Analysis of Composite Failure

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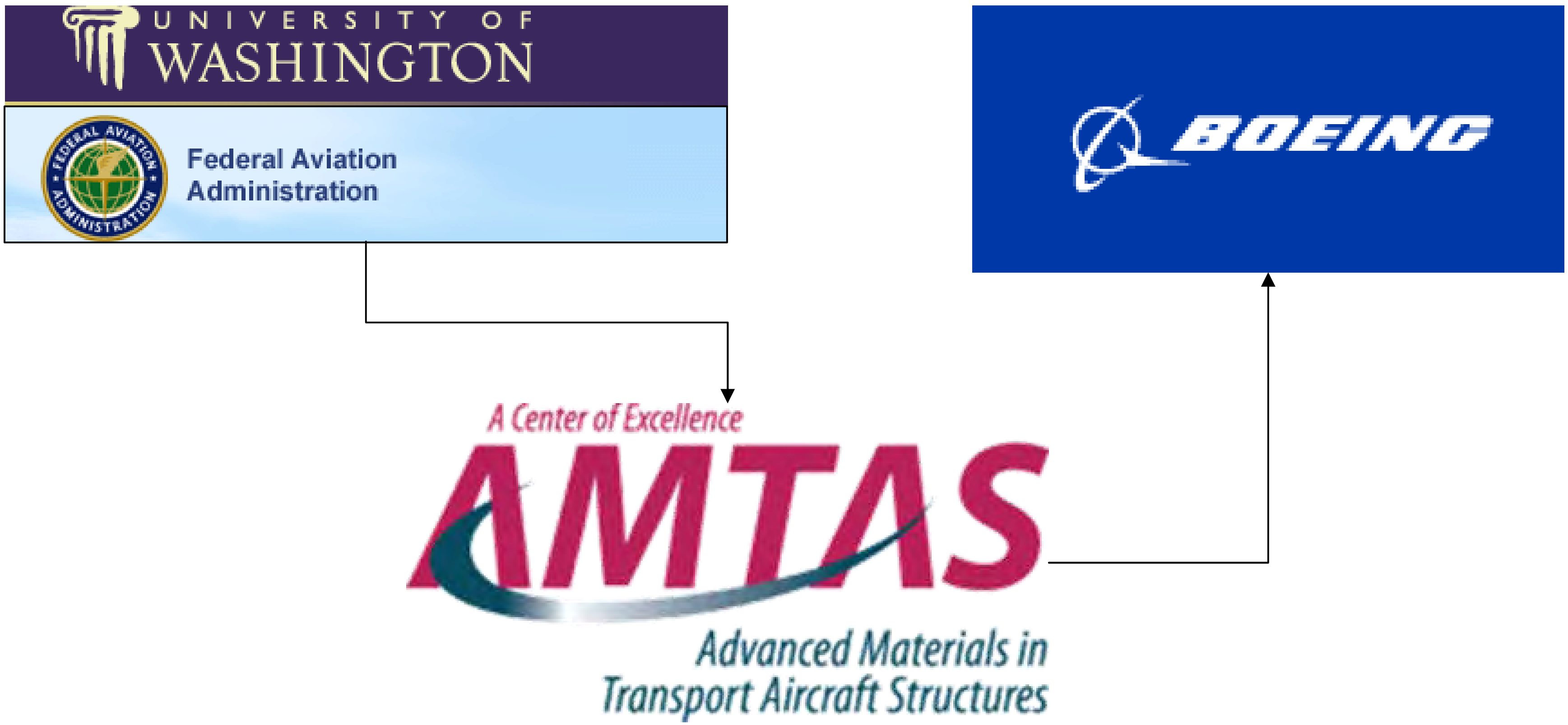
Potential Interaction



Agenda

- Initiate Discussions Regarding the FAA Evaluation of Boeing Composite Failure Analysis Methods
- Suggest the Evaluation Involve AMTAS (University of Washington and the FAA)
- Objective/Approach of Boeing Composite Failure Analysis Methodologies
- Brief Overview of Boeing Composite Failure Analysis Methodologies
- Brief Overview of Existing Evaluation Efforts
- Suggestions for Initiating the Evaluation

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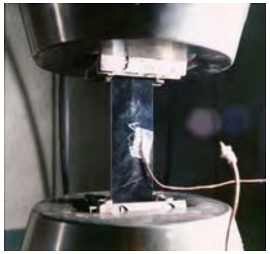
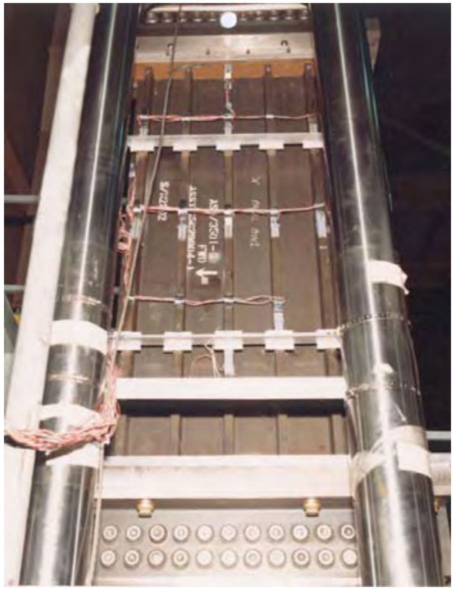
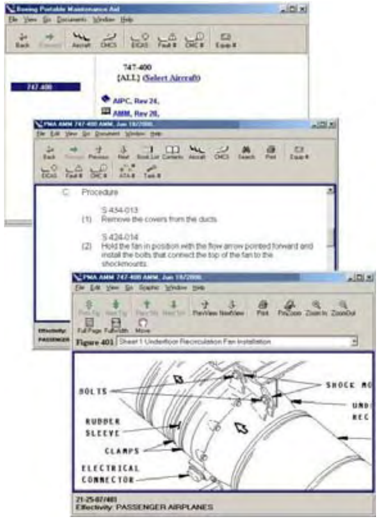
Objective

Preliminary Design





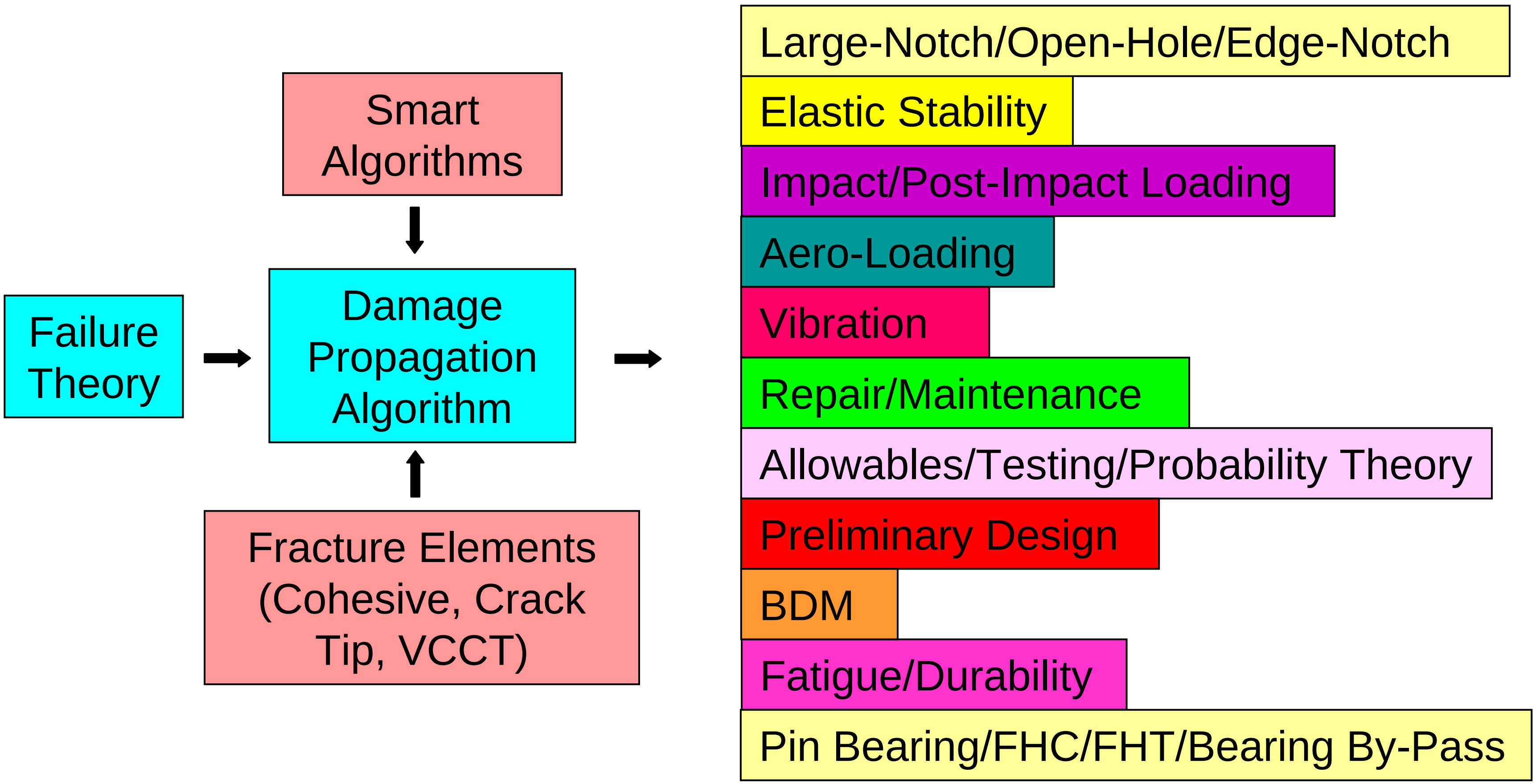


BOEING
Structural Methods & Allowables

Allowables
Structures Workstation
Metal Methods
Composite Methods/Repair
L-22

SHM/Prognostics/Repair

Approach


Smart Algorithms
Failure Theory
Damage Propagation Algorithm
Fracture Elements (Cohesive, Crack Tip, VCCT)
Large-Notch/Open-Hole/Edge-Notch
Elastic Stability
Impact/Post-Impact Loading
Aero-Loading
Vibration
Repair/Maintenance
Allowables/Testing/Probability Theory
Preliminary Design
BDM
Fatigue/Durability
Pin Bearing/FHC/FHT/Bearing By-Pass

Comments

<u>All</u> Analysis is Numerical

Smart Algorithms are a Function of the <u>IMPLICIT</u> Use of Data

No Curve Fitting!

No Calibrations!

No Factor Extractions!

No Similitude Requirement

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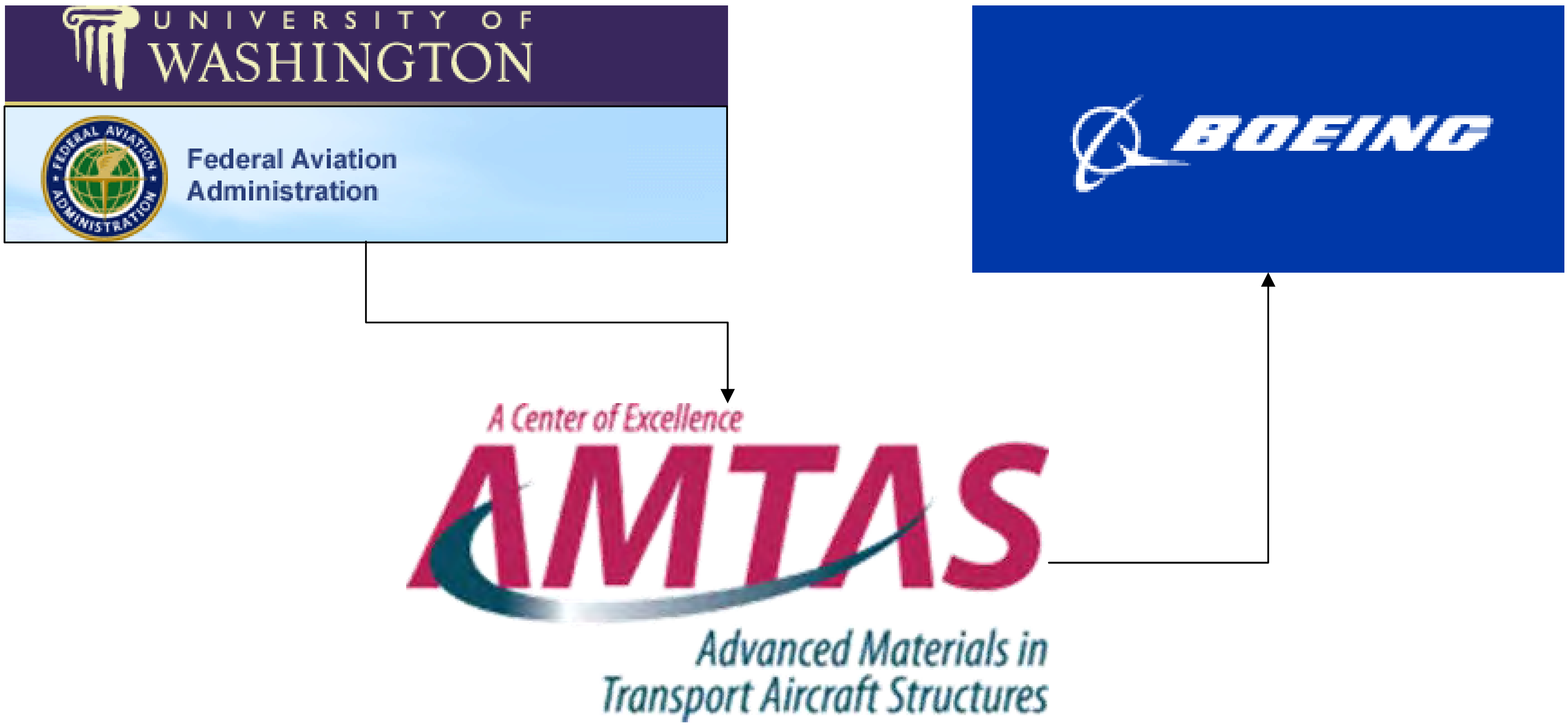
Potential Interaction



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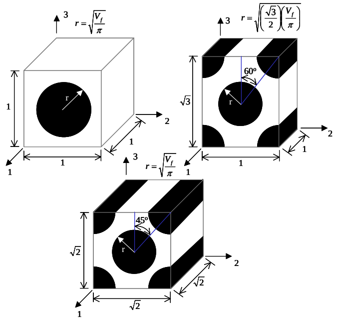
Phantom Works/IDS

Onset: Composite/Bonded Structure

Boeing Commercial
Onset/Propagation

Failure Theory Requirements

Requirement 1: Constitutive-Based Theories,
Explicit Micro-Mechanical Enhancement



Requirement 2: Fundamental Tensor Entities

$$\left|\eta_{ij} - \varphi\delta_{ij}\right| = -\varphi^3 + I_1\varphi^2 - I_2\varphi + I_3 = 0$$

Requirement 3: Small-Strain Anelasticity (*use the most efficient and most accurate measure*)

Requirement 4: Physically Consistent (*Satisfy the Easy Test Program*)

Consistent/Complete/Accurate/Addresses the General Condition

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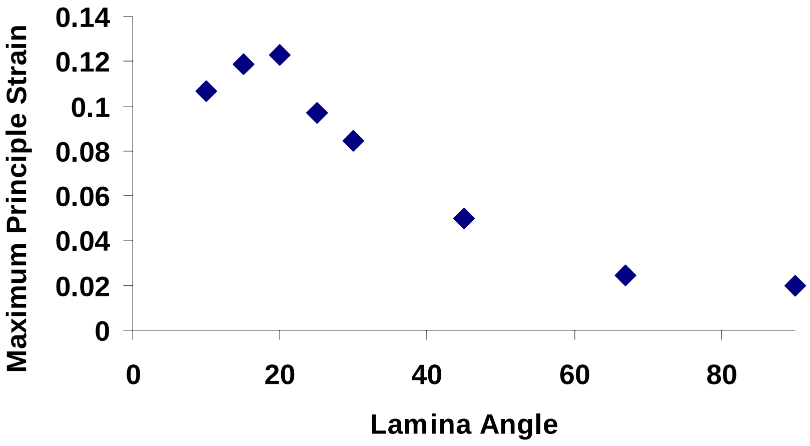
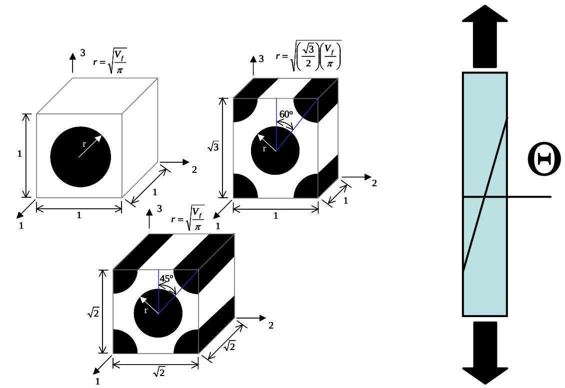
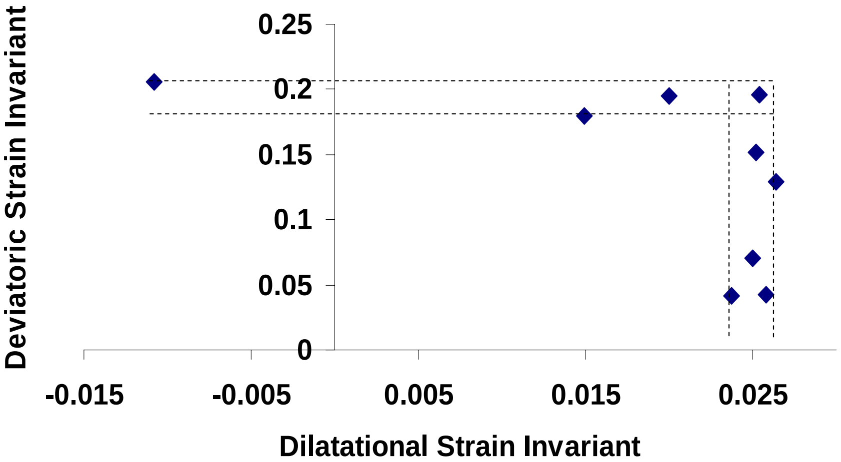
Easy Test Program

Easy Test Program





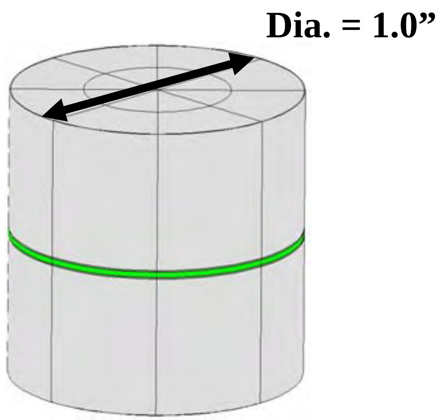
Physically Consistent

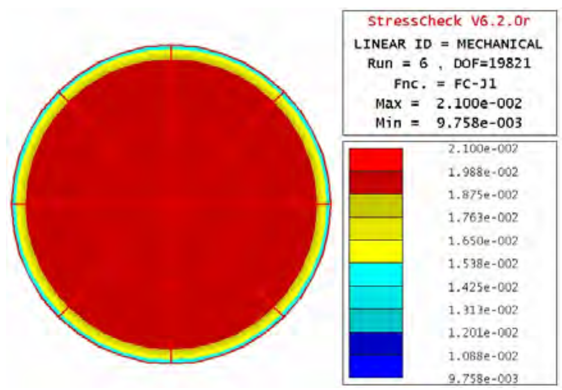


No Coupling Between Deformation Modes

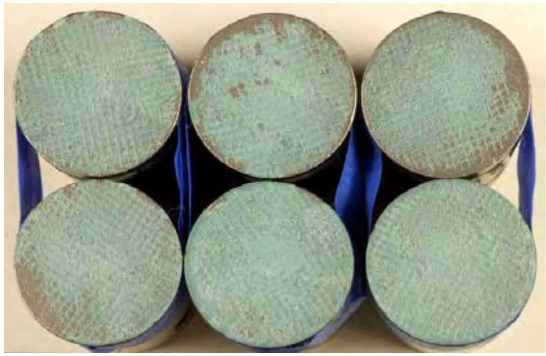
Easy Test Program

Flat-Wise Tension Specimen





Critical Dilatational Deformation



Journal of Macromolecular Science®, Part B: Physics, 44:993–1005, 2005

ISSN 0022-2348 print/1525-609X online
DOI: 10.1080/00222340500393881

Taylor & Francis

Yielding Behavior of Model Epoxy Matrices for Fiber Reinforced Composites: Effect of Strain Rate and Temperature

SHABNAM BEHZADI AND FRANK R. JONES

Department of Engineering Materials, The University of Sheffield, Sheffield, UK

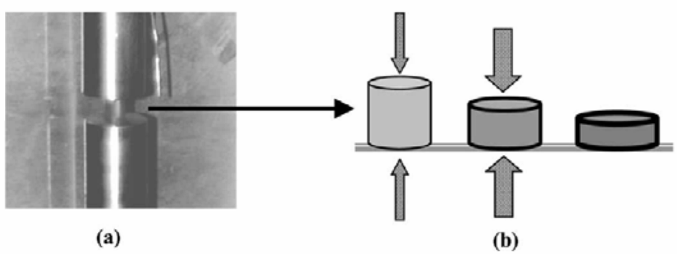


Figure 2. (a) The cylindrical specimen under the load between crossheads (b) Schematic of compression progress before and after applying the load.

Critical Deviatoric Deformation

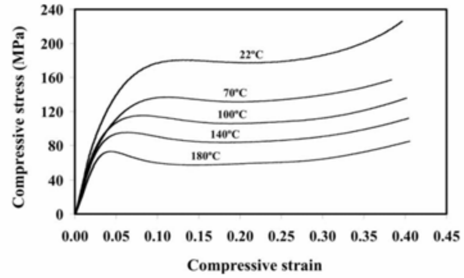
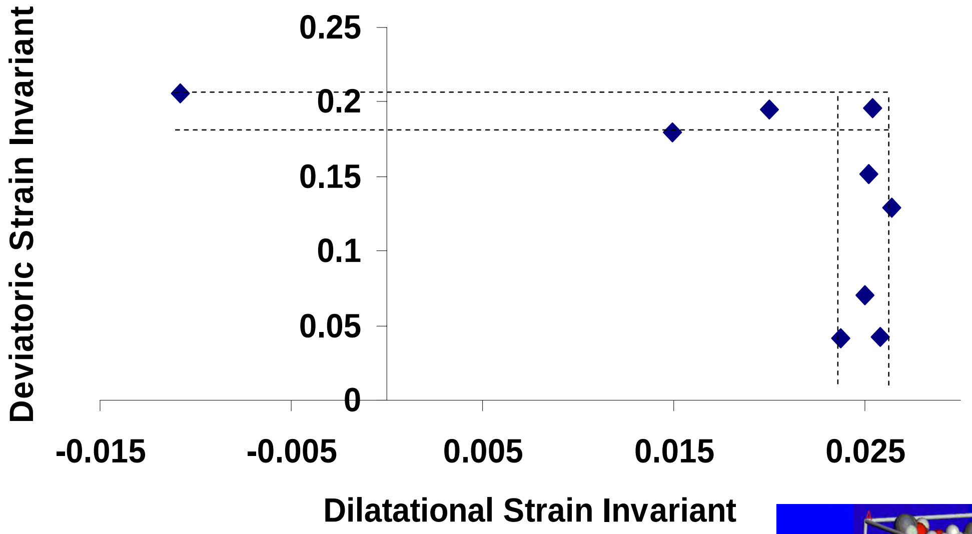
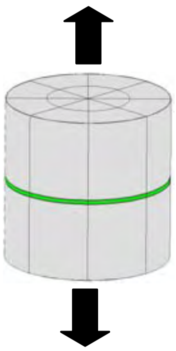
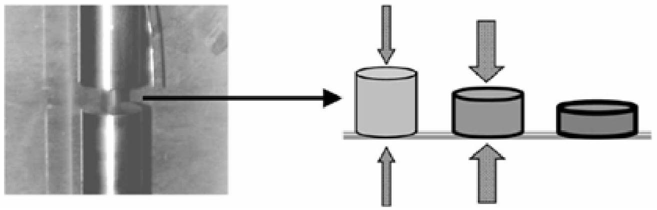


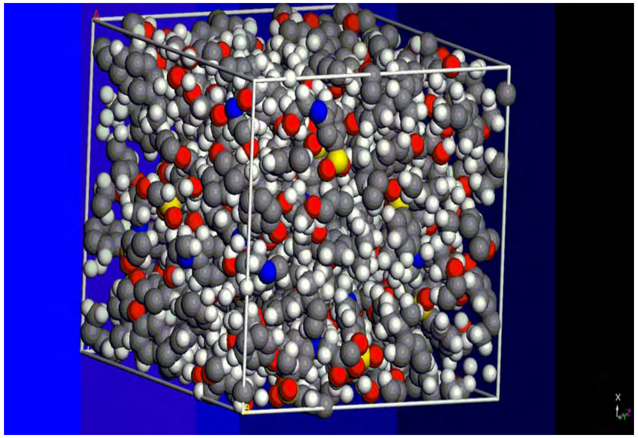
Figure 3. True compressive strain-stress curves of MY0510/DDS over a range of temperatures at strain rate of $1.67 \times 10^{-3}\,s^{-1}$.

Easy Test Program









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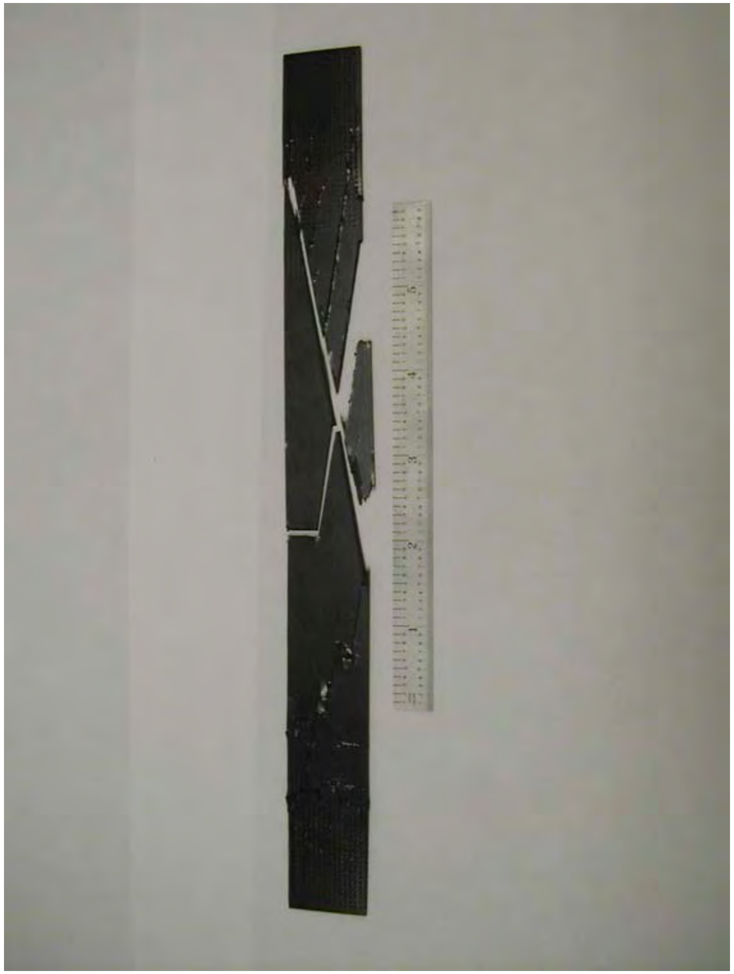
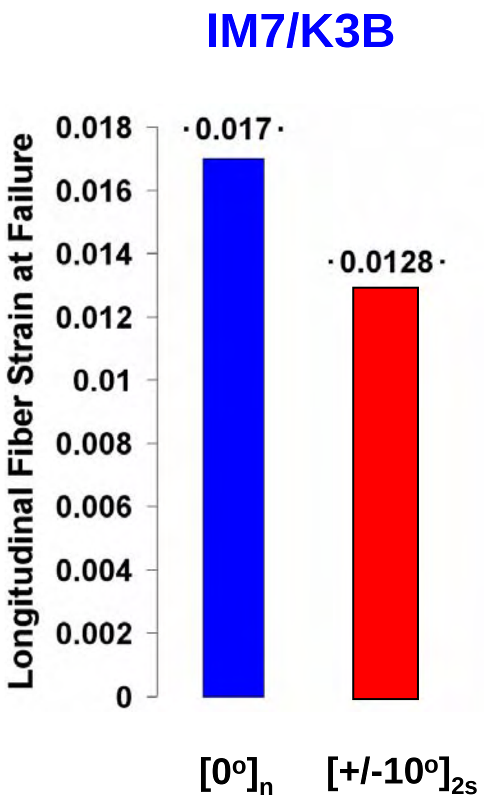
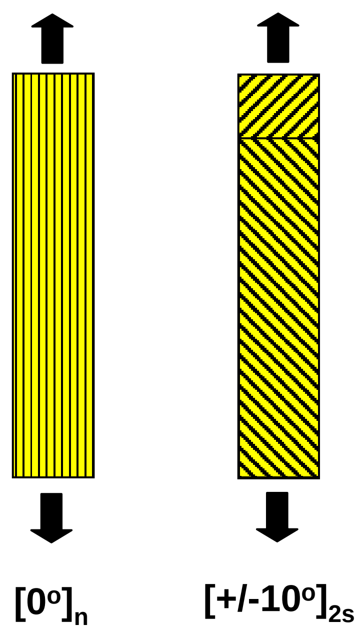
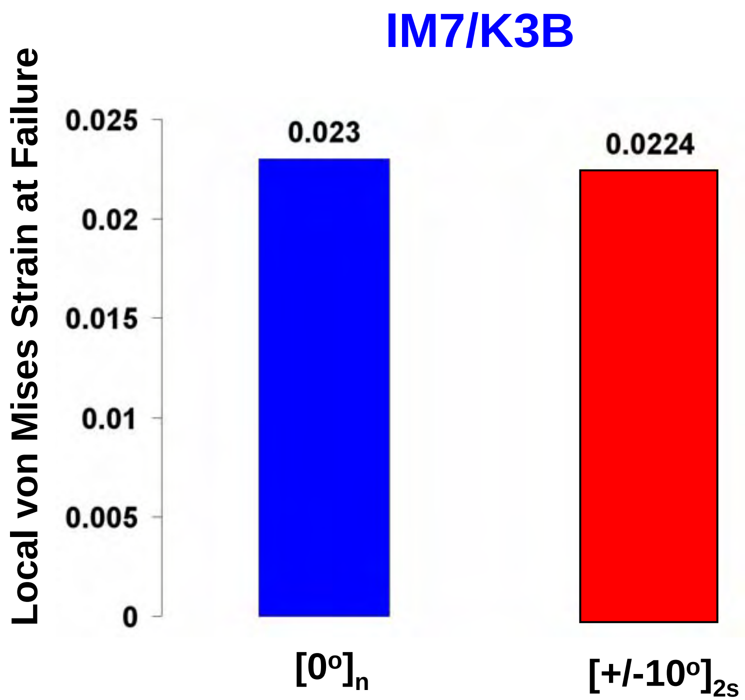
Easy Test Program



Easy Test Program







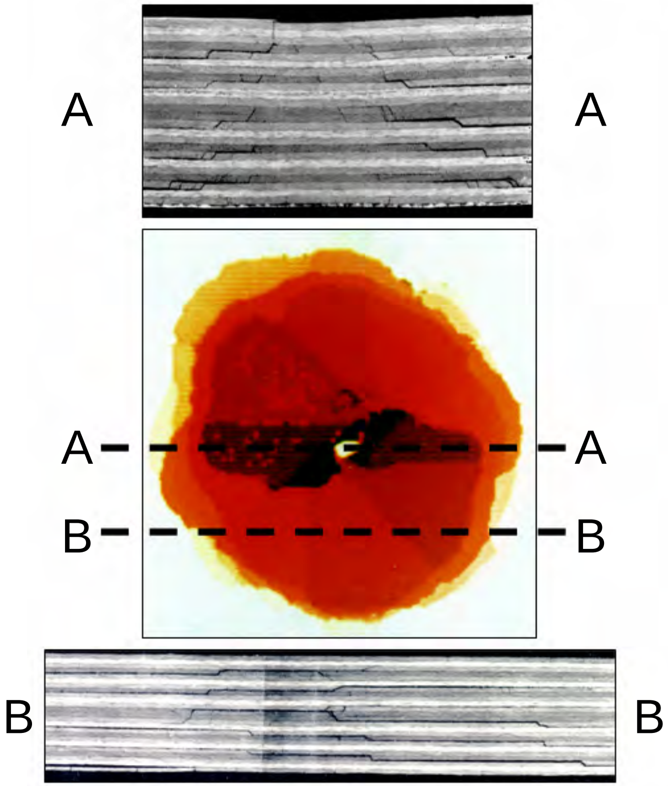
Damage Algorithm Requirements

$$[K][a] = [f]$$

$[K][a] = [f]$; Arbitrary Input, Solution is No Longer Unique and Can be Numerically Unstable

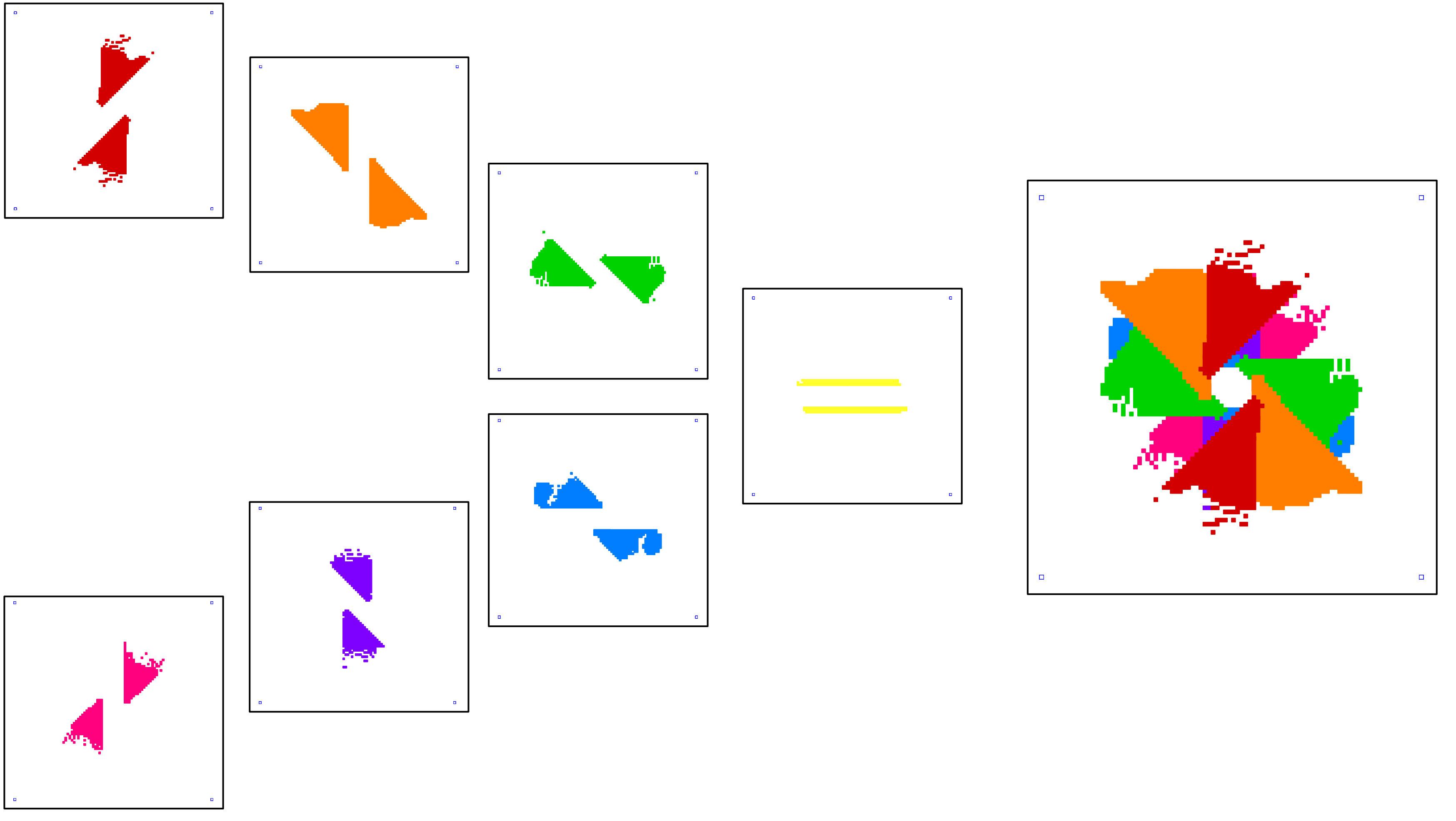
➡ $[K][a] = [f]$; No Arbitrary Input, Solution Remains Unique and Numerically Stable

Smart Algorithm for a Problem Class

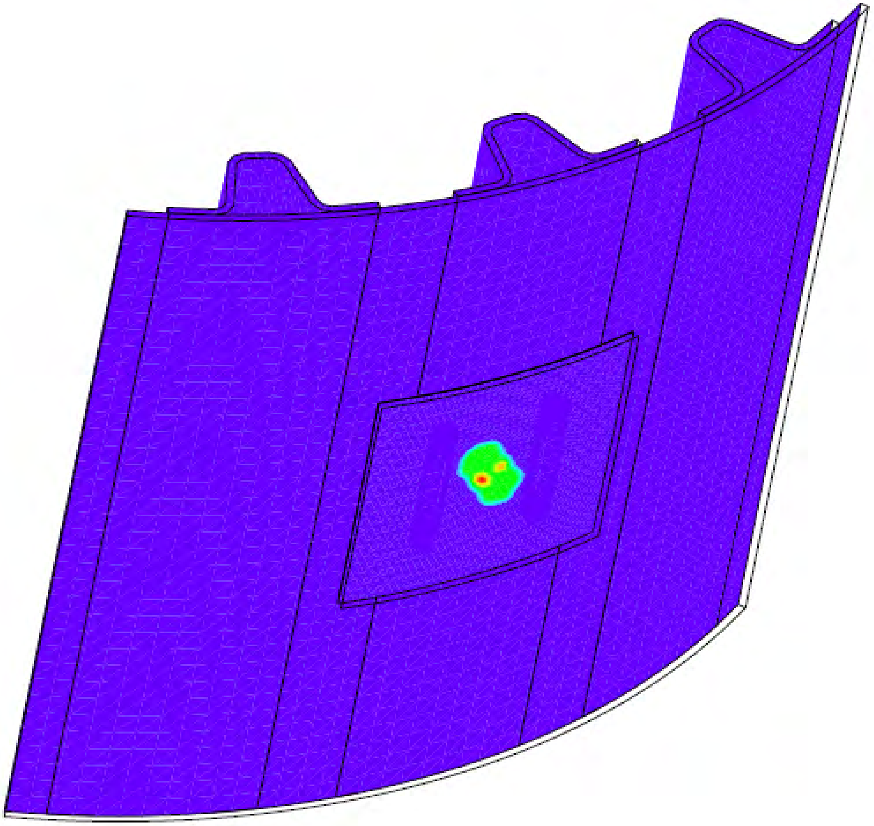


(45/0/-45/90)3s

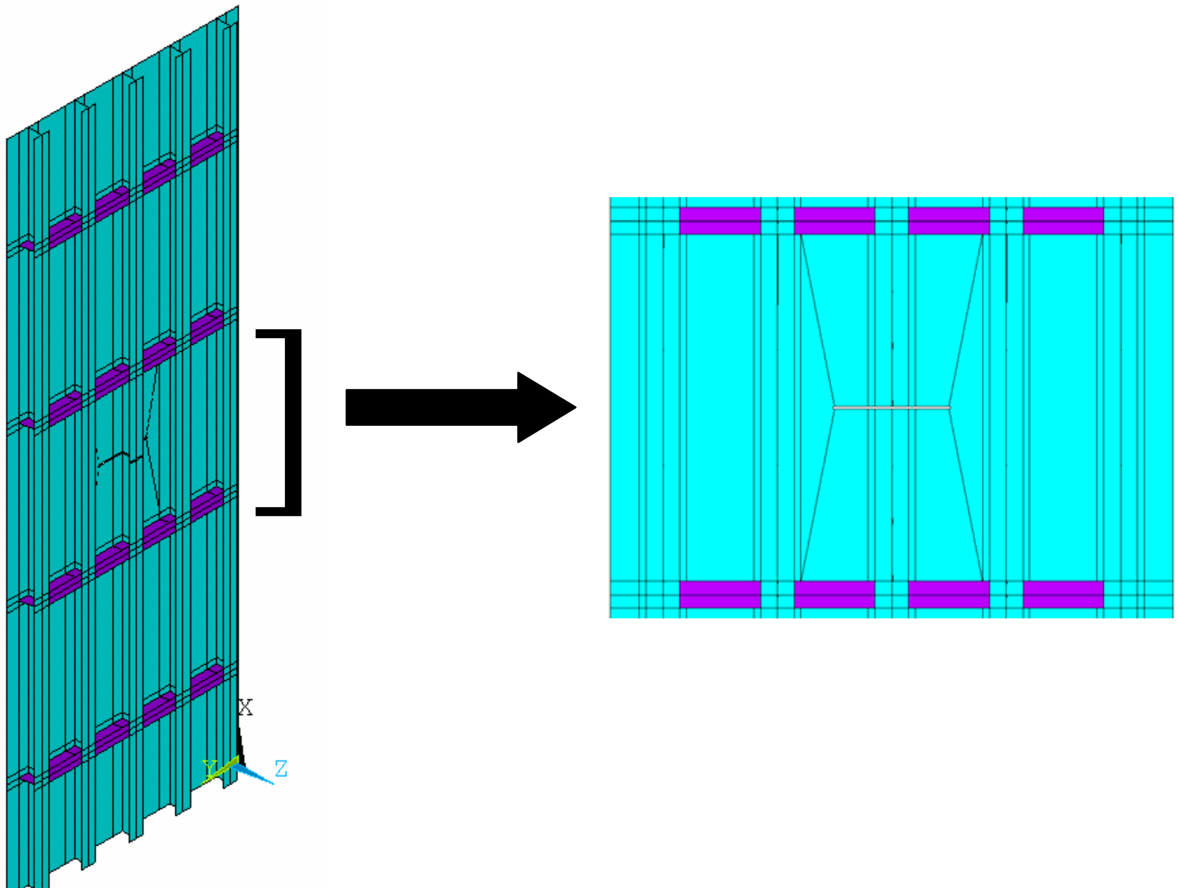
Smart Algorithm for a Problem Class



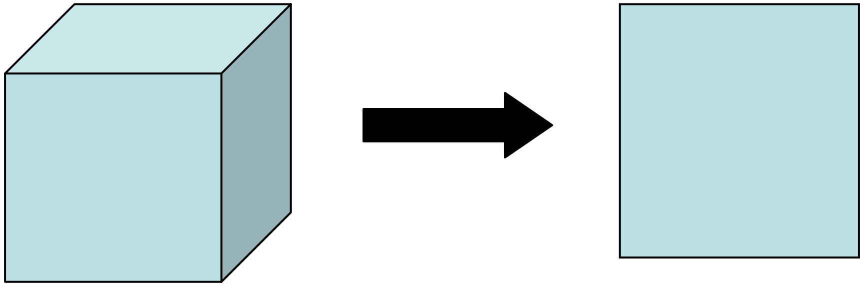
Smart Algorithm for a Problem Class



Smart Algorithm for a Problem Class



Smart Algorithm for a Problem Class

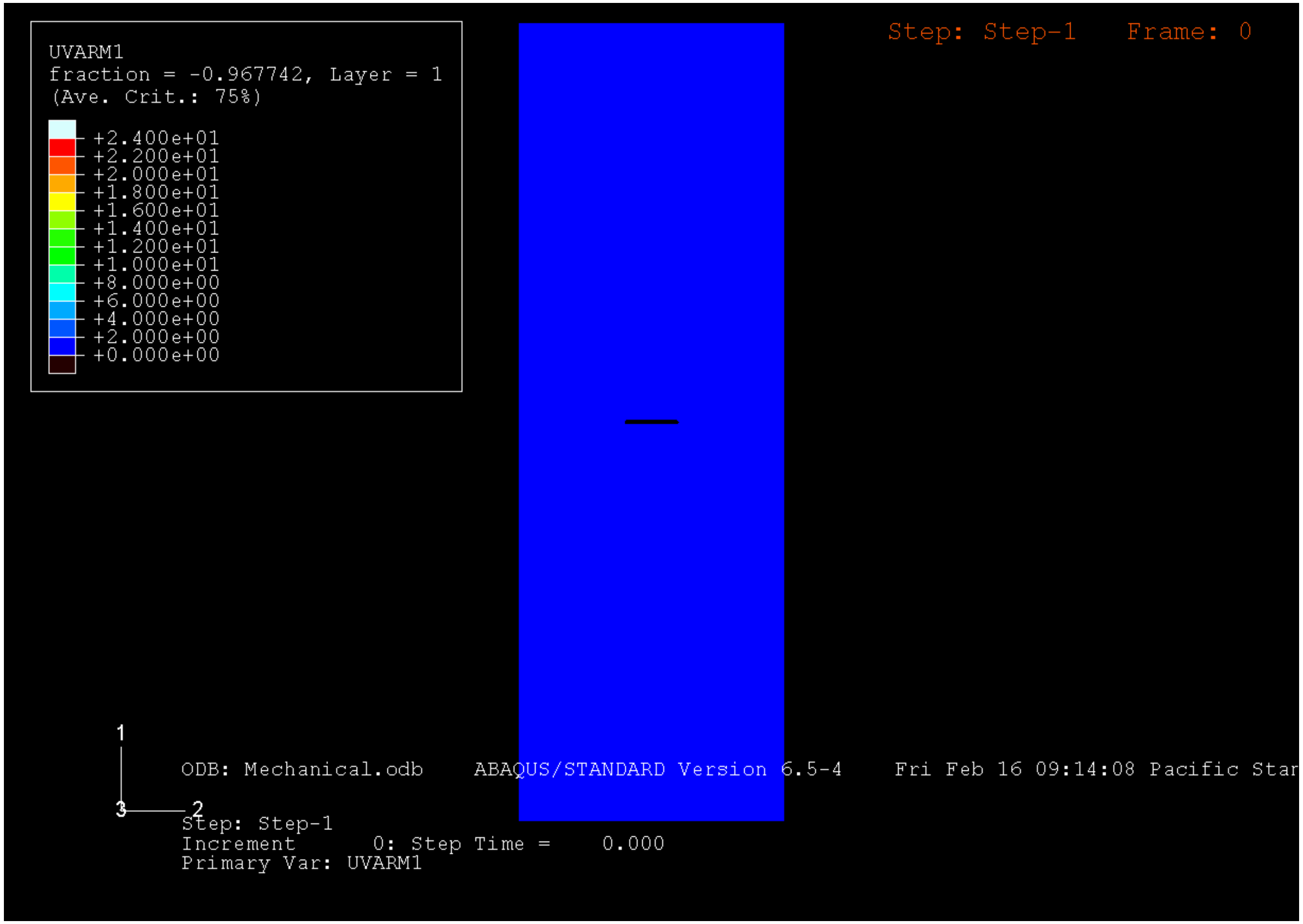


$$\Omega = \Gamma(\varphi)$$

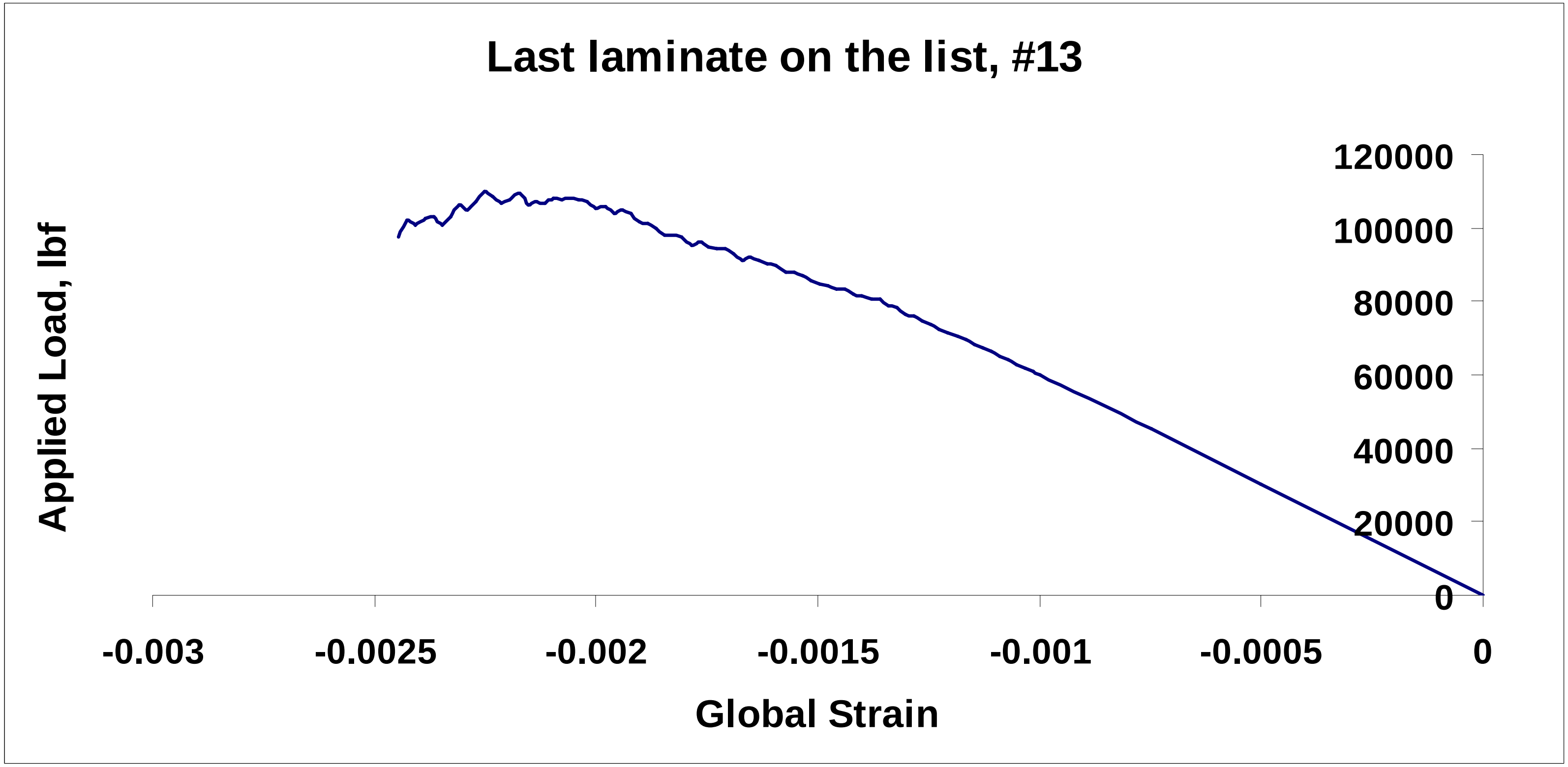
Preliminary Results (W/NL=5.0 & L/W=3.0 *arbitrary normalization)

Laminate Layup	Notch Length (in.)	Nominal Thickness (in.)	Average Failure Stress (Far-Field), ksi
1) 39/52/9	1	0.1702	0.672
2) 39/52/9	2	0.1702	0.540
3) 39/52/9	4	0.1702	0.404
4) 40/50/10	1	0.2960	0.844
5) 40/50/10	2	0.2960	0.676
6) 40/50/10	1	0.5920	0.952
7) 40/50/10	2	0.5962	0.764
8) 50/40/10	4	0.1480	0.400
9) 25/50/25	4	0.2368	0.683
10) $[(+/-15)/(+/-60)/(+/-15)_3/(+/-60)/(+/-15)_2]s$	4	0.2368	0.460
11) $[((+/-15)/(+/-60))_4]_s$	4	0.2368	0.474
12) $(45/(+/-5)/-45/90/-45/(-/+5)/(45)_2/(+/-5)/-45/90/-45/(-/+5)/45/-45/+/-5)/45)_s$	4	0.3256	0.522
13) $(+/5)/45/(+/-5)_2/-45/90/-45/(-/+5)_2/45/90/45/(+/-5)_2/-45/90/-45/(-/+5)_2/45/(-/+5)$	4	0.2294	0.478

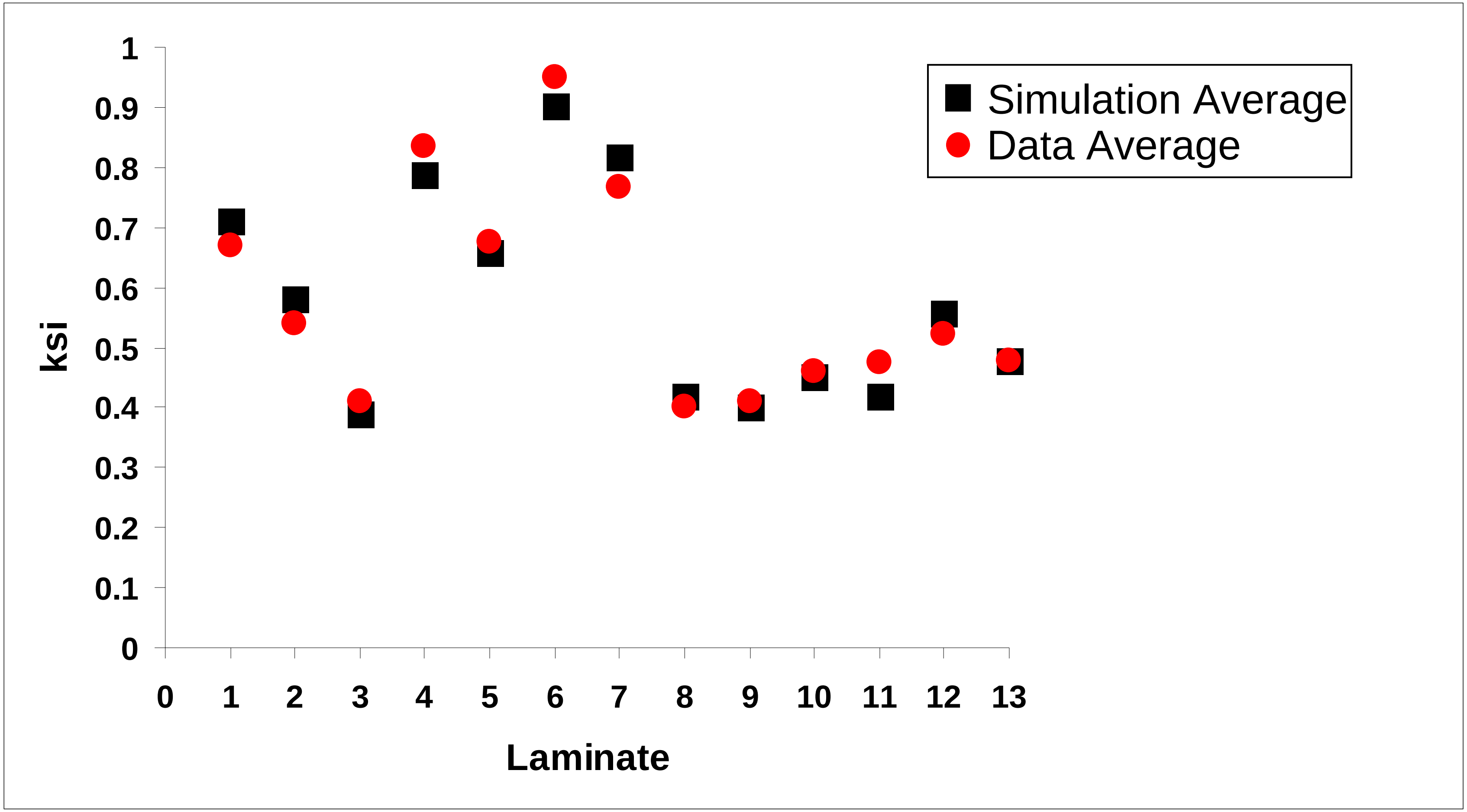
Representative Damage Progression



Representative Load-Global Strain Simulation



Preliminary Results



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Current Government Interaction

NAVAIR
NAVAL AIR SYSTEMS COMMAND

NAE

AFRL
THE AIR FORCE RESEARCH LABORATORY
LEAD | DISCOVER | DEVELOP | DELIVER

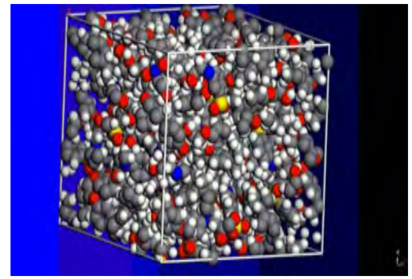
CRC-ACS

UNSW

CSIRO

University Interaction

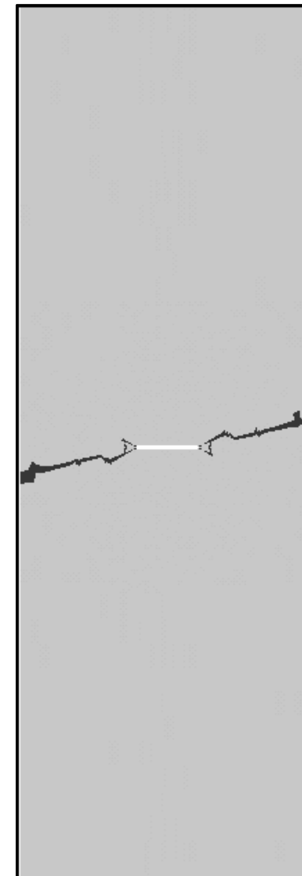
THE UNIVERSITY OF SOUTHERN MISSISSIPPI

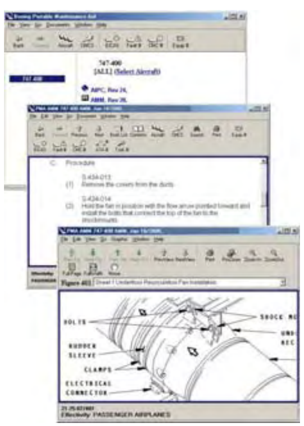


Georgia Tech

Vibration SDL

NUS National University of Singapore





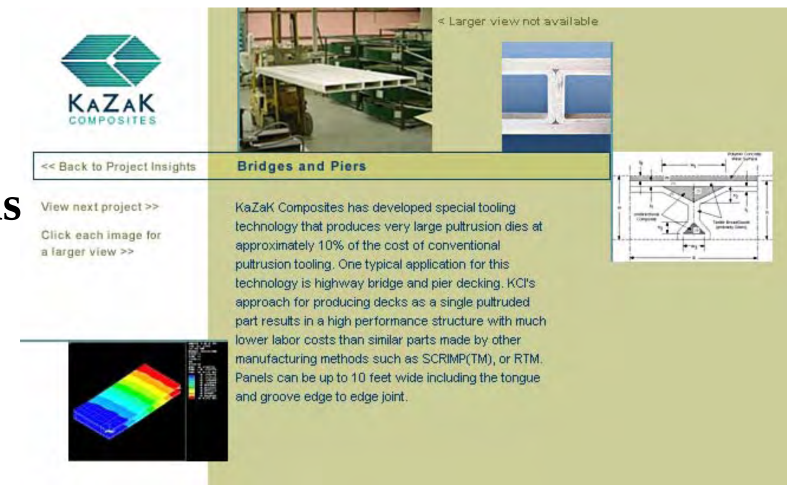
Leland Stanford Junior University 1891

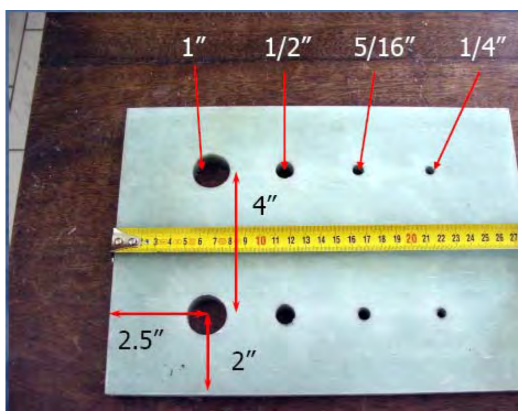
University of Bolton

Small Business Interaction

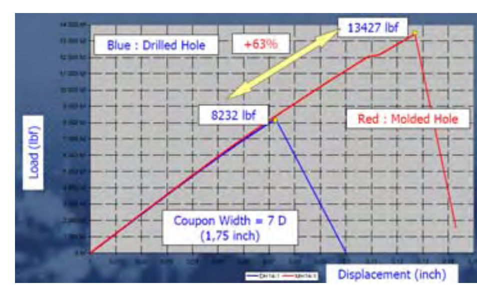
p-Element Technology

Non-Aerospace Applications

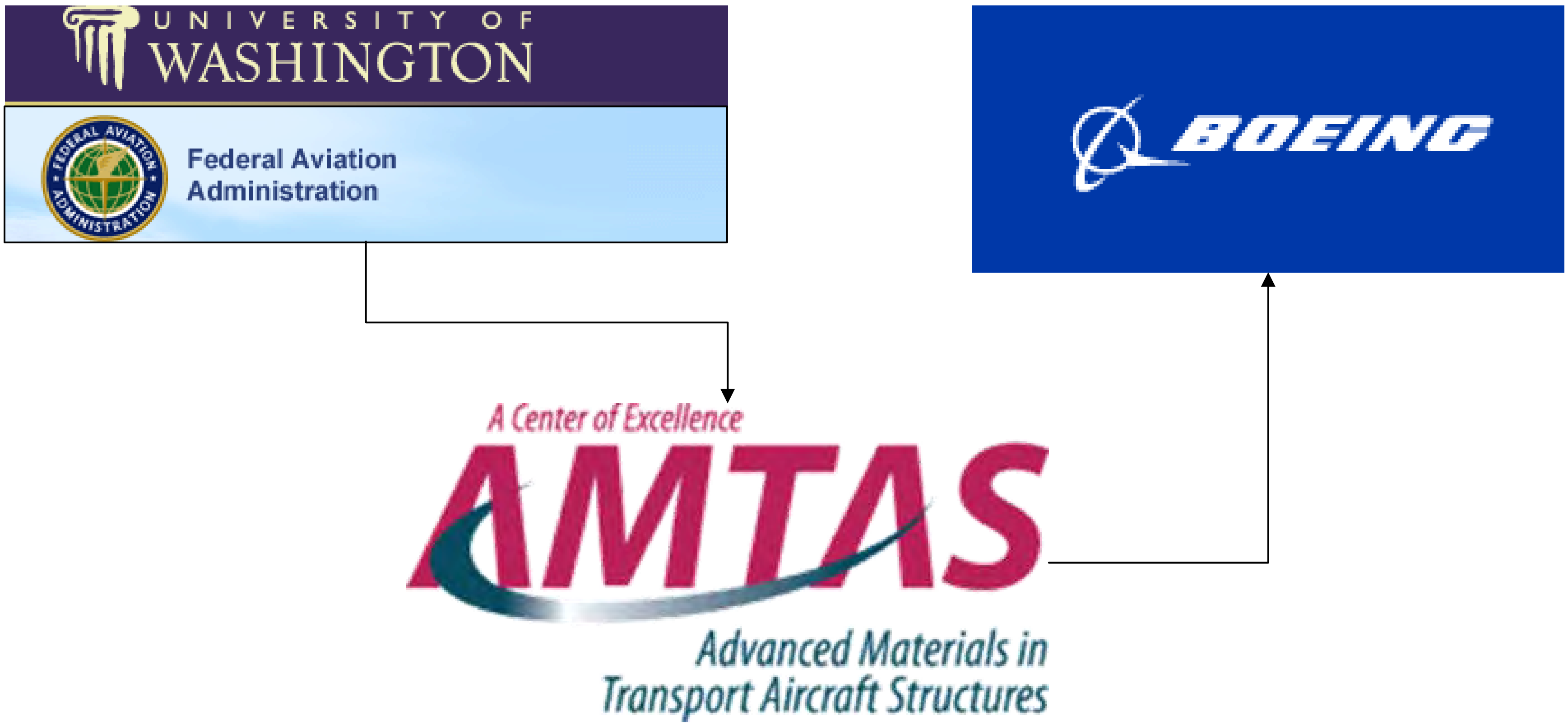




Molded Holes



Potential Interaction



Potential Interaction

- **Funding**
- **In-Depth Studies to Support the Evaluation**
- **Start Slow, Low Level**
- **Establish Relationships**
- **Flexible in Content and Time**
- **Discussion**