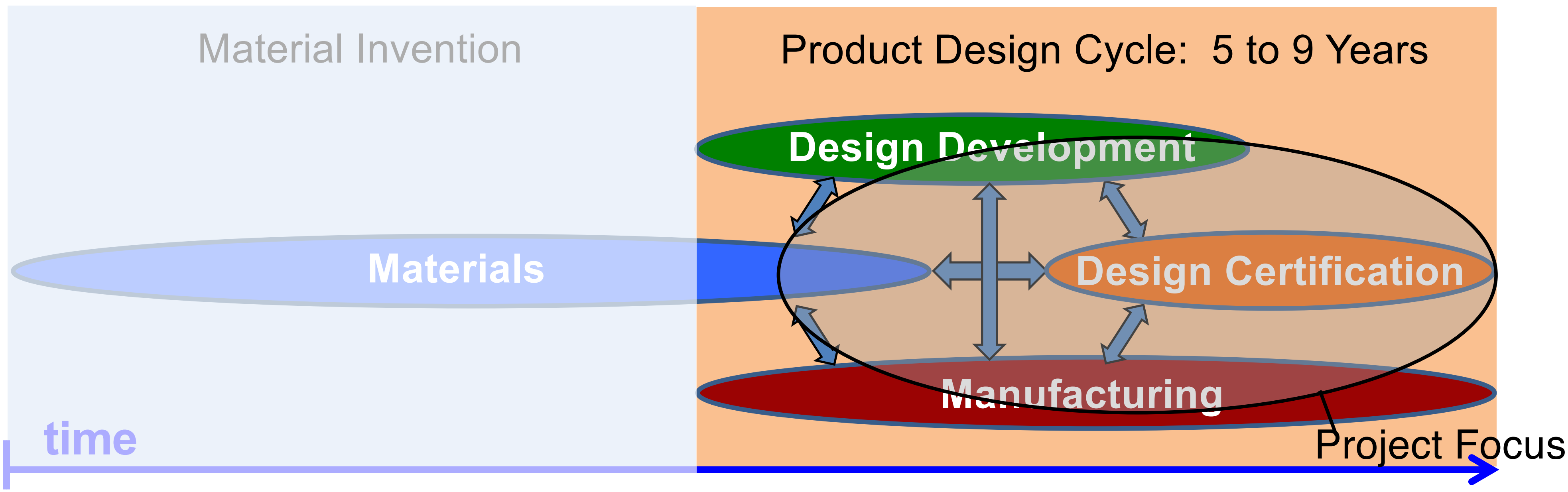




Dr. Richard D. Young, Project Manager

Advanced Composites Project (ACP) Goal and Scope

Focus on reducing the time to develop and certify composite materials and structures, helping American industry retain their global competitive advantage in aircraft manufacturing.



Goal: Reduce product development and certification timeline by 30%

Scope:

- **Aeronautics vehicle applications**
- **Existing material systems**
- **Finite (5 yr) project duration**
- **Community team approach**

Team Approach: NASA and Partners

NASA

Industry

Academia

FAA

ACP Partners

Advanced Composites Consortium (ACC), Jan. 2015

NASA
Federal Aviation Administration

BOEING
LOCKHEED MARTIN
Aurora Flight Sciences

GE Aviation
United Technologies
SPIRIT AEROSYSTEMS

Executive Steering Committee

Technical Oversight Committee

National Institute of Aerospace
(Integrator)

Collier Research Corporation

NORTHROP GRUMMAN

NIAR Wichita State University National Institute for Aviation Research

University of South Carolina McNAIR Center

Cooperative Research Teams

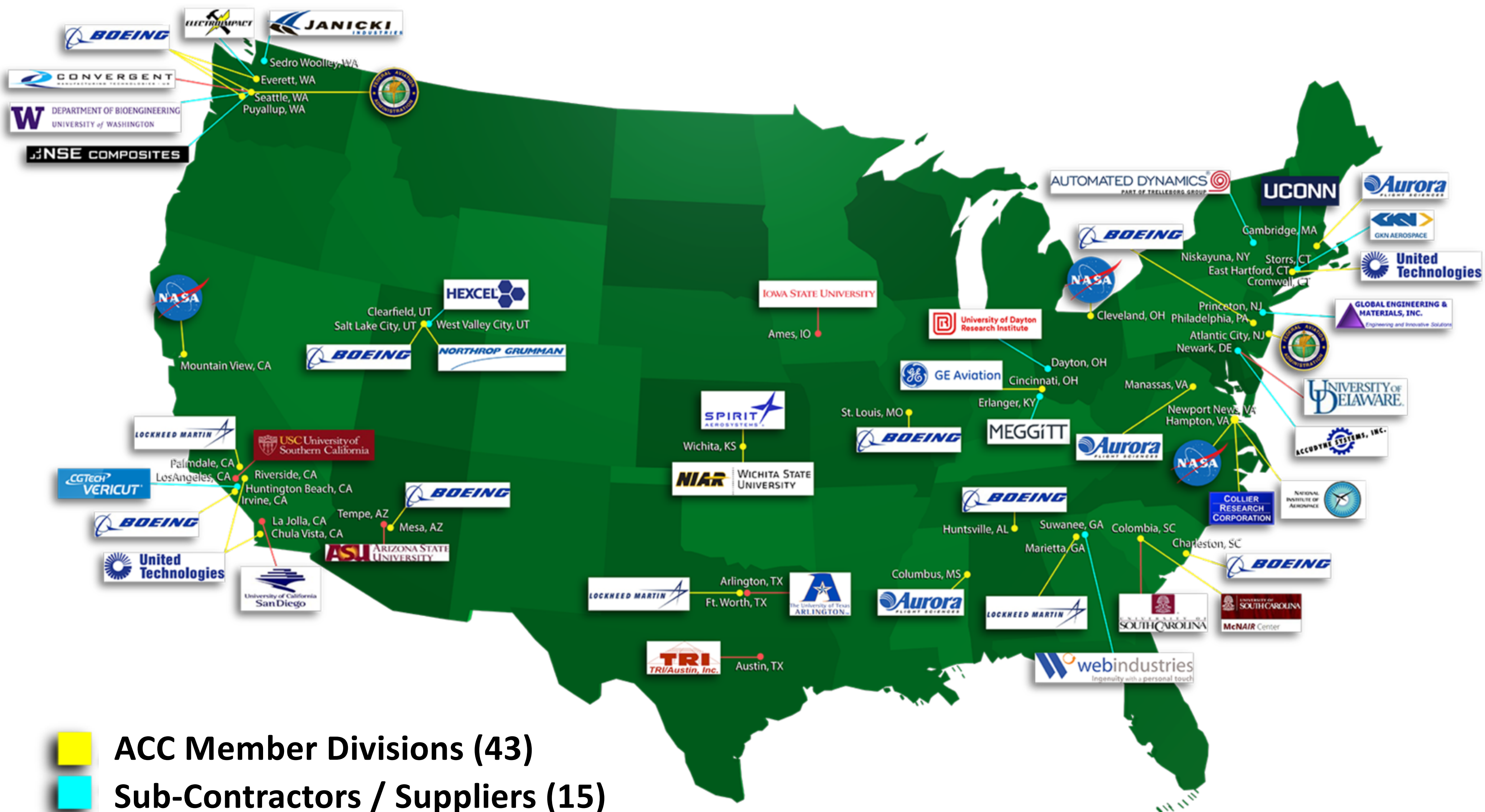
NASA Research Announcement (NRA) 2015

University of California San Diego
Arizona State University
The University of Texas Arlington

University of South Carolina
Iowa State University
TRI/Austin, Inc.

USC University of Southern California
University of Delaware
CONVERGENT Manufacturing Technologies · US

ACP Partners



- ACC Member Divisions (43)
- Sub-Contractors / Suppliers (15)
- NRA Recipients (9)

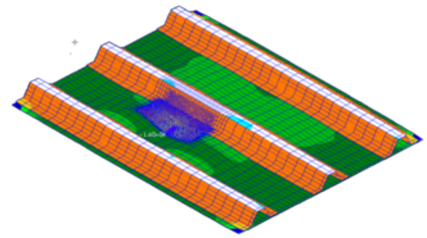
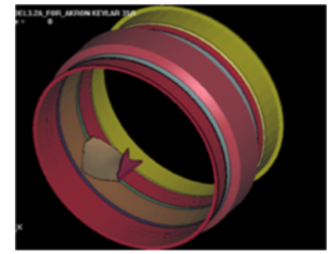
Teamwork Approach to Maximize Impact

- Industry prioritization: select use cases where success will have big impact
- Select technologies on potential to meet requirements
- Focus on collaborative development, leverage:
  - past experience
  - partner resources
  - concurrent efforts
- Comprehensive V&V for reliable application
- Transition by participation

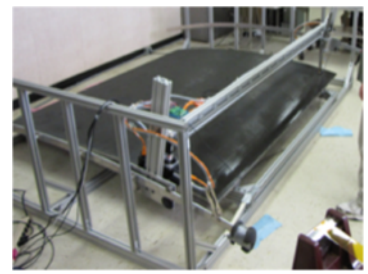
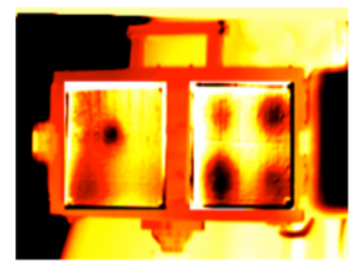
GOAL: Maximize impact of products from 5-year focus project

ACP Technical Challenges

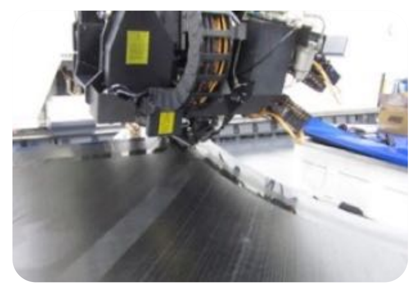
TC 1 - Accurate Strength & Life Prediction
Develop validated strength and life prediction tools with known accuracy for complex composite structures and standardized procedures for their reliable use.

TC 2 - Rapid Inspection & Characterization
Develop and demonstrate NDE systems and enabling technologies to fully inspect and rapidly disposition findings in complex composite structures.

TC 3 - Efficient Manufacturing Process Development
Develop and demonstrate new computational methods to relate manufacturing parameters to defect formation, and connect to commercial design and analysis software to allow structural optimization while resolving predicted manufacturing issues.




Accurate Strength & Life Prediction:

Framework for Method Verification and Validation

Description:

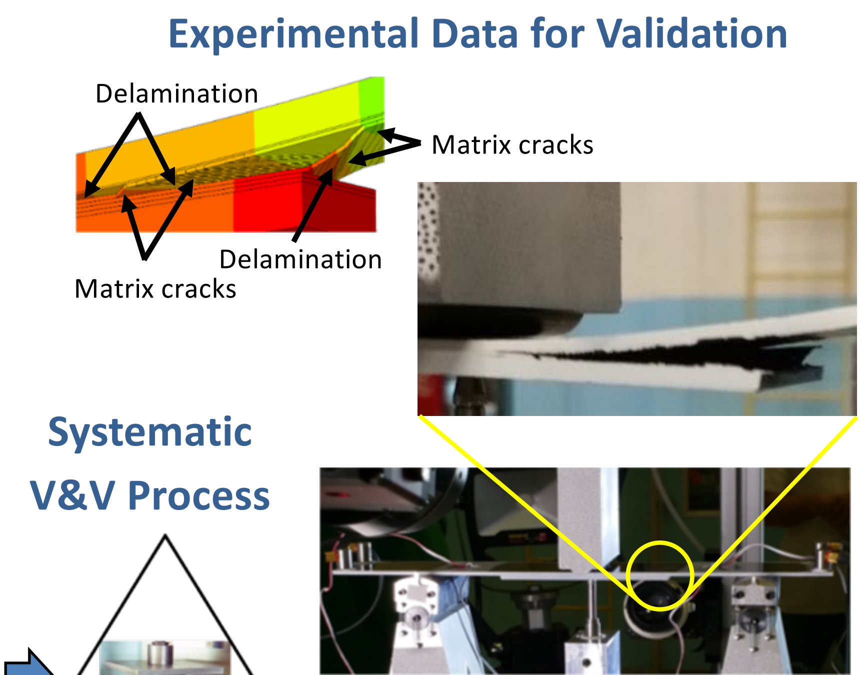
- A systematic approach to verify and validate progressive damage and failure analysis methods
  - Benchmarks to verify software implementation of theory is correct
  - Experimental data to systematically validate predictive capability for relevant failure modes
  - Progressively larger building blocks to address model size limits and modeling best practices

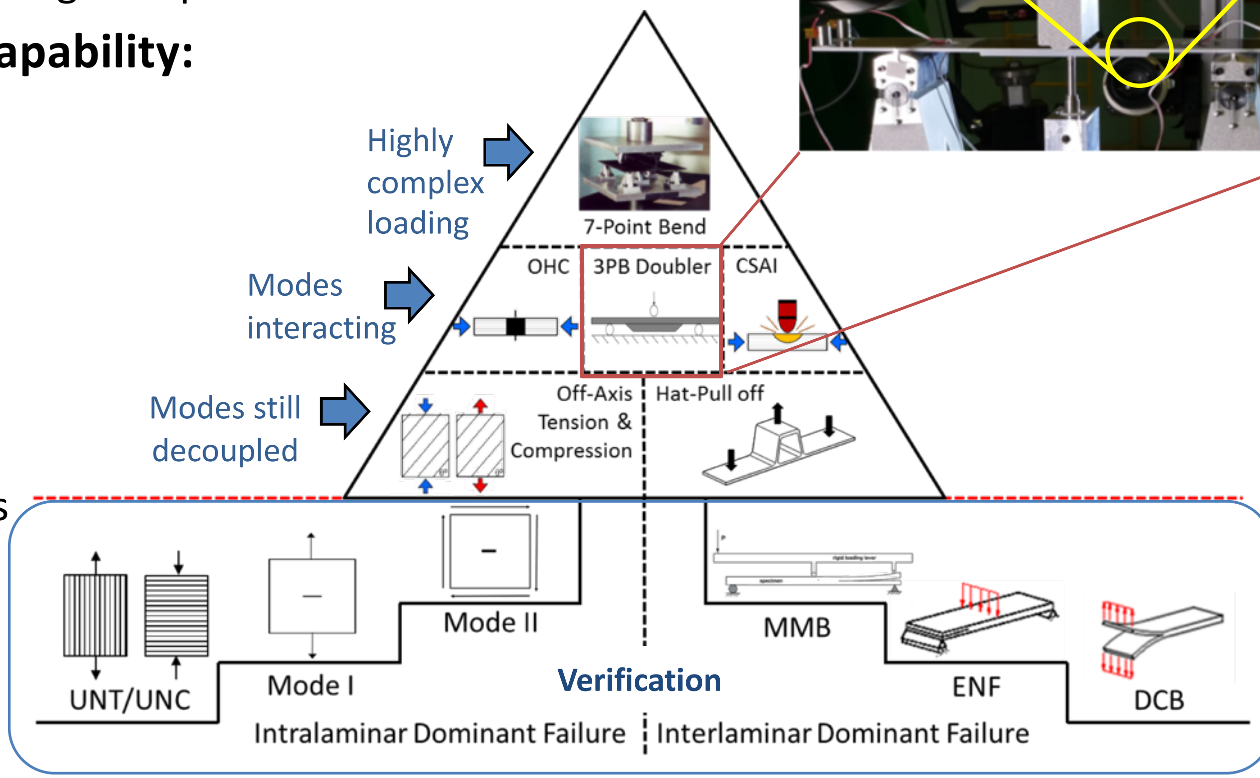
Validation / Demonstration of Capability:

- Validated using multiple types of composite structures
- Used on NASA ACC 2C18, 2C19, and AFRL CALE projects

Transition Path:

- CRT member use
- Conference papers/publications
- CMH-17 in “Guidelines”





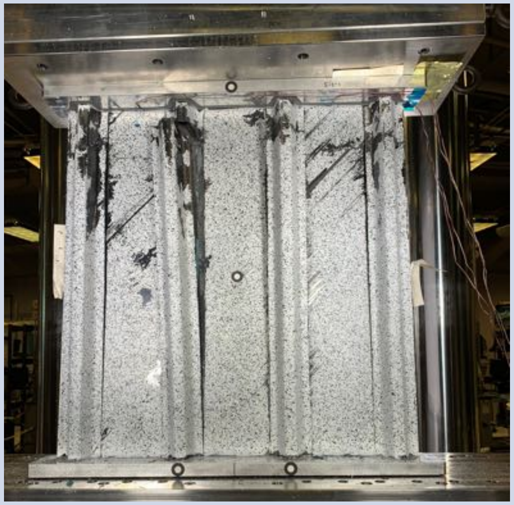
Accurate Strength & Life Prediction:

High-Fidelity Progressive Damage Analysis Tools

Progressive Damage Analysis (PDA)

VCCT (Abaqus)
CompDam
FNM, RxFEM

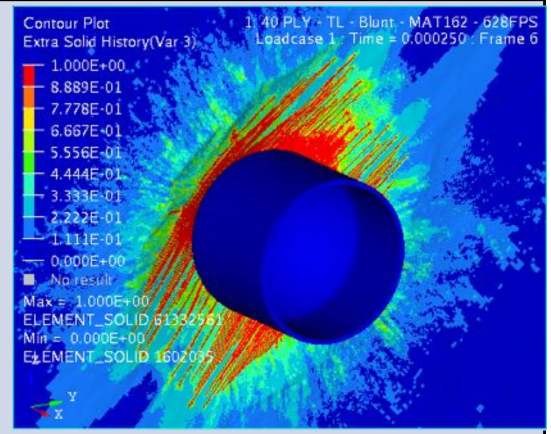
Geometric non-linearity,
Fiber kink band,
Cohesive fatigue law,
Convergence; Efficiency



High Energy Dynamic Impact (HEDI)

MAT 162, MAT261
Peridynamics
MAT 213, MAT299

Improved MAT261;
New models to
address deficiencies



Extensive material characterization for model inputs; new test methods, databases developed

Verification using benchmark cases: Interlaminar and intralaminar, static and fatigue

Validated by tests: coupon, element, sub-components (multi-stringer panel, blade spar, fuselage section)

Best practices for reliable, repeatable results: material property input, moving up building block

PDA:

- Accurate prediction of complex damage morphology with interacting matrix cracks and delaminations
- Peak load generally within 15% of tests
- Fatigue life underpredicted: within one order of magnitude

HEDI:

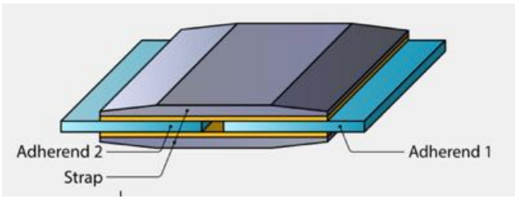
- Predicts threshold velocity within 20% of test
- Deformation within 25% for ply-by-ply methods, within 50% for aggregated-ply methods
- Damage area consistently under-predicted by 40-60%

Use: production programs, IRAD projects, or interested; Integration into COTS needed for industry adoption

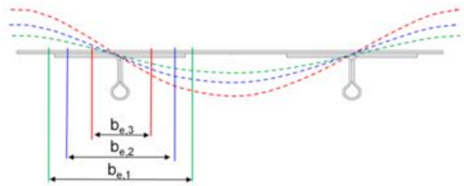
In use on production programs; some tests eliminated; calibration used; true predictive highly desired

Accomplishments: Understanding, Advances, Experienced users, Confidence, Databases

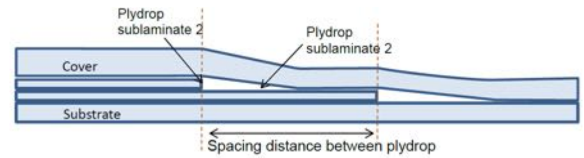
Accurate Strength & Life Prediction:
Rapid Design Tools



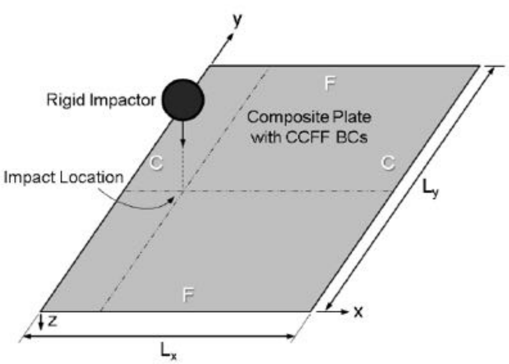
Bonded Joint Tool
Within 20% from tests
0.2 sec



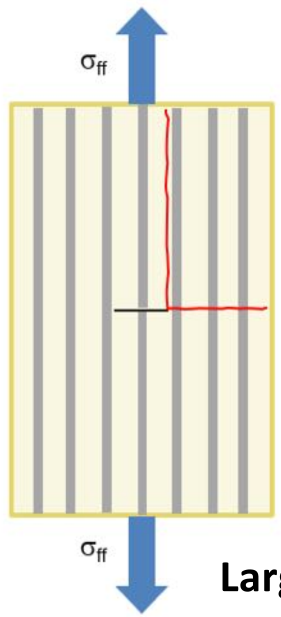
Stiffened Panel Postbuckling
Within 15% of FEA and tests,
0.1 sec



Ply-Drop Failure Estimation
Within 30% for 75% of tests,
0.2 sec

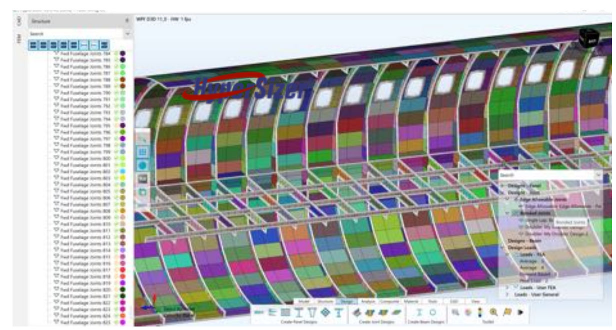


BVID Residual Strength
Impact area within 40%,
CAI within 20% from tests
3 min. (3 weeks FEA)



Large-Notch Damage
Within 15% of FEA,
26% of panel tests
0.01 sec

Rapid Tools integrated into a stress framework (HyperSizer)



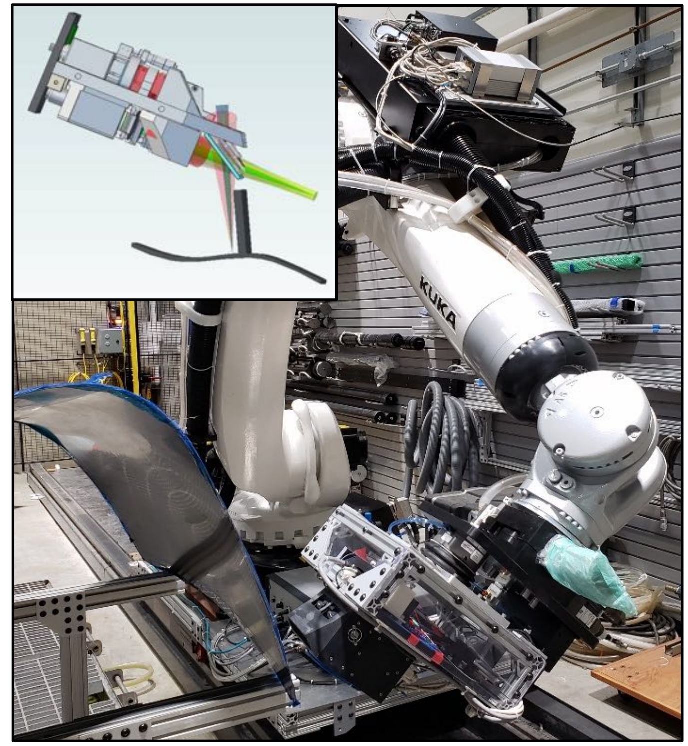
Evaluate efficiency over stand-alone tools

Benefit: Account for damage & defects in preliminary design, 1000’s of load cases

Rapid Inspection & Characterization

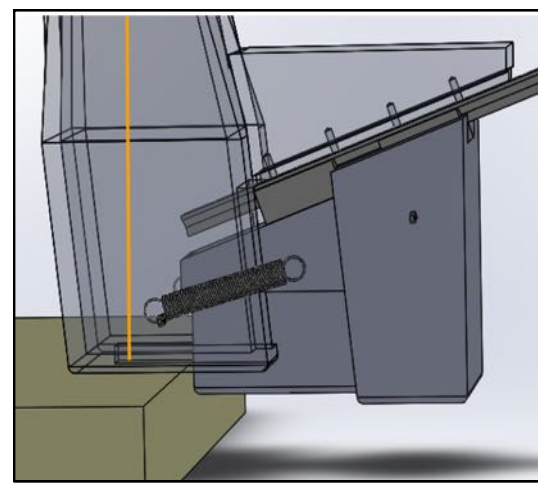
NDE Tools for Critical Defects

Automated UT Enhancement to IR Inspection (GIRAFFE)



Robotic Low-cost PULSAR Ultrasonic Laser UT System

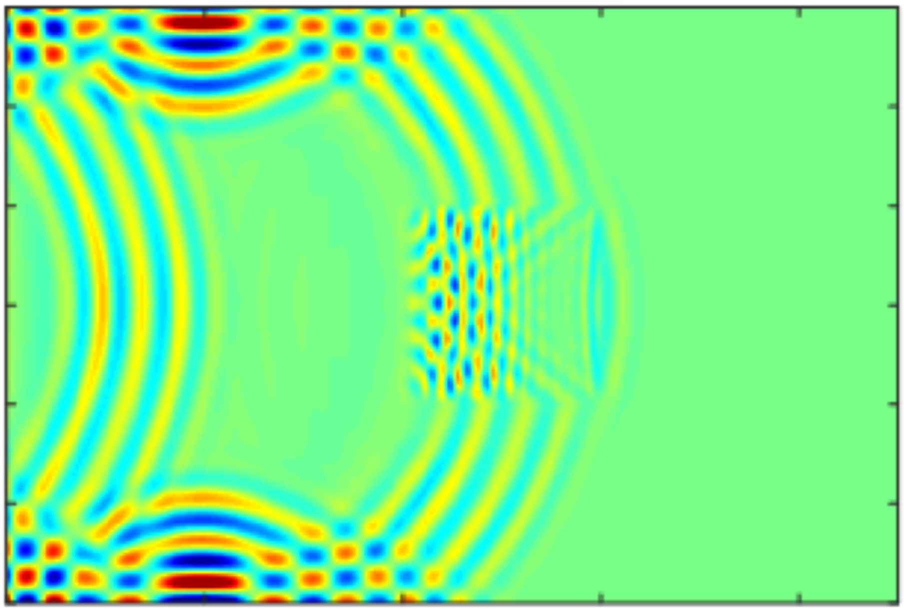
Dual Collaborative Robot Line Scan Thermography



ISAFE for Local Shielding of High-Power Laser UT

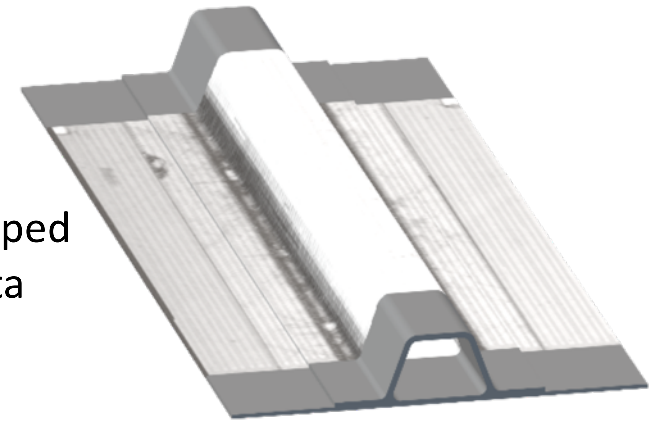
Digital NDE Pipeline

Ultrasonic NDE Simulation for Composite Structures

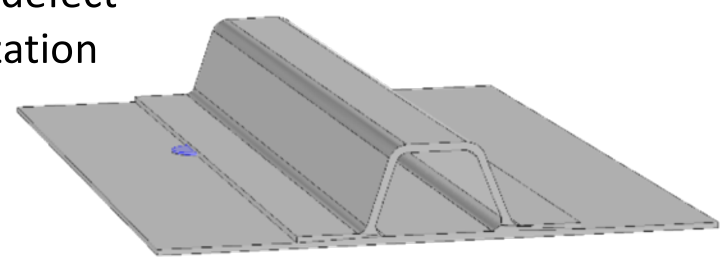


Simulated interaction of a wavefield on delaminated panel

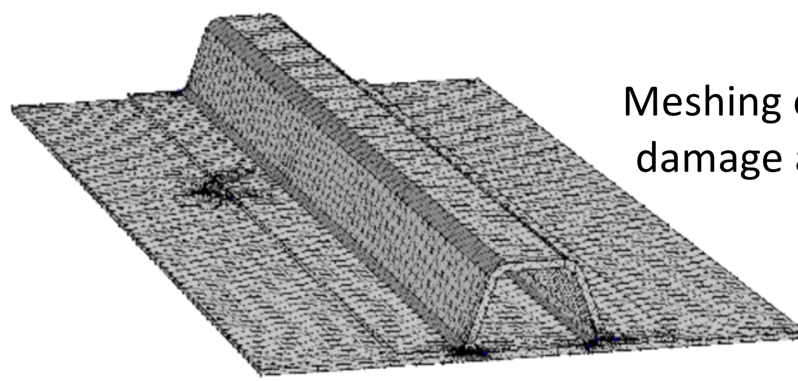
NDE Data to FEA



Model with mapped inspection data



Automated defect characterization

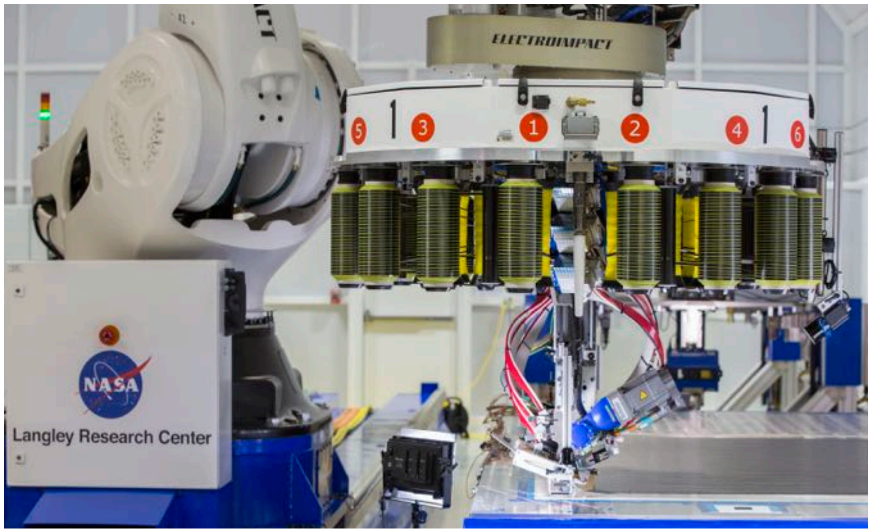


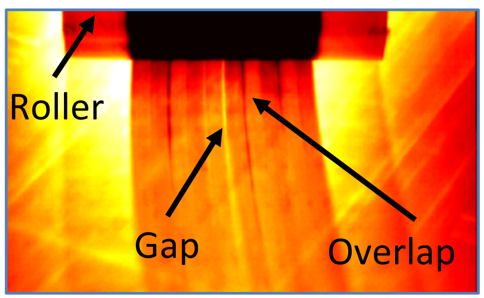
Meshing of defect for damage assessment

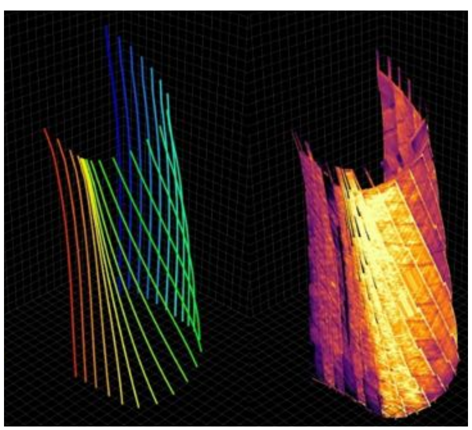
Rapid Inspection & Characterization

In-situ NDE of AFP Manufacture Process

On-head, in-process, infrared-based NDI



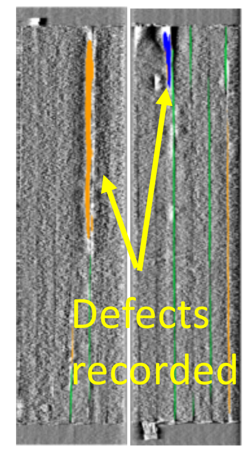




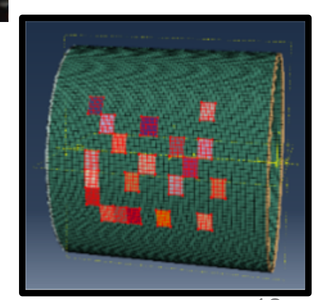
“Saddle” part demo:
AFP head path (l)
Processed thermal data (r)

Off-head profilometer based inspection

- Defect classification and recording
- Machine learning algorithm
- Exports: data analytics, rapid analysis

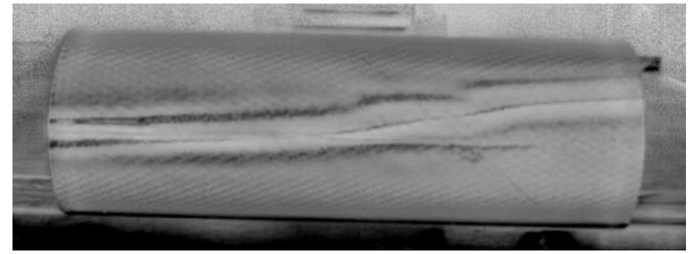


Rapid tool: AFP Go/ No go
Property reduction based on digital coupon database



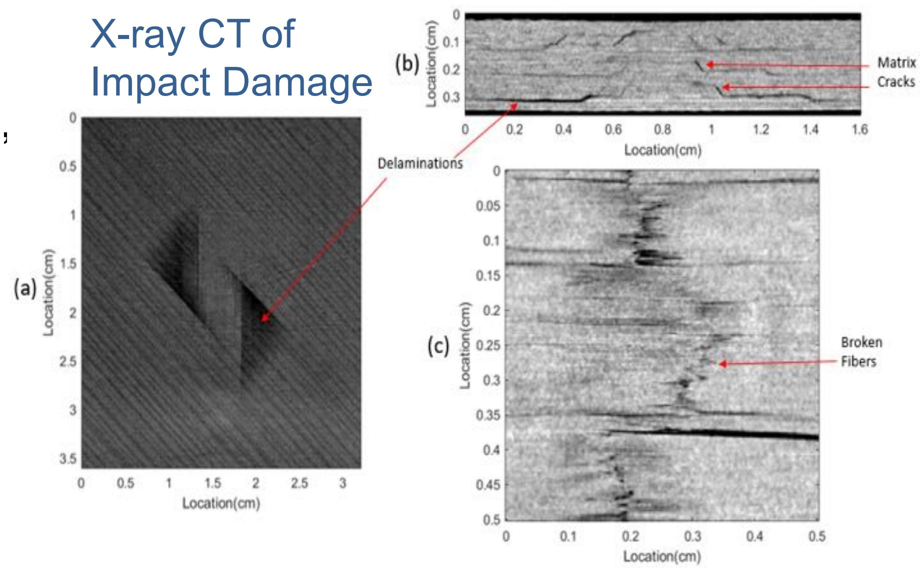
Rapid Inspection & Characterization
NDE Methods and Capabilities Handbook

- Reference guidance on NDE methods and techniques for composites
  - Ultrasound, Thermography, X-ray, etc.
  - Defect types: Porosity, delamination, low energy impact, wrinkles, AFP (twists, folds, laps, gaps)
- Guidance on techniques, settings, best practices, and limitations, for specific flaw types and geometries
- Supporting material available through NIAR:
  - Library of NDE Standards: solid laminates with manufacturing-type defects
  - NDE data collected on Standards for simulation and data processing algorithm development

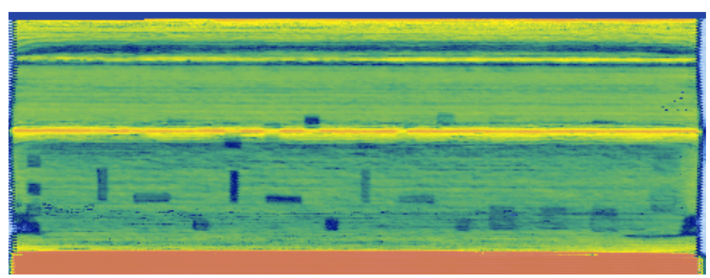


Thermography of ply wrinkles

X-ray CT of Impact Damage

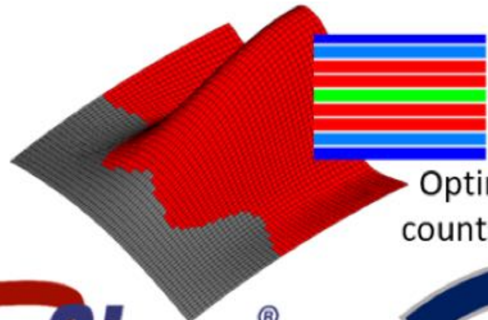


Ultrasound of imbedded flaws in S-curve Panels

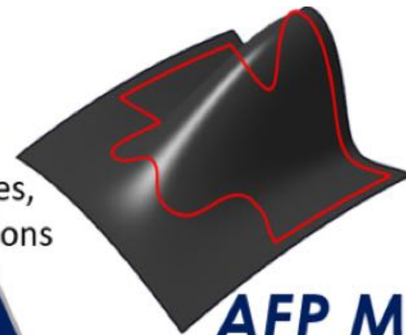


Efficient Manufacturing Process Development

Design for Manufacturing Software



Optimized ply shapes, counts, and orientations



Computer Aided Process Planning

UNIVERSITY OF SOUTH CAROLINA CAPP

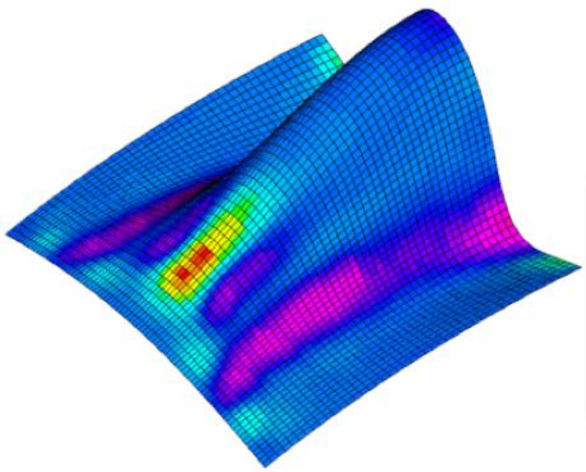
McNAIR Center

HyperSizer®

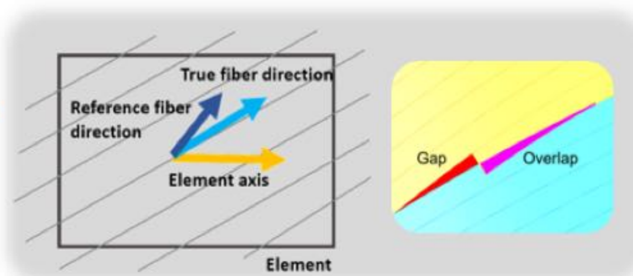
Stress analysis and laminate optimization for thousands of load cases

AFP Manufacturing Simulation

Tow path generation, lap/gap identification, defect prediction



True fiber directions and defect predictions

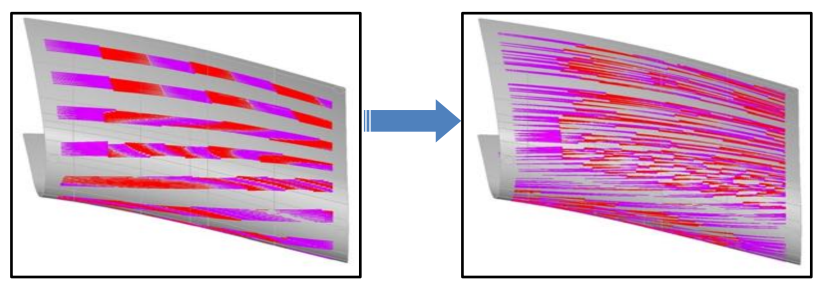


VERICUT

VCP

COMPRO

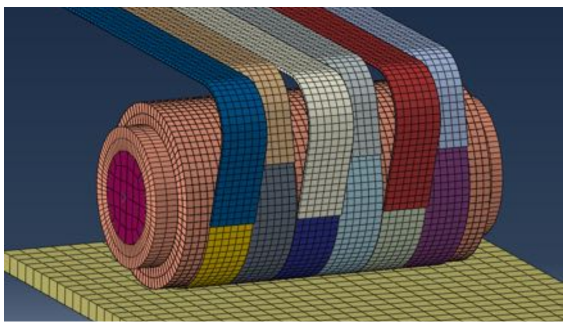
Distribution of Gaps / Laps to improve strength & surface quality



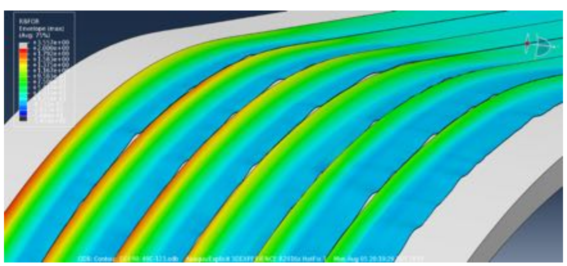
Efficient Manufacturing Process Development
Process Models to Predict Defect Formation

AFP Process Model

Out-of-plane AFP Defects (puckers)

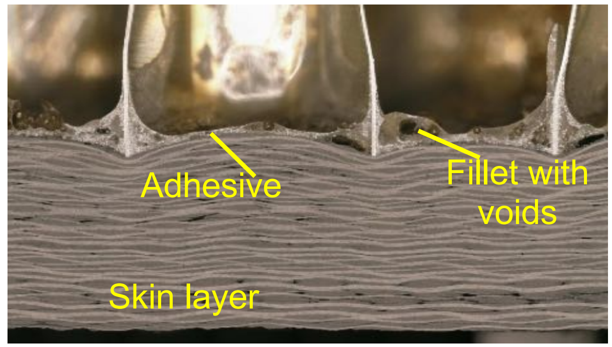


FEA AFP Roller, Tow, and Tool Model

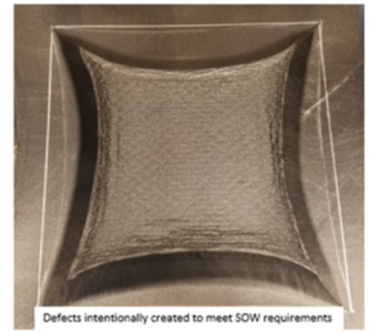


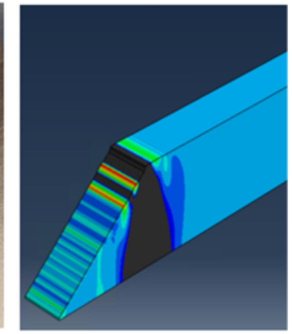
ABAQUS Explicit simulation of six ½" wide tows on complex contour

SANDWICH Cure Defects

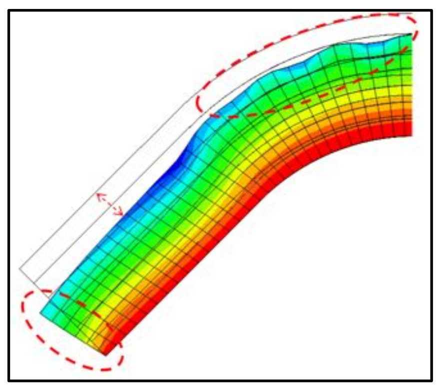


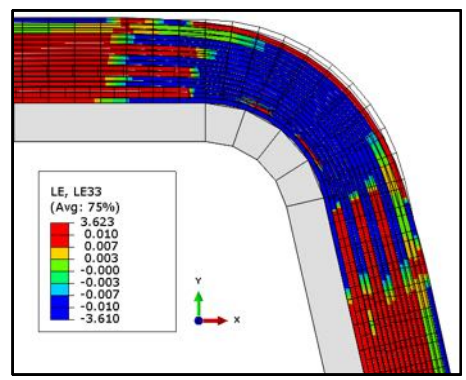
Core Crush Model





Laminate Cure Process Model

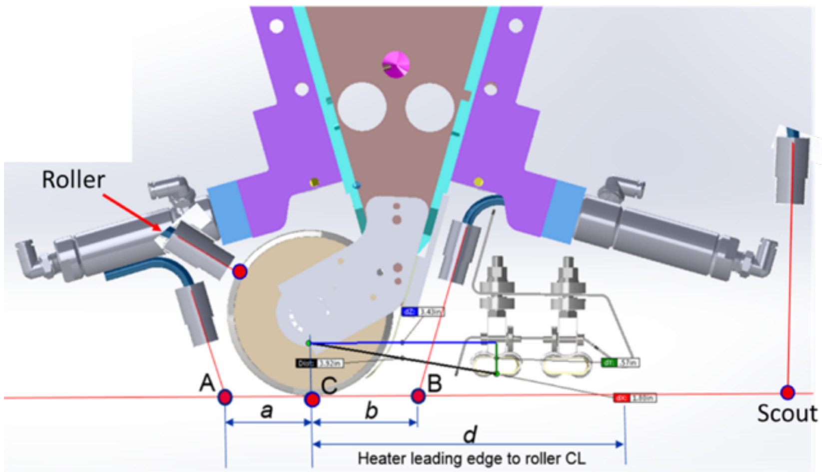




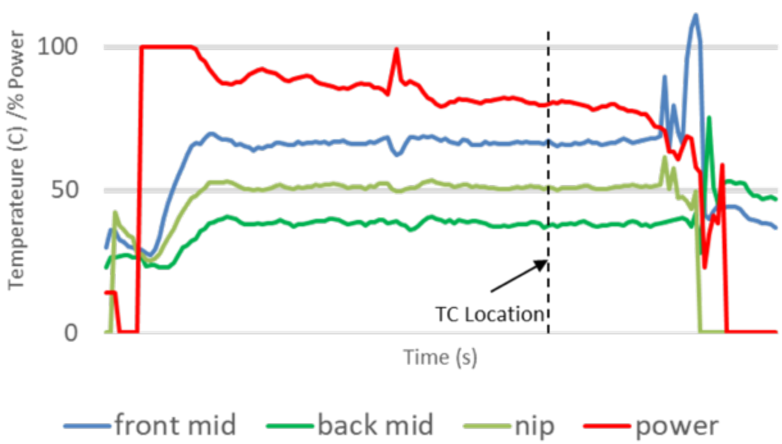
Fiber Waviness & Corner Thinning Predictions:
- Corner Thickening on Concave Mold Geometry (Left)
- Corner Thinning on Convex Mold Geometry (Right)

Closed Loop Control of AFP Heating

Closed-Loop IR (CLIR) Heater for AFP



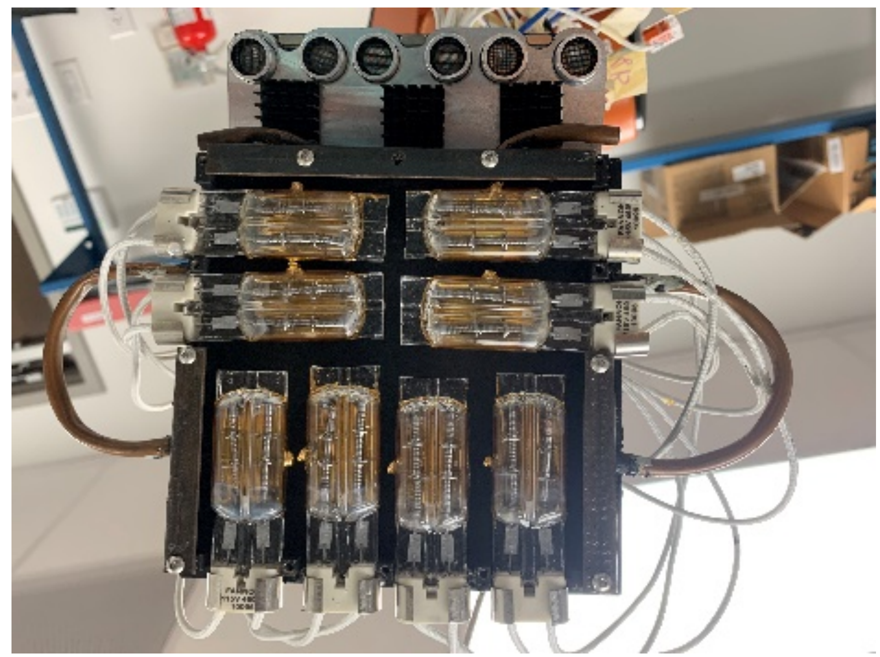
A = Sensors after nip
B = Sensors before nip
C = Inferred Nip Point under compaction roller



CLIR Data vs Time: 50° C Setpoint

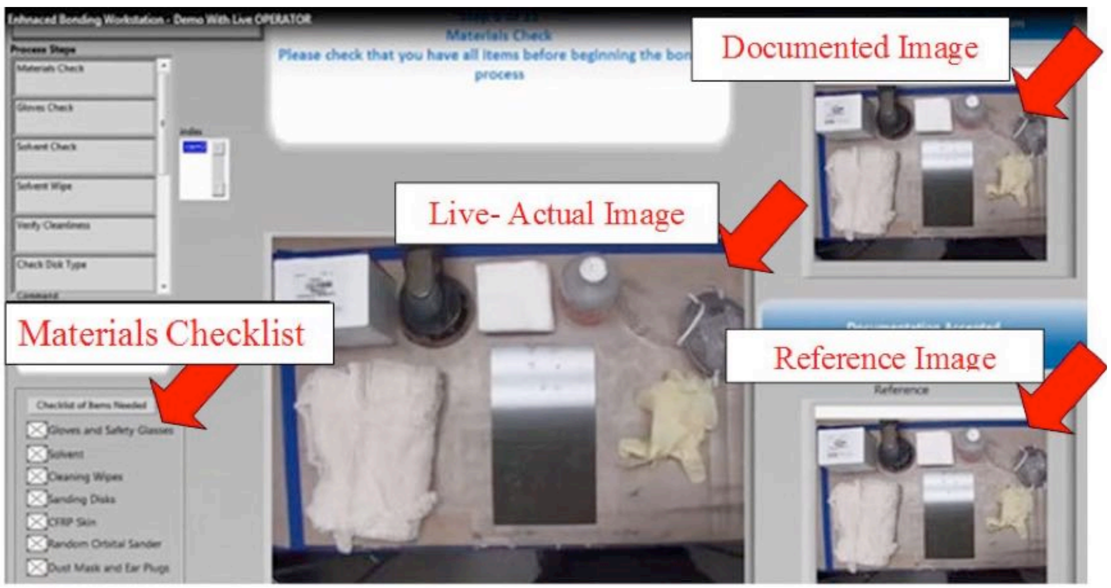
Arrayed IR (AIR) Heater

- Individual lamp controls for complex surface
- FLIR camera for feedback

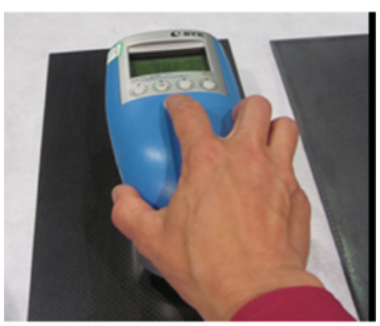


Efficient Manufacturing Process Development
Bonded Structure Surface Treatment

In-Line Bond Process Monitoring System: Hand Sanding



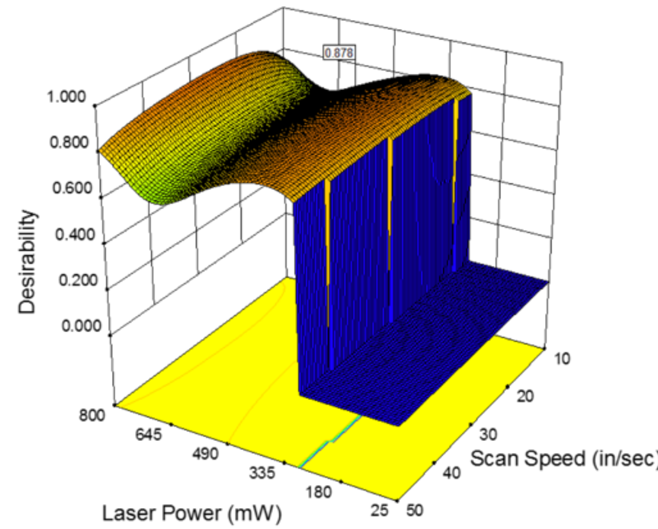
Optically Enhanced Bonding Workstation



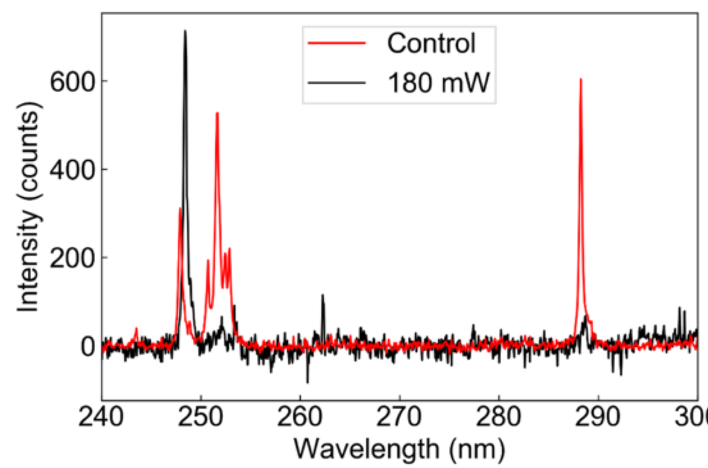
In-line color and gloss measurements verify surface preparation

Laser Ablation Surface Treatment

No adhesive failures above 200 mw



LIBS Contamination Measurement



Technology Transfer Success

- **By Participation:**
  - Consortium: Govt, Industry, University; prioritization & cost share
  - Development & validation by diverse cooperative research teams
  - Research labs ↔ Development centers ↔ Commercial programs
  - Transfer experience, skilled users, confidence → use → growth
  - Shared data to evaluate future methods & commercial software
  - Personal relationships established

- **By Publications, Standards / Handbooks**
  - Composite Materials Handbook-17 revisions: Guidelines, Testing, Crash, Damage Tolerance, Materials & Processes
  - NDI for Composites Handbook
  - ASTM Test Standards

- **By Products**
  - Software: Open Source, NASA software release, and Commercial
  - Hardware technology licensing

Future Work Driven by Emerging Markets: Commercial Aviation Market

Global Growth in Aviation

Opportunities and Challenges

2017

4 BILLION PASSENGER TRIPS

2036

7.8 BILLION PASSENGER TRIPS

- Bombardier / Canada
- Airbus / Europe
- Irkut / Russia
- Comac / China
- Embraer / Brazil
- Global Competitors

41,030 New Aircraft Deliveries

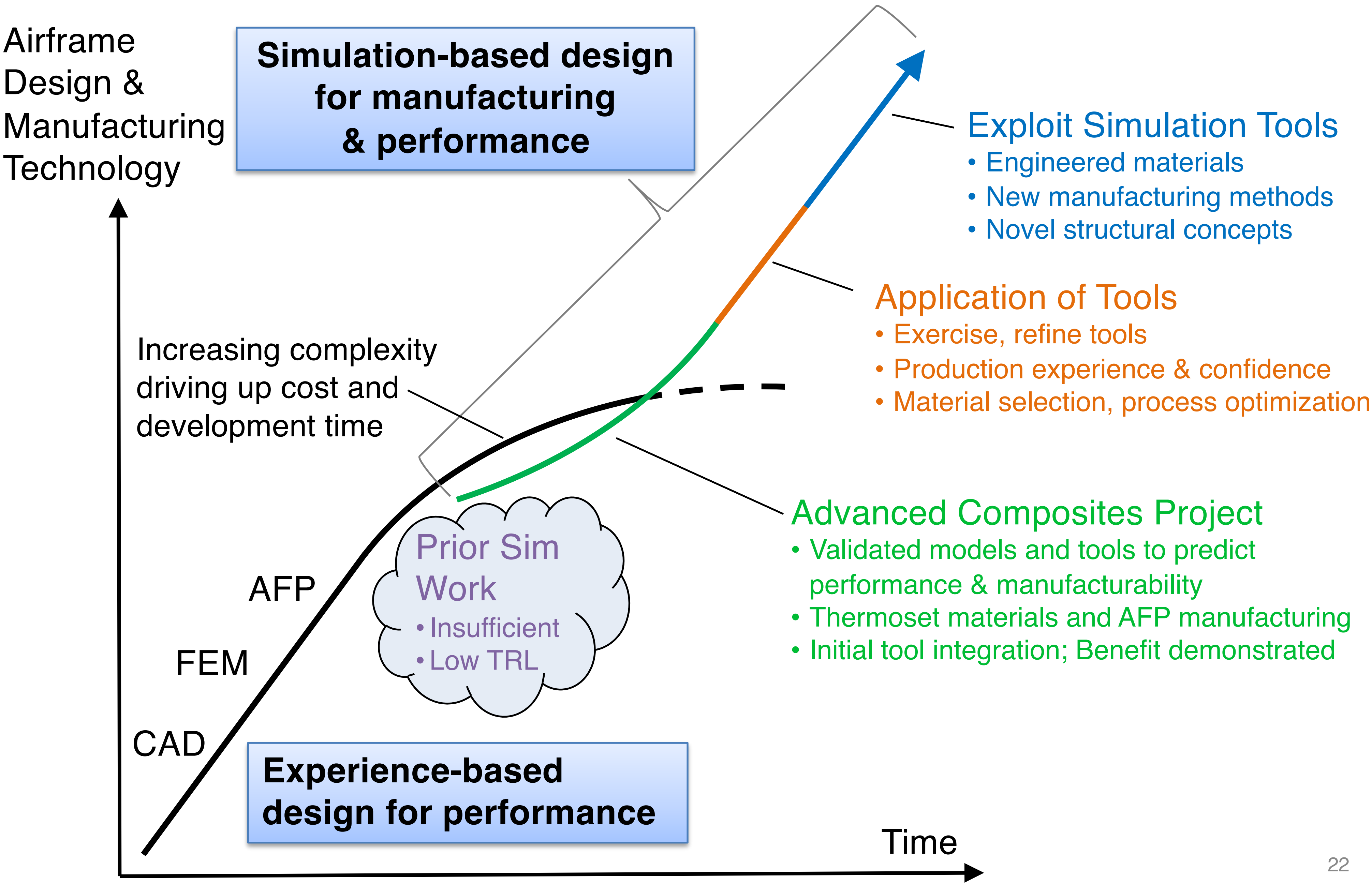
$6.1 Trillion Market Value

78% of New Aircraft Deliveries are Single Aisle Class (including Regional Jets)

Asia-Pacific Market is Nearly **40%** of New Aircraft Deliveries

NASA Aeronautics: Priorities

Enabling Technology Advancement



Questions ?