FULL-SCALE DAMAGE TOLERANCE OF COMPOSITE SANDWICH STRUCTURES

J.S. Tomblin & K.S. Raju
National Institute for Aviation Research

A Center of Excellence AMTAS Advanced Materials in Transport Aircraft Structures

WICHITA STATE UNIVERSITY

CECAM Center of excellence for composites and advanced materials

The Joint Advanced Materials and Structures Center of Excellence

FAA Sponsored Project Information

- Principal Investigators & Researchers
  - J.S. Tomblin
  - K.S. Raju, J. Dietiker
  - J. Bakuckas
- FAA Technical Monitor
  - Curtis Davis
- Other FAA Personnel Involved
  - F. Leone (Drexel Co-op)
- Industry Participation
  - Adam Aircraft Co.(P. Harter, B. Allbritten)
  - Toray Composites (L. Cook)
  - NSE Composites (T. Walker)
  - Hostert Technical Services (R. Hostert)
  - Peter Rohl (Advatech Pacific)

FULL-SCALE DAMAGE TOLERANCE OF COMPOSITE SANDWICH STRUCTURES

Background

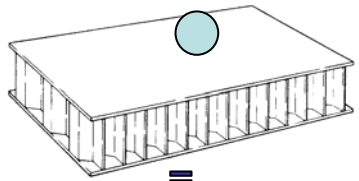
- **Literature Review**
- **Experimental Investigation of Damage Resistance & Tolerance**
- **NDI Techniques, Curvature effects, Fatigue**
- **Design of experiments, CAI modeling**
- **Scaling effects**
- **Open-Hole Testing**
- **Independent Review**

1998

1999

2001

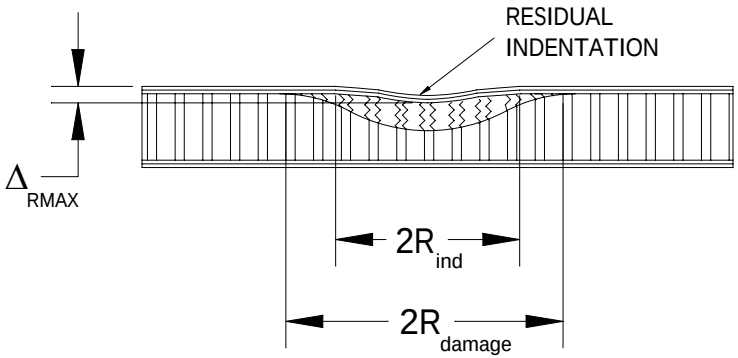
2004

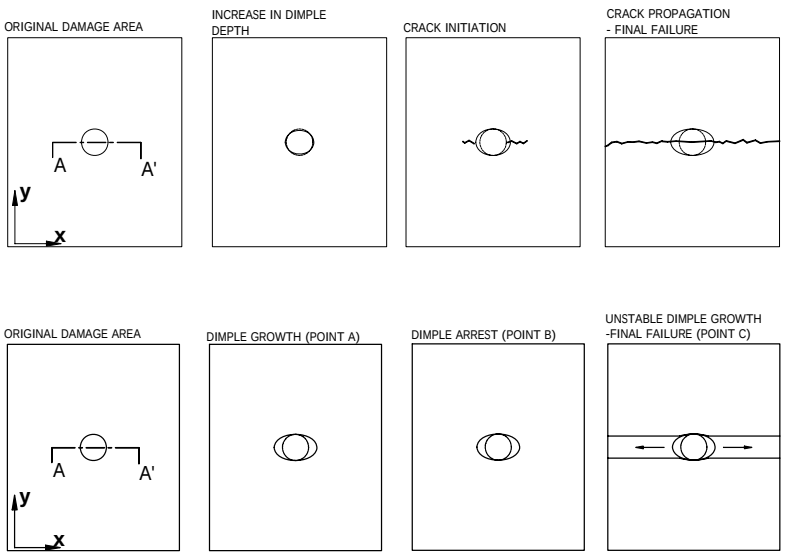


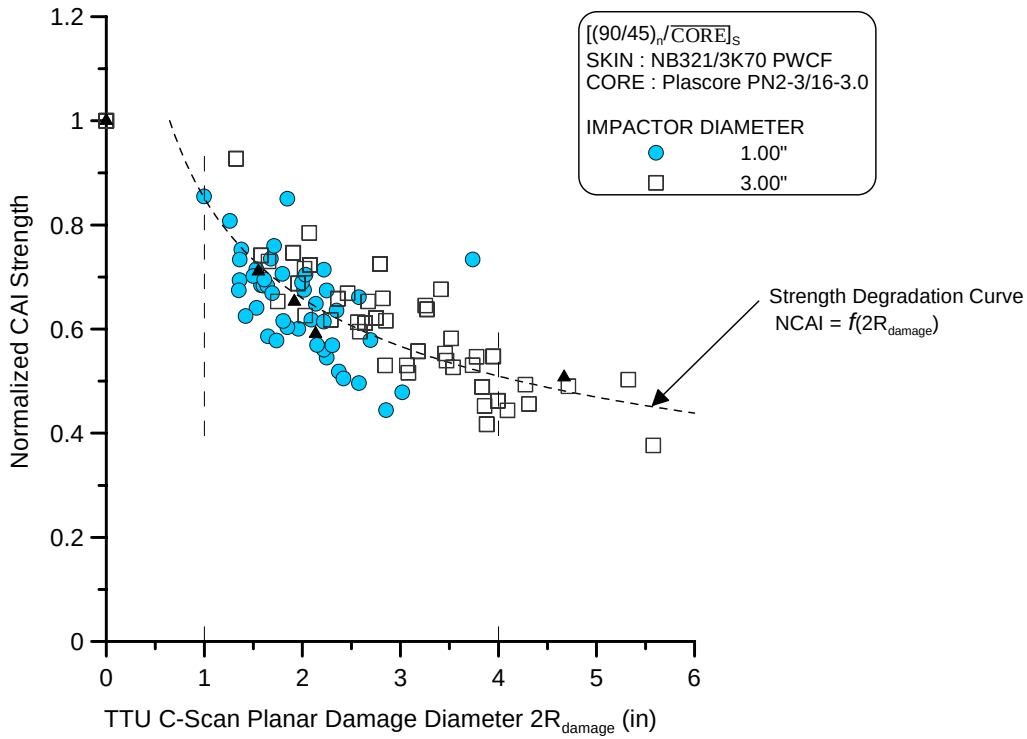
REPORTS-

DOT/FAA/AR-99/49, 1999
DOT/FAA/AR-00/44, 2001
DOT/FAA/AR-02/80, 2002
DOT/FAA/AR-02/121, 2003
DOT/FAA/AR-03/75, 2004
DOT/FAA/AR-0?/??, 2005

FULL-SCALE DAMAGE TOLERANCE OF COMPOSITE SANDWICH STRUCTURES

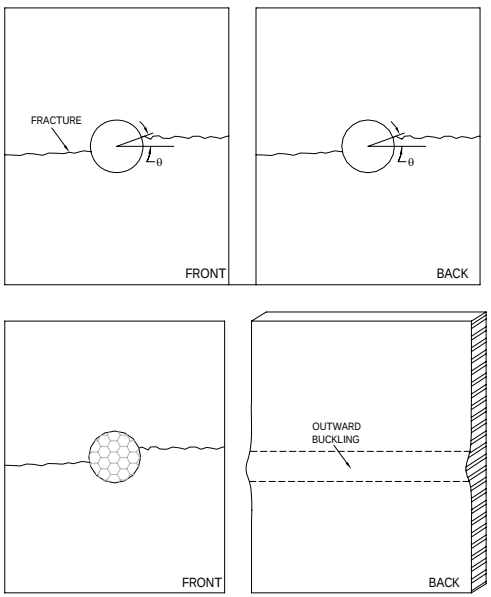


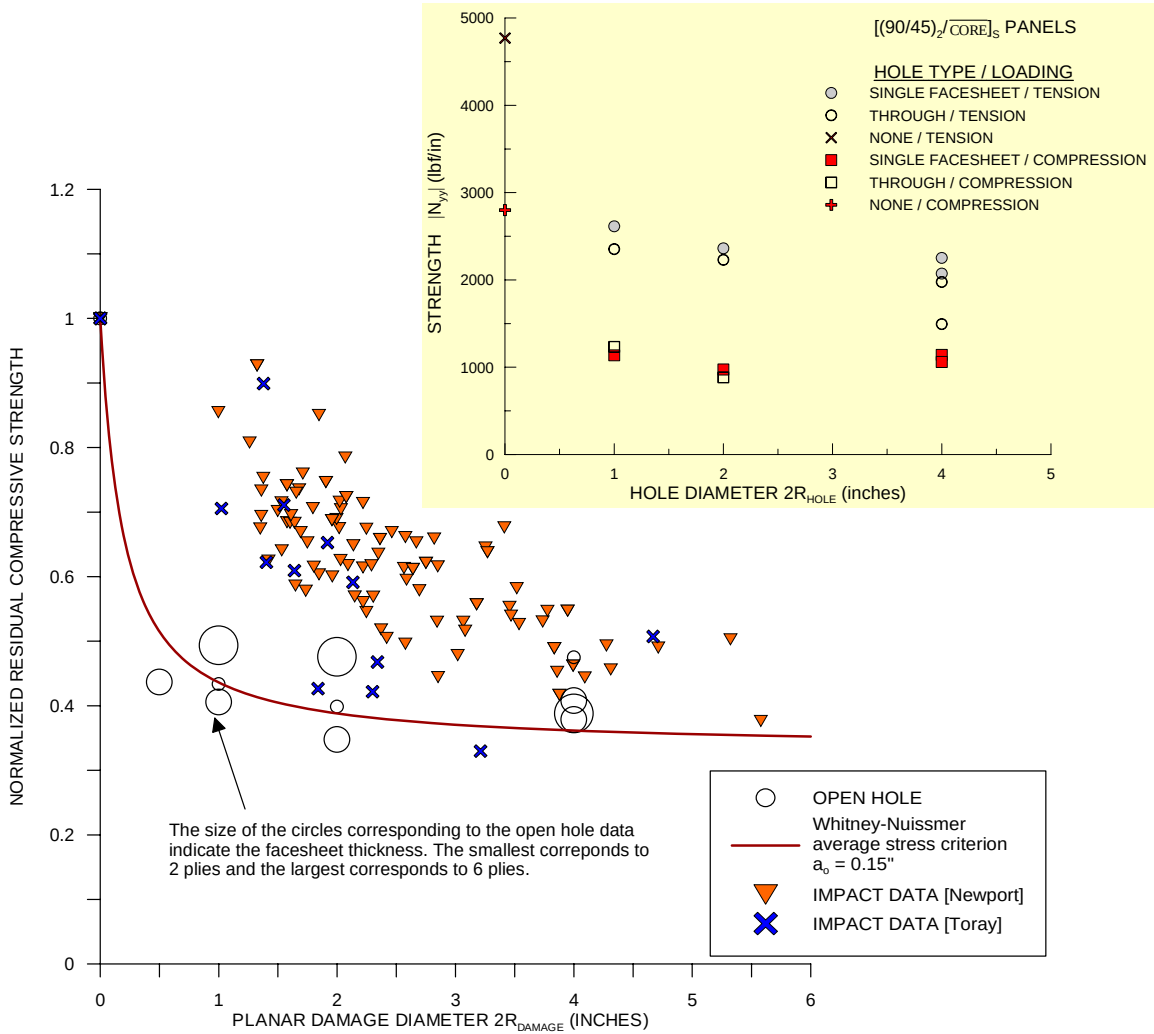




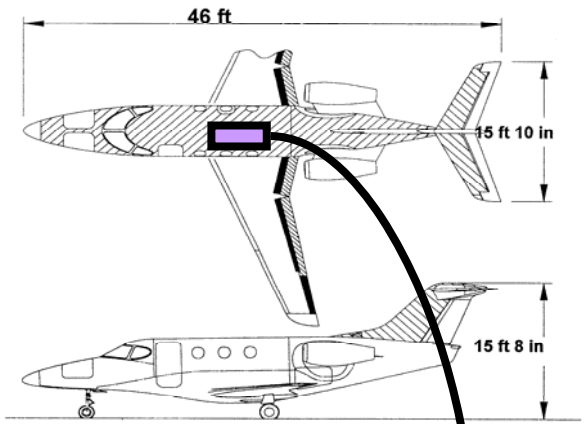
FULL-SCALE DAMAGE TOLERANCE OF COMPOSITE SANDWICH STRUCTURES

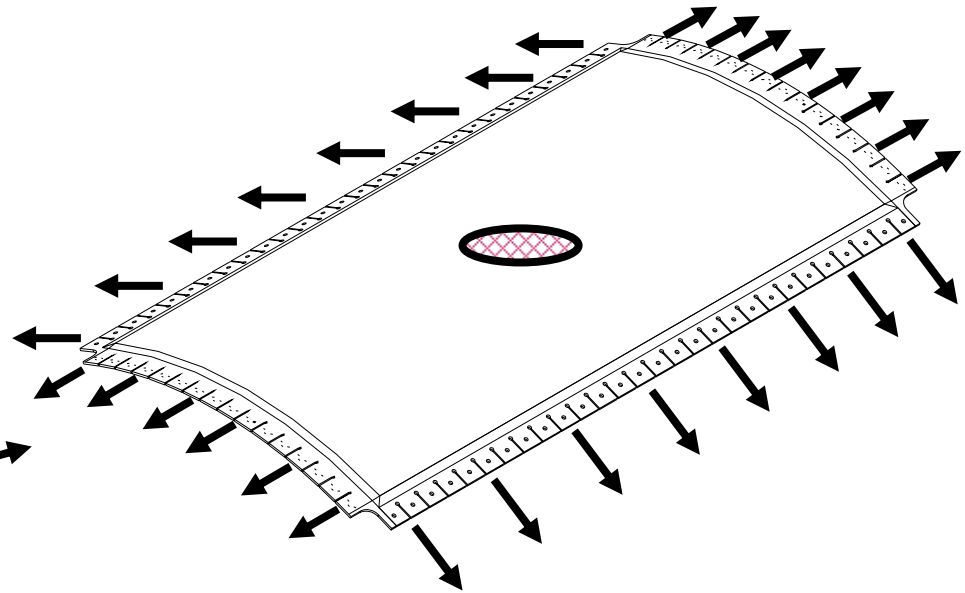
- **Critical Damage States**
  - **IMPACT DAMAGE – Load transfer through damage region**
  - **OPEN HOLE – No load transfer through damage region**



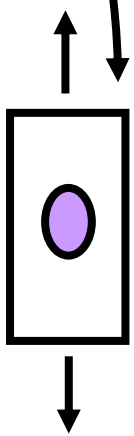


FULL-SCALE DAMAGE TOLERANCE OF COMPOSITE SANDWICH STRUCTURES





- Coupon Level Testing
- Uniaxial Loading

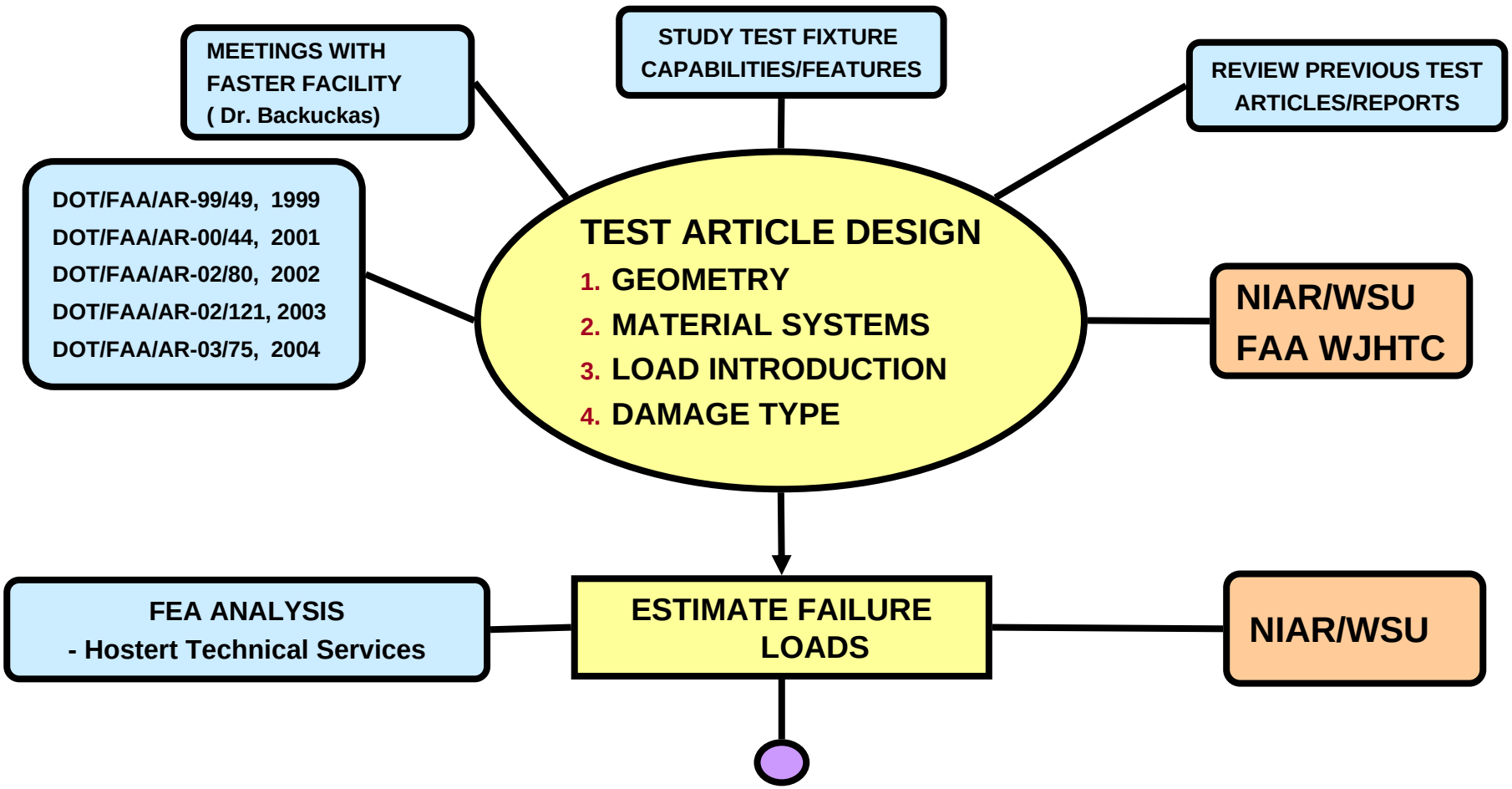


- Full-scale testing
- Combined loading – Longitudinal, Hoop & pressurization.

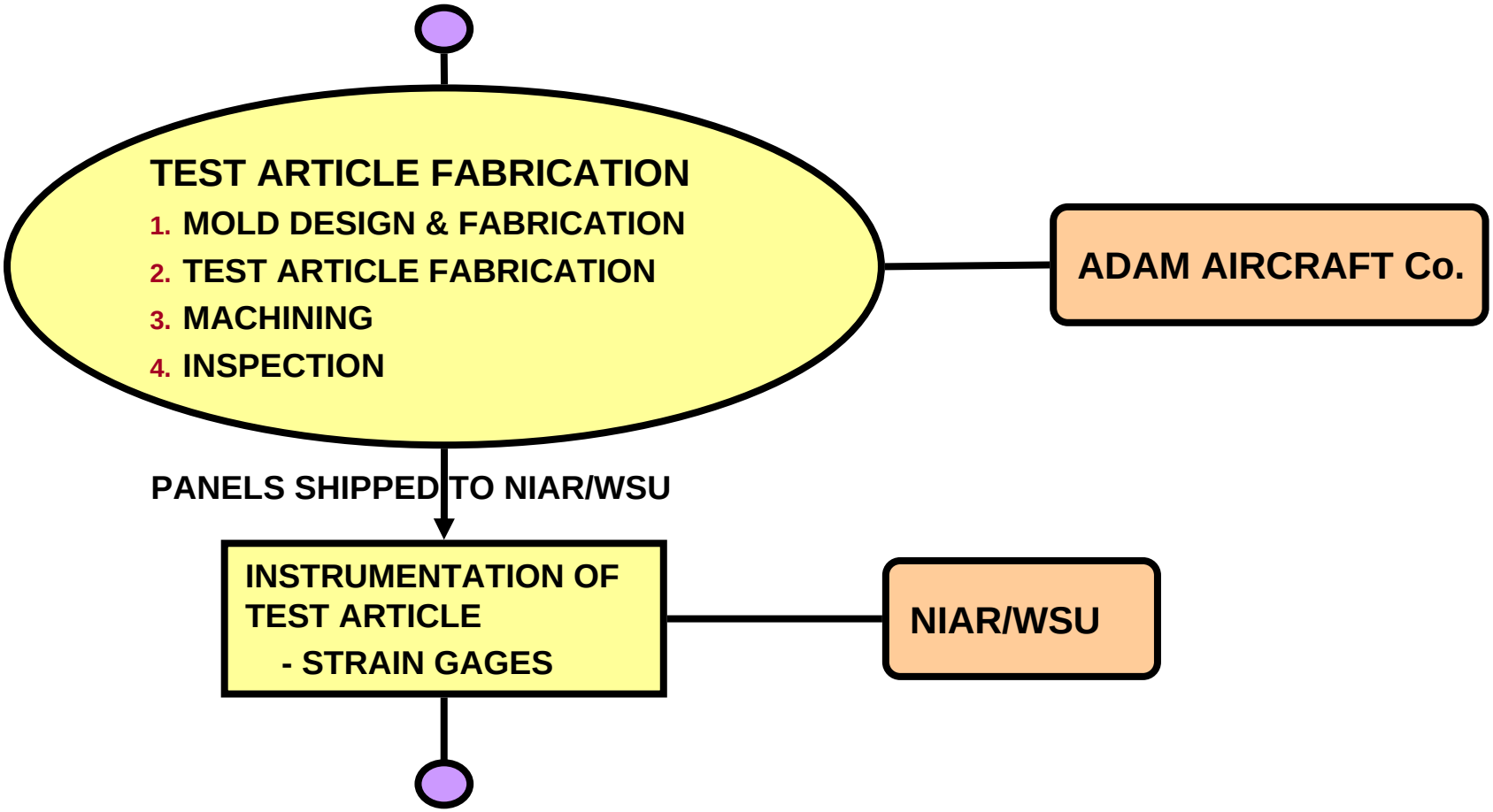
FULL-SCALE DAMAGE TOLERANCE OF COMPOSITE SANDWICH STRUCTURES

- Objectives
  - Design, fabrication & Testing of sandwich test article(s) under combined loading at WJHTC test facility
    - Material Systems & Sandwich Configuration
    - Geometry
    - Load-introduction
      - Attachments,etc.
    - Damage configurations – notches, holes, impact damage, etc..
    - Instrumentation
    - Loading Scenarios
    - Failure load predictions
    - Testing

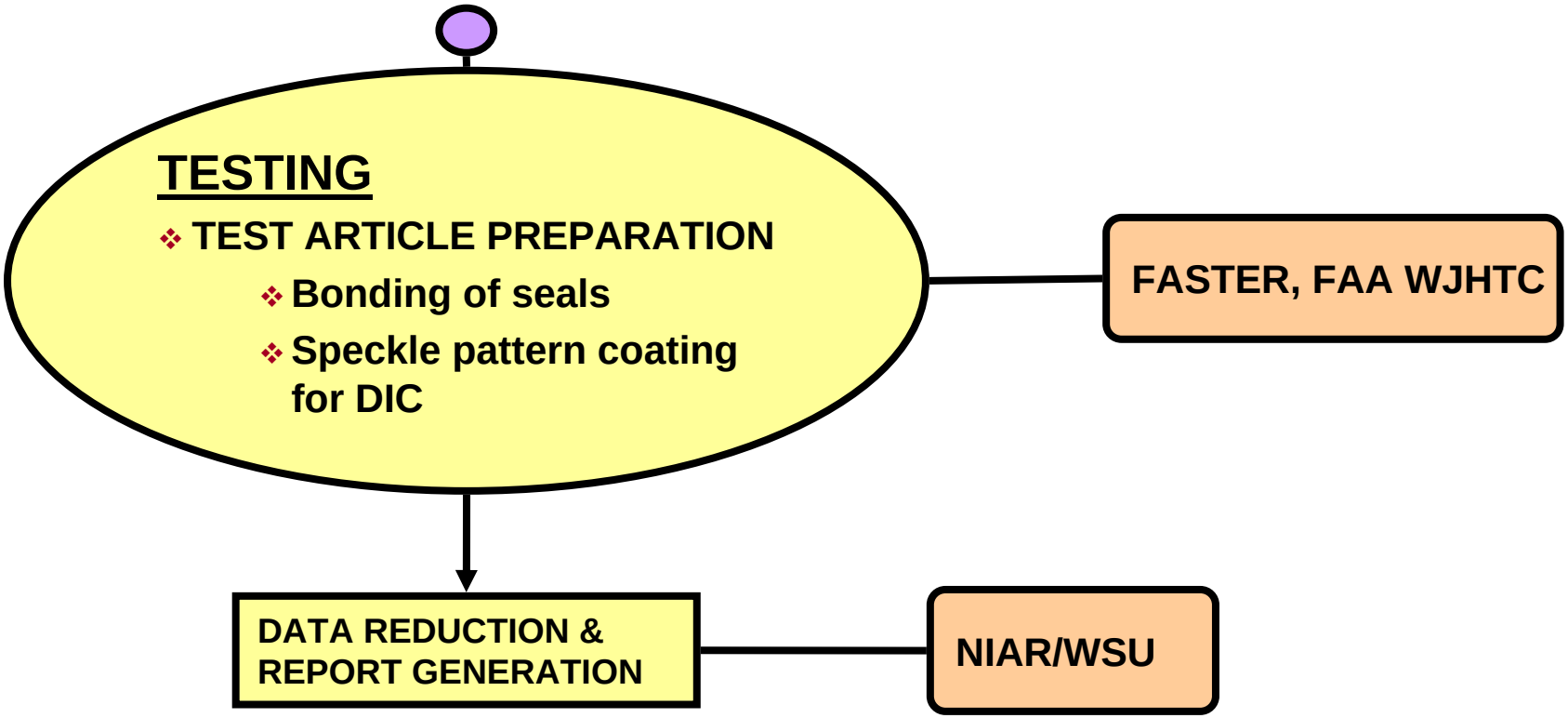
APPROACH


MEETINGS WITH FASTER FACILITY (Dr. Backuckas)
STUDY TEST FIXTURE CAPABILITIES/FEATURES
REVIEW PREVIOUS TEST ARTICLES/REPORTS
DOT/FAA/AR-99/49, 1999
DOT/FAA/AR-00/44, 2001
DOT/FAA/AR-02/80, 2002
DOT/FAA/AR-02/121, 2003
DOT/FAA/AR-03/75, 2004
TEST ARTICLE DESIGN
1. GEOMETRY
2. MATERIAL SYSTEMS
3. LOAD INTRODUCTION
4. DAMAGE TYPE
NIAR/WSU
FAA WJHTC
FEA ANALYSIS
- Hostert Technical Services
ESTIMATE FAILURE LOADS
NIAR/WSU

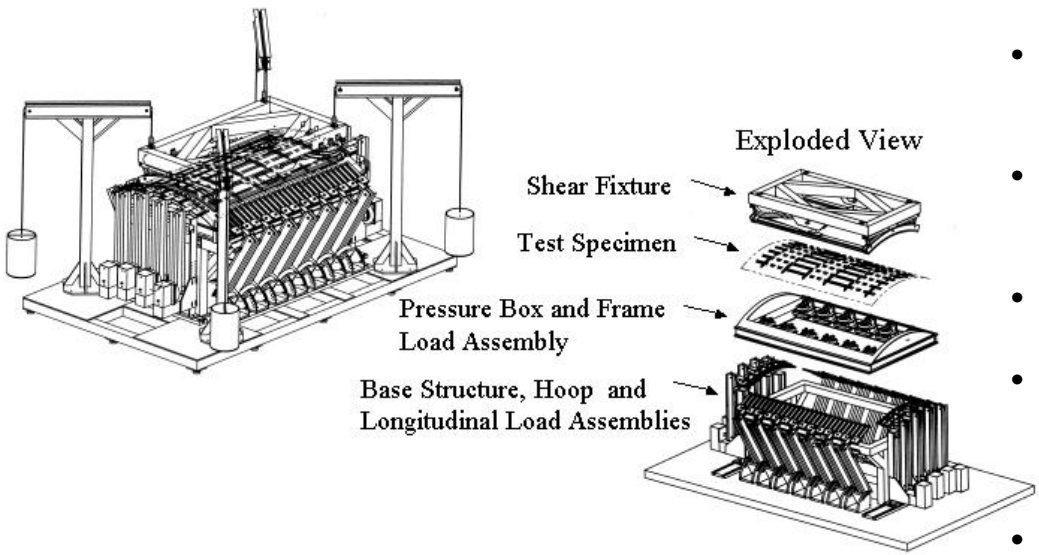
APPROACH


TEST ARTICLE FABRICATION
1. MOLD DESIGN & FABRICATION
2. TEST ARTICLE FABRICATION
3. MACHINING
4. INSPECTION
ADAM AIRCRAFT Co.
PANELS SHIPPED TO NIAR/WSU
INSTRUMENTATION OF TEST ARTICLE
- STRAIN GAGES
NIAR/WSU

APPROACH


TESTING
TEST ARTICLE PREPARATION
Bonding of seals
Speckle pattern coating for DIC
FASTER, FAA WJHTC
DATA REDUCTION & REPORT GENERATION
NIAR/WSU

Full-Scale Aircraft Structural Test Evaluation & Research (FASTER) Fixture



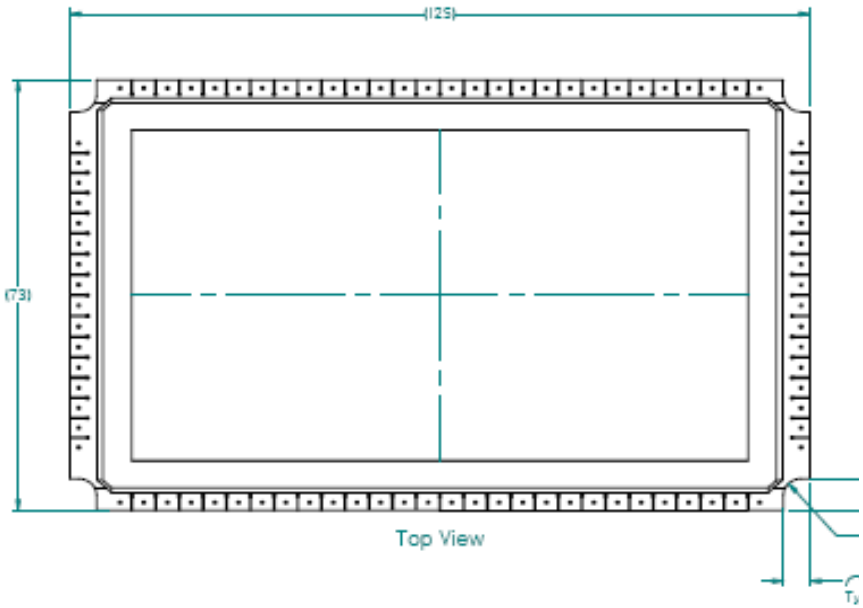
TEST FIXTURE SPECIFICATIONS[Ref]

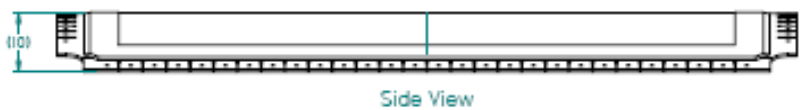
- **Longitudinal loading**
  - 1800 lbf/in
  - 16 load introduction points
- **Circumferential (Reactive) loading**
  - 1800 lbf/in
  - 28 load introduction points
- **Frame Loads**
  - 360 lbf/in
- **Pressurization loading**
  - 15 psi
  - Water / Air

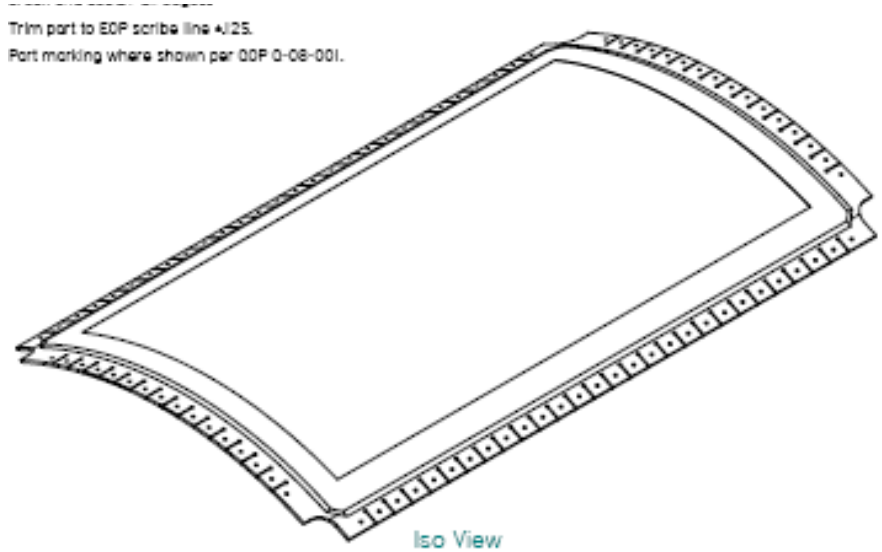
- **SPECIMEN GEOMETRY**
  - Radius : 60 – 130 inches (** 74 inches)
  - Length : 120 inches
  - Width : 68 inches

Ref. *John Bakuckas, "Full-Scale Testing and Analysis of Fuselage Structure containing Multiple Cracks," DOT/FAA/AR-01/46.*

TEST ARTICLE GEOMETRY







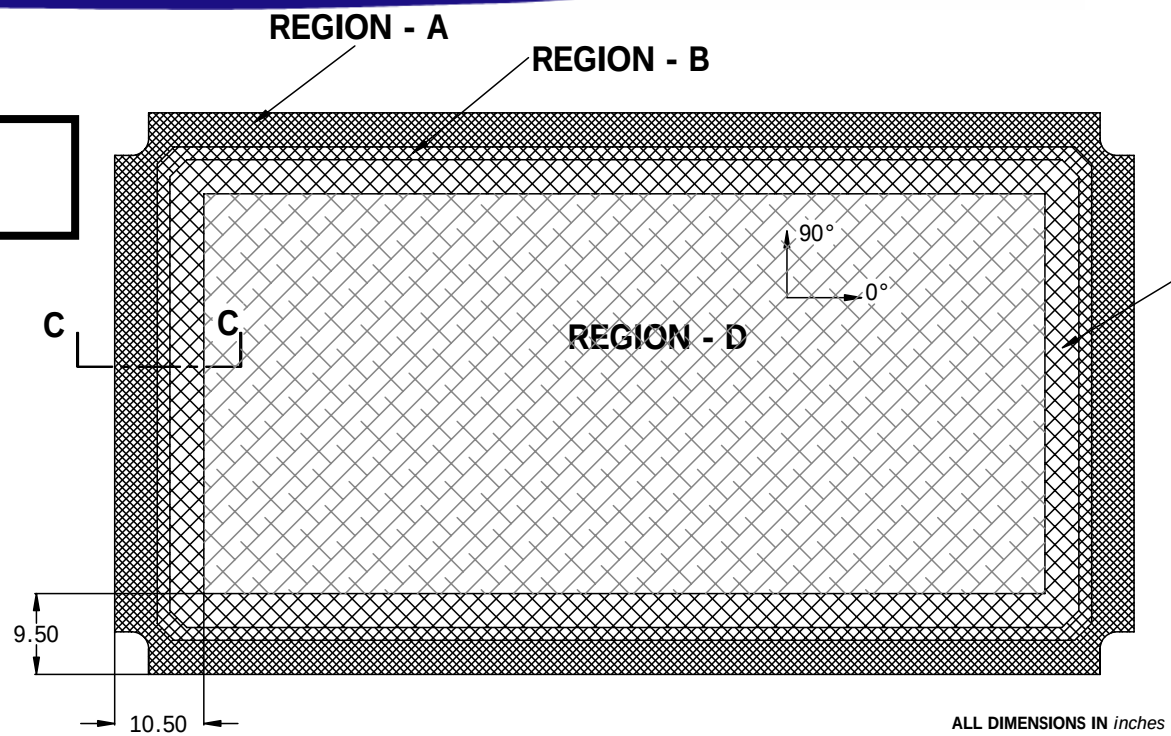
Internal Radius : 74 inches

TEST ARTICLE

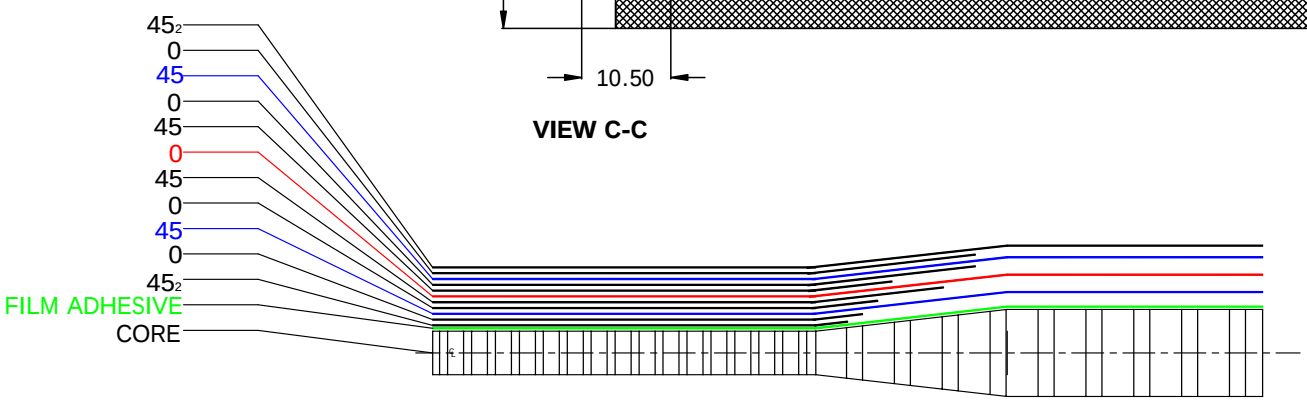
- Material Systems
  - Facesheet
    - **TORAY COMPOSITES T700SC-12K-50C/#2510 PWCF**
  - Core
    - Plascore Nomex PN2-3/16-3.0 honeycomb (0.75 in thick)
- Sandwich Configuration (test section)
    - [45/0/45/core/45/0/45]

TEST ARTICLE

STACKING SEQUENCE LAYOUT



VIEW C-C



TEST PLAN /STATUS

TEST NO	PANEL I.D	FLAW TYPE	LOADING	STATUS	comments
1	CP-1	NONE	Combined	completed	- Trial testing to exercise loading mechanisms, ARAMIS, etc.
2			Pressurization/hoop loading	completed	
3			Longitudinal	completed	
4	CP-1A	" +" notch made in situ (final geometric details to be provided by FASTER)	Longitudinal loading to 1500 lb/in	completed	
5	CP-1B		Combined loading (1:1) 435 lb/in	completed	
6	CP-1B		Hoop loading to 435 lb/in	completed	
7	CP-1B		Longitudinal loading to 435 lb/in	completed	
8	CP-2	10" diameter hole on convex side facesheet	Combined loading (1:1) (1750 lb/in)	completed	
9			Longitudinal loading (1500 lbf)	completed	
10			Hoop loading (1750 lbf)	completed	Failure initiation

TEST PLAN /STATUS

TEST NO	PANEL I.D	FLAW TYPE	LOADING	STATUS	comments
11	CP-3	10" circumferential notch	STRAIN SURVEY 1. Longitudinal loading: 300 lb/in 2. Combined loading – Pressure 3.4psi ; Longitudinal 300 lb/in RESIDUAL STRENGTH 1. Increase pressure to 8 psi and hold 2. Increase longitudinal loading until failure	Under progress	To failure
12	CP-4	10" Circumferential notch (offset)	Longitudinal loading	Specimen shipped	To failure
13	CP-5	10" Longitudinal notch	Circumferential loading	Specimen shipped	To failure

TEST PLAN /STATUS

TEST NO	PANEL I.D	FLAW TYPE	LOADING	STATUS	comments
14	CP-6	10" notch at 45°	STRAIN SURVEY 3. Longitudinal loading: 300 lb/in 4. Combined loading – Pressure 3.4psi ; Longitudinal 300 lb/in RESIDUAL STRENGTH 3. Increase pressure to 8 psi and hold Increase longitudinal loading until failure	Machining under progress	
15	CP-7	TBD	TBD		
16	CP-8	TBD	TBD		

FABRICATION OF TEST ARTICLES

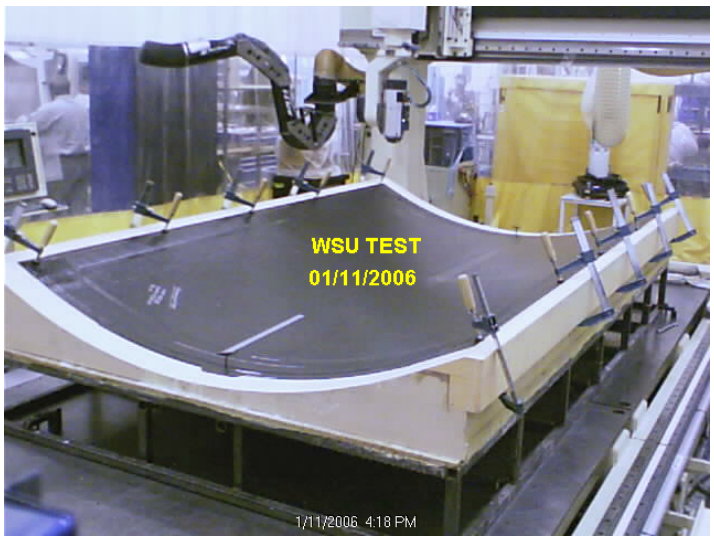
TOOLING FABRICATION

COMPLETED TOOLING

FABRICATION OF TEST ARTICLES

LAYUP

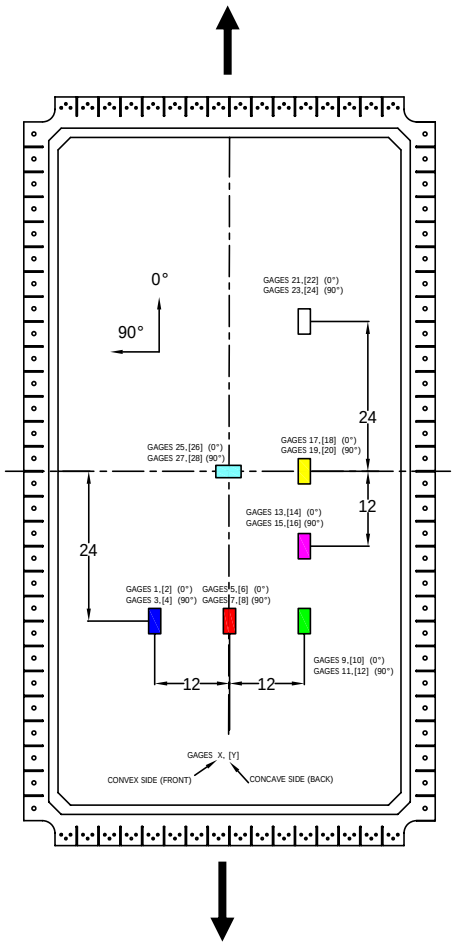
MACHINING

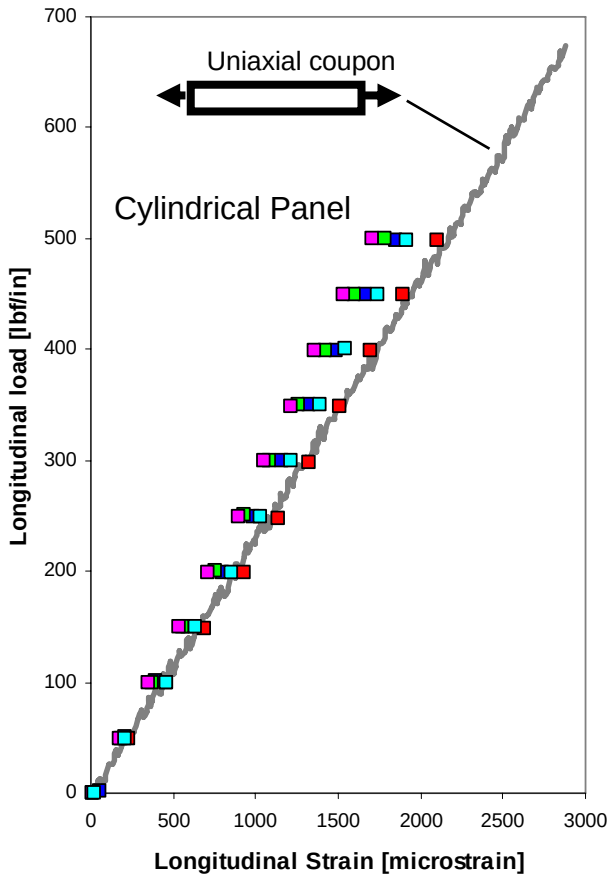


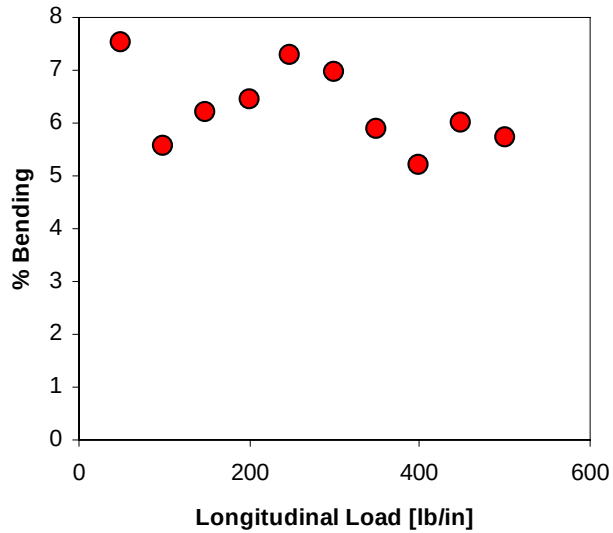
TEST RESULTS

- UNDAMAGED PANEL TEST(S)
  - OBJECTIVES
    - CHECK LOAD INTRODUCTION & UNIFORMITY OF LOADING
    - CHECK INSTRUMENTATION & PHOTOGRAMMETRY METHOD
  - LOAD CASES
    - CASE-1 : LONGITUDINAL LOADING (500 lb/in)
    - CASE-2 : PRESSURIZATION/HOOP LOADING (6.7 psi /500lb/in)
    - CASE-3 : COMBINED LOADING (1000 lb/in longitudinal / 13.4psi)

Longitudinal Loading

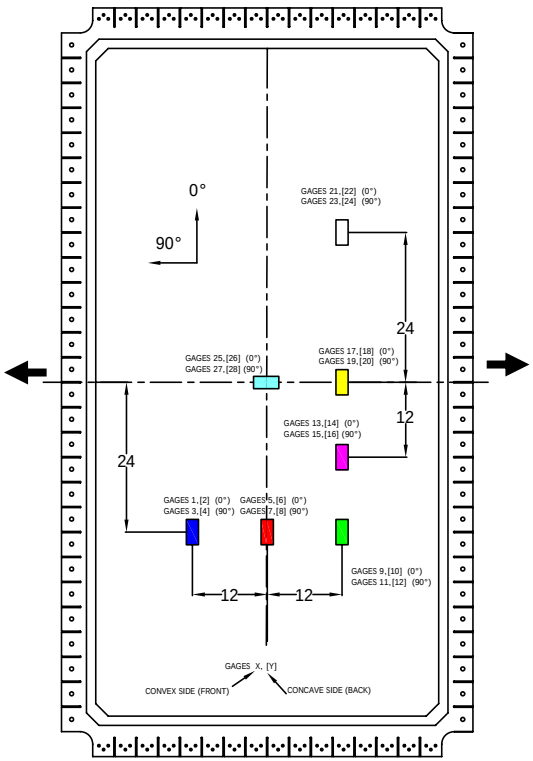


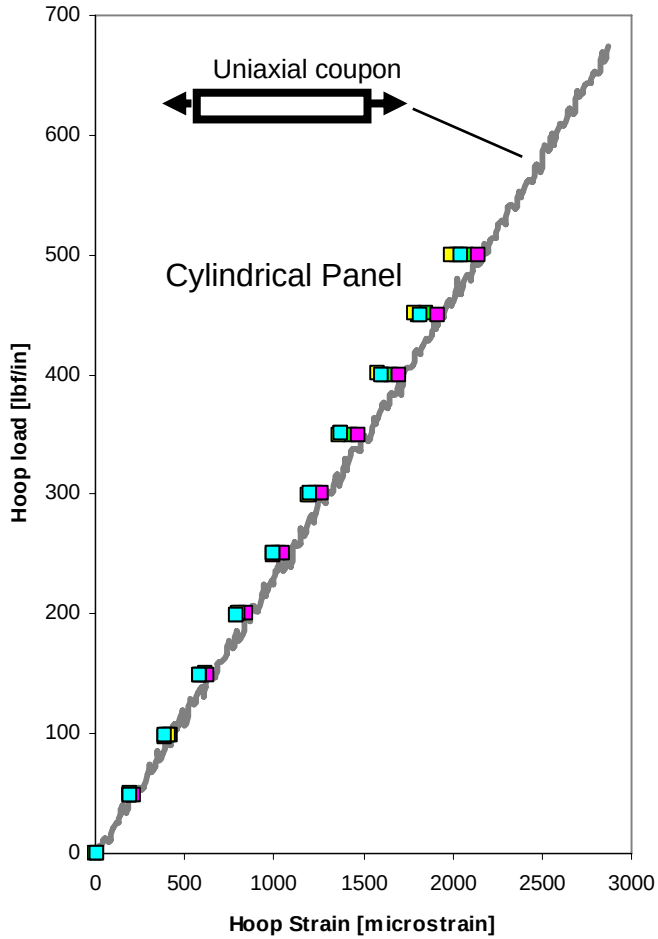


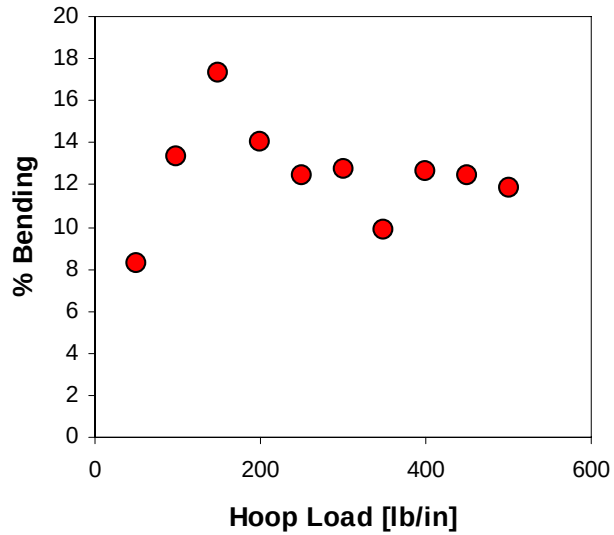


- **Loading approaches that of pure uniaxial case at the center of the panel**
- **Secondary bending of ~6.5% observed**

Pressurization/Hoop Loading







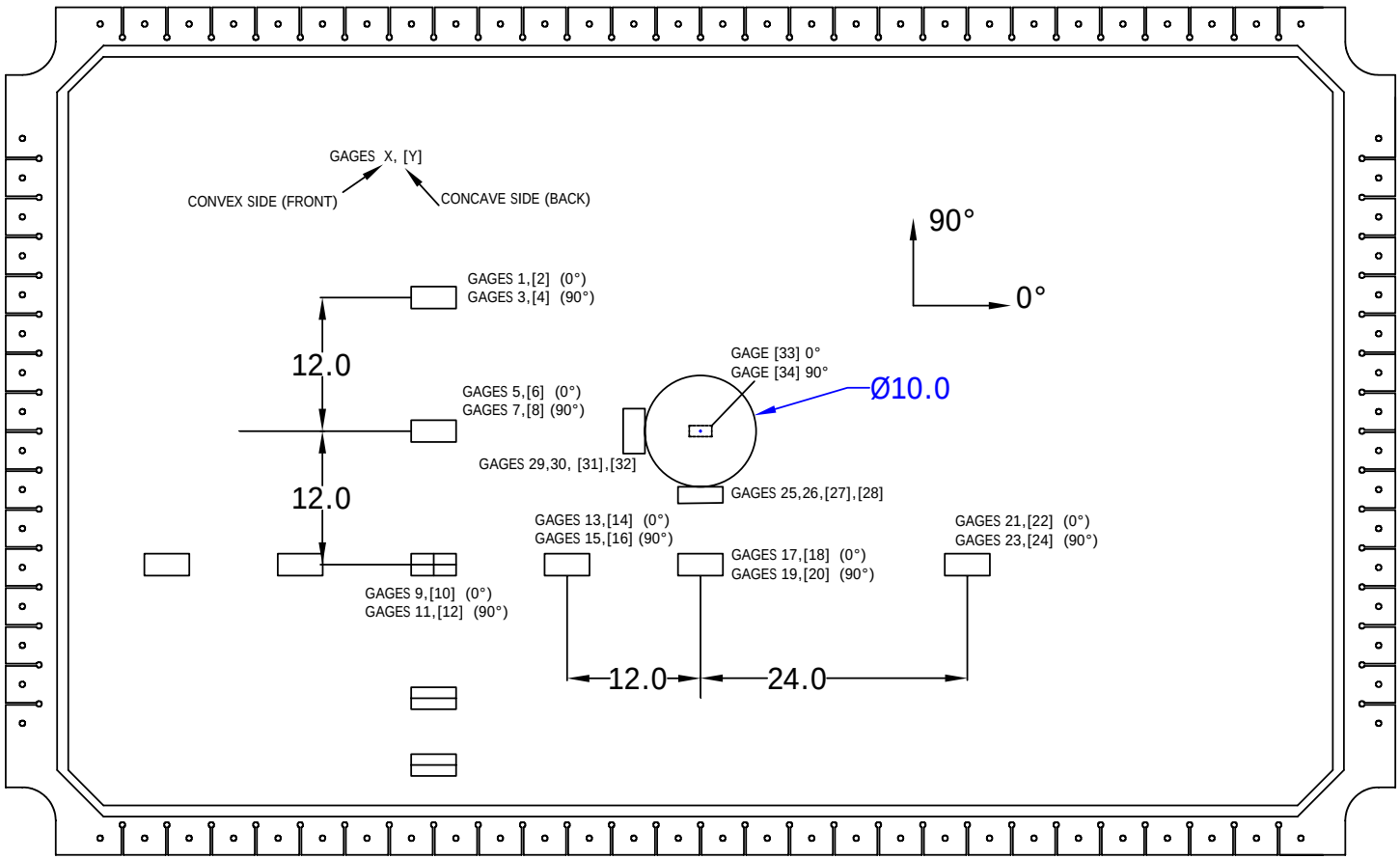
- Loading uniform across panel length & width
- Secondary bending of ~13% observed

TEST RESULTS

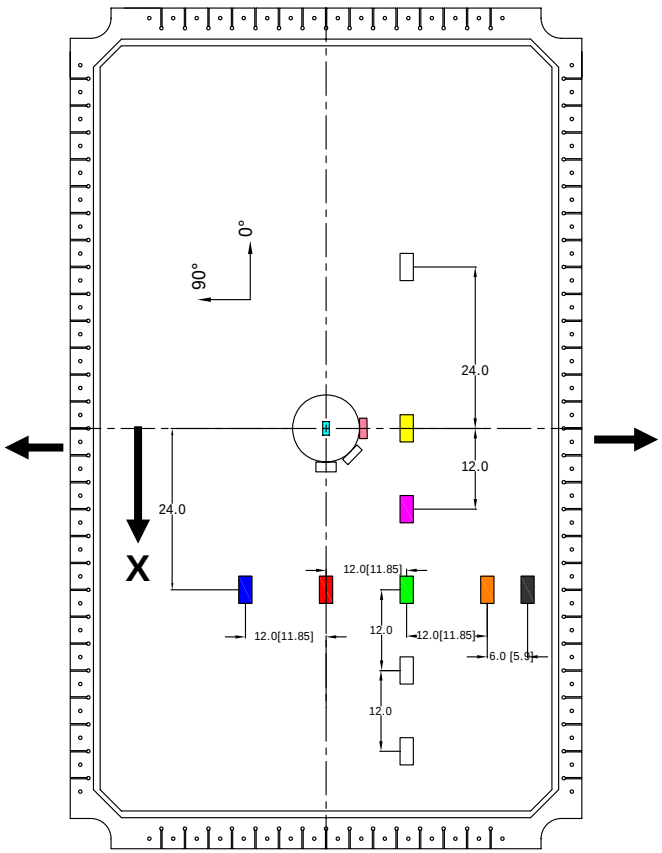
- SANDWICH PANELS WITH OPEN-HOLE IN SINGLE FACESHEET
  - LOAD CASES
    - CASE-1 : LONGITUDINAL LOADING (1750 lb/in)
    - CASE-2 : COMBINED LOADING (1750 lb/in longitudinal / 23.63psi)
    - CASE-3 : PRESSURIZATION/HOOP LOADING (23.63 psi /1750lb/in)

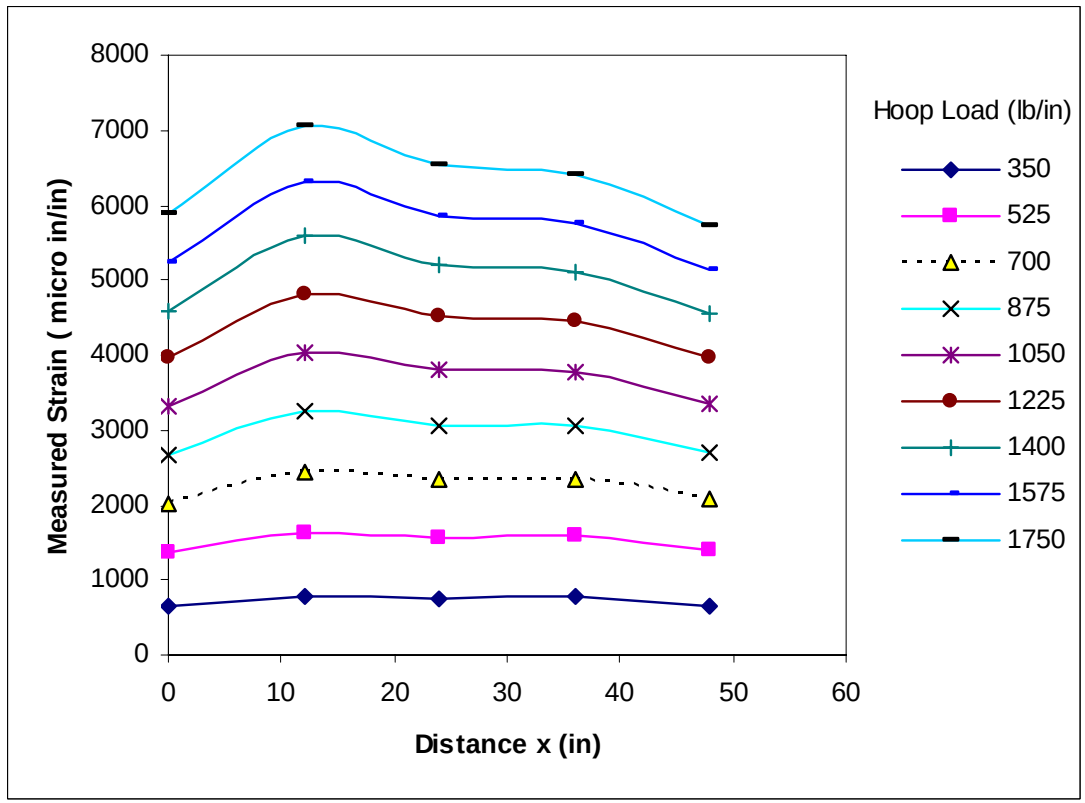
TEST RESULTS

- PANEL GEOMETRY & INSTRUMENTATION

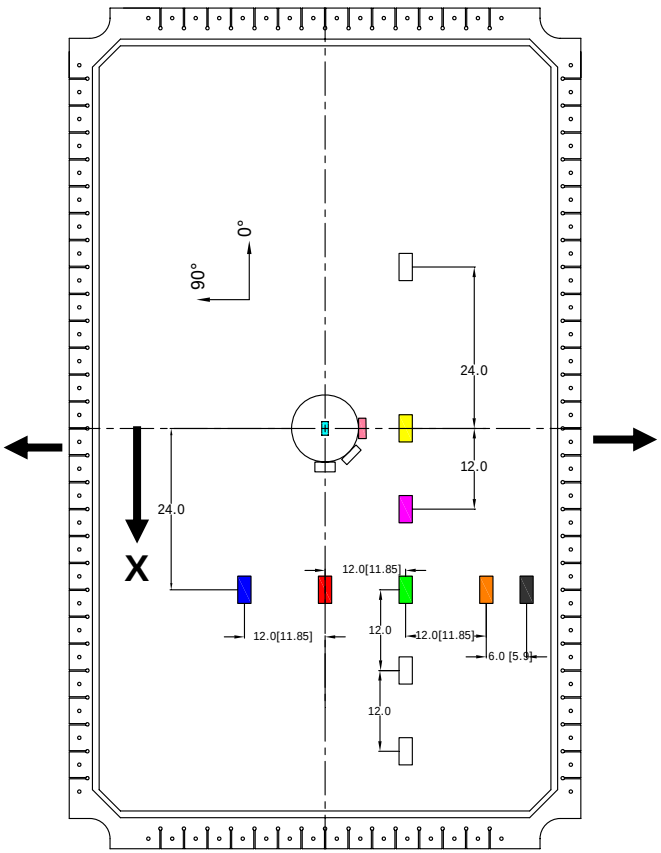


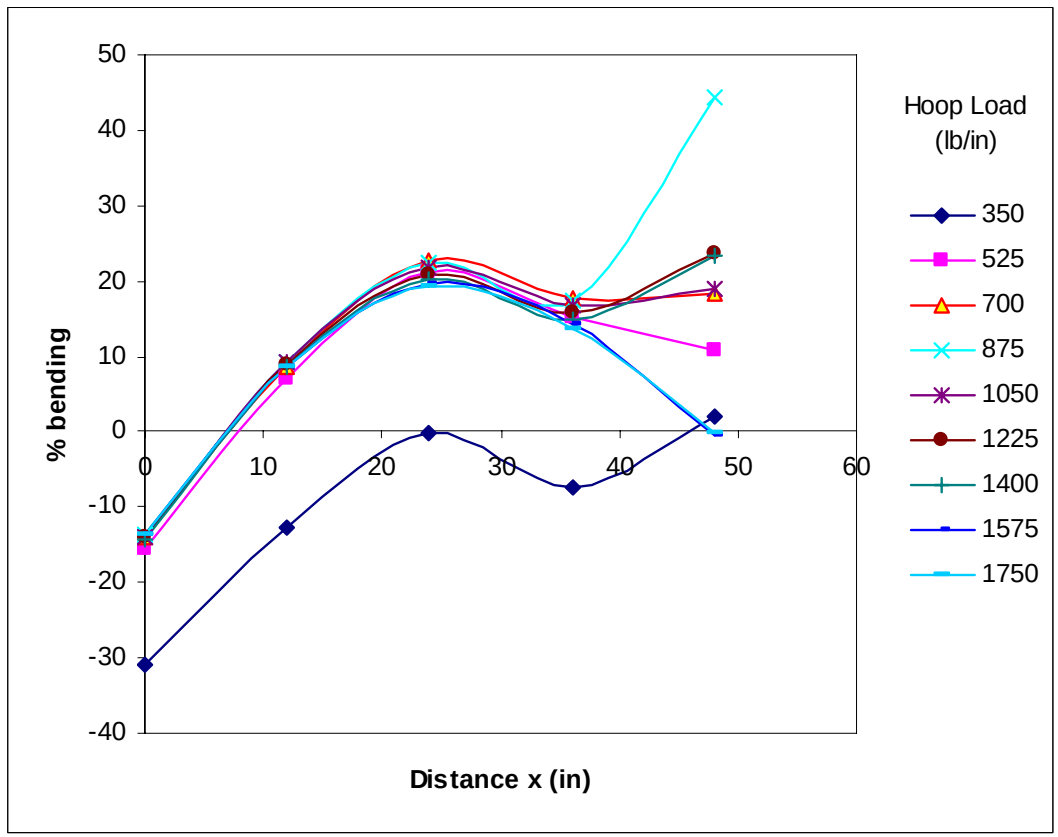
HOOP LOADING – Hoop Strain Distribution



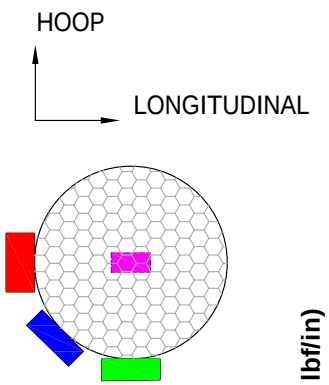


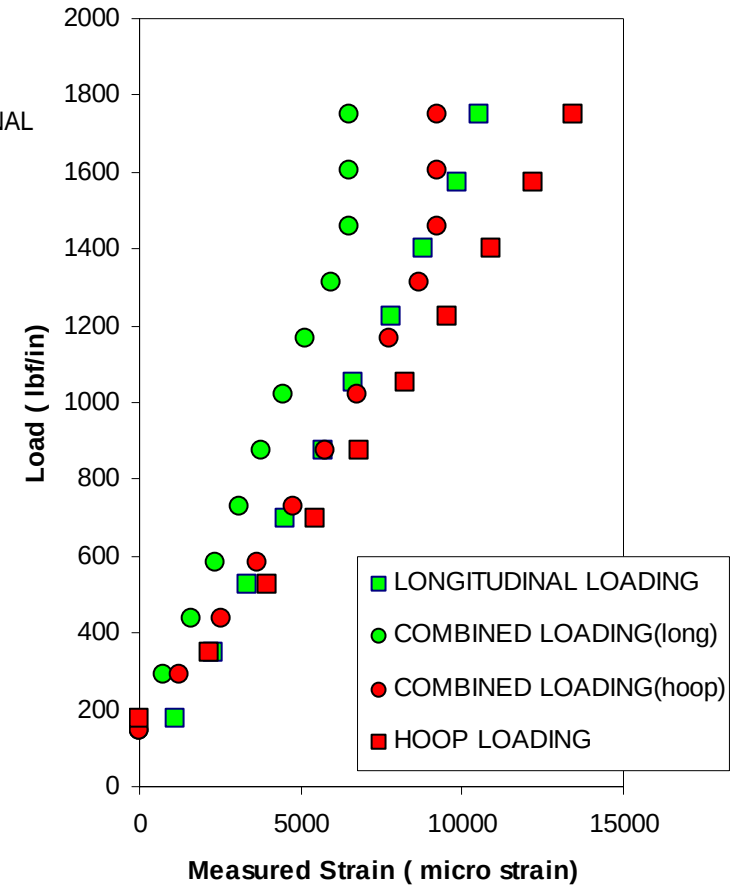
HOOP LOADING – Bending of panel





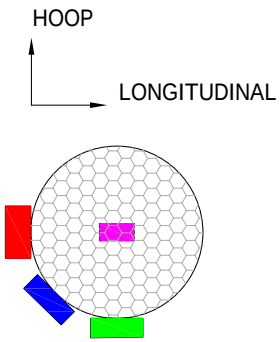
COMPARISON OF TANGENTIAL STRAINS

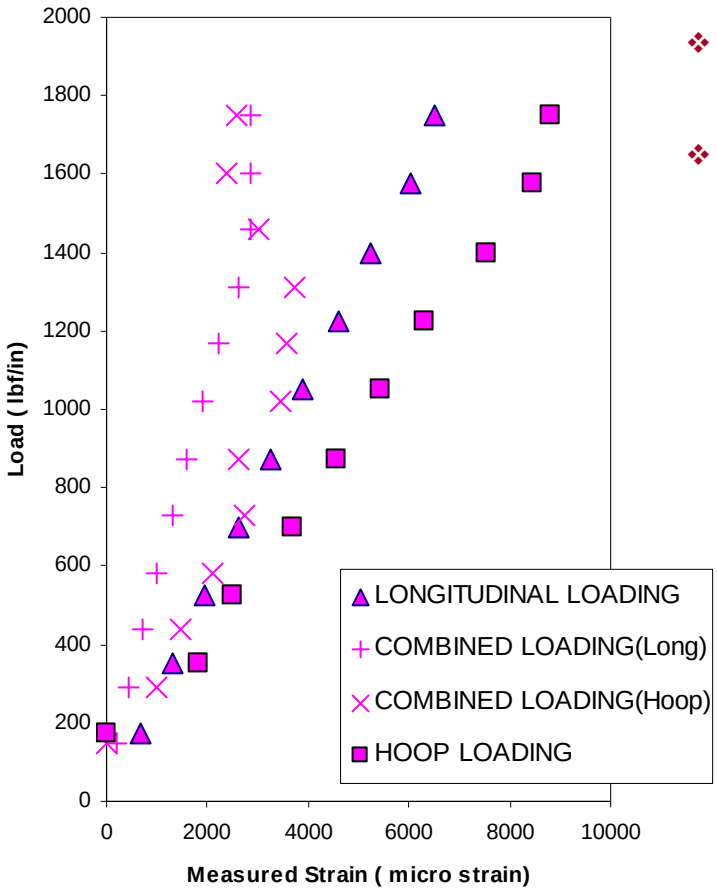




- Tangential strains vary linearly with applied loading under pure longitudinal and hoop loading
- Tangential strains under hoop loading was significantly higher than longitudinal & combined loading cases
  - Failure initiated under hoop loading
  - Bulging at hole edge adds to tangential component
- Under combined loading, tangential strains along hoop & longitudinal directions are unequal
  - Bulging effects

COMPARISON OF backside facesheet STRAINS

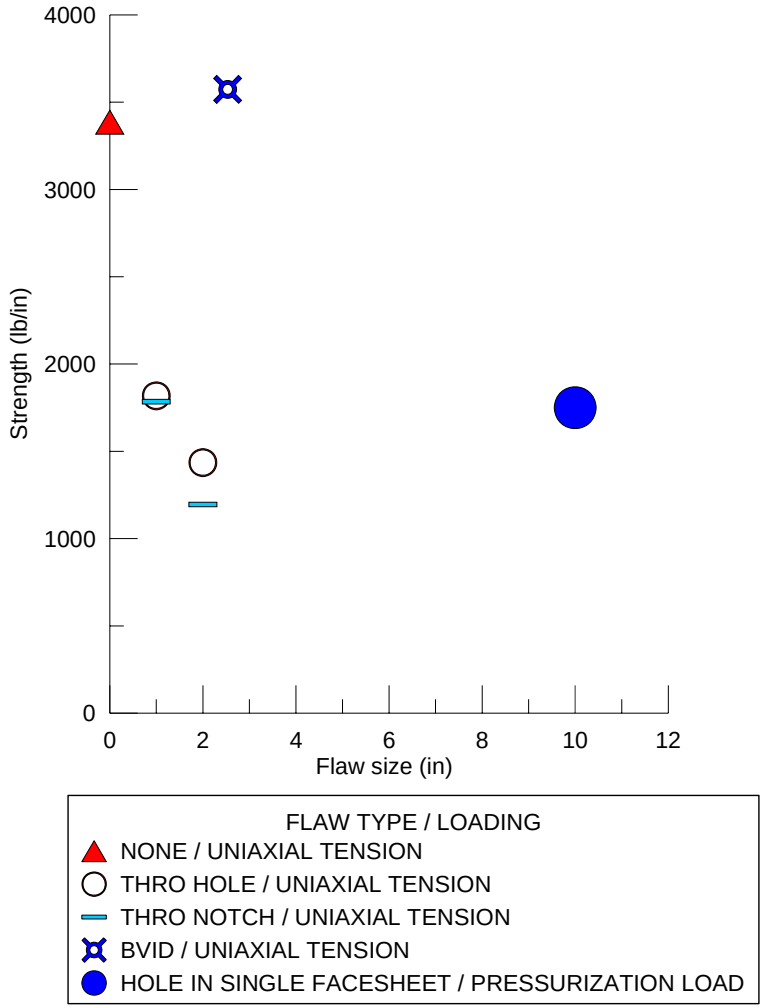




- **Significant membrane strains in backside facesheet under hoop loading**
- **Under combined loading, the membrane strains due to backside facesheet bulging and strains due to longitudinal & hoop loads interact**
  - **Non-linear load-strain relationship**

Comparison with coupon data

- **Hole in single facesheet is less severe as through holes or notches**
- **The failure load for single facesheet hole (pressurization) corresponds to failure initiation**
  - **Could carry additional load**
  - **Test discontinued as fixture could not accommodate the tangential displacements required for additional loading**



Ongoing Work

- Analysis of photogrammetry data and failure modes
- Testing of Specimens with notches
  - Longitudinal notch
  - Circumferential notch
  - Notch at 45° to longitudinal axis
- Two additional damage/loading configurations –TBD
- Analysis
  - Advatech Pacific : Failure prediction using GENOA program

A Look Forward

- Future needs
  - Longitudinal compression loading capability in the fixture
  - Inclusion of shear loading
  - Fatigue
  - Structural details – cut-outs, adhesive joints, etc.