Buckling Response of In- and Out-of-Autoclave Cured Sandwich Composite Panels For Payload Fairing Structures

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- Program Name: Composites for Exploration
- Period of Performance: Jan., 2011 – Jan., 2012
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- Program Technical POC: Sotiris Kellas

Distribution A: Approved for public release, distribution unlimited.

Composites for Exploration (CoEx) Objective

- **Demonstrate Weight and Cost Savings for 33-ft Diameter Payload Fairing When Compared to Metallic Options. Cost Savings are Addressed by:**
  - **Utilizing automated manufacturing processes**
  - **Minimizing part count**
  - **Using out-of-autoclave (OoA) material systems**

CoEx Technology Demonstration – Building Block Approach

- **Preliminary Phase**
  - **Concept Downselection**
  - **Two 8-ply QI 1/16th-Arc Segment Manufacturing Demo Panels**
    - **Automated Tape Placement**
      - **Sandwich construction (3.1 pcf 1.0-in Thick Al Core)**
      - **Facesheet stacking sequence $(+45^\circ/90^\circ/-45^\circ/0^\circ)_s$**
      - **OoA System: T40-800B/5320-1**
      - **In Autoclave System: IM7/977-3**
  - **Relevant Loading: Compression (Buckling)**
    - **Coupon Tests to Assess Manufacturing Quality and to Provide as Built Analysis Input Data**
    - **Element Tests to Evaluate Buckling Performance**
- **1/6th-Arc Segment Panels Will be Fabricated and Tested**

Preliminary Testing Presentation Outline

- **Basic material properties – manufacturer data**
- **Supporting Coupon Tests**
  - **Thickness measurement technique**
  - **Facesheet tension**
  - **Edgewise compression**
- **Buckling tests**
- **Summary of results**
- **Conclusions**
- **Further work**

Distribution A

Manufacturer Provided Material Properties (Room Temperature Ambient)

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	T40-800b	IM7 -12K
Strength ksi	800	822
Modulus, Msi	40.0	40.0

← IM7 2.8% Stronger

40 Msi Class Fiber

	T40-800b/5320-1	XXX/977-3
0° Tension Strength, ksi	392	364
0° Tension Modulus, Msi	22.7	23.5
90° Tension Strength, ksi	11.7	9.3
90° Tension Modulus, Msi	1.41	1.21

← OoA 7.7% Stronger

← IA 3.5% Stiffer

← OoA 25.8% Stronger

- For Matrix Dominated 90° Tension, OoA System is 25.8% Stronger

http://www.cytec.com/engineered-materials/products/Datasheets/CYCOM%20977-3.pdf

https://www.cytec.com/engineered-materials/products/Datasheets/CYCOM_5320-1_Rev0_051210.pdf

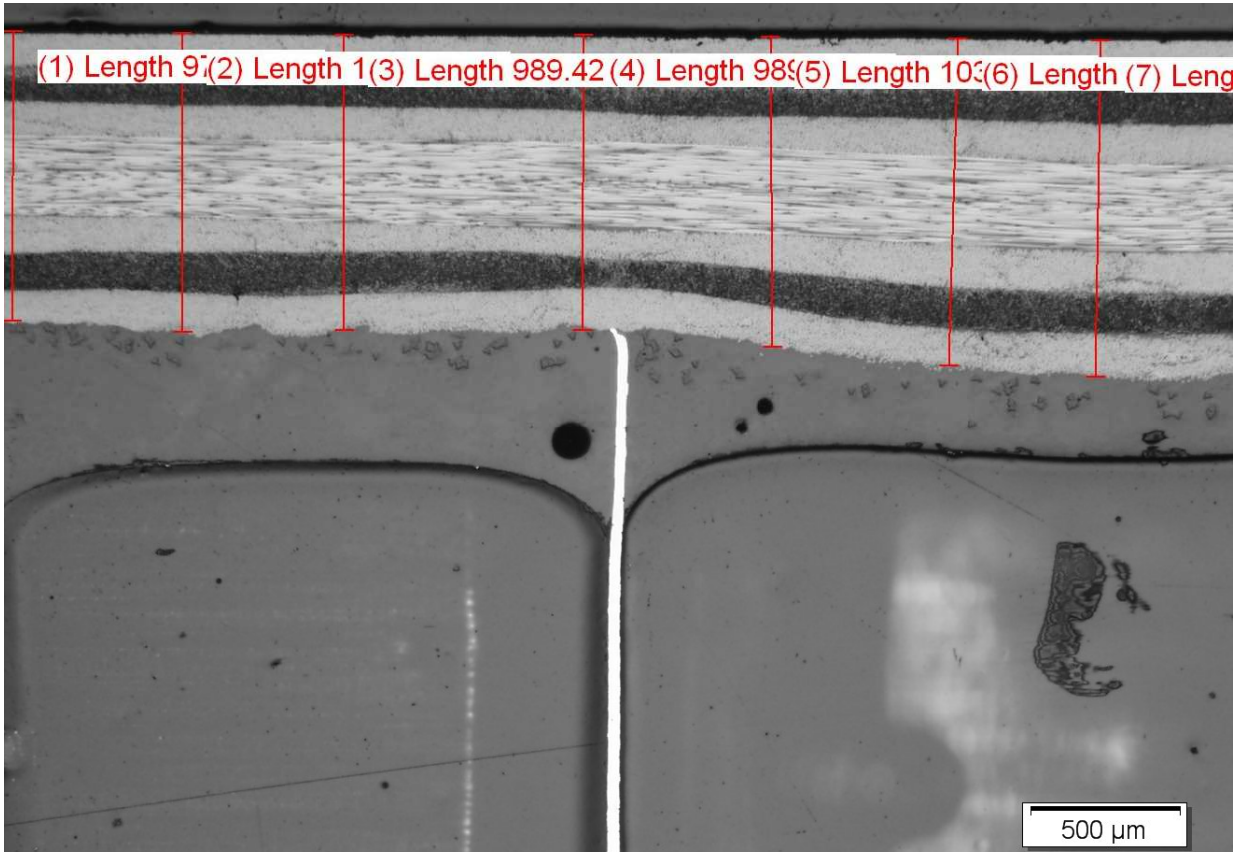
1/16th–Arc Panel Imperfections

- **Both panels had tape gaps (0.05”- 0.07”) in all ply orientations**
- **ID facesheet of both panels had bulge due to core splice along the center of each panel**
  - **For IM7/9773: ~ 0.003” high**
  - **For T40-800B/5320-1: up to 0.03” high and 0.25” wide**
- **IM7/9773 had a dry ID surface**
- **T40-800B/5320-1 contained wrinkles on the ID**

- **NDE Revealed no internal defects**

Facesheet Thickness Measurements

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Aver. Facesheet Thicknesses:

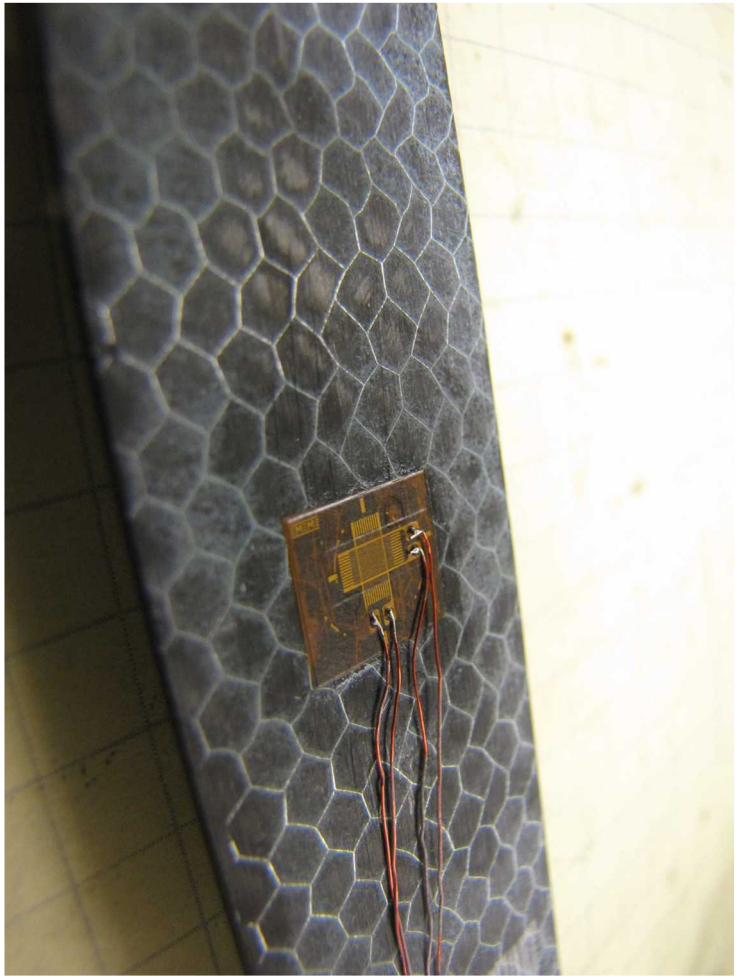
977-3 = 0.039-in

5320-1 = 0.041-in

Thickness was measured using several micrographs from both sides of each panel.

- 5320-1 facesheets are on average 5% thicker than 977-3
- Facesheet density is approximately the same.

Facesheet Tensile Test (1.0-in by 10-in)



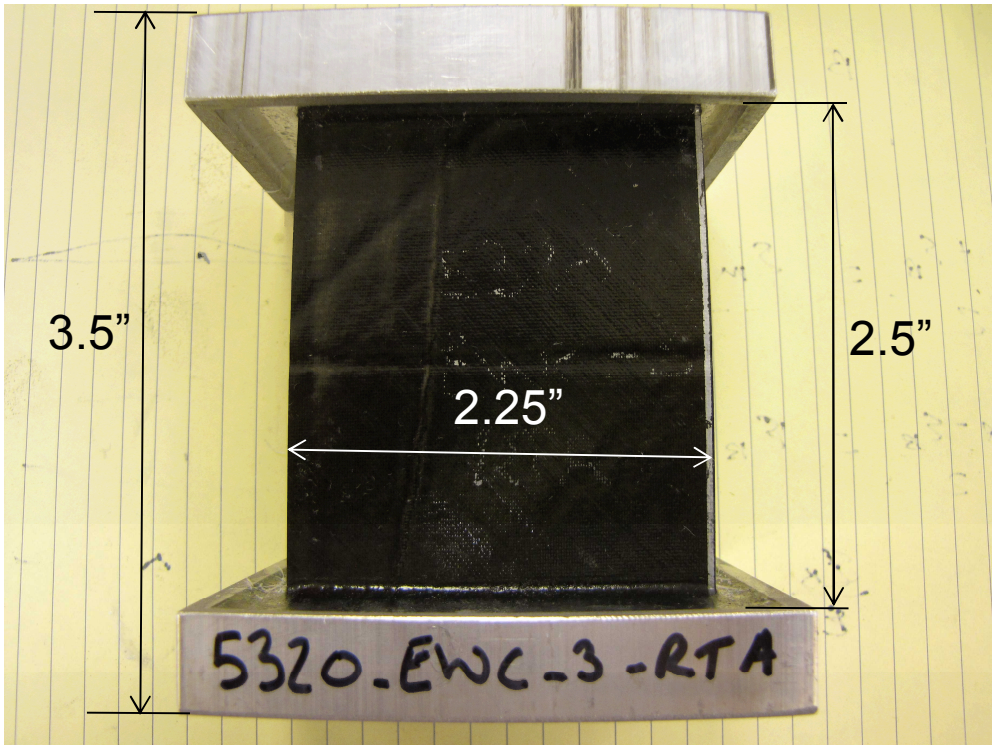
- As Built Facesheet Tensile Properties
  - Strength
  - Young's Modulus
  - Poisson's Ratio
  - Effect of environment
- Provided data to compare against compressive results
- Provided data to compare against previous studies

Facesheet Tensile Test – Room Temperature Test Results

Material System	Maximum Stress Ksi	Tensile Modulus Msi	Failure Strain %
IM7/977-3 LSSM (ACT)	115.4 (90.1)	9.14 (8.98)	1.25
T40-800b/5320-1 LSSM (ACT)	116.9 (99.6)	8.57 (8.43)	1.35

- OoA System is 6.2% More Compliant than IM7/977-3

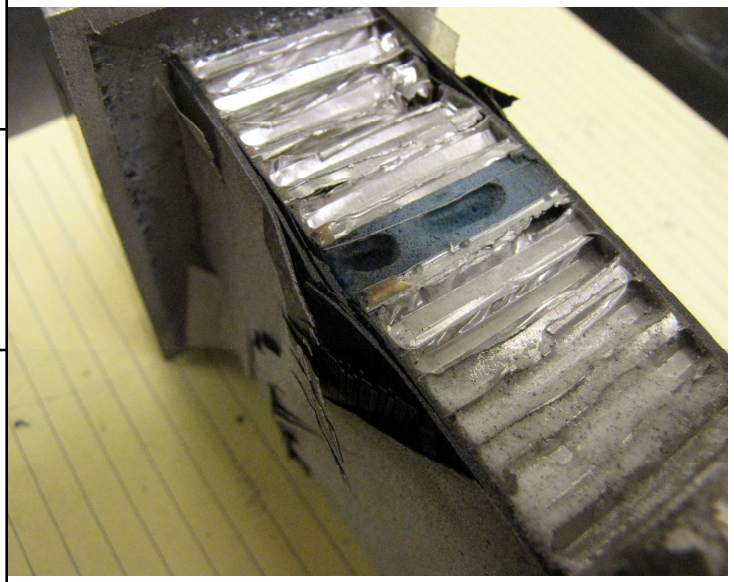
EdgeWise Compression (2.25-in by 2.5-in)



- As Built Facesheet Compression Properties
  - Strength
  - Young’s Modulus
- Effect of manufacturing imperfections including the core splice
- Effect of environment

EdgeWise Compression (2.25-in by 2.50-in) – Room Temperature Test Results

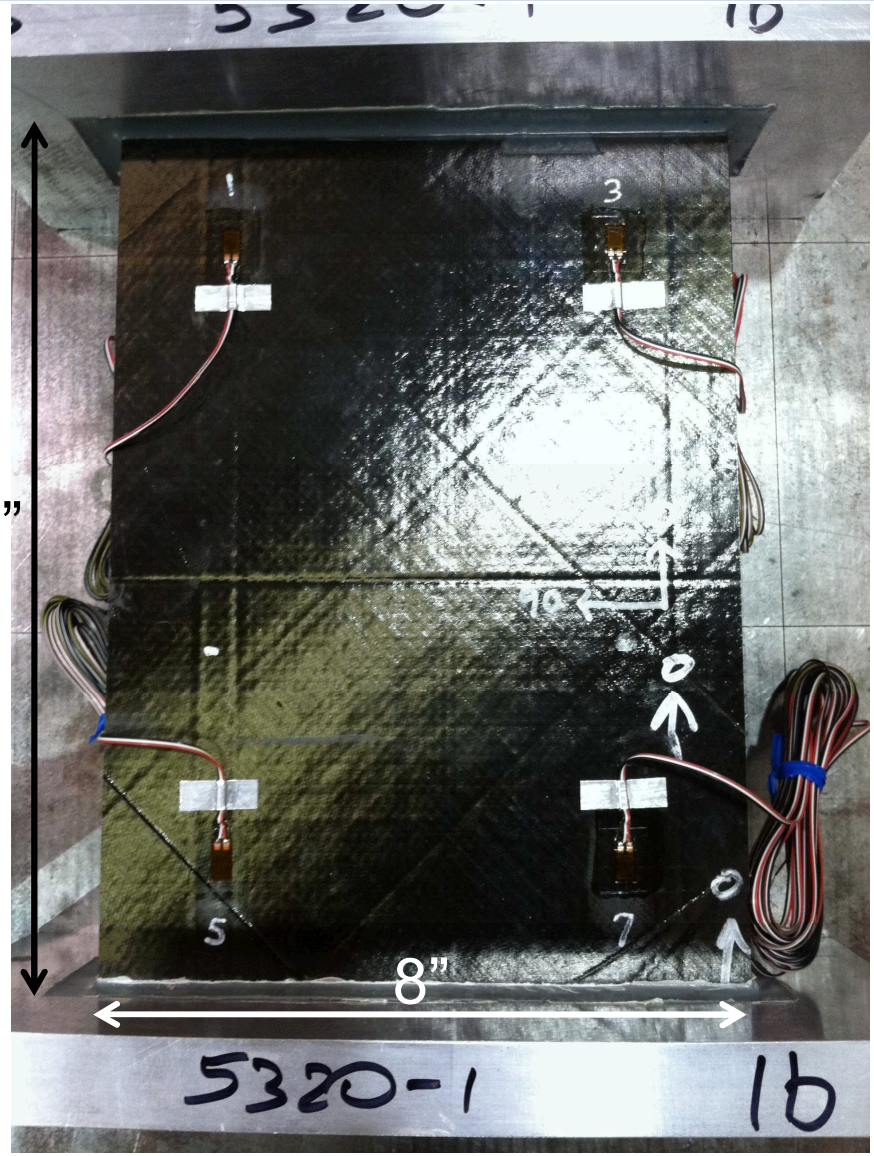
Material System	Maximum Stress Ksi	Compressive Modulus Msi	Failure Strain %
IM7/977-3 LSSM (ACT)	80 (76)	9.15 (9.95)	0.92 (0.77)
T40-800b/5320-1 LSSM	96	8.48	1.25



- 5320-1 is 20% Stronger and 7.3% more Compliant than 977-3
- For 5320-1, the core splice caused a 16% reduction in strength and 20% in strain to failure. Splice failure at ~ 10,000 με.

Young's Modulus (chord) was calculated between 1,000 and 3,000 με
ACT used a QI laminate of different stacking sequence than LSSM

EdgeWise Compression (8-in by 11-in)



- As Built Facesheet Compressive Properties
  - Strength
  - Young’s Modulus
- Effect of Manuf. imperfections including the core splice on compressive strength
- Effect of specimen size on compressive response

Distribution A

EdgeWise Compression (8-in by 11-in) – Room Temperature Test Results

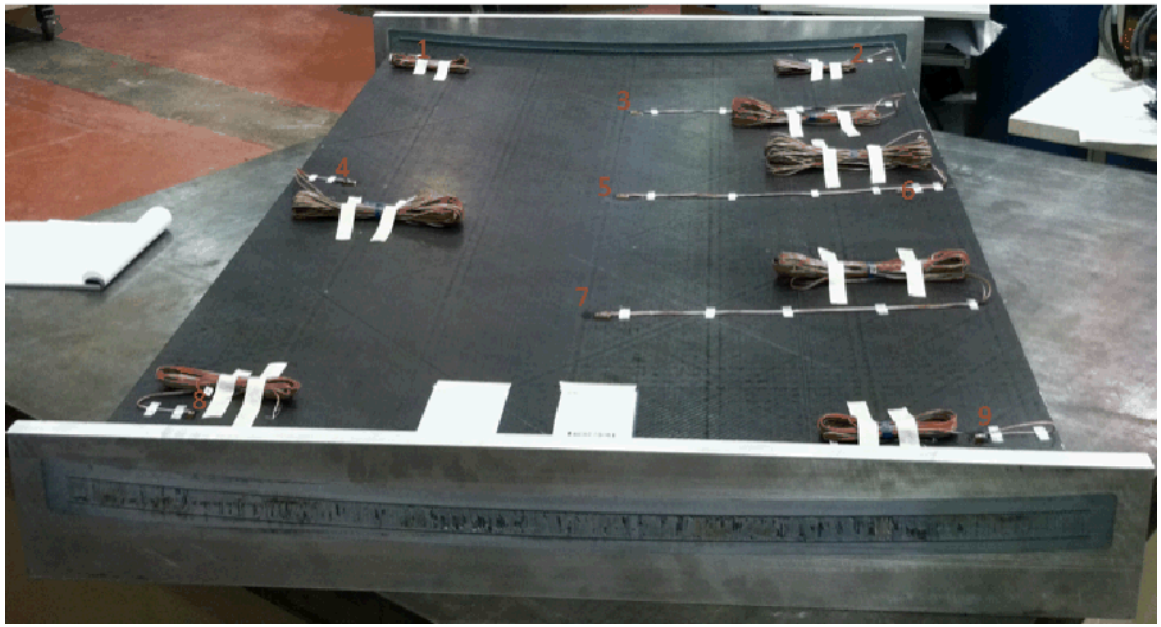
Material System[1]	Maximum Stress Ksi	Compressive Modulus[2] Msi	Failure Strain %
IM7/977-3 LSSM	51.6	9.13	0.59
T40-800b/5320-1	65.4	8.64	0.83

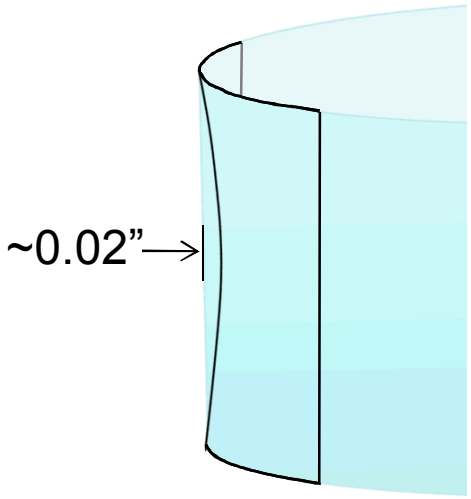
- Similar trend as more stubby specimen – 5320-1 is 26.7% Stronger and 5.4% more Compliant than 977-3
- 5320-1 sample with splice failed at the splice at ~7,500 με. All other samples failed close to the ends
- Splice failure occurred at lower strain compared to smaller specimens

[1] Both sets of data include one sample with core splice

[2] Modulus was calculated between 1,000 and 3,000 με.

Buckling Test – Specimen 3-ft by 5-ft





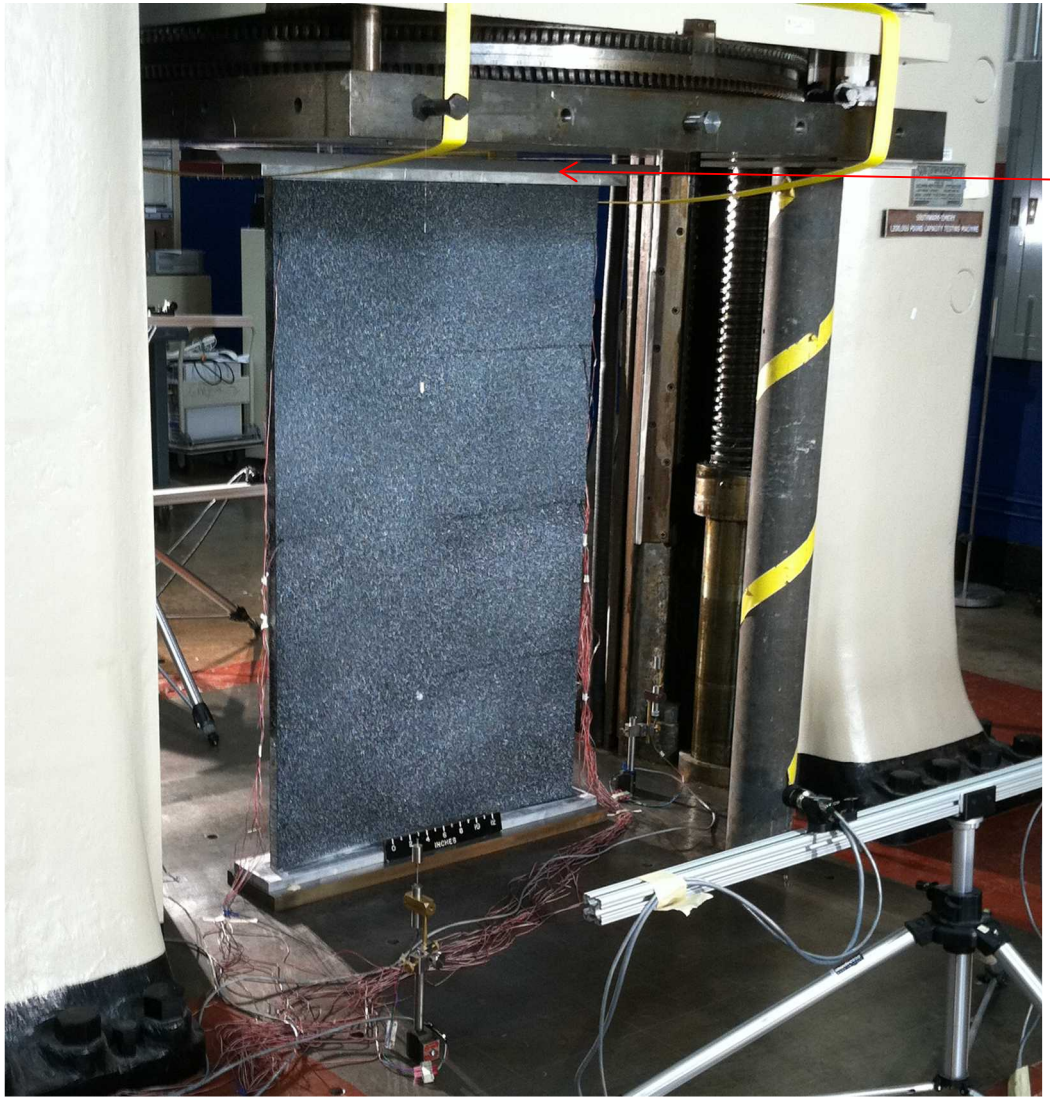
- 28 back-to back strain gages. Gages at positions 3, 4, 5, 6 and 7 are Orthogonal rosettes. Positions 1, 2, 8, and 9 are uniaxial.
- Both panels contained a small bow due to residual stresses

3-ft by 5-ft Buckling Test – Instrumentation

- **28 strain gages – 8 used for alignment**
- **Photogrammetry (both surfaces) provided full-field deformations and strains of the entire panel surface.**
- **Four DCDTs (one at each corner) between the load platens provided an accurate measurement of the average end shortening.**

Distribution A

977-3 Test Set-up – 1.2-Mlb Test Frame

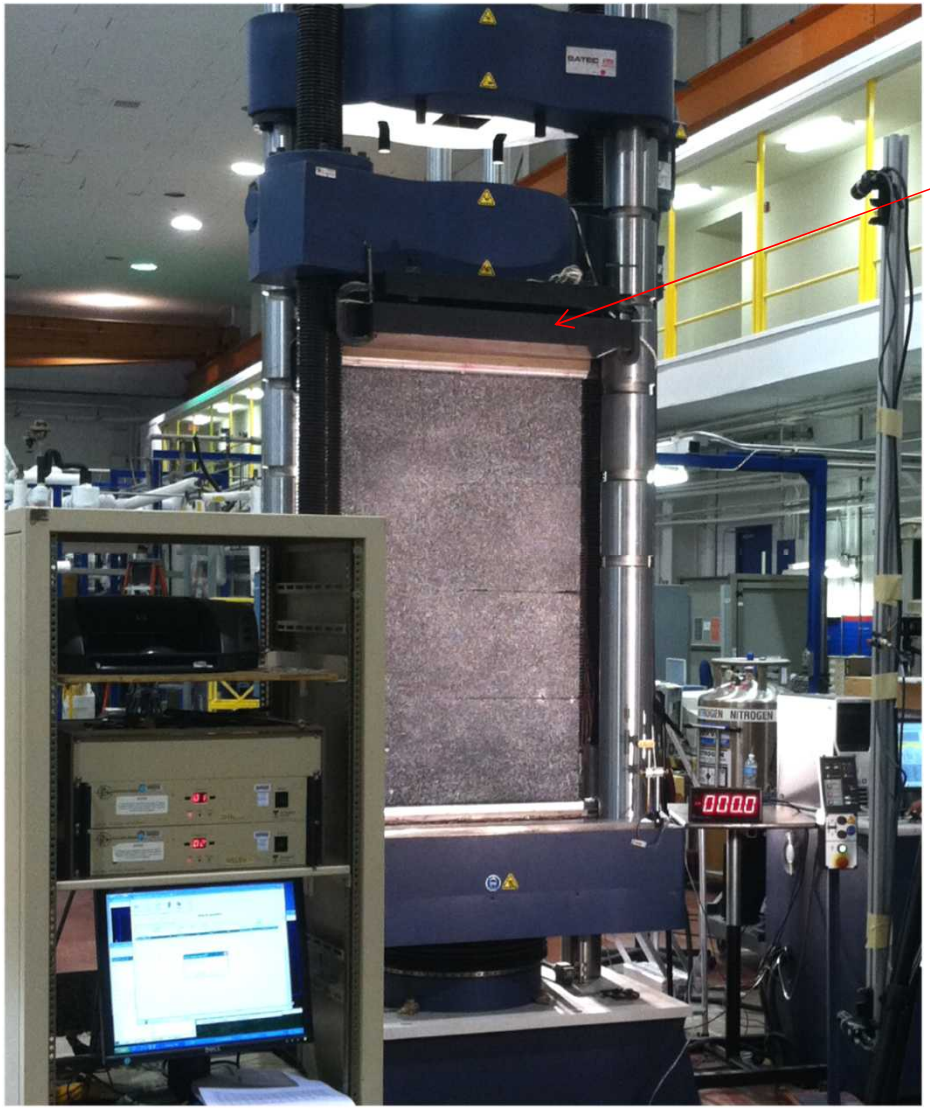


Steel plate is shimmed against the platen

Plate was shimmed so that at 20% expected ultimate load, the bending strains at the corner gage positions were < 2%.

Specimen loaded beyond buckling which resulted to end failure – no damage associated with the core splice

5320-1 Test Set-up – 600 kip Test Frame



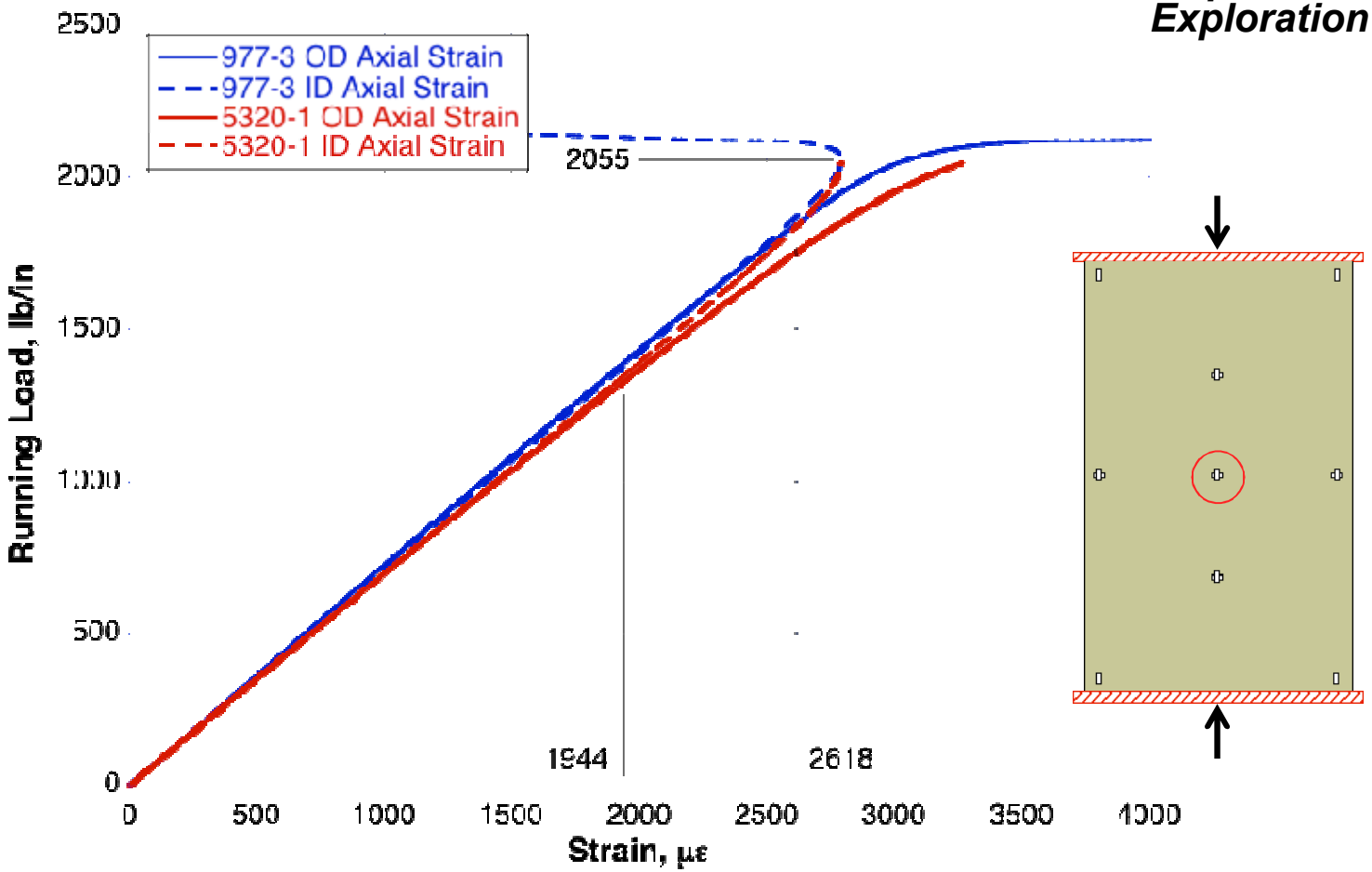
Adjustable Platen – Provided easy adjustment – NOT as rigid as fixed platen of 1.2-Mlb Machine

Platen was adjusted so that at 20% expected ultimate load, the bending strains at the corner gage positions were < 2%.

Specimen loaded until buckling was verified and then unloaded. NDE revealed no damage.

Distribution A

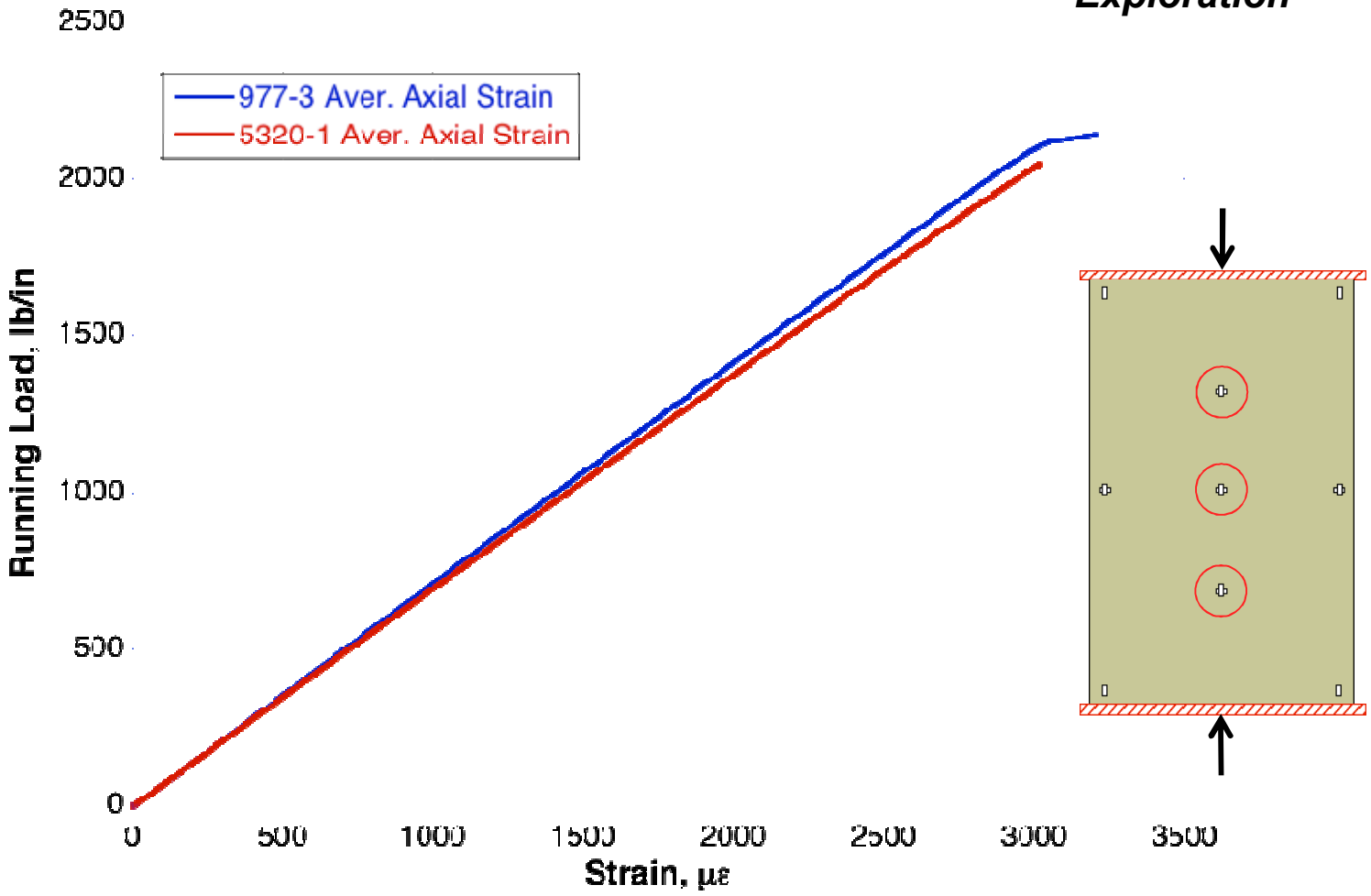
3-ft by 5-ft Specimens – Running Load Vs Center Axial Strain Response



- Based on center <u>axial</u> strain responses, the magnitude of the buckling load for the two systems is appr. the same at 2055-lb/in. Buckling strains were < 3,500-με
- Note: Bulge due to core splice was on ID – max. compressive strain was on OD

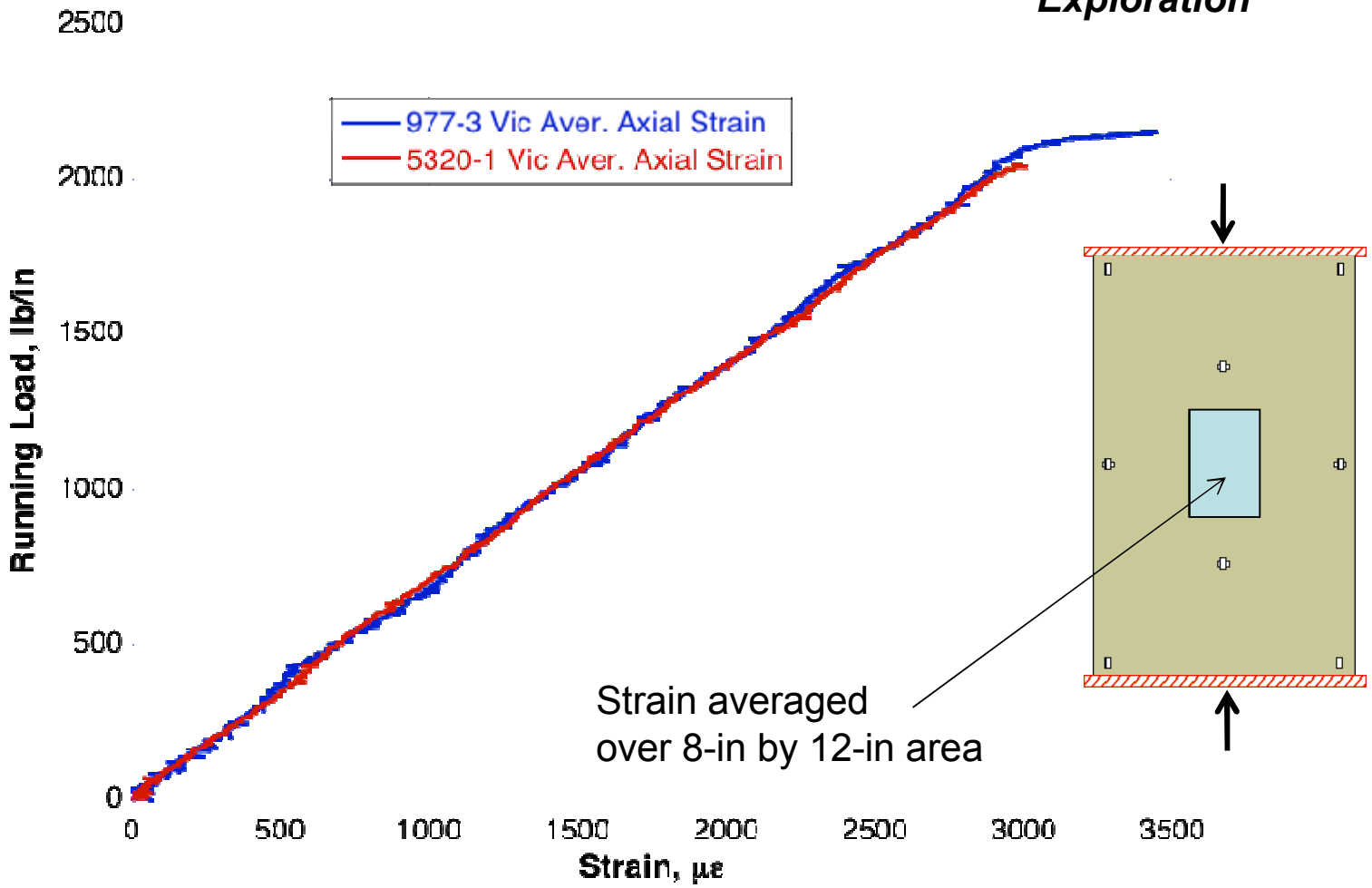
3-ft by 5-ft Specimens – Running Load Vs Aver Central Axial Strain Response

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Based on the average of all central gages, 977-3 is 3.3% stiffer than the 5320-1 Specimen

3-ft by 5-ft Specimens – Running Load Vs Photogram. Central Axial Strain Response



Based on the average (ID and OD) photogrammetry derived axial strain, 977-3 is 0.8% stiffer than the 5320-1 panel

Summary of Compressive Test Results

Measured Property	IM7/977-3	T40-800b/5320-1
2.25-in by 2.5-in EWC Strength, Ksi	80.0	96.0
2.25-in by 2.5-in Compr. Young's Modulus, Msi	9.15	8.48
2.25-in by 2.5-in EWC Strain-to-Failure due to Core Splice, με	9,000*	10,000
8-in by 11-in EWC Strength**, Ksi	51.6	65.4
8-in by 11-in Compr. Young's Modulus, Msi	9.13	8.84^
8" by 11" EWC Strain-to-Failure due to Core Splice, με	5,900*	7,500
3-ft by 5-ft Compr. Young's Modulus, Msi	9.03	8.31

* Core splice did not have a noticeable effect – Average Strain-to-Failure shown

** All specimens except for the 5320-1 sample with splice, failed at the ends

^ Measured by photogrametry over a 2-in wide by 3-in long central area

Summary of Results

- **The core splice irregularity was more pronounced for the OoA system.**
  - **The 5320-1 2.25-in by 2.5-in coupons failed at the splice at ~ 10,000-με as opposed to ~ 7,500-με for the 8-in by 11-in samples**
- **Based on running load, the buckling response of the two panels was very similar with stiffness differences of only 3.3% and 0.8% for strain gage and photogrammetry data, respectively.**
- **Buckling test results showed conclusively that manufacturing imperfections that caused coupon strength degradation did not affect the buckling response of 5320-1 panel.**
  - **Buckling strain is simply too low for existing defects (wrinkles, tape gaps, core splice) to be detrimental**

Distribution A

Future Work

- **Complete testing of remaining coupons**
- **Retest the OoA 3-ft by 5-ft specimen with damage (energy level and position TBD)**
- **Test Larger Specimens at relevant loading conditions including elevated temperatures. Specimens will include:**
  - **Joints**
  - **Cutouts/Design Details**
  - **Damage**

Distribution A

Related Presentations

- *Jake Stavana,* "**Fabrication of OoA and Autoclave Sandwich Structures**"
- *Sandi Miller,* "**Quality Comparison of ATL'd Autoclave and OoA; Progress in OoA Processing of IM7/8552-1**"